INSTITUT FÜR BETRIEBLICHE BILDUNGSFORSCHUNG

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VYTAUTO DIDŽIOJO UNIVERSITETAS

CEMIVET

CEMIVET WP4 (IO4)

Training courses

Centrum Promocji Innovacji i Rozwoju

Verslo konsultacinis centras

Reindustria Innovazione

CEMIVET WP4 (IO4-IO5)

Training courses

COURSE 1. CIRCULARITY AND SUSTAINABILITY IN WELDING – WHAT IS IT AND WHY IT IS IMPORTANT?

Scope and learning outcomes of the course

The aim of this course is to introduce the principles of circular economy and to explain the importance of these principles for the development of work processes of welding.
After completing this course, the learners will be able to:

- Define the concept of circular economy and to recognize it's main principles.
- Explain the importance of circular economy principles for the development of metalworking sector and, in particular, welding of metals.
- Explain environmental impact of welding processes and the implications of welding for the consumption of raw materials.
- Evaluate the possibilities of implementation of circular economy principles in the work processes of welding.

Target audience
VET teachers and trainers, welding specialists.

Learning materials

Topic 1. What is circular economy?
Circular economy can be defined as economic system which seeks to eliminate, or at least to reduce the waste of economic and productive processes by re-using, recycling different products, as well as extending their service life. Circular economy aims at several key planetary goals, starting from the protection of environment and sustaining wildlife (survival of which is challenged by the over-consumption) and ending with real rationalization of the usage of non-regenerative raw materials and thus preventing their soon depletion and eliminating damage to environment posed by their extraction.
For more information, please read the following factsheet developed by the Erasmus+ project "CEMIVET" here: http://cemivet.eu/circular-economy-factsheets/.

Topic 2. Why circular economy is important for metalworking and welding? What challenges/problems of this sector and area of activity it can help to solve?
Welding is one of the most important technological processes of the modern metalworking and engineering industry in terms of production volumes, application scale in the industries and many other factors. In the same time, welding and related technological processes “consume” a very significant part of depleting materials (e.g., metals) and produces highly significant volumes of rests, waste and polluting emissions. Therefore, implementation and following of the circular economy principles in welding work processes can help to solve several global problems: 1) preventing fast and soon depletion of the available raw materials and other resources (e.g., iron ore); 2) reducing high negative environmental impact of the production of metals and other raw materials and consumables for welding; 3) reducing negative environmental impact of the welding industries and processes to the environment and people. For more information, please read the following factsheet developed by the Erasmus+ project “CEMIVET” here: http://cemivet.eu/circular-economy-factsheets/.
Topic 3. How can we change /adjust execution of welding processes and operations in order to follow the principles of circular economy?
Following the principles of circular economy requires significant revision of the existing work processes of welding starting from the design of the welded products, planning and organization of the production process, supply and usage of welding technologies and materials, executing and quality assurance of all welding operations. Besides, it requires intensive and collaborative communication between the product designers, production engineers and welding operators.

There can be distinguished different problems or shortages of work organization which contribute to the increasing pollution, usage of materials and consumables, as well as increase of waste in the process of welding:

1) Communication problems - failures in defining clear goals and clear work plan of welding process - customer, designer and welder must have the joint responsibility to understand and implement the order correctly; lack of a transparent and constant cooperation between the technological department (welding engineers, technologists), experienced welders and welding operators; a shortage of sharing information between the marketing department, which is familiar with the customer's requirements and environmental preferences, and the welders department, which focuses primarily on the quality of the

product; the question of the scope and manner of such an exchange remains to be resolved.

2) Lack of concentration, lack of will, insufficient motivation of welders in performing of work problems typical for handling individualised production processes - handling differences of the working time needed to produce standard products and specially designed ones (classical chassis could require 8h, special construction -up to 3 weeks); in case of individualised production customers often request changes and adjustments, whereas introduction of new parameters in the welding process can lead to undesired effects, while learning to handle them may require volume of production and time.
3) Problems caused by the defects of materials, what requires control by procurement and QC departments.
4) Ensuring the quality of processes in the initial phase of robotization implementation; employment of welding operators (with a shortage of welders) to operate robots may lead - during the implementation period - to an increase in the consumption of materials and energy (higher shortage rate), nevertheless, the implementation of supervision and the control of the process which are led by experienced welders is the reason to increase the efficiency and quality of production.

Topic 4. What kind of skills, abilities and attitudes of welders and welding operators are needed for implementation of circular economy principles?

Erasmus+ project CEMIVET developed a competence profile which discloses the skills, abilities and attitudes needed for the welding specialists in implementing circular economy principles: http://cemivet.eu/circular-economy-competences/.

Erasmus+ project CEMIVET developed a factsheet containing recommendations on the content of vocational training curricula for welders containing competencies needed for the implementation of the circular economy principles in the work processes. Please read it here: http://cemivet.eu/circular-economy-factsheets/.

There are other Erasmus+ projects which have developed VET curricula and training materials in welding including the competences and learning outcomes related to sustainability of work processes.

The Erasmus+ project “Health, Safety and Environment Training curriculum development for joining technologies” provides several related outputs. Special attention should be paid to the competence matrix presented in the document “O1

Harmonised Curriculum for HSE implementation in Joining" (page 36) which includes competencies related to health, safety and environment protection:
https://erasmus-plus.ec.europa.eu/projects/search/details/2016-1-BE02-KA202-017322#!

Erasmus+ project "EU weld" developed comprehensive curriculum containing general welding aspects (materials used in fusion welding, materials weldability and heat treatment , quality assurance and qualifications in welding, specific norms of health and safety for welding processes), as well as basics of fusion welding processes (oxy-gas welding, manual metal arc welding processes – TIG welding, gas metal arc welding GMAW, submerged arc welding, laser welding, electron beam welding, plasma welding). http://www.camis.pub.ro/euweldlms/
The MAKE IT project redefines the "European Welding Practitioner" professional profile, providing information of the competencies pertinent to the different welding processes, including the competencies related to sustainable work performance. This project also developed a European sector-oriented qualification system into the LOs approach and established a European harmonized scheme for Recognition of Prior Learning (RPL) in the Welding sector, which can be useful tools for the design and implementation of the training modules related to application of circular economy principles in welding. The materials of this project can be found here: MAKE-IT (makeitproject.eu).

Erasmus+ project "WeldChance" developed manual for designing of the innovative VET curricula and organization of training processes in welding: Training-manual_VWTS_final.pdf (struka.hr)

Tasks for independent learning

Discuss the welding processes that you are working with or studying by answering the following questions:

1) What principles of circular economy are particularly relevant and important for these welding processes? Why?
2) What is necessary to do, in order to make this welding process "greener" (more friendly to environment) and more effective in terms of saving costs of materials, consumables and energy?

3) How do you personally contribute to working in more green and sustainable way at your workplace? What challenges and problems do you face in doing so?
4) Please look for and find any data about the negative environmental impact of your practiced/studied welding process/es. Please analyse the dynamics of your find indicators within any period of time and make conclusions.

Self-assessment of learning outcomes

Answer the following questions in written:

1) What is circular economy?
2) What principles of circular economy are important for welding? Why?
3) How the following of circular economy principles in welding can help to save the costs of companies?
4) What are the biggest negative impacts of welding to the environment?
5) What raw materials are being consumed and depleted by welding processes?
6) What are the key supporting factors and obstacles for implementing circular economy principles in welding processes?

COURSE 2. Savvy, circular and environmentally friendly usage of materials and consumables in welding.

Scope and learning outcomes of the course

The aim of this course is to introduce the instructions and suggestions of sustainable usage of materials and consumables in the welding practice.
After completing this course, the learners will be able to:

- Apply the principles of savvy usage of materials and consumables in the work processes of welding.
- Eliminate /optimise procedures and processes leading to the increase of the volume of rests and/or waste.

Target audience
VET teachers and trainers, VET students, welders (EQF level 4).

Learning materials

Topic 1. How does rests and waste result in the welding processes? What are the most important sources of rests and waste?

Welding processes produce different rests and waste, including gases, rests of welded metal materials, rests of welding consumables (wire and electrodes), rests of packing materials and others. Here we will discuss in more detailed way resulting and impact of some of these reseat and waste which have the most negative impact for the environment and people.

One of these wastes is welding gases and fumes. For example, Nakhla, Shen, Benthea in their article (2012) state, that highly popular in welding of steel MAG-welding produces one of the highest emission rates of welding fumes. MAG welding permits to adjust different sizes of arcs for the welded metals and thicknesses of sheets.

The usage of active gases is one of the key factors defining the MAD welding influence of the exposures of welders to hazardous substances as gases and fumes. The change of the chemical composition of inert gas carbon dioxide turning into carbon monoxide during MAGC welding, increases the impact of such dangerous and hazardous gases to welders and environment. Working with active gas processes also create a strong elaboration of welding fumes (mainly iron oxides), especially when applying MAGC-welding unalloyed and low alloy steel and created by the thermal decomposition of the carbon dioxide which is used as inert gas.

MAGM-welding of unalloyed or low alloy steel also produces CO formation when the mixed gas contains carbon dioxide. MAGM-welding when used in welding chrome-nickel steel produces fume based on nickel oxide. MAG-welding with cored wire electrodes produces larger quantities of welding fumes compared to welding with solid wire electrodes, as well as by increasing intensiveness of the arc as well as increasing wire feed speed.

Elaboration of the carbon monoxide also creates the risk of concentration of carbon monoxide in the working environment causing the danger for health and even life of people working in such environment. Other toxic substances, like manganese oxide, which is created when MAGM-welding of chrome-nickel steel with solid wire, in high concentrations irritates the respiratory tract and may damage the nervous system, in the same welding process originating nickel oxide can cause cancer when using chrome VI compounds for MAGM-welding of chrome-nickel steel with cored wire electrode. It necessitates to use effectively functioning extraction plants and filter systems to prevent getting these hazardous gases and fumes into ambient air.

Extensive use of shield gases also negatively impacts environment and creates additional expenses to enterprises, including the environmental implications and costs of large scale transportation of industrial gases used for welding. There are applied some practical steps to solve these problems, like using weld regulators which reduce the amount of used gas while maintaining the weld region saturation with lower gas flow. Besides, the transport of these gases has a significant environmental imprint. Cryogenic processes for liquefying CO2 and argon consume a lot of electricity and produces won emissions.
For more information:
Environmental Impacts of Using Welding Gas By Dr. Hany Nakhla, Dr. Ji Y. Shen, & Mr. Malcom Bethea 2012,
https://cdn.ymaws.com/www.atmae.org/resource/resmgr/Articles/Nakhla-Environmental-Impacts.pdf

Golbabaei, F., & Khadem, M. (2015). Air Pollution in Welding Processes — Assessment and Control Methods. In (Ed.), Current Air Quality Issues. IntechOpen. https://doi.org/10.5772/59793

Topic 2. What kind of rests and waste do we receive in the welding processes? What rests/waste can be reused and recycled?

The key emissions/ sources of pollution of the executed welding process to the workplace environment (pollution of air, water, soil, etc.) are the following:

Industrial gases, aerosols and dust generated during welding processes: argon gases when welding with TIG, NOx, CO,CO_2 PM2.5 and PM10 suspended dust, total dust with separated compounds MnO2, FexOy, CuO2, NiO2, cromium particles from welding of austenitic steel, nitric acid vapours from the chemical pickling of welds, Al_2O_3 in case of welding of aluminium.

UV radiation, dusts, noise, especially at plasma or gas cutting stations, welding fumes, metal active gas in case of MAG welding waste after cleaning of chemically treated wastewater from the pickling process (neutralised sludge with coagulated heavy metal particles and grinding remains) cutting with waterjet cutters also generates water pollution and large amounts of abrasive used.

There are also rests a d waste produced at the workplace which can be grouped in two groups:

- Non-hazardous waste: scrap metal, iron scrap, paper/cardboard of packing, wood, industrial waste type 1, metal residues, grinding residues, dusts, electrode rods and electrode welding rod caps, welding wire, tungsten welding needles, protective clothing, spare parts of the welding machines, grinding discs and other grinding tools,
- Hazardous waste: waste oil, packaging that has contained RP, rags or material soaked in RP, WEEE, used batteries, spare parts of the welding machines.

Some emissions are being produced during the preparatory stage, executing of welded joints, quality control and finishing of the surface:

- Waste from the preparation process or remnants of cutting openings (most often treated as segregated scrap, depending on the shape and dimensions, also used for secondary production, e.g. fences); noise, spark, splash, grinding dust, solvents.
- Dust and swarf from the grinding and cleaning process are collected by extractors and filters, and then transferred for disposal to external companies
- Welding phase emissions: smoke, light, waste, slag, projections; smoke is filtered with filters containing cleaning bags that are separated by compressed air, dust is disposed of; the extraction units are regularly checked by dealers and replaced if necessary.
- After-welding processing emissions: grinding and polishing material residues, emissions from the heat treatment furnace, sand and metal blasting residues, surface pickling and passivation materials, residues of painting lines.

Very often welding processes and operations also leave large amount of plastic, cardboard and wood waste in the form of various types of packaging, damaged pallets, oils and consumables (collected by external companies); cardboard used as a filling and protective material when packing own products.

Topic 3. How to manage the rests and waste resulting in the welding processes (separating, sorting, collecting, re-using)?

There can be applied different types of procedures of collecting and recycling of waste produced at the workplace:

- implemented waste management system in the enterprise, persons delegated responsibilities for the collecting and sorting of waste in production, having register for waste (national environmental registers for packing waste and chemical materials)
- waste is disposed of according to defined procedures, there are used services of specialized waste collecting companies assisting in the disposal of hazardous filter residues
- general waste management procedures, controlled internal notes with information on waste management, environmental guides
- applied general waste management procedures, controlled internal notes with information on waste management, environmental guides.
- procedures on the sequence of work operations: if cut out, then being deburred, bended, welded
- procedures for collecting of the different types of rest materials : steel CR17, magnetic steel, stainless steel; collection containers per different types of rests procedures of programming the CNC machine in economic regimes
- dust filtered via extraction and disposed of properly , grinding dust swept up at the site (mixing normal dirt) and disposed of professionally; this involves issue of calculating the amount of dust and metals emissions as well as matters related to environmental fees and the collection and disposal of waste, including scrap can be outsourced to specialist external companies
- usage of wood waste as biofuel.

The employees and trainees of the company acquire know-hoe on these and other procedures by training and competence development of in the field of waste collecting and recycling.

Rest management in welding work processes consists of several simple rules:

- Keeping the daily records of the all consumed welding materials, such as welding rod, solvents used in surface preparation.
- Keep closed and hermetic the containers with used volatile organic compounds (solvents) to avoid evaporation. Operators using such materials must always have them on sight at the workplace and monitor the usage.
- Rests of the welding must be sorted according to the requirements of disposal by using separate tuns of other containers for unusable weld rods, scrap metal, packaging materials.

- Sorting includes separation of the metal scrap which is recyclable (according to dimensions, quality etc.) from the scrap which is not recyclable. During the sorting the scrap of ferrous metals is separated from the non-ferrous metals by using magnet.
- Waste solvents and contaminated rests, such as rags and unusable tools soaked with waste solvent have to be disposed in a containers of hazardous waste.
- It is necessary to prevent the release of welding rests, including metal chips and scrap, waste solvents into environment, especially into soil and water.
- Following and, if necessary, updating the waste management system in the enterprise by accomplishing responsibilities for the collecting and sorting of waste in production, registering of the rests and waste in the special registers (national environmental registers for packing waste and chemical materials).
- Disposing of waste is executed by following clearly defined procedures, the disposal of the harzardous waste can be delegated to specialized waste collecting companies.
- Welders should follow clear and transparent procedures on the sequence of work operations in seeking to avoid non-conformities and increased volume of rests.
- Dust is filtered via extraction and disposed of properly , grinding dust sweeps up at the site (mixing normal dirt) and disposed of professionally.
- Wood rests used for packaging of welding materials and metals can be used as biofuel.

Topic 4. How to reduce the volume of rests and waste resulting from the welding processes?

There can be suggested wide range of methods applied to reduce the volume of emissions at the each stage of work process.

At the stage of the design of welded products and constructions: minimising the volume of joints, taking into consideration the volume of waste and it’s management options resulting from the design; positioning of the workpieces for cutting from the sheets; registering and ensuring traceability of the remaining sheet materials after cuttting for usage in the production of other parts and products; optimisation of the weld joint design

At the stage of the selecting of technological process of welding: selecting the most economic and environmently friendly welding processes for the each case by taking into consideration technological and product requirements (not compromising quality but avoiding excessive welding regimes, e.g. very often use of submerged arc welding for thick sheets helps to economise on the preparatory edge cutting of sheets and to reduce emissions from this process); excessive requirements to welding in the design stage often become the core source of increased polution and waste; very often these overshoots in the design and technological preparation of welding process occur because of the speedy / hasty execution of the design, lack of „patiency" and time for high quality calculations of the needed volume of materials.
To avoid the rests in the process of cutting of the sheet metal, the workpieces for cutting from the sheets have to be positioned with the intermediate gaps which include the cutting width and measuring tolerations. Remaining sheet metal materials has to be marked and registered to ensure their traceability and enable usage in the production of other parts and products. Larger amounts of waste and increased material consumption occur in the case of small series manufacturing, where the cut details do not occupy the entire surface of the sheet; free spaces then can be filled with parts for future orders. The arrangement of items on the sheet should also take into account the placement of smaller elements inside the holes punched in larger details. What can no longer be used in the production process is sometimes used for "by-product" production.
Suitable and optimal selecting of the welding regimes according to the technological requirements of the concrete case; optimal selection of the welding procedures and regimes according to the required types of joints, control of the selection of welding regimes and avoiding applying excessive regimes in terms of thermal impact; while executing welds keeping within the limits of thermal impact defined in the welding procedure
Executing proper quality control of the metal sheets, avoiding the practices of economising on the quality of the metals by using cheap and low quality materials (rusted, contaminated, low-quality), what requires additional preparations and involves additional emissions; choosing and using less „contaminating" welding consumables, like, for example, welding with solid welding wires produces much less emissions that when using „powder" based welding wire.
Applying savy procedures of the preparation of raw materials for welding and optimal welding regimes also permit to save on the surface treatment operations after welding (metal and sand blasting)

Strict quality control of the worksheets helps to prevent non-conformities before welding.
The usage of abrasive materials for surface treatment of welds can be reduced by using more cutters, grinding plates.
It is possible to minimise the volume of welding work by maintaining high quality of welding (avoiding repairs of welds); emission reduction is sought by improving the quality of welds, by selecting and fine-tuning the composition of shielding gases and welding wires.
It is recommended to optimise the volume and intensiveness of the welding processed by the edge preparation before the welding proces, to apply the X welds, as well as to minimise the zones of weld area.
There can be applied solutions that allow for the reduction of subsequent work expenditure on cleaning the connection. The shift to work with the use of welding robots and laser cutters (especially fiber type) helps to eliminate the human factor and non-conformities. Tghis can also
allow a greater use of the starting material and reduce waste through optimized nesting. The robots perform welds in a repeatable manner, which, with the right choice of means and parameters of the technological process, leads to the reduction of defects.

In case of MAG welding it is recommended usage of protective gas (mixed gas: argon [own silo] 92%+ Co2 & oxygen helps to avoid of spattering and gives better burn-in; focused arc (1000 degrees) avoids radiated heat on the workpiece; temperature rise 1-2 degrees at a distance of 30 cm from the body.

Experienced welders can favour „faster" welding in seeking to use fewer materials and save emissions (however, it entails the risks of mistakes and non-conformities what can increase the usage of materials, consumables and waste of welding process).

Wire welding allows the operator to use only the amount of material necessary for processing, without producing waste due to the use of metals exceeding the actual production needs.
Usage of CNC machines (plasma cutters, lasers) significantly limit the harmful impact of welding processes on the operation of other stations (machining in a closed machine space).

Usually welding quality assuranxe involves strict quality management procedures, approval of the WPS and preparation of the welding instructions, executing test pieces of welding, certification of applied welding processes and welders in the company with the approved international/national audit and certification bodies, standard DIN 15085 -2 (incl. 3834).

Welding can also be partially replaced with screwing and riveting.

What regards surface treatment of welds, the environmental impact of this process very meuch depends on the quality and cleanliness of the received welded joint. For example, the quality and environmental impact of pickling of welds highly depend on the quality of cleaning of surface after welding (remaining slags before pickling requires additional pickling operations with negative environmental implications). Surface treatment by painting requires optimal calaculation of the needed volume of paint and choosing optimal painting system (C2, C3, C4, C5) according to the corrosiveness of the environment of product usage, avoiding excessive painting.

Using metal blasting for treatment of welds is more environmentaly friendly compared to sand blasting because of repetitive use of abrasive materials.
Choosing the welder of the right profile and level of qualification for the foreseen welding processes is also important to attain sustainable and circular welding: here the production and human resource managers can use competence frameworks of welders aligned with the levels of complexity of welded constructions/objects.

There are also different practices/ methods applied to reduce the volume of main materials (e.g. metals) and consumables in the welding process. For example:

- Concentration of purchases of raw materials, integration of materials from engineering to make the most of raw materials.
- Applying lightweight design and modular construction of products also permit to save materials.
- Finite element design and product performance simulation technicques permit not to oversize the weld seams and the extent of the welds themselves. As a result, savings are generated on the amount of metal deposited, energy consumed, etc.

In case of sheet metal cutting before the ewleding larger amounts of rests and increased material consumption occur in the case of small series, where the cut details do not occupy the entire surface of the sheet. Free spaces then can be filled with elements for future orders. The arrangement of items on the sheet should also take into account the placement of smaller elements inside the holes punched in larger details. Here the right sorting of the remaining rests of sheet metal and welding consumables according to the type of materials is very important.

What can no longer be used in the production process sometimes can be used for "by-product" production.
Permanent security measures are also relevant here, e.g. seals on gas regulators installed after setting the process conditions and various levels of access to the machine process settings.
In the field of weld treatement there can be considered options to apply the used materials and consumables repetitively. For example, the filtered wastewater of the pickling units and baths can be reused for the same purpose.

The processing of surface of the welded joint involves different operations, such as cleaning of the all residues and contamination occurring from the welding flux, grinding and polishing of the surfaces of welded joints.
Regarding the grinding of welds it is important to evaluate the surfaces of the welds themselves before this operation to verify if it complies with the set standard quality requirements. If so, the grinding is not needed. Rough profiles, badly formed start-stops, sharp undercut, adherent weld spatter should be removed by careful grinding or blasting.
For more information: Surface preparation - SteelConstruction.info

Other strategy to reduce the emissions and wastes from the welding process is usage of eco-friendly welding equipment. This is a focus of the EU regulation on the eco-friendly performance of welding machines taken into effect from 1st January 2021**.**
New regulations from the EU addresses the ecodesign requirements of welding equipment which includes the environmental aspects of welding equipment (such as energy consumption when the product is being used) and ensuring a level of efficiency with your resources. By 2030, it is estimated that the ecodesign requirements in this Regulation will result in annual energy savings of 1,09 TWh, corresponding to total annual savings of about 0,27 Mt CO_2 equivalent – better for the environment and cost-efficient.
To comply with *energy efficiency requirements*, the welding equipment must be in-line with the power source efficiency and idle state power consumption:
Welding equipment powered by three-phase power sources with direct current (DC) output. Minimum power source efficiency must be at *85%*, and maximum idle state power consumption must be at *50W*.
Welding equipment powered by single-phase power sources with direct current (DC) output. Minimum power source efficiency must be at *80%* and maximum idle state power consumption must be at *50W***.**

Welding equipment powered by single-phase and three-phase power sources with alternating current (AC) output. Minimum power source efficiency must be at *80%* and maximum idle state power consumption must be at *50W*.
Providers of welding equipment are expected to adhere to the updated *resource efficiency requirements, updated resource efficiency and information requirements to ensure that provided welding equipment is more eco-friendly.*

The energy consumption of the product and any of the other declared parameters shall not deteriorate after a software or firmware update when measured with the same test standard originally used for the declaration of conformity, except with explicit consent of the end-user prior to the update. No performance change shall occur as result of rejecting the update. A software update shall never have the effect of changing the product's performance in a way that makes it non-compliant with the ecodesign requirements applicable for the declaration of conformity. For more information on the Directive: **https://eur-lex.europa.eu/eli/reg/2019/1784/oj**

In the field of vocational training one of the key technological innovations permitting to reduce the volume of rests is usage of welding simulators.

There is experience of usage of these simulation technologies in many countries. For example, in Poland, the students at Krakow University of Technology acquire the basic skills and know-how of welding by working on "VRTEX 360" welding simulator.

The welding simulator uses virtual reality technology that replicates real welding conditions. Just by putting on VR goggles, you can see a realistic view of the welding pool and hear the sounds of real welding. "VRTEX 360" is also equipped with a full-size visor and welding fixtures. The simulator helps to teach the basics of the arc welding process and enables users to acquire so-called muscle memory, i.e. to practice the correct hand movements to, among other things, maintain the correct torch angle and direction. The device gives users the opportunity to learn about extended welding processes, several process techniques using many types of welded materials - primary and secondary. Students learn about different types of joints and welding equipment settings, etc. And all this at a low cost, because without the actual consumption of materials and with reduced energy consumption.

A very useful feature of the simulator is also the possibility to take advantage of several training modes: presentation of the settings of the "real" machine, workstation instructions, lesson mode, the so-called demo welding (demonstration of a perfectly executed joint), prompting mode during virtual welding, virtual bending test (allows immediate assessment of the correctness of the execution of the welded joint) or replay mode. The latter functionality permits the student and his/her tutor to follow the virtual welding process from the beginning, check where they made mistakes and easily correct them.

https://www.youtube.com/watch?v=iBwKd6fIRH0&t=4s

Usage of augmented reality applications for training of welders also helps to save the environment and costs:

https://www.youtube.com/watch?v=npdmFfG6ydA

https://www.youtube.com/watch?v=6e2pEXL4IXY

The case of usage of AR application for training of welding apprentices at Volkswagen:

https://www.youtube.com/watch?v=Ypb77z2nk9g

Erasmus+ DIGIWELD project provides digital tools for VET students, apprentices in welding and for welders who want to keep abreast of the new skills and competences required for new welding technologies. The project offers an open and innovative digital learning system (SIMTRANET) and education materials in welding technology, providing a flexible learning tool for those looking to improve their existing skills. It entails curricula for training welders using simulators and updating EU Guidelines for the European/International Welder IAB – 089r5 – 14 and digital tool to be inserted in simulators as modules dedicated to the training of apprentices (16-20 years old). Learning materials and curricula for training with digital welding simulators can be accessed here: http://www.digiweld.eu/
The project "Digital training for European Welding Inspectors" (D-EWI) offers an innovative digital training course for the welding inspectors with open digital educational materials to support implementation of innovative digital technologies for teaching and learning in initial and continuing VET in the field of welds inspections: https://d-ewiproject.eu/docs/D-EWI%20PR.pdf

Tasks for independent learning

Test/apply some of the above-described ways and methods of savvy and sustainable usage of welding materials and consumables in your work practice. Report on the following questions:

1. To what extent the applied way/method works in the concrete welding process? What are the resulting savings of materials and consumables?
2. What are the shortages/challenges in applying this way/method of savvy and sustainable welding? Any suggestions on how to deal with these challenges?

Self-assessment of learning outcomes

Analyse your performed welding operations and answer the following questions:

1. Do I apply any methods of savvy and sustainable usage of welding materials and consumables? If so, in which welding processes these methods are applied?
2. What quantities of welding materials and consumables usually I save in my work? Is this a limit or it is possible to further reduce the consumption?
3. What new methods and ways I could apply to further reduce consumption of welding materials and consumables in my work?

COURSE 3. Savvy and circular preparation of materials and workpieces for welding.

Scope and learning outcomes of the course

The aim of this course is to acquire know-how and skills of savvy and environmentally friendly preparation of metal workpieces for welding.

After completing this course, the learners will be able to:

- Select environmentally friendly ways and materials of edge cutting and sheet surface preparation.
- Choose preparatory operations of surface and edges of the workpieces and sheets to reduce the volume and intensiveness of welding process.
- Apply the know-how on how to prepare the surfaces and edges of worksheets in order to ji minimize the zones of weld area.

Target audience

VET teachers and trainers, VET students, welders (EQF level 4).

Learning materials

Topic 1. Environmentally friendly ways and materials of edge cutting and sheet surface preparation. Preparatory operations of surface and edges of the workpieces and sheets to reduce the volume and intensiveness of welding process.

1. Material control is necessary before the production, when sheets applied in the production are checked for surfaces on delivery; production preparation involves comparison of individual orders with each other to ensure material utilisation; dimensional accuracy has to be checked with VQC machine and checked on the first piece.
2. Edge preparation is defined by the following parameters: 1) type of welding process, 2) position of welding, 3) access for arc and electrode, 4) volume of deposited weld metal which should be kept to a minimum, 5) cost of preparing edges, 6) shrinkage and distortion. For more information: http://fgg-web.fgg.uni-lj.si/~/pmoze/esdep/master/wg03/l0300.htm.
3. Ins some welding technologies, like narrow gap welding, edge preparation can also be done by flame cutting, what increases the productivity and partially reduces in incurred waste: https://www.cloos.de/public/processes/brochures/EN_Engspaltschweissen.pdf

Topic 2. Preparation of the surfaces and edges of worksheets in order to ji minimize the zones of weld area.

Inadequate and insufficient preparation of the metal surfaces before welding very often leads to the non-conformites and non-economic usage of materials, creates additional waste.

1. Cleaning of the material surface before the welding is very important in order to remove the dirt and grime by preventing contamination of the purity of a weld. This action can help to avoid the porosity of welds, because the grease, oil or moisture on the surface causes the trapping of welding gas during the welding process.

2. Some contamination of welded surface occurs during the welding surface – oxidation occurs when oxygen reaches unhindered the weld seam. Oxidation of surface makes the metal non resistant to corrosion and requires additional treatment. To prevent it there are used oxygen monitors during purging of welds.

For more information: **https://www.aquasolwelding.com/welding-preparation**

3. Burrs caused by lasers and punches van be removed with different surface grinding machines, grinding plates and rollers with the conveyor belt; bending of parts. To reduce the volume of such grinding it is reccomended to apply cold forming approach and/or specific welding technologies, which permit to avoid burrs, such as faster welding.

Topic 3. Usage of more environmentally friendly produced steel in the work processes related to joining and welding.

The issue of greener steel production technologies and more environmentally friendly steel is rather widely discussed between researchers, experts and industrialists. Here is a link to an interesting article on this topic: https://weldingvalue.com/2021/06/how-ready-are-we-for-green-steel/?ref=rns_cp

Tasks for independent learning

Select 1 -2 materials preparation procedures which you never applied before in your work and try them in the presence of supervisor, technician or engineer. Report on the results of testing by indicating whether it has been successful, what is the impact for consumption or materials and consumables, what problems or challenges were encountered in applying the chosen recommendation and how these problems can be solved (to be done later).

Self-assessment of learning outcomes

Examine and discuss your applied processes and procedures of the surface and edge preparation in terms of their fit to the principles of sustainable and 'circular' performance by answering the following questions:

1) To what extent the applied surface preparation and edge cutting operations help to reduce the volume of welding and related energy demands?
2) What kind of waste is generated by the surface preparation and edge cutting operations? What are the average quantities of these wastes?

3) Is it possible to skip/circumvent the surface preparation and edge cutting operations by altering the welding parameters? What are the advantages/disadvantages of such solution?

COURSE 4. Savvy and circular welding/joining operations.

Scope and learning outcomes of the course

The aim of this course is to acquire know-how and skills of applying savvy and circular technological solutions of welding regimes.

After completing this course, the learners will be able to:

- Recognize the features of savvy and circular technological solutions and welding regimes.
- Know how to keep within the limits of the thermal impact defined in the welding procedure.
- Apply know-how on savvy regimes in welding (pulse regime, synergetic regimes, submerged-arc welding and it's combinations, using contact welding instead of full joint welding).
- Know-how to apply CNC processes (plasma cutters, lasers) in seeking to limit the harmful impact of welding processes on the operation in the other stages (e.g., machining in the closed machine space).

Target audience

VET teachers and trainers, VET students, welders (EQF level 4).

Learning materials

Topic 1. The features of savvy and circular technological solutions and welding regimes.

Sustainability of welding depends on the welding speed, welding system costs, quality of raw materials, applied processing time, used filler metals and seam quality. Production of the components and consumables of w welding system also plays important role because it required extraction of raw materials.

What regards the role of applied welding technologies and equipment, the reliability and versatility of welding systems contribute to the efficiency of the welding processes by permitting operators to use suitable technology to increase the welding speed, while consistently maintaining high quality and maintaining the ideal conditions, thus enabling to dispense with entire production cells and helping to reduce the use of energy and production resources.

Technological solutions in the different welding processes can help to prevent the accumulation of rests and to improve intensiveness and efficiency of work. For example, usage of processes involving endless electrode (MAG) helps to avoid the rests of welded electrodes and pauses for changing electrodes. For these and other features MAG process is highly sustainable and clean, as well as laser gas metal arc welding. These welding processes are very speedy and require less filler material.

Parameters of welding process which help to reduce the harmful emissions:

1. **Amperage**: starting welding from the lowest possible amperage which permits enough weld penetration.
2. **Gas usage**: do not use 100% CO_2 gas over an argon gas blend, as it increases the heat in the arc and more metal vaporization and fumes.
3. **Cleanliness of metal surface before welding**: properly clean the metal surface before welding to avoid the fumes, especially remove the residues from solvents, paint, oil, rust inhibitors, zinc on galvanized steel. Use a stripping product to remove the contaminants and any residue that remains before initiating the weld.
4. **Welding equipment**: in choosing the welding equipment a company should pay attention to the environmental impact of related welding process and how the equipment helps to reduce it.

Here are some tips for economically savvy welding processes:

1. Eliminate overwelding by controlling the proper sizing of welds and using prints.
2. Reduce the amount of reinforcement in the multiple pass welds on a groove joint by targeting just above flush to prevent underfill.
3. Use proper polarity – in applications were penetration is not important or desired, such as hardfacing, use DC- to achieve greater deposition rates.
4. Reduce gaps, which increase the volume of weld needed in order to achieve the same load carrying capacity.

5. Control Shielding Gas Usage by using no more flow than necessary, as well as checking for surges and leaks.
6. Increase electrode diameter for stick welding or mig welding to achieve higher deposition rates.
7. Consider intermittent instead of continuous fillet for the welds which do not transmit the full load of the structure after consultations with engineering staff.
8. Select the right process depending on the application.
9. Properly position the work for optimal efficiency by maximizing the welding in the flat or horizontal position.
10. Use fixtures.
11. Use procedures and processes that eliminate spatter – Consider using 90/10 gas instead of C25 or 100% CO2, as well as pulse welding instead of CV welding.
12. Keep your welding equipment in good repair.
For more information: 12 Ideas to Reduce Welding Costs | WELDING ANSWERS
Apply welding regimes, which do not require mechanical preparation of surfaces before welding, for example, special arc EWM for welding of steel does not require preparation of materials for welding.
For more information: Using Eco-Friendly Welding Processes to Minimize Pollution (blueandgreentomorrow.com)

13. The quality and environmental impact of pickling of welds highly depend on the quality of cleaning of surface after welding (remaining slags before pickling requires additional pickling operations with negative environmental implications). Therefore it is necessary to clean the surface of welded prieces before the pickling.

14. Surface treatment by painting requires optimal calculation of the needed volume of paint and choosing optimal painting system (C2, C3, C4, C5) according to the corrosiveness of the environment of product usage, avoiding excessive painting.

15. Using of metal blasting for the surface treatment is more environmentaly friendly compared to sand blasting because of repetitive use of abrasive materials.
16. Usage of the X welds helps to minimise the zones of weld area and to reduce the volume of subsequent surface treatment of welds.
17. Using of cutters and grinding plates for the surface treatment and finishing of welds helps to reduce the usage of abrasive materials.
18. The consumption of welding gases can be significantly reduced by using special protective valves on the gas container: https://www.youtube.com/watch?v=TikJL1VSp3Q

Opening of these valves helps to adjust the gas quantity. A practical rule of thumb for this: ***Gas quantity (liters/minute) = wire diameter (millimeters) x 10.*** For example, if a wire electrode with a diameter of one millimeter is used, ten liters per minute are sufficient in a closed workshop. If there is a draft, a little more gas is needed.
https://blog.perfectwelding.fronius.com/en/welder-settings/
19. Usage of tools helping to define the optimal welding parameters:
https://weldingvalue.com/2020/03/find-right-tig-welding-parameters/#27e461fb

Topic 2. Typical savvy welding regimes (pulse regime, synergetic regimes, submerged-arc welding and it's combinations, using contact welding instead of full joint welding).

Submerged Arc Welding (SAW)

Researchers from Germany suggest that in welding a 20 mm thick plate of structural steels, LAHW is the best option regarding the environmental impact caused, because of it's high-power density permitting to proceed welding with the least number of passes and overall weld volume, as well as allowing for high welding speed, high productivity and lower electricity and gas consumptions. According to these authors, the less environmental impact in LAHW is ensured by the better ratio between power consumed and welding time, when the low efficiency is overcompensated by welding time savings. The filler material and electric energy can be optimized by means of enlargement of the root face width and a smaller opening angle. Electric energy consumption could be reduced significantly by increasing the beam source efficiency. They also identified that MMAW process due to low performance, necessary edge preparation and electrode coting lead to the highest environmental effects. This effect can be minimized by applying smaller root gaps and opening angles.
Reducing opening angles leads to approximately 40 % reduction of the environmental impact level.

Sproesser et al also suggest that welding robot movements for all technologies require lower electricity consumption. The preference of LCA technology due to positive environmental effects should be evaluated in the light of different welding process requirements, such as edge preparation, different welding positions and mobility of equipment.

Welders working with manual welding processes face higher health risks than in automatic processes, what suggests the minimization the application of manual welding processes and keeping welders out of process zone in automatic welding processes. Assessment of the risks of welding for health should not be limited to the impact of welding fumes, but also include other factors, such as electrical, thermal and radiation hazards occurring at the workplace.

Use of submerged arc welding for thick sheets helps to economise on the preparatory edge cutting of sheets and to reduce emissions from this process.
For more information: Sproesser, G., Chang, YJ., Pittner, A., Finkbeiner, M., Rethmeier, M. (2017). Sustainable Technologies for Thick Metal Plate Welding. In: Stark, R., Seliger, G., Bonvoisin, J. (eds) Sustainable Manufacturing. Sustainable Production, Life Cycle Engineering and Management. Springer, Cham. https://doi.org/10.1007/978-3-319-48514-0_5
Nimker and Wattal (2020) investigated the utilization of Submerged Arc Welding (SAW) slag as a fresh flux for sustainability. In testing it they added certain alloying elements to the crushed slag to adjust the resultant composition of the weld metal as per American Welding Society (AWS) A5.17 and operational characteristics such as arc stability. By selecting controllable variables such as welding speed, arc voltage, welding wire feed rate and nozzle to plate distance as process parameters they compared the weldments produced with fresh flux, pure slag and recycled slag. Analysis of mechanical strength, microstructure, and weld defects shows significant improvement in the weld specimens produced with recycled slag, while tensile and impact tests disclosed that the weldments made with recycled slag were able to fulfil the AWS requirements.
For more information: Deepanjali Nimker & Reeta Wattal (2020) Recycling of submerged arc welding slag for sustainability, Production & Manufacturing Research, 8:1, 182-195, DOI: 10.1080/21693277.2020.1774813
In case of MAG welding usage of protective gas (mixed gas: argon [own silo] 92%+ Co2 & oxygen helps to avoid of spattering and gives better burn-in; focused arc (1000 degrees) avoids radiated heat on the workpiece; temperature rise 1-2 degrees at a distance of 30 cm from the body.
Faster welding also helps to save welding materials materials and reduces emissions, However, it entails the risks of mistakes and non-conformities what can increase the usage of materials, consumables and waste of welding process.
Pulse regime in welding helps to control the thermal input and to regulate the volume of energy, using of synergetic regimes of welding which help to control and optimise the energy consumption.
Usage of submerged-arc welding or combination of welding regimes with submerged arc welding for the welding of high thickness metal sheets (e.g. in welding 100 mm sheets the root of weld is welded by semi-automatic welding, the remaining weld- with the tractor of submerged arc welding by using the wire of 4 mm diameter), what permits to reduce the number of welding passes.

Wider usage of contact welding (point welding) instead of full joint welding also helps to economize welding consumables and to save time.

Other sustainable welding processes are friction welding, vacuum soldering and diffusive welding. Friction welding by using thermal energy of friction eliminates the need of flux and auxiliary materials, vacuum soldering uses for welding hydrogen, diffusive welding combines both pressure and heat to produce high-quality joints by also removing the need for flux.

Organization of welding work can also significantly improve sustainability of welding processes. Different approaches of lean work organization can be applied here. Manzanares-Cañizares et al. (2015) analyse application of 5S lean methodology in the work organization in welding. The 5S methodology aims to improve and maintain the organisation, order, and cleanliness of the workplace. The aim is to improve working conditions by increasing safety through the elimination or mitigation of risks. In our case, the methodology has a dual purpose: improving working conditions by reducing risk for the people involved in manufacturing the products, while at the same time reducing the risk of defective welding seams. The methodology is based on the holistic analysis and control of the welding processes in production by following 5 phases of the lean work organisation: SEIRI—SORT: identify and separate necessary and unnecessary materials, discarding the latter;
SEIT ON—SET IN ORDER: establish how the necessary materials should be located and identified so that they can be easily and quickly found, used, and replenished;
SEISO-SHINE: identify and eliminate the sources of dirt, ensuring cleanliness of equipment and workplace
SEIKETSUS-STANDARDISE: distinguishing normal from abnormal production situations by using simple rules
SHITSUKES-SUSTAIN: working with the rules and principles established in the previous phases.
The study of Manzanares-Cañizares et al (2022) indicates, that usage of this methodology in organising the work processes of welding can significantly improve sustainability of welding processes by reducing the unnecessary transport operations inside the company, improvement of the storage of materials, preventing of contamination of metals sheets and welding consumables, preventing cross-contamination in usage of different materials, reducing non-conformities in welding and improving ergonomic conditions of work. For more information:

Manzanares-Cañizares, C.; Sánchez-Lite, A.; Rosales-Prieto, V.F.; Fuentes-Bargues, J.L.; González-Gaya, C. A 5S Lean Strategy for a Sustainable Welding Process. Sustainability 2022, 14, 6499. https://doi.org/10.3390/su14116499.

Tasks for independent learning

Select 1 -2 described savvy welding procedures which you never applied before in your work and try them in the presence of supervisor, technician or engineer. Report on the results of testing by indicating whether it has been successful, what is the impact for consumption or materials and consumables, what problems or challenges were encountered in applying the chosen recommendation and how these problems can be solved (to be done later).

Self-assessment of learning outcomes

Which economically savvy welding procedures and hints are the most relevant and suitable for your practiced welding processes? Why?
What savings can be gained by applying your preferred used savvy welding practices?
How these gains could be maintained and increased?

COURSE 5. Control of usage of welding materials and consumables for savvy and circular welding.

Scope and learning outcomes of the course

The aim of this course is to acquire know-how and skills on control and distribution of materials and welding consumables according to the principles of circular economy.

After completing this course, the learners will be able to:

- timely recognize and signal the cases of excessive consumption of materials and consumables of welding,
- organize proper quality control of the metal sheets, avoiding the practices of economizing on the quality of the metals by using cheap and low-quality materials (e.g., rusted, contaminated),

- with the approval/supervision of welding engineers to select and use less „contaminating” welding consumables, like, for example, solid welding wires which produce much less emissions that when using „powder” based welding wire.

Target audience
VET teachers and trainers, welding supervisors and technicians (EQF level 5).

Learning materials

Topic 1. Timely recognizing and signaling the cases of excessive consumption of materials and consumables of welding.

In the Article “**How To Reduce Energy Consumption When Welding” (A**pril 26, 2022) authors analyze the possibilities to save energy costs of welding in the face of significant impact of welding to the excessive energy consumption having detrimental impact for the global warming.
They suggest four tips to reduce energy consumption when welding:

1. Examining the power efficiency of welding equipment, calculating total operating costs of the equipment’s power consumption when welding and when idle in order to decide about replacement the current welding equipment with the latest welding appliances with increased energy efficiency, sustainable shielding gases and other improvements.
2. Addressing idle power consumption by using in-built cooling systems that cut-off power consumption when idling, what permits to obtain more than 80% idling efficiency, applying standby mode in older welding equipment, or turning off the power supply when welding equipment is idle.
3. Using Inverter Technology, which allows to produce more output power using much lower input power, when the input power is converted to a direct current, substantially reducing input power and increasing the overall energy efficiency.
4. Using power monitoring tools, helping to track the power consumption during the welding process, especially by applying software and internet-based applications in this field, which provide the key data, including voltage, the welding arc, heat information, etc., what helps to make relevant decisions about energy saving. . Most of these tools also have a user-friendly interface with simple digital controls that allow easy access to the available statistics.

For more information: https://usgreentechnology.com/how-to-reduce-energy-consumption-when-welding-2/

Welding materials could be controlled in a sustainable way by following below provided recommendations:

1. The planning document for use of welding materials should be prepared by welding engineers or other responsible staff members and this document should serve as a abasis for the issuing of welding materials for the defined period of time (week, 2 weeks, etc.).
2. Moisture content of welding electrodes should be checked before issuing and if needed electrodes should be redried.
3. Foremen prepare the special form or document for releasing welding material for each welder, which should foresee the separation of the different types of electrodes (e.g., low alloy/low hydrogen electrodes).
4. The electrodes of different types and characteristics should be kept at the workplaces in the different boxes to avoid misuse.
5. Unused and damaged electrodes should be collected in the special boxes or containers for re-usage or re-cycling.
6. Welding consumables should be properly stored at up to 70 per cent relative humidity, with protection from the weather or other adverse conditions. The storage facilities should be installed to keep the constant temperature at the variations of the temperature outside (heating, conditioning).

For more information:
https://www.canadianmetalworking.com/canadianfabricatingandwelding/product/welding/managing-welding-consumables

Topic 2. Selecting and using less „contaminating” welding consumables, like, for example, solid welding wires which produce much less emissions that when using „powder” based welding wire.
Currently there exist different options and technological solutions on how to reduce the negative environmental impact of the welding consumables, especially on how to

deal with the contamination of welding workplaces and environment with the fume from usage of welding electrodes.

For example, welding fume can be reduced by applying nano-coating of conventional welding electrodes with aluminium (Sivapirakasam, 2015). A core welding wire before it's flux coating is dipped in a sol containing aluminium iso-propoxide, to obtain a thin film of nano alumina coating. Such nano-coated electrodes reduce the concentration of fumes up to 62% in the welder's breathing zone, when tested vis-à-vis the concentration from uncoated counterpart. A substantial reduction in the concentration of metallic constituents in the fumes of coated electrodes was noted too. https://www.sciencedirect.com/science/article/abs/pii/S0959652615008653

Similarly there can be applied electrodes covered with cupper, which also reduce the production of fume at the workplaces: https://www.welding-alloys.com/news/sustainability-starts-at-the-cored-wire/

Tasks for independent learning

Describe and discuss your currently applied procedures and practices of control of usage of welding materials and consumables. To what extent and how these procedures and practices help to save materials and consumables of welding?

Self-assessment of learning outcomes

How do you control the consumption and materials and consumables in welding? How do you inform the welders about the risks of over-consumption and instruct them on how to deal with these risks?

Do you tend to select and use less „contaminating" welding consumables, like, for example, solid welding wires which produce much less emissions that when using „powder" based welding wire? What are the factors which support such decision? What factors do not permit to use less "contaminating" welding consumables?