2021

Innovative digital tools for training in the field of welding

Digital Learning Materials for Welding Simulator

IO2 – DIGITAL LEARNING MATERIALS FOR WELDING SIMULATOR

2018-1-RO01-KA202-049218

Index

Executive Summary

DIGIWELD Innovative digital tool for training in the field of Welding is an Erasmus+ funded project that addresses the European Council's Communication "Rethinking Education: Investing in skills for better socio-economic outcomes, which states the importance of promoting the use of technology for an effective learning and for reducing barriers to education, allowing individuals to learn anywhere, at any time, in individualized learning pathways.
This project aims to develop:

- A proposal for updating the European EWF-IAB-089r5-14 Guideline (i.e. the European Welder Guideline) that supports the introduction of a new module about Digital Competences and the use of welding simulators in practical training, in specific conditions, as viable and innovative tools for education and training of future welders,
- A digital tool to be inserted in simulators as modules dedicated to the training of young trainees (aged 16 to 20 years old).

In this sense, DIGIWELD Partners (six entities from Belgium, Spain, Italy and Romania with expertise in Education, Welding and in developing welding simulators) gathered to propose an updated component of the education and training European Guidelines for welding to attract young trainees to the knowledge and responsibilities of the Welder profession. Another goal was to create an open and innovative digital learning system (SIMTRANET) in the field of arc-welding technology and digital educational materials that allow trainees to access information and to perform practice time using welding simulators. To achieve DIGIWELD purposes, partners are also working towards the creation of conditions for international groups of trainees to actively participate in simultaneous training and welding contests in the safest conditions possible by using specific stand-alone simulators or virtual classrooms.

The present result is one of the tasks that has been carried out in the scope of DIGIWELD project's **Intellectual Output (IO) 2- Digital learning materials for welding simulator**. It focuses on the work done by DIGIWELD partners towards the development of the digital learning materials dedicated to MIG/MAG, TIG and MMA welding processes and to Quality Assurance in Welding, which will be uploaded on SIMTRANET, a digital learning system created in the scope of DIGIWELD. In addition, taking into consideration the restrictions imposed by COVID-19 pandemia, the DIGIWELD partners decided to develop supplemental material for welding processes: Gas Welding.

It aims to be a critical analysis towards standardization, applicability and relevance points of view, focusing on the compatibility of these contents with the European Welder Guideline having in consideration that these digital learning materials were based on the updates proposed for the European Welder Guideline (EWF-IAB-089r5-14 Guideline). Therefore, the topics addressed by *Module 2 Welding Processes* (MIG/MAG, TIG and MMA welding processes) and *Module 3 Quality Assurance in Welding*, part of DIGIWELD course, are in line with the referred Guideline.

Hence, this Technical Report explains how the alignment between the subjects/topics of the European Welder Guideline were ensured by DIGIWELD partners involved in the development of the learning contents and how the technical revision was conducted towards the final version of the above mentioned modules/contents, considering their compliance with standardization. Their applicability and relevance to trainees' education and training and theoretical knowledge complies with the European Welder Guideline and the most updated state of the art.

Digital Competences - Introduction in Computer and Simulation

1.1 Course name

Introduction in Computer and Simulation

1.2 Course duration

4 hours

1.3 Course purpose

The purpose of the course is to ensure the accumulation of digital skills necessary for the use of digital devices that create virtual and augmented reality. The implementation of the virtual environment and augmented reality in the practical training of future welders ensures the access of the new generation to a training mode close to the reality in which they live and carry out their daily activities. The unit deals with aspects regarding the methodology and tools used in digital training, learning management systems and a brief presentation of welding simulators.

1.4 Objectives of the course

- To understand how to use the digital tools in theoretical and practical training
- To be able to use and exploit the modules developed in LMS
- To know how welding simulators work

1.5 Contents

1. Training digital tools and methodology
   - 1.1. Digital tools used in welding training
   - 1.2. Advantages and disadvantages of digital tools in welding
2. Learning Management System
   - 2.1. Virtual Learning Environments
   - 2.2. Definition and characteristics of LMS
   - 2.3. Setting and functionalities of LMS
   - 2.4. LMS – challenges and advantages
   - 2.5. Available solutions for developing LMS
3. Welding simulators
   - 3.1. Welding simulators systems
   - 3.2. Augmented reality
   - 3.3. Virtual reality
   - 3.4. Difference between welding simulator and real welding system
   - 3.5. Set-up of welding simulators

1.6 Participants

Learner characteristics:	*VET students at welding specialization.*

1.7 Entry requirements

Education level requirement:	*Secondary school certificate (EQF 3)*

Previous knowledge needed	*Basic welding knowledge* *Basic ICT knowledge*
Age requirements:	*Learners must be a minimum 16 years*

1.8 Assessment activities

- *Theoretical test on every unit: multiple choice questions*
- *Practical setting up the simulator*

1.9 Bibliography (used or supplementary)

[1] Savu SV – Welding simulator, alternative digital tool for practical training of the future welders, ASR Conference, Buzau, 2015
[2] Open source (Moodle based) example: https://themefisher.com/moodle-bootstrap-themes/
[3] Off-the-shelf LMS product: https://learnbox.co.za/off-the-shelf-lms/
[4] University of Craiova, LMS - https://cis01.central.ucv.ro/evstud/
[5] Susannah J. Whitney, Ashley K. W. Stephens – Use of Simulation to Improve the Effectiveness of Army Welding Training, Commonwealth of Australia, 2014
[6] Soldamatic – Augmented Training for Welding, http://www.soldamatic.com/soldamatic2018/
[7] Lincoln Electric – VRTEX360 Virtual Welding Trainer, https://www.lincolnelectric.com/en-gb/equipment/training-equipment/vrtex360/pages/vrtex-360.aspx
[8] BEApplied Research, HoloLens Plant Maintenance, https://www.youtube.com/channel/UCdXVL3uTXP-icWKB7K2Yivw
[9] Phoenix Contact - Augmented reality in use for industry 4.0 and building technology, https://www.youtube.com/watch?v=UhW12bILH7U
[10] Lily Prasuethsut, Meta thinks Pokémon Go is perfect for the AR headset, https://www.wareable.com/ar/meta-pokemon-go-2962
[11] Industry Reports, Global Augmented Reality Market to Witness a Pronounce Growth During 2024– Top Key players like Google Inc., Microsoft Corporation, Vuzix Corporation, Samsung Electronics Co., Ltd., Qualcomm Inc., Oculus VR, LLC, EON Reality, Inc. Infinity Augmented Reality Inc & Others, https://industryreports24.com/430907/global-augmented-reality-market-to-witness-a-pronounce-growth-during-2024-top-key-players-like-google-inc-microsoft-corporation-vuzix-corporation-samsung-electronics-co-ltd-qualcomm-i/
[12] Husain Sumra, The best augmented reality glasses 2019: Snap, Vuzix, Microsoft, North & more, https://www.wareable.com/ar/the-best-smartglasses-google-glass-and-the-rest
[13] Google, https://virtualrealitypop.com/what-is-real-vr-content-3e66e3810894
[14] MindRend Technologies, VR Robotics Simulator, https://www.youtube.com/channel/UCDWYlQAzV8qIhxa4yXbjmpQ
[15] Fronius Virtual Welding, http://www.funworld.com/en/funworldtech/projects-and-partners/fronius-virtual-welding
[16] Weld VR simulator, http://weld-vr.com/en/
[17] Lincoln Electric VRTEX 360, , https://www.lincolnelectric.com/de-de/support/application-stories/Pages/Pitt-Community-College.aspx

UNIT NUMBER: Didactic Unit 1
UNIT TITLE: *Introduction in Computer and Simulation*

UNIT PRESENTATION

The present learning unit ensures the accumulation of digital skills necessary for the use of digital devices that create virtual and augmented reality. The implementation of the virtual environment and augmented reality in the practical training of future welders ensures the access of the new generation to a training mode close to the reality in which they live and carry out their daily activities. The unit deals with aspects regarding the methodology and tools used in digital training, learning management systems and a brief presentation of welding simulators. The first module covers subjects related to digital tools used in welding training and which are the advantages and disadvantages of using digital tools in welding. The second module introduces the trainees in the virtual learning environments where they can learn and interact with digital tools or with other trainees. The learning management systems (LMS) are the best digital tools to register users, to provide content and to assess the performance of the trainees. How an LMS can be defined, set up and which are the functionalities of a LMS as well as the advantages and disadvantages of a LMS are presented in this module. The trainees will also learn about available solutions for developing their own LMS. The third module deals with welding simulators. Typical welding simulator system are presented in the introduction of the module. The virtual reality (VR) and augmented reality (AR) are explained in order to provide to the trainees the necessary knowledge in order to be able to understand and to use how these technologies work. At the end of the module a brief presentation of the difference between welding simulator and real welding system as well as a short example regarding the setting of a welding simulator.

OBJETIVES

The objectives of the teaching unit are:

- To understand how to use the digital tools in theoretical and practical training
- To be able to use and exploit the modules developed in LMS
- To know how welding simulators work

CONTENTS

4. Training digital tools and methodology
    - 4.1. Digital tools used in welding training
    - 4.2. Advantages and disadvantages of digital tools in welding
5. Learning Management System
    - 5.1. Virtual Learning Environments
    - 5.2. Definition and characteristics of LMS
    - 5.3. Setting and functionalities of LMS
    - 5.4. LMS – challenges and advantages
    - 5.5. Available solutions for developing LMS
6. Welding simulators
    - 6.1. Welding simulators systems
    - 6.2. Augmented reality
    - 6.3. Virtual reality
    - 6.4. Difference between welding simulator and real welding system
    - 6.5. Set-up of welding simulators

CONTENTS DEVELOPMENT

1. Training digital tools and methodology

This module covers subjects related to digital tools used in welding training and which are the advantages and disadvantages of using digital tools in welding. Several software applications used in welders training are presented in order to show the importance and the relevance of digital tools in learning process.
There are two ways in which information is transmitted to students: the first refers to the teacher being at the center of the learning activity, and the second one puts the student in the middle of all activities. The use of digital tools in the learning activity can be successfully applied to the second option, considering the affinity of young people for everything that means connectivity and making information available in any place, time and way.

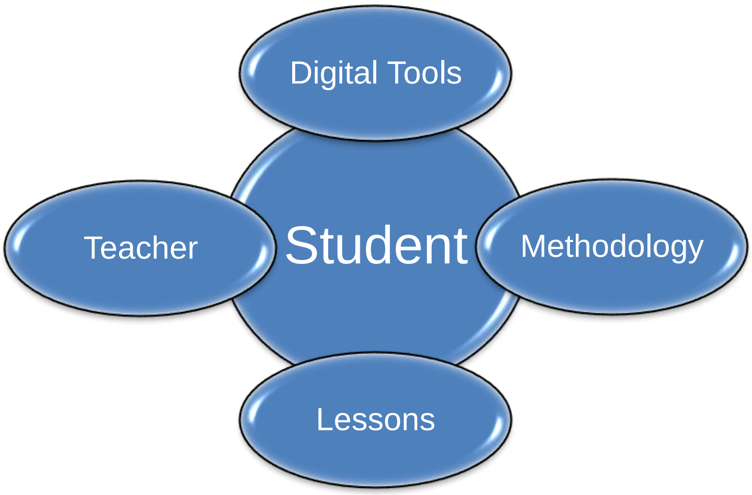


Fig. 1.1 Student-centered learning

Student-centered learning can be achieved if a few rules are followed:

- Being clear about how you will promote, measure, and celebrate understanding
- Modeling **how to think** for students
- Helping students understand what's worth understanding
- Diversifying what you accept as evidence of understanding
- Creating curriculum and instruction around a need to know
- Collaborating with students to create the rubric or scoring guide
- Letting students choose the project's purpose
- Letting students choose their own media form that reflects the purpose of the reading
- Using the on-demand writing prompt as the summative assessment
- Framing learning in terms of process and growth and purpose

1.1. Digital tools used in welding training

The digital tools used mainly in the training of people in the welding profession are largely dedicated to the theoretical aspects presented in digital format (doc., pdf., ppt., Images and videos) as well as the evaluation process related to the subjects taught. Newly, the information is incorporated into applications dedicated to learning that include both electronic documents and video images and animations all being compiled in an interactive way.

a. b.

c. d.

Fig. 1.2 Example of digital tools used in welding training

a. FutureWeld learning app, b. FutureWeld assessment app, c. Microbond learning app, d. Microbond assessment app

The next step is to combine theoretical and practical training and this can be achieved through welding simulators. Welding simulators can support both theoretical, practical and online or offline assessment of the student.

Fig. 1.3 Welding simulators [1]

REMEMBER TIPS

1. Digital tools means any software application or electronic device which is used in training
2. Software applications are mostly used for theoretical training and examination of the trainees knowledge

3. Welding simulators can be used both for theoretical and practical training in welding, as well as in examination process

1.2. Advantages and disadvantages of digital tools in welding

The use of welding digital tools presents both advantages and disadvantages for the process of learning and training future welders. The main advantages of simulated welding are:

Fig. 1.4 Advantages of the use of digital tools in learning process

Economical

- Reduced costs with energy and simulator servicing
- Reduced costs with teachers/trainers
- Reduced costs with preparation of base materials and increasing the time on arc of the trainees
- Specific industrial components for welded structures can be simulated

Ecological

- No emissions taking in to consideration that all welding operations are simulated
- No waste materials which can affect the environment
- Low carbon footprint taking in to consideration the low energy consumption

Safety

- Training takes place in a safe environmental without dangers from heat, radiation and gas
- No risks regarding 3 phases electrical power

Educational

- Easy user interface in VR/AR environment
- Increased potential for self-learning and self-assessment
- Development of competition scoring system which will lead to increase the learning readiness of the trainees
- Different levels of the difficulty for practical exercises
- Cover of the main arc welding processes
- Distance learning using internet connection between servers and welding simulators
- In-depth analysis of the welds and welding processes performed by trainees

In terms of disadvantages, the simulation of welding processes cannot substitute the real welding. There two categories of disadvantages identified:

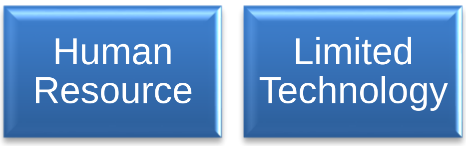


Fig. 1.5 Disadvantages of the use of digital tools in learning process

Human Resource

- Lack of digital skills of the teachers/trainers regarding the integration of welding simulators into the learning process

- Lack of digital skills of the teachers/trainers regarding the integration of welding software applications into the learning process

Limited Technology

- The welding simulators allow the practical training in order to improve the skills of the trainees but it doesn't cover the other aspects related for instance to base material preparation
- There are some technological limitations regarding the arc ignition which are different by the real welding
- Not all welding processes can be digitalized in welding simulator

2. Learning Management System

Digital tools can be defined as any devices and technologies of transmitting knowledge from teacher to student with computer applications, online course media or practical training through devices that use augmented reality, virtual reality, etc.
Digital tools are designed to help the students and teacher in the learning process. This sub-chapter contains basic information regarding digital tools and specific methodologies for learning process in a digital environment.

2.1. Virtual Learning Environments

Virtual Learning Environment (VLE) consists of a digital system that provides educational materials (courses, presentations, videos, animations and software applications) to the students using online webpages. Using an Internet connection on their own digital tools (computers, tablets, smartphones, etc.) the users can access the information both on and off school 24 hours a day and 7 days a week. A VLE supports student's registration, tracking of their activities, collaboration and communication between students, teachers, and assessment. There are three different types of VLEs:

- Open source – are offered free of charge for use and adapt but in most cases some fee are required for support activities

Fig. 2.1 Open source VLE [2]

- Bespoke – are developed by educational and training institutes in order to comply with their own needs

Fig. 2.2 Bespoke VLE [4]

- Of-the-shelf – products are packaged solutions that are then adapted to satisfy the needs of the purchasing organization, rather than the commissioning of custom-made.

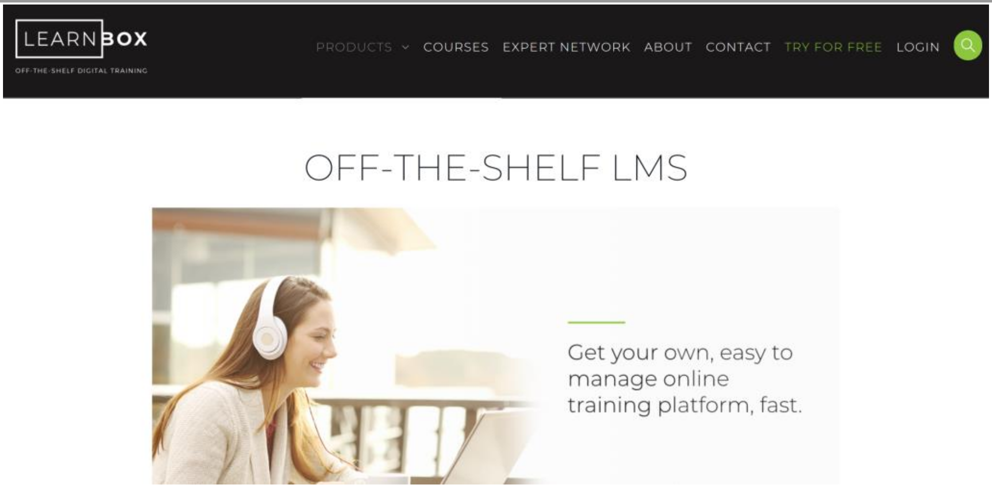


Fig. 2.3 Off-the-shelf LMS product [3]

2.2. Definition and characteristics of LMS

A Learning Management System (LMS) is the same thing as Virtual Learning Environment (VLE). Another name for LMS is Course Management System (CMS). As a general definition, the Learning Management System is a software application or web-based technology for planning, implementing and assessing a specific learning process. The main characteristics of LMS are:

- Possibility to upload or create and deliver content related to educational materials
- Monitor the student participation and continuous assessment for improvement the learning process and student performance
- Tool for interactive features such threaded discussions, video conferencing, forums, etc

2.3. Setting and functionalities of LMS

The functionalities of a LMS are defined in most cases by the developer. However, minimal functionalities should be provided by any LMS.

Reports

The teachers can benefit from LMSs reports in order to assess the student performance. Information regarding the individual study time, modules used during learning process, case studies and any other activities performed by the students will represent inputs for analysis.

Analysis

This feature will allow the teacher to evaluate the student performance as well as to find the best solution for filling the knowledge gaps.

Customization

The LMS support platforms allow the developer to customize the e-Learning experience. Starting with company logo and embedding all educational materials in one consolidated structure will increase the performance of the learning management system. The developer can also create customized learning path for each student in order to improve the learning process. In case of use of digital tools like simulators for practical training, the teacher/trainer can decide which assessment, method can be used for evaluation of the student's competences and skills. Another important component is related to types and formats of the educational materials. The LMS should accept at least documents in doc and pdf format, presentations and the common video types such as avi, mp4, etc.

Assessment

Represents one of the most important feature of the LMS. The system allows the evaluation during course through multiple choice tests in order to determine how well the students know it, as well as how they are able to apply the information in real world settings.

Communication

This feature allows the participants to share knowledge and experience in order to improve the learning process. Moreover, students can work together at the same projects and case studies in the same time.

2.4. LMS – challenges and advantages

The advantages of LMS in learning process are well known by the institutions, which are using the system. At least three major benefits can be identified when a LMS is implemented and use in learning process.

The challenges are also high when a LMS is implemented for more than one programme study. The digital templates for courses, presentations, videos and software applications must cover all aspects related to the development of educational materials. One major challenge is related to harmonization and exchange of information between two learning management systems. Students from different school should be able to exchange information with other colleagues using the features of the LMS.

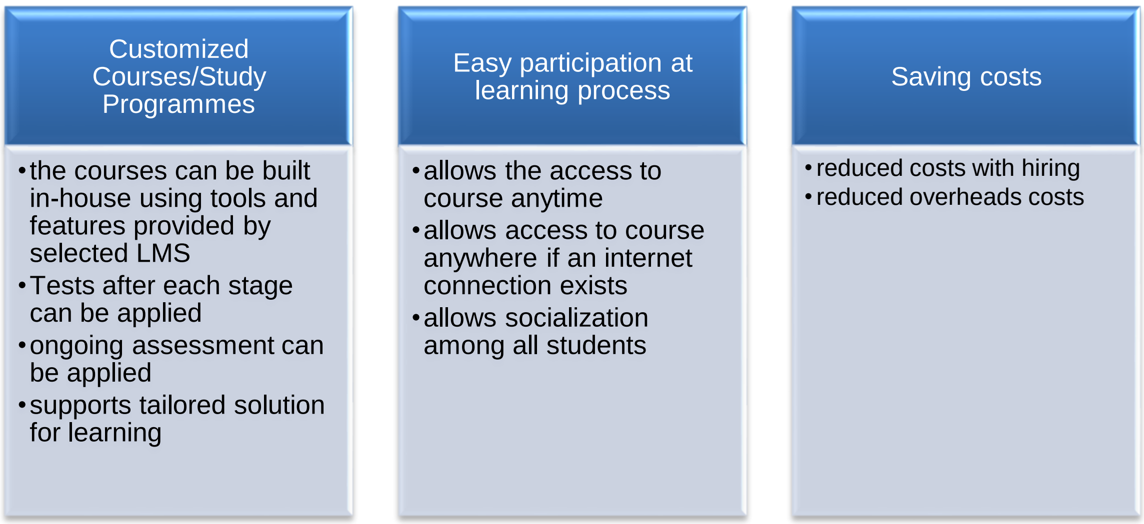


Fig. 2.4 Benefits of using LMS in learning process

2.5. Available solutions for developing LMS

There are several available options regarding the development of a LMSs. The options for developing an LMS are in direct correlation with both the technical aspects (platform, structure, etc.) as well as with the financial ones. A diagram of LMS options is presented below.

Fig. 2.5 LMS – development options

Installed vs Webbased

There is a big difference between LMS installed in your own computer / server as a dedicated application and a learning management system developed on a web platform. Adopting a solution installed on your own server means both the need for adequate technical support and higher costs for installing the application. The technical support and maintenance of the application will be realized by the own personnel, and the financial costs are mainly related to the actual cost of the application. If this application is a customized one then the acquisition costs will be higher. The second option is also the most recommended. Implementing an online LMS will reduce acquisition costs, and the IT staff of the online platform support maintenance. Moreover, LMS is in continuous development and updating, and the costs are borne by those who support the online platform.

Cloud vs Hosted

These options are also important when implementing an LMS. If the HOST variant is adopted then the LMS control is exclusively available to the developer. The advantage of this option is that the LMS developer will have full control over the application and can make all the changes it deems appropriate. However, full control also comes with responsibilities regarding data security and updates available to the server. The second variant, CLOUD, does not provide full control over the application but only its use. From the point of view of the learning process and of the teachers / trainers this option is the best considering that all the attention will be given to the development of the courses, presentations, videos and practical case studies that the users are going to use.

Free vs Commercial

Free LMS are available in a variety of software solutions. If the budget allocated to the development of LMS is a small one then this option is the best one to consider. However, there is a major disadvantage, namely that the installation of the platform and its maintenance will be the responsibility of its own staff. It is recommended to purchase an LMS platform that offers a very good experience in terms of appearance, interface, access to documents, performance evaluation, etc.

Open Source vs Closed Source

Open source software (OSS) is distributed under a licensing agreement which allows computer code to be shared, viewed and modified by other users and organizations. O**pen source software is available for the general public to use and modify from its original design free of charge**. What it means is that a piece of software can evolve and be iterated upon by other developers anywhere in the world. Ideally, this means that the software is improved over time, but it can often take plenty of interesting twists and turns with all of that evolution and can change form and shape entirely. However, the open source software is vulnerable to rogue developers who choose to break things for their own benefit.

Closed source software (CSM) can be defined as proprietary software distributed under a licensing agreement to authorized users with private modification, copying, and republishing restrictions. Generally, the key differentiators between open and closed come down to a few factors:

Fig. 2.6 Key differentiators between OSS and CSM

3. Welding Simulators

The technological evolution has allowed the use of simulators for the training of welded apprentices in order to obtain the necessary skills for insertion in the labour market. Most modern simulators are run by a personal computer and employ software, which enables a variety of processes. These include setting up (i.e. selection of materials, weld type and weld settings), performance assessment, and provision of feedback, in line with the second and third training principles. [5]

3.1. Welding simulators systems

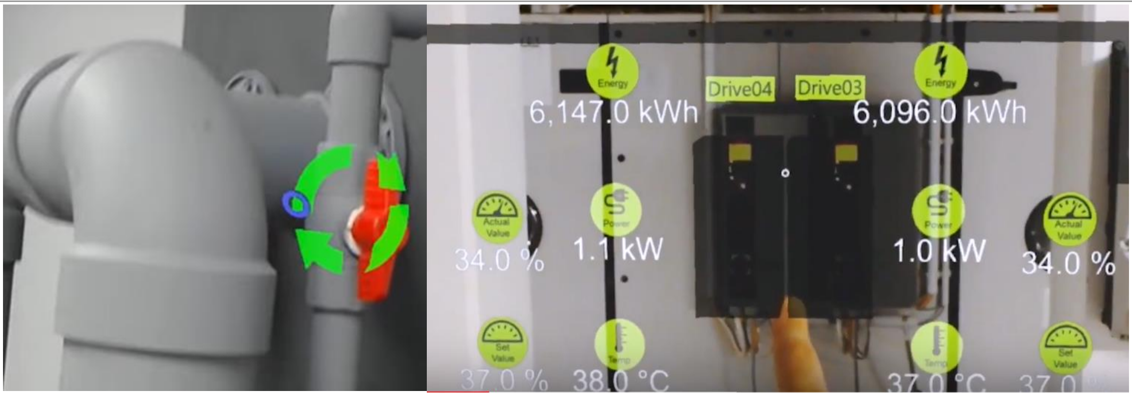
Welding simulators are built using modern technologies like Virtual Reality (VR) or Augmented Reality (AR). These technologies provide the simulator display and visual feedback. In VR systems, a Head Mounted Display (HMD) creates the LVE. The welder cannot see the actual gun and welding surfaces; instead, they see a virtual representation of these projected onto the HMD. In AR systems, a digital image or animation is superimposed on the real image that can be viewed through monitors. Unlike the VR systems, in the AR systems, the welder can see the gun and welding surfaces they are interacting with. In both VR and AR systems, virtual imagery is used to provide visual feedback. A separate monitor is also generally included to allow instructors to view student performance and review feedback after welding completion.

a. b.

Fig. 3.1 AR and VR welding simulators
a. AR welding simulator [6], b. VR welding simulator [7]

3.2. Augmented Reality

Augmented Reality (AR) technology allows the blending the real and virtual worlds. AR applications can translate that particular coded image into a virtual item on the screen. Some camera apps even include the option to add virtual elements to a photo, along with some measure of 3D sensing that allows them to move around the picture as if they were part of the scene. AR is a live direct or composite view of a physical, real-world environment superimposed with virtual elements, which have augmented (enhanced) by computer-generated sensory input such as sound, video, graphics or GPS data. The most common applications known by users are related to QR scanning codes and games such Pokemon Go.



a. b.

Fig. 3.2 Applications of AR technology
a. HoloLens Plant Maintenance, BEApplied Research, [8], b. Phoenix Contact - Augmented reality in use for industry 4.0 and building technology, [9]

The three major components of the AR technology are: hardware, software and a remote server.

Hardware | Software | Remote Server

Fig. 3.3 Basic architecture of AR system

Hardware
Hardware components of an AR system consist of a processor for computational purposes, a display device such Head Mounted Displays (HMD), Smartphone Screen (SS), Eyeglass (EG), an input device which can be a webcam and position sensors such GPS, gyroscope, accelerometer. Also for better interactivity, the AR systems have sensors.

a. b. c.

Fig. 3.4 Displays for AR applications
a. HMD [10], b. SS [11], c. EG [12]

Software
Virtual images, used for overlapping over the real live image, can be generated using 3D software. Software can be AutoCad3D, StudioMax or Cinema4D. CT and MRI data can also be added to the real world. Also, to experience Augmented reality, the end-user has to download a software application or browser plug-in.

Remote Server
The remote server is required for storing the virtual images created using software. The remote server can provide virtual images stored from web or cloud server.

3.3. Virtual Reality

Virtual Reality (VR) technology aims to create realistic 3D environment that user can perceive as real. The user can even interact with in realistic way. The LVE can be created on a display computer or on VR headset (HMD). A VR headset can integrate both hardware and software components and can include only software components but, in this case, a computer is required. A complete VR device should contain the necessary components in order to provide best experience.

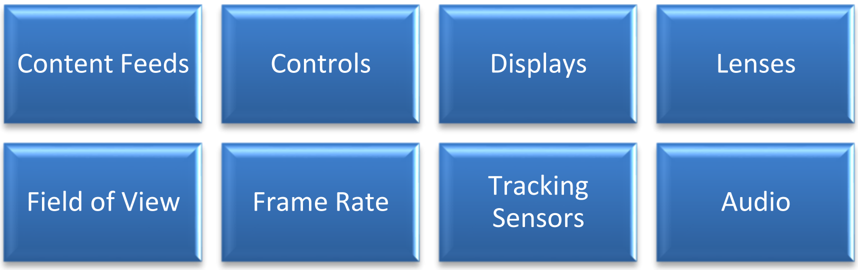


Fig. 3.5 Complete VR system

Content Feeds

Content feeds are supplied by hardware, typically the hardware in a computer, console, or phone. This is data that makes up the digital world, and it needs to come from somewhere. The VR training experience can be achieved within a single app or game. Also, by using VR technologies, students can communicate and share their projects or study cases. According to Google [13], VR content means a computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors.

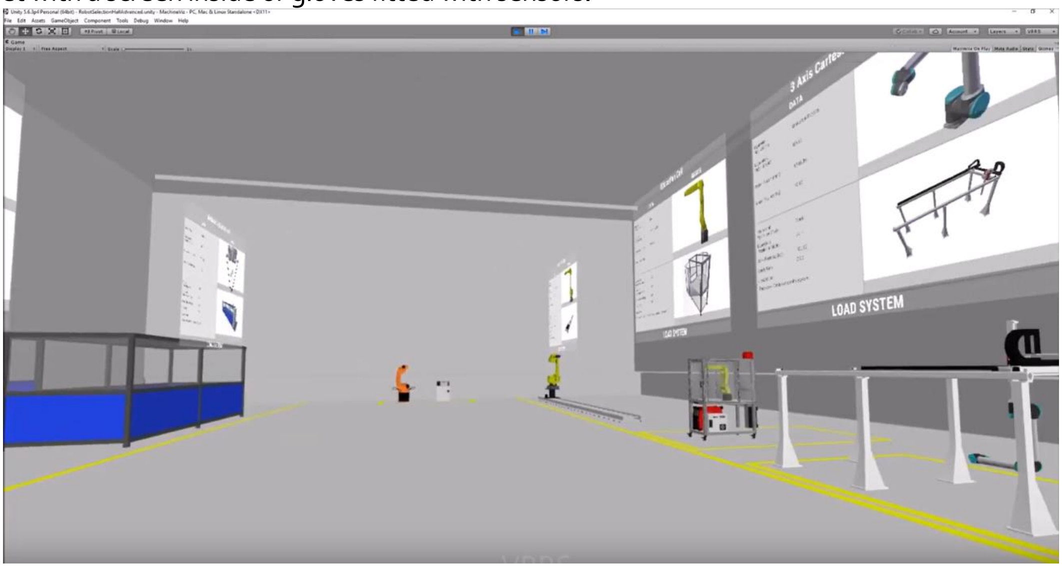


Fig. 3.6 VR content [14]

Controls

Very simple VR headsets allow basic exploration and interaction with a few buttons located on the headset. More advanced headsets offer handheld controllers (Nintendo Wii). The most advanced offer controllers that mimic real devices, such as welding gun and electrodes. They interact directly with the hardware that sends the feed.

Fig. 3.7 VR controls [15]

Displays

The display is where the VR image is pushed out to your eyeballs. In the old days, two separate displays, one for each eye, were included in the goggles, and this remains a popular approach for headsts like the Oculus Rift. But because of the extra cost and components, this is less common these days. Many inexpensive headsets simply use the full smartphone screen as a display, or a single OLED screen. Actually VR welding simulators use displays embedded in welding helmet in order to be more close to real welding.

a. b.

Fig. 3.8 Displays for VR welding simulators
a. Simple smartphone [16], b. VR helmet [17]

Lenses

The role of the lenses in human eyes is to alter the incoming light in a way that it gets focused on our receptors on the back of eyes. The lens bends depending on the distance between eyes and the thing the eye are focusing on. If the user looks at something really close his lenses have to bend a lot to give you a sharp image. If the user look at something in the distance the lens does not need to bend a lot. Many headsets include lenses that help focus the eyes on the screen so that it appears the user is looking into a real environment. This is what allows VR to work on single screens like smartphones have. More advanced versions also allow for lens adjustment, which is very important for both eyestrain and realism.

Field of view

A perfect field of view would, of course, be 360 degrees. Since this isn't possible on a headset, most VR headset creators settle for around 100 to 120 degrees, which helps improve immersion. However if the virtual images are generated on monitors, the 360 degrees view can be achieved.

Frame rate

The higher the frame rate, the better the immersion, so the goal here is frequently 60 FPS to 120 FPS and powerful hardware to back it up. Less ambitious experiences may not worry much about frame rate, but if it starts slowing down then all immersion is lost and headaches often result.

Tracking Sensors

Advanced headsets need to know when the user moves his head, hands, and even body, so they can move the content feed in a similar fashion. So headsets also come with movement sensors on the headset — and sometimes also on additional hardware to map out your space. Most tracking sensors are using magnetic fields which requires an additional power source to generate the current required for operation.

Audio

Audio is either supplied as part of the content feed in the headset itself, or as a separate feed that uses an additional speaker headset that the user needs to wear.

3.4. Difference between welding simulator and real welding system

The use of welding simulation present many differences from real welding system. The following table shows you the most relevant ones:

Welding Simulator

- Practices in an Augmented lab
- Less pollutant
- More safe – Less accidents
- Less costs
- Unlimited AR/VR practices
- Less time
- Reduce the environmental impact
- More qualified welder

Real Welding System

- Practices in small space
- Gas emission
- Burn risks
- Expensive – More money
- Numerous repetitions
- More time
- More emissions
- Less qualified welder

Fig. 3.9 Differences between welding simulator and real welding system

3.5. Set-up of welding simulators

We can find different configurations depends on the manufacturer that we choose. In all cases, the welding simulator includes a complete user manual (pdf-doc, online or both). These tend to be more or less extensive depending on the benefits they offer. For example, the first and one of the most completed welding simulation solution called "SOLDAMATIC" includes an owner´s manual with a dedicated section about set-up tasks. Normally these tasks are grouped in:

General

- Language
- Mode
- Date and Time
- Units
- Standards

Login

- Username
- Password

SOLDAMATIC homepage

- Courses
- Predefined welding practices
- User guides and tutorials
- Open practices for demos

Course selection

- General courses
- Specific courses

Welding parameters

- Welding process
- Joint type
- Position
- Base material
- Thickness
- Filler material type
- Filler metal diameter
- Gas

Welding passes design

- Lenght of weld
- Number of passes
- Weave pattern
- Welding sequence
- Welding technique

Lighting calibration

- More light
- Less light

On-screen guides

Analysis module

- View results
- Clear weld and restart
- Continue weld
- Back to activity selection

Fig. 3.10 Set-up SOLDAMATIC welding simulator

UNIT BIBLIOGRAPHY

[1] Savu SV – Welding simulator, alternative digital tool for practical training of the future welders, ASR Conference, Buzau, 2015
[2] Open source (Moodle based) example: https://themefisher.com/moodle-bootstrap-themes/
[3] Off-the-shelf LMS product: https://learnbox.co.za/off-the-shelf-lms/

[4] University of Craiova, LMS - https://ciso1.central.ucv.ro/evstud/
[5] Susannah J. Whitney, Ashley K. W. Stephens – Use of Simulation to Improve the Effectiveness of Army Welding Training, Commonwealth of Australia, 2014
[6] Soldamatic – Augmented Training for Welding, http://www.soldamatic.com/soldamatic2018/
[7] Lincoln Electric – VRTEX360 Virtual Welding Trainer, https://www.lincolnelectric.com/en-gb/equipment/training-equipment/vrtex360/pages/vrtex-360.aspx
[8] BEApplied Research, HoloLens Plant Maintenance, https://www.youtube.com/channel/UCdXVL3uTXP-icWKB7K2Yivw
[9] Phoenix Contact - Augmented reality in use for industry 4.0 and building technology, https://www.youtube.com/watch?v=UhW12bILH7U
[10] Lily Prasuethsut, Meta thinks Pokémon Go is perfect for the AR headset, https://www.wareable.com/ar/meta-pokemon-go-2962
[11] Industry Reports, Global Augmented Reality Market to Witness a Pronounce Growth During 2024– Top Key players like Google Inc., Microsoft Corporation, Vuzix Corporation, Samsung Electronics Co., Ltd., Qualcomm Inc., Oculus VR, LLC, EON Reality, Inc. Infinity Augmented Reality Inc & Others, https://industryreports24.com/430907/global-augmented-reality-market-to-witness-a-pronounce-growth-during-2024-top-key-players-like-google-inc-microsoft-corporation-vuzix-corporation-samsung-electronics-co-ltd-qualcomm-i/
[12] Husain Sumra, The best augmented reality glasses 2019: Snap, Vuzix, Microsoft, North & more, https://www.wareable.com/ar/the-best-smartglasses-google-glass-and-the-rest
[13] Google, https://virtualrealitypop.com/what-is-real-vr-content-3e66e3810894
[14] MindRend Technologies, VR Robotics Simulator, https://www.youtube.com/channel/UCDWYlQAzV8qlhxa4yXbjmpQ
[15] Fronius Virtual Welding, http://www.funworld.com/en/funworldtech/projects-and-partners/fronius-virtual-welding
[16] Weld VR simulator, http://weld-vr.com/en/
[17] Lincoln Electric VRTEX 360, https://www.lincolnelectric.com/de-de/support/application-stories/Pages/Pitt-Community-College.aspx

GLOSSARY

It includes the main concepts, new and / or complex seen in the unit, as a dictionary.This type of resource is important especially when the course is aimed at students with no knowledge of the subject. Glossary entries are ordered alphabetically.

Welding Processes - GMAW

1.1 Course name

GMAW Welding

1.2 Course duration

5 hours

1.3 Course purpose

In this unit it is showed specific items related to GMAW welding process, specifically related to the welding equipment, welding parameters, typical welding techniques and filler metals used.

The student in this unit will learn notions on welding equipment, parameters, techniques; this will let him/her improve knowledge on GMAW welding process.

1.4 Objectives of the course

Knowledge	Skills	Attitudes
Assume general competences on GMAW welding process	General introduction on GMAW welding process	The students shall, during course, demonstrate good cooperation with teacher and classroom mates, in order to improve knowledge and share informations.
Identify principal components of welding equipment and know about its maintenance	Identify components of welding machine Identify general competence on maintenance	
Improve competence on welding parameters measurement	Identify main parameters of GMAW welding process Measure and control of welding parameters	
Improve competence on shielding gases	Identify shielding gases Choice of correct shielding gas and its main properties	
Improve competence on filler metal	Identify difference on filler metal Choose correct filler metal as a consequence of properties of joint	
Identify transfer modes on GMAW welding process	Apply different transfer modes on welding process Choose the correct transfer mode as a consequence of type of welding	
Identify different welding techniques, with specific explanation on correct way of welding	Assume competence on different welding techniques Know correct welding technique on different welding position	
Improve competence on welding practice	Know how to prepare a piece Have competence on principal welding defects and how to avoid them	

1.5 Contents

1. Introduction

1.1 Principal features

1.2 Principal components

2. Equipment

2.1 Welding power source

2.2 Wire feeder

2.3 Torch

2.4 Contact tip and stick out

2.5 Nozzle

2.6 Mass cable

3. Welding parameters measurement

3.1 Voltage and current

3.2 Travel speed

3.3 Heat input calculation

3.4 Shielding gas flow

4. Consumables

4.1 Shielding gas

4.2 Welding with inert gas

4.3 Welding with active gas

5. Wires

5.1 Solid wires

5.2 Cored wires

6. Parameters and transfer mode

7. Technique

7.1 Parameters

7.2 Position of the torch and stick out

7.3 Travel speed and weaved techniques

8. Welding practice

8.1 Preparation of piece

8.2 Arc trigger

8.3 Welding technique

8.4 End of welding

8.5 Restart of welding

1.6 Participants

Learner characteristics:	Basic technical competences

1.7 Entry requirements

Education level requirement:	Students from VET schools
Previous knowledge needed	Basic knowledge in welding
Age requirements:	16 and 20 years old

1.8 Assessment activities

Summative assessment: nothing required

1.9 Bibliography (used or supplementary)

[1] General course on GMAW welding: IIS training material

UNIT NUMBER: Didactic Unit 2
UNIT TITLE: *Gas Metal Arc Welding (GMAW)*

UNIT PRESENTATION

The present learning unit shows specific items related to GMAW welding process, specifically related to the welding equipment, welding parameters, typical welding techniques and filler metals used. The student in this unit will learn notions on welding equipment, parameters, techniques; this will let him/her improve knowledge on GMAW welding process.

OBJETIVES

The objectives of the teaching unit are:

- Assume general competences on GMAW welding process
- Identify principal components of welding equipment and know about its maintenance
- Identify transfer modes on GMAW welding process
- Improve competence on welding practice

CONTENTS

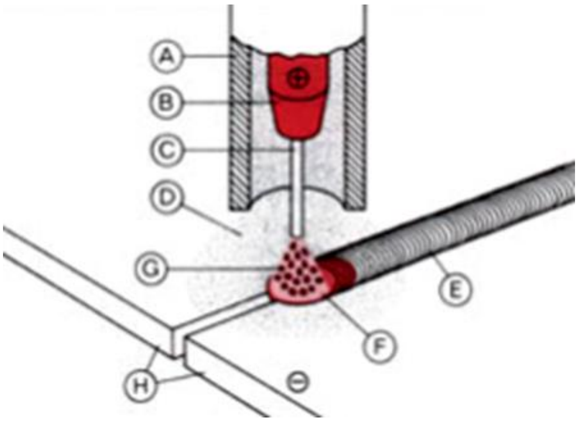
7. Introduction
   - 7.1. Principal features
   - 7.2. Principal components
8. Equipment
   - 8.1. Welding power source
   - 8.2. Wire feeder
   - 8.3. Torch
   - 8.4. Contact tip and stick out
   - 8.5. Nozzle
   - 8.6. Mass cable
9. Welding parameters measurements
   - 9.1. Voltage and current
   - 9.2. Travel speed
   - 9.3. Heat input calculation
   - 9.4. Shielding gas flow
10. Consumables
    - 10.1. Shielding gas
    - 10.2. Welding with inert gas
    - 10.3. Welding with active gas
11. Wires
    - 11.1. Solid wires
    - 11.2. Cored wires
12. Parameters and transfer mode

13. Technique
    - 13.1. Parameters
    - 13.2. Position of the torch and stick out
    - 13.3. Travel speed and weaved techniques
14. Welding practice
    - 14.1. Preparation of piece
    - 14.2. Arc trigger
    - 14.3. Welding technique
    - 14.4. End of welding
    - 14.5. Restart of welding

CONTENTS DEVELOPMENT

1. Introduction

Metal arc welding is a process in which the heat is generated by an arc that is struck between a consumable wire and the piece. Consequently, the wire performs both as an electrode function and as a function of providing material to the joint, since the passage of the current causes its fusion and it is continuously fed into the welding area by a torch (fig. 1).



A – NOZZLE
B – CONTACT TIP
C – WIRE
D – SHIELDING GAS
E – WELDING
F – WELDING POOL
G – ELECTRIC ARC
H – PIECE

Fig.1: scheme of gas metal arc welding

This wire can be solid or cored, that is constituted by a tubular electrode that contains inside a particular flux, which can have different characteristics based on the intended use (figure 2).

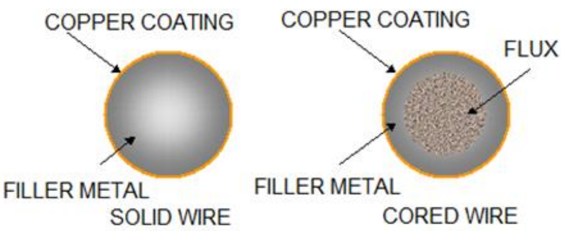


Fig.2: solid and cored welding wire

The protective atmosphere necessary to allow the electric arc to work and to avoid contamination of the welding by the atmosphere can be provided by a gas flowing from the torch (welding under gas protection) or directly from the cored wire, so as is the case for coated electrodes (welding without gas protection).

Consequently, different versions of this process are available, as indicated by the following table which shows, in addition to a synthetic description, the classification according to international standards (EN ISO 4063: 2010) and according to the American terminology AWS A3.0.

Description	Classification	
	EN ISO 4063	*AWS A3.0*
Solid welding wire with inert shielding gas (MIG – Metal Inert Gas)	131	*GMAW*
Solid welding wire with active shielding gas (MAG – Metal Active Gas)	135	*GMAW*
Flux cored arc welding (flux cored), with active shielding gas	136	*FCAW-G*
Flux cored arc welding (metal), with active shielding gas	138	*FCAW-G*
Flux cored arc welding without shielding gas	114	*FCAW-S*

This welding process can also be used in a semi-automatic mode, when the welder handles the torch, both in automatic or robotized mode, when the torch is moved through appropriate systems (motorized beams, welding robots, etc.). Consequently, metal arc welding represents one of the most applied welding processes, thanks above all to the high productivity that can be obtained because of high currents and large quantity of material that can be deposited continuously and without interruptions.

Fig.3: partly mechanized and flully mechanized welding

1.2 Principal components

Figure 3 shows the scheme of a welding plant for gas-protected welding. It includes a power source, a wire feeder device, a flexible torch supply hose (generally 3 m long) and a welding torch.
In particular, the torch cooling water, used for high welding currents, the shielding gas (if provided), and for some particular applications, the welding fumes are also sucked through the torch supply hose.

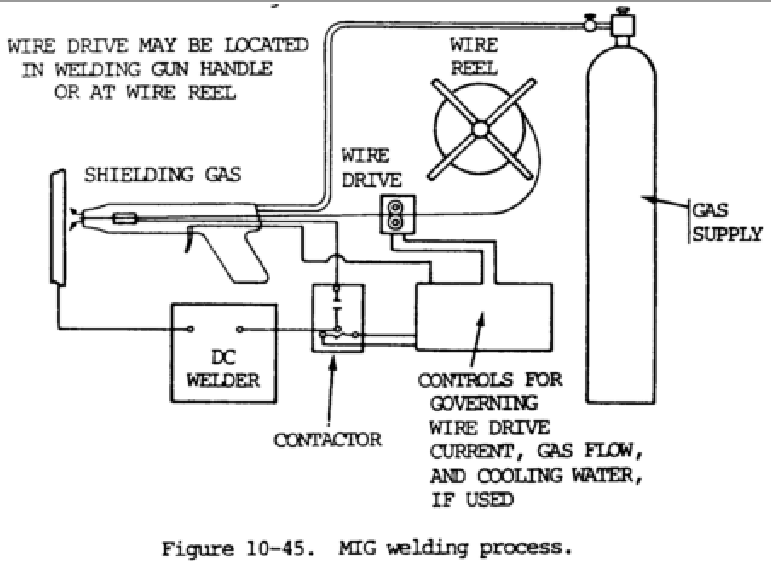


Fig.4: welding wire machine

These elements and their operation will be described in detail in the following chapters, where the characteristics of consumables, executive techniques and the main aspects of safety and accident prevention will also be reported.

2. Equipment

2.1 Welding power source

In gas metal arc welding, the peculiarity of having a wire that is automatically led to the torch, e.g. without direct control of the welder, determines the need to have constant voltage power sources; this is related both to the fact that the triggering of the arc is possible also for modest values of the no-load voltage, and to the fact that this characteristic allows, thanks to the particular operating system of the process, to keep the welding current strictly linked to the wire feed speed.
Consequently, in the power sources for wire welding there is no current command (measured in Ampére), since this is set directly with the wire feed speed, while there is a voltage regulation command (measured in Volts), which acts on the power source operating characteristic (fig. 5).

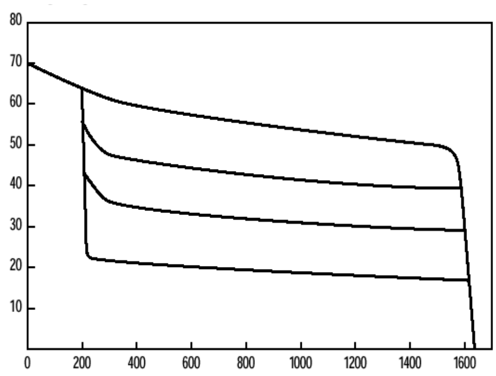


Fig.5: characteristic curve of a welding power source

As regards instead the types of power sources, we can consider the dynamos (now not longer used), the transformers-rectifiers (cheaper and more reliable) and electronically controlled machines or inverters (more expensive and lighter).

The latter, in particular, are machines characterized by relatively low weight and size, combined with considerable versatility, since they allow welding with particular techniques (for example the pulsed arc - see chapter 4) and with an automatic management of the parameters. However, it must be considered that these machines can often present greater difficulty in the use of the commands, as these are generally complex, so that programs pre-set by the manufacturer are generally used.

With regard to the arc supply mode, alternating current is rarely used, which causes instability of operation of the arc due to current and voltage fluctuations, while the use of direct current reverse polarity (or DC reverse) is preferred, e.g. with the positive polarity connected to the clamp and the negative one connected to the piece, which guarantees a more stable operation and better transfer of the filler material from the electrode to the pool.

2.2 Wire feeder

The wire feeder device is one of the most important elements for the equipment; in fact it must allow a regular advancement of the wire inside the line that leads to the torch, through the torch itself and up to the electric arc. A system malfunction (wire jamming, irregular wire speed) would certainly lead to the emergence of operational difficulties or even welding defects.

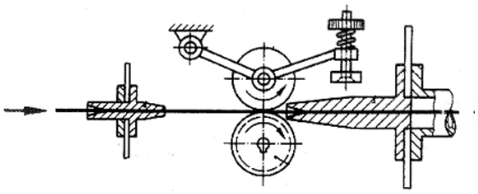


Fig.8: wire feeding system

In some cases, for example when welding with soft materials (such as aluminum) or with particularly high torch supply hose lengths (e.g. above the classic 3 meters), the advance motor can also be present on the torch (push-pull systems), from which it will also be possible to adjust the wire feed speed.

Finally, the choice of the pressure to be exerted on the wire through the contact spring and the geometry of the rollers is fundamental, in order not to deform the wire avoiding consequently jamming of the same inside the wire line. Figure 9 shows two typical geometry of the rollers used for welding steels and aluminum.

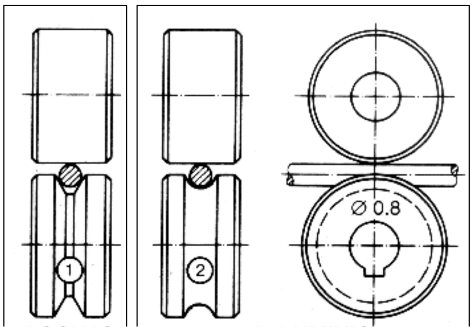


Fig.9: different feeding system for steel (left) and aluminium (right)

2.3 Torch

There are different types of torches; however the most common ones are the "goose-neck" ones, like the one presented in figure 10.

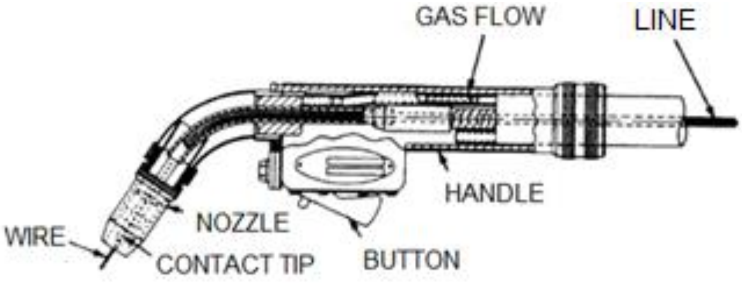


Fig.10: torch

When using high current values, the torches are also characterized by water cooling systems to prevent the torch from overheating.

2.4 Contact tip and stick out

The contact tip (figure 11) has the purpose of conducting the wire regularly and bringing the electrical power to the wire; it is therefore particularly important that this device has a diameter corresponding to the wire used (generally it is constructed with hole diameters greater than a few tenths of a millimeter with respect to the wire), and does not present excessive wear.

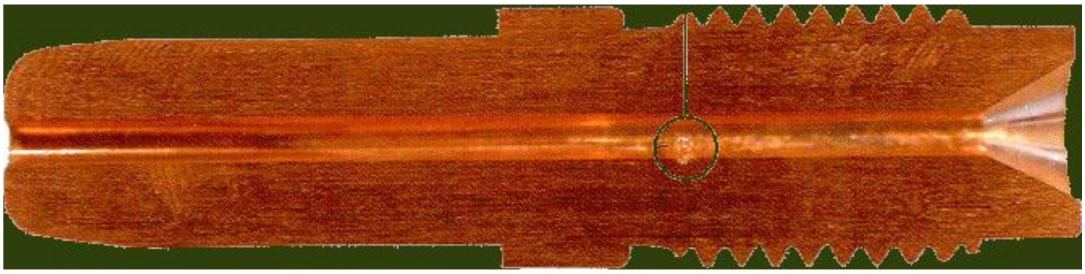


Fig.11: contact tip

It should also be noted that only the length of wire running from the contact tip to the electric arc is crossed by a current (fig. 12); this section is referred to as a stick-out or free length of the wire and is particularly important in welding, as it directly affects the welding current and consequently the penetration (which decreases as this parameter increases).

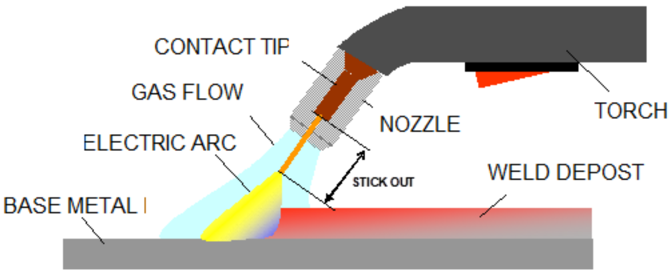


Fig.12: stick out

This parameter is managed directly by the welder, which increases its extension simply by removing the torch (consequently decreasing the current and depth of penetration) and decreasing its extension by acting vice versa.

2.5 Nozzle

The shielding gas nozzle can have different diameters depending on the gas flow rate, and variable lengths, since longer nozzles are needed when welding with particularly high stick out values.

Finally, it is very important to avoid that during the welding period the status of the nozzle periodically occurs, in order to avoid the blocking of the nozzle due to spatters of material (which appear as a series of glued "pellets"), in order to ensure a laminar flow of shielding gas, thus reducing the risk of porosity in the welding pool.

In general, nozzles of different lengths can also be commercially available, as those with greater extensions are useful for protecting the welding pool when working with high stick out values.

2.6 Workpiece cable

The ground cable connects the power source to the piece, thus closing the electrical circuit. Consequently, the following considerations apply:

- since in the circuit current losses must not occur, which would result in loss of process efficiency, the workpiece connection must always be firmly attached to the piece (strong attachments are strongly recommended, such as metal elements simply placed on the pieces, or sockets of mass connected to the positioning template);

- since in the lead runs the same intensity of current used for welding, it is advisable that the workpiece cable has a suitable section and also in good condition and not frayed or damaged;

- since the heat produced by the passage of current increases as the current increases, the point where the workpiece clamp is placed may be subject to overheating, especially if the clamp is not fixed properly.

Furthermore, the operation of the electric arc can be subject to strong deviations, called "magnetic blow", due to the magnetic action of the current passing from the arc to the piece, up to the workpiece clamp (fig. 13).

This is generally possible for any type of material (both magnetic and "non-magnetic"), moreover the phenomenon tends to develop with a certain ease in the case of a welding near one end of the piece in the welding of low-alloy steels.

The consequence can be a considerable disturbance to the welder, making it very difficult to control the welding pool, and can lead to the onset of serious welding defects (eg lack of fusion, gaseous inclusions).

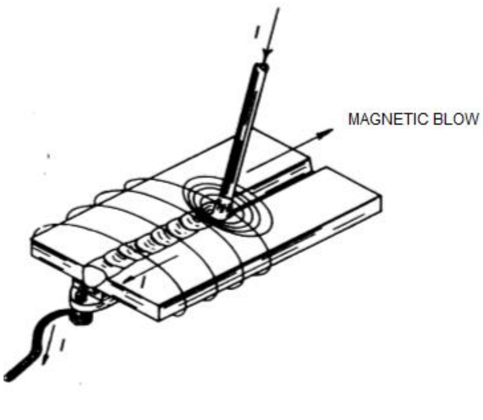


Fig.13: magnetic blow

To minimize the disturbance caused by the magnetic flux (which occurs only in the welding with direct current) it is necessary to correctly position the workpiece clamps in order to favor situations in which the current runs in a symmetrical way through the piece, as shown for example by the figure 14. As an alternative, it is possible to consider the alternating current supply which eliminates the problem, even if, as already mentioned, problems of instability of the arc can arise.

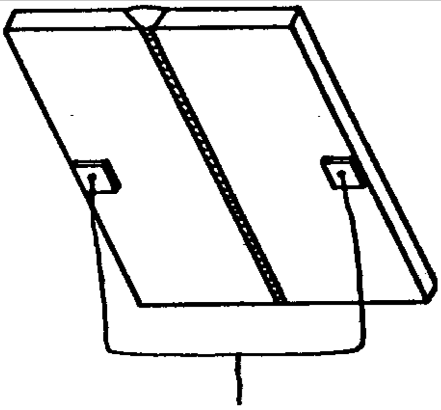


Fig 14 workpiece clamps positioning

3. Welding parameters measurement

During the welding operations, it is important to evaluate the main parameters, in order to verify that these are the optimal ones (for example evaluated with the qualification of the welding procedure), obviously kept within appropriate tolerance.

3.1 Voltage and current

The tools to measure these welding parameters are:
- the voltmeter (to measure the voltage, in Volts)
- the ammeter (to measure the current, in Amperes)

These instruments are generally incorporated in the welding machines, even if for specific applications (for example the qualification of the welding process) it may be necessary to use separate instruments, of greater precision and possibly suitably calibrated.
The next figure shows the Volt-Amperometric clamp, which is certainly the most used tool for these operations.

Fig.6: voltamperometric clamp

3.2 Travel speed

This parameter is generally measured in centimeters of welding carried out in one minute.
The measurement is therefore quite comfortable, as it is sufficient to measure the distance traveled with a centimeter during a welding minute, marked by a chronometer.

3.3 Heat input calculation

A very important parameter from the welding point of view is the so-called "specific heat input", an indication of how much the joint is heated during welding. It depends on the voltage and current parameters, and on the welding speed.

The heat input is generally indicated by the symbol Q1, or by the acronym H.I and is measured in Joules per centimeter [J / cm]; it is derived from the following formula:

$$Q_1 = \frac{\text{Volt} \times \text{Ampere}}{\text{cm/min}} \times 60$$

For example, welding with a current of 300 amperes, a voltage of 24 volts and a welding speed of 36 cm / min yields a heat input of 12,000 J / cm sometimes expressed as 12 kJ / cm or 1.2 kJ / mm.

However, some regulations, such as EN 1011 and EN ISO 15614 consider a multiplicative factor of 0.8 to calculate the heat input, to assess the amount of heat dissipated during welding in gas heating, and in the amount of light issued. In this case, with reference to the previous example, a heat input of 9600 J / cm (or 0.96 kJ / mm) is obtained.

3.4 Shielding gas flow

The flow rate of shielding gas is generally set by acting on the flow meter located near the gas cylinder or the connection to the gas line supply.

Furthermore, it can be carried out, before welding, using a simple instrument (called portable flow meter), which rests directly on the torch. It consists of a transparent tube, which shows a graduated scale, inside which a small steel sphere is pushed by the shielding gas, thus indicating a flow rate (fig. 7).

It is very important that this instrument is the one envisaged for the type of shielding gas considered, in order to have a reliable measurement of the flow rate. For example figure 7 shows a flowmeter that shows two scales, one for shielding gas Ar and one for CO_2 gas.

Fig 7: portable flow meter

4. Consumables

4.1 Shielding gas

During welding, the shielding gas coming from the torch performs two essential tasks:

- favors the functioning of the electric arc of welding, creating an atmosphere that is more stable than air;
- protects the welding pool from air, whose characteristics could also be seriously affected by elements such as oxygen, hydrogen, nitrogen, etc.

In the case in which, instead, wires are used for welding without gas, instead the flow contained in the wires will generate a suitable gaseous atmosphere, the effect of which will in principle be equivalent to that of the external shielding gas.

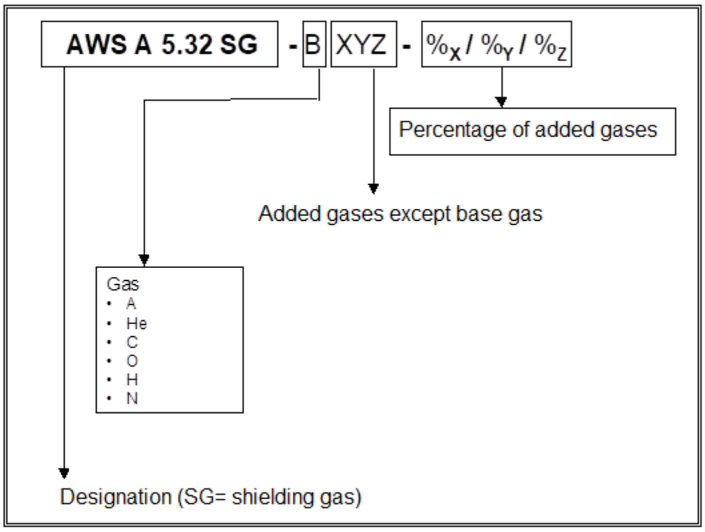
In general, welding gases can be divided into two main categories:

- inert gases, which are argon (chemical symbol Ar), helium (chemical symbol He), or mixtures between the two gases;

- active gases, which are all mixtures also containing very small percentages of gases other than argon and helium, such as carbon dioxide (chemical symbol CO_2), oxygen (indicated by the symbol O_2), nitrogen (indicated by the symbol N_2) or hydrogen (indicated by the symbol H_2); this category also includes pure carbon dioxide, often used in welding with cored wires.

Table shows an extract of the European standard EN ISO 14175, concerning the classification of gases used for welding and cutting of metallic materials, which will be discussed in detail in the following paragraphs.

Symbol		Elements in %						Notes
Group	Ident.	Oxidizing		Inerts		Reducing	Not reactive	
		CO_2	O_2	Ar	He	H_2	N_2	
R	1			Bal.		0÷15		Reducing
	2			Bal.		15÷35		
I	1			100				Inert
	2				100			
	3			Bal.	0÷95			
M1	1	0÷5		Bal.				Lightly oxidizing
	2	0÷5		Bal.				
	3		0÷3	Bal.				
	4	0÷5	0÷3	Bal.				
M2	1	5÷25		Bal.				Oxidizing
	2		3÷10	Bal.				
	3	0÷5	3÷10	Bal.				
	4	5÷25	0÷8	Bal.				
M3	1	25÷50		Bal.				Highly oxidizing
	2		10÷15	Bal.				
	3	5÷50	8÷15	Bal.				
C	1	100						Oxidizing
	2	Resto	0÷30					
F	1						100	Not reactive
	2					0÷50	Resto	Reducing



4.2 Welding with inert gas

In solid-wire welding, using inert gases, the term MIG (acronym for Metal Inert Gas) is also used to indicate this welding process.

These gases are characterized by the minimum effect on the welding pool as:
- they are insoluble in the molten pool, reducing the risk of porosity only to contamination of the weld pool atmosphere by the air or dirt present on the edges
- they are inert from the chemical point of view, so whatever the composition of the wire, it is found unchanged in the deposit

- generate a stable arc.

Since the high cost of these gases, their use is limited to cases where it is absolutely necessary, such as for example in welding aluminum and light alloys.

The characteristics of the welding are however influenced by the percentages of argon and helium contained, as described below.

Welding with pure Argon (EN ISO 14175 - I1)

The characteristics of this gas allow a good stability of the arc and, consequently, a considerable regularity in the transfer of the filler material.

From the operational point of view, this gas allows to have a cold welding pool, that is poorly fluid, and therefore more easily manageable. Furthermore, the gas is heavier than air, and consequently it is necessary, depending on the operating conditions:

- when welding in frontal PC position, weld with the torch slightly tilted upwards (a few degrees), to ensure effective protection of the upper part of the pool;
- in the overhead position, use slightly increased gas flow rates to compensate for the downfall of the gas.

The argon finally determines a shape of the typical cordon, with "finger" penetration (fig. 16); since the poor width of the bead, gluing problems can also occur for excessively high welding speeds.

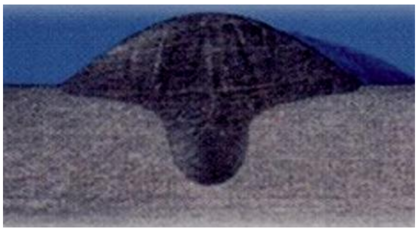


Fig. 15: welding with Ar

Welding with pure helium (EN ISO 14175 - I2)

The characteristics of this gas make the arc more unstable than what was seen for the argon; this means that for each gas flow, the current required for the arc in a helium atmosphere is greater than that in an argon atmosphere. Consequently, being the greater the electric energy (or the power) consumed, a hotter pool is obtained, useful for example on high thicknesses or when it is desired to work with high welding speeds.

Helium has densities lower than that of argon, so:
- it is needed twice gas flow than to those of the argon, to have the same protective effect;
- in the overhead position, gas flows slightly lower than the plane are sufficient, thanks to the natural rise of the gas upwards;
- it may be useful, in frontal welding PC, to weld with the torch slightly tilted upwards (a few degrees), to ensure effective protection also of the lower part of the pool
Finally, the argon determines a shape of the typical cordon, with "goblet" penetration (fig. 16), a situation that also allows welding at high speeds.

Since the high thermal power of the arc with this gas, it is used as a pure protection gas in automatic welding plants, where higher executive speeds are possible.
Finally, it should be emphasized that helium costs about twice as much as argon and, given the higher flow rates that are necessary, the cost of welding operations is often very high.

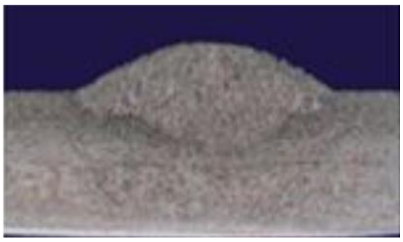


Fig. 16: welding with He

Welding with Argon - He mixtures (EN ISO 14175 - I3)

The purpose of these mixtures is to achieve a compromise between the two gases described above; consequently, good penetrations (helium) are obtained but with good transfer characteristics of the filler material (Argon).

Very different mixtures are therefore commercially available, containing helium in percentages generally ranging from 10% to 80%.

4.3 Welding with active gas

In solid-wire welding, using active gases, the term MAG (acronym for Metal Active Gas) is also used to indicate this welding process.

All the gases that cause any effect on the chemical composition of the welding pool are active gases; therefore all the gases or the excluded argon, helium and their mixtures are considered active.

In general, the use of active gases in welding is linked to obtaining beneficial effects in terms of welding productivity or operative ease.

Welding with pure CO_2 or CO_2-based mixtures (EN ISO 14175 - C1 and C2)

Carbon dioxide can be added, in very high percentages, to obtain a more hot and penetrating welding pool; therefore the gas allows very high welding speeds and consequently high productivity.
However, this gas has some negative effects, including:
- a certain arc instability, so it is difficult to have regular transfer of the filler material, and several spatters in welding
- very marked contamination of the weld pool (oxidation), which makes the mixture unusable on particularly oxidizable materials (e.g. chromium-rich steels).

For these reasons this protective atmosphere is generally used only with cored wires (which allow greater regularity of deposit) and on unalloyed steels.

Welding with inert gas-based mixtures and with the addition of active gases (EN ISO 14175 –M11 ▯ M34)

Since the instability of the use of carbon dioxide-based mixtures, argon-CO_2 mixtures are often used to achieve compromise results, thus managing to obtain good stability (solid wires are also often used) and also good productivity.

In the case of easily oxidizable materials (such as stainless steels or all chromium-rich steels), gas mixtures containing small percentages of carbon dioxide (less than 5%) are used to make the pool more fluid and transfer more regular.

In addition to what we have seen, other gases may be present in small percentages (never more than 5% in total), for some specific purposes:
- oxygen, to smooth the weld bead and reduce spatters;

- hydrogen (only for stainless steels, of austenitic type); to obtain a less oxidized bead and higher welding speeds;
- nitrogen (only for austenitic - ferritic stainless steels), used in very small percentages to obtain specific metallurgical effects.

5. Wires

In continuous wire welding, the filler material is brought to the torch by the advance motor that unrolls it from a spool. Independent from the type of material and wire considered, the unrolling is important, which must be regular, without bending, to avoid uneven or irregular advancement, which could cause excessive fluctuations in the welding current values (current is correlated to the wire advancement speed). In general, the wires have a copper or nickel covering, or in any case supplied with a special surface treatment to facilitate the electrical contact in the current-carrying tube and also, where necessary, to avoid oxidation of the wire.

As already mentioned in chapter 1, it is possible to distinguish between solid and cored wires, whose characteristics will be described in the following paragraphs; the table shows, instead, the expected diameters and relative tolerances, based on the European standard UNI EN 544.

<table>
<tr><th rowspan="2">DIAMETER [mm]</th><th colspan="2">TOLERANCE [mm]</th></tr>
<tr><th>SOLID</th><th>CORED</th></tr>
<tr><td>0,6</td><td>+0,01
-0,03</td><td rowspan="4">-</td></tr>
<tr><td>0,8</td><td rowspan="10">+0,01
-0,04</td></tr>
<tr><td>0,9</td></tr>
<tr><td>1,0</td></tr>
<tr><td>1,2</td><td rowspan="8">±0,04</td></tr>
<tr><td>1,4</td></tr>
<tr><td>1,6</td></tr>
<tr><td>1,8</td></tr>
<tr><td>2,0</td></tr>
<tr><td>2,4</td></tr>
<tr><td>2,5</td></tr>
<tr><td>2,8</td><td rowspan="4">+0,01
-0,07</td></tr>
<tr><td>3,0</td><td rowspan="3">±0,06</td></tr>
<tr><td>3,2</td></tr>
<tr><td>4</td></tr>
</table>

5.1 Solid wires

In solid-wire welding, the characteristics of the deposit are directly related to the chemical composition of the wire. Consequently, there are no operational differences between the different types of wire, except for the characteristics of the individual welded metals. From the classification point of view, the European and American (AWS) classification regulations are summarized in the following table.

Materials	Norma EN	Norma AWS
Carbon and low alloy steels	EN ISO 14341	AWS A5.18
Creep resistant steels	EN ISO 21952	AWS A5.28
Stainless steel	EN ISO 14343	AWS A5.9
High strength steels	EN 13347	AWS A5.28
Aluminium	ISO 18273	AWS A 5.10
Nickel and nickel alloys	ISO 18274	AWS A 5.14
Copper	EN 13347	AWS A5.7
Iron	ISO 1071	AWS A5.15

As an example, tables 6 and 7 also show a diagram relating to the European classification of solid wires for welding carbon and fine grain steels.
Table 8 refers instead to the AWS classification of wires for welding carbon steels, while Table 9 refers to that of wires for welding stainless steels.

EN ISO 14341	G	46	3	M	G3Si1

Welding process (G)

Chemical composition (G3Si1)

Mechanical properties of weld deposit			
	Rs [MPa]	Rm [MPa]	All. %
35	350	440÷570	22
38	380	470÷600	20
42	420	500÷640	20
46	460	530÷680	20
50	500	560÷720	18

Shielding gas	
M	Active mixtures (M21 - M24)
C	Mixtures based on CO_2

Impact test: 47 J	
SYMBOL	TEMPERATURE [°C]
Z	No request
R	+20
0	0
2	-20
3	-30
4	-40
5	-50
6	-60

Symbol	Chemical composition %								
	C	Si	Mn	P	S	Ni	Mo	Al	Ti+Zr
G0	Any further chemical composition not envisaged by the legislation								
G2Si	0,06÷0,14	0,50÷0,80	0,90÷1,30	0,025	0,025	0,15	0,15	0,02	0,15
G3Si1	0,06÷0,14	0,70÷1,00	1,30÷1,60	0,025	0,025	0,15	0,15	0,02	0,15
G4Si1	0,06÷0,14	0,80÷1,20	1,60÷1,90	0,025	0,025	0,15	0,15	0,02	0,15
G3Si2	0,06÷0,14	1,00÷1,30	1,30÷1,60	0,025	0,025	0,15	0,15	0,02	0,15
G2Ti	0,04÷0,14	0,40÷0,80	0,90÷1,40	0,025	0,025	0,15	0,15	0,05÷0,20	0,05÷0,25
G3Ni1	0,06÷0,14	0,50÷0,90	1,00÷1,60	0,020	0,020	0,80÷1,50	0,15	0,02	0,15
G2Ni2	0,06÷0,14	0,40÷0,80	0,80÷1,40	0,020	0,020	2,10÷2,70	0,15	0,02	0,15
G2Mo	0,08÷0,12	0,30÷0,70	0,90÷1,30	0,020	0,020	0,15	0,40÷0,60	0,02	0,15
G4Mo	0,06÷0,14	0,50÷0,80	1,70÷2,10	0,025	0,025	0,15	0,40÷0,60	0,02	0,15
G2Al	0,08÷0,14	0,30÷0,70	0,90÷1,30	0,025	0,025	0,15	0,15	0,35÷0,75	0,15

AWS A5.18	ER	70	S	6

Wire or TIG rod (ER)

Solid wires (S)

Tensile strength (Shielding CO_2)			
Rm [Ksi]	Rm [MPa]	Rs [MPa]	All %
70	500	420	22

DEPOSIT					
N°	Chemical composition				Impact
	C	Mn	Si	Other	
2	0,07 Max	0,9÷1,4	0,4÷0,7	Ti = 0,05÷0,15 Zr = 0,02÷0,12 Al = 0,05÷0,15	27 J a -29°C
3	0,06÷0,15	0,9÷1,4	0,45÷0,7		27 J a -18°C
4	0,07÷0,15	1,0÷1,5	0,65÷0,85		--
5	0,07÷0,19	0,9÷1,4	0,3÷0,6	Al = 0,05÷0,9	--
6	0,07÷0,15	1,4÷1,85	0,8÷1,15		27 J a -29°C
7	0,07÷0,15	1,5÷2,0	0,5÷0,8		
P=0,025 Max, S=0,035 Max, Cu=0,5Max					

AWS A5.9	ER	308 Mo

Welding wire or TIG rod

Chemical composition

CLASS	C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu	Other
209	0.05	20.5-24.0	9.5-12.0	1.5-3.0	4.0-7.0	0.90	0.03	0.03	0.10-0.30	0.75	V 0.10-0.30
218	0.10	10.0-18.0	8.0-9.0	0.75	7.0-9.0	3.4-4.5	0.03	0.03	0.08-0.18	0.75	--
219	0.05	19.0-21.5	5.5-7.0	0.75	8.0-10.0	1.00	0.03	0.03	0.10-0.30	0.75	--
240	0.05	17.0-1q.0	4.0-6.0	0.75	10.5-1.3.5	1.00	0.03	0.03	0.10-0.30	0.75	--
307	0.04-0.14	19.5-22.0	8.0-10.7	0.5-1.5	3.3-4.75	0.30-0.65	0.03	0.03	--	0.75	--
308	0.08	19.5-22.0	9.0-11.0	0.75	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
308H	0.04-0.08	19.5-22.0	9.0-11.0	0.50	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
308L	0.03	19.5-22.0	9.0-11.0	0.75	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
308Mo	0.08	18.0-21.0	9.0-12.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
30LMo	0.04	18.0-21.0	9.0-12.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
308Si	0.08	19.5-22.0	9.0-11.0	0.75	1.0-2.5	0.65-1.00	0.03	0.03	--	0.75	--
308LSi	0.03	19.5-22.0	9.0-11.0	0.75	1.0-2.5	0.65-1.00	0.03	0.03	--	0.75	--
309	0.12	23.0-25.0	12.0-14.0	0.75	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
309L	0.03	23.0-25.0	12.0-14.0	0.75	1.0-2-5	0.30-0.65	0.03	0.03	--	0.75	--
309Mo	0.12	23.0-25.0	12.0-14.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
309LMo	0.03	23.0-25.0	12.0-14.0	2.0-3.0	1-0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
309Si	0.12	23.0-25.0	12.0-14.0	0.75	1.0-2.5	0.65-1.00	0.03	0.03	--	0.75	--
309LSi	0.03	23.0-25.0	12.0-14.0	0.75	1.0-2.5	0.65-1.00	0.03	0.03	--	0.75	--
310	0.08-0.15	25.0-28.0	20.0-22.5	0.75	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
312	0.15	28.0-32.0	8.0-10.5	0.75	1.0-2.5	0-30-0.65	0.03	0.03	--	0.75	--
316	0.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
316H	0.04-0.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
316L	0.03	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
316Si	0.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.65-1.00	0.03	0.03	--	0.75	--
316LSi	0.03	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.65-1.00	0.03	0.03	--	0.75	--
317	0.08	18.5-20.5	13.0-15.0	3.0-4.0	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
317L	0.03	18.5-20.5	13.0-15.0	3.0-4.0	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
318	0.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	Nb 8 x C min I.0 max
320	0.07	19.0-21.0	32.0-36.0	2.0-3.0	2.5	0.60	0-03	0.03	--	3.0-4.0	Nb 8 x C min I.0 max
320LR	0.025	19.0-21.0	32.0-36.0	2.0-3.0	1-5-2.0	0.15	0.015	0.02	--	3.0-4.0	Nb 8 x C min I.0 max
321	0.08	18.5-20.5	9.0-10.5	0.75	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	Ti 9 x C min/I.0 max
330	0.18-0.25	15.0-17.0	34.0-37.0	0.75	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	--
347	0.08	19.0-21.5	9.0-11.0	0.75	1.0-2.5	0.30-0.65	0.03	0.03	--	0.75	Nb 10 x C min/1.0 max
347Si	0.08	19.0-21.5	9.0-11.0	0.75	1.0-2.5	0.65-1.00	0.03	0.03	--	0.75	Nb 10 x C min/I.0 max
383	0.025	20.5-28.5	30.0-33.0	3.2-4.2	1.0-2.5	0.50	0.02	0.03	--	0.70-1.5	--
385	0.025	19.5-21.5	24.0-26.0	4.2-5.2	1.0-2.5	0.50	0.02	0.03	--	1.2-2.0	--
409	0.08	10.5-13.5	0.6	0.50	0.8	0.8	0.03	0.03	--	0.75	Ti 10 x C min/I.5 max
409Cb	0.08	10.5-13.5	0.6	0.50	0.8	1.0	0.04	0.03	--	0.75	Nb 10 x C min/0.75 max
410	0.12	11.5-1.3.5	0.6	0.75	0.6	0.5	0.03	0.03	--	0.75	--
410NiMo	0.06	11.0-12.5	4.0-5.0	0.4-0.7	0.6	0.5	0.03	0.03	--	0.75	--

5.2 Cored wires

The cored wires consist of a tubular element which contains a flux or metal powder inside (fig. 18); the main advantage is that of obtaining greater process efficiency (for the same current a cored wire deposits more material than a solid wire) and a greater arc stability.

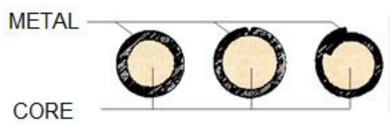


Fig.17: flux cored wires

During welding, the flow contained inside the wire melts, ends up in the melting pool and, thanks to its fluidity properties, it floats on the pool producing in general a slag (fig. 18) that must be removed between the runs.

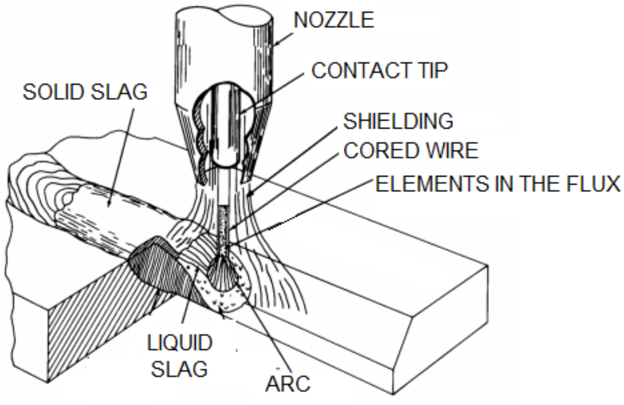


Fig.18: flux cored arc welding

Based on the substances contained in the flux or metal powder, it is possible to distinguish different types of cored wire:
- rutile cored wires; they are the most used because they allow an excellent regularity of deposit, and high arc stability (they are also used with pure CO_2);
- basic cored wires; they allow to obtain excellent welding properties, thanks to the formation of a relatively thick layer which has the purpose of purifying the molten area from impurities;
- metal-filled cored wires (metal cored); they have the highest yield ever, since the core contains essentially metallic powder and consequently produces very little scald; they are widely used in welding with pure CO_2;
- self-protected cored wires for gas-free welding (self-shielded); they are used on site and in general where there is a concern about the presence of air drafts which could eliminate the gaseous protection of other types of welding, and where the absence of systems for supplying shielding gases simplifies their use; however, they produce levels of welding fumes that are clearly superior to other types of wire.

Because of the complex production techniques necessary for their manufacturing, the animated wires have a higher cost than the solid ones.

The following table lists the main European and American AWS standards currently available for the classification of cored wires; Table 11 refers to the AWS classification of cored wires (with or without shielding gas) for welding low-alloy steels; Table 12 refers instead to the European classification.

Material	EN	AWS
Carbon and fine grain steels	EN ISO 17632	AWS A 5.20
Creep resistant steels	EN ISO 17634	AWS A 5.29
Stainless steel	EN ISO 17633	AWS A 5.22
High strength steels	EN ISO 18276	AWS A 5.29

AWS A5.20	E	7	0	T	-	6	M	J	H4

Wire for flux cored welding

Mechanical properties			
	Rm [ksi]	Rm [Mpa]	Rs[Mpa]
6	60	415	330
7	70	480	400

Welding position	
0	Piano ed orizzontale
1	Tutte le posizoni

Tubular cored

Diffusive Hydrogen [Hdm]	
H4	< 4 ml/100 g
H8	4 ÷ 8 ml/100 g
H16	8 ÷ 16 ml/100g

Impact values
47J a –20°C

Shielding gas	
-	CO_2 pura o senza gas (vedere *)
M	Miscela Ar + CO_2 (20% ÷ 25%)

* **Chemical composition and impact test properties**

EN17632	T	46	3	1Ni	B	M	4	H5

Tubular cored wire

Mechanical properties*			
	Rs [MPa]	Rm [MPa]	All. %
35	350	440÷570	22
38	380	470÷600	20
42	420	500÷640	20
46	460	530÷680	20
50	500	560÷720	18

Impact: 47 J	
Symbol	TEMPERATURE [°C]
Z	--
R	+20
0	0
2	-20
3	-30
4	-40
5	-50
6	-60

Chemical composition			
Symbol	Mn	Ni	Mo
None	2,0	-	-
Mo	1,4	-	0,3÷0,6
MnMo	1,4÷2,0	-	0,3÷0,6
1Ni	1,4	0,6÷1,2	
1,5Ni	1,6	1,2÷1,8	
2 Ni	1,4	1,8÷2,6	
3 Ni	1,4	2,6÷3,8	
Mn1Ni	1,4÷2,0	0,6÷1,2	
1NiMo	1,4	0,6÷1,2	0,3÷0,6
Z	Any other		

Diffusive Hydrogen (Hdm)	
H3	< 3 ml/100g
H5	3 ÷ 5 ml/100g
H10	5 ÷ 10 ml/100g
H15	5 ÷ 10 ml/100g

Welding position	
1	All
2	1) except PG
3	PA e PB
4	PA
5	3) and PG

Shielding	
M	Active mixtures (M21 - M24)
C	Mixture base CO_2
N	No shielding

Flux features			
	Chemical	Single or multi-pass	Shielding
R	Rutile – slow freezing	S e M	Required
P	Rutile – fast freezing	S e M	Required
B	Basic	S e M	Required
M	Metal cored	S e M	Required
V	Fluoride – basic	S*	Not req.
W	Fluoride – basic slow freezing	S e M	Not req.
Y	Fluoride – basic fast freezing	S e M	Not req.
S	Other	S e M	Not req.

* **Mechanical properties**

	Ys BM (min.)	Ys weld deposit
3T	355 Mpa	470 Mpa
4T	420 Mpa	520 Mpa
5T	500 MPa	600 MPA

6. Parameters and transfer mode

Since in the metal arc welding the electrode used is also the element that, heated by the passage of the current melts, it is possible to identify a close link between current and quantity of deposited metal.

The parameter fields within which certain transfer modes are obtained, are also a function of the shielding gas, of the diameter and type (solid/cored) of wire.

Combining these effects, it can be understood that the choice of welding parameters may involve different ways in which the drops of filler metal detach from the wire and reach the fusion pool. These "transfer modes" are basically four, as described below.

- Transfer by short circuit or short arc. This transfer mode is obtained for relatively low current and voltage values, and involves the formation of large drops of metal that detach from the wire when they touch the weld pool (fig. 19).

Fig.19: short arc transfer mode

This welding technique allows the realization of joints in different position from the flat, even if it guarantees low deposit rates and involves a certain risk of spatter and lack of fusion.

- Globular transfer. As the current values increase, the drops that are formed are always larger; so an irregular transfer is obtained. An irregular deposit is obtained, with considerable spatter development (fig. 20). Consequently this mode of transfer should be avoided, even if it tends to be easily realized with increasing CO_2 content in the gas mixture.

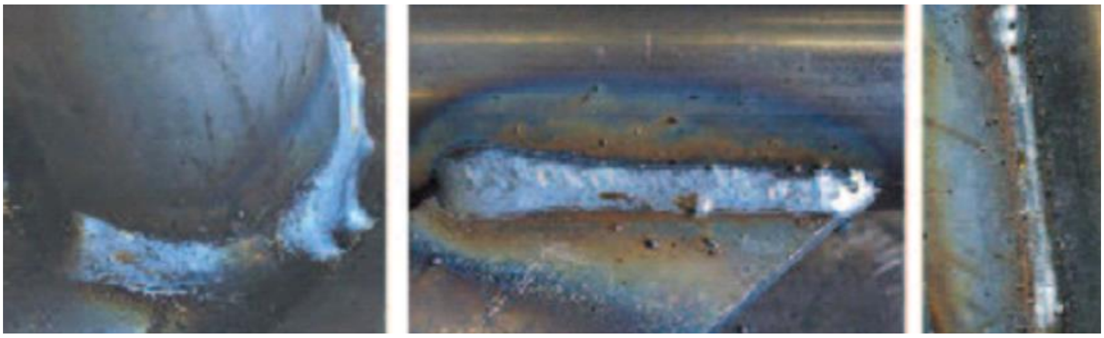


Fig.20: globular transfer mode

- Spray or arc spray transfer. For high voltage and current values, the arc is very stable and directional; consequently the droplets of filler material are finely "nebulized" and are deposited with considerable speed on the weld pool (fig. 21): the deposit appears therefore very regular. This technique is generally used for and cap runs on the flat position on thick materials; however, since gravity has a fundamental role, this mode is used with little success in overhead welding and, often, in positions other than the flat.

Fig.21: spray arc transfer mode

- Pulsed arc transfer. The inverter welding power sources, allow the application of currents that vary over time (modulated current), generally characterized by a base current, such as not to cause deposit and a peak current, such as to cause detachment of a drop, so adjust (fig. 24).

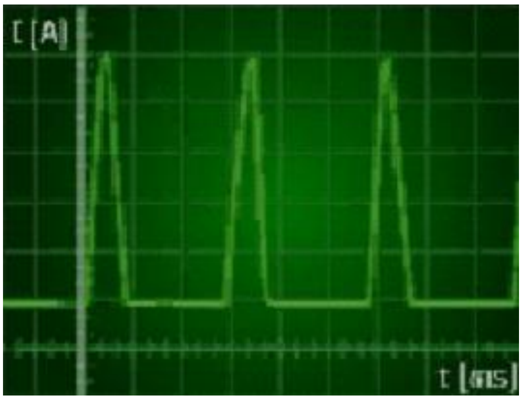


Fig.22: pulsed current

Consequently it is possible to "control" the detachment of the drops (fig. 23) through appropriate adjustments (available on the power source in the form of programs). At the same time, the total specific heat input is low enough to ensure a rather small weld pool ("cold" pool).

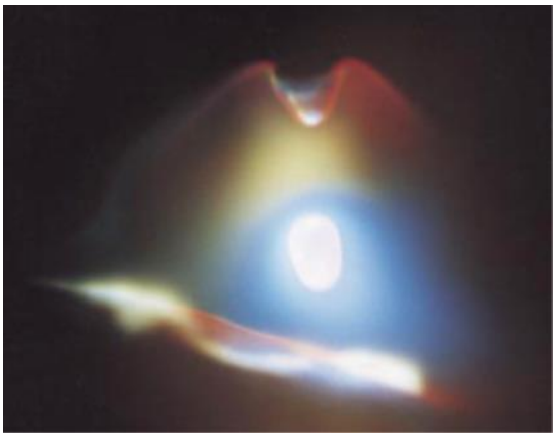


Fig.23: pulsed transfer mode

It will therefore appear evident that the particular combinations of parameters significantly influence the quality and operability of the welding, directly influencing the quantity of metal deposited, the welding position and the appearance of the weld run. The parameter fields within which certain transfer modes are obtained, are also a function of the shielding gas, of the diameter and type (solid/cored) of wire, as already stated. In particular, with the same metal welded, spray arc will be more easily obtained when the percentage of active gases contained in the shielding gas and the wire diameter is reduced; moreover, as already mentioned above.

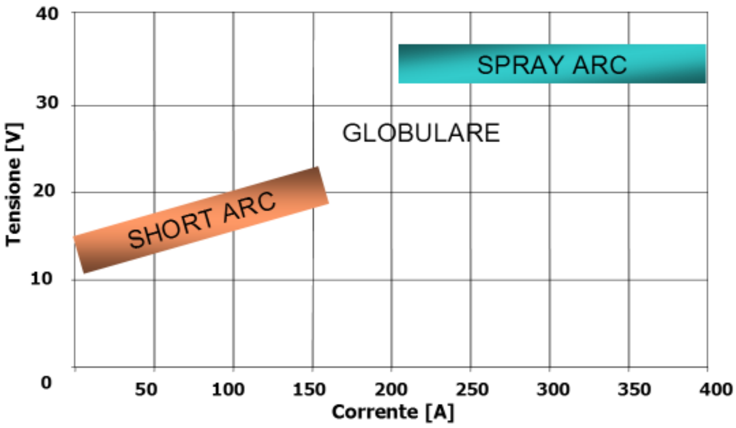


Fig.24: transfer mode curve for solid wire (0,8mm – mixture 92% Argon and 8% oxygen)

7. Technique

7.1 Parameters

The main operating parameters are shown below, and the reactive influence on the bead characteristics is briefly described.

7.2 Position of the torch and stick out

As already mentioned in chapter 2, in this process the particular characteristic of the process and of the power source allows to maintain the wire melting speed exactly equal to the wire feeding speed. This means the intensity of the current is managed by the machine once the welder has set a certain wire advancement speed, leaving the welder free to manage the advancement of the torch and its height with respect to the welding pool.

In particular, variations in the position of the torch with respect to the vertical axis cause the consequences described below.

- If the torch is raised, after a very brief transitory period, there is an increase in the stick-out (free length of the wire), with a consequent decrease in the welding current (Ampère) and consequently of the penetration; the Voltage (Volt) remains constant instead. If the torch distance is excessive, the gas protection (if present) becomes insufficient, the arc begins to be unstable and spatter and porosity develop.

- If the torch is lowered, after a very brief transitory period, there is a decrease in the welding current (Ampère) and consequently in the penetration; the voltage (Volt) remains constant instead. If the torch is lowered too much, short circuits develop (wire contacts with the pool) and the welder feels a push from the torch to raise its position.

Consequently, it can be inferred that in this process penetration and stick out are adjusted simply by moving the torch upwards (increase) or downwards (decrease). Figure 25 shows a comparison for three different torch positions, followed by different stick out, current and penetration values.

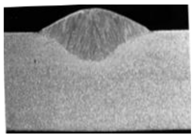
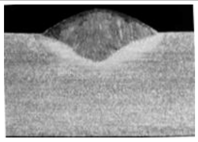
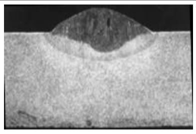
Stick Out	Parameters			Wire		Shielding		MACRO
	V	I	Travel speed	Speed	Diam.	Gas	Flow	
9	31,5 V	263 A	270 cm/min	3,4 m/min	1,2 mm	Ar/CO_2 80 – 20	16 l/min	
15	32,2 V	240 A						
25	33,4 V	228 A						

Fig.20: effects of stick out variation

7.3 Travel speed and weaved techniques

The welding travel speed, in addition to influencing the heat input, also causes variations in the welding: although the "form factor" (ratio width / depth) remains constant, the size may vary; as evident, the greater the speed, the smaller the size of the weld run.
However, due to excessive welding speed, there is a certain risk of melting failures (lack of fusion, undercuts), whereas when the welding speed is too low the bead tends to swell too much.

8. Welding practice

Below are some useful information for the realization of welding on Carbon steel and low alloys.
It should also be emphasized that the information reported here must be considered as simple suggestions, not at all a substitute for adequate practical training, to which, especially for more complex welding positions, an appropriate field experience must be added.

8.1 Preparation of piece

Before carrying out the welding, it is advisable to clean the piece, with grinding, brushing and in some cases, solvents (for example in the welding of light alloys and austenitic stainless steels).

Considering the length of the sections normally deposited during welding, it is advisable to proceed with fixing the parts to be joined in order to avoid significant deformations (e.g tack weld).

8.2 Arc striking

At the beginning of the welding, the button on the torch is pressed to trigger the process, and as soon as the wire touches the piece, the power source delivers the maximum available current and striking the electric arc. The striking of the electric arc occurs therefore by short circuit, that is by contact between the electrode and the piece.

Thanks to the relatively small wire diameter, the heat developed in this initial phase allows the volatilization of a very small portion of wire, consequently freeing up a space between the electrode and the base material within which the arc can strike, which initially has a very reduced length and then it quickly leads to the normal functioning one.
Simultaneously with the supply of welding current, an automatic switch opens the valves of the protection gas and of any cooling water.

Operationally, it is very important to achieve a gradual heating of the pool, which can be achieved by triggering the bow on a heel, and waiting for a few moments until the formation of a pool of appropriate size is seen. If it is not possible to use a bead (for example in a "closed" weld), it is necessary to consider that the starting area must be subsequently removed with a grinding wheel or burr when the structure is closed.

8.3 Welding technique

During welding, the torch is generally kept tilted in the direction of advancement (forehand technique or "push") of about 20 - 30 ° with respect to the vertical; however, in welding with cored wires, due to the presence of the slag, the torch must be inclined towards the weld pool (backhand or "pull" technique), so as to prevent the slag from covering the impact zone of the arc on the welding pool, preventing the passage of current and consequently extinguishing the arch itself (fig. 26).

A special case is that of cored wire or metal cored wires, which do not produce slag and are used as solid wires.

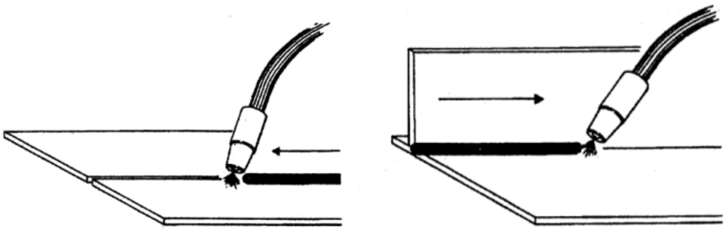


Fig.26: forehand and backhand techniques

It is extremely important that during welding the torch-piece distance is kept as constant as possible to ensure that the stick-out does not undergo variations, with consequent change of current and penetration of the run. To obtain this result it is advisable for the welder to be conveniently convenient with respect to the piece and the deposit to be made, considering a useful length of the not over-deposited section (which should never exceed the meter) so as to be able to remain stationary in the welding position and making progress with the bust; it would also be advisable to consider the trigger position furthest from the torso and the stopping position of the nearest deposit, as it is generally more difficult to manage the welding pool as its temperature increases.

As already mentioned in paragraph 4.1.2, the first run is generally performed in short arc, or possibly in a pulsed arc, in order to obtain an easily manageable pool.

At the end of the first run and between each run it is advisable to carry out an adequate cleaning, through the removal of any slag that has formed and to ensure a properly clean surface to accommodate the subsequent runs. It is therefore necessary to recommend grinding in such a way as to obtain a "groove" and not a "back of a donkey" or squared section (fig. 27).

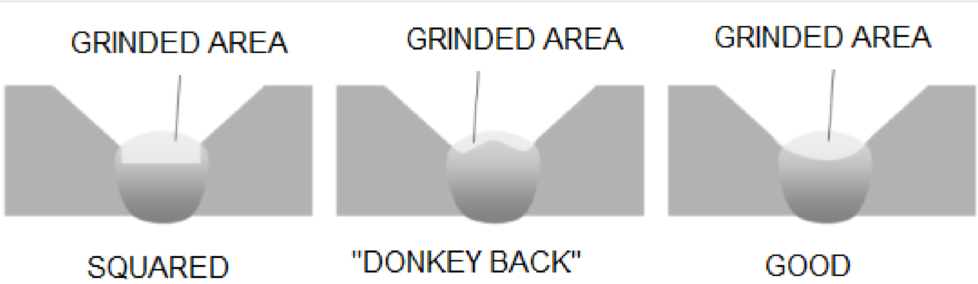


Fig.27

Welding in PA

As already mentioned, in flat welding the first run is performed in short arc or pulsed arc technique, followed by any filling cap runs, generally made with higher currents (and deposits).

We do not recommend the use of weaving welding techniques (also known as "wide beads"), due to the overheating of the pool resulting from low feed rates and the relative high heat input.

Vertical welding in PF
In this case the welding technique requires electrical parameters such as to obtain transfer preferably in short arc for all the runs.
In this case the operating technique is always pushing, regardless of the type of wire used. This in order to support the metal by trying to avoid dripping with the arc pressure.

The filling and cap are typically carried out with weaving movements that embrace the entire width of the groove, and curved upwards (differently from what happens for coated electrode welding). It is also advisable to consider that on each side there will be a stop and when moving side to side this shall be performed as quickly as possible, so as to guarantee the correct joint fusion faces and, for the cap runs, avoid undercuts. As a result the welding pool will have to be elliptical (fig. 29); if the electrical parameters are too high, the pool will be excessively fluid or "hot" and will tend to drip downwards.

Welding in PE
In this case the particular condition places the welding pool to work against the forces of gravity, a situation that makes the operating technique among the most difficult to achieve. For this reason it is even more important to position the welder with respect to the piece and it is strongly recommended to use both hands, holding the torch with one another, supporting the forearm with the other.

The applicable transfer mode is the short and pulsed arc. At the same time, to avoid having too much fluid in the weld pool, it is necessary to have high wire feed rates ("pulled" beads), a situation which consequently leads to higher current values than those used for the first flat run.
In overhead welding it is finally appropriate to slightly increase the gas flow rates to the torch, in order to guarantee adequate protection of the pool and the arc, especially if the Argon shielding gas.

The operative technique is typically to push for solid wires or to pull for cored wires.

Welding in PC
In this case the welding technique is similar to PE, trying however to keep the pool cold, thus limiting the heat input.

It should be remembered that, to ensure adequate protection of the welding pool, it is necessary to tilt the torch slightly upwards (welding with Argon mixtures) or downwards (welding with Helium mixtures).

Welding in PG
Descending vertical welding has as a fundamental problem the fact that the movement of the torch moves in the same direction and in the direction of gravity: consequently the descent of the torch must be faster than the speed of fall of the pool, so as to avoid it going to cover the root of the joint or the subsequent runs without these being fused by the arc.
The result is high welding speeds and low thermal inputs, even if the risk of lack of fusion is so high that it is strongly advised against welding in this position.

8.4 End of welding
The end of welding must be carried out by trying to achieve a gradual shutdown of the arc (for example with a final increase in the welding speed), in order to avoid the formation of craters at the end of welding (fig. 29).
Consequently it is advisable to proceed to the end of the welding on a run, or, if this is not possible (such as for example on the closure of a circumferential weld), it is convenient to prepare the closure previously by realizing a sort of closing chute.
In this case the closure must be completed at the end of the weld run and the excess material must be subsequently reworked with a grinding wheel or burr to bring the joint back to the nominal height.

Finally, it should be pointed out that there are power sources that allow a modulation of the current in closing in such a way as to allow a gradual switching off which takes place in a few moments, possibly with the deposit of a single drop of filler material, as if it were a single pulse of pulsed arc, in order to fill the crater ("crater filler" systems).

8.5 Restart of weld runs

When making joints of a certain length, as in the execution of the qualification test of the welder, it may be necessary to carry out a welding recovery. This can be done by making a starting chute (like the one in fig. 30) on the start/stop location, on which to make the start, with a suitably slow speed so as to form a welding pool in appropriate size.
Before starting the new run, on the end crater of the previous weld run it will be appropriate to remove the excess material with a grindstone or a burr.

UNIT BIBLIOGRAPHY

[1] General course on GMAW welding: IIS training material

GLOSSARY

It includes the main concepts, new and / or complex seen in the unit, as a dictionary.This type of resource is important especially when the course is aimed at students with no knowledge of the subject. Glossary entries are ordered alphabetically.

Welding Processes – Gas Welding

1.1 Course name

GW Welding

1.2 Course duration

5 hours

1.3 Course purpose

In this unit it is showed specific items related to gas oxyacetylene welding process, specifically related to the welding equipment, welding parameters, typical welding techniques and filler metals used.

1.4 Objectives of the course

Knowledge	Skills	Attitudes
Assume general competences on oxyacetylene welding process	General introduction on oxyacetylene welding process	The students shall, during course, demonstrate good cooperation with teacher and classroom mates, in order to improve knowledge and share informations.
Identify principal components of welding equipment and know about its maintenance	Identify components of welding machine Identify general competence on maintenance	
Improve competence on welding parameters measurement	Identify main parameters of oxyacetylene welding process Measure and control of welding parameters	
Improve competence on shielding gases	Identify shielding gases Choice of correct shielding gas and its main properties	
Improve competence on filler metal	Identify difference on filler metal Choose correct filler metal as a consequence of properties of joint	
Identify operating techniques on oxyacetylene welding process	Apply different transfer modes on welding process Choose the correct transfer mode as a consequence of type of welding	
Identify different welding techniques, with specific explanation on correct way of welding	Assume competence on different welding techniques Know correct welding technique on different welding position	
Improve competence on welding practice	Know how to prepare a piece Have competence on principal welding defects and how to avoid them	

1.5 Contents

1. Introduction
2. Oxyacetylene flame
2.1. Regulation of flame
2.2. Properties of flame
3. Equipment
3.1. Oxygen
3.2. Acetylene
3.3. Pressure reducer
3.4. Safety valve
3.5. Economizer
3.6. Pipes
3.7. Torch
4. Operating technique
4.1. Introduction
4.2. Heat input calculation
4.3. Flaps preparation
4.4. Correct operation
5. Application
5.1. Joint type
5.2. Base material
5.3. Typical defects
5.4. Filler metal

1.6 Participants

Learner characteristics:	Basic technical competences

1.7 Entry requirements

Education level requirement:	Students from VET schools
Previous knowledge needed	Basic knowledge in welding
Age requirements:	16 and 20 years old

1.8 Assessment activities

Summative assessment: nothing required

1.9 Bibliography (used or supplementary)

[1] General course on GW welding: IIS training material

UNIT NUMBER: Didactic Unit __
UNIT TITLE: *Gas Oxyacetylene Welding (GW)*

UNIT PRESENTATION

The present learning unit shows specific items related to Oxyacetylene welding process, specifically related to the welding equipment, welding parameters and typical welding techniques.

OBJETIVES

The objectives of the teaching unit are:

- Assume general competences on oxyacetylene welding process
- Identify principal components of welding equipment and know about its maintenance
- Identify operating techniques on oxyacetylene welding process
- Improve competence on welding practice

CONTENTS

1. Introduction
2. Oxyacetylene flame
   - 2.1. Regulation of flame
   - 2.2. Properties of flame
3. Equipment
   - 3.1. Oxygen
   - 3.2. Acetylene
   - 3.3. Pressure reducer
   - 3.4. Safety valve
   - 3.5. Economizer
   - 3.6. Pipes
   - 3.7. Torch
4. Operating technique
   - 4.1. Introduction
   - 4.2. Heat input calculation
   - 4.3. Flaps preparation
   - 4.4. Correct operation
5. Application
   - 5.1. Joint type
   - 5.2. Base material
   - 5.3. Typical defects
   - 5.4. Filler metal

CONTENTS DEVELOPMENT

1. Introduction

In November 1895 the French chemist Le Châtelier discovered that the combustion of equal amounts of acetylene gas and pure oxygen produced a flame whose temperature was higher than those obtained up to that time.
From this reality an autogenous welding process called fusion developed in a few years
oxyacetylene welding (Figure 1.1).
In combustion with oxygen, acetylene, although not having the maximum calorific value among the gases available for welding, provides a considerably higher thermal power than that of the other oxygen gases (methane, propane, butane, hydrogen, city gas).
For the obtainable temperature (of about 3100°C), the oxyacetylene temperature is the only flame that makes it possible to weld ferrous alloys with filler material that is equivalent to the base material.

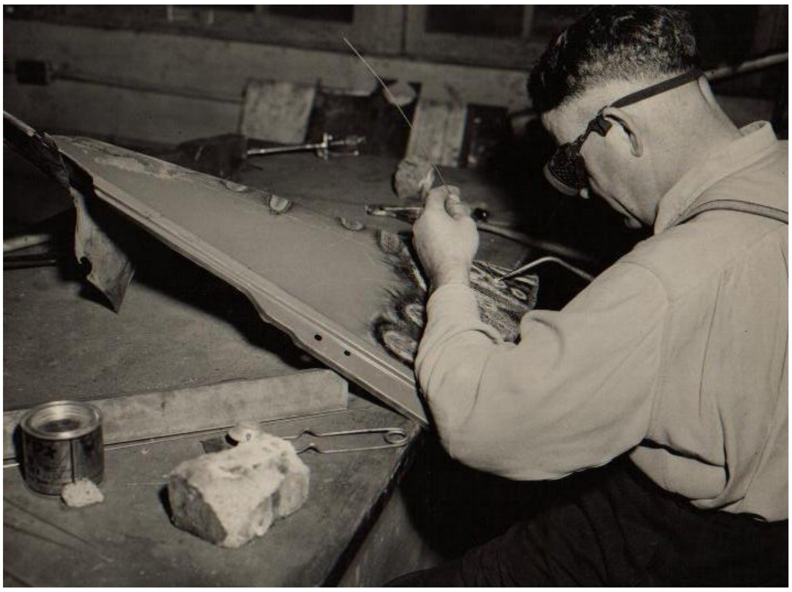


Figure 1.1: oxyacetylene gas welding (chassis'repair), 1949

2. Oxyacetylene flame

The oxyacetylene flame is the effect of the combustion between acetylene (chemical formula C_2H_2 - figure 2.1) and oxygen, which arrive separately at the torch from which they exit together after being intimately mixed (the formation of the acetylene-oxygen mixture is favored by the special shape of the torch, which will be described later).
At the exit of the torch, the combustion takes place with a flame that is the most suitable for satisfying the main needs of the fusion of a metal and its protection in the molten state from atmospheric contamination.
By analyzing the geometry of a correctly regulated flame (Figure 2.2), different zones can be distinguished, each of which has particularly significant properties for the purposes of the process characteristics.
Combustion, in fact, initially gives rise to the formation of carbon monoxide and hydrogen and to the development of a certain amount of heat according to the primary combustion reaction, which generates a first quantity of heat, indicated as q ':

$C_2H_2 + O_2 \rightarrow 2\,CO + H_2 + q'$

The products of this first chemical reaction are not the end products of combustion: this is due to the fact that the amount of oxygen supplied to the torch is less than that required to burn the acetylene completely. The combustion described therefore takes the name of primary combustion: it takes place on a cone-shaped surface, located near the tip of the torch called dart.

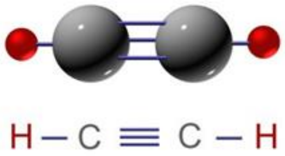


Fig.2.1: formula of acethilene   Fig.2.2: flame areas

Since the final products of primary combustion are still combustible and are found at high temperature, they spontaneously complete their combustion at the expense of other oxygen, which is not supplied by the welding plant, but is taken from the surrounding air. It follows that immediately downstream of the dart a zone greedy for oxygen is established; this is called the reducing zone and in it occurs the secondary combustion which completes the oxidation of the products of the primary reaction with further development of heat (q" and q"'), according to the two reactions:

$CO + \frac{1}{2}O_2 \rightarrow 2CO_2 + q''$
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O + q'''$

The presence of the reducing zone also determines the possibility of using the oxyacetylenic flame without any form of protection from oxygen, finding the welding pool and any filler material in a reducing atmosphere; note also that among the products of combustion there is also water vapor, which however can be considered not particularly dangerous thanks to the particularly mild thermal cycles that are carried out with this process. The development of heat keeps the end products of combustion at high temperature: this gives rise to a considerable brightness of the gases and vapors produced, which lasts for a certain space until it vanishes due to the temperature drop. The luminous area surrounding the dart (which is in turn even brighter) is called plume.

2.1 Regulation of flame

The constitution of a flame with the described characteristics is conditioned by the presence of oxygen in a volumetric measure equal to acetylene, so that the combustion begins in correspondence with the dart and is completed in the first part of the plume, thus giving rise to an area with reducing action; in these conditions the flame is called neutral (like the one shown in figure 2.2).

In the event that the oxygen reaches the torch in excess or in defect compared to acetylene, both the shape of the flame and its properties are changed (Figure 2.3).

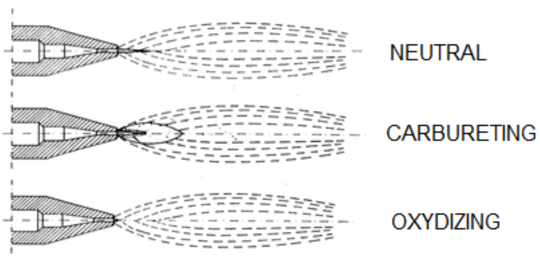


Fig. 2.3: regulation of flame

2.1.1 Welding with low oxygen

When oxygen is insufficient to complete primary combustion, acetylene must procure oxygen from the surrounding atmosphere. However, considering the short time available (the gases flow from the torch at high speed: about 100 m/s), complete combustion is practically impossible. Therefore, a certain quantity of combustion gas remains: bearing in mind that acetylene is formed by hydrogen and carbon, that part of the latter which is not burned remains free in the flame and tends to pass into the pool lapped by it. For this circumstance the flame then takes the name of fuel: downstream of the dart a more extended plume appears, sometimes reddish in color (Figure 2.4). In addition, it should be noted in this case a marked reducing effect.

Fig.2.4: reducing flame

2.1.2 Welding with high oxygen

In this case there is no well-defined primary combustion zone: the combustion takes place completely and almost immediately upon exiting the tip of the pipe and consequently the reducing zone is greatly reduced or disappears completely, depending on the quantity of excess oxygen.
The flame regulated in this way tends to give oxygen to the pool which it lapses and is called oxidizing flame.

Fig.2.5: oxidizing flame

2.2 Properties of flame

Based on the physical properties of the oxyacetylene flame, it is possible to understand some of the fundamental advantages and / or characteristics that make this energy source suitable for welding applications.

As already mentioned, in fact, the oxyacetylene flame allows reaching sufficiently high temperatures to obtain a correct fusion of the metals to be welded; in particular, the distribution of the temperatures is particularly convenient, since the maximum value (of the order of 3100 °C) is reached just downstream of the tip of the dart, i.e. in correspondence with the welding pool (Figure 2.6).
The dart is surrounded by the reducing zone and the plume which extends considerably;
immediately downstream of the dart, the presence of a zone greedy for oxygen shows reducing properties and therefore has deoxidizing action with respect to the metal brought to fusion (melting pool). These characteristics, however, require that the volume of oxygen supplied is equal to that of acetylene: otherwise, the flame tends to oxidize or carburate the fusion pool. Fortunately, when these anomalous operations occur, the appearance of the flame changes considerably, so that the skilled welder can promptly eliminate the inconvenience by easily adjusting the oxygen or acetylene flow rate.

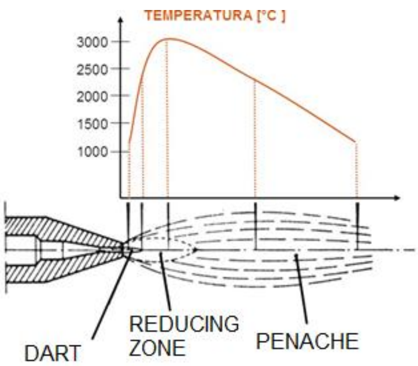


Fig.2.6: temperature of flame

3. Equipment

Figure 3.1 illustrates the layout of a single oxyacetylene welding station: in it there are the oxygen and acetylene cylinders, the pressure reducers of these, the safety valves, the torch and the economizer.

The general requirements for acetylene welding distribution systems are listed in the UNI EN ISO 14113: 1999 - Gas welding equipment - Flexible rubber and plastic pipes for compressed or liquefied gas up to the maximum design pressure of 450 bar.

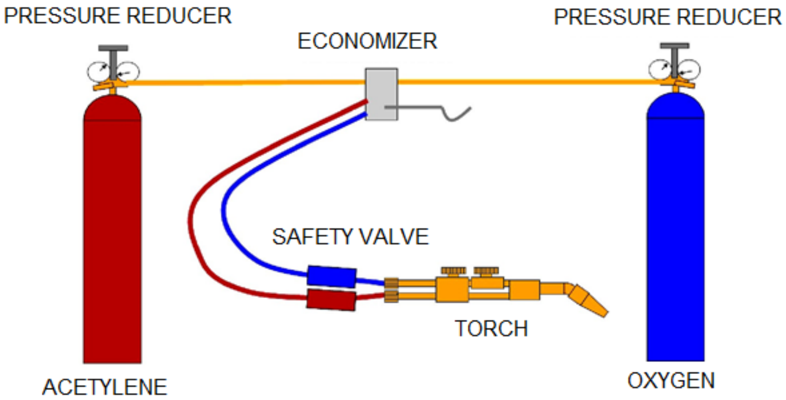


Fig.3.1: equipment

In particular, the standard requires that the distribution systems of acetylene in cylinders include the following components:

 high pressure non-return valve, located immediately downstream of the cylinder outlet or the package of cylinders;

 high pressure distribution pipes, a part of which may consist of flexible pipes;

 rapid, manual or automatic interrupt device;

 cylinder pressure reducer or distribution system pressure reducer;

 pressure indicators from the upstream and downstream sides of the pressure reducer, for example pressure gauges;

 low pressure pipes downstream of the distribution system pressure reducer, which go to the safety devices included, located immediately downstream of the pressure reducer;

 low pressure non-return valve;

 low pressure flame arrest device;

 thermo-block or pressure operated device.

3.1 Oxygen

Oxygen is essential for perfect combustion: only by supplying it to the torch together with the fuel, in a practically unitary volumetric ratio, it is possible to obtain high flame temperatures.
It is produced industrially by fractional distillation of the liquid air and is supplied in steel tubing at a pressure generally of 200 bar, or in liquid form.

3.1.1 Oxygen cylinder

The cylinders can be of different capacities; cylinders of 4 ÷ 8 m3 are normally used (values referred to atmospheric pressure). The volume of oxygen contained in a cylinder is approximately proportional to the pressure indicated by the pressure gauge; this allows to know how much oxygen remains in the cylinder after use.

The oxygen cylinders are equipped with a brass valve with right hand thread and can be identified thanks to a white band at the top on the ogive. The pressure reducer is screwed onto the valve, which has the task of keeping the pressure at the required value in the delivery pipe to the blowpipe.

3.1.2 Safety

Since grease and oil can ignite spontaneously and explode on contact with pure oxygen under pressure, they must never be used in any part of the equipment and particularly on the reducer threads.

Oxygen losses can be detected by applying a soapy solution. Never use an open flame to look for leaks.

In the case of oxygen in a cylinder, it must be placed in a vertical position, suitably fixed (for example with chains) and away from heat sources, to protect against pressure increases with the consequent risk of serious explosions.

3.2 Acetylene

Acetylene is an unsaturated hydrocarbon of the acyclic series, which is not found in nature, but produced by reaction between water and calcium carbide or by ethylene derived from petroleum.

Pure acetylene is practically odorless; the characteristic garlic-like odor that is often felt is in fact due to phosphorus hydrogen (PH3), present as an impurity.

It is an unstable gas that tends to decompose with a strong exothermic reaction, that is, that generates heat, the more violently the greater its pressure.

3.2.1 Acetylene cylinder

To avoid the danger of explosion, the acetylene is stored inside the cylinders in the dissolved and uncompressed state.

It is normally dissolved in acetone which impregnates a porous mass occupying the entire volume of the cylinder. Acetone can dissolve at room pressure a volume of acetyl 25 times its own; furthermore, for each pressure increase of a bar, it can absorb as much (for which at 15 bar a liter of acetone can receive up to 375 liters of acetylene). The dissolved acetylene pressure cannot, by law, exceed 15 bar at 15°C.

To ensure the greatest stability of the acetylene and prevent the local acetylene decomposition from being generated under the action of a mechanical impact or an increase in temperature, the cylinder is filled with porous masses that absorb the acetylene.

These are, in particular, granulated or powdery materials (for example granulated charcoal, which also has the advantage of slightly swelling by filling the voids when it is soaked in acetylene).

Consequently, a cylinder contains acetone, dissolved acetylene, porous material and free space occupied by the gaseous phase (acetylene and acetone vapors) in equilibrium with the liquid phase, with the average percentages shown in Figure 3.2.

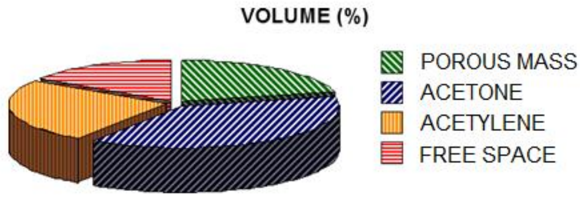


Fig. 3.2: Content of an acetylene cylinder

3.2.2 Safety

Acetylene is a flammable gas and therefore it is necessary to avoid accurate the violence of open flames to cylinders, pipes and pipes.
In addition, acetylene can partly oars strongly conditioned with copper by forming a composite (copper acetylur) which is explosive. Therefore, the international standard UNI EN ISO 9539:2010 imposes that pipes, fittings and materials with which gas is in contact (reducers valves, etc.), has low copper content.

3.3 Pressure reducer

Acetylene and oxygen are contained in cylinders at higher pressure than required for torch operation. Therefore, it is necessary that the pressure is reduced and kept constant at the appropriate value regardless of the gas flow rate required. This function is performed by the pressure reducer, shown in figure 3.3.

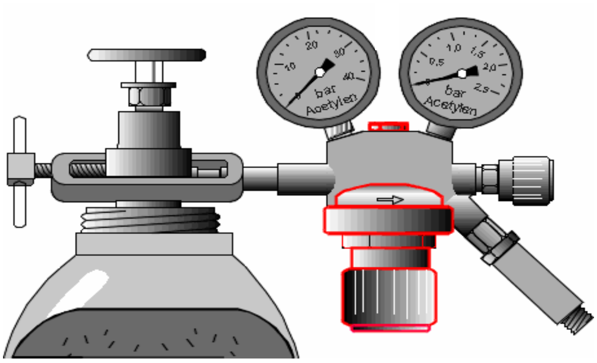


Fig. 3.3: pressure reducer

3.4 Safety valve

In most applications, the pressures of acetylene and oxygen can also be very different from each other (even of some order of magnitude). This can cause the acetylene / oxygen mixture to return to the lower pressure line; considering moreover that this return starts from the torch, it is possible to consider that this backstroke is accompanied by the combustion of the mixture (it is the "backfire").

3.5 Economizer

The economizer is a typical component of fixed stations, with the task of allowing the flow of the two gases only during welding, eliminating their consumption during work stoppages.
It consists essentially of a valve that closes the passage of both gases to the discharge line to the torch (Figure 3.16). The valve, normally open, is controlled by a hook lever, lowering which determines its closure.

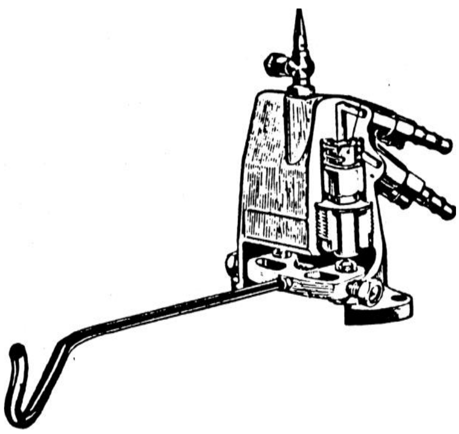


Fig. 3.4: economizer

3.6 Pipes

At the economizer outlet, or from the pressure reducers, the gases are conveyed to the torch through flexible rubber pipes, to allow the welder adequate mobility of the flame. These tubes consist of a series of rubber sheaths, reinforced with a metal or non-metallic reinforcement.

3.7 Torch

It is the appliance to which the combustible gas and the comburent gas come and into which their intimate mixing takes place, necessary to allow regular combustion at the exit of the point. The performance of these functions and the need for maximum maneuverability (so as not to tire the welder) require adequate construction.

Depending on the gas pressure for torch operation, we distinguish low-pressure torches (oxygen regulated between 1 and 2 bar, acetylene between 0.01 and 0.02 bar) and high pressure (oxygen and acetylene at the same pressure of 0.5 - 0.75 bar).

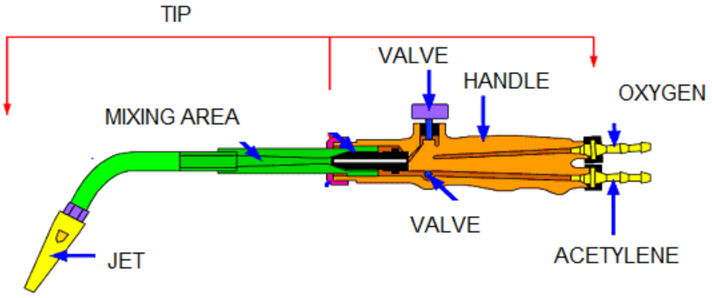


Fig. 3.5 Torch

4. Operating technique

4.1 Introduction

The operative techniques used with the oxyacetylene process are different depending on the welding position. Consequently, the welding parameters are also different.
Regardless of the techniques from the positions, it is still important that the tip of the rod and the molten pool are always kept inside the flame protection zone (reducing zone).

4.1.1 Welding in PA

Flat welding can be performed with a leftward technique (in which the torch is pointed in the direction of advancement) or rightward (with the torch pointed in the opposite direction), as shown in Figure 4.1.

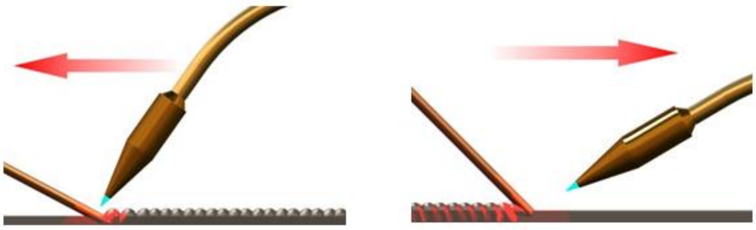


Fig. 4.1: welding techniques (leftward, on the left and rightward, on the right)

The push technique involves a rectilinear movement of the torch with an angle of 30 ÷ 40° with respect to the horizontal plane, the tip of the dart at 2 ÷ 3 mm with respect to the pool and uses the rod with transversal U-shaped lateral movements (Figure 4.2), so as to bring the dart to the bottom in time to ensure the fusion of the lower edge and, if necessary (welding of thicknesses greater than 3 mm), to widen the fusion to the whole width of the staking. This technique is particularly suitable for welding thin sheets with straight edges, even if there is a risk of grain growth, since the thermal source invests a big area.

The leftward operating technique is instead used with the dart constantly pointed towards the welding pool with an angle varying between 45° and 75° depending on the thickness. Only in the case of higher thicknesses a small circular movement is added to this motion, in order to obtain a good fusion.
The filler rod is constantly in contact with the welding pool (Figure 4.3).

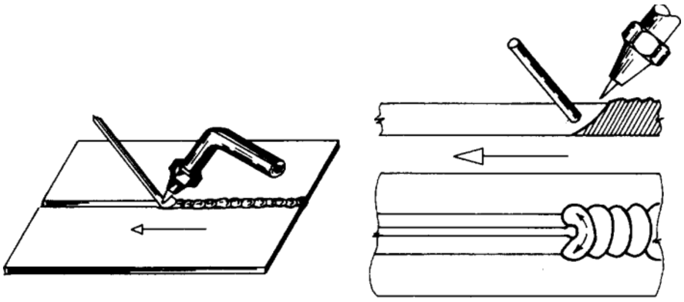


Fig.4.2: leftward

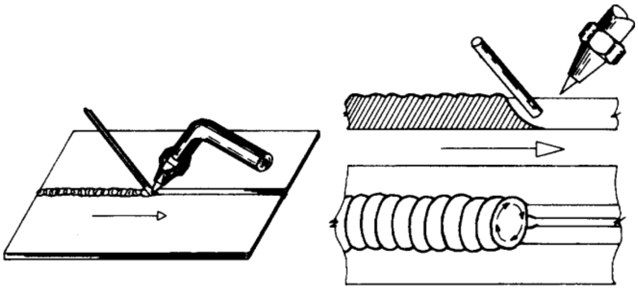


Fig. 4.3: rightward

Tecnique	Acetylene flow [l/h]	Travel speed [mm/min]	Diameter of filler metal [mm]
Leftward	100 s*	200 / s*	s*/2 +1
Rightward	100 s*	250 / s*	s*/2
s* is the thickness of joint (mm)			

4.1.2 Welding in PF

When the axis of the joint to be welded is vertical, the welding can be performed from top to bottom (descending method) or from bottom to top (ascending method). The latter is certainly to be preferred as it allows better control of the pool and penetration, with consequent better characteristics of the joint.

For the realization of this type of junctions, a position of the torch tilted 30° below the horizontal is used and the filler rod inclined at 20 ÷ 30° above the horizontal itself.
The torch simply has a longitudinal movement of translation, and a speed such as to produce and keep an open hole that allows the molten metal to penetrate the back and make it a continuous bead. The tip of the dart must graze the surface of the fusion pool and not come off until it is just enough to allow the introduction of the filler rod into the fusion pool (Figure 4.4).

The filler rod is animated by a vertical advance movement accompanied by a succession of rapid juxtapositions and setbacks of the order of 3 ÷ 4 mm, so as to deposit successive drops of molten metal in the fusion pool.

For higher thicknesses (over 4 mm) it is also necessary to give the rod a slight transversal oscillatory movement. In any case the technique is applicable for thicknesses not exceeding 6 mm.

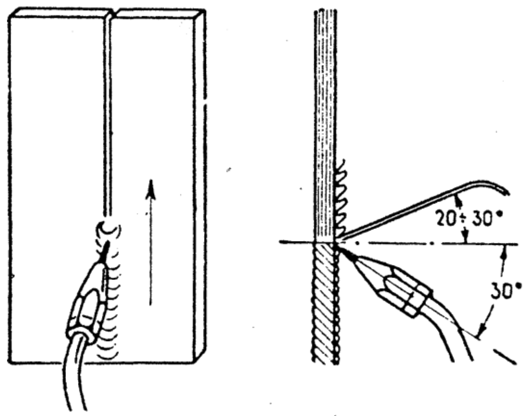


Fig. 4.4: vertical welding

Tecnique	Acetylene flow [l/h]	Travel speed [mm/min]	Diameter of filler metal [mm]
Verticale ascendente	60 s*	150 / s*	s*/2
s* Is the thickness of the joint (mm)			

4.1.3 Welding in PC

As long as the thickness is thin (s <3 mm) it is operated in similar way of previous positions.

4.2 Heat input calculation

In the case of arc welding, the specific heat input is calculated with reference to the electrical parameters and as the ratio between the electrical power used (in W) and the welding speed. Similarly, in the case of oxyacetylene welding, the thermal power can be calculated with a good approximation by referring to the lower calorific value of acetylene (Hi) of acetylene, assuming a perfect combustion.

Consequently, being Hi equal to 36 kJ / dm3, the specific heat input (Q1) can be calculated based on the following relation:

$$Q_1 = \frac{P \cdot H_i}{v_{sald}} = \frac{36 \cdot P}{v_{sald}} \quad \left[\frac{kJ}{mm}\right]$$

since P is the flow rate in l/min and vsald the travel speed in mm/min.

4.3 Flaps preparation

The preparation of the flaps for oxyacetylene welding can be square or V-shaped, as shown below.

The preparation with square edges is possible up to thicknesses of about 6 mm, as follows:

 for thickness “s” up to 3 mm, the distance between the flaps must be between 0 and 2 mm;

 for thicknesses "s" from 3 to 6 mm (only for welding carried out in flat to push or vertical), the distance between the edges must be between s/2 and (s/2 + 1) mm.

The V preparation can be used for thicknesses greater than 6 mm, although the use of oxyacetylene welding for thicknesses greater than 8 mm must be considered quite exceptional.

 For thickness "s" between 3 and 6 mm, the opening angle of the groove must be at least 80°, the shoulder 0 mm and the gap between s/4 and (s/4 + 1) mm;

 for thicknesses "s" between 6 and 12 mm, the opening angle of the groove must be between 60° and 70°, the face 0 mm and gap as above.

4.4 Correct operation of the equipment

Assuming that the welder has already adjusted the gas pressure to the expected values, the torch ignition procedure must start from acetylene. Therefore, proceed by opening the acetylene tap and turning on the gas using a special flint lighter or the flame of the economizer; in this way a long and sooty flame is obtained. At this point proceed by opening the oxygen tap, adjusting the flame (neutral, oxidizing or fuel) as needed.
With regard to switching off, we will proceed similarly by first interrupting the flow of acetylene and subsequently that of oxygen, letting the efflux of the latter cool the tip of the torch.
A torch in good state of maintenance and well used should not give rise to serious accidents in the course of use; however, it is a general rule to stop the arrival of the acetylene and oxygen in the event of any accident, thus limiting its range.

5. Application

Considering the characteristics of the heat source (and in particular the low concentration of energy), it is easy to see that the oxyacetylene flame welding process is generally limited to the execution of joints between elements of limited thickness (6 or 8 mm at maximum), also in consideration of the high thermal inputs, which on thicknesses greater than 2 mm can easily exceed 10 kJ / mm, with the consequent implications in metallurgical and mechanical terms (tensions and welding deformations).

5.1 Joint type

The possibility of having the thermal source separate from the filler metal and the good controllability of the welding pool make the process particularly useful in cases where it is not possible to perform the welding from both sides (for example in the case of pipe joints of small diameter, and, of course, of limited thickness). In fact, the welder is allowed to manage a quiet and methodical thermal source, adaptable to the circumstances for each section of the joint, without the need for continuous and timely interventions, which always lead to irregularities more or less evident at the back of the joint (such as defective recharging, dripping, porosity, lack of local penetration).

Finally, it should be noted that the oxyacetylene process easily allows in cases where accessibility is considerably compromised by obstacles that can be found near the joint.

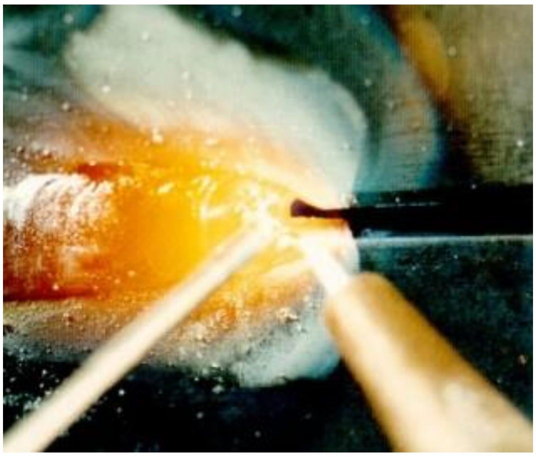


Fig. 5.1: welding of a pipe

5.2 Base materials

The reduced thermal power of the oxyacetylene flame can give rise to phenomena of grain growth. It occurs mainly in the heat affected zone of the base material, due to the relatively long stay at high temperature and the slow cooling of the area surrounding the joint, due to the modest welding speed. A grain growth is, in a sense, inevitable with a "slow" procedure such as the oxyacetylene one, but it can manifest itself in a more or less acceptable way depending on the operating ability of the welder. The grain growth reduces the toughness of the joint. It is particularly fearsome in fine grain steels (such as those for low temperature service pipes, so the use of the oxyacetylene process is substantially inadvisable) and in low-alloyed ones (such as those with Mo and Cr-Mo , for boilers, so a verification of the toughness of the joints, with percentage tests, appears desirable in this case).

Consequently, the materials on which the process can be applied are today limited mainly to carbon steel and low-alloy (with a maximum limit represented by the 1.25 Cr steel - 0.5 Mo). For other materials, such as alloyed Cr-Mo steels, alloys, Cr and Cr-Ni stainless steels, aluminum and its alloys, copper and its alloys, etc., processes with inert gas protection (TIG and MIG) have completely replaced the application of the oxyacetylene process. Finally, the process is widely used for brazing applications, where the "sweetness" of the flame and its reducing characteristics lend themselves particularly to the characteristics of the brazing itself.

5.3 Typical defects

Welding imperfections can be related to metallurgical problems (as in the case of hot or cold cracks) or operational problems, that is related to the combination of welding process, working conditions and capacity of the welder.

The welding welding process with the oxyacetylene flame, due to its characteristics, can mainly give rise to lacks of fusion and knit irregularities. Other defects are possible, but are due to the welder.

5.4 Filler metal

The oxyacetylene flame welding process is applied to the case of carbon and low-alloy steels. The two regulations currently in use are dedicated to these materials. The European classification is treated by UNI EN 12536: 2001, which provides a symbol consisting of the process identification letter (an "O"), followed by a Roman number that refers to the chemical composition and behavior in welding.

The classification AWS A 5.2: 2007 "Specification for carbon and low-alloy steel rods for oxyacetylene gas welding" also uses an alphanumeric code, characterized by an R, followed by a reported number to the breaking load of the deposit, measured with longitudinal tensile test and expressed in kPSi.

Symbol	Chemical composition								Behaviour		
	C	Si	Mn	P*	*S	Mo	Ni	Cr	Fluidity**	Spatter**	Porosity**
O Z	No specific requirement										
O I	0,03÷0,12	0,02÷0,20	0,35÷0,65	0,03	0,025	-	-		A	A	A
O II	0,03÷0,20	0,05÷0,25	0,50÷1,20	0,025	0,025	-	-		M	M	A
O III	0,05÷0,15	0,05÷0,25	0,95÷1,25	0,02	0,02	-	0,35÷0,80		B	B	B
O IV	0,8÷0,15	0,10÷0,25	0,90÷1,2	0,02	0,02	0,45÷0,65			B	B	B
O V	0,10÷0,15	0,10÷0,25	0,80÷1,2	0,02	0,02	0,45÷0,65		0,80÷1,20	B	B	B
O VI	0,03÷0,10	0,10÷0,25	0,40÷0,70	0,02	0,02	0,90÷1,20		2,00÷2,20	B	B	B

Notes:
* Maximum values
** A = High; M = Medium; B = Low

Symbol	Tensile strength (Rm)		A%
	ksi	MPa	
R45	No requirement		
R60	60	410	20
R65	65	450	16
R100	100	690	14
RXXX-G	XXX*		No requirement

* Admitted values 45, 60, 65, 70, 80, 90, 100.

UNIT BIBLIOGRAPHY

[1]

GLOSSARY

It includes the main concepts, new and / or complex seen in the unit, as a dictionary.This type of resource is important especially when the course is aimed at students with no knowledge of the subject. Glossary entries are ordered alphabetically.

Welding Processes – MMA

1.1 Course name

MMA Welding

1.2 Course duration

5 hours

1.3 Course purpose

In this unit it is showed specific items related to MMA welding process, specifically related to the welding equipment, influence of welding parameters on the quality of the weld and health and safety.

To develop properly the tasks as welder, the student shall be familiarize with the use of equipment and the influence of welding parameters on the quality, so this didactic unit is really important for the student that want apply MMA welding in his/her professional life, of course, being care on all health and safety aspect.

1.4 Objectives of the course

Outline the objectives of the course

- *The student is able to:*

Knowledge	Skills	Attitudes	Contests of learning
Explain the terminology associated with MMA Welding procedures.	Use terms and definitions that are consistent with generally accepted welding terminology as recorded in national and international welding standards; Describe the applications, advantages and limitation of the MMA welding process;	Collaborate with the members of the working team in order to fulfill the task; Assumption within the work team of the responsibilities for the work task.	Introduction to MMA Welding. Welding process using covered electrodes.
Identify basic and major components of shielded metal arc welding equipment and explain their function and purpose. Explain the importance of correct assembly welding equipment,	Identify, select and prepare of welding equipment and specific component elements used in MMA welding process: power sources, electrode holder; Choosing the materials, SDVs and equipment		Equipment and specific component elements used in MMA welding process; Power Source.

	and the consequences of incorrect assembly. Explain the importance of the correct setting of the power source and choice of electrode and the consequences of incorrect selection. Explain the thickness of materials in relation to size and type of welding electrode used, and the influence of electrode manipulation during the welding process.	required to perform the assembly by MMA welding; Demonstrate setting up procedures using simulator/real equipment.		Electrode Holder. Ground Connection. Cables and Terminals.	
	Establish the parameters of use of the electric arc and the part of it; Identify what type of electrode to be use with DC or AC current;	Prepare the welding environment. Identify potential causes of welding defects or imperfections prior to welding, and take action to meet requirements. Choose welding consumables/ additives for welding joints through welding processes; Practice MMA welding of semi-finished products/parts using simulator/ real equipment. Execute the (MMA Welding) welding of common welding joints in all positions using		MMA welding technologies.	

		simulator/ real equipment. Inspect the end product for conformance to specifications as reflected on drawing or job requirement. Identify welding defects and take corrective action. Identify the different welding positions, defined in the ISO 6947: 2011 standard.			
	Identify welding hazards and eliminate in accordance with standard working practices.	Adhere to safety precautions. Apply measures to be taken regarding the prevention of accidents related to noise, smoke, fire, electric shock.		Health and safety measures in MMA Welding.	

1.5 Contents

1. Introduction to MMA Welding
2. Welding Equipment
2.1. Power Source
2.2. Electrode Holder
2.3. Ground Connection
2.4. Cables and Terminals
3. Welding Technology
3.1. Characteristics of Arc
3.2. Welding Parameters
3.3. Ignition of the Arc
3.4. Coated Electrode
3.5. Welding Positions
4. Health and Safety in MMA Welding

1.6 Participants

Learner characteristics: *(Outline the profile of the target learner group for the course)*	*Basic knowledge in Welding*

1.7 Entry requirements

(Outline the entry requirements of the course- if necessary)

Education level requirement:	*Students from VET schools (background on compulsory education)*
Previous knowledge needed	*Basic knowledge in welding*
Age requirements:	*Ages between 16 and 20 years old*

1.8 Assessment activities

Summative assessment

- *Theoretical examination using stand-alone simulator/computer or SIMTRANET virtual classroom*

1.9 Bibliography (used or supplementary)

[1] General Course on Welding Technology. Training Fund-CESOL. Module 1 and 2. 1994.

[2] Documentation of the course "European Welding Specialist". Modules 1 and 2. 1995.

[3] UNE-EN ISO 17633:2006, Welding consumables. Tubular wires and rods for arc welding with or without gas protection of stainless and heat-resistant steels. Classification.

[4] AWS A5.1-04: Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding.

[5] AWS A5.4-06: Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding.

[6] AWS A5.30-07: Specification for Consumable Inserts.

UNIT NUMBER: Didactic Unit 2
UNIT TITLE: *MMA Welding*

UNIT PRESENTATION

In this unit it is presented specific items related to MMA welding process, specifically related to the welding equipment, influence of welding parameters on the quality of the weld and health and safety.

To develop properly the tasks as welder, the student shall be familiarize with the use of equipment and the influence of welding parameters on the quality, so this didactic unit is really important for the student that want apply MMA welding in his/her professional life, of course, being care on all health and safety aspect.

OBJETIVES

The objectives of this units are:

- The student is able to:

Knowledge	Skills	Attitudes	Contests of learning
Explain the terminology associated with MMA Welding procedures.	Use terms and definitions that are consistent with generally accepted welding terminology as recorded in national and international welding standards; Describe the applications, advantages and limitation of the MMA welding process;	Collaborate with the members of the working team in order to fulfill the task; Assumption within the work team of the responsibilities for the work task.	Introduction to MMA Welding. Welding process using covered electrodes.
Identify basic and major components of shielded metal arc welding equipment and explain their function and purpose. Explain the importance of correct assembly welding equipment, and the consequences of incorrect assembly.	Identify, select and prepare of welding equipment and specific component elements used in MMA welding process: power sources, electrode holder; Choosing the materials, SDVs and equipment required to perform the		Equipment and specific component elements used in MMA welding process; Power Source. Electrode Holder.

Explain the importance of the correct setting of the power source and choice of electrode and the consequences of incorrect selection. Explain the thickness of materials in relation to size and type of welding electrode used, and the influence of electrode manipulation during the welding process.	assembly by MMA welding; Demonstrate setting up procedures using simulator/real equipment.		Ground Connection. Cables and Terminals.
Establish the parameters of use of the electric arc and the part of it; Identify what type of electrode to be use with DC or AC current;	Prepare the welding environment. Identify potential causes of welding defects or imperfections prior to welding, and take action to meet requirements. Choose welding consumables/ additives for welding joints through welding processes; Practice MMA welding of semi-finished products/parts using simulator/ real equipment. Execute the (MMA Welding) welding of common welding joints in all positions using simulator/ real equipment.		MMA welding technologies.

	Inspect the end product for conformance to specifications as reflected on drawing or job requirement. Identify welding defects and take corrective action. Identify the different welding positions, defined in the ISO 6947: 2011 standard.		
Identify welding hazards and eliminate in accordance with standard working practices.	Adhere to safety precautions. Apply measures to be taken regarding the prevention of accidents related to noise, smoke, fire, electric shock.		Health and safety measures in MMA Welding.

CONTENTS

CONTENTS DEVELOPMENT

1. Introduction to MMA Welding

Manual metal arc welding is a process in which metal fusion is achieved by the heat energy produced by an electric arc established between the end of a covered electrode and the parent metal of the joint to be weld.

The filler material is melted in form of small drops, which together with the melted base material become the weld. A slag is obtained by the electrode coating, which acts as a protection of the melting pool from the environment (see figure 1).

Manual metal arc welding is known by following designations

- SMAW, Shielded Metal-Arc Welding (ANSI/AWS A3.0)
- 111, Manual metal arc welding (metal arc welding with covered electrode) (EN ISO 4063)
- MMAW, Manual Metal-Arc Welding (United Kingdom).

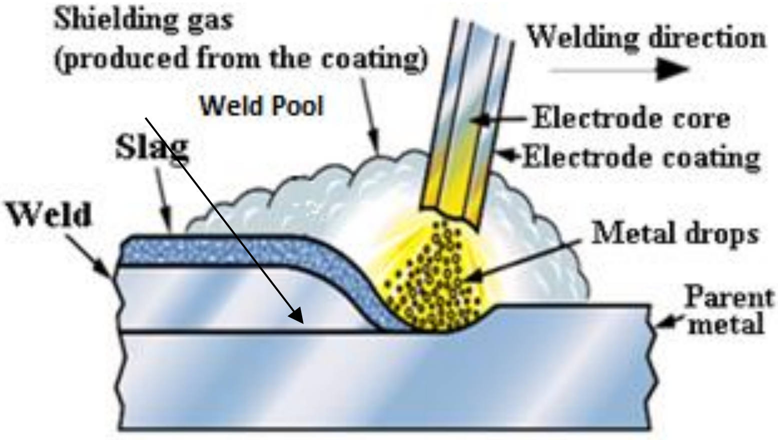


Figure 1. Welding process using covered electrodes

Applications, advantages and limitations

This type of welding process is the most widespread among all arc welding processes, mainly because of its versatility, in addition of the equipment necessary for its implementation is simple, portable and cheaper than others.

By other hand, the manual metal arc welding is applicable to almost all types of steel: carbon, low alloy, stainless steel, heat resistant, etc., and many alloys such as copper-zinc (brass), copper-tin (bronze), nickel and nickel alloys.

The filler metal and the means for their shielding during welding come from the coated electrode itself. No additional protection by auxiliary gases or granular fluxes is necessary.
It is less sensitive to wind and air currents that gas-shielded arc processes. This makes it ideal for onsite work. But the process must be used whenever protected from wind, rain and snow, unless the appropriate equipment is available.

Also, the MMA welding can be used in all types of joints and positions. However, factors such as productivity and greater uniformity of the welds obtained for certain, though numerous, applications, are making that others welding processes are shifting the manual metal arc welding.

MMA welding is not applicable to metals of low melting point such as lead, tin, zinc and its alloys, because the intense heat of the arc is too much for them. Neither, it is applicable to metals with high sensitivity to oxidation, such as titanium, zirconium, tantalum or niobium, since the protection provided by coating is insufficient to avoid oxygen contamination of the weld. Nor does it apply to upper 38 mm thickness, because there are more productive processes for large thicknesses. For small thicknesses, there are small electrodes of 1.6 and 2 mm that allow to weld plates of 1.5 mm of thickness, although for these thicknesses there are other more efficient processes.

MMA welding can be used in combination with other welding processes, applying either the root pass or filling (it is generally used in combination with the TIG process for the welding of pipe, where the root is made with TIG and the filling and capping layers are made with MMA welding).

The major application sectors are shipbuilding, machinery, structures, storage tanks and spheres, bridges, pressure vessels and boilers, oil refineries, oil and gas pipelines and any other similar work. This process is also suitable for making repairs.

2. Welding Equipment

Essentially, the method consists in establishing a closed electrical circuit, which requires a suitable power source equipped with two terminals, one connected by a cable to an electrode holder, in which clamp a coated electrode is fastened, and the other terminal is connected to the piece, by a return cable and a ground clamp. The circuit is closed through the arc which is established between the electrode tip and the welding point on the workpiece (figure 2).

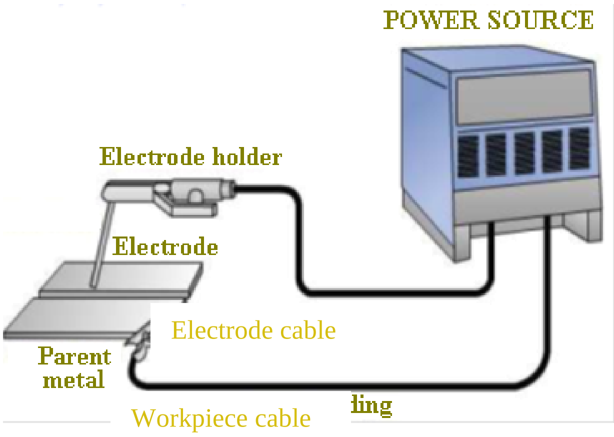


Figure 2: Welding equipment

2.1. Power Source

This process requires low voltage and high current. This is just the opposite that the power companies provide to workplace. The power source is the element that is responsible for transforming and/or converting electrical power network in other, AC or DC, with a voltage and current suitable for the establishment and stabilization of the arc.

These energy sources are electrical machines which, according to their structures are called transformers, rectifiers or converters.

In choice of the power source the electrode to be used must be considered, so that it can provide the type of current (AC or DC), current range of and no-load voltage required.

Features of the power source.

Each welding power supply has its own voltage-current characteristic curve, as shown in Figure 3.

The characteristic of the power supply is a graphical representation of the relationship between the voltage and current of the source. The current and voltage obtained in the actual welding process is determined by the intersection of the characteristic curves of the machine and the arc. This is the operating point or working point defined by the welding current and voltage.

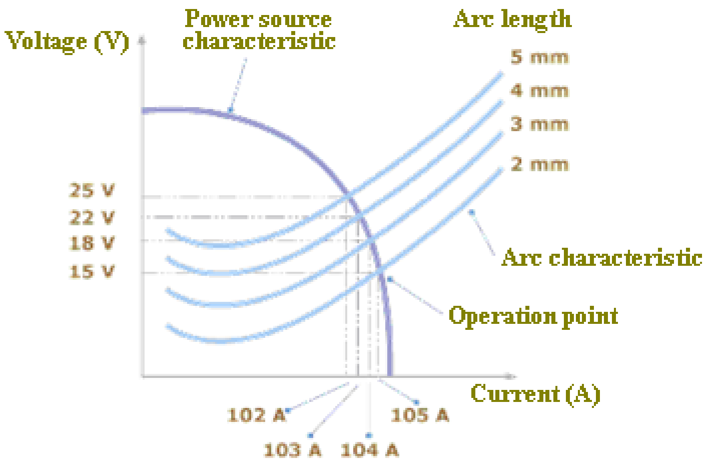


Figure 3: Variation of the arc length.

The power source for welding must present a downward slope characteristic (constant current), so that the welding current look unaffected by variations in the arc length.

In order to understand how to control the characteristic of the source is important to understand two key parameters: open-circuit voltage and short-circuit current.

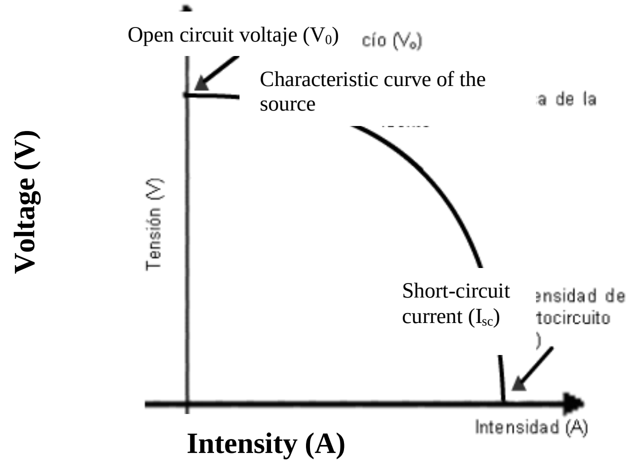


Figure 4. Characteristic curve of welding source

Open-circuit voltage
The open circuit voltage (Vo) is the maximum voltage that the power source can supply and is the voltage at the terminals of the source when it is not welding. The open circuit voltage of the circuit is usually greater than twice the welding voltage. It is mainly used to ensure ease of ignition and stability of arc, so what because of the increased instability of the arc when welding with AC, the transformers have greater open circuit voltage that the rectifiers.
Short-circuit current
The short-circuit current (Isc) is the maximum current supplied by the power source. To start the arc, a short circuit is produced, at this time the voltage is vanished, and current flowing is the maximum (Isc), thanks to this the electrode is heated and it can stablish the arc.

These two parameters are of particular relevance in TIG welding, helping to facilitate arc establishment.

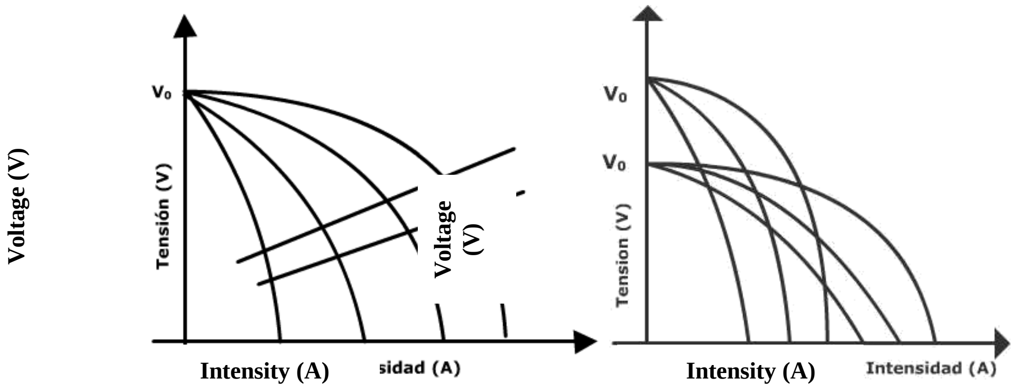


Figure 5. Variation of the power source characteristic curves

In general we can say that the variation in the slope of the curve is achieved by acting on the magnetic field generated in the transformer, while variations in open-circuit voltage are carried out by lead in the primary circuit or secondary, it is merely varying the number of turns in the primary or secondary coils by derivations.

Types of the power source

The most important components of a power source are:

- **Transformer** ─ⓞⓞ─. It is the device which carrying electrical power. The current with certain voltage and amperage enters to the transformer and it comes out with different amperage and voltage, being the initial power input and output practically the same.

  Although there are very complex transformers, here a very simple one that serves to the reader as a reference will be shown.

- **Rectifier** ─▷|─**.** It is a device that allows the passing of the current in only one direction, thus converting alternating current to direct current. The rectifier element, the diode, can be described as the electric equivalent of a one-way valve.

- **Converter and gensets** ─(M)═(G)─**.** Converters and gensets consist of a motor, which can be electrical or can be internal combustion and a generator, which can be DC (also called alternator) or AC.

2.2. Electrode Holder

Electrode holder conducts electricity to the electrode and the hold it. To avoid overheating in the jaws, they must be kept in perfect condition. Overheating would result in reduced quality and a difficult performance of the welding.

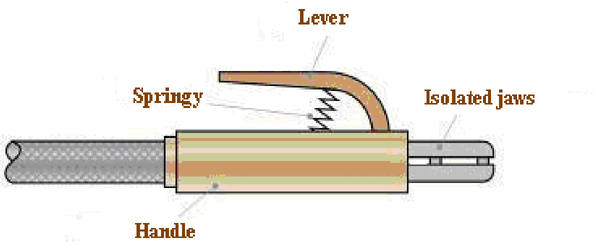


Figure 6: Electrode holder

A suitable clamp according to the electrode diameter to be used must always be selected.

During welding, it is not advisable to melt the full length of the covered electrode, because heating produced in the electrode can affect the isolated jaws, burning it. Usually about 60 mm are left unconsumed. Figure 6 represents a typical electrode holder.

2.3. Ground Connection

The correct connection of the workpiece is very important. The positioning of the workpiece clamp has special relevance in welding with direct current. An unsuitable location can cause the magnetic blow, that difficult to control the arc.

The method of fastening the workpiece clamp is also important, because a workpiece that is badly fasten does not provide a consistent electrical contact and the connection will heat up, causing an interruption in the circuit and the disappearance of the arc. The best method is to use a copper contact pad secured with a clamp. If due to this device the contamination of base metal by copper would be detrimental, the copper shoe must adhere to a plate that is compatible with the workpiece, which is attached to the piece.

For rotating parts, the contact must be made by shoes that slip on the piece or by bearings on the shaft on which the piece is mounted. When sliding shoes are used at least two ones must be placed, because if a losing contact occurs in a shoe, the arc would be extinguished.

2.4. Cables and Terminals

Cables must drive power from the welding power source to the electrode holder and workpiece connection.

It must be ensured that the cable section is suitable for the current to be employed (see section Safety and Health). Cables are heated due to the flow of electric current through it, for an effect known as Joule effect. At higher current welding used, the higher is the heating experienced by cables, which necessitates the use of larger diameter cables. The terminals are the elements used to connect cables to the power source. It is important that these connections are firm, in order to avoid the appearance of false arcs that can produce welds in these terminals, which would disable partially the equipment.

3. Welding Technology

It is very important to know and study the technology of each welding process, as there are several parameters to consider when welding. As far as MMA welding is concerned, we will focus on properties of arc, welding parameters, ignition of arc, coated electrode and welding positions.

3.1. Properties of Arc

The arc is defined as an electric discharge through an ionized gas, called plasma, between an electrode and the workpiece. If the arc is maintained, the flowing of an electric current occurs through it, releasing a large amount of energy, as heat and electromagnetic radiation. The heat produces a high temperature and causes the melting of the electrode and the workpiece in contact with the arc.

The arc consists of two concentric parts, the inner called plasma and outer called flame.

- **Flame.** It is the area outside the arc. It is cooler than the plasma and is generally composed of atoms generated by the gas molecules that either when in contact with the surface of the plasma column are dissociated, or once dissociated are broken off from it, which in the flame are recombined forming molecules and releasing the absorbed energy, for it dissociation, as heat.

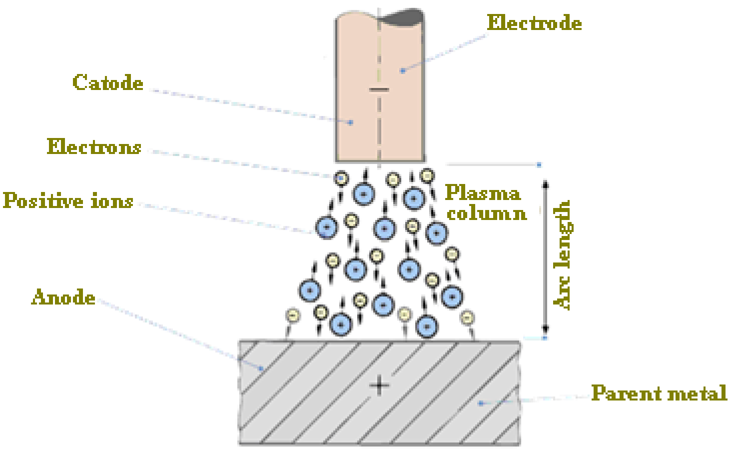


Figure 7: Arc electric description.

- **Plasma.** The plasma is an ionized gas which transports the current and the following components:
  - The electrons, which move from the negative pole (cathode) to the positive one (anode).
  - Metal ions, which move in opposite direction.
  - Molten metals, mostly, from the electrode.
  - Slags.
  - Metallic and non-metallic vapors.
  - Gaseous atoms and molecules, some ionized.

The electrons and negative ions are strongly accelerated by the electric field established between the cathode and the anode and collide violently against it, transforming its kinetic energy into heat, while the metal ions do the opposite, hitting the cathode and producing raising its temperature.

Furthermore, collisions between particles traveling in opposite directions also are produced inside the plasma, which, in turn, contributes to the high emission of heat energy and high intensity radiation.

The heat is an effect of the high kinetic energy of the particles because their movement within the plasma, which is increased by the effect of current and voltage across the arc. Heat is generated by braking of the particle, because of the particle collision or impact. Due to before described, three areas of heat generation can be seen, depending on which causes of braking are predominant:

- **Cathode:** The impact of the positive ions is the phenomenon predominant, but also contributes in some way that the phenomenon is accompanied by a heat release due to the electron emission.

- **Plasma:** Collisions between electrons, ions, atoms and other particles are produced, which produce large heat emission.

- **Anode:** The impact of electrons, animated by a high speed, is the reason of the transforming their high kinetic energy into heat.

3.2. Welding Parameters

The main parameters that must be controlled in the manual metal arc welding with coated electrode process are as follows:

- **Welding current.** In MMA welding power sources, before welding, the welder must adjust the welding current. The amperage is selected depending on the diameter of the electrode used, thickness of the workpieces, welding position and joint type, that is, if it is a butt weld or fillet weld. Usually, the electrode manufacturer limits a current range in which the electrode can be used, although as indication the values in table 1 could be taken.

(A) (B) (C) (D) (E) (F) (G)

Figure 8: Effect of amperage, arc length, and travel speed.

Welds made on carbon steel plate of 5 mm thickness using rutile electrodes (E 6013) diameter 2.5 mm

- (A) High travel speed.
- (B) Low welding speed.
- (C) Too low amperage (50 A).
- (D) Optimum voltage, current (75 A) and travel speed.
- (E) Too high amperage (90 A).
- (F) Too high voltage.
- (G) Too low voltage.

An electrode must not be used at higher amperages that indicate, because undercuts, projections, intensifying the effects of the magnetic blow and even cracks would occur.
Figure 8 (B and C) shows the effect of the current in a weld. As higher is the current used, the penetration will be greater.

Table 1: Approximate current ranges depending on the diameter of the electrode in the welding of steel.

Diameter	Current range
2,5 mm	60 – 90 A
3,25 mm	90 – 150 A
4 mm	120 – 180 A

The current used depends on the welding position, the joint type, material thickness, etc. As higher is the current used, the heat input will be greater the heat supplied to the material and the greater will be the size of the molten pool.

- **Arc voltage.** The arc voltage used depends on the type of electrode, diameter, welding position and current. In general, it must be equal to the electrode diameter (in rutile cellulosic electrode), except in case on a basic electrode is used, where the voltage should be half of the electrode diameter.

  The arc length should always be maintained equal, in order to avoid oscillations in voltage and current intensity and thus an irregular penetration.

  In general, any electrical arc has a cone shape with an opening angle which depends on the polarity used, but it is practically independent of the other welding parameters used.
  If the arc length is increased, the arc acts on a larger surface, further dissipating the heat generated in the arc, so the penetration is reduced.

- **Travel speed.** The travel speed must be set so that the arc forward slightly to the molten pool. As higher the travel speed is, the bead width will be smaller, the heat input will be lower and the weld cools faster. If travel speed is excessive undercuts occur, slag removal is difficult, and the appearance of pores is promoted. In figure 8 (F and G) the effect of travel speed is shown.

- **Electrode diameter.** The diameter of the electrode is an indirect process parameter, because once the electrode has been chosen and the material, position and thickness of the sheet to be welded have been known, the welder set the welding current, which is a direct parameter.

  In general, it must be chosen the largest possible diameter to ensure heat input requirements and allow easy use, depending on the position, the material thickness and type of joint, which are the parameters from which the selection electrode diameter depends.
  Larger diameter electrodes are selected for welding of thick materials and for welding in flat position.

  In horizontal, vertical and overhead position the molten pool tends to fall by gravity. This effect is much more pronounced, and therefore the use of smaller diameter electrodes is suitable when it is welded in these positions.

- **Current Type. Polarity.** Current type and polarity are, in addition the amperage, other parameters which the welder set up in the welding power source. Manual metal arc welding can be performed both with AC or DC current in both polarities.

  The choice depends on the type of power source available and the electrode and base material to be used.

- **Direct current.** Two types of polarity, ***straight polarity*** when the electrode is connected to the negative pole and the workpieces are connected to the positive pole and ***reverse polarity,*** when the electrode is connected to the positive (anode) pole and the workpieces to the negative pole (cathode).

- **Alternating current.** When an arc is established in alternating current, the electrode acts as anode during half cycle and as cathode during the other half cycle, alternately producing a cycle in which the electrode acts positive and negative. In Europe, this change occurs 100 times per second (50Hz), so it is imperceptible to the naked eye. Due to this continuous change, the AC arc is more unstable than in DC.

Table 2: Comparison between DC and AC

Parameters	DC	AC
Welding at a great distance from the power source	-	Preferable
Welding using small diameter electrodes which require low welding current	The operation is easier	If work is not performance carefully, the electrode can be deteriorated due to the difficulty of arc ignition
Arc striking	The operation is easier	It is more difficult particularly when small diameter electrodes are employed
Arc maintenance	It is easier for greater stability	It is more difficult, excepting when high performance electrodes are used
Magnetic blow	It may be a problem in the welding of ferromagnetic materials	No problems arise
Welding positions	It is preferred in vertical and overhead position because lower currents are used	If the proper electrodes are used, welding can be performed in any position
Electrode type	It can be used with any type of electrode	It cannot be used with all electrodes. The coating must contain substances that restore the arc
Workpiece thickness	It is preferred for thin thicknesses	It is preferred for large thickness because an electrode of larger diameter and greater current can be used, so better performance are achieved
Welding using short arc lengths (it is important in	Welding is easier	-

some kind of electrodes, especially basic type)		
Polarity	DC+ or DC-, it depends of parent metal and electrode to be used.	-

3.3. Ignition of the Arc

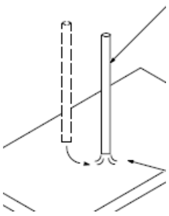
In manual metal arc welding with covered electrode, the arc is established when the electrode touches the workpiece (promoting an electrical short circuit) and rising the minimum open circuit voltage necessary to strike the arc, the arc is stricked itself.

It shall be noted the difference with other processes such as MAG welding. In second case, the wire may be in contact with the workpiece without the arc is established. The arc is set when the gun trigger is pressed.

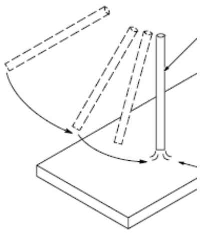
At the beginning of welding, the electrode is completely cold, which has influenced regarding the establishment of the welding arc.

For the establishment an operation as is known as arc striking and basically consists in establishing small arcs between the electrode and the workpiece so that heating of the electrode tip is produced. For this, two techniques can be used:

- Tapping the tip of the electrode on the workpiece closed of where the welding is going to be started, and then the electrode is removed quickly to produce an arc with the required length.



- To establish the arc by a scraping movement like that is applied to strike a match.



During the establishment of the arc, is often that the electrode is welded to the workpiece. When this happens, it is necessary to swing the electrode right to left to break the "weld", if necessary, open the electrode holder. The problem with the second option is that the arc can be established between the clamp and the electrode thereby deteriorating the clamp. Pulling hard on the electrode, the piece can fall out causing damage to welder or persons in the vicinity. If the clamp gets away, leaving the electrode attached to piece it is necessary to use a hammer and chisel to remove it.

Either by gently beating electrode or through scraping, the striking arc causes small marks on the piece surface due to the surface melting on electrode and workpiece. Since the melting in these areas is very small, cooling rates are very large, so that these brands are cracked. To avoid these defects, it is essential to establish the arc in the welding area and ahead of it, never out of the edges of the joint.

3.4. Coated Electrode

The key element of this process is the electrode, which establishes the arc, protects the molten pool and, when is consumed, provides the filler, that together with the molten base material, forms the weld.
The electrode is basically constituted by a rod, like the base metal composition, with or without a coating. Under this condition, the electrodes are classified into two groups:

- **Bare electrodes.** Bare electrodes are not used, excepting in very little responsibility joints and on mild steel, because the welds produced have very poor mechanical properties.

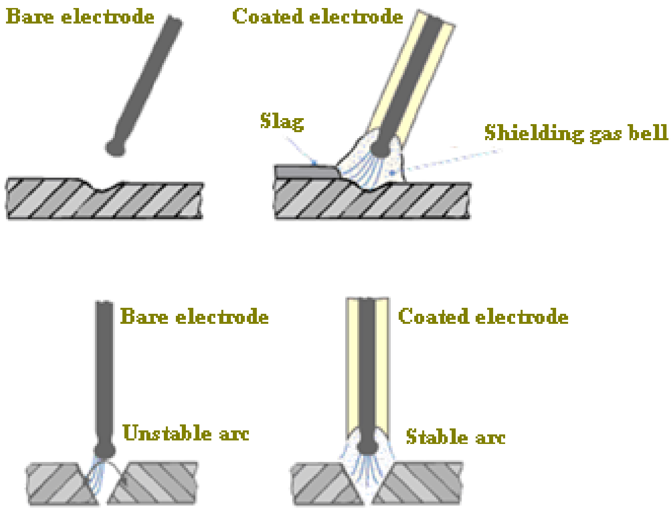


Figure 9: Differences between coated and bare electrodes

The arc absorbs the components of air and incorporates them into the molten pool, so many oxides, nitrides, pores and slag will be contained in the weld metal, which produces these poor mechanical qualities.

Also, it is very difficult to maintain the arc, which is impossible with AC.

- **Coated electrodes.** The coated electrodes have two parts (see *figure 10*).
    - **Core:** Basically, it is a circular rod uniform composition and generally like the base metal.
    - **Coating:** It is a cylinder that surrounds the core, concentric with it and of uniform thickness. It is composed by a mixture of components that characterize the electrode and which has several functions, which avoid the disadvantages of the bare electrode.

The electrodes have standard lengths of 150, 200, 250, 300, 350 and 450 mm, depending on the diameter of the rod and the type of the rod material. One end of the core is not coated in a length of 20 mm-30 mm, for the insertion thereof in the clamp holder.

The diameters of the electrodes are also standardized, the most common being 2.5, 3.25, 4 and 5 mm. The electrode diameter is measured by the diameter of the rod.

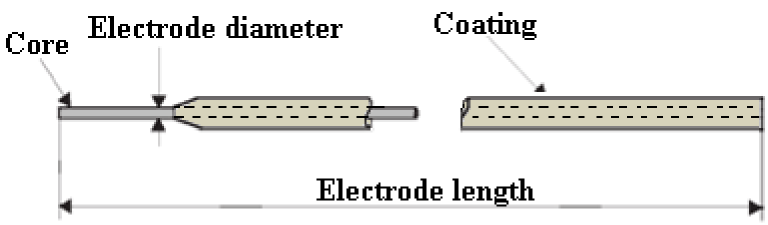


Figure 10: Coated electrode

Considering the relationship between the diameters of the rod and coating, the electrodes may be classified as:

- **Thin:** thin coating electrodes protect little bit the molten pool, so they are only used in learning of welding techniques. But with cellulosic electrodes you use a thin covering.
- **Mediums:** These electrodes produce greater arc stability, allow welding with alternating current and also direct current in both polarities, and protect the weld metal better; the slag covers the solidified metal, which reduce the cooling rate and oxidation.
- **Thick:** Electrodes with thick coating allow to obtain the best qualities of welded metal normally, but in some cases not all thick coverings will give the best weld metal quality.

Functions of the coating.

The basic functions to be fulfilled by a coating can be summarized in three:

- **Electrical function of the coating:** From this viewpoint, the main function of the coating is to ensure a good ionization grade between the anode and cathode, providing arc stability and ignition. This is achieved by including in the coating components of low voltage ionization and high thermionic power, mainly those of sodium, potassium, barium and in general, alkali metals. Also, other products such as silicates, carbonates and oxides of iron and titanium favor striking and arc stability.

- **Physical function of the coating:** The coating fulfils several physical functions in manual metal arc welding process, being the main gas generation and formation of slag. The resulting gases perform a dual function:

  - To set a gas shielding around the arc column which prevents direct contact of oxygen and nitrogen from air both metal droplets emerging from the end of the electrode, on its way to the molten pool, and to the surface thereof.

  - Second, the gas undergoes a large expansion generated by heat of the arc and contributes to removing metal droplets form the end electrode. Also, this gas expansion drives the metal drops, giving it a high speed. This allows the welding in vertical, horizontal and overhead positions, would otherwise not be possible.

Slag performs a protection task of metal from the time that is melted. The surface tension of the molten slag is much lower than that of steel, that produces a layer of solidified slag is formed on the molten pool which protects it when it is not covered by the gas surrounding the arc. The protection continues when the welded metal is solidified, avoiding its contact with the atmosphere.

The slag also sweeps bath collecting impurities as oxides, sulfides, etc., that adhere to the impurities and are carried by to the surface where they solidify, due to their higher melting temperature than steel.

- **Metallurgical function of the coating:** Metallurgically coating has influence in two ways in the weld:

  - On the one hand, the coating contains alloying which can improve the mechanical properties of the joint and make up the elements that the base material can lose during welding. Furthermore, the coating may also contain iron powder that will increase the deposition rate of the electrode.

  - By the other hand, the slag which covers the weld reduces the cooling rate, producing that the amount of hydrogen of the weld is reduced, avoiding or minimizing the occurrence of hard and brittle structures and lowering the level of internal stresses.

Coating types. UNE-EN ISO 2560:2010

The classification of coated electrodes is primarily made by the coating composition. Generally, carbon steels are welded with coated electrodes with a composition of rod similar to the composition of the base metal, however, for stainless steels such composition may vary considerably.

According to the compounds forming part of the coating and the proportion in which they are present, the electrodes behave differently, so that, according to the application that will make them and, depending on the characteristics of the joint, thickness, type of preparation, welding position, geometry of the joint, composition of the metal, etc., a type of electrodes and the appropriate welding parameters can be selected.
The coating is classified according to their composition, as mentioned above, because this determines its qualities and applications, being grouped and designated as follows:

- Acid (A).
- Basic (B).
- Cellulose (C).
- Rutile (R).
- Rutile - acid (RA).
- Rutile - basic (RB).
- Rutile - cellulosic (RC).
- Rutile thick (RR).
- Other (S).

The most important and most used electrodes are the basic, rutile and cellulosic electrodes. For example: rutile electrodes are used in zones of difficult access to weld, basic electrodes are used in welds with high mechanical properties and cellulosic electrodes are used in downward vertical pipe welds.

3.5. Welding Positions

Figure 11 shows the main positions, PA, PB, PC, PD, PE, PF and PG as well as some typical examples in those positions. These positions are applicable to both plates as pipes. It is also important to note that the PB and PD positions are referred only to fillet weld joints and have no application in butt joints.

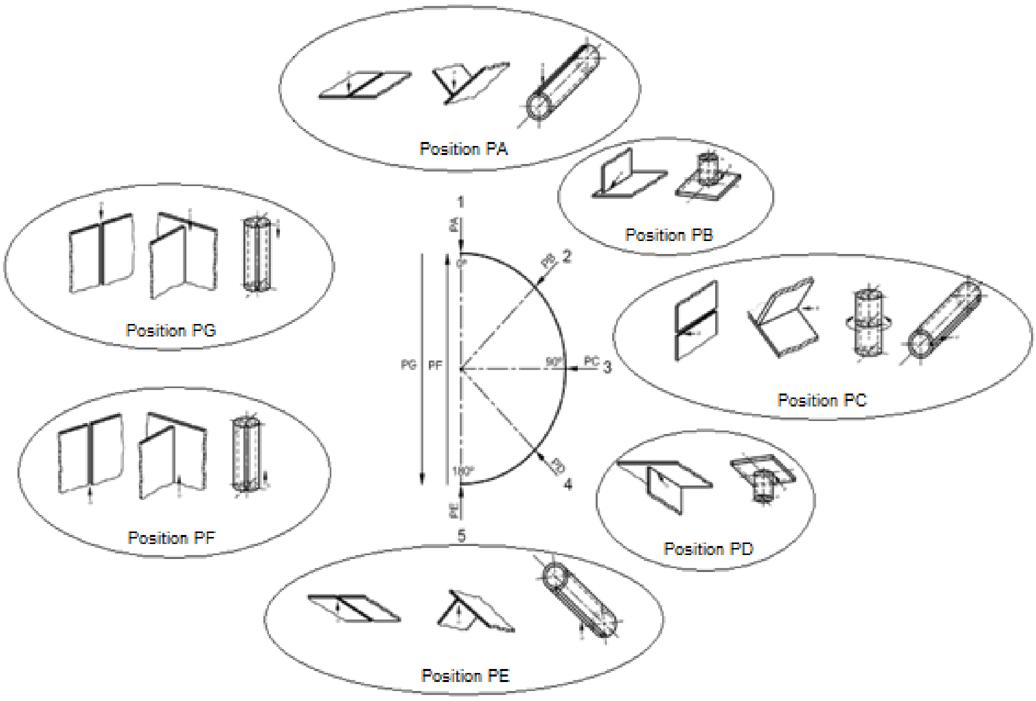


Figure 11: Main Welding positions.

Besides the above, there are other main welding positions that apply exclusively to the pipes and which are PH (in vertical uphill pipe welding), PJ (in vertical downhill pipe welding) and PK (orbital welding of tubes) positions. Figure 12 shows some examples of these welding positions.

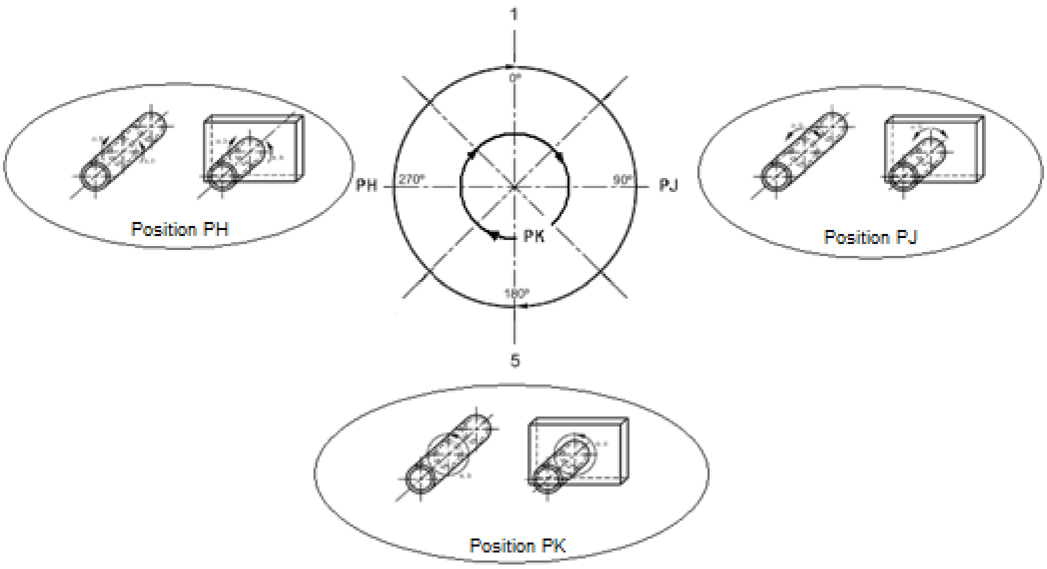


Figure 12: Main Welding positions.

The welding position is critical since it is an essential variable in the qualification of welders. Welders should know the welding positions to be sure that the qualification covers them for the positions in which they are welding.

In the MMA, there are two fundamental factors that prevent detach of the molten weld pool:

- **The slag.** The slag helps hold the molten weld pool.

- **The surface tensions.** Surface tension is a force that acts on the surface of the liquid and which tends to keep the molecules together preventing liquid from spreading. For example, if you deposit a drop of water on a surface, you can see how it looks with a rounded look. This is due to surface tension.

Surface tension is not uniform over the liquid surface but is much greater at the edges. This justifies why when we pour water on a surface, the water forms a thin film on the surface, except at the edges, where it acquires the rounded appearance like a gout.

In other words, while the molten weld pool is small, the effect of surface tension is strong enough to hold the molten weld pool and prevent it from detaching or sliding. If the molten weld pool is large, the surface tension at the center would be very low and the molten weld pool tends to slip or fall off.

Consequently, **"when welding in position it is to constantly monitor the size of the weld while maintaining a small size. This implies welding with low heat input."**

Horizontal welding.

When doing weld runs in this position, the electrode is performed on a vertical plate, displacing the electrode horizontally. This means that the molten weld pool doesn't have tendency to be held back, so that the main subject comes from surface tension. The risk the molten weld pool to slip on surface is very high, so that this welding is made with as low heat input as possible (low intensity and fast welding speed) so, on the one hand there is a small molten weld pool, and secondly, the molten weld pool is not very fluid.

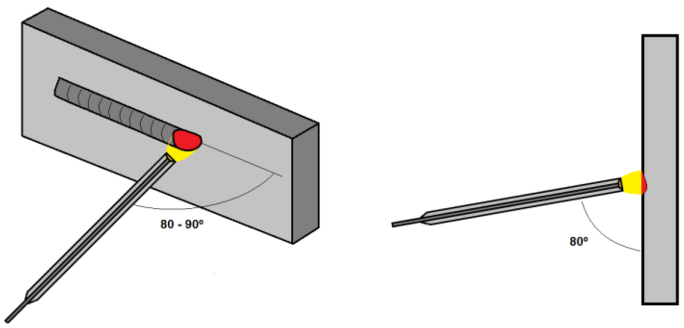


Figure 13: Guidance of the electrode in horizontal position.

Welding in vertical uphill

In weld runs in this position, welding is performed on a vertical plate, moving the electrode vertically upward, with or without oscillation. As in the previous case, the bath tends to slide by gravity, however, in this position, the deposited bead acts as backing and tends to hold the molten weld pool. This holding is effective while the accumulation of material in the molten weld pool is not very large.

Generally, in this welding position it is to weld with low current to prevent an excessive growth of the molten weld pool and becomes very fluid, thereby increasing the risk of sagging. Nevertheless, the heat input is usually very high, because the welding position does not allow welding as fast as in other positions.

in this position the electrode should be taken slightly tilted in the opposite sense to form an angle of 90 ° in perpendicular direction to the sheet (see Figure 14).

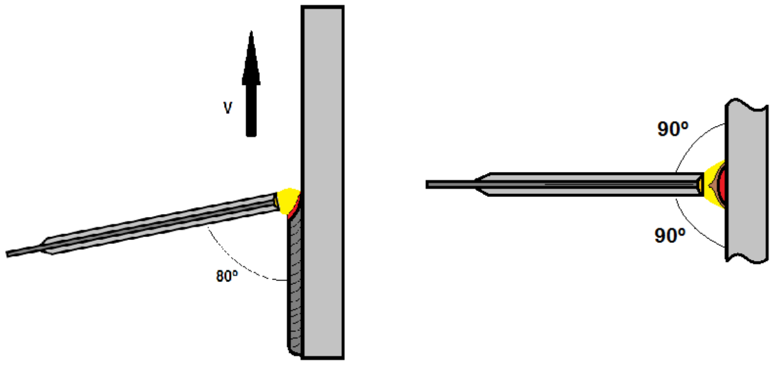


Figure 14: Orientation of the electrode in vertical uphill.

Welding in vertical downhill.

In weld runs in this position, welding is performed on a vertical plate, moving the electrode vertically downwards, normally without oscillation.

Again, the molten weld pool tends to slide by gravity without if there isn't any element holding the molten weld pool. To prevent the slag to overtake us comparing to flat welding position, welding must be performed at a higher travel speed, which requires a higher welding current to compensate the heat input.

It is also suitable to use the electrode orientation to direct the arc uphill and hold the molten weld pool. It is therefore common to use an angle of about 70°, (see Figure 15).

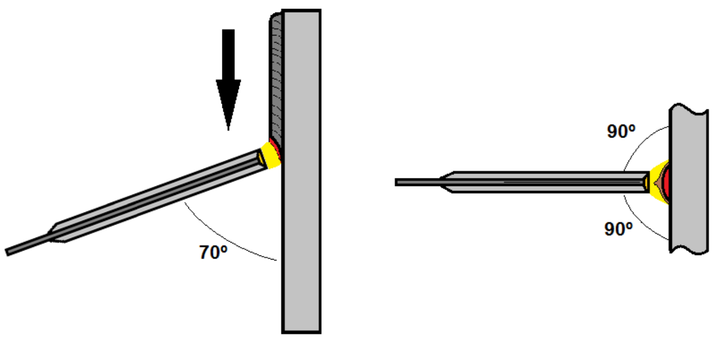


Figure 15: Orientation of the electrode in vertical downhill.

Finally, it is worth mentioning that it shouldn't be weld in this position, except when expressly stated and specific electrodes are used for welding in vertical downwards, normally cellulosic electrodes.

Overhead welding.

In weld runs in this position, welding is performed on a horizontal plate, by welding the bottom surface. The main problem, again, is that the molten weld pool can sag and even slip. Generally, this welding position should use a higher current than PC position. The risk that the molten weld pool slips or sags is not as high as in position horizontal position, but it can occur if welding with very high currents or very large molten weld pools.

Another problem, typical of this position is the increased risk of entrapment of slag in the bead since the density difference between the slag and molten weld pool tends to cause the mixture of both.

Regarding the orientation, the electrode should be slightly tilted in the forward direction (see Figure 16).

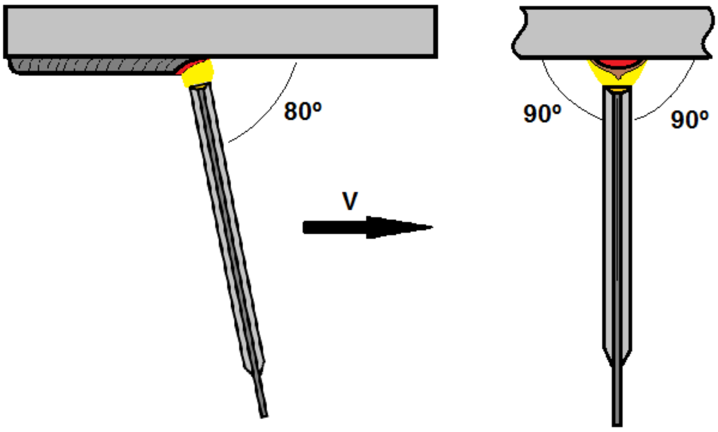


Figure 16: Orientation of the electrode in overhead position.

4. Health and Safety in MMA Welding

In the field of welding there are many factors to be considered from the point of view of safety. These dangers are caused both by the welding process itself (heat, gas, spatters, electricity, ultraviolet radiation…) and by the environment where the activity (welding workshop, on site, height or underwater develops, confined spaces, etc.).

To avoid personal injury is very important to follow some basic rules of risk prevention. Some guidelines to follow are going to exhibit at this subject with the aim of that will be followed by personnel involved in welding for their sake and for the sake of their colleagues.

Identification of risks associated with welding operations

The identification of risks is the result of the search for possible elements or situations that may affect the health of the worker. In addition, identification of occupational hazards is a fundamental tool to further implement the appropriate security measures.

Table 3: Common risk types to consider in welding operations.

Spatters and projections	The projections of incandescent particles produced during welding, can reach up to 10 meters horizontally. In addition, during chopping slag particles are emerge and from which the worker must be protected.

Fumes and toxic gases	They appear by chemical reaction of different components of the process. The various hazardous chemicals have different characteristics depending on their origin, being able to highlight the following sources: • Produced by metal parent. • Produced from the base material coated (galvanized, nickel, chromium, cadmium plated, painted, plastic coatings, oiled). • Produced by degreasing or cleaning products used in the the base and filler material. • Produced by the filler material • Produced by reacting with the surrounding air • Produced from liquids or gases which were contained in the tanks to be welded.
Electric shock	Caused by the poor condition of cables and / or connections or incorrect handling of electrical equipment.
High temperature	The temperature reached in the welding process should be sufficient to melt both the base metal and the electrode. This high temperature directly affects the welder.
Fire	Produced generally by projections of incandescent particles that reach an area where flammable items have accumulated. It can also be produced by welding in areas where large amount of fuel gas.
UV	Occurs when coated electrodes are used
Accidents with tools and equipment	The arc welding processes produce visible, infrared and ultraviolet radiation, which produce eye injuries and skin being the most dangerous ultraviolet radiation.
Noise	The noise produced by the action of complementary operations to welding such as grinding, chopping, hammering, etc.
Bad positions	Sometimes the welder must operate in awkward postures due to the poor accessibility of the joint. This position taken in time can lead to injury.

Prevention measures

When potential risks have already identified, it's the time to take preventive measures and protection against them.

Two fields of activity are differentiated: personal protection measures and collective protection measures.

Personal protection

They are aimed at the protection of personnel directly engaged in welding tasks, and their helpers.

Protective clothing

The purpose of personal protection is to reduce the consequences of risk, therefore, the priority is discovering the particular risk, as it cannot be removed or collective protection measures can be adapted, it will be when we use PPE (Personal Protection Equipment). It is important to remember that personal protections do not eliminate the risks;

they are simply physical barriers that stand between the risks and the people. The recommended protective clothing is listed below, being selected those that are approved by the Ministry of Labour and have CE marking.

Cotton clothing are not recommended because ultraviolet degrades it breaking won it in a period between one and fifteen days. Leather and wool are two materials that offer better results against ultraviolet radiation.

Table 4: Recommended protective clothing.

Safety helmets for protection against falling heavy or sharp objects.	
Security boots.	
Screens or helmets provided with filters of radiation chosen as detailed below.	 
Gloves, sleeves, leggings and leather aprons.	   
Electricity insulating gloves for handling welding power sources.	
Seat belts for work at height.	
Hearing protection, which may be plugs, earplugs or anti-noise helmets.	

Eye protection

To protect the eye from harmful radiation during the welding operation, it is necessary to use glasses or screens with appropriate filters.

The filters are classified according to the degree of protection against ultraviolet and infrared radiation. In the case of welding using coated electrodes, radiation will be a direct function of the current, that is, as higher is the amperage used greater the emitted radiation.

Preventions in the use of materials and equipment

Arc welding using coated electrodes, as well as related operations such process, involves the use of electric current. Improper handling or poor maintenance of these equipment can cause accidents by direct or indirect electrical contacts.

Fume protection

To prevent harmful fumes from welding operations, reach airway, both welder and other workers that circulate around the area, must be two types of actions.

- To performances on elements that can emit fumes to reduce as far as possible.
- Once the fumes have been emitted, to avoid that they do not reach the welder, using vacuum cleaners, extractors, welder posture correction, etc.

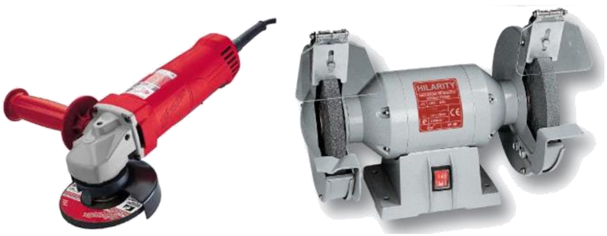
Risks and precautions associated with allied operations to welding

Welding not only involves the melting of the base material and the filler. To make a joint with guarantees, a series of operations to quash or limit the number of defects in the weld are required. These operations also bring a number of hazards that must be taken into account.

Grinding

For interpasses cleaning or edge preparation, grinders are used. There are fixed or portable grinders (see figure 17). The risks associated with the grinding action are:

- Electric shock.
- Accidents in eyes.
- Escape or breakage of the disk.
- Burns and hand injuries.
- Dust and particles aspiration.



a) *b)*

Figure 17: a) portable grinder. b) fixed Grinder.

To avoid the hazards associated with the grinding, the correct status of the electrical cables and ground shall be checked, always work with glasses or protective screen of clear crystals, use the appropriate grinding wheels for the material to be worked, not overtighten the nuts because the grinding wheels can be damaged, prevent vibration in grinding wheels once assembled, to use jigs to work with small parts, always wear gloves and use a fume and particles extraction system.

Slag removal

In the removal of the slag produced in the welding using coated electrodes, pickaxes are used. The risks associated with the slag removal are:

- Burns.
- Eye injuries.

Figure 18: Pickaxe and goggles

Burns can be avoided by using gloves and protective clothing in the handling of the parts that are still hot. It is also necessary to cool the slag. To prevent possible eye injury, pickaxe always has to be used with glasses or transparent glass screen.

UNIT BIBLIOGRAPHY

[1] General Course on Welding Technology. Training Fund-CESOL. Module 1 and 2. 1994.
[2] Documentation of the course "European Welding Specialist". Modules 1 and 2. 1995.
[3] UNE-EN ISO 17633:2006, Welding consumables. Tubular wires and rods for arc welding with or without gas protection of stainless and heat-resistant steels. Classification.
[4] AWS A5.1-04: Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding.
[5] AWS A5.4-06: Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding.
[6] AWS A5.30-07: Specification for Consumable Inserts.

Welding Processes - TIG

1.1 Course name

TIG Welding

1.2 Course duration

5 hours

1.3 Course purpose

In this unit corresponding to TIG welding we will get the knowledge referring to the equipment of the welding process, how the parameters (current, voltage, speed, etc.) affect the process, technologies of the TIG process and a section related to health and safety. When higher finishing requirements are required, it is necessary to use the TIG system to achieve homogeneous welds with a good appearance and a completely smooth finish.

1.4 Objectives of the course

Outline the objectives of the course

- *The student is able to:*

Knowledge	Skills	Attitudes	Contests of learning
Use and explain the terminology associated with the TIG welding process. Describe the advantages and limitation of the TIG welding process; Identify of welding equipment such as tungsten electrodes, filler metal rods, or torch holders and specific component elements used in TIG welding process;	Identify, select and prepare the TIG equipment for the welding process.	Collaborate with the members of the working team in order to fulfill the task; Assume within the work team of the responsibilities for the work task.	Equipment used in TIG welding process.
Explain the importance of the correct equipment assembly, setting of the power source and choice of electrode and the consequences of incorrect selection.	Identify Power source, tools and accessories used for TIG welding. Describe the principle, formation, nature, power of the electric arc used for welding welded joints;		Parameters (current, voltage, speed, etc.) which affect the process. Power Source. Cables. Ground Devices.

	Establish the parameters of use of the electric arc and the possibilities of protection of the electric arc;		Voltage Drops.
Inspect and prepare the workpiece/s according to drawings and working practices, for TIG welding. Explain the importance of the correct equipment assembly, setting of the power source and choice of electrode and the consequences of incorrect selection. Explain the thickness of materials, in relation to size and type of welding electrode used, and the influence of electrode manipulation during the welding process. Prepare the TIG welding environment using simulator /real equipment.	Identify what type of electrode to be use with DC or AC current; Select and use welding consumables as per requirements for welding carbon steel, aluminium and stainless-steel plate. Use the gas tungsten arc welding (TIG) process in all positions. Weld the work-piece material in accordance with work instruction sheet and drawing requirements using simulator /real equipment. Apply quality checks on process. Inspect welded workpiece for defects (use visual and non-destructive testing), conforming to specifications as reflected on drawing or job requirement. Identify welding defects and take corrective action.		TIG welding technologies. Arc Ignition on TIG Welding. Sharpening of Electrode Non-Consumable Electrodes. Classification of Filler Rods and Wires. Classification of Shielding Gas for Arc Welding and Cutting. Influence of Welding Parameters on TIG welding technologies. Welding Positions.
Identify and rectify possible welding hazards in accordance with standard work site practices. Explain the safety requirements relating to welded products. Provide examples of failures and explain their causes and consequences.	Observe safe working practice during welding; Apply other measures to be taken regarding the prevention of accidents related to noise, smoke, fire, electric shock.		Health and safety measures. Safety precautions applicable to Welding machines, hand tools, equipments, tools and during welding operations.

1.5 Contents

1. Introduction of TIG Welding
2. Welding Equipment
2.1. Power Sources
2.2. Cables
2.3. Ground Devices
2.4. Voltage Drops
3. Welding Technology
3.1. Arc Ignition on TIG Welding
3.2. Sharpening of Electrode
3.3. Non-Consumable Electrodes
3.4. Classification of Filler Rods and Wires
3.5. Classification of Shielding Gas for Arc Welding and Cutting
3.6. Influence of Welding Parameters
3.7. Welding Positions
3.8. Typical Weld Defects
4. Health and Safety of TIG Welding

1.6 Participants

Learner characteristics: *(Outline the profile of the target learner group for the course)*	*Basic knowledge in Welding*

1.7 Entry requirements

(Outline the entry requirements of the course- if necessary)

Education level requirement:	*Students from VET schools (background on compulsory education)*
Previous knowledge needed	*Basic knowledge in welding*
Age requirements:	*Ages between 16 and 20 years old*

1.8 Assessment activities

Summative assessment

- *Theoretical examination using stand-alone simulator/computer or SIMTRANET virtual classroom*

1.9 Bibliography (used or supplementary)

[1] General Course on Welding Technology. Training Fund-CESOL. Module 1 and 2. 1994.
[2] Documentation of the course "European Welding Specialist". Modules 1 and 2. 1995.
[3] UNE-EN ISO 6848:2005, Tungsten electrodes for arc welding in inert atmosphere with refractory electrode, and for welding and plasma cutting. Symbolization.
[4] AWS A5.12-98: Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting.
[5] AWS C5.5-03, Recommended Practices for Gas Tungsten Arc Welding.
[6] AWS Z49.1-05, Safety in Welding, and Cutting and Allied Processes.

UNIT NUMBER: Didactic Unit 1

UNIT TITLE: *TIG Welding*

UNIT PRESENTATION

In this unit corresponding to TIG welding we will get the knowledge referring to the equipment of the welding process, how the parameters (current, voltage, speed, etc.) affect the process, technologies of the TIG process and a section related to health and safety. When higher finishing requirements are required, it is necessary to use the TIG system to achieve homogeneous welds with a good appearance and a completely smooth finish.

OBJETIVES

The objectives of this units are:

- The student is able to:

Knowledge	Skills	Attitudes	Contests of learning
Use and explain the terminology associated with the TIG welding process. Describe the advantages and limitation of the TIG welding process; Identify of welding equipment such as tungsten electrodes, filler metal rods, or torch holders and specific component elements used in TIG welding process;	Identify, select and prepare the TIG equipment for the welding process.	Collaborate with the members of the working team in order to fulfill the task; Assume within the work team of the responsibilities for the work task.	Equipment used in TIG welding process.
Explain the importance of the correct equipment assembly, setting of the power source and choice of electrode and the consequences of incorrect selection.	Identify Power source, tools and accessories used for TIG welding. Describe the principle, formation, nature, power of the electric arc used for welding welded joints; Establish the parameters of use of the electric arc and the possibilities of protection of the electric arc;		Parameters (current, voltage, speed, etc.) which affect the process. Power Source. Cables. Ground Devices. Voltage Drops.

Inspect and prepare the workpiece/s according to drawings and working practices, for TIG welding. Explain the importance of the correct equipment assembly, setting of the power source and choice of electrode and the consequences of incorrect selection. Explain the thickness of materials, in relation to size and type of welding electrode used, and the influence of electrode manipulation during the welding process. Prepare the TIG welding environment using simulator /real equipment.	Identify what type of electrode to be use with DC or AC current; Select and use welding consumables as per requirements for welding carbon steel, aluminium and stainless-steel plate. Use the gas tungsten arc welding (TIG) process in all positions. Weld the work-piece material in accordance with work instruction sheet and drawing requirements using simulator /real equipment. Apply quality checks on process. Inspect welded workpiece for defects (use visual and non-destructive testing), conforming to specifications as reflected on drawing or job requirement. Identify welding defects and take corrective action.		TIG welding technologies. Arc Ignition on TIG Welding. Sharpening of Electrode Non-Consumable Electrodes. Classification of Filler Rods and Wires. Classification of Shielding Gas for Arc Welding and Cutting. Influence of Welding Parameters on TIG welding technologies. Welding Positions.
Identify and rectify possible welding hazards in accordance with standard work site practices. Explain the safety requirements relating to welded products. Provide examples of failures and explain their causes and consequences.	Observe safe working practice during welding; Apply other measures to be taken regarding the prevention of accidents related to noise, smoke, fire, electric shock.		Health and safety measures. Safety precautions applicable to Welding machines, hand tools, equipments, tools and during welding operations.

CONTENTS

Example: 1. Introduction of TIG Welding 2. Welding Equipment 2.1. Power Sources 2.2. Cables 2.3. Ground Devices

2.4. Voltage Drops 3. Welding Technology 3.1. Arc Ignition on TIG Welding 3.2. Sharpening of Electrode 3.3. Non-Consumable Electrodes 3.4. Classification of Filler Rods and Wires 3.5. Classification of Shielding Gas for Arc Welding and Cutting 3.6. Influence of Welding Parameters 3.7. Welding Positions 3.8. Typical Weld Defects 4. Health and Safety of TIG Welding

CONTENTS DEVELOPMENT

1. Introduction of TIG Welding

TIG welding is a fusion welding process and gas shielding which uses as a power source an electric arc established between a non-consumable electrode and the workpiece, while an inert gas protects the weld pool. The filler material, when used, is applied by means of rods as the same way that oxyacetylene welding.

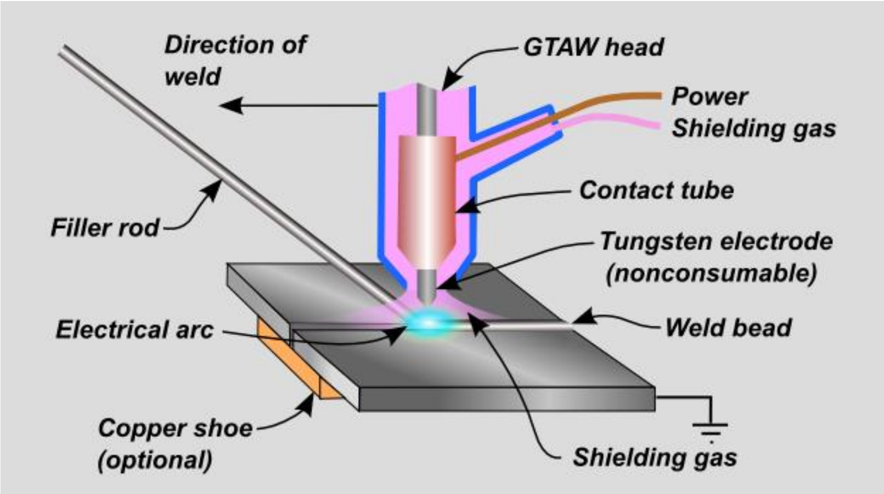


Fig. 1. TIG process scheme

The TIG welding process also receives the names of:

- GTAW, Gas Tungsten Arc Welding, AWS 3.0
- Gas-shielded arc welding with non-consumable tungsten electrode (EN ISO 4063: 2011)
- Arc welding with non-consumable tungsten electrode (EN 14610:2006)

The following table shows the main advantages and limitations own process are as follows:

Advantages	Limitations
It's a suitable process for joining most metals	The deposition rate is lower than that achievable with other arc welding processes
It provides a stable and concentrated arc	Because it is a manual application requires, in general, great skill by the welder
Although this is an essentially manual process, it has been automated for some series manufactures, as small pipe thickness longitudinal or spirally welded and for fixing pipes to plates in heat exchangers	It is uneconomical for thicknesses greater than 10 mm
No projections are produced (because metal transport in the arc doesn't exist)	In the presence of air currents, it may be difficult to achieve adequate protection of the welding area
Slag is not produced	It produces more ultraviolet radiation than other processes, requiring adequate protection

Advantages	Limitations
Smooth and regular welds are obtained	
It can be used with or without filler metal, depending on the application	
It can be used in all types of joints and positions	
It is possible to obtain high welding speed in thicknesses below 3-4 mm	
High quality welds can achieve	
It provides excellent control of penetration of the root pass	
The use of prohibitively expensive energy sources is not required	
It allows independent control of the power source and filler metal	
Smoke is not produced	

Table 1. Advantages and limitations of TIG welding.

2. Welding Equipment

Identify the welding equipment used in each process is very important, since depending on the equipment, some properties or others are obtained. In this equipment, we must learn all the elements necessary to perform a TIG welding, such as: power supplies, cables, workpiece clamps or voltage drops.

2.1. Power Sources

TIG welding is, mainly, a manual welding process, implying that the power source to provide us with a stable working conditions, regardless of small variations in the arc length that will occur during welding as a result of the pulse of welder. That is beca n TIG welding, power sources constant current or vertical characteristic are employed.

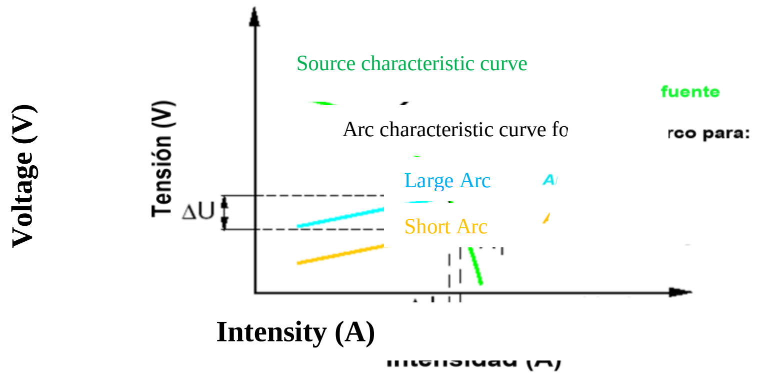


Fig. 2. Downward slope characteristic curve

As we can see in Figure 2, working with this type of power source (downward slope characteristic curve) implies that significant variations in the welding voltage means very small variations of current. This is critical in manual welding processes, such as TIG welding, since the welding voltage is closely related to the variation in the arc length. In a manual process is impossible for the welder always take the same arc length, so that it will vary along the welding.

However, with this type of welding sources we get that these variations in the arc length, and therefore the welding voltage, not entail variations in the welding current, and thus avoid problems such as lack of fusion and penetration, perforations of the workpiece, etc.
Furthermore, TIG welding can be carried out both with alternative current or direct current, which will require different characteristics of the power source.

AC Power Sources. Transformers:

The main function of the power sources is to obtain an electric current suitable for welding, i.e., an electric current of low voltage and high amperage.

The current supplied by the mains is alternating current to low current and high voltage, which makes it not suitable for welding. Hence it is necessary to modify it to suit the welding. This is the objective of electrical transformers, that what is "taking" alternating current network, high voltage, low current, and "return" an AC with high current and low voltage, suitable for welding. Power sources for TIG welding with alternating current are formed, mainly by:

- Transformer
- Generator High Frequency Pulses
- Fan
- Magnetic valve welding gas
- Control of welding current

DC Power Sources. Rectifier:

When TIG welding shall be performed with direct current, the power source must perform two "modifications" to the current of the electrical network to which it is connected:

1. Transform AC network (high voltage and low current) into alternating current suitable for welding (low voltage and high intensity).
2. Rectifying the alternating current form, the secondary winding of transformer to direct current used in the welding.

Power sources for direct current TIG welding is formed mainly by:

- Transformer
- Rectifier
- Fan
- Magnetic valve welding gas
- Control module
- Control of welding current

When the welding current is regulated using the potentiometer of the TIG power source, what we do is vary the characteristic curve of the source it works.

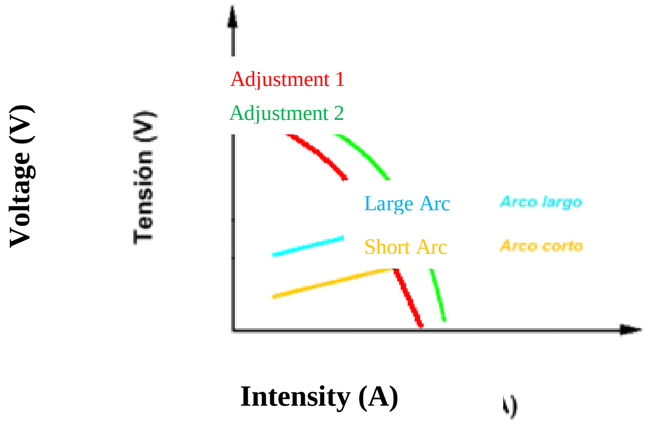


Fig. 3. Different welding current settings.

In order to understand how to control the characteristic of the source is important to understand two key parameters: open-circuit voltage and short-circuit current.

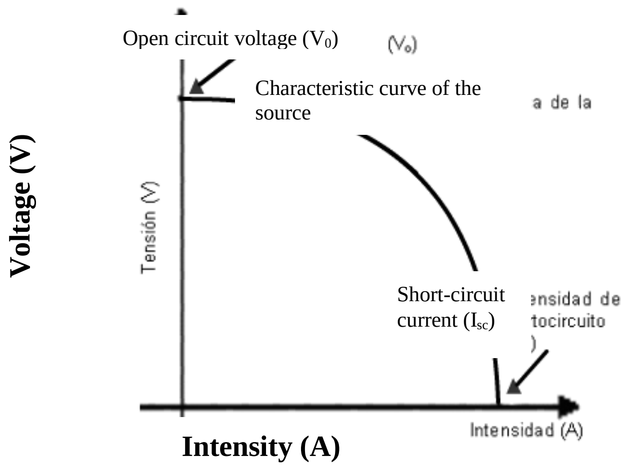


Fig. 4. Characteristic curve of welding source

Open-circuit voltage
The open circuit voltage (Vo) is the maximum voltage that the power source can supply and is the voltage at the terminals of the source when it is not welding. The open circuit voltage of the circuit is usually greater than twice the welding voltage. It is mainly used to ensure ease of ignition and stability of arc, so what because of the increased instability of the arc when welding with AC, the transformers have greater open circuit voltage that the rectifiers.
Short-circuit current
The short-circuit current (Isc) is the maximum current supplied by the power source. To start the arc, a short circuit is produced, at this time the voltage is vanished, and current flowing is the maximum (Isc), thanks to this the electrode is heated and it can stablish the arc.

These two parameters are of particular relevance in TIG welding, helping to facilitate arc establishment.

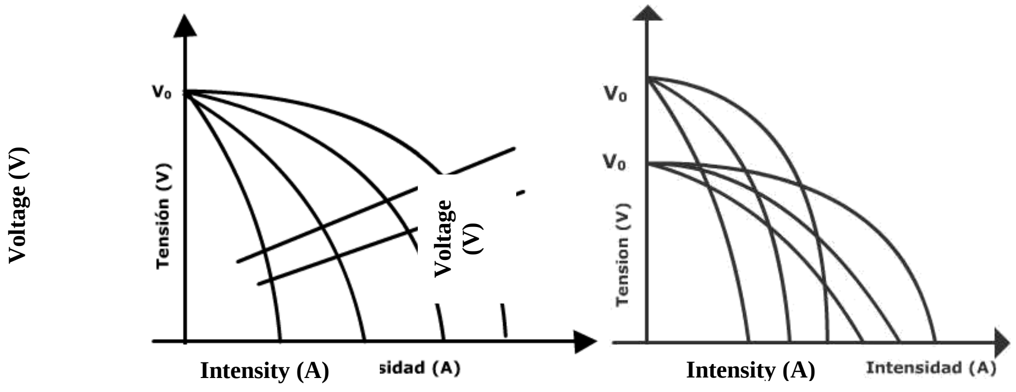


Fig. 5. Variation of the power source characteristic curves

In general we can say that the variation in the slope of the curve is achieved by acting on the magnetic field generated in the transformer, while variations in open-circuit voltage are carried out by lead in the primary circuit or secondary, it is merely varying the number of turns in the primary or secondary coils by derivations.

2.2. Cables

Cables are responsible for transporting the electric current from the power source to the workpiece and return it to the welding power source.

The cables length must be selected according to the current that has to be supported, and this is a function of electrode diameter and the size of the power source.

It is preferable that both the clamp and the torch have the same diameter, however, occasionally one of the cables, generally the workpiece clamp, may be larger in diameter, but not smaller diameter.

It is advisable to have good conductors in welding current. In workshops usually, bars, water pipes, and all kinds of metallic elements are used to close the circuit, leading often to failures in the welds.

2.3. Workpiece clamps devices

It is connection device from power source to the workpiece, and it is available in various sizes and configurations for different applications. The condition to be fulfilled is that it must be in good condition and must make good contact with the base metal. A clip shabby does not provide the security of a good electrical conduction, causing instability in the arc during welding.

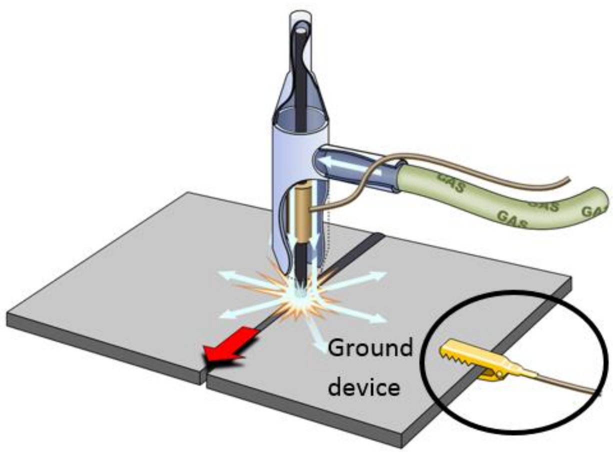


Fig. 6. Example of a workpiece clamp

2.4. Voltage Drops

The voltage drop of a conductor is the voltage difference between the ends thereof.

When a voltage V is indicated in welding equipment display, this voltage is not exactly the welding voltage. This is because, the voltage indicated by the voltmeter of the machine is the total output voltage, which is the arc voltage plus the voltage drops over cables, electrode, electrode holder, workpiece and workpiece clamp. These voltage drops are directly proportional to the current, so it is easy to understand that being welding a process that requires a high current; these voltage drops have considerable value.

In order that these voltage drops do not adversely affect the welding, are limited to value 2 volts.

The common **points of voltage drop and resistance heating** are:

- **Power cable too small or damaged.**
- **Workpiece clamp loose or damaged.**
- **Loosely (loose) power cables connections.**

Loose connections produce a voltage drop larger than the permissible for arc stability (2 V) from the power source to the electrode holder. For this reason, bad connections or steel elements or tubes or bars as conductors shall not be used rather than a ground cable with a clamp in good condition, to secure it properly to the sheet or structure to be welded.

3. Welding Technology

It is very important to know and study the technology of each welding process, as there are several parameters to take into account when welding. As far as TIG welding is concerned, we will focus on arc ignition, non-consumable electrodes and their shape, classification of filler material and protective gases, welding parameters, welding positions and typical welding defects.

3.1. Arc Ignition on TIG Welding

The simplest arc ignition method is touching (by scraping) with the electrode, very carefully, against the base metal. However, the risk of tungsten inclusions in the base metal is high. To avoid this, the arc can be turned on in a further copper plate, known as starting piece. Another disadvantage of turn on by "touching" (scraped) is the ease with which it can damage the electrode.

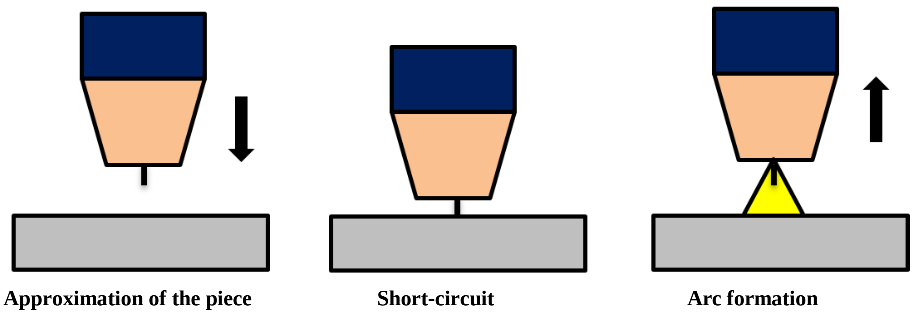


Fig. 7. Arc striking on by "playing" (scraped).

To avoid the disadvantages of ignition by "touching" (by scraping) (fig. 7) a current of high frequency and high voltage is used. This method is always used for alternating current and sometimes for direct current.

Therefore, when AC power is used is not necessary to touch the electrode on the workpiece to establish the arc, but load the welding circuit and hold the torch, so that the electrode is approximately horizontal and 50 mm on the piece. Then, by a twist of the wrist, bring the tip of the electrode to the workpiece, until about 2 or 3 mm of it. At this point, the high frequency current overcome air resistance and the arc is established. The approach movement of the electrode must be performed quickly; getting it reaches the maximum flow of shielding gas to the welding area.

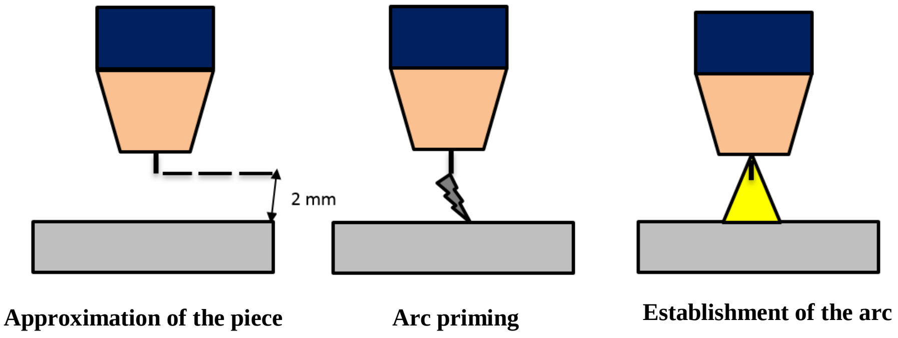


Fig. 8. Arc turning on by high frequency current.

There are other arc turning on systems such:

- Application of a high voltage pulse between the non-consumable electrode and the workpiece, which is generally used with direct current.
- Capacitor discharge.
- "Lift-Arc"™: This method involves tapping gently (without scraping) the workpiece with the electrode, maintaining perpendicularly the torch to the piece. At that moment the machine detects a short circuit and establishes a low voltage current in the circuit. This current is not enough to establish the arc but contributes to heat the electrode. When the electrode is lifted, the machine detects no short circuit and automatically the arc is established, which is helped by the electrode preheating.

The torches have the mission to conduct current to the non-consumable electrode and the shielding gas to the welding area. They may be natural cooling (by air) or forced cooling (by circulating water). The first is used in welding thin materials that do not require high currents, and forced cooling is recommended for jobs requiring intensities above 150 - 200 amps. In these cases, the water circulation inside the torch prevents overheating. In works where are necessary 300 amps or more, even if discontinuous mode, it is necessary that the nozzle is also cooled by water.

The figure 9 shows various TIG torches configurations.

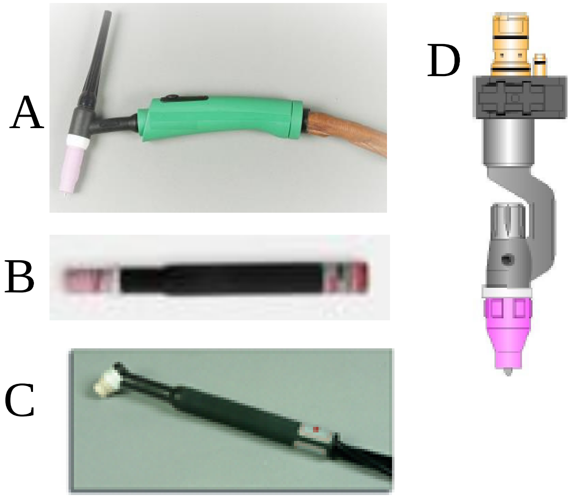


Fig. 9. TIG torches configurations. (A) Normal, (B) straight, (C) with short top, (D) for robot

The tungsten electrode that carries welding current to the welding area is rigidly secured by clamp housed in the torch body. Each torch has a set of collects, of different sizes, allowing the clamping electrodes of different diameters. It is very important to have a good electrical contact between electrode and clamp.

Fig. 10. Image of TIG collects

3.2. Sharpening of Electrode

The shape of the tip of the electrode is very important as, if it is not correct; there is a risk that the electric arc is unstable. From this it is concluded that the sharpening electrode has a great influence on the final result of welding, so that:

- An electrode having a good sharpening will result in a stable arc, with the focused heat and obtaining good penetration.

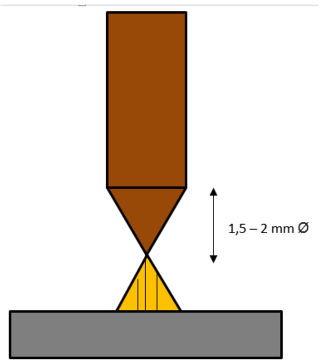


Fig. 11. Well sharpened electrode

- A badly sharpened electrode causes an erratic arc, generating a wide weld pool and poor penetration.

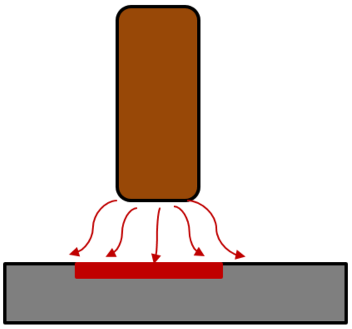


Fig. 12. Badly sharpened electrode.

- The electrodes have sharp excessive risk that tungsten inclusions occur. After sharpening the electrode, the tip should be rounded, and not sharpened as a pencil.

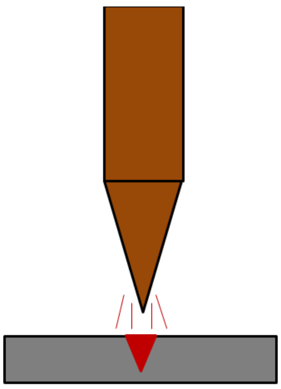


Fig. 13. Very sharp electrode

Geometry variations of the electrode tip

Depending on the type of current used in the welding process, the electrode tip must have a given geometry:

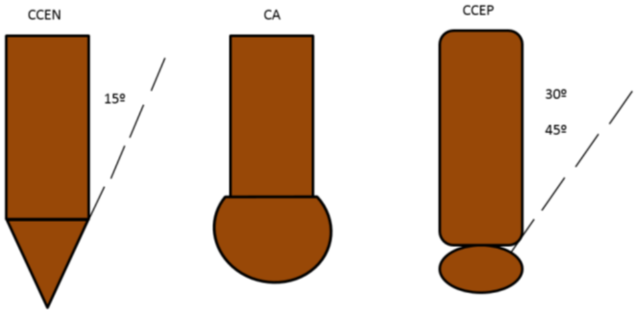


Fig. 14. Geometry variations of the electrode tip according to the type of stream

Electrode tip

Electrodes for welding with DC shall have tipped. When grinding is used to achieve proper electrode geometry, must be made with a wheel or abrasive belt fine grain and only used for the preparation of tungsten electrodes, thus avoiding contamination. It is important that the grinding is carried out correctly, it must be done in the longitudinal direction of the electrode. A correct length of the electrode tip is twice its diameter. The pointed end in excess of the electrode must be removed by the grindstone as there is risk that is melted and incorporated into the weld pool.

In **welding with alternating current**, the end of the tip shall be slightly rounded. The tip is rounded off by itself if the electrode is carefully overloaded, making it unnecessary to grind it.

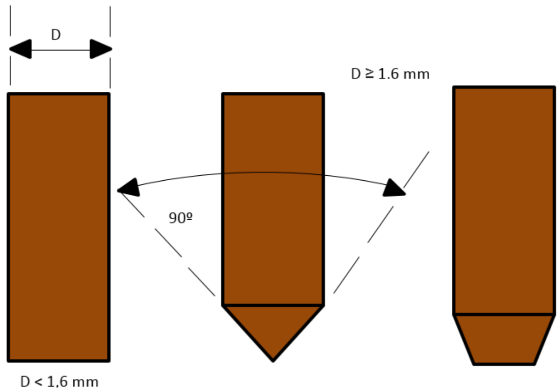


Fig. 15. Tip electrode for welding with alternating current

3.3. Non-Consumable Electrodes

The task of the electrode in this process is only to maintain the arc without providing filler material. For this reason and to prevent wear, it is very important that has a high melting temperature.

In general, five types of electrodes, which are classified according to their composition, are used:

- Pure tungsten
- Tungsten alloyed with thorium
- Tungsten alloyed with zirconium
- Tungsten alloyed with cerium
- Tungsten alloyed with lanthanum

At the beginning electrodes were pure tungsten, but later it was found that the addition of metal oxides of thorium or zirconium, cerium or lanthanum, the behaviour of the electrode was improved in several aspects:

- Increased electron emission capacity, which favours arc stability and ease of turning on it.
- Increasing the electrode melting temperature, allowing working at higher welding currents.

The Standard that defines the classification of tungsten electrodes is EN ISO 6848 and in it are specified from the various dimensions that we can find to the symbolization of the electrodes according to their chemical composition, passing the data to be displayed in the electrode packets.

Electrode selection

Electrode selection is done primarily based on the type of current used, which is determined by the base material. Generally speaking, we can say that DC (-) is employed with all kinds of materials, except those forming a layer of refractory oxide, such alloys as aluminium and magnesium, in which the alternating current is used.

3.4. Classification of Filler Rods and Wires. UNE-EN ISO 636:2017

TIG welding filler metal is not always necessary when welding thin pieces (less than 3 mm thick), for which we will use a straight edge preparation or with raised edges. When it is necessary to use filler material, we can do it either manually or automatically.

In order to use defect-free joints, it is very important that we keep the filler metal free of contamination, whether in the form of moisture, dust or dirt. We must therefore keep it in its packaging until the time we use it. When welding, pay special attention to the fact that the hot part of the rod is always close enough to the molten pool to be covered by the shielding gas.

As TIG is a slag-free process and is carried out in an inert atmosphere that does not cause reactions in the bath, the input material, when we have to use it, must basically have a chemical composition similar to that of the base material.

Normally, we will find rods of different diameters: 1.0; 1.5; 2.0; 2.5; 3.0; 4.0; and 5.0 mm, with a length of 1000 mm.

3.5. Classification of Shielding Gas for Arc Welding and Cutting

The classification of shielding gases, according to EN ISO 14175, is based on the reactivity of the gas or gas mixture and the chemical composition.

Argon

The characteristics of this gas are:

- It's inert. It does not react during welding.
- It is odourless, colourless, tasteless and non-toxic

- Efficient protection due to its high density. Argon is 1.4 times heavier than air, which helps in its shielding function, to evacuate air from the weld area. Helium, by contrast, is much lighter than air and therefore requires higher flow rates to provide the same shielding level than argon.
- Easy turning on and good stability of the arc. Argon has a low ionization energy (7.15 eV), which facilitates the characteristics mentioned.
- Cost effective. It is obtained in the distillation of air which is in proportion of approximately 1%. Argon is much less expensive than helium, for this and its other advantages; argon is much used in TIG welding.
- Suitable for small thicknesses. By having low ionization energy, it can be welded with low voltages and low heat input, resulting suitable for welding pieces of small thicknesses.
- Bead shape and penetration. Argon has a lower thermal conductivity than helium, so the heat is concentrated in the central area of the arc forming penetrations and characteristic appearance similar to that shown in figure 16.

Helium

The most important characteristics of helium are:

- High ionization energy (24.5 eV)
- High conductivity so the plasma column is wide
- Very low density

Therefore, the most important properties of helium are:

- Very high heat input
- Wide and high penetration beads are obtained
- Welding can be performed at higher speed

Because of these characteristics the main applications of helium are:

- Welding of high thicknesses
- Automated welding in which high speeds can be used
- Welding of high conductivity materials, for example copper, reducing the need for preheating
- Although in aluminium welding, the gas argon is used, the helium can be used in automated CC- welding. Helium produces greater penetration and welding speed, but to achieve this it is necessary to clean the surface of oxides.

However, helium has the following **disadvantages**:

- Bad arc stability compared to argon, it is due to its high ionization energy.
- Because of its low density is required a flow rate around 2-2.5 times higher than that needed with argon. This means that in principle, economically **less profitable**, but before dismissing its use, there should be an economic calculation.

Often helium to argon is added to increase the penetration and heat input.

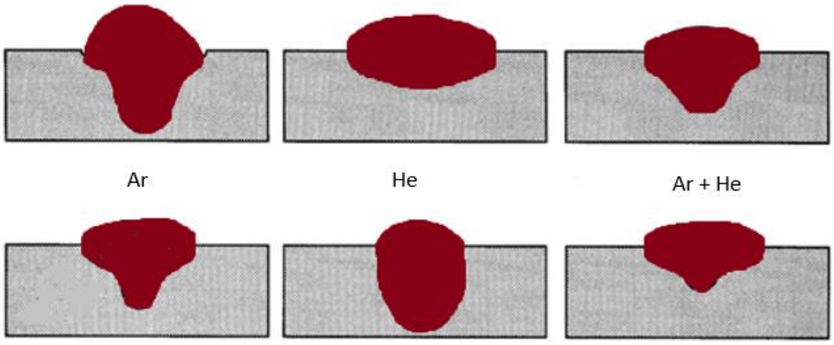


Fig. 16. Bead shape based on shielding gas

Mixtures He/Ar

The mixture of these two inert gases provides additional **benefits under the rate at which intervenes each.**

Penetration is intermediate between typical of each pure gas, as shown in figure 16.

3.6. Influence of Welding Parameters

Basically, the main parameters that you will have to control are the following:

- Electrode diameter.
- Selection of current type.
- Welding current.
- Arc voltage.
- Welding speed.

It is essential that you have a clear understanding of the influence of these parameters before facing any welding. We also recommend that you carry out tests in the workshop using different values, so that you can check for yourself the information that is being presented.

Electrode diameter

The first parameter you need to adjust is the diameter of the electrode.

The diameter determines the welding current. If we use a low current for a given electrode diameter, this will cause arc instability. If on the contrary we use an excessive intensity we can cause erosion and fusion of the tip of the electrode, as well as inclusions of tungsten in the welded metal.

With direct current the electrodes have their maximum current carrying capacity. With reverse current only 10% of the amount that could be driven under the direct current straight polarity. In the case of alternating current, we could obtain 50% of the maximum current carrying capacity. UNE-EN ISO 6848:2015.

Selection of current type

The TIG process can be used in both direct and alternating current. The choice of current class and polarity is made according to the material to be welded. In order to make this choice correctly, we will highlight some differential aspects of both alternatives.

- **Direct current arc:**

When using direct polarity, i.e. the electrode connected to the negative pole, the arc energy is mainly concentrated on the part, resulting in relatively acceptable thermal performance, faster welding speed and good penetration. On the other hand, the electrode supports intensities of the order of 8 times greater than if it were connected to the positive pole without melting or deteriorating.

If we invert the polarity, the electrode connected to the positive pole, the thermal distribution is less favorable, which translates into a relatively wide bath, with little penetration and an excessive accumulation of heat in the electrode, which causes overheating and quick deterioration, even at low current intensities. According to this, the recommended polarity in direct current is the direct polarity. It's important to know, aluminium is welded with DC+ and steel with DC-.

- **Alternating current arc:**

The alternating current combines, although reduced, the advantages of the two polarities: the good behaviour during the direct polarity semi cycle and the pickling effect of the bath during the inverse polarity cycle, so that it can be used in the welding of light alloys, such as Al and Mg. As its main disadvantages, it presents difficulties in priming and arc stability, which makes it necessary to incorporate a high frequency generator into the equipment.

With alternating current, the arc is turned off each time the voltage is lower than the priming voltage, twice each cycle. To improve stability, we must increase the open-circuit voltage. To avoid this inconvenience, we will add a high frequency source.

Welding current

The value of the welding current is the only parameter that you can regulate in the welding equipment, once the polarity has been adjusted. You should always select a current value as indicated in the specification of the welding procedure.

When you weld, there are indications that let you know if the intensity you are using is adequate:

If the welding intensity is too low, you'll find out:

- it's hard to strike the arch,
- that the arc emits little light,
- that it's hard to move forward without arc instability,
- that your molten pool is uncomfortably small,
- that it is difficult for the rod to melt.

If the welding intensity is too high, you'll find out:

- that the arc is very energetic and emits a lot of light,
- that the molten pool is large, fluid and has a great deal of agitation,
- which enlarges the keyhole in the root pass,
- that the bathroom tends to sag,
- that projections and splashes may occur (not usual),
- the electrode is melted and tungsten inclusions appear in the cord.

What problems can occur if the welding intensity is NOT adequate?

As a general rule, an electrode should not be used at currents outside the range recommended by the manufacturer. Apart from the indications described in the previous section, which you can see while welding, you can also find defects in the cord when the intensity is not adequate:

If you welded with a very low intensity:

- The weld run will be tight and excessively bulky, with the possibility of lack of fusion at the edges, overlaps, etc.

If you welded with a very high intensity:

- In the PA position, the weld run will tend to be very wide and flat, and undercuts may appear on the edges.
- In position PB, PC and PD, the cord tends to drop, leaving bites on the top plate and overlaps on the bottom.
- In PF and PE position, the bead tends to drop towards the centre of the weld, becoming bulky in the central part and with bites on the sides. In the PE position, the bath may even fall off.
- The piece may present cracks.
- The piece can present an excess of penetration, sagging and even perforations in the root.
- The solidification marks on the weld face will have an elongated appearance, forming peaks.

Arc voltage

The arc length is a parameter that you must control continuously to obtain the most homogeneous weld possible. The voltage is directly related to the arc length, as the voltage increases, the arc length also increases.

Which arc length is adequate?

The length of the arc depends mainly on the type of electrode and its diameter. Generally, it should be equal to the diameter of the electrode.

It is convenient to always maintain the same arc length, in order to avoid oscillations in the voltage and intensity of the current and with it an unequal penetration.

When the length of the arc used is not adequate or when it is modified during welding (for example, due to a bad pulse of the welder or lack of dexterity), defects may occur on the cord.

Welding speed

The welding speed is another parameter that the welder must control manually. Again, the welder must use the welding speed specified in the WPS. Normally we are given a range, but it is essential that the welder maintains a uniform speed.

How does the welding speed influence?

The higher the welding speed, the smaller the bead width, the lower the heat input and the faster the weld will cool down.

- If the welding speed were too fast, there will be undercuts on the bead.
- If the welding speed were too slow, the slag can overtake the weld pool resulting in lack of fusion and slag inclusions.

Orientation of the torch

The electrode orientation can be defined by two angles:

- **Angle of advance**: it is the angle that forms the torch with the direction of weld. Between 100º and 110º.
- **Working angle**: the angle formed by the torch with respect to the surfaces of the parts that make up the joint. Depends on the geometry, in a butt joint by 90º and in fillet joints 45º.

The welder must take into consideration, at all times, that the electric arc has an important directional character in relation to the supply of energy.

3.7. Welding Positions

The welder must know how to identify the different welding positions, defined in the EN ISO 6947: 2011 standard. Figure 17 shows the main positions, PA, PB, PC, PD, PE, PF and PG, as well as some typical examples of these positions. These positions are applicable to both sheets and pipes. It is also important to note that positions PB and PD are exclusive of angle joints and do not apply to butt joints.

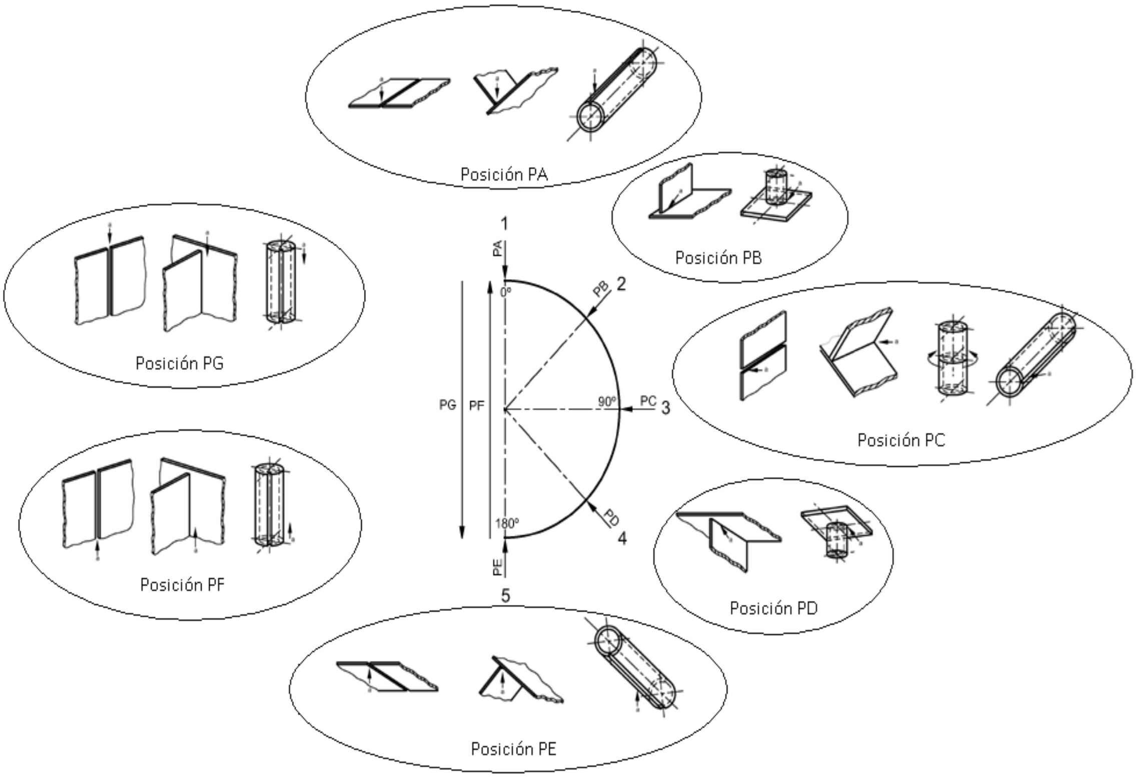


Fig. 17. Main welding positions.

In addition to the above, there are other main welding positions which are exclusively applicable to pipes and which are the positions PH (ascending pipe welding), PJ (descending pipe welding) and PK (orbital pipe welding). Figure 18 shows some examples of these welding positions.

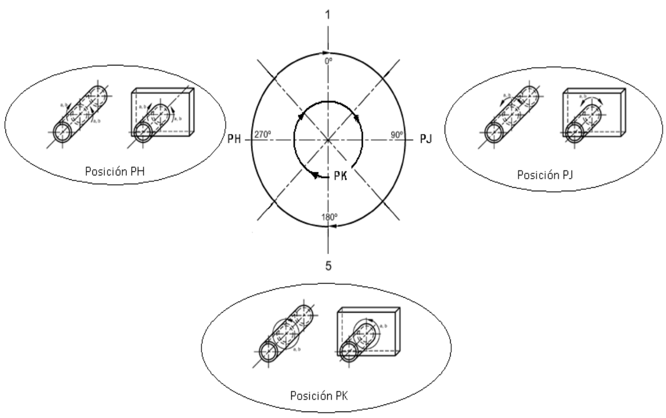


Fig. 18. Main welding positions.

The welding position is fundamental as it is an essential variable of the welders' qualification. Welders need to know the welding positions to be sure that the qualification they have covers them for the positions they are welding in.

3.8. Typical Weld Defects

During the TIG process a number of typical defects may appear, that can cause that the workpiece to be defective.

Lack of penetration	
Appearance: Notch or slit root.	
Cause	**Solution**
Too low welding current.	To increase current.
Too high travel speed.	Slowing welding.
Incorrect joint preparation	Increase the bevel angle, reduce the root face length or increase the separation at the root.
Too long arc.	To reduce the arc length.
Appearance: concave root Tack welds not completely melted completely during welding.	Reduce the size of the tack welds.
In flat position, backing gas flow too high.	Reduce backing gas flow.
Unacceptable joint preparation.	To use U preparations and ensure that the molten metal is not a bridge between the faces of the edges of the joint.

Undercut	
Appearance: Canal along the weld toe.	
Cause	**Solution**
Too low welding current.	To increase current.
Too high travel speed.	Slowing welding.
Torch inclined laterally.	Put the torch perpendicularly to the plate.

Figure 19. Typical weld defects

Lack of fusion
Appearance: It usually is not visible, only detectable by NDT or lateral bending 

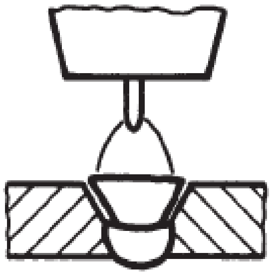
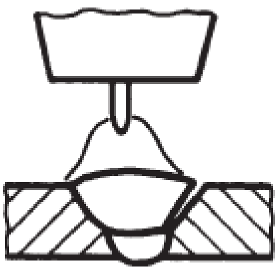
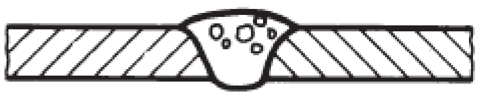
Cause	Solution
Too low welding current. Too high travel speed. 	To increase current. Slowing welding. To increase the bevel angle, to reduce root face or to increase the separation at the root. Reduce the arc length
Wrong angle torch. Not centred position relative to the edges. 	To tilt the torch back and maintain the arc on the leading edge of the molten metal drop Place the torch centred relative to the edges of the joint.
Wrong joint preparation. Excessive rod diameter for welding sheet thickness. Poor cleaning.	Increase the joint bevel. Reduce the rot diameter. Clean the workpieces.

Figure 19. Typical weld defects (Continuation)

Porosity	
Appearance: Surface and subsurface normally detectable by radiography. 	
Cause	**Solution**

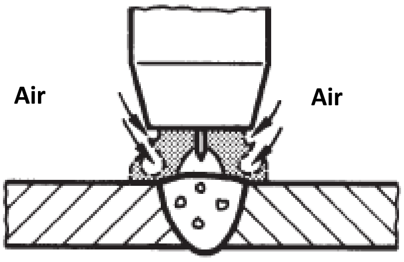
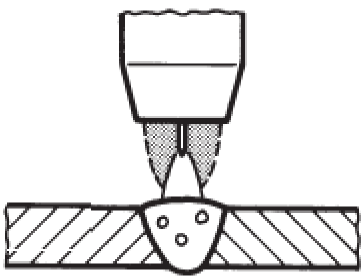
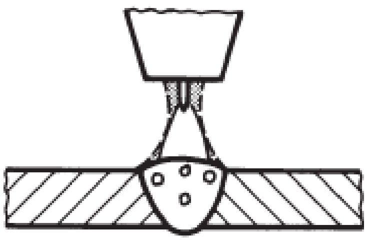
Insufficient shielding.	Increase the shielding gas flow.
Turbulences in shielding gas.  	Reduce the shielding gas flow. Use a laminating flow or change the nozzle if it has any one.
Wrong distribution of the shielding gas.	To protect all weld area.
Dirt, oil, grease, paint, etc. on the plate	Clean and degrease the surfaces.
Dirt on the filler rod.	Clean and degrease the filler rod.
Contaminated gas shielding.	Change gas cylinders. Purge gas lines before welding. Check connections. Use copper or neoprene tubing.

Figure 19. (Continuation)

Porosity	
Cause	**Solution**
The torch is separated from the workpieces. 	To reduce the torch-piece distance.
Small nozzle diameter. 	Select the appropriate nozzle.
On site welding. High wind speed.	Protect the welding area from the wind.

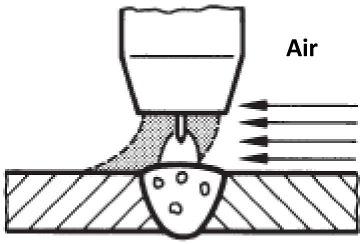
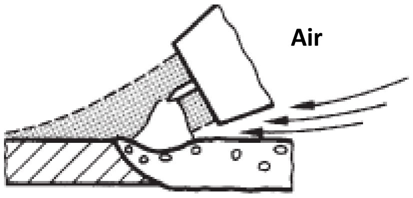
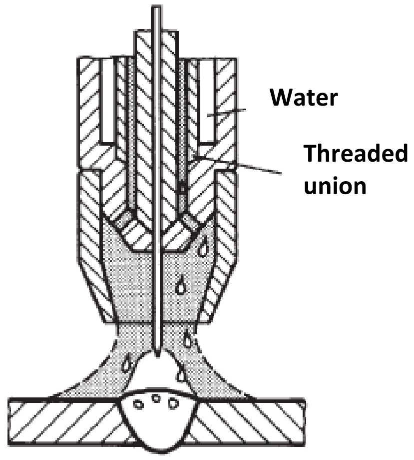
	
Inclination angle of the gun too small. (high travel angle). 	Decrease the inclination angle.

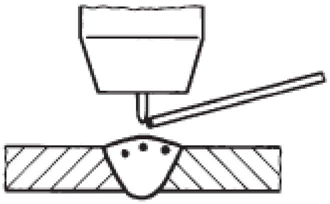
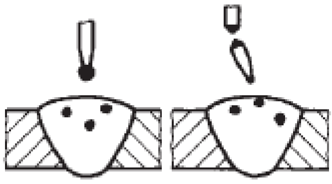
Figure 19. (Continuation)

Porosity	
Cause	**Solution**
Input cooling water in the shielding gas due to a leak 	– Check periodically the welding equipment.

Cracks in weld metal	
Appearance: Crack along the centre of the weld.	
Cause	**Solution**
Excessive transverse stress in constrained welds. Relationship depth/width too low. Surface contamination. Poor fit between parts in fillet welds there being high separations.	Modify the welding process to reduce the stresses due to thermal effect. Set parameters to work with a depth/width ratio 1:1. Clean surfaces, removing especially cutting lubricants. Improve the fit of the plates at the joint.

Figure 19. (Continuation)

Tungsten inclusions	
Appearance: it is visible on radiographs. Tungsten inclusions have the same effect as the notches, being areas of potential and rapid corrosion. 	
Cause	**Solution**

Contact between workpiece and tungsten electrode. Contact between filler rod and tungsten electrode. 	Separate the torch from the piece. To reduce the free length of the tungsten electrode. Introduce the filler rod into weld pool, without touching the electrode.
Excessive current 	Use the suitable current

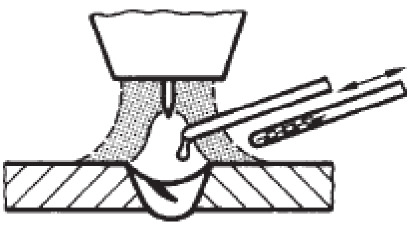
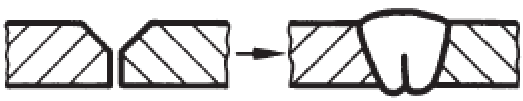
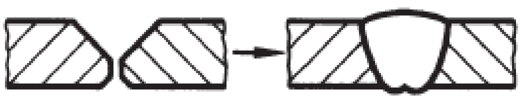
Oxide inclusions

Appearance: Irregularly inclusions. Visible radiographically.

Cause	Solution
Insufficient cleaning of the surfaces of the base metal and of the rod, especially in refractory oxides materials: aluminium and magnesium.	Perform mechanical and/or chemical cleaning. It shall also be brushing between passes.

Figure 19. (Continuation)

Oxide inclusions

Cause	Solution
Not suitable welding technique. Repeatedly pull the rod out of the "curtain" of protective gas in the reciprocating motion of the rod during welding. 	Use proper technique.
Inadequate joint preparation. Excessive root face. 	Reduce the root face. 

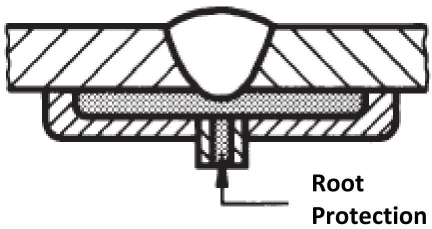
<table>
<tr><th colspan="2">Rusted root</th></tr>
<tr><td colspan="2">Appearance: Oxide at the root of the weld.
</td></tr>
<tr><th>Cause</th><th>Solution</th></tr>
<tr><td>Lack of shielding in the root.
Root oxidation.</td><td>Use backing gas.

</td></tr>
</table>

Figure 19. (Continuation)

4. Health and Safety of TIG Welding

TIG welding carries the same risks as any arc welding process, which have been described in previous topics, plus another series of risk specific of this process and which should be paid special attention risks.

These inherent TIG welding risks can be grouped into two main groups:

- Risks relating the process.
- Risks relating to the handling of compressed gases

Risks relating the process

The main risks inherent to TIG welding and are not present, or present to a lesser extent in other welding processes, lies in the increased ultraviolet radiation emitted by the arc in TIG welding over other welding processes:

- The eye protection must be more intense because the arc is brighter and more intense ultraviolet radiation, so that the filters must be something darker. Crystals No. 6 to 30 amperes currents are used to No. 14 when the current is greater than 400 amperes. It should not use darker than necessary crystals.
- A higher level of ultraviolet radiation, increased formation of ozone and as nitrogen oxides, gases all very harmful to health. Hence, in TIG welding becomes more important the protection of the respiratory system. This is rarely taking into a count, since not generate an excessive amount of smoke, so it is often assumed, wrongly, that TIG welding is not necessary to take measures to protect the respiratory system welder.

Risks relating to the handling of compressed gases

The main gas employed in TIG welding is argon. The risks from handling compressed gases and prevention measures to be taken to avoid such risks are:

- Asphyxiation by displacing air with inert gases, so when welding it is performed in confined spaces, these should be well ventilated. If it is impossible to control atmospheric oxygen, the welding should be performed with welding screens with built-drive or removing fumes.
- By bottle handling entrapments.

UNIT BIBLIOGRAPHY

[1] General Course on Welding Technology. Training Fund-CESOL. Module 1 and 2. 1994.
[2] Documentation of the course "European Welding Specialist". Modules 1 and 2. 1995.
[3] UNE-EN ISO 6848:2005, Tungsten electrodes for arc welding in inert atmosphere with refractory electrode, and for welding and plasma cutting. Symbolization.
[4] AWS A5.12-98: Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting.
[5] AWS C5.5-03, Recommended Practices for Gas Tungsten Arc Welding.
[6] AWS Z49.1-05, Safety in Welding, and Cutting and Allied Processes.

Quality Assurance in Welding

1.1 Course name

Quality Assurance in Welding

1.2 Course duration

5 hours

1.3 Course purpose

This Unit is crucial to learn how to perform a welding job that meets all quality requirements. From material imperfections to inspection actions that lead to welder qualification, this Unit covers all specific standards that will help you ensure a good work and, ultimately, your success in Welding.

1.4 Objectives of the course

General Objectives

- *Describe specific standards used in quality assurance in welding to perform a good welding,*
- *Interpret WPS and WPQR to deliver a welding job that matches all criteria,*
- *Inspect a welded piece using specific standards to identify material imperfections,*
- *Identify test coupons and its connections to qualification and validity standards.*

Specific Objectives

<table>
<tr><th>Knowledge</th><th>Skills</th><th>Attitudes</th></tr>
<tr><td>Describe and explain the role and operation of specific standards about quality in welding:
• ISO 3834 Quality Requirement for Welding Group
• ISO 9001:2015 - Quality Management Systems
• ISO 14731:2019 - Welding coordination – Tasks and Responsibilities</td><td>Use terms and definitions that are consistent with generally accepted welding terminology as recorded international welding standards</td><td rowspan="2">• Communicate to others,
• Assumption within the work team of the responsibilities for the work task.</td></tr>
<tr><td>Describe and explain the role of WPS (Welding Procedure Specification) and WPQR (Welding Procedure Qualification Record) for quality level referring to:
Describe and explain the role of WPS (Welding Procedure Specification) and WPQR (Welding Procedure Qualification Record) for quality level referring to:
• ISO 15607:2019 - Specification and qualification of welding procedures for metallic materials - General rules</td><td>• Identify general rules for the specification and qualification of welding procedures for metallic materials,
• Understand WPS abbreviations and terminologies,
• Prepare his job according to WPS.</td></tr>
</table>

• ISO 15609-1:2019 - Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding • ISO 15614-1:2017 - Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys		
Identify potential causes of welding defects or imperfections prior to welding, and take action to meet requirements : • ISO 6520-1:2007 Welding and allied processes – Classification of geometric imperfections in metallic materials – Part 1: Fusion welding; • ISO 5817:2014 -Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections; • ISO 10042:2018 -Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections	• Carry out pre-operational checks in accordance with manufacturers' specifications, • Identify welding defects and take corrective action.	
Describe and explain standards for quality and co-ordination in welding referring to: • ISO 9606-1: 2012 Qualification testing of welders - Fusion welding - Part 1: Steels	• Inspect welded workpiece for defects (use destructive testing) and apply quality checks • on process, • Inspect the end product for conformance to specifications as reflected on drawing or job requirement.	

1.5 Contents

1. Quality in Welding

1.1. Generals

1.1.1 Standardization and related activities

1.2 Specific Standards

1.2.1.ISO 3834 – Quality Requirements for Welding

1.2.1.1 ISO 3834 – Part 1: 2005

1.2.1.2 ISO 3834 – Part 2: 2005 and Part 3:2005

1.2.1.3 ISO 3834 – Part 4:2005

1.2.1.4 ISO 3834 – Part 5:2015
1.2.1.4 ISO/TR 3834 – Part 6 :2007

1.2.2 ISO 9001:2015 - Quality Management Systems
1.2.2.1 (Context of the organization)
1.2.2.2 (Leadership)
1.2.2.3 (Planning)
1.2.2.4 (Support)
1.2.2.5 (Operations)
1.2.2.6 (Performance evaluation)
1.2.2.7 (Improvement)

1.2.3 ISO 14731: 2019 – Welding coordination – Tasks and Responsibilities

2.WPS & WPQR
2.1 Standards
2.1.1 ISO 15607:2019 - Specification and qualification of welding procedures for metallic materials - General rules
2.1.2 ISO 15609-1:2019 Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding
2.1.3 ISO 15614-1:2017 - Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys

3. Welding Imperfections
3.1 ISO 6520-1:2007 – Welding and allied processes -- Classification of geometric imperfections in metallic materials -- Part 1: Fusion welding
3.2 ISO 5817:2014 - Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections
3.3 ISO 10042:2018 - Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections

4. Welder Qualification and Inspection
4.1 ISO 9606-1:2012 Qualification testing of welders - Fusion welding - Part 1: Steels
- Examination
- Testing
- Specific Standards
- Test piece
- Range of Qualification
- Validity

1.6 Participants

Learner characteristics: *(Outline the profile of the target learner group for the course)*	*Basic knowledge in Welding*

1.7 Entry requirements

(Outline the entry requirements of the course- if necessary)

Education level requirement:	*Students from VET schools (background on compulsory education)*
Previous knowledge needed	*Basic knowledge in welding*
Age requirements:	*Ages between 16 and 20 years old*

1.8 Assessment activities

Summative assessment

- *Theoretical examination using stand-alone simulator/computer or SIMTRANET virtual classroom*

1.9 Bibliography (used or supplementary)

Institute of Risk Management (2019). *About Risk Management*. (www.theirm.org) Date of consultation: August, 2019

ISO (2003). *ISO 15607:2003 Specification and qualification of welding procedures for metallic materials — General rules*. (https://www.iso.org/standard/28388.html). Date of consultation: July, 2019

ISO (2005). *ISO 3834-1:2005 Quality requirements for fusion welding of metallic materials — Part 1: Criteria for the selection of the appropriate level of quality requirements*. (https://www.iso.org/standard/35144.html). Date of consultation: July, 2019

ISO (2005). *ISO 3834-2:2005 Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements. (*https://www.iso.org/standard/35145.html). Date of consultation: July, 2019

ISO (2005). *ISO 3834-3:2005 Quality requirements for fusion welding of metallic materials — Part 3: Standard quality requirements*. (https://www.iso.org/standard/35146.html). Date of consultation: July, 2019

ISO (2005). *ISO 3834-4:2005 Quality requirements for fusion welding of metallic materials — Part 4: Elementary quality requirements*. (https://www.iso.org/standard/35147.html). Date of consultation: July, 2019

ISO (2007). *ISO 6520-1:2007 – Welding and allied processes -- Classification of geometric imperfections in metallic materials -- Part 1: Fusion welding.* (https://www.iso.org/standard/40229.html). Date of consultation: July, 2019

ISO (2012). *ISO9606-1:2012 Qualification testing of welders -- Fusion welding -- Part 1: Steels*. (https://www.iso.org/standard/54936.html). Date of consultation: July, 2019

ISO (2014). *ISO 5817:2014 - Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections*. (https://www.iso.org/standard/54952.html). Date of consultation: July, 2019

ISO (2014). *ISO 5817:2014 Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections.* (https://www.iso.org/standard/54952.html). Date of consultation: July, 2019

ISO (2015). *ISO 3834-5:2015 Quality requirements for fusion welding of metallic materials — Part 5: Documents with which it is necessary to conform to claim conformity to the quality requirements of ISO 3834-2, ISO 3834-3 or ISO 3834-4*. (https://www.iso.org/standard/63729.html). Date of consultation: July, 2019

ISO (2015). *ISO 9001:2015 Quality management systems — Requirements*. (https://www.iso.org/standard/62085.html). Date of consultation: July, 2019

ISO (2017). *ISO 15614-1:2017 Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*. (https://www.iso.org/standard/51792.html). Date of consultation: July, 2019

ISO (2018). *ISO 10042:2018 - Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections*. (https://www.iso.org/standard/70566.html). Date of consultation: July, 2019

ISO (2019). *ISO 15609-1:2019 Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding*. (https://www.iso.org/standard/75556.html). Date of consultation: July, 2019

Lexico Dictionaries (2019). *Definition of the word "Quality" in English*. (https://www.lexico.com/en/definition/quality). Date of consultation: July, 2019

Wikipedia (2019). Picture of SS Schenectady. Retrieved from https://en.wikipedia.org/wiki/SS_Schenectady. Date of consultation: July, 2019

UNIT NUMBER: Didactic Unit 3

UNIT TITLE: *Quality Assurance in Welding*

UNIT PRESENTATION

Each of the units (or subjects) of the course (or module) should have a brief presentation in which, in an attractive and motivating way, you emphasize its importance and present the most important points that can be seen in it.

This Unit is crucial if you want to learn how to perform a welding job that meets all quality requirements. From material imperfections to inspection actions that lead to welder qualification, this Unit covers all specific standards that will help you ensure a good work and, ultimately, your success in Welding.

OBJECTIVES

Indicates 2-3 specific unit objectives. These refer to what the students can get to know after the unit study.
*The objectives formulation must be clear, using a language adapted to the knowing level of the students and must be **expressed in infinitive**.*

General Objectives

- *Describe specific standards used in quality assurance in welding to perform a good welding,*
- *Interpret WPS and WPQR to deliver a welding job that matches all criteria,*
- *Inspect a welded piece using specific standards to identify material imperfections,*
- *Identify test coupons and its connections to qualification and validity standards.*

Specific Objectives

<table>
<tr><th>Knowledge</th><th>Skills</th><th>Attitudes</th></tr>
<tr><td>Describe and explain the role and operation of specific standards about quality in welding:
• ISO 3834 Quality Requirement for Welding Group
• ISO 9001:2015 - Quality Management Systems
• ISO 14731:2019 - Welding coordination – Tasks and Responsibilities</td><td>Use terms and definitions that are consistent with generally accepted welding terminology as recorded international welding standards</td><td rowspan="2">• Communicate to others,
• Assumption within the work team of the responsibilities for the work task.</td></tr>
<tr><td>Describe and explain the role of WPS (Welding Procedure Specification) and WPQR (Welding Procedure Qualification Record) for quality level referring to:
Describe and explain the role of WPS (Welding Procedure Specification) and WPQR (Welding Procedure Qualification Record) for quality level referring to:
• ISO 15607:2019 - Specification and qualification of welding</td><td>• Identify general rules for the specification and qualification of welding procedures for metallic materials,
• Understand WPS abbreviations and terminologies,
• Prepare his job according to WPS.</td></tr>
</table>

procedures for metallic materials - General rules • ISO 15609-1:2019 - Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding • ISO 15614-1:2017 - Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys		
Identify potential causes of welding defects or imperfections prior to welding, and take action to meet requirements: • ISO 6520-1:2007 Welding and allied processes – Classification of geometric imperfections in metallic materials – Part 1: Fusion welding; • ISO 5817:2014 -Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections; • ISO 10042:2018 -Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections	• Carry out pre-operational checks in accordance with manufacturers' specifications, • Identify welding defects and take corrective action.	
Describe and explain standards for quality and co-ordination in welding referring to: • ISO 9606-1: 2012 Qualification testing of welders - Fusion welding - Part 1: Steels	• Inspect welded workpiece for defects (use destructive testing) and apply quality checks • on process, • Inspect the end product for conformance to specifications as reflected on drawing or job requirement.	

CONTENTS

Present the unit index correctly numbered

1. Quality in Welding

1.1. Generals
1.1.1 Standardization and related activities

1.2 Specific Standards
- 1.2.1.ISO 3834 – Quality Requirements for Welding
- 1.2.1.1 ISO 3834 – Part 1: 2005
- 1.2.1.2 ISO 3834 – Part 2: 2005 and Part 3:2005
- 1.2.1.3 ISO 3834 – Part 4:2005
- 1.2.1.4 ISO 3834 – Part 5:2015
- 1.2.1.4 ISO/TR 3834 – Part 6:2007

1.2.2 ISO 9001:2015 - Quality Management Systems
- 1.2.2.1 (Context of the organization)
- 1.2.2.2 (Leadership)
- 1.2.2.3 (Planning)
- 1.2.2.4 (Support)
- 1.2.2.5 (Operations)
- 1.2.2.6 (Performance evaluation)
- 1.2.2.7 (Improvement)

1.2.3 ISO 1473: 2019 – Welding coordination – Tasks and Responsibilities

2.WPS & WPQR
2.1 Standards
2.1.1 ISO 15607:2019 - Specification and qualification of welding procedures for metallic materials - General rules
2.1.2 ISO 15609-1:2019 Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding
2.1.3 ISO 15614-1:2017 - Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys

3. Welding Imperfections
3.1 ISO 6520-1:2007– Welding and allied processes -- Classification of geometric imperfections in metallic materials -- Part 1: Fusion welding
3.2 ISO 5817:2014- Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections
3.3 ISO 10042:2018- Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections

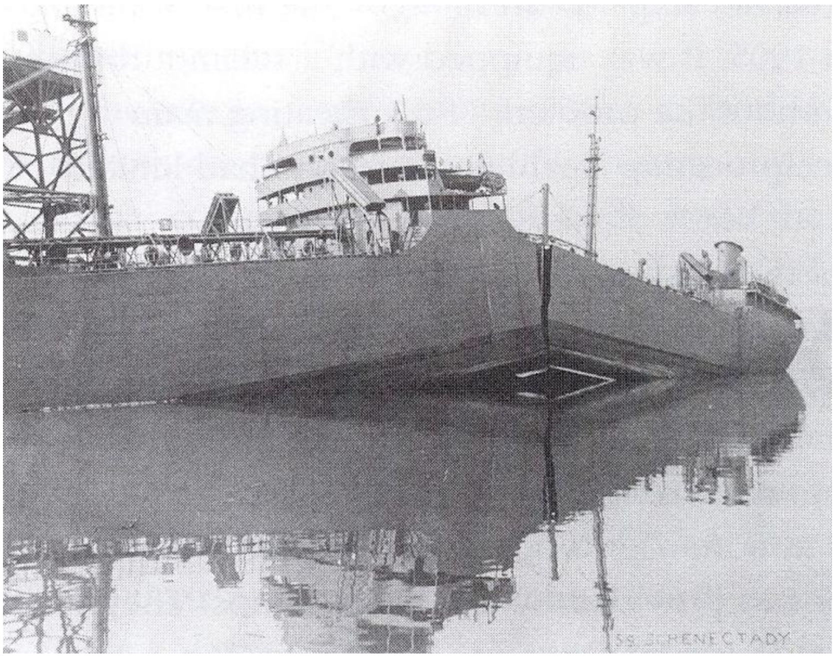
4. Welder Qualification and Inspection
4.1 ISO 9606-1:2012-Qualification testing of welders -- Fusion welding -- Part 1: Steels
- Examination
- Testing
- Specific Standards
- Test piece
- Range of Qualification
- Validity

CONTENTS DEVELOPMENT

FIRST SECTION OR POINT: 1. Quality in Welding

SUB-SECTION: 1.1. Generals

Quality is a concept that has accompanied production for a long time. It is a very important topic, since it dictates the specifics for how a welded joint should look/act like.
Quality, by definition, means *"The standard of something as measured against other things of a similar kind; the degree of excellence of something." (in* Lexico Dictionaries, 2019).
The consequences for lack of quality can range from simple loss of "beauty" of the part, to a catastrophic failure of the entire system that depends on it. Also, welding can be defined as a "special process", which, according to the ISO 9000 standard, refers to processes whose quality cannot be readily or economically verified at the end of the manufacturing process. Because of this, it is important to establish measures for quality control and assurance during the welding process.
To make sure quality control is effective, an inspection testing plan (ITP) shall be developed and implemented. The ITP activities include documental verification and also destructive and non-destructive tests.
The welder also plays a very important role in this process, making evidence of his/her qualifications/experience necessary to ensure good welds and prevent possible welding failures.



In the image we can see the wreck of the "SS Schenectady" T2 tanker. The cause for the wreck was the placement of a defective weld in an area of stress concentration. The rupture happened while lying at the outfitting dock in the constructors' yard in Portland, after its sea trials.

Source: Wikipedia

SUB-SECTION 1.1.1. Standardization and related activities

Standardization is the process of creating standards to guide the creation of a good or service based on the consensus of all the relevant parties in the industry. The standards ensure that goods or services produced in a specific industry come with consistent quality and are equivalent to other comparable products or services in the same industry.

The goal of standardization is to ensure uniformity to certain practices within the industry. The standardization focuses on the product creation process, operations of the businesses, technology in use, and how specific compulsory processes are delivered.

In essence, a standard is an agreed way of doing something. It could be about making a product, managing a process, delivering a service or supplying materials – standards can cover a huge range of activities undertaken by organizations and used by their customers.
Standards are the distilled wisdom of people with expertise in their subject matter and who know the needs of the organizations they represent – people such as manufacturers, sellers, buyers, customers, trade associations, users or regulators.
Standards are knowledge. They are powerful tools that can help drive innovation and increase productivity. They can make organizations more successful and people's everyday lives easier, safer and healthier.

SUB-SECTION: 1.2. Specific Standards

We will further discuss three standards for quality requirements: the ISO 3834 series, the ISO 9001, and the ISO 14731.

SUB-SECTION: 1.2.1. ISO 3834:2005 *Quality Requirement for Welding Group*

The ISO 3834 series provide quality requirements suitable for fusion welding processes of metallic materials. These requirements can, however, be adopted for other welding processes. They relate only to the aspects of product quality, not being assigned to a specific product group. It also provides guidance for assessing a manufacturer's welding capability.
This standard is divided in 5 standards and 1 technical report (part 6):

1. Criteria for the selection of the appropriate level of quality requirements,
2. Comprehensive quality requirements,
3. Standard quality requirements,
4. Elementary quality requirements,
5. Applicable documents,
6. Guideline for implementation of ISO 3834.

The first part is then used to choose between quality requirements - second, third and fourth parts (being the second the strictest, then third and lastly, fourth) - which contain the standards' quality requirements, at different levels of quality. The fifth part contains the documents required to meet the quality requirements, defined in the different parts of the standard series (parts two, three and four. The sixth part is a technical report which to aim of helping in the implementation of the standard. Even when it is explaining down but to be a complete introduction to all parts.

This standard series defines the quality requirements that are needed to achieve a certain level of quality for a certain welded construction. It can be used in contractual situations (in the specification of the quality requirements), by manufacturers (in establishing and maintaining welding quality requirements), by committees drafting manufacturing codes (in the specification of welding quality requirements), or by organizations assessing the quality performance (e.g. customers)

If the criteria for one of the levels is met, it is assumed that the ones for all lower levels are met as well (e.g. if a manufacturer is compliant to ISO 3834-2, he is also compliant to ISO 3834-3 and ISO 3834-4).

SUB-SECTION: 1.2.1.1 ISO 3834 - Part 1:2005

Choosing which part of the standard is to be consulted should be done based on the following, related to the products:
– Extent and significance of safety-critical products,
– Complexity of manufacture,
– Range of products manufactured,
– Range of materials used,
– Extent to which metallurgical problems may occur,
– Extent to which manufacturing imperfections, e.g. misalignment or distortion, affect product performance.

SUB-SECTION: 1.2.1.2 ISO 3834- Part 2:2005 and Part 3:2005

These parts of the standard include the comprehensive and standard requirements (respectively) for fusion welding of metallic materials in workshops and onsite installations. It provides guidelines based on the following requirements:

- Parent material(s) and welded joint properties,
- Quality and acceptance requirements for welds,
- Location, accessibility and sequence of welds, including ones for inspection and non-destructive testing,
- The specification of welding procedures, non-destructive testing procedures and heat-treatment procedures,
- The approach to be used for the qualification of welding procedures,
- The qualification of personnel,
- Selection, identification and/or traceability of the process,
- Quality-control arrangements, including any involvement of an inspection body,
- Inspection and testing,
- Sub-contracting,
- Post-weld heat treatment,
- Other welding requirements, e.g. ferrite content of weld metal,
- Use of special methods, e.g. to achieve full penetration without backing when welded from one side only,
- Dimensions and details of joint preparation and completed weld,
- Welds which are to be made in the workshop, or elsewhere,
- Environmental conditions relevant to the application of the process (e.g. necessity to provide protection against adverse weather conditions),
- Handling of non-conformances.

SUB-SECTION: 1.2.1.3 ISO 3834- Part 4:2005

This part of the standard includes the elementary requirements for fusion welding of metallic materials. It provides guidelines, based on the process's requirements, such as:

- Sub-contracting,
- Welding personnel qualification,
- Inspection and testing personnel qualification,
- Equipment status,

- Welding techniques and consumables availability,
- Non-conformance and corrective actions,
- Quality record retainment period
- Inspection and testing.

SUB-SECTION: 1.2.1.4 ISO 3834- Part 5:2015

This part of the standard provides information on which ISO documents are necessary for the application of the norms in the ISO 3834 group.

SUB-SECTION: 1.2.1.5 ISO/TR 3834- Part 6:2007

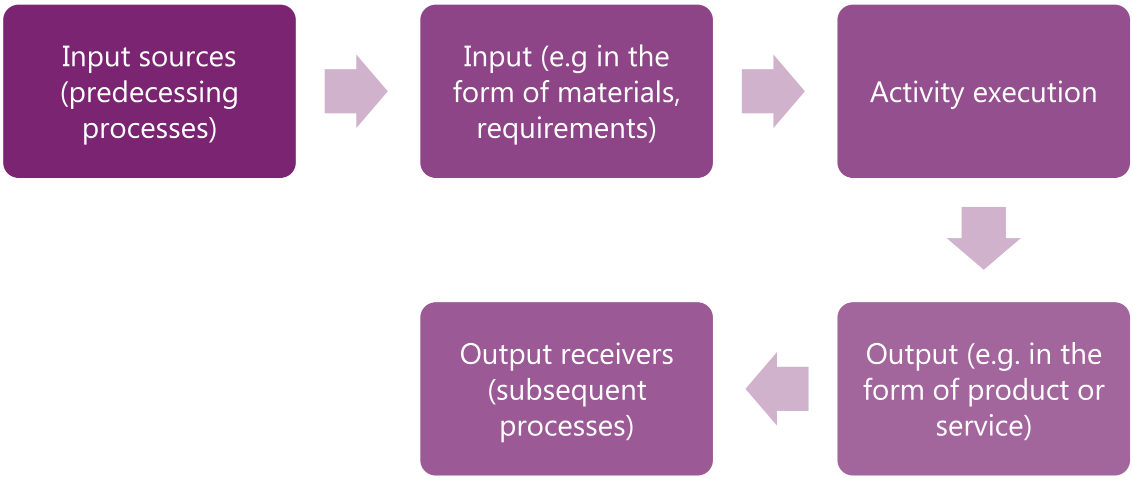
This one gives guidelines for the implementation of requirements given in the parts 2, 3 and 4 of ISO 3834. It is intended to help manufacturers on the implementation of the relevant part of ISO 3834.

SUB-SECTION: 1.2.2. ISO 9001:2015 *Quality Management Systems*

This standard refers to the requirements for a company's Quality management system (management of the entire enterprise). It can be employed by organizations of all sizes.
ISO 9001 can be broken down into seven major groups of requirements:

- Context of the organization,
- Leadership,
- Planning,
- Support,
- Operation,
- Performance evaluation,
- Improvement.

The following image, based on the ISO 9001, shows the necessary steps to implement a project/activity. Note that every one of these phases can be used to monitor/measure quality and performance.



SUB-SECTION: 1.2.2.1 ISO 9001 (Context of the organization)

This section sets the necessary steps to the foundation of the ISO 9001 quality management system. It requires that the organization identifies its strengths and weaknesses, needs and expectations, and through process approach determine the ISO 9001's processes. The quality management system will then need to be implemented, maintained and continually improved upon.
Documentation in this system must include procedures and work instructions, to ensure effective control of all processes. Records should also be established in order to provide evidence of the usage of a properly maintained ISO 9001.

Tip: Since this norm relies on proper documentation, the use of templates is advised to streamline the procedures.

SUB-SECTION: 1.2.2.2 ISO 9001 (Leadership)

This section is about the involvement of Top management in the quality management system.
It summarizes its various responsibilities (ISO 9001-wise), such as the integration of the system into the operational processes of the company.

Top management must take leadership when it comes to customer focus (determining customer requirements and related risks, an addressing them, maintaining a focus on customer satisfaction).
It should ensure that responsibilities and authorities within the organization are clearly established.
Lastly, the norm states that Top management is responsible for the quality management system. An ISO 9001 representative can, however, be appointed.

SUB-SECTION: 1.2.2.3 ISO 9001 (Planning)

This section is focused on the planning of operations, as the title implies.
Firstly, it addresses the way the organization should engage in risk management (understanding, analyzing, and addressing risk, for the organization to achieve their objectives).
Secondly, quality objectives should be established, as well as plans on how to achieve them.
Lastly it addresses the planning of changes, to be done in a systematic manner.

SUB-SECTION: 1.2.2.4 ISO 9001 (Support)

This section focuses on the operations' support functions, such as resources, competence/training, communication, and documentation.
First, it states that a company should determine and provide, in a timely manner, the resources necessary to the implementation and improvement of the processes in the Quality management system. These include human resources (people), as well as their competences, and the training necessary to achieve the required ones.
Then, the infrastructure needed to achieve conformity of the products/services should be identified, provided and maintained.
Equipment, machinery, and the work environment should be maintained as well. Measuring devices should be taken special care of and properly calibrated.
Organizational knowledge (e.g. best practices) should be determined, maintained, and shared.
What's more, the company should have both internal and external communications channels established.

Lastly, it should be ensured that the right people have the current version of the right document available. Records should be kept for the numerous activities performed.

SUB-SECTION: 1.2.2.5 ISO 9001 (Operation)

This section addresses the requirements for the processes needed to achieve the product or service.
It places emphasis on how the company understands, communicates and meets customer requirements, and the path it should follow should they change. It states that both design and development reviews, as well as verification and validation must be planned for at the very beginning of the process.
It also specifies controls for the actual production and service provision, from work instructions to quality control inspections.
It also addresses the non-conformity of the output to requirements.

SUB-SECTION: 1.2.2.6 ISO 9001 (Performance evaluation)

This part addresses measuring and evaluating.
It discusses the definition, planning, and implementation of measurement and necessary monitoring activities, in order to assure conformity, as well as achieving improvement.
It also focuses on the analysis of the data resulting from these activities, and systematic internal auditing to understand if the ISO 9001 system is working as planned.
Lastly, it addresses management reviews. These should cover a wide range of topics related to the ISO 9001, ranging from customer satisfaction to supplier performance. This results in decisions and actions regarding improvements, changes, and resource needs.

SUB-SECTION: 1.2.2.7 ISO 9001 (Improvement)

This section requires companies to identify opportunities for improvement.
It discusses the need for the improvement of both products and services with an eye to current and future market needs. It also specifies that nonconformity should be controlled and corrected, if possible.
Finally, processes for the continual improvement of the quality management system should be planned and managed, using the data acquired in the previous sections.

SUB-SECTION: 1.2.3. *ISO 14731:2019 Welding coordination – Tasks and responsibilities*

This International Standard identifies the quality-related responsibilities and tasks included in the coordination of welding-related activities.
These activities include, in accordance with ISO 3834: review of requirements, technical review, sub-contracting suitability, welding personnel qualification, equipment review, production planning, qualification of the welding procedures, welding procedure specifications, issuing of work instructions, welding consumables review, materials review, inspection and testing before welding, inspection and testing during welding, inspection and testing after welding, post-weld heat treatment, non-conformance and corrective actions, calibration and validation of measuring, inspection and testing equipment, identification and traceability, and quality records preparation and maintenance.

These activities can be associated with a few tasks/responsibilities, such as:

- Specification and preparation,
- Control,
- Inspection,
- Checking or witnessing.

In the occasions where welding coordination is carried out by more than one person, tasks and responsibilities should be properly allocated, such that responsibility is clearly defined and qualification for each specific task is assured. This coordination is the sole responsibility of the manufacturer, being the coordinator appointed by him/her.

The standard also specifies that an accurate job description is required for the coordination personnel, which should include their tasks and responsibilities.
The tasks should be assigned according to information in the standard's annex B
The responsibilities should be identified as:

– their position in the manufacturing organization and their responsibilities;
– the extent of authorization accorded to them to accept by signature on behalf of the manufacturing organization, needed in order to fulfil the assigned tasks, e.g. for procedure specification and supervision reports;
– the extent of authorization accorded to them to carry out the assigned tasks.

Lastly, it discusses the topic of technical knowledge, by specifying that the coordinators should be able to demonstrate the adequate amount to ensure satisfactory performance of the tasks. The extent of experience/education/knowledge required is to be decided by the manufacturing organization and should depend on the assigned tasks/responsibilities. For example, regarding Welding Coordination Personnel, there are three levels of knowledge: comprehensive, specific and basic.

FIRST SECTION OR POINT: 2. WPS & WPQR

The section's introduction must be contextualized and arouse interest and motivation in the students. The section must be introduced indicating what can be seen in it, which are the different sub-sections or themes that it includes, how they are interconnected ... in other words, it is about Present the key ideas that will be seen.

Both WPS (Welding Procedure Specification) and WPQR (Welding Procedure Qualification Record) play major roles in a welded joint, because through those, the required quality level can be ensured. A WPS serves the same purpose for a welder as a recipe does for a cooker. This allows welder to (with enough welding knowledge), perform sound welds, as specified, as many times required. The WPQR comprises all the necessary data needed for the qualification of the preliminary WPS - pWPS (to be discussed later in this section).

SUB-SECTION: 2.1. Standards

Develop this section and the successive ones with all the theoretical content including informative complements like illustrations, images, figures, tables, charts, graphs and diagrams

Three standards should be reference when talking about these two topics: ISO 15607:2019, ISO 15609-1:2019, and ISO 15614-1:2017.

SUB-SECTION: 2.1.1 ISO 15607:2019 *Specification and qualification of welding procedures for metallic materials - General rules*

Develop this section and the successive ones with all the theoretical content including informative complements like illustrations, images, figures, tables, charts, graphs and diagrams

ISO 15607 defines general rules for the specification and qualification of welding procedures for metallic materials. It provides some information on the WPS and WPQR, as well as which standards to refer to.
Firstly, it states that a preliminary WPS should be elaborated by the manufacturer, that is applicable for the actual production, using experience from previous productions.

Then the WPQR is made by using one of four possible qualification methods, each with their own application:
-Welding procedure test, which can always be applied, except for when the procedure test does not correspond to the joint geometry, restraint, or accessibility of the actual welds. These tests are specified in the ISO 15614 standard;
-Tested welding consumables, which is limited to welding procedures that make use of consumables. Further limitations for this method can be found in the ISO 15610 standards;
-Previous welding experience, limited to procedures frequently used in the past, in comparable items, joints, and materials. This method's requirements are discussed further in the ISO 15611 standard;
-Standard welding procedure, which is like the "welding procedure test", with its limitations specified in the ISO 15612 standard;
- Pre-production welding test, whose principle can always be applied, but requires manufacture of a test piece, under production conditions (further explained in ISO 15613 standard - *Specification and qualification of welding procedures for metallic materials -- Qualification based on pre-production welding test*).

These qualifications are valid indefinitely, unless otherwise specified.

SUB-SECTION: 2.1.2 ISO 15609-1:2019 *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding*

Develop this section and the successive ones with all the theoretical content including informative complements like illustrations, images, figures, tables, charts, graphs and diagrams

This standard specifies the contend that should figure in a WPS for arc welding processes.
It states that the WPS should include:
- Identification of the manufacturer;
- Identification of the WPS;
- Reference to the WPQR
- Designation of the material(s), and reference standard(s);
- Material dimensions
- Thickness ranges of the joint;
- Outside diameter ranges for pipes.
- Welding process(es) used in accordance with EN ISO 4063 (Welding and allied processes -- Nomenclature of processes and reference numbers).
- A sketch of the joint design/configuration and dimensions or reference to standards which provide such information.
- Weld run sequence given on the sketch if essential for the properties of the weld.
- Applicable welding positions in accordance with EN ISO 6947.
- Joint preparation methods, cleaning, degreasing, including methods to be used;
- Jigging, fixtures and tack welding.
- Weaving if applicable.
    For manual welding: maximum width of the run.
    For mechanized and automatic welding: maximum weaving, frequency and dwell time of oscillation;
- Torch, electrode and/or wire angle.
-Back gouging:
    The method to be used, depth and shape.
    The method and type of backing, backing material and dimensions. (For gas backing, gas in accordance with ISO 14175.)
-Welding consumables:
    Designation, make, dimension, handling
-Type of electrical current
-Pulse welding details if applicable.
-Current range.
-Mechanized and automatic welding:
    Travel speed range, wire/strip feed speed range.
-The minimum temperature applied at the start of welding and during welding.
-Maximum and if necessary minimum Interpass temperature.

-The minimum temperature in the weld zone which shall be maintained if welding is interrupted.
-Post-heating for hydrogen release:
Temperature range. minimum holding time.
-The minimum time and temperature range for post-weld heat treatment or ageing, or reference to the respective standards.
-Shielding gas
Designation in accordance with ISO 14175:2008 and, where applicable, the composition, manufacturer and trade name.
-Range of heat input (if specified).

It also includes information on some process-specific parameters for the following processes: Manual metal arc welding, Submerged arc welding, Gas-shielded metal arc welding, Gas-shielded welding with non-consumable electrode, and Plasma arc welding.

SUB-SECTION: 2.1.3 ISO 15614-1:2017 *Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

Develop this section and the successive ones with all the theoretical content including informative complements like illustrations, images, figures, tables, charts, graphs and diagrams

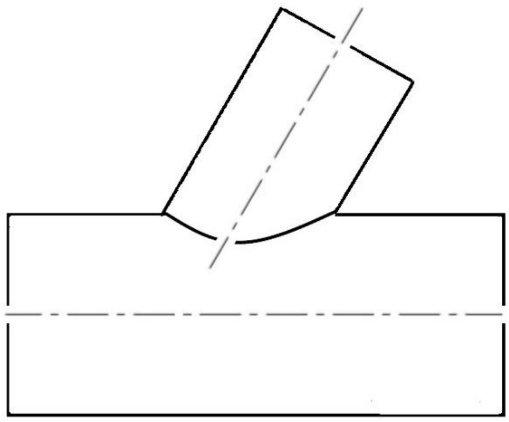
This standard specifies how a preliminary Welding Procedure Specification (pWPS) is qualified by welding procedure tests in the arc and gas welding of steels and arc welding of nickel and its alloys, in all product form.
It states that "Two levels of welding procedure tests are given in order to permit application to a wide range of welded fabrication". They are designated by levels 1 and 2, being level 1 based on requirements of ASME (Section IX – Welding Qualifications) and level 2 based on the previous issues of this standard.
Level 2, that qualifies level 1 automatically (but not the other way around). In it, the extent of testing is larger, and the ranges of qualification are more restrictive than the ones in level 1. All level 2 requirements apply when no level is specified in a contract or application standard.

ISO 15614-1:2017 mentions that firstly, a standardized test piece (or pieces) should be made to represent the welded joint in question. Where no standardized pieces accurately represent the production/joint geometry requirements, the ISO 15613:2004 standard should be consulted.

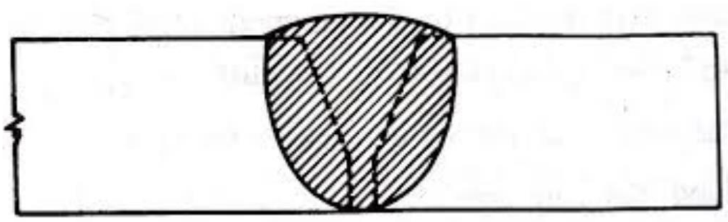
These test pieces should be prepared in accordance with the following:

- The length or number of test pieces should be enough to allow all required tests to be carried out;
- Additional test pieces, or longer test pieces than the minimum size, may be prepared in order to allow for extra and/or for re-testing specimens;
- For all test pieces except branch connections and fillet welds the material thickness, t, shall be the same for both plates/pipes to be welded;
- If required by the application standard, the direction of plate rolling shall be marked on the test piece when impact tests are required to be taken in the Heat Affected Zone;
- The thickness and/or pipe outside diameter of the test pieces shall be selected in accordance with the respective tables;
- Butt joints in plate with full penetration, butt joints in pipe with full penetration, t-joints, and branch connections should be made in accordance to the standard's respective figures (consulting them is advised).

Source: Tiago Núncio

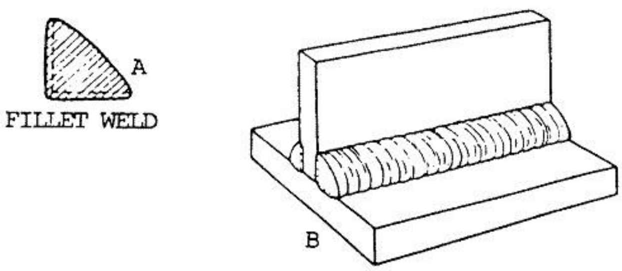


1



2

Source: ecoursesonline.com



3

Source: Quora.com

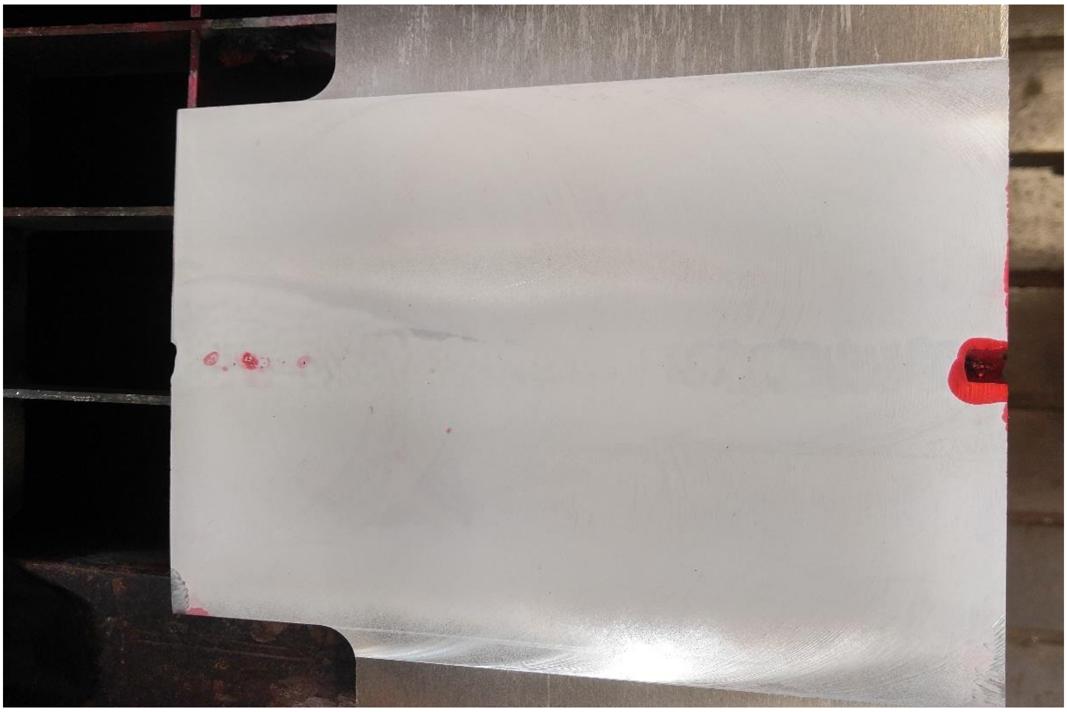
In the images above are represented a branch weld (1), a butt joint (2), and a fillet T-joint (3)

The test pieces should be welded in accordance with the pWPS, and under the general conditions of welding in production which they represent. The welding of these pieces should be witnessed by and examiner/examining body.

These pieces should then be tested by both non-destructive and destructive methods, such as visual testing, radiographic or ultrasonic tests, surface crack detection tests, transverse tensile test, transverse bend test, impact test, hardness test, macroscopic examination. Some application standards may specify additional tests, such as longitudinal weld tensile test, all weld metal bend test, corrosion tests, chemical analysis, micro examination, delta ferrite examination, and/or cruciform tests.

After all non-destructive testing (NDT) has been carried out and passed, test specimens shall be taken out (in accordance to the standards respective figures). It is acceptable to take these from areas avoiding imperfections as seen through the NDT methods.

NDT methods should be applied after any post-weld heat treatment. For materials susceptible to hydrogen cracking with no post heating/ post weld-heat treatment, these tests should be delayed.



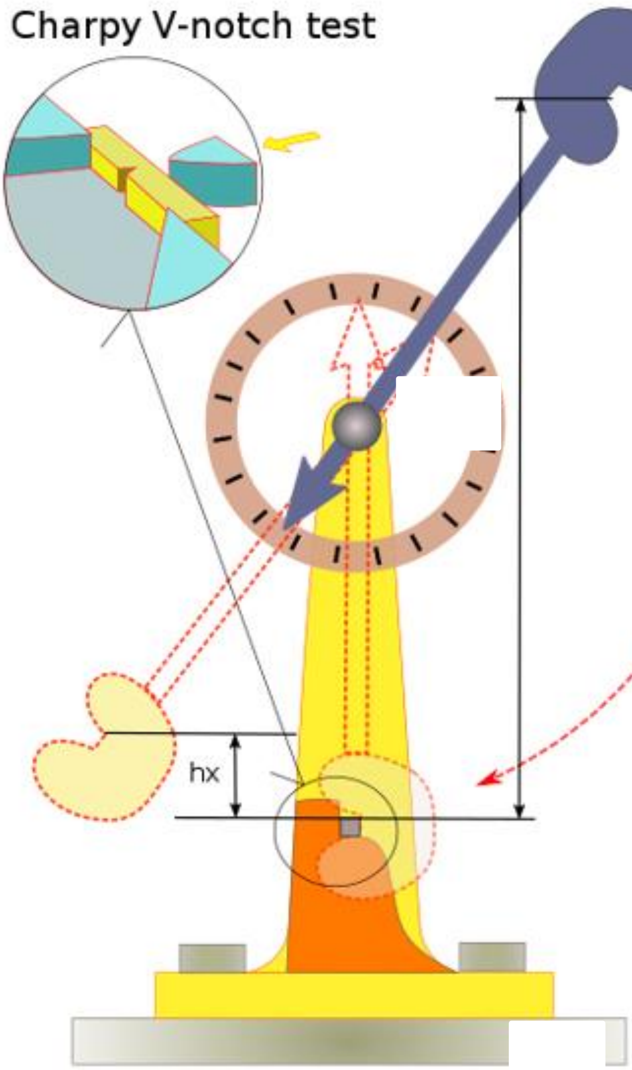
Source: Philip Carvalho

In this image we can see the results of a die penetrant test on a butt weld in aluminum that has been machined over.

If the test piece fails to comply with any of the requirements for the NDT methods, one additional test piece should be welded and subjected to the same examination. If this second piece does not comply as well, then the test has failed.
If any specimens fail to comply with the requirements for destructive tests due to weld imperfections, two further test specimens need to be tested for each one that failed. These additional specimens can be taken from the same test piece if there is enough material or from a different test piece. If any of these two does not comply with the requirements, then the test is considered a failure.

If there are single hardness values in different test zones above the values indicated, then additional tests may be carried out. None of the additional hardness values should exceed the maximum values indicated.

For Charpy impacts tests, where the results from a set of three specimens do not comply with the requirements, with only one lower value below 70 %, three additional specimens shall be taken. The average value of these specimens together with the initial results should not be lower than the required average.



Source: Wikipedia

In this image we can see a representation of a Charpy impact test.

A qualification of a pWPS by a welding procedure test, according to the ISO 15614-1 standard, is valid for welding in workshops or sites under the same technical and quality control of the manufacturer (the manufacturer who performed the welding procedure test retains complete responsibility for all welding carried out to it).

The ranges of qualification for nickel and alloys, steel, and for dissimilar joints between steels and nickel alloys are given in the respective tables of ISO 15614-1.

Qualification ranges are then specified for essential variables, that vary at quality levels 1 and 2. They are:

- Related to the Manufacturer;
- Material thickness, pipe diameter and angle of branch connection;
- Welding processes;

– Welding positions;
– Type of joint;
– Parent material
– Filler material, type and size;
– Type of current;
– Heat Input;
– Preheat temperature;
– Interpass temperature;
– Post-heating for hydrogen release;
– Post-weld heat-treatment;
– Some process-specific criteria.

The WPQR is a statement of results from the tests carried out, including re-tests. The relevant items for the WPS listed in the ISO 15609 should also be included, with details of any features that would be rejectable by the testing requirements. If no rejectable features or unacceptable results are found, then the WPQR is qualified and can be signed by the examiner/examining body. A standard format should be used, in order to facilitate presentation and assessment of the data.

FIRST SECTION OR POINT: 3. Welding Imperfections

The section's introduction must be contextualized and arouse interest and motivation in the students. The section must be introduced indicating what can be seen in it, which are the different sub-sections or themes that it includes, how they are interconnected ... in other words, it is about Present the key ideas that will be seen.

Usually, the quality of a product depends on its imperfections. Because of that it is necessary to link the two of them so that the products meet the required imperfection criteria, and therefore, the specified quality levels.

SUB-SECTION: 3.1. ISO 6520-1:2007 Welding and allied processes – Classification of geometric imperfections in metallic materials – Part 1: Fusion welding

Develop this section and the successive ones with all the theoretical content including informative complements like illustrations, images, figures, tables, charts, graphs and diagrams

This standard has the objective of cataloging and sorting possible imperfections in welding. It is divided in two parts: Part one refers to fusion welding, whereas part two focuses on welding with pressure.

It also divides said imperfections into six groups:

1 — Cracks;
2 — Cavities;
3 — Solid inclusions;
4 — Lack of fusion;
5 — Imperfect shape;
6 — Any other imperfections not included in groups 1 to 5.

The id code of each imperfection given by this catalogue is accepted globally, providing a streamlined designation that allows for all the involved parties to communicate without misunderstandings (when it comes to imperfection designation at least)

SUB-SECTION: 3.2. ISO 5817:2014 - *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections*

Develop this section and the successive ones with all the theoretical content including informative complements like illustrations, images, figures, tables, charts, graphs and diagrams

The ISO 5817:2014 standard specifies the maximum allowable dimensions of typical imperfections in normal fabrication. These dimensional limits vary according to the quality level chosen. This level should be defined by the responsible designer in conjunction with the manufacturer, user and/or other parties involved. It should consider the design considerations, subsequent processing, mode of stressing, service conditions, and the consequences of failure. Economic factors should also be considered.

Quality levels range from B to D, being D the least strict one.

This standard is adapted to fusion welding processes in welded joints of steel, nickel, titanium, and their alloys, for welding thicknesses ≥0,5mm. It can, however, be used for other fusion welding processes or weld thicknesses.

The imperfections' identification code is the one that can be found in ISO 6520 standard.

Source: Philip Carvalho

In this image we can see the results of a magnetic particles test on a butt weld that has been partially machined over (red circle).

SUB-SECTION: 3.3. ISO 10042:2018 - *Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections*

Develop this section and the successive ones with all the theoretical content including informative complements like illustrations, images, figures, tables, charts, graphs and diagrams

The ISO 10042 is the equivalent of the ISO 5817 standard but adapted to aluminum and its alloys. It follows the same B to D quality level system, as well as the numeration from the ISO 6520 standard.

FIRST SECTION OR POINT: 4. Welder Qualification and Inspection

The section's introduction must be contextualized and arouse interest and motivation in the students. The section must be introduced indicating what can be seen in it, which are the different sub-sections or themes that it includes, how they are interconnected … in other words, it is about Present the key ideas that will be seen.

Often the quality of a welded joint depends, among other factors, on the operator's skill level. For that matter, it is considered necessary to ensure it before the weld is done. In order to guarantee this, the ISO standard series 9606 was created, to streamline the qualification method to be used.

This standard family is divided into five parts, for five different material groups: steel, aluminum and alloys, copper and alloys, Nickel and alloys, Titanium/zirconium and alloys.

In this document only the first part will be discussed, being the reading of the other ones highly advised.

SUB-SECTION: 4.1. ISO 9606-1: 2012 Qualification testing of welders -- Fusion welding -- Part 1: Steels

Develop this section and the successive ones with all the theoretical content including informative complements like illustrations, images, figures, tables, charts, graphs and diagrams

This standard specifies the requirements for qualification testing of welders for fusion welding steels, providing a set of technical rules for a test, independent of the product type, location, and examining body.

It covers manual and partly mechanized fusion-welding processes, not covering, however, fully mechanized ones.

Firstly, it offers a series of abbreviations and reference numbers, as listed in ISO 4063, for the different welding processes, test pieces, filler materials, types of arc welding, bend test-wise terms, and other details.

It then offers a series of essential variables, for which a range of qualification is defined. If it is deemed necessary that a welder has to weld outside of his "qualification range", then a new test is required.
These essential variables are: welding processes, product type, type of weld, filler material group, welding consumable, dimensions (thickness and diameter), welding position, and some weld details (material backing, gas backing, flux backing, consumable insert, single side welding, both side welding, single layer, multi-layer, leftward welding, rightward welding).

- Welding processes: each test qualifies for only one welding process, with some exceptions. A change of process usually requires a new qualification test. It is possible, however, to obtain qualification for two or more processes, through the welding of a "multi-process joint", or by taking two or more separate tests.
- Product type: the tests should be carried out on plate, pipe, or one other suitable product form, each with their own criteria.
- Type of weld: performed either as butt or fillet welding, each with their criteria
- Filler material grouping: the test should be carried out with the appropriate filler material from the appropriate group. Welding with filler material from one group qualifies for welding with all other materials in that group. Also, welding with filler material qualifies for welding without one.
- Dimensions: For butt welds, the test is based on the deposited thickness and outside pipe diameters, as for fillet ones, it is based on the thickness of the test part.
- Welding position: the test pieces should be welded according to the testing positions in ISO 6947. Pipes with outside diameter > 150mm can be welded in two different positions.
- Details: The ranges of qualification vary according to its details.

It then addresses the topic of examination and testing, where the standard specifies that the welding of the test pieces should be witnessed by the examining body and verified by them. The piece should then be identified with both the identification of the welder and the examiner, as well as the welding position used. The examiner has the right to stop the test if the welding conditions are not correct or if the welder appears not to have the skill to fulfil the requirements.

The test pieces, for plates should be of at least 200 mm in length, since the examination length is of 150 mm. For pipe circumferences of less than 150mm, additional test pieces will be used, with a maximum of three pieces. The post treatments specified in the WPS, or pWPS, can be omitted at the discretion of the manufacturer.

The test piece shall then be submitted to tests, namely visual, radiographic, bending, and fracture. The rest of the tests need only be done if the part passes visual inspection.

Afterwards, all the results from the testing should be documented in accordance to the relevant standard.

The test pieces are then evaluated according to the acceptance requirements.
Prior to any testing, the piece should be checked for the following elements:
- Removal of all slag and spatters
- No signs of grinding on the root and the face side of the weld
- Identification of the stop and start in the root run and in the capping run
- Profile and dimensions

The acceptance requirements should, unless specified otherwise, be in accordance with ISO 5817, quality level B (C for some imperfections, e.g. excess weld metal). Bend-test specimens should not reveal any discrete discontinuity longer than 3 mm in any direction. Discontinuities at the edges are to be ignored, unless there is evidence that cracking is due to incomplete penetration, slag or other discontinuity. The sum of the greatest discontinuities exceeding 1mm but less than 3mm in any ne bend specimen should not exceed 10mm.
Needless to say, if the imperfections in the test piece exceed the permitted limits, then the test is failed.

If the test itself fails to comply with the requirements of this part of ISO 9606, the welder may be given the opportunity to repeat the qualification test once without further training.
As for the validity of these tests, assuming the results were acceptable, are of 6 months, the certificate needing to be confirmed by the person responsible for welding activities or the examining body, on the risk of becoming invalid if not.
Every three years the welder will be retested, or two specimen pieces (welded in the last 6 months of the certificate) from the welder every two years will be taken and tested.

If there is a specific reason to doubt the welder’s ability to make welds that meet the required standards of his qualifications, then those qualifications will be revoked. Once the welder has passed the qualification according with the quality requirements, a certificate is issued with all the details of the welding.

UNIT BIBLIOGRAPHY

Units will include a section of bibliographic references on which we must ensure that all the information sources consulted and used for the development of the contents are collected.
It is presented at the end of each unit, organized alphabetically following the advice given in the document “Annex 0. General recommendations.pdf”.

Institute of Risk Management (2019). About Risk Management. (www.theirm.org) Date of consultation: July, 2019

ISO (2003). ISO 15607:2003 Specification and qualification of welding procedures for metallic materials — General rules. (https://www.iso.org/standard/28388.html). Date of consultation: July, 2019

ISO (2005). ISO 3834-1:2005 Quality requirements for fusion welding of metallic materials — Part 1: Criteria for the selection of the appropriate level of quality requirements. (https://www.iso.org/standard/35144.html). Date of consultation: July, 2019

ISO (2005). ISO 3834-2:2005 Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements. (https://www.iso.org/standard/35145.html). Date of consultation: July, 2019

ISO (2005). ISO 3834-3:2005 Quality requirements for fusion welding of metallic materials — Part 3: Standard quality requirements. (https://www.iso.org/standard/35146.html). Date of consultation: July, 2019

ISO (2005). ISO 3834-4:2005 Quality requirements for fusion welding of metallic materials — Part 4: Elementary quality requirements. (https://www.iso.org/standard/35147.html). Date of consultation: July, 2019

ISO (2007). ISO 6520-1:2007 – Welding and allied processes -- Classification of geometric imperfections in metallic materials -- Part 1: Fusion welding. (https://www.iso.org/standard/40229.html). Date of consultation: July, 2019

ISO (2012). ISO9606-1:2012 Qualification testing of welders -- Fusion welding -- Part 1: Steels. (https://www.iso.org/standard/54936.html). Date of consultation: July, 2019

ISO (2014). ISO 5817:2014 - Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections. (https://www.iso.org/standard/54952.html). Date of consultation: July, 2019

ISO (2014). ISO 5817:2014 Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections. (https://www.iso.org/standard/54952.html). Date of consultation: July, 2019

ISO (2015). ISO 3834-5:2015 Quality requirements for fusion welding of metallic materials — Part 5: Documents with which it is necessary to conform to claim conformity to the quality requirements of ISO 3834-2, ISO 3834-3 or ISO 3834-4. (https://www.iso.org/standard/63729.html). Date of consultation: July, 2019

ISO (2015). ISO 9001:2015 Quality management systems — Requirements. (https://www.iso.org/standard/62085.html). Date of consultation: July, 2019

ISO (2017). ISO 15614-1:2017 Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys. (https://www.iso.org/standard/51792.html). Date of consultation: July, 2019

ISO (2018). ISO 10042:2018 - Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections. (https://www.iso.org/standard/70566.html). Date of consultation: July, 2019
ISO (2019). ISO 15609-1:2019 Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding. (https://www.iso.org/standard/75556.html). Date of consultation: July, 2019

Lexico Dictionaries (2019). Definition of the word "Quality" in English. (https://www.lexico.com/en/definition/quality). Date of consultation: July, 2019

Wikipedia (2019). Picture of SS Schenectady. Retrieved from https://en.wikipedia.org/wiki/SS_Schenectady. Date of consultation: July, 2019

GLOSSARY

It includes the main concepts, new and / or complex seen in the unit, as a dictionary. This type of resource is important especially when the course is aimed at students with no knowledge of the subject. Glossary entries are ordered alphabetically.

Back gouging - The removal of weld metal and base metal from the weld root side of a welded joint to facilitate complete fusion and complete joint penetration upon subsequent welding from that side.

Backing material - Material placed at the root of a weld joint to support molten weld metal

Calibrate - Correlate the readings of a measuring tool with those of a standard in order to check the instrument's accuracy.

Capping run - The final layer of a groove weld

Conformance - Compliance with standards, rules, or laws

Filler materials - Material to be added during fusion welding

Fusion welding - The melting together of filler metal and base metal, or of base metal only, to produce a weld

Hardness values - Value given by the result of a hardness test (e.g. Vickers)

Heat-treatment - Use of heat to change the properties of a metal

Imperfection - A fault, blemish, or undesirable feature

ITP - Inspection Testing Plan

Interpass temperature - Temperature at which subsequent weld runs are deposited

Joint - The junction of members or the edges of members that are to be joined or have been joined

Manufacturing - The making of articles on a large-scale using machinery

NDT – Non-destructive testing

Parent material - Parent material is the base material from the part to be welded

Procedure - A series of actions conducted in a certain order or manner

Root run - A weld pass made to produce the first weld bead

Slag - Coating left on the weld by the flux

Specimens - A sample of a test coupon subjected to testing

Spatters - Droplets of molten metal that are generated at or near the welding arc

Subcontracting - To employ a firm or a person outside one's own to work as part of a larger project

Template - Something that is used as a pattern for producing other similar things

Test piece - Example pieces that represent the piece being tested

Weaving - A welding technique in which the energy source is oscillated transversely as it progresses along the weld path