Hochschule Esslingen

Mechanical and Systems Engineering Faculty

Master Thesis

Digitalized Welding Training Powered by Augmented Reality against Traditional Training Method

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Certification of authenticity

I hereby declare that I have written the attached work alone and without any other reference works than those mentioned. All thoughts or quotations taken directly or indirectly from other sources have been noted as such. Furthermore, I have not used this work, parts of this work or basic ideas from this work to achieve credits in any academic course at any time.

Esslingen am Neckar, 22.03.2022

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Vladislav Kadochnikov

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Abbreviations and formula symbols

%	Percentages
€	Euro
AG	Joint Stock Company
AR	Augmented Reality
Butt weld	Butt joint
CAD	Computer-aided design
CO_2	Carbon dioxide
$CO_{2\ electricity}$	Carbon dioxide emitted into the atmosphere from electricity production
$CO_{2\ metal}$	Carbon dioxide emitted into the atmosphere from metal production
Fig.	Figure
g	Gram
G_{EWM}	Consumption of Gas by EWM welding machine
G_{fin}	Final consumption of Gas
G_{Lorch}	Consumption of Gas by Lorch welding machine
GmbH	Limited Liability Company
G_{Rehm}	Consumption of Gas by Rehm welding machine
Group 1	Group of participants who used Augmented Reality simulator SOLDAMATIC during research
Group 2	Group of participants who used traditional way of welding training during research
h	hour
HE	Hochschule Esslingen
I	Amperage
kg	Kilogram
kWh	Kilowatt hour
L	Liter
L/h	Liter per hour
L/min	Liter per minute
m	mass or meter (context)
m/h	meter per hour

m/min	meter per minute
MAG	Metal Active Gas
MIG	Metal Inert Gas
MMA	Manual Metal Arc
m_{total}	Final amount of spent metal by Group of participants
Overlap	Overlap weld
PA	Flat position for butt and fillet welds
Part.	Amount of participants
PB	Horizontal vertical position
PC	Horizontal position
PD	Horizontal overhead position
PE	Overhead position
PF	Vertical up position
P_{fin}	Final consumption of electricity
$P_{Soldamatic}$	Consumption of electricity by SOLDAMATIC
P_{welder}	Final consumption of actual welding machine
t	Time
TIG	Tungsten Inert Gas
T-joint	Tee joint welding
tot.	Total
V	Voltage
W_{EWM}	Consumption of wire by EWM welding machine
W_{fin}	Final consumption of wire
W_{Lorch}	Consumption of wire by Lorch welding machine
WPS	Welding Procedure Specification
W_{Rehm}	Consumption of wire by Rehm welding machine
ρ	Density

Abstract

The topic of this research paper is welding training with the help of augmented reality technology.

The aim of the investigation is to find out the best way to train welding skills, namely by using the SOLDAMATIC augmented reality simulator or the traditional method of training.

The research was conducted by experiment. Two groups of participants at Hochschule Esslingen and at AUDI were trained under equal conditions in different ways. The first way was training with the SOLDAMATIC augmented reality simulator and the digital E-Learning platform (60% of the training time) followed by training in a workshop on the welding equipment (40% of the training time). The second way was training only in a workshop on welding equipment and the use of paper media (100% of the training time).

As a result of the investigation, it was proven that the modern method of welding training using the SOLDAMATIC augmented reality simulator is a good training method with good results and much lower resource costs, and it is the leader which provides sustainable and climate friendly welding training method.

The results will be used to improve AR technology applied to education and more specifically to skills development, and the SOLDAMATIC welding training simulator.

Key words: SOLDAMATIC, E-Learning, digital welding training, AR welding training, welding technologies, learning of welding, MAG welding.

Preface

This research was done for Seabery, which is a manufacturer of SOLDAMATIC augmented reality simulators for welding training. The company already had a similar study about 6 years ago, but during this time there have been many changes both in technology and in the products that the company produces, namely SOLDAMATIC and E-Learning platform. So, in order to gain better understanding about their achievements and to improve upon further, Seabery has decided to repeat the study. This work took place in the laboratories of Hochschule Esslingen where SOLDAMATIC Augmented Reality welding simulator was used already about 1 year for welding training, as well as at Audi AG who purchased SOLDAMATIC Augmented Reality welding simulators just before the experiment began. and lasts for 5,5 months.

This thesis is developed with the objective to analyze the results and benefits of the application of new technologies such as Augmented Reality for welding training versus traditional training. The purpose of this work is to conduct an experiment and conclude which way of teaching welding technologies is more efficient and productive: training with modern augmented reality technology or traditional training on a real welding machine. It is important to note that Augmented Reality does not seek to replace real welding practices, but rather to improve the educational process of welders to meet higher quality standards.

I express my deep appreciation to my supervisor Prof. Dr.-Ing. Martin Greitmann for his help and assistance during the preparation of my thesis. Thank you very much for the time and effort you put into my Master Thesis!

Also, I would like to express my special thanks to my thesis advisors Maria Calvo Garrido and Alvaro Linzoain Pontigas from Seabery who gave me opportunity to perform this research!

I would also like to express my thanks to Anke Richter and Lukas Kraemer from WeldPlus who gave invaluable inputs for my paper and helped me to get a deeper insight into SOLDAMATIC during the training, which was a great experience for me!

Furthermore, I would like to thank Audi employee Juergen Heidinger, without whom this study would not have been as interesting. Thank you very much for giving the Audi lab the opportunity to conduct the research.

Finally, I must express my sincere gratitude to my parents and my wife for their support and attention throughout my studies and my Master Thesis. Without these people it would not have been possible. Thank you very much!

1. Introduction

In the 21st century technology does not stand still and every year it develops more and more in all spheres of our life. With the advent of the Industrial Revolution 4.0, the transformation of ordinary things using advanced and innovative technologies such as automation, machine learning and smart digital technology has become possible. New technologies allow us to treat nature more carefully, save resources and at the same time improve the quality of life. Also, in the sphere of metal welding such technology as augmented reality has entered widely into this sphere and helps millions of people to get knowledge under more careful control of the simulator and most importantly using the minimum of resources such as electricity, metal, gas and wire. Moreover, there is another factor that makes this technology more noble, and that is the reduction to zero of harmful gases in the atmosphere during the training process. People using augmented reality simulators learn welding skills by literally sitting in front of a computer, which increases their safety in the learning process and in conventional classrooms. These aspects make welding training more effective.

This Master Thesis compares two ways of learning welding skills: 1) Using augmented reality technology, namely the SOLDAMATIC Augmented Reality welding simulator and real practice 2) Using real welding machines during the whole training course.

Once the research is completed, the advantages and disadvantages of the two training models will be discussed and the conclusions will be reviewed. The main point to be analyzed on this study is: *Is augmented reality technology the best choice for welding training?* In the progress of the work, this question will be gradually revealed as experimental data become available, and it will be possible to answer this question based on the values of the numbers. For a more structured understanding of this work, below is a table (Tab.1) with the research plan.

Month	1st part of month	2nd part of month
October	-	Studying of SOLDAMATIC and Literature Checking
November	Welding Practice and Experiment Preparation	Experiment in Hochschule Esslingen Group 1
December	Experiment in Hochschule Esslingen Group 1	Experiment in Hochschule Esslingen Group 1
January	Experiment in Hochschule Esslingen Group 2	Experiment in Hochschule Esslingen Group 2
February	Experiment in Hochschule Esslingen Group 2 and Research in Audi	Metallographic examination of weld seams
March	Analysis	Conclusions

Table 1: Master Thesis Timetable

Source: self-developed

2. Theory

2.1 Welding status quo

In any industry, welding processes are among the most important processes in production and must therefore be carried out to the highest standards and by highly qualified professionals. Moreover, the focus on energy efficiency and sustainability as well as the increasing quality requirements are fundamental for the industry at a time when raw material prices are rising. Welding process in the 21st century is an integral part of many industries such as transport, automotive, shipbuilding, etc. At the moment there are quite a few different types of welding, both new and proven for ten years, but progress does not stand still and every year there are new and improved technologies in this area.

To this day, there are 12 basic types of welding (based on: The Crucible n.d.; TWI n.d.; William Andrew 2008)

1. MIG welding
   Metal inert gas welding (MIG) is a type of arc welding that requires a solid wire electrode. The electrode is pushed into the gun from the welder and heated, after which welding takes place (Fig.1).

Figure 1: MIG welding
Source: https://rime.de/en/welding/mig-welding/

2. MAG welding

This type of welding is very similar to MIG welding, but MAG welding uses an active gas (Fig.2).

Figure 2: MAG welding

Source: https://rime.de/en/welding/mag-welding/

3. TIG welding

   Tungsten inert gas (TIG) welding is a type of arc welding that uses a tungsten non-fusing electrode to weld. This type of welding is accurate and the welder can adjust different parameters on the machine. Welding is suitable for welding both ferrous and non-ferrous metals, very well suited for brittle metals (Fig.3).

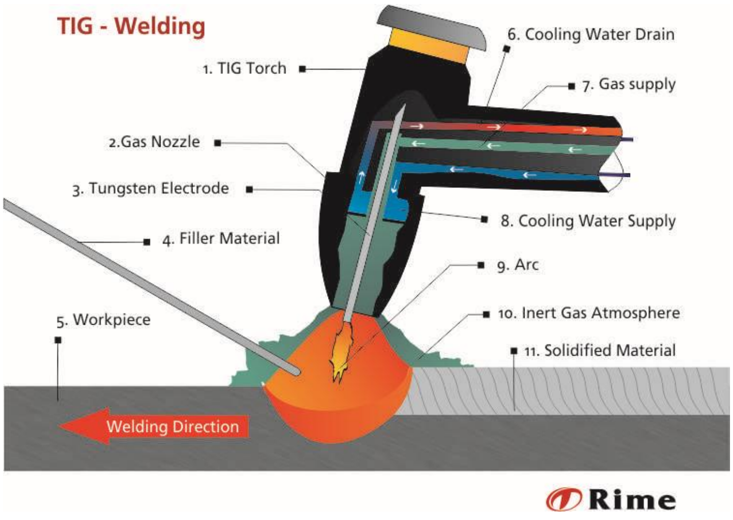


Figure 3: TIG welding

Source: https://rime.de/en/welding/tig-welding/

4. Stick or Arc welding

   Stick welding is a type of manual arc welding that uses a flux-coated fusible electrode to weld. This type is well suited for welding thick materials and is easy both to use and to set up (Fig.4).

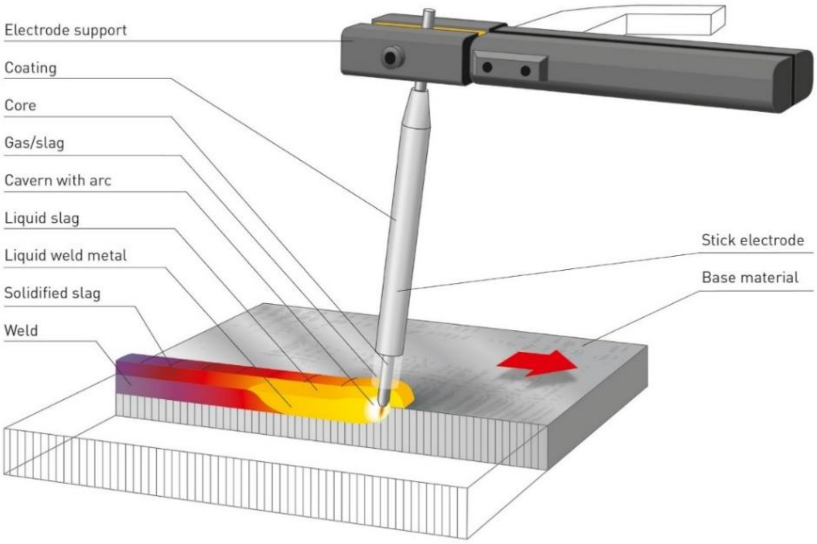


Figure 4: Arc welding

Source: https://www.kjellberg.de/en/provesses-manual-metal-arc-welding.html

5. Flux welding

   Flux welding is a semi-automatic or automatic arc welding process that uses a continuously fed consumable electrode. The fusible electrode is continuously fed, the center part of the electrode consists of flux and provides protection of the weld from the environment (Fig.5).

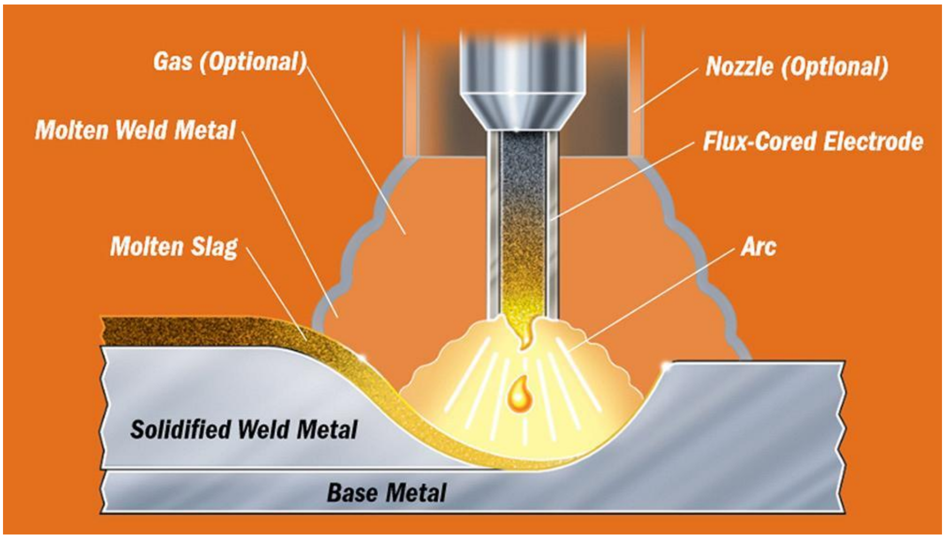


Figure 5: Flux welding

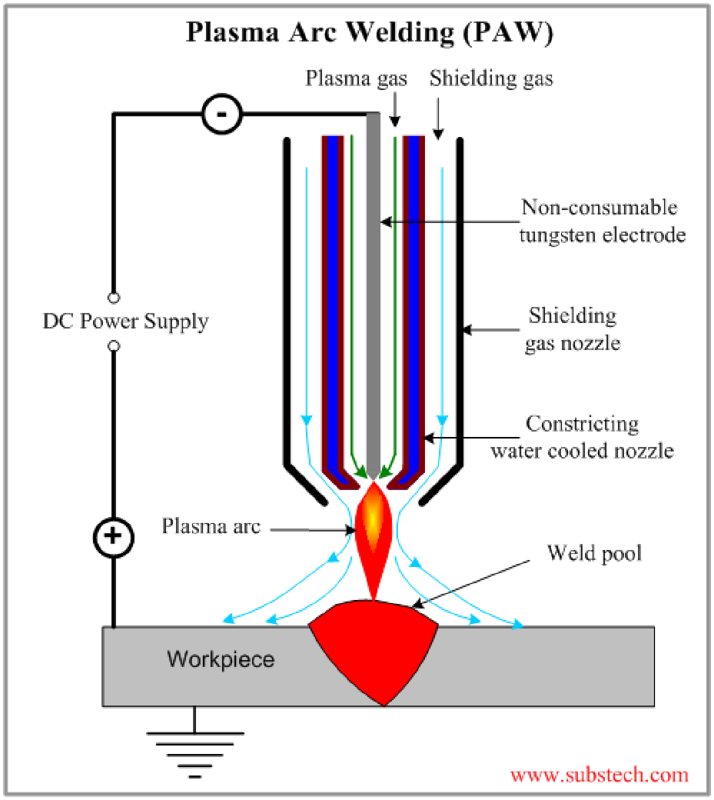
Source: https://www.thefabricator.com/thewelder/article/consumables/getting-to-know-flux-cored-wires

6. Plasma arc welding

   Plasma arc welding is a process that uses a non-consumable electrode, an arc is formed between the surface and the electrode. This high-temperature process makes it possible to weld deep and narrow seams at high speed (Fig.6).

7. Oxy-acetylene welding

   The oxygen-acetylene welding process is carried out by means of gas and oxygen combustion. An increase in the palm temperature is possible due to oxygen for quality metal melting (Fig.7).



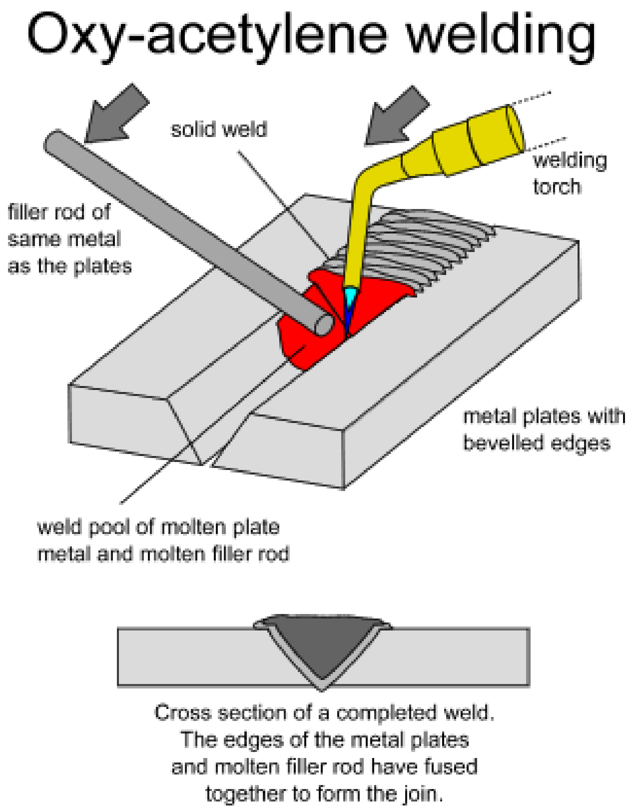


Figure 6: Plasma arc welding
Source: https://www.substech.com/dokuwiki /doku.php?id=plasma_arc_welding_paw

Figure 7: Oxy-acetylene welding
Source: https://scotthaywood.weebly.com/oxy-acetylene.html

8. FS welding

   Friction Stir Welding (FSW) - this process uses friction between the rotating tool and the surfaces to be welded, resulting in an increase in temperature and melting of the metal. The non-fusing electrode rotates at high frequency, plunges into the weld and stirs the metal in the weld, the movement is along the weld (Fig.8).

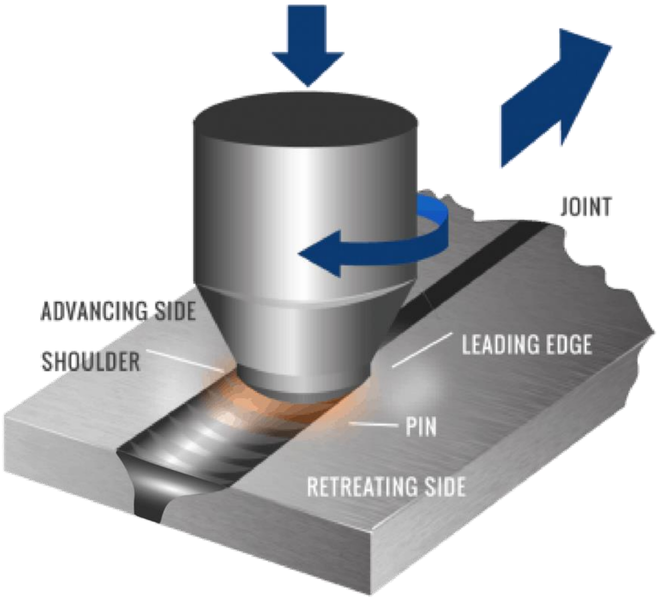


Figure 8: Friction stir welding

Source: https://megastir.com/friction-stir-welding-vs-traditional-welding/

9. US welding

   Ultrasonic welding (USW) is welding with an ultrasonic vibration frequency. During the welding process, the parts to be welded are placed on an anvil and pressed with a reed with a certain force, then a high frequency vibration is emitted, which generates heat, causing the metal to melt and weld (Fig.9).

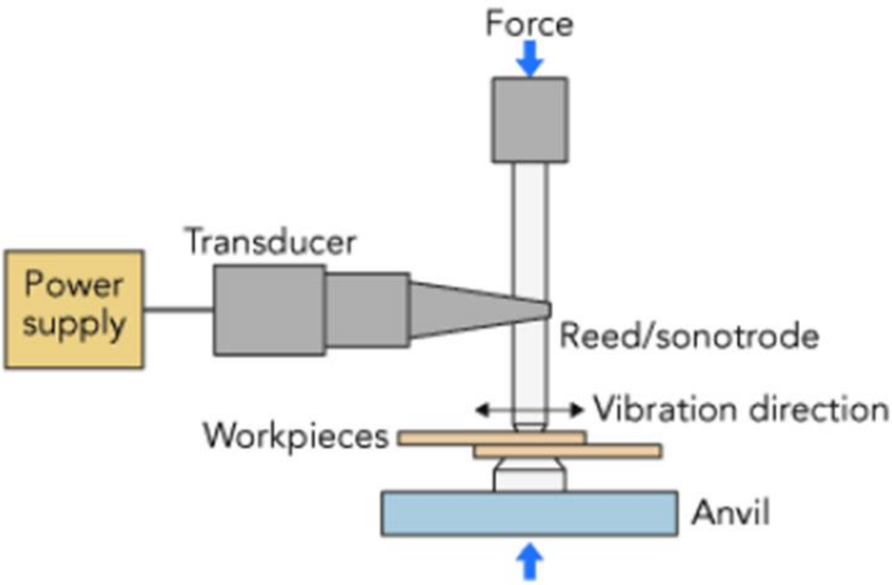


Figure 9: Ultrasonic welding

Source: https://www.teletecsi.com/blogs/ultrasonic-welding-in-contract-manufacturing

10. Laser welding

Laser welding is the process of welding metal with a laser beam. This type of welding is high-speed, with speeds up to 10 meters per minute. It is well suited for welding thick metals and narrow, deep seams (Fig.10).

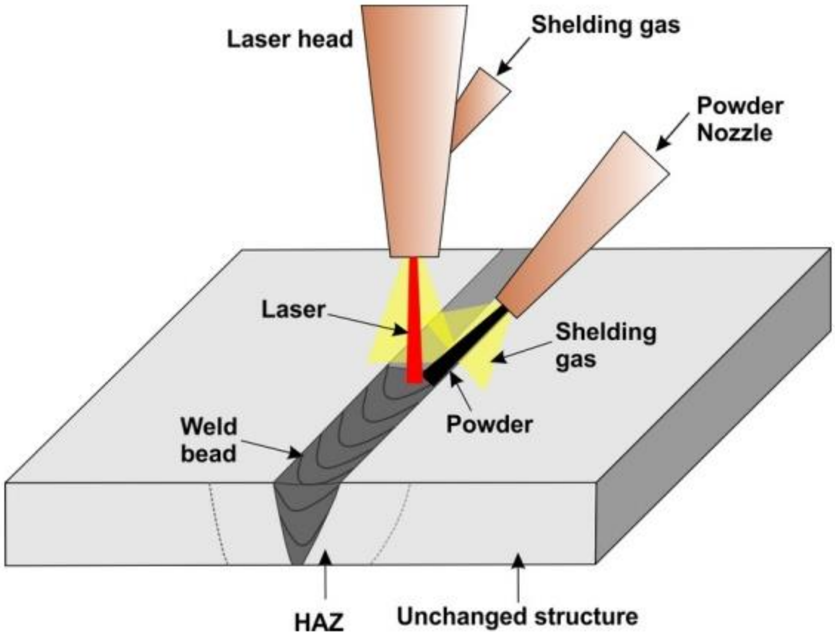


Figure 10: Laser welding

Source: https://www.eurobots.net/laser-welding-and-cutting-robots-subc-13-en.html

2.2 MAG Welding

Metal Active Gas welding (MAG) During this process, a melting electrode from the gun is used, creating an electric arc between the electrode and the surface. This type of welding uses an active gas, which also comes continuously from the nose of the gun to protect the weld from the environment. (TWI n.d.) The gases that can be used for this process and their ratios are given in the Table below (Tab.2):

Gas	Ar	CO_2	O_2
CO_2	0%	100%	0%
ArO_2	95-98%	0%	2-5%
$ArCO_2$	75-95%	5-25%	0%
$ArCO_2O_2$	85%	10%	5%

Table 2: MAG welding gas ratio

Source: self-developed based on (https://www.twi-global.com/technical-knowledge/faqs/faq-what-is-mig-mag-welding)

There are also different regimes for transferring metal from the melting electrode to the molten pool of metal. For the most part, these modes are selected by changing the characteristics on the welder, such as amperage and voltages. There are four modes for transferring metal from the electrode to the molten pool (Fig.11):

- Short circuiting,
- Globular transfer,
- Spray transfer,
- Pulsed transfer. (shtorm-its n.d.)

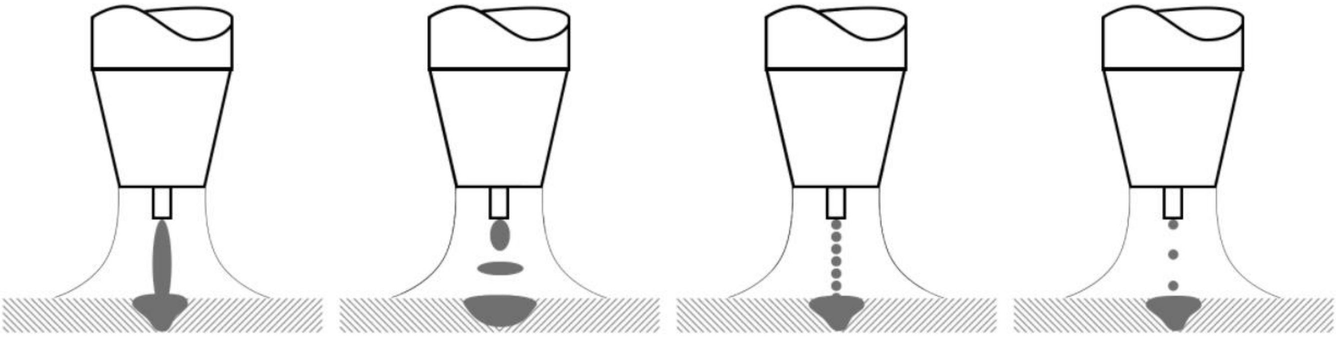


Figure 11: 4 modes in MAG welding

Source: https://www.aedmotorsport.com/news/mig-welding-transfer-methods

The Short circuit welding mode is good for wires with a diameter of 0.5-1.6 mm and a short arc with a voltage of 15-22 V. The metal melts after the short circuit, collects in a drop, which gives an increase in arc voltage and arc length to its maximum value. The wire feed rate is constant but the melt rate of the electrode varies in the different phases, so when the electrode with the drop at the end is close to the molten pool the voltage and the arc decreases until a new short circuit. During the short circuit, the current increases, thereby tearing the droplet away from the electrode and the droplet falls into the molten pool of metal. This cycle is repeated countless times during welding. The frequency of short circuits during this welding mode is about 90-450 times per second, depending on the parameters of the welding machine. If the welding parameters are correct, the splashing of metal from the electrode is no more than 7%.

For the globular transfer mode, the current density and arc length increase, this gives a change in the electrode drop and the transfer of the molten metal drop from the electrode to the pool. The molten droplets are not carried continuously and are large in size so this is quite visible to the eye. The properties of the arc deteriorate, the splashing and burning of metal from the electrode increases by up to 15%.

In Spray Transfer mode, without any additional devices, it is possible to see how the metal from the electrode moves continuously as a spray. This mode is only possible when the current is increased to the maximum for the thickness of the wire used. If the gas supply is changed, the current may change.

To improve the properties of the arc, pulse transfer is used, i.e., pulse increase of its power. The electrode does not have time to fall at the speed of its feeding from the welding machine. During the current pulse, the electrode melts faster and forms a drop at the end. The increase in amperage pulls the droplet away from the electrode and into the pool. This mode allows to weld in all positions. (shtorm-its n.d.)

There are a number of pros and cons to this type of welding given in Table below (Tab.3):

Pros	Cons
Good weld protection	Electrode combustion and spattering is high
No slag formation	Strong arc emission
Welding is allowed in all orientations	Amperage is restricted
Well suited for automation of the welding process (connecting of robotic arm)	Only DC current is used during the welding process

Table 3: Pros and cons of MAG welding
Source: self-developed based on (https://www.shtorm-its.ru/info/articles/tekhnologiya-svarki-mig-mag/)

A MAG welder is a body with electrical components inside. On the outside there is a control panel with buttons and controls for amperage, voltage, wire feed speed. Also, there is always a welding gun and a ground wire with a clamp (Fig. 12).

Figure 12: MAG welder

Source: https://allweldsupplies.com/en_GB/p/MIG-MAG-Welder-Magnum-190-II-MMA-NEW-Welding-Machine-230-V/2615

A welding gun for this type of welding consists of gun housing, conducter tube and nozzle. Under the nozzle there are gas diffuser for distributing of gas and contact tip from which the wire is fed - the melting electrode. When the welder pushes a button on the gun gas, wire and current begins to flow. Striation of welding gun given on Figure below (Fig.13).

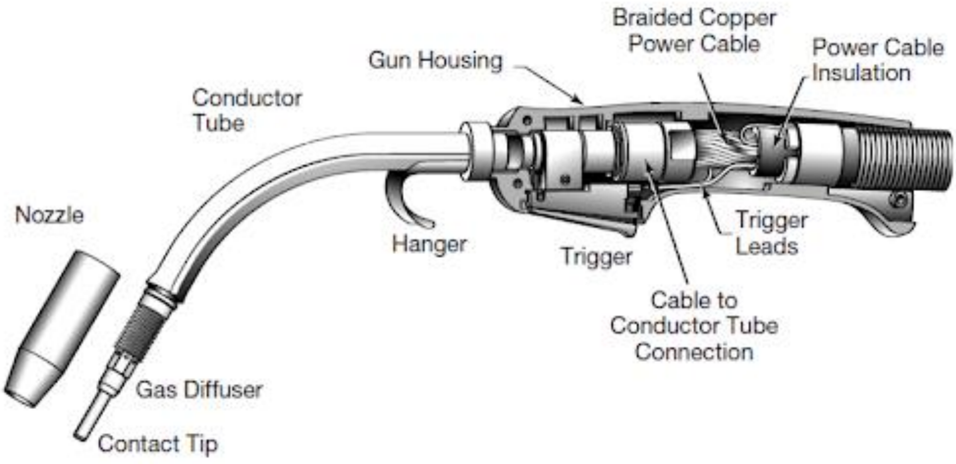


Figure 13: Welder gun

Source: http://www.imagequiz.co.uk/quizzes/329589001

2.3 Welding Education in Germany

In Germany, as in many other countries, welding technology develops every year. An important role in Germany is taken by DVS - the German Association of Welding and allied processes. This organization provides certification, accreditation and attestation of both personnel and organizations that want to become welding training schools. DVS has many partner companies throughout Germany, this can be seen on their website. Moreover, DVS has partnerships not only with companies but also with universities around the country, Hochschule Esslingen can be seen in this list. This university has a DVS student group headed by Prof. Dr.-Ing. Martin Greitmann, who develops this area and each student who is interested can join the university DVS community. The list of university partners also includes RWTH Aachen University, Technical University Chemnitz, University of Technology and Economics Berlin and many others. (DVS 2022)

2.4 Augmented Reality Welding

Augmented reality (AR) technology is an enhancement of the real environment where a person is in the present moment using digital information such as visualization of various elements, sounds and even smells. Basically, it uses the camera of a phone or some other device to broadcast pictures in real time. Then the Augmented Reality software recognizes the objects and downloads the desired 3D objects from its server. Then the digital objects are superimposed on the real image and the final broadcast is displayed on the screen or on smart glasses. For example, a person who uses this technology can control what is happening in the Augmented Reality using hand gestures, voice or on the touch screen of the device. Also, when changing the place of the person, i.e., while moving, the Augmented Reality system changes the output image that the person sees. The new graphic appears and the old one is no longer visible to the person.

These days, this technology is widely used in industry. One example of this is employees at any factory in various positions. The repairman looks at the machine and sees information only relevant to his/her line of work, for example in what order to disassemble the machine to access the repair of the unit that is broken. And the operator of this machine has information and instructions for the correct and quality setting of the machine. By using this technology in production, training costs, material usage, and productivity can be reduced. Thus, the possibility of using Augmented Reality in the 21st century helps people in all areas ranging from online shopping to medicine (Alsop 2021), (Hayes 2021), (Porter & Heppelmann 2017), (PTC n.d.).

Also, an example of Augmented Reality technology to aid in industry training are welding simulators from companies such as Seabery and Miller Electric. These welding simulators have been used for more than ten years to train novel and professional welders, integrate the simulation into the real world, together with the different elements used in the actual welding process: torch, helmet, parts and equipment, allowing the user to interact with the practice using the natural movements of the body, just as if he/she were performing a real practice; developing muscle memory and exercising real posture. The use of Augmented Reality Welding helps to reduce the cost of materials, electricity and emissions of harmful substances into the atmosphere.

However, there are virtual reality welding simulators, but unlike augmented reality, the student does not interact with the real environment and does not see anything but the virtual world.

2.5 SOLDAMATIC

SOLDAMATIC is an innovative simulator with Augmented Reality technology for training new and advanced welders. The advanced company Seabery, the creator of this welding solution, invested all of the most important qualities during its creation. At the moment the simulator combines advanced training concepts, training anywhere in the world, a safe training process, environmental friendliness, attracting young professionals with its concept and also reduces training costs to a minimum (Fig.14). This welding simulator is an aid in the welding training process, but it is not a substitute for actual welding practice. (WeldPlus n.d.).

It is the most realist welding training simulator available in the market, because:

- The welding simulation is parameterized based on the behavior of a WPS in a real environment and under different scenarios
- Real Sound recorded in a real welding shop.
- Augmented Reality- integrates the simulation into the real world
- Design similar to a welding equipment
- Real amperage foot controller/server for TIG welding.
- Real torches for MIG/MAG, TIG and MMA welding. Manufactured by Abicor Binzel.
- Real welding mask
- Real welding gloves
- Custom welding joints made according to customer needs.

Figure 14: SOLDAMATIC

Source: https://weldplus.de/de/products/soldamatic/concept/

Seabery supplies this product in a variety of packages such as Education, Edication +, Advanced, Robotics and Industry. Let's take a look at the standard Education kit. In this kit the buyer receives a basic set of tools: SOLDAMATIC, a welding helmet, welding guns for MIG/MAG, TIG and MMA welding, a pair of electrodes and 5 work surfaces (overlap joint, butt joint, butt pipe joint, T-joint, T-joint pipe to plate). The design of the simulator is identical to a professional welding machine, i.e., details such as the control panel, welding mask and welding guns are fully consistent with the real thing.

The table below (Tab.4) shows the possible processes, materials, material thicknesses, gases and modes of the Education package on the SOLDAMATIC simulator.

Welding Process	• MIG/MAG • TIG • MMA
Base Material	• Carbon steel • Stainless steel • Aluminum

Thicknesses	• 3 mm • 6 mm • 10 mm
Gases	• Argon/CO_2 • Argon • CO_2 • Argon/O_2
Transfer Modes	• Short circuit • Globular • Spray

Table 4: Possibilities of Education package

Source: self-developed based on Seabery website

SOLDAMATIC also includes E-Learning platform for managing and developing the training. Welding school instructors can easily monitor students' progress, evaluate their work, create and edit existing courses and interact with students on real time. E-Learning platform is designed not only for administrators but also for students. Every student gets a personal web page to access theoretical exercises, either at home or anywhere else. In this way, an excellent welding training package, as close to reality as possible, is available to the customer (WeldPlus n.d.).

A SOLDAMATIC unit was purchased a bit more than one year ago for the Hochschule Esslingen laboratory to train students in welding. In the table below is a list of what has been purchased from WeldPlus (Tab.5).

Also, the E-Learning has a wide range of courses for the training of welders ready to use and with which the teacher can teach courses of electric arc welding procedures (MMA, MIG-MAG and TIG), the most common positions, thicknesses and materials in the industry. These contents have been developed in collaboration with some of the most prestigious welding experts, such as the German Welding Institute (DVS).

Name of position	Part/Invoice number	Note
SOLDAMATIC 3.0 Basic PLUS Version - Lifetime Augmented Reality Simulator, Welding Simulator for MIG/MAG, MMA and WIG, Router, Antenna and standard accessories. Software License - Lifetime 5 years	WP19306D/12809	SOLDAMATIC and E-Learning software version 3.2.1

Software Upgrades & Support License. After the 5 years system still usable! Included in delivery: MIG / MAG, MMA and TIG for the standard workpieces (Overlap weld, T-joint, fillet weld, pipe-flange 6", pipe-pipe 6") with Mild steel, aluminum and stainless steel. Teacher software (LMS) and e-learning platform.		
WORK STAND SHORT for fixing the workpieces in different positions.	WP19004D/12809	-
CASE for TRANSPORTATION consisting of upper & lower case.	WP19003D/12809	-
DVS based TIG course with theoretical and practical exercises, German language.	So_O-Sc02.2-DE/12809	-
DVS based MMA electrode course with practical and theoretical exercises, in German language.	So_O-Sc03.2-DE/12809	-
DVS based MIG/MAG course with practical and theoretical exercises, in German language.	So_O-Sc01.2-DE/12809	-
DVS aligned MIG/MAG course with practical and theoretical exercises, in English language.	SOGMAWKM/12929	-
SOLDAMATIC SERVER 3.0 required for network connection 10 devices can be connected, additional devices via cable.	WP19002D/12941	Server version 3.2.1

Table 5: Purchased equipment for Hochschule Esslingen

Source: self-developed based on documents from Hochschule Esslingen

2.6 Metallography Examination

Metallography is the analysis of the microstructure of metal, which gives an insight into the processing of metal and provides answers to questions such as whether the part is reliable and the causes of product failure.

In the process of this study, it is possible to collect quite a lot of information about the microstructure of a metal, such as color, size, shape of grain, segregation effect, shape of the second phase, inclusions, distribution, percentage of ferrite and pearlite, porosity, nodularity. The microstructure also strongly affects the properties of the material, namely the tensile strength, thermal conductivity and electrical behavior.

There is a specific procedure for conducting a metallographic analysis, which includes 5 main points (Fig.15):

- Cutting with water cooling
- Embedding
- Grinding / Polishing
- Etching
- Analysis with Microscope (Kemet n.d.), (Metallurgical Engineering Services n.d.)

Figure 15: Metallography Examination stages

Source: https://www.kemet.co.uk/blog/metallography/what-is-metallography

This test method is only used for real welding joints, the SOLDAMATIC welding simulator does not provide this possibility to test the weld because it has other purposes.

2.7 Ultrasonic Testing

Ultrasonic testing is a non-destructive method of testing metal and welds based on the principle of high-frequency vibrations of about 20,000 Hz. The waves emitted by the device pass through the metal until they encounter cracks or other defects, then they are reflected and the detector registers them. If there are no defects inside the metal, the wave is reflected only from the surface on which the piece of material lies. The type of flaw can be determined by such indicators as the distance to the crack or cavity using the time of the wave passing and establishing its size with the help of the pulse amplitude (Fig.16).

There are a total of 5 testing methods, but the only difference is in the recording and analysis of the readings.

There are also basic steps for testing:

- Clean the area to be tested of dirt, rust, or any coatings,
- Treat the area with a special gel to improve contact,
- Set up the ultrasonic testing device,
- The transducer moves over the test site in a zig-zag pattern,
- If the defect is located, it is recommended to locate it more accurately in order to stabilize the probe signal,
- Record the position of the defect,
- To verify the data, it is worth checking the seam twice.

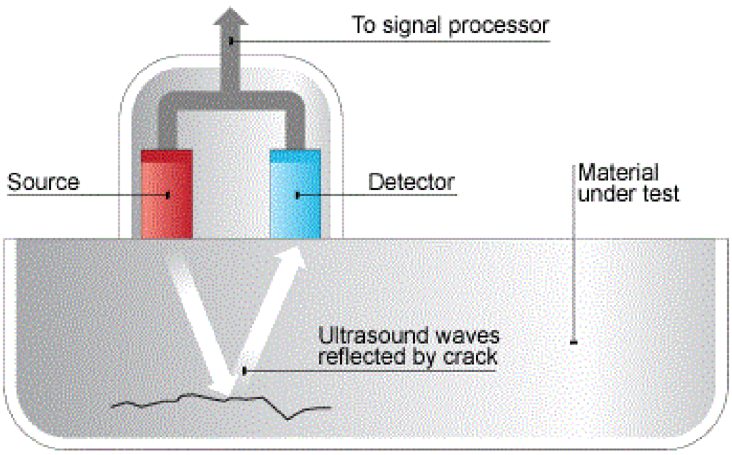


Figure 16: Ultrasonic Testing

Source: http://novotest.biz/ultrasonic-testing-of-welds/

Thus, the results of this study can determine such defects as cracks, pores, corrosion damage, and delamination. (Novotest n.d.)

This method of checking welds is widely used in this field, but it was not used in this research because of the large number of final works and as a consequence it would be very time consuming. Therefore, another method was chosen to analyze the results. Moreover, the welding simulator does not provide nondestructive testing results because its main task is training.

2.8 Electricity Measurement with Dewetron DEWE-2600 and Rogowski belt

“The flexible DEWE-2600 system is a portable all-in-one measurement instrument with up to 80 analog channels. With 16, 22 or 24-bit resolution, the sampling rate is up to 10MS/s per channel and each one has its own anti-aliasing filter.” (Power Technology 2014).

“The Rogowski coil is defined as an electrical device that is used to measure alternating current (AC). It is also used to measure the high-speed transient, pulsed current or sinusoidal current. A Rogowski coil is an evenly wounded coil with N number of turn and constant cross-section area A. There is no metal core in a Rogowski coil. The end terminal of the coil is returned through the central axis of the coil to another end. Therefore, both terminals are at the same end of the coil. This entire assembly wrapped around the current-carrying conductor whose current we need to measure.” (Electrical 4u 2020).

The Rogowski coil allows current measurements to be made using only one wire strand, e.g. phase or neutral (220V), phase 1, phase 2, phase 3, neutral (380V). If the coil is placed around a pair of strands of one wire, however, the measurements will not be correct. Concluding from the above words for correct measurements it is required to remove cable jacket of the wire preparing access to each wire for Rogowski coil (it is supposed to remove only the top protective jacket of the wire, not remove the wire insulation from the wires).

Thus, the Dewetron and Rogowski belt can measure the current, record the measurements, make plots and make calculations based on the obtained values (Fig. 17). In the future it will be possible to measure the current on the SOLDAMATIC, welding machine and calculate the real power consumption.

Figure 17: DEWE-2600

Source: self-made

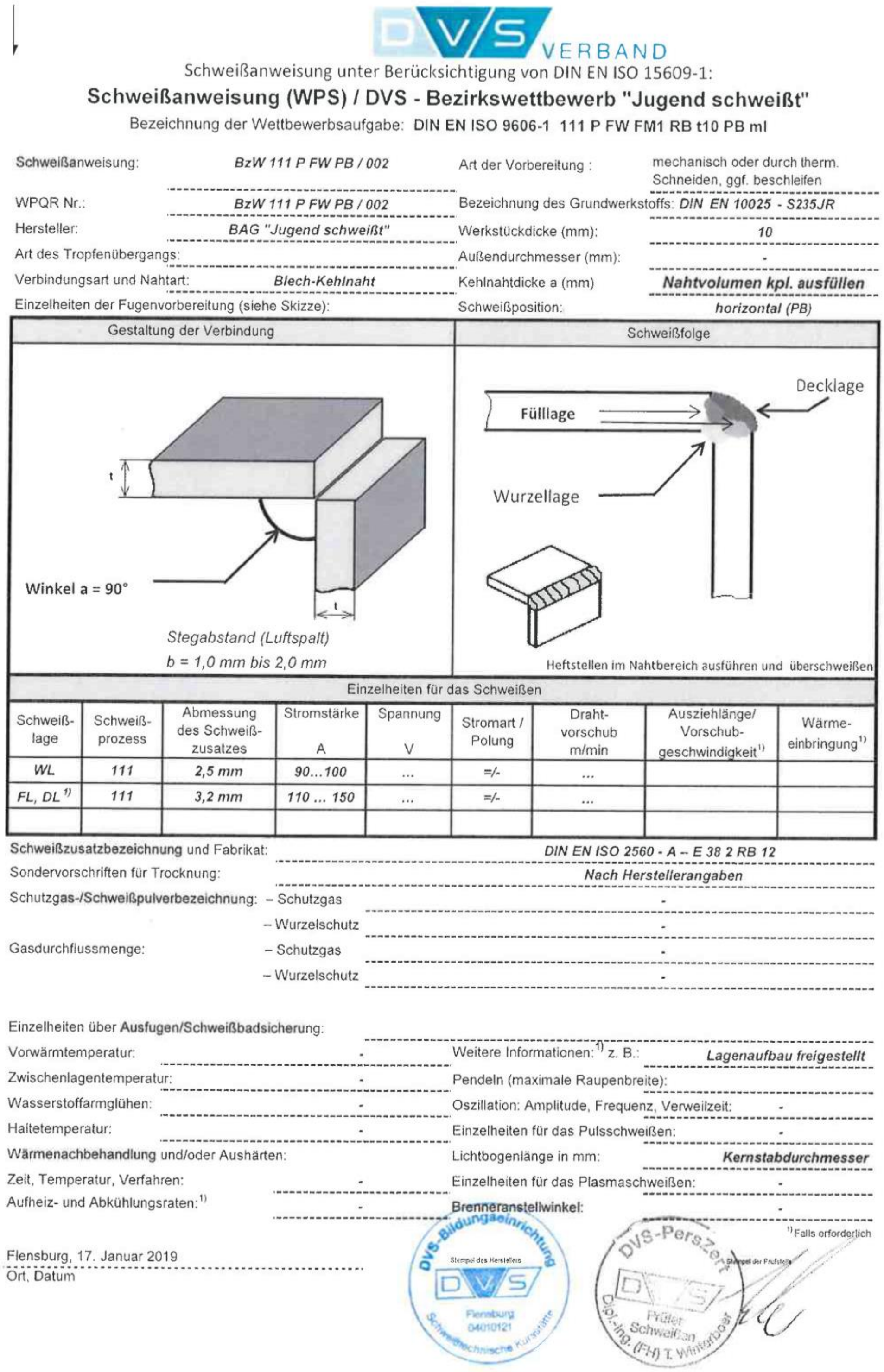
2.9 Welding Procedure Specification (WPS)

The Welding Procedures Specification (WPS) is an official document and a precise indication for the person who will perform the welding work. This document always clearly indicates all the parameters to be adhered to as well as what additive, material, gas, and titer should be used. It is also necessary to take into account the position in which the welder should perform his work. This document is always in accordance with the norms and standards to produce quality welds in the future and as a result quality product. Every company that performs products by welding should use the WPS for welding work to comply with safety laws. In addition to this, welders who use this document should independently verify the correctness of the document for safety purposes (Technoweld 2019).

There are many different computer programs for creating WPS, but they all follow the same principles. It is possible to highlight the basic points for writing this document:

1. Basic information (Company, developer, date, number and etc.),
2. Type of joint (Material, distance between joints, pictures),
3. Materials (Main material and type of wire),
4. Gas and Position of welder,
5. Electrical settings,
6. Welding sequence (Seabery 2018).

A good example of a professionally made WPS is the document from DVS - German Welding Society (Fig.18).



DVS VERBAND

Schweißanweisung unter Berücksichtigung von DIN EN ISO 15609-1:

Schweißanweisung (WPS) / DVS - Bezirkswettbewerb "Jugend schweißt"

Bezeichnung der Wettbewerbsaufgabe: DIN EN ISO 9606-1 111 P FW FM1 RB t10 PB ml

Schweißanweisung:	*BzW 111 P FW PB / 002*	Art der Vorbereitung :	mechanisch oder durch therm. Schneiden, ggf. beschleifen
WPQR Nr.:	*BzW 111 P FW PB / 002*	Bezeichnung des Grundwerkstoffs:	*DIN EN 10025 - S235JR*
Hersteller:	*BAG "Jugend schweißt"*	Werkstückdicke (mm):	*10*
Art des Tropfenübergangs:		Außendurchmesser (mm):	-
Verbindungsart und Nahtart:	*Blech-Kehlnaht*	Kehlnahtdicke a (mm)	***Nahtvolumen kpl. ausfüllen***
Einzelheiten der Fugenvorbereitung (siehe Skizze):		Schweißposition:	*horizontal (PB)*

Einzelheiten für das Schweißen

Schweiß-lage	Schweiß-prozess	Abmessung des Schweiß-zusatzes	Stromstärke A	Spannung V	Stromart / Polung	Draht-vorschub m/min	Ausziehlänge/ Vorschub-geschwindigkeit[1]	Wärme-einbringung[1]
WL	*111*	*2,5 mm*	*90…100*	...	*=/-*	...		
FL, DL[1]	*111*	*3,2 mm*	*110 … 150*	...	*=/-*	...		

Schweißzusatzbezeichnung und Fabrikat:		*DIN EN ISO 2560 - A – E 38 2 RB 12*
Sondervorschriften für Trocknung:		*Nach Herstellerangaben*
Schutzgas-/Schweißpulverbezeichnung:	– Schutzgas	-
	– Wurzelschutz	-
Gasdurchflussmenge:	– Schutzgas	-
	– Wurzelschutz	-

Einzelheiten über Ausfugen/Schweißbadsicherung:

Vorwärmtemperatur:	-	Weitere Informationen:[1] z. B.:	*Lagenaufbau freigestellt*
Zwischenlagentemperatur:	-	Pendeln (maximale Raupenbreite):	
Wasserstoffarmglühen:	-	Oszillation: Amplitude, Frequenz, Verweilzeit:	-
Haltetemperatur:	-	Einzelheiten für das Pulsschweißen:	-
Wärmenachbehandlung und/oder Aushärten:		Lichtbogenlänge in mm:	***Kernstabdurchmesser***
Zeit, Temperatur, Verfahren:	-	Einzelheiten für das Plasmaschweißen:	-
Aufheiz- und Abkühlungsraten:[1]	-	Brenneranstellwinkel:	-

[1] Falls erforderlich

Flensburg, 17. Januar 2019
Ort, Datum

DVS-Bildungseinrichtung – Stempel des Herstellers – DVS – Flensburg 04010121 – Schweißtechnische Kursstätte

DVS-PersZert – Stempel der Prüfstelle – Prüfer Schweißen – Dipl.-Ing. (FH) T. Winterboer

Figure 18: Example of WPS from company DVS - German Welding Society

Source: https://www.dvs-home.de/fileadmin/Images/Bezirksverbaende/Flensburg-Kiel/2021-11-Schweissanweisungen_111.pdf

3. Methodology

This chapter covers the main points of the research methodology, such as the concept, the research methods and the research process to identify the best method of welding training. This chapter also introduces the companies involved in the research.

3.1 Concept and Methods of research

3.1.1 Concept of research

This research is developed to determine the advantages and disadvantages of welding training using new technologies such as Augmented Reality versus 100% traditional training. As previously mentioned, the new technologies do not seek to eliminate the real practice, but to obtain better results from the training process. The research analyzes and compares two study methods: traditional learning and learning through Augmented Reality simulator. The appearance of Augmented Reality technology in this field has significant advantages: environmental friendliness, while reducing the cost of materials and training time spent in a real workshop.

The objective of this research is to demonstrate experimentally that welding training using an Augmented Reality simulator, in this case SOLDAMATIC, allows:

- Saving of consumables
- Reduced costs: materials, electricity, classroom…
- Reduced real training time in the workshop
- Improved training quality
- Respect for the environment thanks to reduced emissions
- 0 risk for the trainee

3.1.2 Methods of research

The experiment is chosen as the main method of this research. It is one of the quantitative research methods. *«Quantitative research is defined as a systematic investigation of phenomena by gathering quantifiable data and performing statistical, mathematical, or computational techniques»* (Question Pro 2022). *«Experimental studies are ones where researchers introduce an intervention and study the effects. Experimental studies are usually randomized, meaning the subjects are grouped by chance»* (IWH 2016). Using this method, the first group was able to work with SOLDAMATIC AR welding simulator in metal welding. While the control group followed traditional training.

The main advantages of this experimental method are the possibility of obtaining specific results from which specific conclusions can be drawn, thereby establishing cause-effect relationships, as well as this type of research allows the researcher to control the process. However, the main disadvantages worth noting are subjectivity and possible unreliability of the results due to human errors of the researcher, as well as the current situation, past experience and extraneous factors affecting the subjects. All of this can ultimately cast doubt on the results obtained (Gaille 2017).

3.1.3 Process of research

The research began with an introduction to SOLDAMATIC augmented reality welding solution. After that the preparation for the experimental part began. The questionnaires for the participants of the experiment, the plan of work with the students, various test tasks to check the knowledge gained at the end of the course, as well as the samples for the final test assignment were developed.
The research has been developed in two parts:

1. First part of the research taking place at **Hochschule Esslingen** divided the students into two groups of 10 people each. All participants are students of Automotive, Mechanical or Computer engineering. The first group was trained on the SOLDAMATIC simulator and then consolidated their knowledge on a real welding machine. Group two was trained on real welding equipment. After that, each group took final tests before the end of the course. Based on the results of the tests, the two training methods will be compared and the best one will be identified.
2. Second part of the research took place at **Audi**. The research process is similar to that of the Hochschule Esslingen, but the number of participants is 6 in each group and everyone is from Mechatronics department.

3.2 Cooperation with companies

This research has been carried out for the Spanish company Seabery, which is a representative in the field of augmented reality welding training solution - SOLDAMATIC. The company is interested in analyzing traditional method versus simulated education to see the advantages and disadvantages of each.

WeldPlus is also a partner and official distributor of Seabery equipment in Germany.

Part of the research was conducted in the laboratories of Hochschule Esslingen and also in Audi AG in Neckarsulm.

4. Preparation for the research

4.1 First steps

This is the first and most important step for whole work and preparation should be done brilliant for latest success of the project.

First of all, work was started with reading of the SOLDAMATIC user's manual. There are a lot of primary information in this file that show to user how to use the augmented reality welding simulator, with detailed instructions for setting up, and calibrating. After reading the instructions, a clear plan to start working on the simulator was created as well as a solid understanding of SOLDAMATIC.

WeldPlus provided a package of additional information about SOLDAMATIC as well as a couple of old studies already done by students from other institutions. These documents gave a good idea of the capabilities of this unit and its prospects.

In addition to all of the above, the instructions for the actual welding machines in the laboratory of Hochschule Esslingen were studied at this step.

4.2 Understanding of SOLDAMATIC

The Augmented Reality welding simulator SOLDAMATIC it is easy to use and flexible, with a similar look and feel to a real welding machine the students learned how to use it and became familiar in just 30 minutes.

This was an introduction, the students learned how to use SOLDAMATIC Augmented Reality welding simulator, how to connect the real welding torches to the simulator (MIG/MAG, MMA and TIG with electrode stick and filler rod) and the different ports the welding simulator has for USB and HDMI wire to be able to share the practices on a screen.

Then it was understood which SOLDAMATIC set is available at Hochschule Esslingen (Fig.14):

- SOLDAMATIC Education License
- MIG/MAG, TIG and MMA
- Materials: Carbon steel, Stainless steel and Aluminum
- Thicknesses of material: 3, 6, 10 mm
- Argon, Argon/CO_2, CO_2, Argon/O_2
- Welding joints: Overlap joint, Butt joint, Butt pipe joint, T-joint, T-joint for pipe (tube to plate)

To continue working on this simulator, an account needs to be set up. There are two types: for students and for the administrator. The university provided the administrator which means the ability to use the full functionality of such as the creation of custom courses, as well as control of all students. Students have a limited number of functions only for study and do not have access to the settings. So having all the functions of SOLDAMATIC took some time to learn them.

The following step was to calibrate the cameras on the welding helmet. The calibration was done by following the instructions and using the special sheet provided by Seabery.

This process is not complicated, but requires attention and accuracy. When calibrating the helmet, a helmet is placed in front of the calibration paper and the SOLDAMATIC starts to show on its screen the positions in which the helmet should be positioned while the calibrator should hold the helmet in the correct position. The helmet must be held in these positions until the frame on the screen changes color from red to green (Fig.19). There are eight such positions.

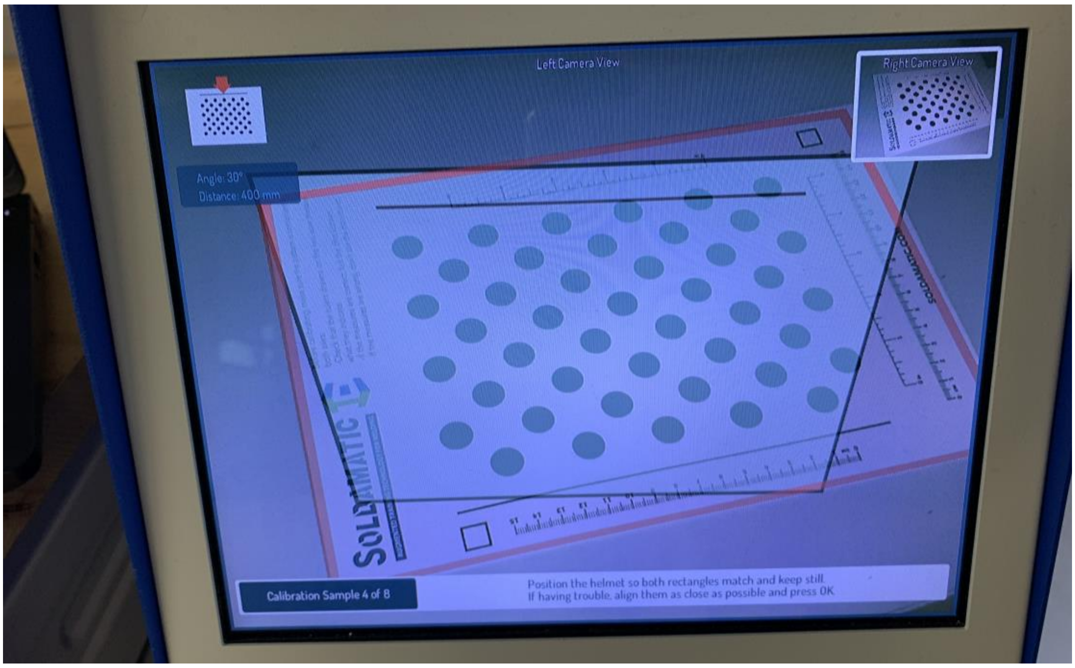


Figure 19: Calibrating of SOLDAMATIC
Source: self-made

After a complete understanding and setup of the machine, it was time to decide the training course which will be used for the training from a guide range of contents available, the DVS-Media Grundkurs MAG course was selected, which had been previously purchased and by Hochschule Esslingen. The welding process on this simulator is close to the real one, that is, during the work students hear the sounds during welding and see everything to the smallest detail, even the splashing of metal when welding.

To sum it all up, the first impression of the SOLDAMATIC is very good, because the engineers have done everything on a high level, starting from the body of the device and ending with a very accessible and user-friendly interface. However, in future versions it would be good to add a touch screen which could simplify the use and a wireless welding helmet.

4.3 Understanding of E-Learning Platform

When working with new software for the first time, it is important to understand all the features and capabilities as well as try to use them, that is to practice. This step began with obtaining the licensed software from Hochschule Esslingen and installing it on the computer for future use. The software SOLDAMATIC E-Learning V3.2.1 (for administrator) does not require high technical specifications, it is easily installed on Windows 10. So, after installation, it is ready to use. The instructions manual provided by Seabery also include explanations on how to use the software and digital platform. At the first start-up there is a connection to the SOLDAMATIC via WLAN, later through this connection will be synchronization of computer and simulator. In this project the work with the E-Learning platform started with understanding the structure and studying each tab.

In the SOLDAMATIC E-Learning platform there are two different accesses: instructor and students. In this case the instructor profile has been set up to be able to select a course and manage all the students. For a more complete understanding it is necessary to explain that the trainers have access to the digital platform and the software on the computer and the students have access only to the E-Learning platform.

In the teacher profile first tab at the top of the program window is “Courses”. Here can be found all the training courses such as Seabery provides in the Education license: Augmented Training: SOLDAMATIC Welding Curricula (in three languages English, German, Spanish). It is also possible to import training courses bought from other companies or to create own training course. For a better practical experience with SOLDAMATIC, it was decided to create a test course called "Master Thesis Test Course". The E-Learning platform is easy to use and friendly, so it took about a couple of minutes to create own training course. In this toolkit it is still possible to edit courses, delete, create students and receive a pdf report on each of the courses (Fig.20).

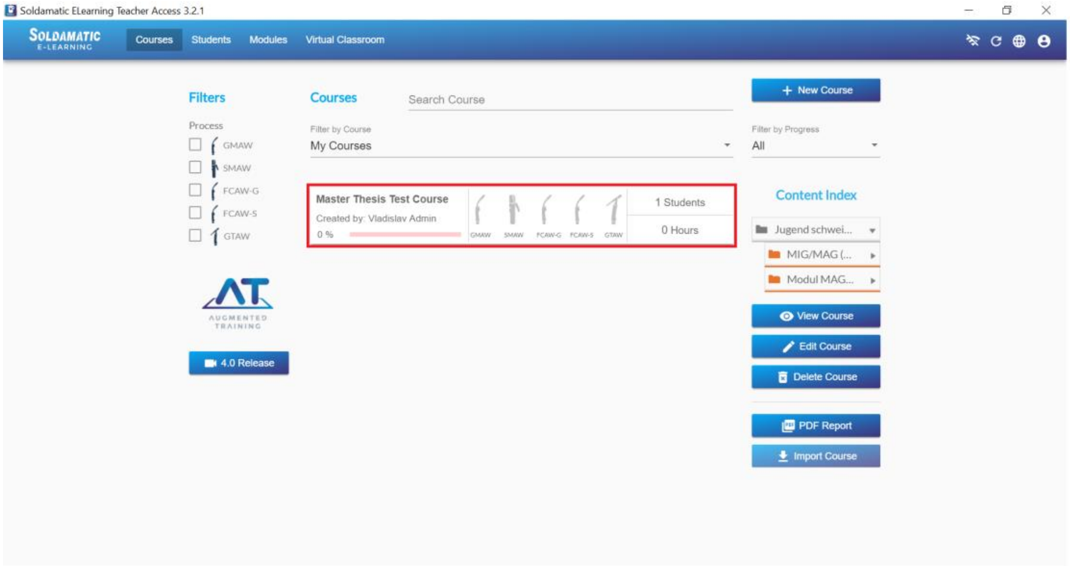


Figure 20: Test course in E-Learning platform V3.2.1

Source: self-made

The second tab “Students” is equally important to understand. Here was learned how to manage students, that is, create an account for new student, delete accounts if they are no longer needed, register for a training course and manage the progress of each student through reports. Here it is also possible to review information about the student and check his/her activity, his/her grade level and the subjects he/she is attending. In addition, download the student's report in pdf format. Summarizing everything learned, a test student with the name "Master Thesis" was created. During the creation process, a newly created course "Master Thesis Test Course" was added. (Fig. 21).

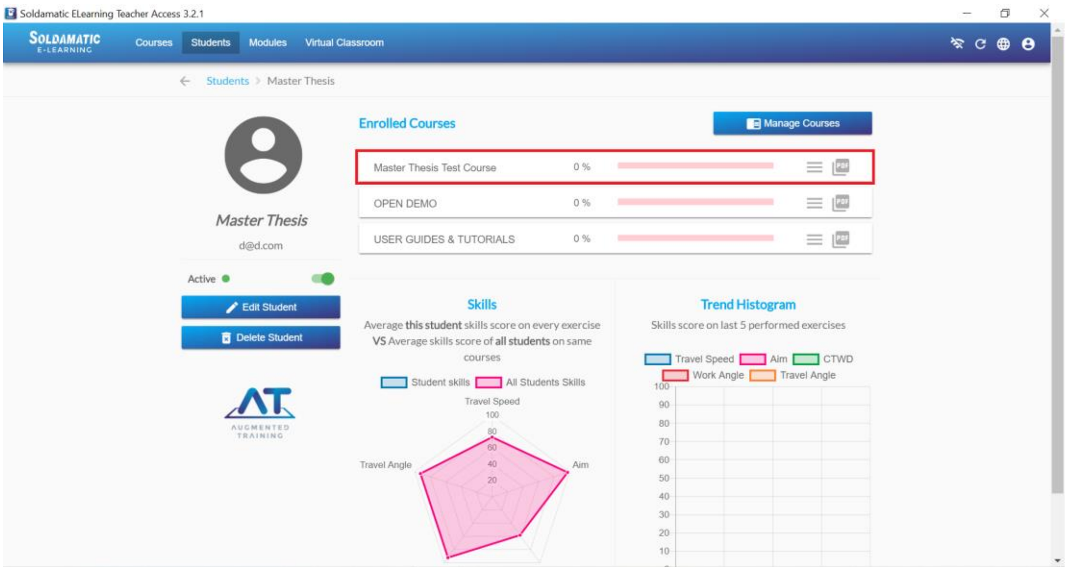


Figure 21: Test Student in E-Learning platform V3.2.1

Source: self-made

In the third tab "Modules" the process of creating modules, blocks and various tasks was explored: theoretical, practical and quizzes. In the future, the created module "Module Master Thesis" will be added to the previously created test course (Fig.22).

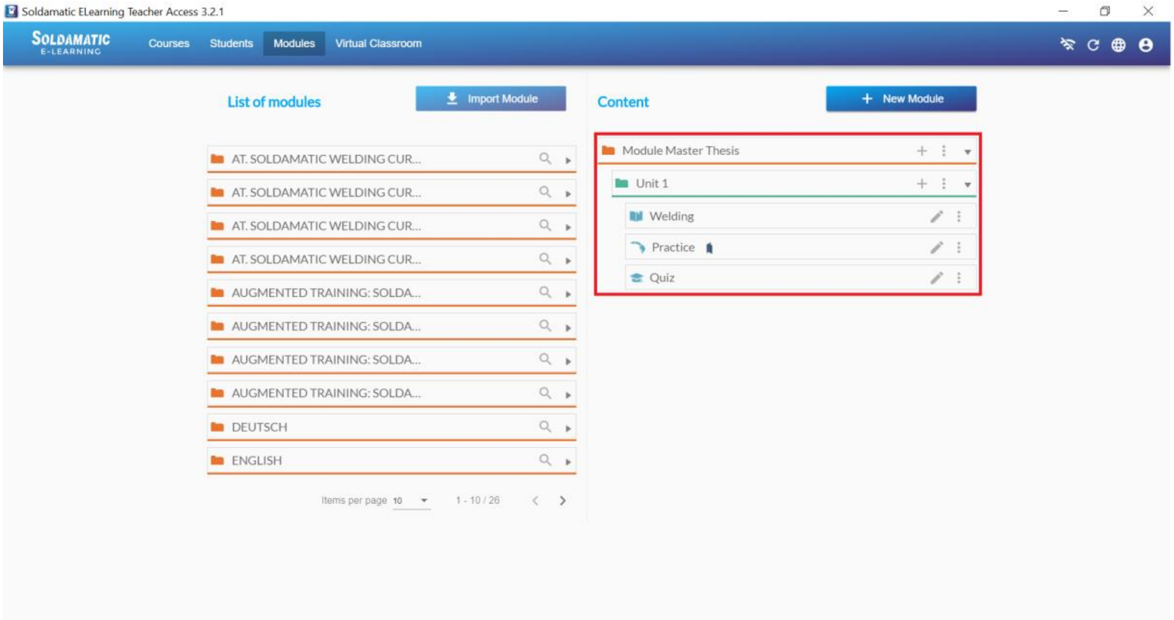


Figure 22: Test Module in E-Learning platform V3.2.1
Source: self-made

All of the above was said about the E-Learning platform for teachers. Now is the time to review the web page for students. This site is a cut down version of the teacher platform as mentioned above. Here the student with his/her email and password can easily access to the courses and learn the theory. Thanks to this possibility everybody can access to the system from anywhere and anytime, these speeds up the learning process of welding by leaps and bounds. Also, the E-Learning platform allow teachers and students to interact on real time thanks to the chat, being able to share practices.

Thus, in the totality of the practice in this platform have been studied and understood the most important functions that will be actively used in further work on the project. In addition to this it is possible to say that this software works steadily on the computer, the interface is made clear and easy to understand.

4.4 Understanding of Database for SOLDAMATIC

At this stage a database was obtained from Hochschule Esslingen with the names of all students who would like to start welding training in the near future. To start training it is necessary to create a student account for each participant. So should have started with this step and figured out how to do it. Since there is a detailed user manual "SOLDAMATIC 4.0 owner's manual" it was easy to find the answer to this question (Seabery 2021, p. 23)

The first step was to download already existing data from the welding simulator. This can be done in the tab "Students" with the button "Export" in the software SOLDAMATIC E-Learning 3.2.1, administrator version. This file was then downloaded to the computer in .csv format. It can be opened in Microsoft Office Excel. Thus, after all these actions, following the instruction, the database was obtained and it could be corrected and new students could be added quickly.

The second and most important step was to enter and sort the new names of the students so that there were no duplications because some of the students already had experience on this simulator and accordingly, they already had an account. After a happy sorting, the final version of the list of students was obtained.

The third and final step was to save the list of students correctly and upload it to the welding simulator. Following the manual, the result was saved as a .csv file. Then I had to open it in a standard Windows 10 application "Notepad" and replace all the semicolons with commas to SOLDAMATIC simulator was able to correctly arrange the resulting database. To upload the obtained file in .csv format in SOLDAMATIC E-Learning 3.2.1 software, one had to click on "Import" and choose the corrected file, after that the document was uploaded to the device (this process took several minutes).

So, after three steps the result has been achieved namely the database has been successfully approved by SOLDAMATIC and the simulator displays the accounts of all the students in the list on its screen.

4.5 Comparison List of Augmented Reality Welding Training and Traditional Welding Training

Before the research will be on a step of work with students, good to know what parameters should be include and need to calculate for comparing SOLDAMATIC welding simulator with real welding machine. So, that is why the company Seabery offered parameters which important for latest development of SOLDAMATIC and digital platform E-Learning for it (Tab.6).

Except standard values such as number of students, training hours and hours in workshop, were included very important consumption settings as Electricity in [kWh], Metal weight in [kg] and Emitted gas in [L]. Also, this experiment includes 3 tests for participants to check their skills after completed study course. Each test is more difficult than the previous one. In addition, after each test there will be results on the basis of which conclusions will be made about how well the participant has mastered the skills of welding. All these points are including in the Table below (Tab.6).

	Real Welding	Augmented Reality
№ Students		
№ Training hours (estimated)		
№ Training hours (real)		
Workshop training hours		
Materials detail cost		
Electricity		
Weld seam length		
Content material		
№ Students pass		
№ Students fail		
Welding instructor hours		
Gases emitted during welding		

Table 6: Comparative list from Seabery

Source: developed by Seabery

5. Training in WeldPlus

In order to deepen the knowledge WeldPlus held a training on working with SOLDAMATIC. WeldPlus is *"leading provider of augmented reality-based products and solutions for education and training, as well as the qualification of professionals. We develop and distribute the latest digital technologies and education solutions for our customers and partners, and help to actively shape the digital transformation of the world of work."* (WeldPlus 2021) The training took place in the office of the company in Müschenbach. The workshop was conducted by Mr. Lukas Krämer for 6 hours.

During the course the following topics were covered:

- different possibilities of creating WPS in the E-learning platform,
- creating and correcting databases,
- adding personal assignments to courses that already exist on the device,
- the process of creating a custom work surface for SOLDAMATIC simulator,
- more detailed understanding of student workflow tracking,
- brief discussion of robotic arm connections to SOLDAMATIC simulator,
- working with different advanced and industrial joints (Fig.23),
- overview of the new generation of software: SOLDAMATIC 4.0.

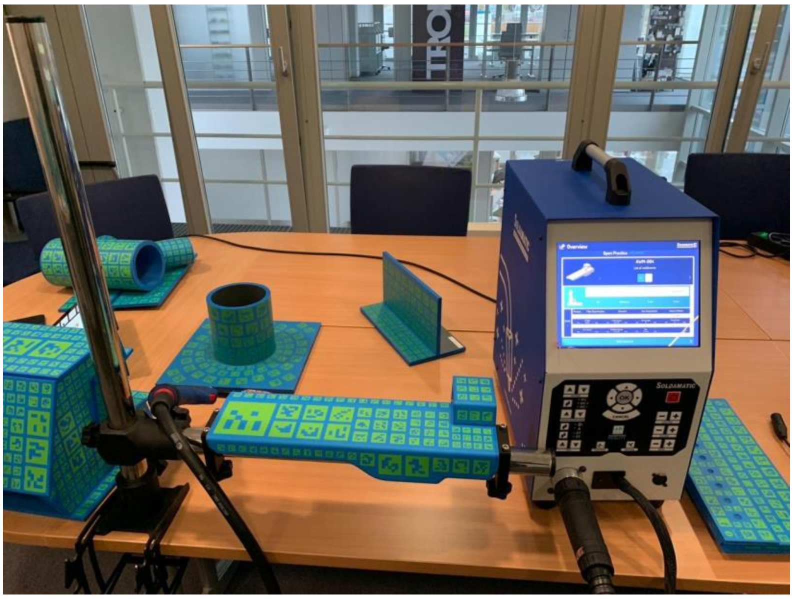


Figure 23: Training in WeldPlus
Source: self-made

As a result of this training, an understanding of how to correctly correct courses, create WPS, prepare documents for individual surfaces, install licenses and new software on SOLDAMATIC.

6. Research in Hochschule Esslingen

This chapter describes the first phase of the research, which was carried out at the Hochschule Esslingen. This phase included questionnaire design, practical tests, theoretical tests, WPS, work with Group 1 and Group 2.

6.1 Equal learning conditions

A key role in this experiment is equality of conditions for all groups and, in particular, for each student in front of the other participant. Therefore, during the training sessions all conditions were equal, namely:

- Subject of study.
  Both groups in the research will be supposed to learn welding technique and have good welding skills at the end of the course.
- Course time.
  Each group has 10 hours to complete the course. The first group has 6 hours of training and theory on the SOLDAMATIC welding simulator and then moves on to a workshop for 4 hours of training on a real welding machine. The second group has 10 hours of workshop time on a real welding machine and theory.
- Content
  The training content was the same for all groups. First Group used "DVS Media Grundkurs MAG" on SOLDAMATIC simulator which contains the theoretical and practical tasks. For the second group was used the same content of theory but in printed version and practical tasks on actual welding machines, all was based on "DVS Media Grundkurs MAG".
- Theoretical knowledge.
  Each group has the same theoretical content, but different ways to get it. Group 1 learns all of the theory using the E-Learning platform, and Group 2 learns the theory textbook.
- Terms.
  Both groups work under equal conditions receiving equal support from the trainers.
- The final test.
  The tests that each student gets after 10 hours of work are exactly the same for each participant of the experiment, regardless of which group the person was in.

To summarize the equality of the participants it can be written that during the experiment absolutely the same conditions are created in all areas and that is why this work will be objective.

6.2 Questionary list for Students before start of study

A person's life experience is an important part of the experiment that needs to be known for further objective evaluation of the final tests. For this purpose, a special list of questions was developed for students to answer before the start of the training. This questionnaire includes a number of questions that give specific information about what kind of welding the person has already used, at what level he/she has mastered this kind of welding, have already studied welding on the SOLDAMATIC, as well as what goals he/she has after the course. For example, it can be assumed that one of the students may be a professional in this field or has a personal welding machine that he/she uses daily in his/her garage. So, the results will not be objective because it is not known how many dozens of hours, he/she has already spent to acquire the skill of welding, and the other participants have spent only 10 hours on the entire course.

Below are all the questions and possible answers from this student questionnaire:

1. What is your name and surname?
    - Written response
2. Have you ever tried to use welding before?
    - Yes
    - No
3. If yes, what type of welding did you use?
    - MIG/MAG
    - TIG
    - MMA
4. Your level of welding skills
    - Grade from 1 (Did not use) to 10 (Professional)
5. Have you ever tried to use SOLDAMATIC?
    - Yes
    - No
6. If yes, what type of welding did you study on SOLDAMATIC?
    - MIG/MAG
    - TIG
    - MMA
7. Your level of welding skills on SOLDAMATIC
    - Grade from 1 (Did not use) to 10 (Professional)

8. What level do you want to reach?
    - Just to know how to weld
    - Intermediate
    - Upper-Intermediate (have a welder's certificate)
    - Professional

After completing the experiment, the above questions will help in comparing the two groups of students and in analyzing for a final conclusion.

6.3 Practical Tests for Students

After completing this experiment, it is necessary to determine the results and that is what 3 practical tests were designed for. Each of the participants must complete a full course of practical classes (10 hours) after which they have the opportunity to take 3 tests and complete the experiment.

The first test is the Hochschule Esslingen logo, namely the outline of the logo. The student has to write all the letters of the logo by welding without exceeding the borders (the seam should be exactly in the center between the contour lines). In the first test, all beads must be straight lines.

Test number two uses the same HS logo plates, but the level of difficulty has been increased, namely each of the letters must be written in several continuous lines with a change of welding directions without stopping.

The third practical test is one of the most difficult because it is a butt weld in the vertical position. The workpiece is placed in front of the student and the main task is to weld two strips of metal in a bottom-up direction without stopping.

6.4 Theoretical Test for Students

In addition to practical tests, each of the participants in the experiment was offered one practical test. This type of test is needed to compare the quality of learning theory from different sources. Group 1, which uses mixed learning: augmented reality welding and real welding, learns the theoretical course using the online E-Learning platform. Group 2 works with the usual ways of learning theory, namely with a textbook. Both groups receive exactly the same content of theoretical material and the same questions for the final test. There are a total of 17 questions in the test, each of which is scored 1 point. Later, in the "Analysis" section, it will be summarized which way of learning is more productive.

A couple of examples from the final test are shown below:

- What type of filler is used for MAG?
  - stick electrode
  - wire electrode
  - rod
  - welding powder
- Which type of shielding gas is used for MAG welding?
  - active shielding gas
  - lethargic shielding gas
  - inert shielding gas
  - noble gas
- What dangers are connected with welding?
  - heart attack
  - falling from great height
  - optical radiation and spatter
  - stumbling over objects
- What is the abbreviation for the horizontal position?
  - PA
  - PC
  - PE
  - PF

6.5 Creating of Welding Procedure Specification for Tests

6.5.1 Possibilities

Welding Procedure Specification (WPS) is the most important document for each welder because it is the instruction from engineers for welding process. Each person who welds components on small production or in industry should allow to read and understand WPS. It is not allowed to have misunderstanding or do not take into account this important document.

So that is why in the step of preparation material for this Master Thesis was developed two ways of creating WPS for students who will participate in experiment.

The first way is a special professional software for creating Welding Procedure Instructions and cost calculations. The name of this software is Weldassistant 8. On this step trial version was used.

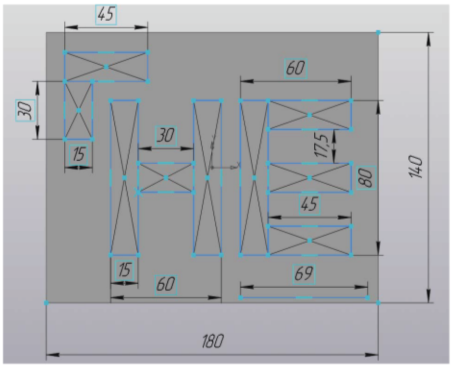
For the first test of students was developed WPS with Hochschule Esslingen logo. Example of this document is given below (Fig. 24).

HOCHSCHULE ESSLINGEN Nah an Mensch und Technik.	Welding Procedure Specification (WPS)	WPS no. 1	Rev. 1
	Hochschule Esslingen Logo		Page 1 of 1

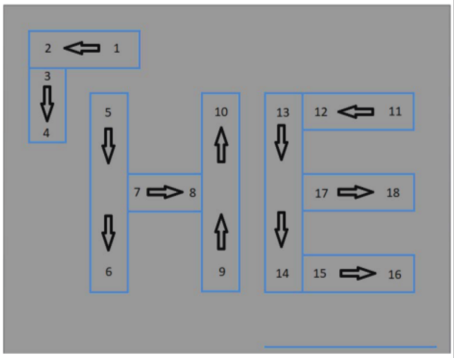
WPQR No.:	BzW 135 P BW PG/003	Method of preparation and cleaning:	Mechanically or by Thermal
Welder qualification:	-	Processing the root weld:	-
Manufacturer:	Hochschule Esslingen	Parent material specification:	Group no ISO/TR 15608:
Joint type:	Bead on Plate	DIN EN 10025 - S235JR	-
Customer:	-		
Order no.:	-	Material thickness:	5 mm
Drawing no.:	1	Outside diameter:	-
Part no.:	1	Welding position:	Horizontally (PB)

Dimensions:

Joint design:



Welding sequence:



Welding details

	Welding pass	Process	O weld filler [mm]	Gas [l/min]	Current [A]	Voltage [V]	Current / Polarity	Wire feed rate [m/min]	Travel speed	Heat input [kJ/mm]
1	Filler pass	135	1	10...12	120...150	17...20	+	3.0...4.5	-	-

Welding filler / welding flux — **Special regulations for drying**

Welding process	Designation	O weld filler [mm]	Brand name	Manufacturer	Time [h]	Temperature [°C]
1	DIN EN ISO 14341 - A - G3S11	0.8	-	-	-	-

Shielding gas

No	Designation	Brand name	Manufacturer	Volume [l/min]	Pre-purge time [s]	Post-purge time [s]
1	DIN EN ISO 14175 - M21 - ArCo2 - 82/18	-	-	10...12	-	-

Preheat

Preheat temperature	-	Interpass temperature	-

Process data

Process	135	Distance	15...20 mm
Process type	semi automatic	Burner angle of attack	75...80°

	Date	Name	Signature
Prepared by	08.11.2021	Vladislav Kadochnikov	
Checked by	12.11.2012	Martin Greitmann	
Released by	12.11.2012	Martin Greitmann	

Source: Weldassistant V8

Figure 24: Welding Procedure Instruction for the first test

Source: own developed in Weldassistant 8

The second way to create WPS is to use SOLDAMATIC E-Learning platform. In the program section "Modules" possible to create new module and add new exercises. During the process of creating exercise, it is possible to create WPS. Example of WPS from SOLDAMATIC E-Learning given in (Fig.25) below.

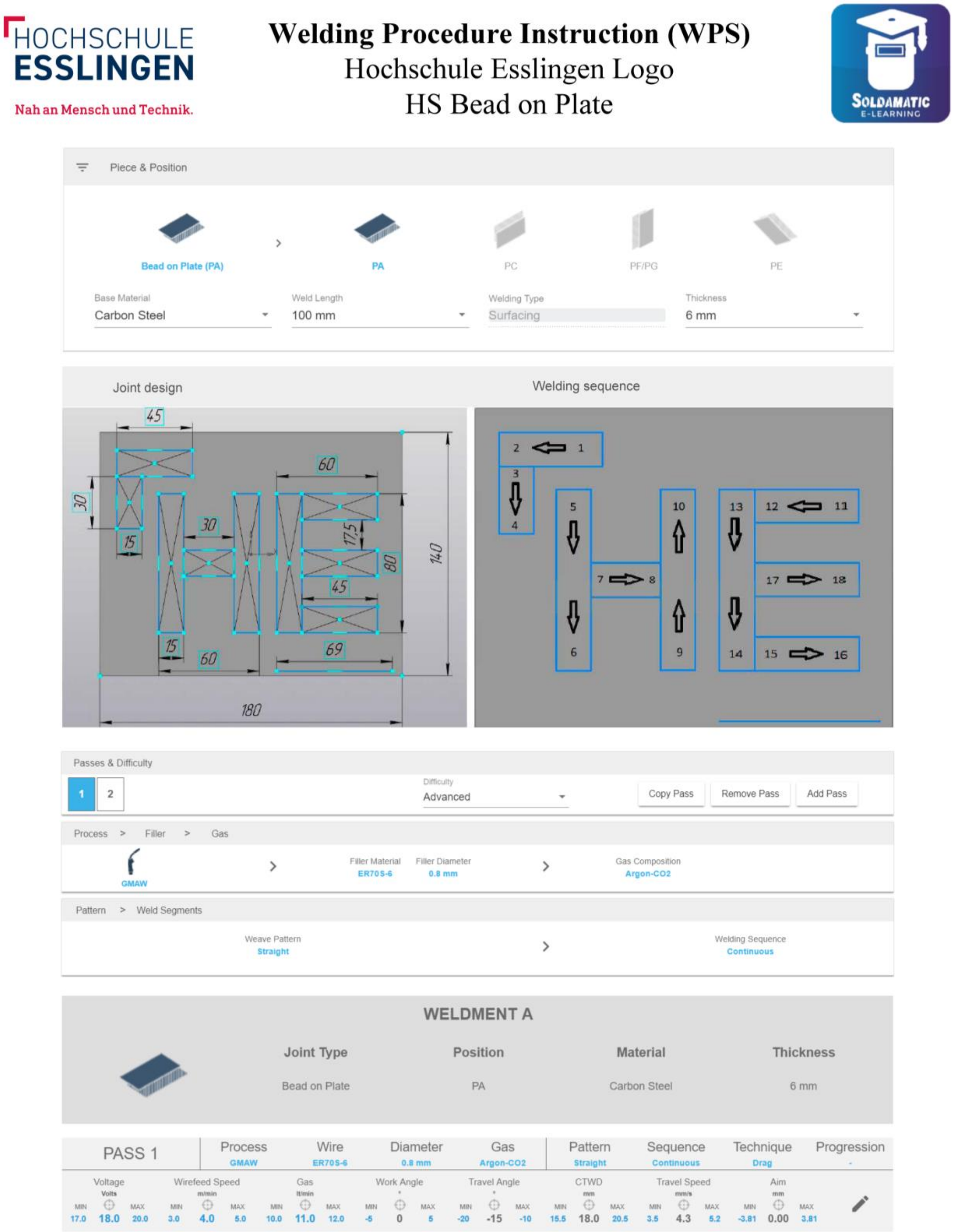


Figure 25: Welding Procedure Instruction for the first test

Source: own developed in SOLDAMATIC E-Learning V3.2.1 platform

6.5.2 Demands and Problems

During the development of the WPS, several key issues for this work were identified as follows.

The first problem is related to the professional software Weldassistant 8. It is not allowed to use this program more than 30 days (trial period) after person who use it should buy full version for later use. Also, there are restrictions for trial version.

The second problem is more interesting for this experiment. In E-Learning platform not possible to create final version of WPS in pdf file because it is allowed only to open windows with pictures of this document (Fig. 26). To generate pdf format only available to do screenshots and then compose WPS in pdf editor. Adobe Acrobat DC software was used for this purpose as it shown in (Fig. 25).

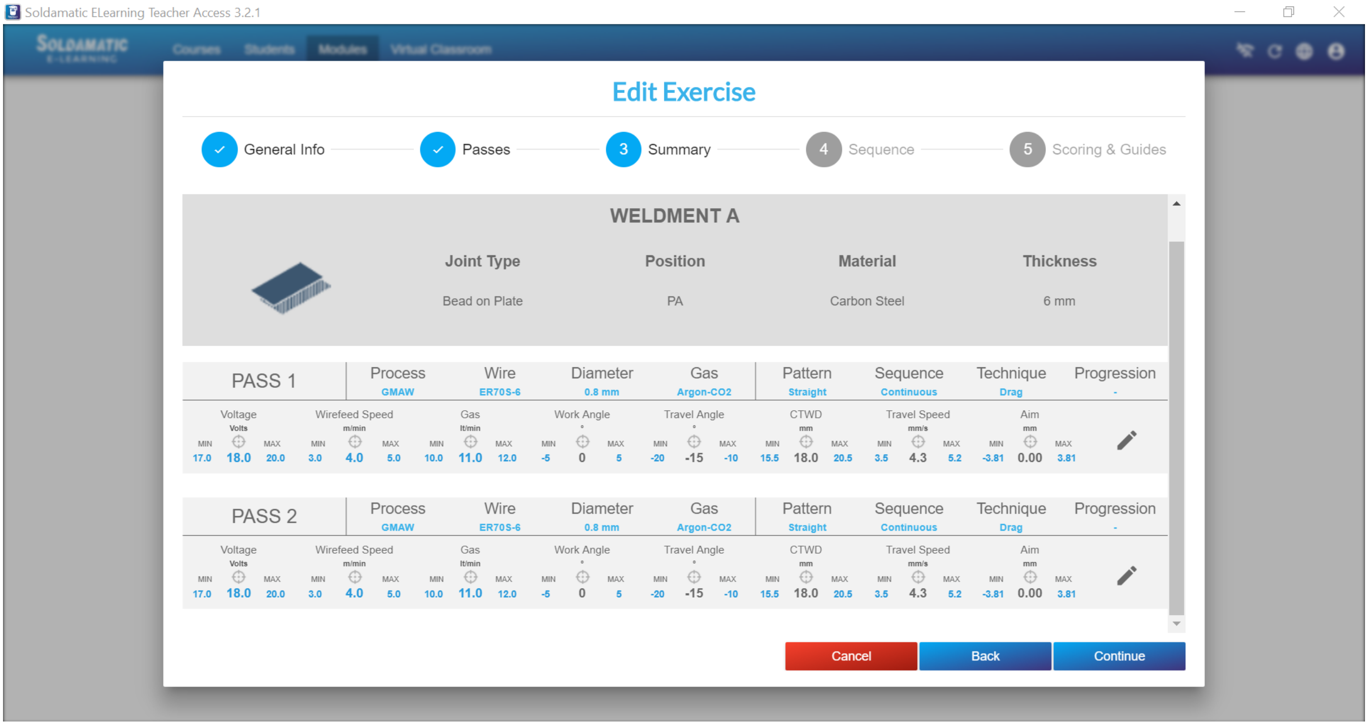


Figure 26: screenshot of WPS example in SOLDAMATIC E-Learning V3.2.1

Source: own developed in SOLDAMATIC E-Learning V3.2.1 platform

6.5.3 Results

To summarize all of the above in this chapter, there are several important points that can improve this E-Learning platform:

- Add more metal thicknesses to the list for user selection
- Add the ability to download the Welding Procedure Specification in pdf format after creating a new practical task
- Add the possibility to upload own CAD data in order to create a new bead contour on surface.

These three points are important for users because after the training on augmented reality welding simulator SOLDAMATIC, user should be allowed to work in workshop with real welding machine with the same tasks and for it WPS needs to be saved in pdf and printed without any problems.

6.6 Test Specimens for Students

A design based on the Hochschule Esslingen logo was developed for the first and second tests.

The first step was to come up with a design and sketch it on paper with approximate dimensions. After that the design was transferred to an electronic form, i.e. the design was made in Creo 5.0.4. The drawing is a virtual CAD model of the future sample made of metal (Fig.27).

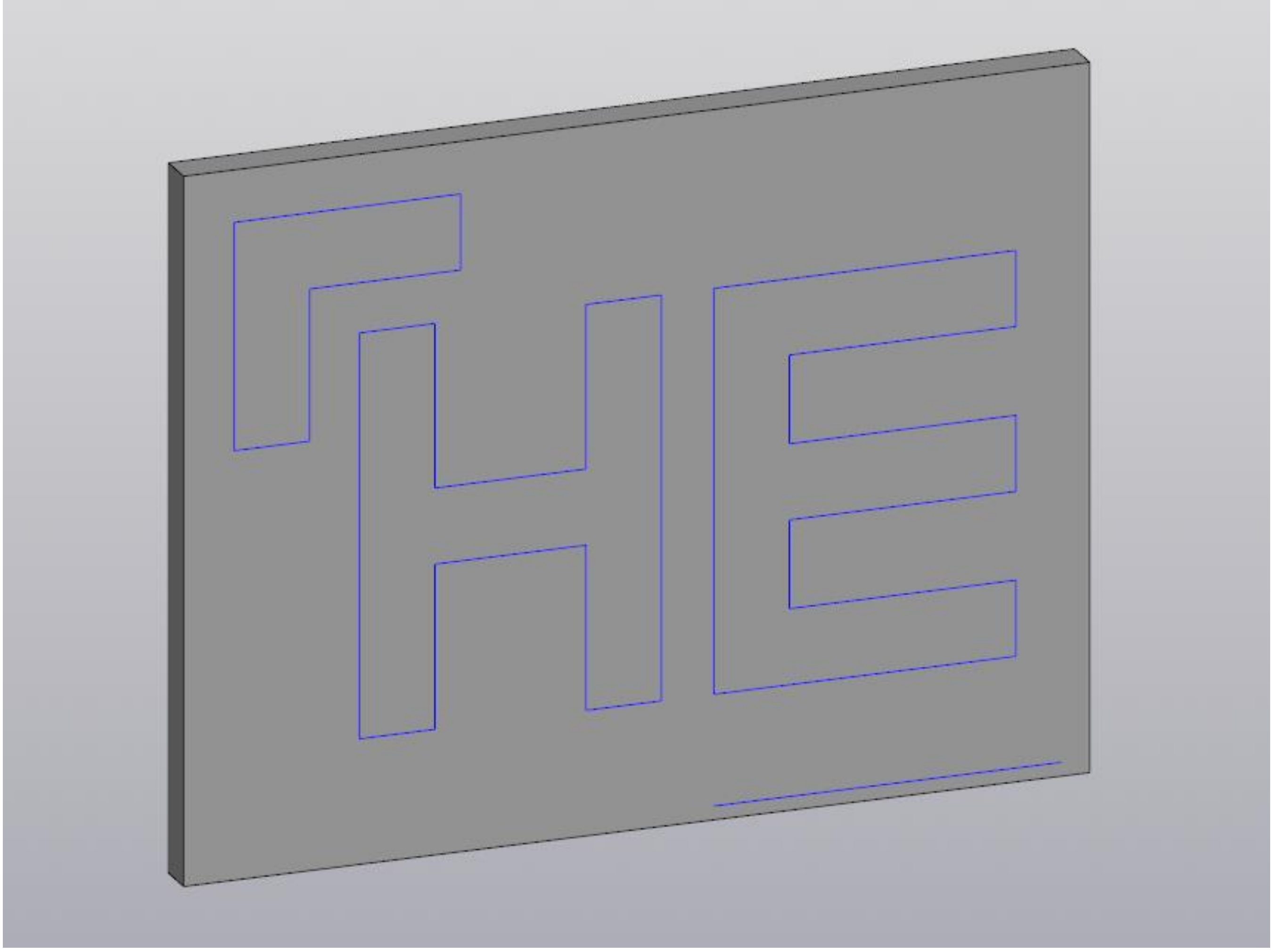


Figure 27: CAD HS logo model for the first test
Source: own developed in Creo 5.0.4

Next step was conversion of the received CAD drawing into .dxf format and loaded into TruTops program for further cutting out on laser TRUMPF TruLaser Cell 3000 in Hochschule Esslingen Lab (Fig.28).

Figure 28: TRUMPF TruLaser Cell 3000 in Hochschule Esslingen Lab

Source: self-made

After the previous step, a laser had to be used to cut this plate out of a 5 mm thick sheet of carbon steel. In the last step, in addition to uploading the CAD sketch to TruTops, the laser sequence was also created in the same software. Namely the order in which the laser will move along the lines and at what power the contour line and the lines that make up the letters will be cut. The use of different laser powers is explained by the fact that it takes more power to cut a sign out of metal than just drawing the outline of the letters on a sheet of metal. So after successfully uploading a file from the TruTops software to the laser, two plates were cut from a sheet of metal (Fig.29).

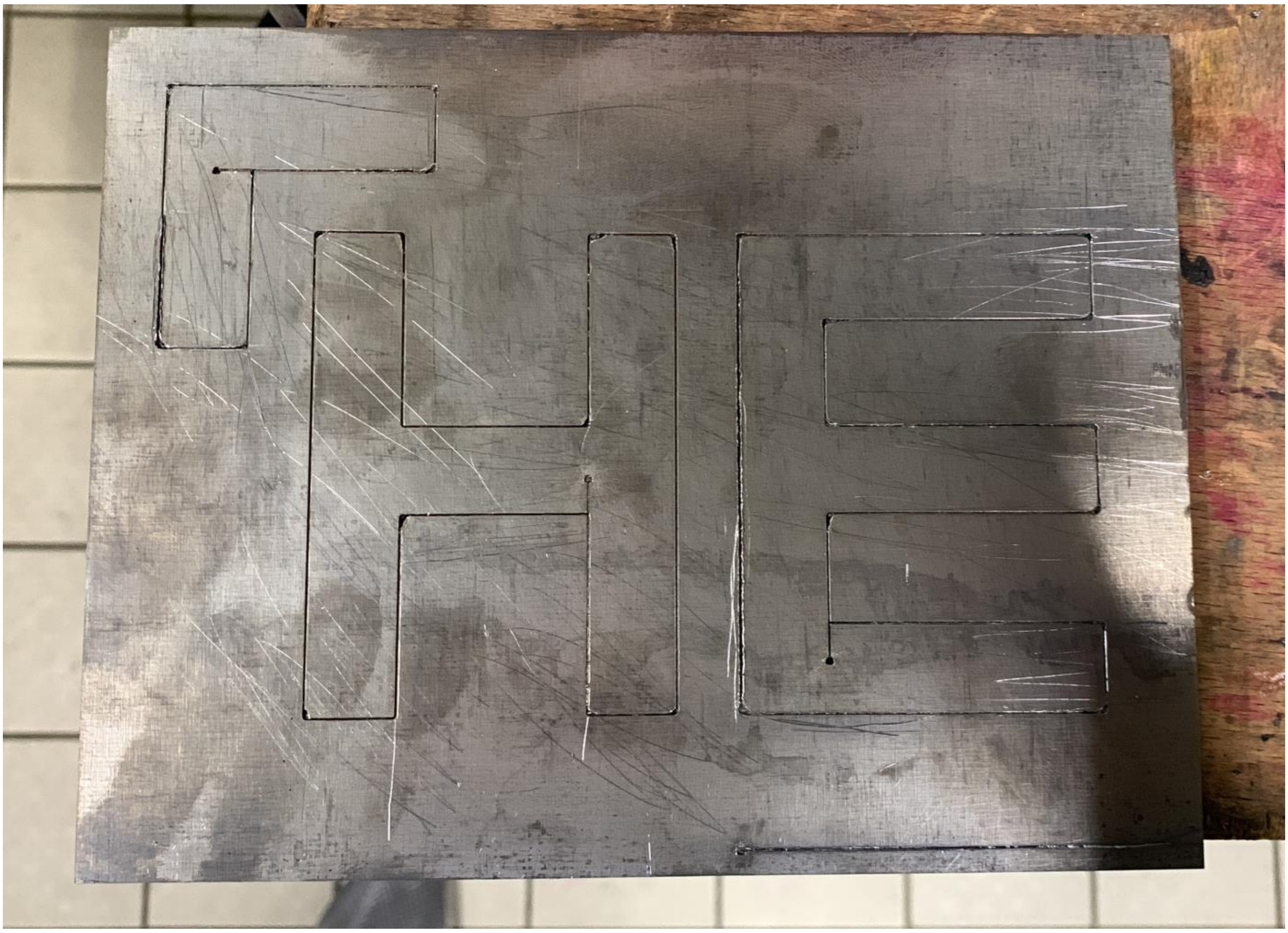


Figure 29: First specimen of the HS plate
Source: self-made

In addition to the above, the dimensions of the plate (Fig.30). The dimensions of the plate are 140x180x5 mm and letters are 80x60 mm, thickness is 15 mm. The thickness of the letters was chosen based on the thickness of the actual welding seam. In the laboratory of Hochschule Esslingen several pieces of metal were found welded together and the real dimensions of the weld were measured.

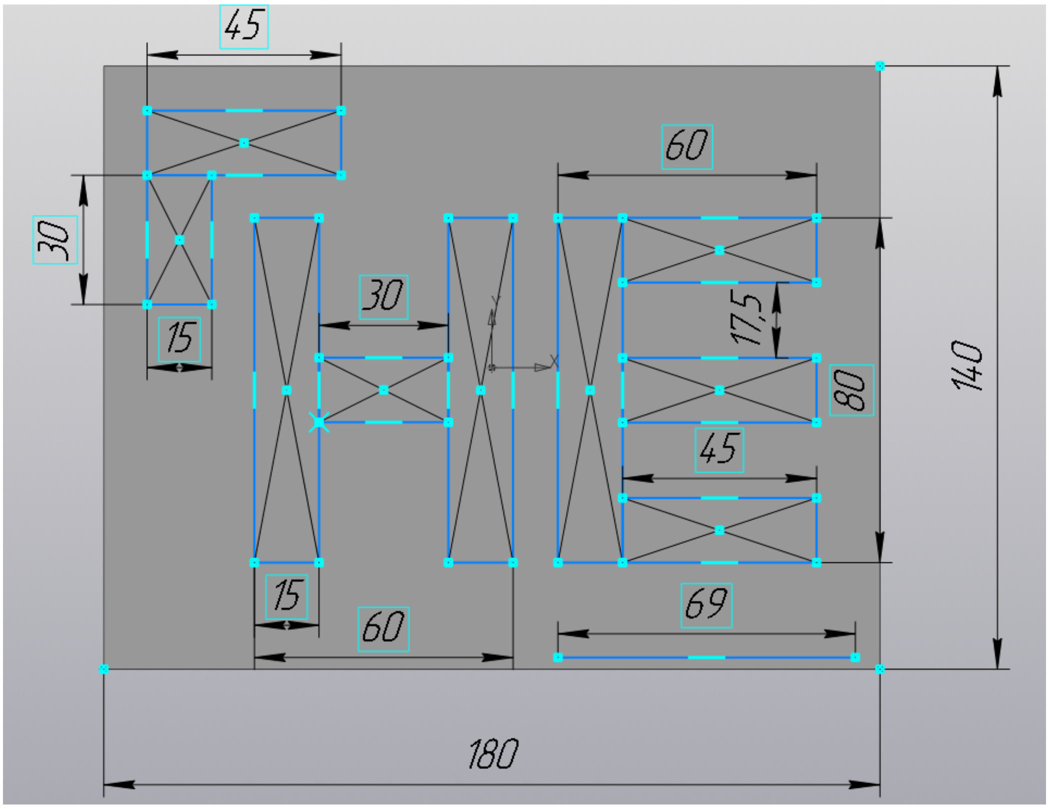


Figure 30: Dimensions of the HS plate

Source: own developed in Creo 5.0.4

For the third test, 200x60x5 metal strips were prepared for the butt weld (Fig.31).

Figure 31: Metal strips

Source: self-made

6.7 Work with Mixed training Group 1: Augmented Reality Welding and Workshop

6.7.1 Student's profile

All participants are studying in Hochschule Esslingen. Students participating in the experiment are studying Mechanical Engineering, Automotive Engineering and Computer Engineering and some of the them already had a theoretical course "Joining Technology" at university, but in any case, everyone has to take a theoretical course "DVS-Media Grundkurs MAG" on E-Learning platform in order to have the same level of knowledge. People belong to the age category of 20 to 32 years old. Also, only few students have slight experiment with real welding so that's why it can be considered that the group is fresh without any practical welding skills.

6.7.2 Step 1. Working on SOLDAMATIC

In this course, each participant receives 6 hours of practical training on the SOLDAMATIC before moving on to actual welding (Fig.32). During the course "DVS-Media Grundkurs MAG" the student has 7 units and 3 practical lessons in each unit. These tasks are of different difficulty levels: beginner, intermediate and advanced. During the allotted time for the course, each participant goes through a different number of practical tasks (a total of 21 exercises). According to practice, each student completes more than two-thirds of the course (14 exercises). But it was also found that 2 tasks are not available for execution due to an unknown error with the license, respectively, the total number of tasks is reduced to 19. From all of the above it is possible to conclude that each participant from group 1 completed at least 74% of the course, and many more.

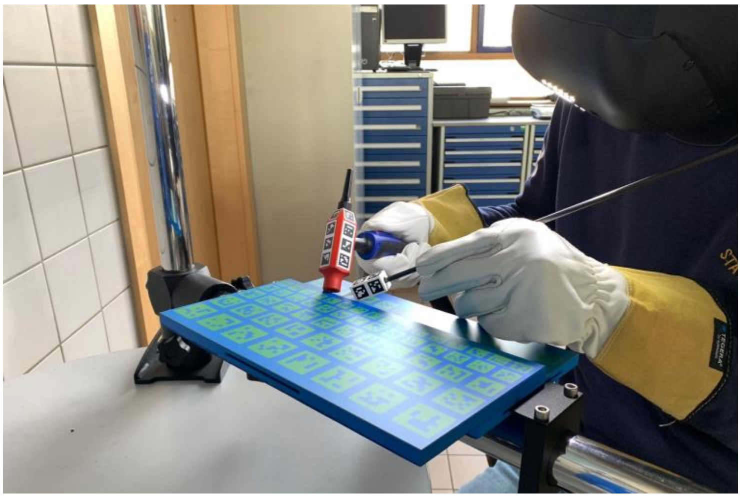


Figure 32: Augmented Reality Welding

Source: self-made

6.7.3 Step 2. Studying theory in E-Learning

A parallel step in this experiment is the study of theory. Participants learn theoretical material in parallel with practice using an online platform from anywhere convenient for them. "DVS-Media Grundkurs MAG" can be accessed in the personal accounts depending on which course the student is taking. There are also seven units in the course and each unit contains one theory section and one question section to reinforce the theory readings. Each participant must complete 100% of the theory for the course. During the experiment there were no problems with this item, all students safely completed the theoretical part.

6.7.4 Step 3. Working in Work Shop

One of the most important steps in welding training in this course is to move from a simulator to a workshop for training on a real welding machine (Fig.33). This step takes 4 hours, which is enough time to get used to and transfer all the knowledge gained in the simulator to real welding conditions. Students perform similar tasks to those studied at SOLDAMATIC welding simulator. Also, the resources used at this stage such as metal, gas, wire are monitored. Preparation of welding machines and metal for the research was carried out by the technical specialist of the university.

Figure 33: Workshop
Source: self-made

6.7.5 Step 4. Final Tests

In this final step of the experiment, students are tested both theoretically and practically. More detailed descriptions of the tests are given in the paragraphs: 6.3 and 6.4. Each participant spends on average about 20 minutes for the 3 practical tests and about 20 minutes for the theoretical test. Samples of the final three tests are shown below (Fig.34).

Figure 34: Final tests
Source: self-made

6.7.6 Work process tracking

A special point in the work with Group 1 is the control of the training process of the participants. This process is possible with the help of E-Learning platform and is especially convenient for instructors. In this program there is an opportunity to receive a report on the student, on the work done, on the skills acquired and an understanding of how much they have improved. In the process of working with students this possibility was used to monitor the training and to give each participant individual advice on what to pay attention to in order to improve welding technique and quality. So below are an example of such a report and a couple of charts that the platform provides (Fig.35).

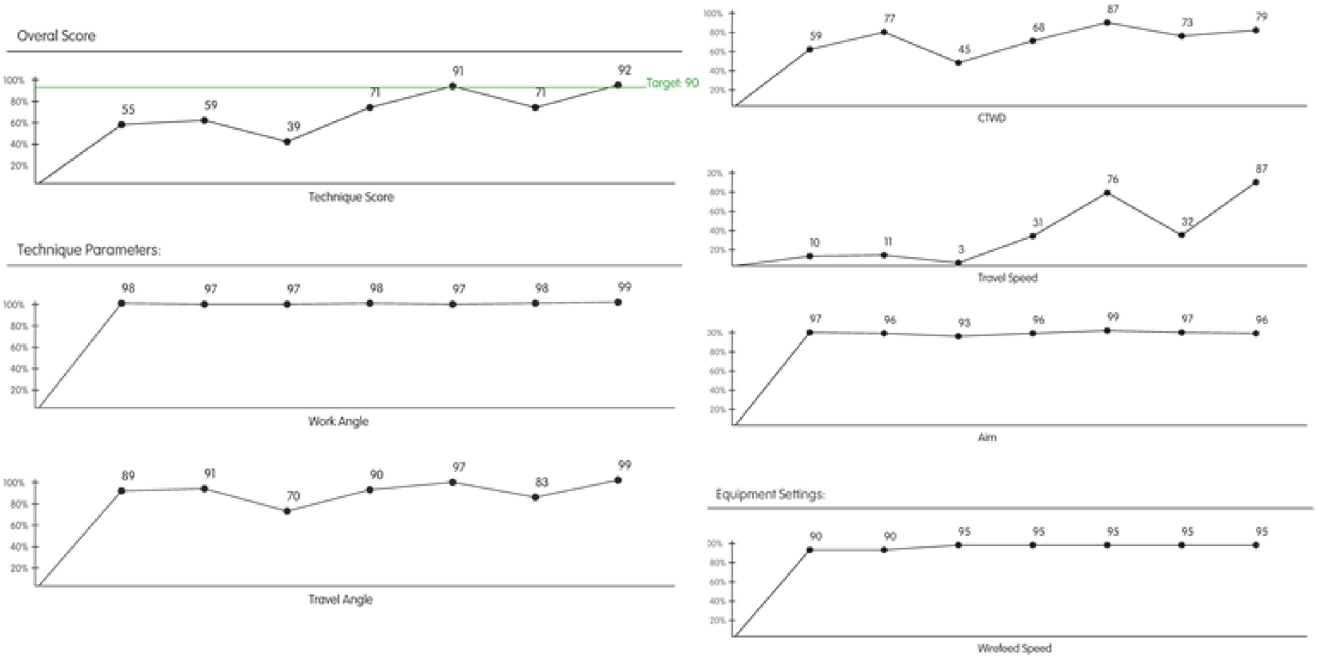


Figure 35: Report from E-Learning v3.2.1

Source: self-made in E-Learning v3.2.1

This report provides graphs for improving various parameters that are important for the welding process, such as work angle, travel angle, distance between the welding gun and the surface, travel speed, etc. As the course progresses, new points are added to the chart and it is good to keep track of improvements in a participant's skills. Also, the first chart: Overall Score gives a good understanding of the progression of the student's work.

Why is this point given special attention?

The main purpose of welding training is to train students as well as possible in this skill. In traditional workshop training there is no possibility for such a detailed control of students' welding techniques and parameters. That's why special attention was paid to this point. For example, in the training of group 2 there is no possibility to monitor all welding parameters of the students in such a detailed way.

6.8 Working with Group 2 in Work Shop on Real Welding Machine

6.8.1 Student’s profile

All Group 2 participants are Hochschule Esslingen students pursuing a Bachelor's or Master's degree in fields such as Mechanical Engineering or Automotive Engineering. The age range of the participants is 20-33 years old. Similar to the people in Group 1 some have already had a "Joining Technology" course in the course of their studies. To create a level playing field for both groups, all participants learned the theory, the content is the same for all groups.

6.8.2 Step 1. Studying theory with textbook

Before the beginning of the practical training, the student learned the theoretical part. In order to compare and further understand which method of learning the theory of welding is more productive: using the digital platform E-Learning or using the printed version of the textbook, this group worked with the printed textbooks. The content of the theory is the same for all groups.

6.8.3 Step 2. Working in Work Shop

The Group 2 training took place in a workshop for the entire 10 hours, during which each participant learned different methods of welding metal starting with straight lines on the surface and ending with such methods as overlap weld, t-joint weld, butt weld in different positions.

6.8.4 Step 3. Final Tests

At the end of the training, each participant was given the opportunity to take practical tests (Fig.36); there were three of them as described in paragraphs 6.3 and 6.4. In addition, everyone performed theoretical tests to help get the results of the research in the future. In total, each participant spent about 40 minutes for both types of tests.

Figure 36: Final tests
Source: self-made

6.8.5 Work process tracking

During the experiment, control of the learning process was carried out personally by the author of the research. In this way it was possible to show, answer questions and help students in the process of work. This type of training does not have any other possibility to control the participants as for example in Group 1, where the E-Learning digital platform provides reports on the progress of each student.

6.9 Questionary list for Students from Group 1 after the training

After each participant finishes the experiment, ask about their feelings and feedback on the course and equipment. A second questionnaire was developed for this purpose. Each student has to answer 9 questions from the questionnaire and indicate what they liked and disliked about SOLDAMATIC. This information will help to further analyze the experiment and draw conclusions. Below are shown all the questions from the questionnaire:

1. What is your name?
   - free answer
2. What is your age?
   - free answer
3. How would you rate your experience with SOLDAMATIC?
   - Rate from 1 (Bad) to 10 (Perfect)
4. What did you like the most in work with SOLDAMATIC?
   - free answer
5. What did you like the least in work with SOLDAMATIC?
   - free answer
6. What advantages do you think digital training has over traditional training?
   - free answer
7. What disadvantages do you think digital training has over traditional training?
   - free answer
8. Do you know of any other simulators?
   - Yes/No
9. Would you recommend SOLDAMATIC to a colleague?
   - Yes/No

6.10 Resources consumption by SOLDAMATIC

The issue of resource consumption is very important in the 21st century, every company that produces any kind of equipment is trying to reduce the consumption of resources with its products. In this case, the company Seabery developing an augmented reality simulator SOLDAMATIC also improves its product and struggles to reduce the consumption of electricity by this simulator.

6.10.1 Electricity consumption

Why only electricity?

SOLDAMATIC simulator is essentially a computer. Using Seabery technology this computer is transformed into an augmented reality simulator for training people in welding. So apart from SOLDAMATIC nothing consumes more than electricity.

Based on the technical documentation for this device can be calculated electricity consumption and to confirm this information were also made real measurements of electricity consumption.

To calculate SOLDAMATIC electricity consumption, simple formula needs:

$$P_{fin} = V \times I \times t,$$

where P_{fin} – final consumption of electricity [kWh], V – voltage [V], I – amperage [A], t – time [h]

- Calculation based on values from the technical documentation:
  From the documentation the required parameters of the power supply unit are known, such as Voltage=220V and Amperage=2.95A

$$P_{fin} = V \times I \times t = 220V \times 2.95A \times 1h = 650\ Wh = 0.65\ kWh$$

  Thus, obtained that the electricity consumption of the SOLDAMATIC is 0.65 kW per hour.

- Calculation based on figures from actual measurements with Dewetron:
  After measuring in different modes, a number of current values were set and the average current value was calculated. Thus, the SOLDAMATIC welding simulator requires I=0.89A to power the unit. The actual value is lower than the stated value on the power supply, which is a good sign for power consumption.

$$P_{fin} = V \times I \times t = 220V \times 0.89A \times 1h = 196\ Wh = 0.196\ kWh$$

Graph below shows a graph of the current received in the course of measurement on the Dewetron device (Fig.37).

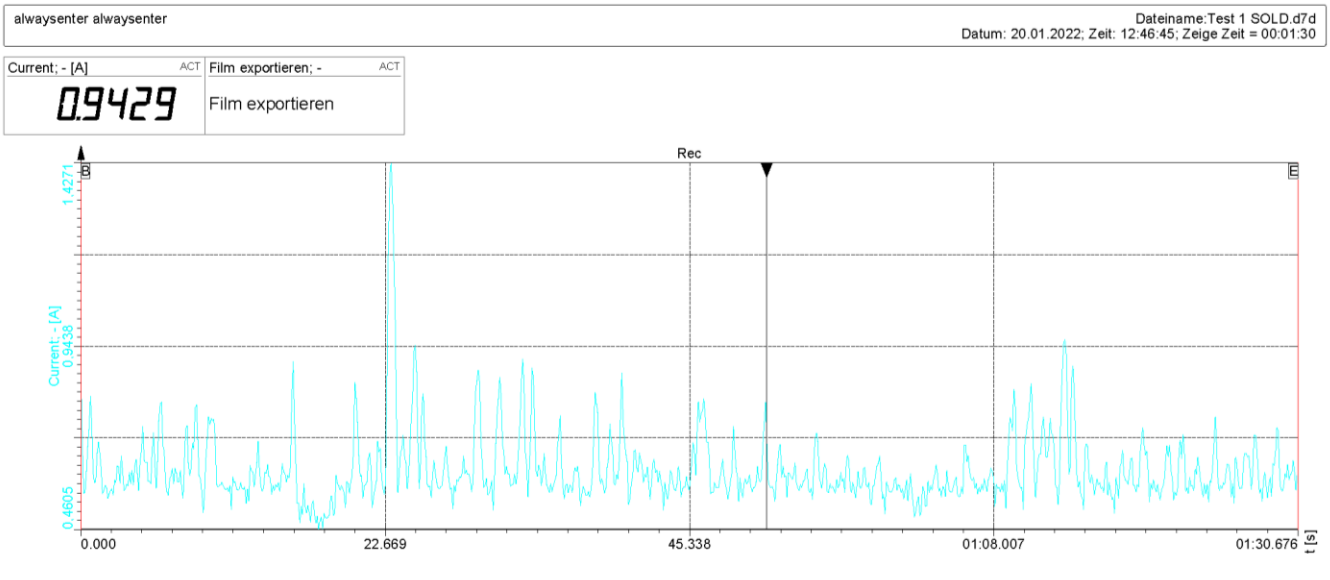


Figure 37: Measurement of Current on Dewetron

Source: own measured values with DEWESoft

The SOLDAMATIC is a computer so it consumes electricity all the time when this simulator is on and consumption is independent of whether it is being worked on or not. In further calculations will be used the value obtained in the experimental measurement: 0.196 kWh.

6.11 Resources consumption by Welding Machine

This chapter discusses the consumption of various resources by the actual welding machine. Unlike the SOLDAMATIC the welding machine not only consumes electricity during the welding process but also consumes fusible electricity and gas. All factors must be taken into account, therefore the calculation of the consumptions of the different resources of the welding machine will be described below in the following subchapters.

6.11.1 Electricity consumption

One of the most interesting questions is the comparison of the electricity consumption of a real welding machine and the SOLDAMATIC welding simulator. It is clear in advance that the difference in electricity consumption will be tremendous, but it is better to confirm this point of view with numbers. That's why below the calculation of electricity consumption by the welding machine will be made and then the real measurement of electricity consumption in the laboratory will be given. It is also possible to verify the validity of the data from the manual for the welder, comparing the calculated consumption and the real one after the measurements.
For calculating electricity consumption of real welding machine formula from last calculations should be used:

$$P_{fin} = V \times I \times t,$$

where P_{fin} – final consumption of electricity [kWh], V – voltage [V], I – amperage [A], t – time [h]

- Calculations based on values from instruction for welding machine: V= 380 V, I=34.5 A

$$P_{fin} = V \times I \times t = 380V \times 34.5A \times 1h = 13110\ Wh = 13.1\ kWh$$

That is mean that real welding machine consumes 13.1 kW per one hour. In few words, consumption of one welding machine per hour = consumption of 20 SOLDAMATIC units per hour.

- Calculations based on obtained values during the real measurement in lab:
  It is not possible to measure the current on the actual welding machine with the Dewetron because it is necessary to cut the wire coming out of the welding machine into the socket. The Rogowski belt can only measure the current correctly if the measurement is made on one wire

strand. Therefore, the value obtained in the previous point will be used in further calculations: 13.1 kWh.

Moreover, there was an additional measurement of time participants worked on the welder. Each participant spends on average 80-85% of the total time on the welding process, because it is not possible to get this number absolutely accurate, let's assume that on average each participant worked 82.5% and rounded to 83%. In accordance with this, the power consumption will be calculated later on.

6.11.2 Consumption of Shielding gas, Feed wire

As previously mentioned, the welder not only consumes electricity and additional resources during the welding process or training such as wire and gas. In this paragraph a discussion of these costs is presented. Since in the experiment only the MAG process is used, the gas that is consumed is Argon-CO_2 with a percentage of 95-5%. The melting electrode used for MAG welding is ER70S-6 with a diameter of 0.8 mm.

Calculations are based on values from actual measurements at the Hochschule Esslingen laboratory. During the experiment two welding machines from different manufacturers are used: EWM and Rehm. The wire consumption is different, the EWM machine has a consumption of 3.4 m/min and the Rehm machine 5 m/min. Similarly, the consumption of ArCo2 gas EWM is 18 l/min and Rehm's consumption is 12 l/min. Consumption per hour for these materials is calculated below.

- Filler Wire: since two welding machines are used by 10 participants, namely, each of the machines in use by 5 people, the calculation of W_{fin} is made as average value of wire consumptions.

$$W_{EWM} = 3.4\frac{m}{min} = 204\frac{m}{h}, \text{where } W_{EWM} - \text{consumption of wire by EWM machine per 1 hour}$$

$$W_{Rehm} = 5\frac{m}{min} = 300\frac{m}{h}, \text{where } W_{Rehm} - \text{consumption of wire by Rehm machine per 1 hour.}$$

$$W_{fin} = \frac{W_{EWM} + W_{Rehm}}{2} = \frac{204\ \frac{m}{h} + 300\frac{m}{h}}{2} = 252\frac{m}{h}, \text{where } W_{fin} - \text{final consumption per 1 hour.}$$

After that, this gives us the actual wire consumption per hour while working with the welders.

- Gas: similarly, for gas consumption, because the participants work on two welding machines in equal quantities, the average value of gas consumption per hour will be calculated.

$G_{EWM} = 18\frac{l}{min} = 1080\frac{l}{h}$, where G_{EWM} – comsumption of gas by EWM machine per 1 hour.

$G_{Rehm} = 12\frac{l}{min} = 720\frac{l}{h}$, where G_{Rehm} – consumption of gas by Rehm machine per 1 hour.

$G_{fin} = \frac{G_{EWM} + G_{Rehm}}{2} = \frac{1080\frac{l}{h} + 720\frac{l}{h}}{2} = 900\frac{l}{h}$, where G_{fin} – final consumption of gas per 1 hour.

The values of W_{fin} and G_{fin} will be used in calculations of total consumptions for Group 1 and Group 2.

As in the previous chapter, it should be taken into account that each participant spent 83% of the time working on the welder, respectively this will affect both the consumption of wire and gas.

6.12 Emissions of CO_2 in atmosphere due to Metal and Electricity consumption

The topic of sustainability and environmental protection has been raised more and more in recent years. Mankind is actively fighting to reduce emissions into the atmosphere and is trying to produce more environmentally friendly, less resource-intensive products.

Therefore, in this chapter to calculate the CO_2 emissions from the main resources used in welding training, namely electricity and metal.

In order to prepare the calculations, the average values of CO_2 per 1 kg of metal and 1 kWh of electricity were analyzed and found. By studying the articles on this topic in the internet, 6 useful articles were found.

The amount of CO_2 per 1 kg of metal?

Three companies have asked themselves this question and have written useful articles on which the calculation for this job is based. Carbon Clean, Bellona and McKinsey & Company agree in their articles on one value, 1.85 tons of CO_2 emissions per 1 tons of steel produced.

$$1.85 \text{ tons } CO_2 = 1 \text{ ton Metal}$$

$$1850 \text{ kg } CO_2 = 1000 \text{ kg Metal}$$

$$1.85 \text{ kg } CO_2 = 1 \text{ kg Metal}$$

After conversion into the right units received that in the process of production 1 kg of metal emits 1.85 kg of CO2 into the atmosphere. The obtained ratio is used for further calculations. (Carbon Clean 2021), (Bellona 2019), (Hoffmann et al. 2020)

The amount of CO_2 per 1 kWh of electricity?

In order to establish this ratio, three articles were also identified on which the calculation is based. Companies such as EIA, Volker-Quaschning and Quora wrote that 1 kWh of electricity produces 0.39/0.33/0.62 kg of CO_2, respectively. These values are for combined type power plants, which are more modern. Thus, an average value is taken for further calculations.

$$\text{Mean Value of } \mathrm{CO_2} \text{ emissions} = \frac{0.39 + 0.33 + 0.62}{3} = 0.45 \text{ kg of } \mathrm{CO_2}$$

$$0.45 \text{ kg } \mathrm{CO_2} = 1 \text{ kWh Electricity}$$

Thus, the production of 1 kWh of electricity produced 0.45 kg of CO_2 emissions into the atmosphere. (EIA 2021), (Volker-Quaschning 2021), (Barnard 2017)

7. Research in Audi

The Audi Academy in Neckarsulm was also interested in this research and provided the opportunity to conduct the investigation at their academy as well. The research was based on the same principle of organization as at Hochschule Esslingen.

7.1 Equal Learning Conditions and Participant's Profiles

The research at the Audi Academy involved 11 Audi employees who were trained at the academy as mechatronics specialists. Most of the participants had no experience in this field prior to the training. They were divided into two groups: the first group was trained in welding technology using the SOLDAMATIC augmented reality simulator (5 participants), the second group was trained in the traditional welding method from the first day using real welding machines (6 participants). This training was planned for 12 participants, but for an unforeseen reason one participant dropped out of the experiment, but even so, the research was successfully completed.

The training took place for 5 working days, every day from 7:00 to 15:00 (7 hours per day), so that the total number of training hours was 35. The material used in the welding training was Mild Steel 1.0 mm and 1.5 mm thick.

7.2 Questionary list for Participants

For further, more qualitative analysis, a questionnaire was developed for research participants to understand their background and their attitudes toward the research conducted. The following are two lists of questions for each of the groups. These questionnaires are different because both groups had different welding training paths.

Audi Questionary. Group 1.

1. What is your name?
   - free answer
2. What is your age?
   - free answer
3. Have you ever tried to use welding before this training?
   - Yes
   - No
4. If yes, what type of welding did you use?
   - MIG/MAG

- TIG
- MMA

5. Your level of welding skills before this training
   - 1 (Didn't hold a welding gun in my hands) – 10 (Professional)
6. Have you ever tried to use SOLDAMATIC before this training?
   - Yes
   - No
7. If yes, what type of welding did you study on SOLDAMATIC?
   - MIG/MAG
   - TIG
   - MMA
8. Your level of welding skills on SOLDAMATIC before this training
   - 1 (Didn't hold a welding gun in my hands) – 10 (Professional)
9. What level do you want to reach?
   - Just to know how to weld
   - Intermediate
   - Upper-Intermediate (have a welder's certificate)
   - Professional
10. How would you rate your experience with SOLDAMATIC?
    - 1 (Bad!) – 10 (Perfect!)
11. What did you like the most in work with SOLDAMATIC?
    - free answer
12. What did you like the least in work with SOLDAMATIC?
    - free answer
13. What advantages do you think digital training has over traditional training?
    - free answer
14. What disadvantages do you think digital training has over traditional training?
    - free answer
15. Do you know of any other simulators?
    - Yes
    - No
16. Would you recommend SOLDAMATIC Augmented Reality to a colleague?
    - Yes

- No

Audi Questionary. Group 2.

In this list of questions, the first 10 are the same as the questions for Group 1.

11. What did you like the most in work with real welding machine?
    - free answer
12. What did you like the least in work with real welding machine?
    - free answer
13. What advantages do you think has traditional training over digital training? (Just your assumption)
    - free answer
14. What disadvantages do you think traditional training has over digital training? (Just your assumption)
    - free answer
15. Would you recommend training to a colleague?
    - Yes
    - No
16. Would you like to have training on a SOLDAMATIC Augmented Reality simulator in the future?
    - Yes
    - No

7.3 Test Specimens

For the final practical test, the same metal was used as during the entire training. Sheet metal was cut by the participants of the experiment into strips 62x150 mm in size. For the last test, the Audi logo plate, the metal was cut to a size of 160x250 mm (Fig.38). After that, each participant independently marked the points of each letter with a puncher and then connected them with a special metal marking rod. Also, by the real Audi logo (four rings), using the same tool, the contour of these rings was outlined. After that, for a more comfortable vision in the welding process the markings were outlined with a special metal marker.

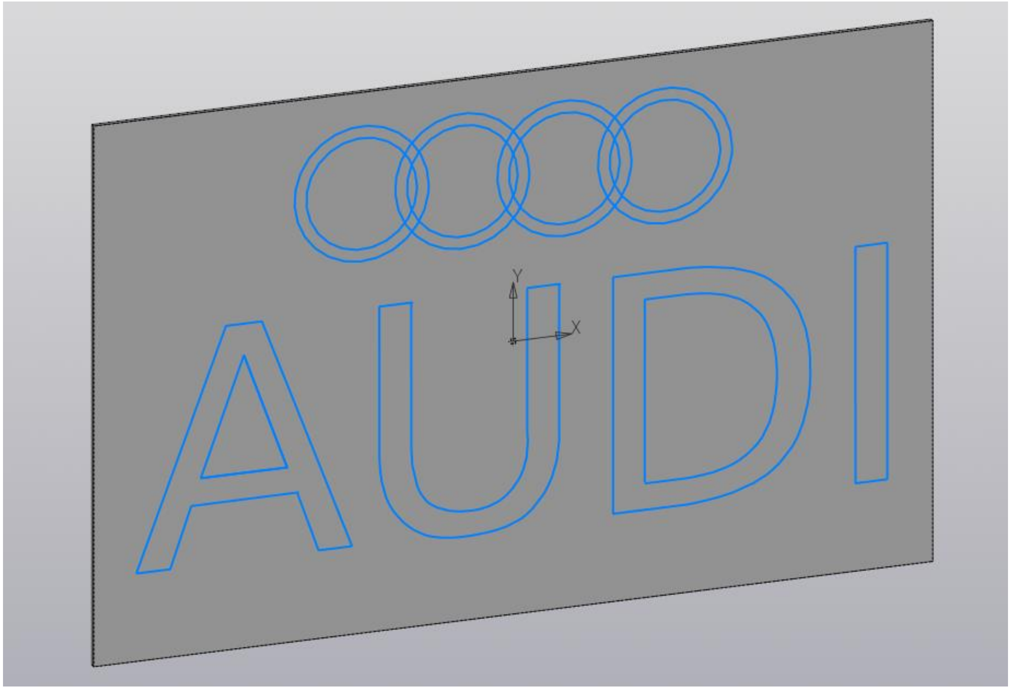


Figure 38: CAD Audi logo model

Source: own developed in Creo 5.0.4

7.4 Tests for Participants

To conduct the research at the Audi Academy, a test was developed to check the welding skills acquired during the training. The theoretical test used was the same as the one at Hochschule Esslingen. The practical test included four parts:

1. Overlap welding in horizontal position (PA), steel thickness 1.0 mm (Fig.39, Fig.40).

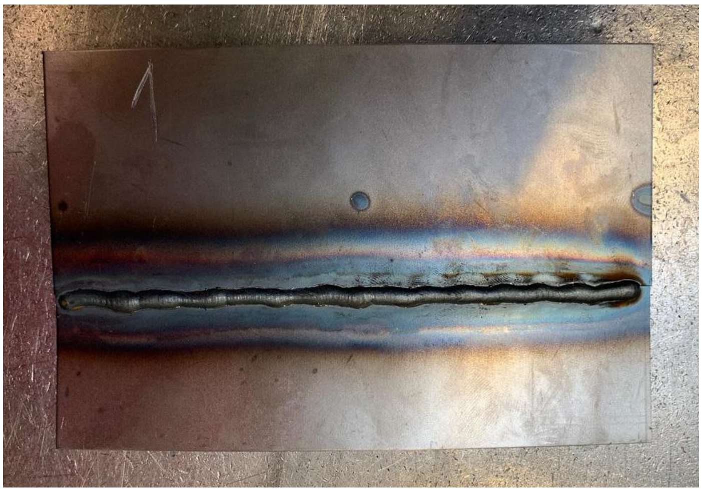


Figure 39: Overlap welding

Source: self-made

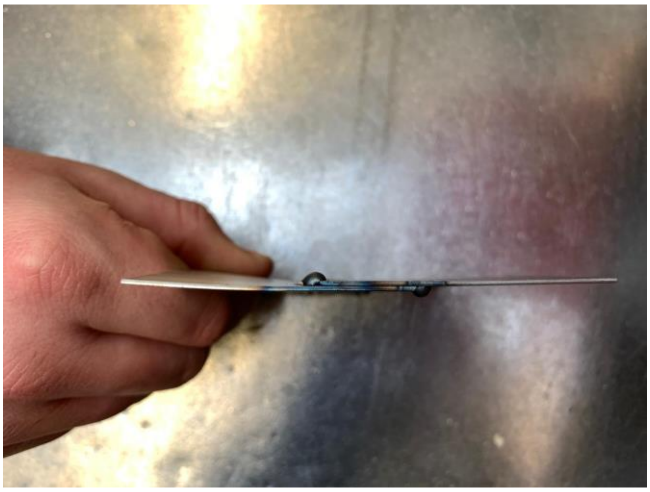


Figure 40: Overlap welding side view

Source: self-made

2. T-Joint in horizontal position (PB), thickness of 1.0 and 1.5 mm (Fig.41).

Figure 41: T-Joint weld

Source: self-made

3. Butt weld in vertical position (PF), welding from the bottom up, 1,5 mm steel thickness (Fig.42).

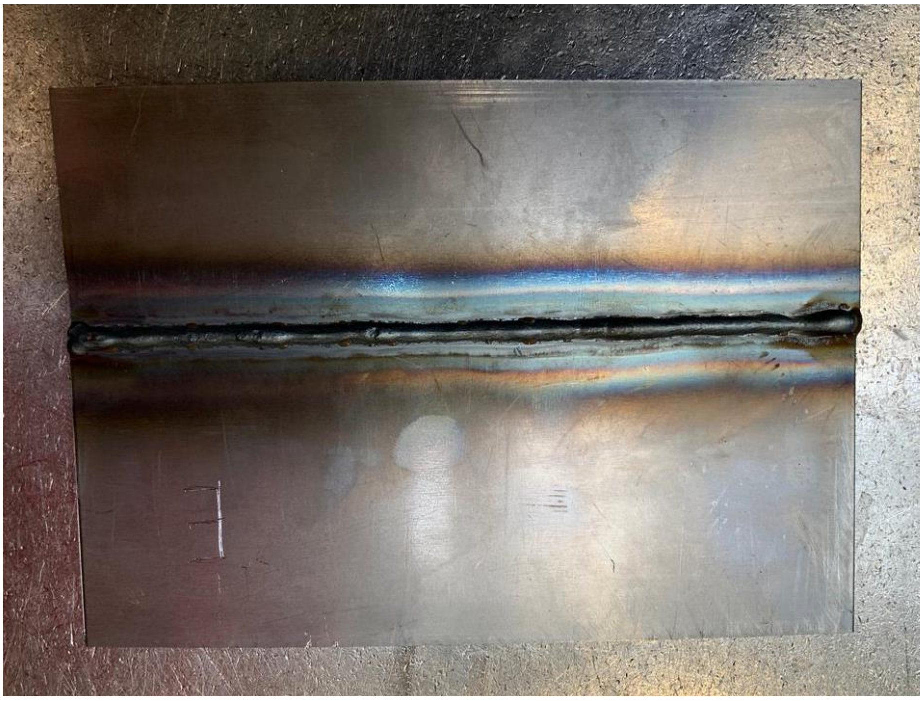


Figure 42: Butt weld

Source: self-made

4. Audi logo plate in horizontal position (PA), steel thickness 1.5 mm (Fig.43).

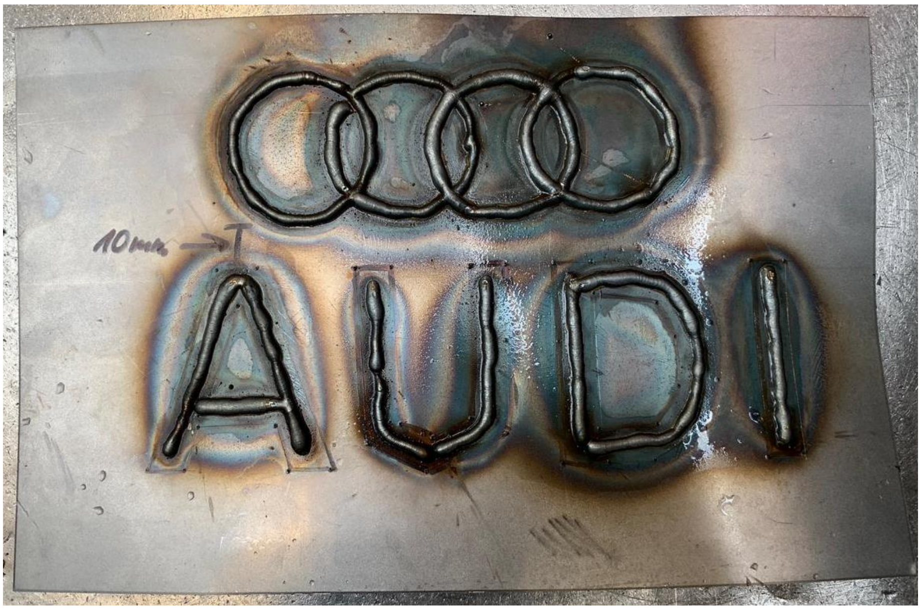


Figure 43: Audi logo plate

Source: self-made

7.5 Group 1. Augmented Reality Training on SOLDAMATIC + Workshop

The AUDI AG study began on February 7, 2022 at 7:00. The schedule for the first Group was as follows:

- Learning the theory
- Working on the SOLDAMATIC simulator
- Workshop work
- Taking a questionnaire
- Final tests

The work followed the same principles and rules as those of Group 1 in the Hochschule Esslingen part of the research as described in chapter 6.7. Each of the participants successfully completed the course "DVS-Media Grundkurs MAG" on SOLDAMATIC simulator and studied the theory on the E-Learning platform. The process of monitoring each student's progress was done using reports from the E-Learning platform. After completing day 3, each student wrote a theoretical test using the E-Learning platform and on day 4 went into a workshop to apply what he or she had learned to the real metal welding process. At the end of day 5, participants were surveyed and completed the final tests (it took 35 min). After that, the practical test was evaluated by the trainers. Photos from this training can be seen below (Fig.44, Fig.45).

Figure 44: Augmented Reality Training at AUDI

Source: self-made

Figure 45: Augmented Reality Training at AUDI

Source: self-made

7.6 Group 2. Traditional Training in Workshop

The second Group of AUDI employees also started training on February 7 at 7:00 am. All 35 hours of training for Group 2 took place in the workshop. First of all, the theory was studied, after which it was decided to start the practical training. All participants had a private cabin (Fig.46, Fig.47) where they studied welding on their own, but under the strict supervision of the trainers. As well as Group 1 at the end of the 3rd day everyone wrote a theoretical test, but in the paper version. At the end of day 5, Group 2 took a survey and completed the practical tests (it took 35 min). At the end of the same working day the intermediate results of the study in AUDI were summed up.

All participants received the knowledge in complete form and successfully finished the training offered to them.

Figure 46: Workshop at AUDI
Source: self-made

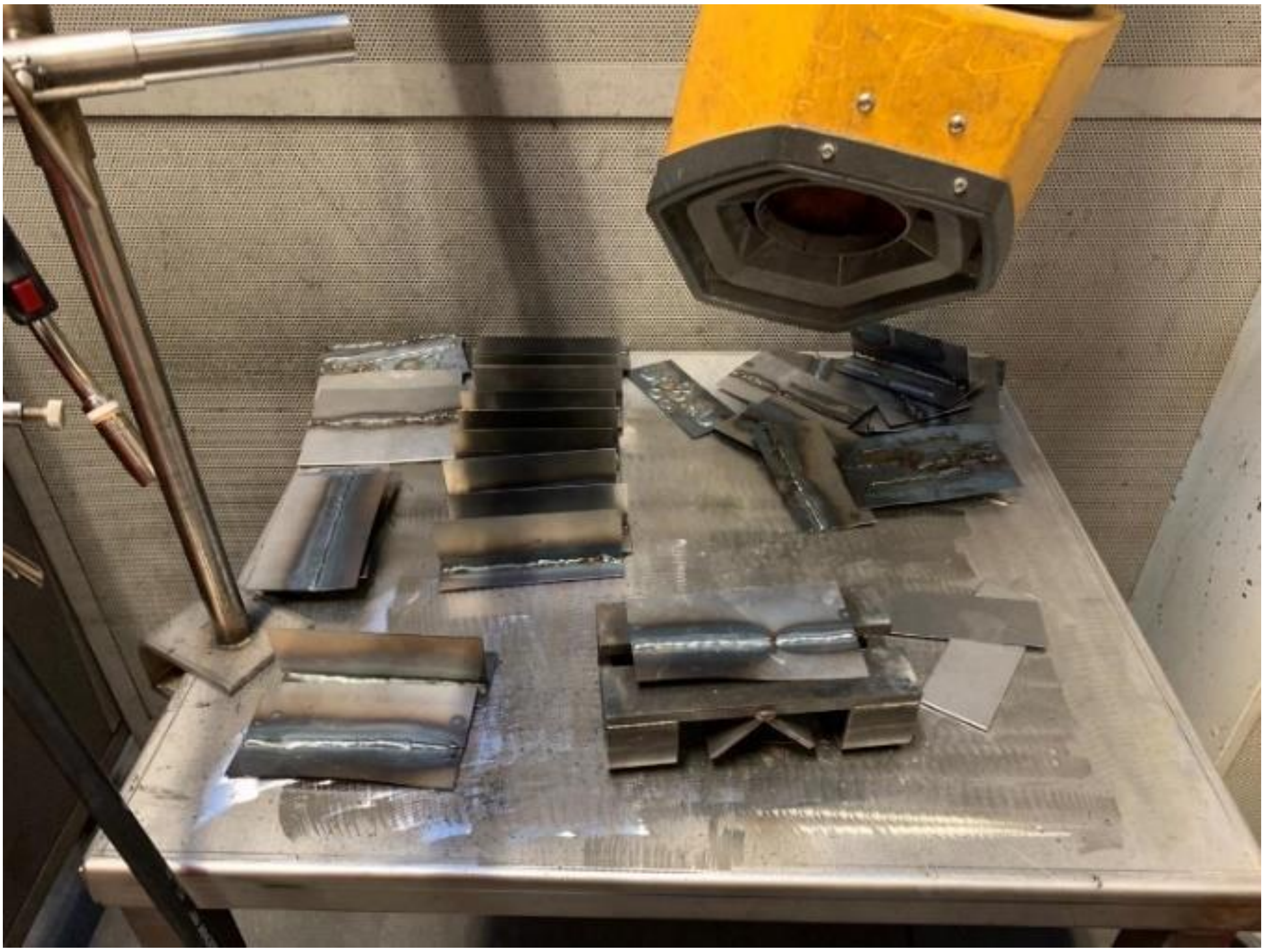


Figure 47: Workplace

Source: self-made

8. Metallographic and Microscopic examination

This chapter describes the process of metallographic and microscopic examination for the obtained welds by the participants of the experiment.

The first step in working with the practical tests from the university and AUDI part of the research was to prepare, namely to cut the welds to the right dimensions. That step was carried out with a water-cooled band saw in the laboratory of Hochschule Esslingen.

The next step is to embed the cut-out pieces of the welds into the polymer black. For this purpose, a special machine ATM Opal 460 was used, which for 5 minutes heats the granulated polymer to a temperature of 190 degrees Celsius at a pressure of 190 Bar, followed by a cooling process for 5 minutes. After this procedure a cylinder with a diameter of 4 cm is obtained with a welded seam blank inside. Next, it is necessary to polish the obtained sample. The polishing process starts with 320 sand paper (polishing with water) and ends with 3 micron polishing fluid. The polished samples are shown in the photo below (Fig.48).

Figure 48: Specimens for Microscopy

Source: self-made

The third step was to etch the polished metal with a 3% Nitalic acid solution to reveal the metal grains and so that the HAZ zone could be clearly seen. After this stage, it is possible to proceed to the examination of the metal under the microscope. A modern Olympus microscope with different degrees of magnification was used.

To give an example for this examination in the photo below (Fig. 49) at a magnification of x1.25 the HAZ around the weld can be clearly seen. And in the next photo (Fig. 50) with magnification x10 it is possible to understand that the metal was produced by rolling technology it can be understood by the flattened shape of grains on the right part of the photo, the metal after recrystallization is visible on the left side of the photo. The structural components such as Ferrite (black) and Perlite (white) can also be seen.

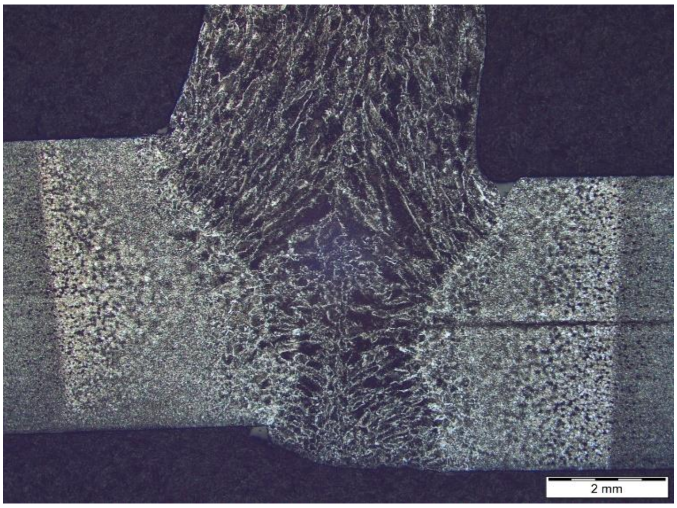


Figure 49: HAZ on Butt weld
Source: self-made

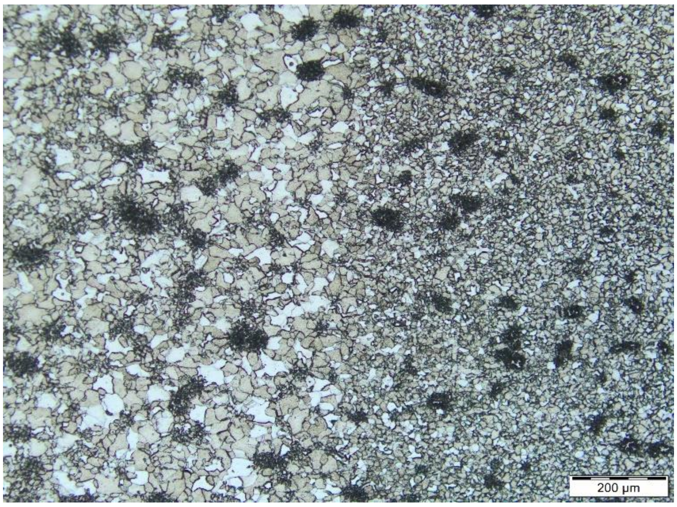


Figure 50: Metal Grains with Magnification x10
Source: self-made

Furthermore, a metal analysis was carried out with a spectrometer to determine the steel type and it was found that in both parts of the study: Hochschule Esslingen and AUDI AG used the same steel S335J2 (material name 1.0577).

9. Analysis

9.1 Analysis of Welding Training in University

9.1.1 Comparing of Theoretical Results

Each participant was provided material to study and were asked to give exams thereafter. The test results look as follows (Tab.7).

Group 1 – SOLDAMATIC Training	Theoretical Test Results	Group 2 – Traditional Training	Theoretical Test Results
Participant 1	39%	Participant 1	65%
Participant 2	63%	Participant 2	95%
Participant 3	59%	Participant 3	71%
Participant 4	78%	Participant 4	89%
Participant 5	67%	Participant 5	100%
Participant 6	81%	Participant 6	53%
Participant 7	92%	Participant 7	47%
Participant 8	64%	Participant 8	71%
Participant 9	46%	Participant 9	65%
Participant 10	27%	Participant 10	89%
Mean Value	62%	Mean Value	75%

Table 7: Results of Theoretical Tests Group 1 and Group 2 at Hochschule Esslingen

Source: self-developed based on Results at Hochschule Esslingen

Group 1, which used the E-Learning platform to learn welding theory, received a group average of 62% out of 100% possible, while Group 2, which learned exactly the same theory from printed material, scored 75%. The difference between the two groups is 13%. The results of this study indirectly confirmed the results of the research conducted by scientists comparing the two learning methods: electronic and printed. Research scientists prove that reading from printed media are more productive and as a result people understand and remember information better.

"This study noted that when students have a choice, they spent less time on digital reading, and had lower comprehension scores. Schugar et al (2011) found that participants reading on-screen used fewer study strategies such as note-taking. Baron's article also cited more recent research by Kaufman and

Flanagan (2016) that found that students reading digitally did well on answering concrete questions. However, those reading in print did better on abstract questions needing inferential reasoning." (Allcott 2021)

To conclude, this phenomenon influenced the results of this study and revealed that the printed format is better for learning.

9.1.2 Comparing of Practical Results

This chapter analyzes the results of the practical tests and then compare the two groups of participants.

Grading system: max. 50 points

- HE Plate 1 – 20 points
- HE Plate 2 – 20 points
- Butt Weld – 10 points

After scoring each participant's work, add up the three results and divide by 0.5 to get this result as a percentage. An example is shown below:

Participant X got 13 points for the first test (HE Plate 1), 9 points for the second (HE Plate 2) and 8 points in third test (Butt weld).

$$\text{Grade} = \frac{13 + 9 + 8}{0.5} = 60\%$$

Grading Criteria:

- HE Plate 1: Visual inspection of the accuracy of the work, the welding line must be between the engraved contours.
- HE Plate 2: Visual inspection of the accuracy of the work, the welding line must be between the engraved contours, as well as without stopping at places of change of direction.
- Butt weld: Visual inspection of the accuracy of the work, the welding line must run evenly along the weld, visual inspection of the back side of the weld to see if there was enough penetration during welding. The best and worst work from both groups will be examined with a microscope to show the differences in joint quality.

Practical tests for university results are evaluated using this grading system.

In the pictures below it is possible to see the practical tests of groups 1 and 2 (Fig.51, Fig.52). Each participant passed 3 tests, namely HE plate 1 (writing letters in a straight line only), HE plate 2 (writing letters without stopping and changing direction), butt welding in a vertical position from bottom to top. The table (Tab.8) below also shows the results of each participant in each group.

Group 1 – SOLDAMATIC Training	HE Plate 1	HE Plate 2	Butt Weld	Practical Test Results	Group 2 – Traditional Training	HE Plate 1	HE Plate 2	Butt Weld	Practical Test Results
Participant 1	12	12	3	54%	Participant 1	20	8	10	76%
Participant 2	10	10	5	50%	Participant 2	18	4	8	60%
Participant 3	8	8	4	40%	Participant 3	6	4	3	26%
Participant 4	4	4	2	20%	Participant 4	14	4	2	40%
Participant 5	8	6	2	32%	Participant 5	6	12	9	54%
Participant 6	6	8	4	36%	Participant 6	14	10	4	56%
Participant 7	16	14	3	66%	Participant 7	12	8	6	52%
Participant 8	12	10	3	50%	Participant 8	10	14	2	52%
Participant 9	14	16	8	76%	Participant 9	16	14	2	64%
Participant 10	18	16	9	86%	Participant 10	16	16	5	74%
Mean Value				51%	Mean Value				55%

Table 8: Results of Practical Tests Group 1 and Group 2 at Hochschule Esslingen

Source: self-developed based on Results at Hochschule Esslingen

Figure 51: Practical Tests of Group 1 at Hochschule Esslingen

Source: self-made

Figure 52: Practical Tests of Group 2 at Hochschule Esslingen

Source: self-made

Therefore, Group 1 completed the practical test at 51% (the average result for the group) and Group 2 at 55%. These results differ by 4%, which is not a significant difference and can be said that these two groups received the same result in this study. Such a small difference in the results may indicate the influence of human factors such as: more motivated people in the second group (one person learns welding for themselves, the other learns for professional activities), excitement before the test, feeling unwell, etc.

9.1.3 Comparing of Welding Specimens under the Microscope

This paragraph describes the difference between the best and worst work from both groups. By means of metallographic analysis, errors in the welding process will be smoothly shown and described. These photos are made after annealing the samples with 3% Nital (nitric acid in alcohol), after which it is possible to see better all the imperfections and also consider the HAZ (Heat-affected zone).

- Best Practical Tests

Below are two pictures of the samples obtained after microscopy. On the left side the best work from Group 1 can be seen (Fig.53), and immediately it can be understood that this weld is of high quality, there are no cracks, porosity and cavities in this weld. Also, the joint is well welded, which indicates complete penetration into the weld, but the seam is not smooth. In general, it may be concluded that the participant of the experiment who welded this seam had a correct technique. On the right is a photo of the best work from the Group 2 (Fig.54). Immediately visible a section of the weld and the quality of the joint is clearly understandable: no porosity, no cavities inside the weld, no cracks, full penetration and the weld is quite smooth. Both works are quite well done and present a quality joint.

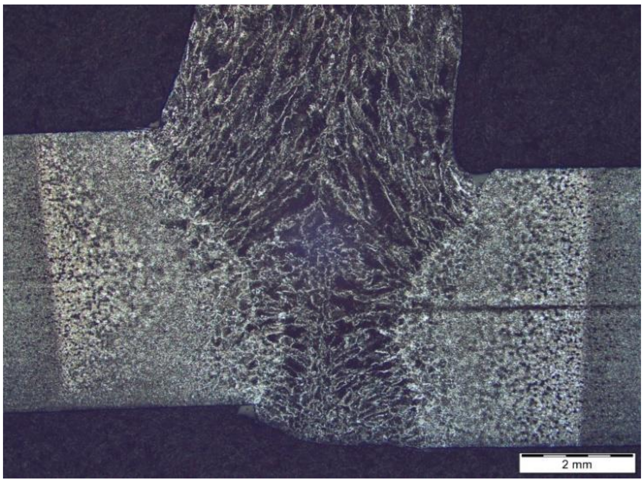


Figure 53: Group 1, Best Practical Test
Source: self-made

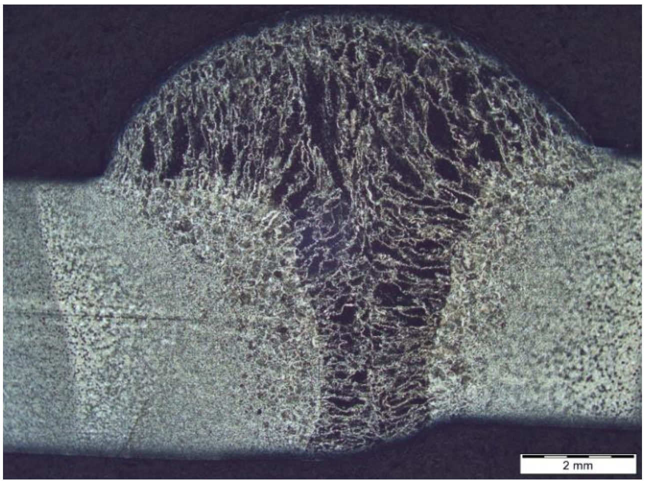
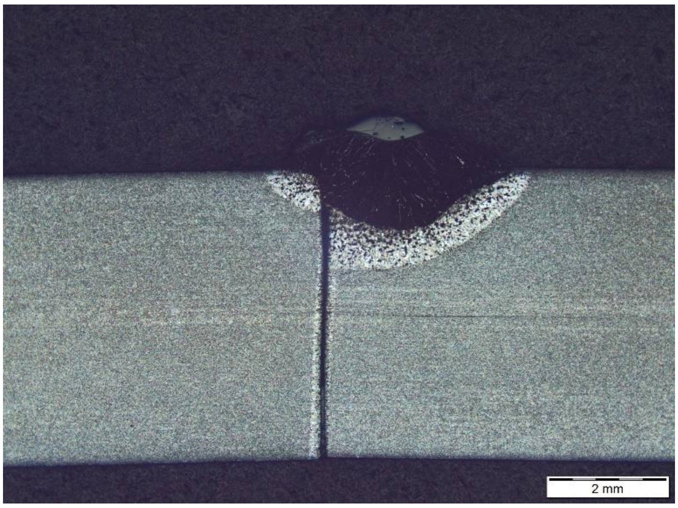


Figure 54: Group 2, Best Practical Test
Source: self-made

- Worst Practical Tests

In Group 1, the left photo (Fig.55) shows errors: welding was not precisely in line connection of two pieces of metal, there is no complete penetration in the weld respectively this seam is not performed qualitatively and will not last long. Making a conclusion about this connection, it is possible to assume that this participant has not fully mastered the technique. On the right picture from Group 2 (Fig.56), immediately visible is that there is no full penetration, the seam was not made exactly halfway along the joint line and the cavities inside the seam can be seen.



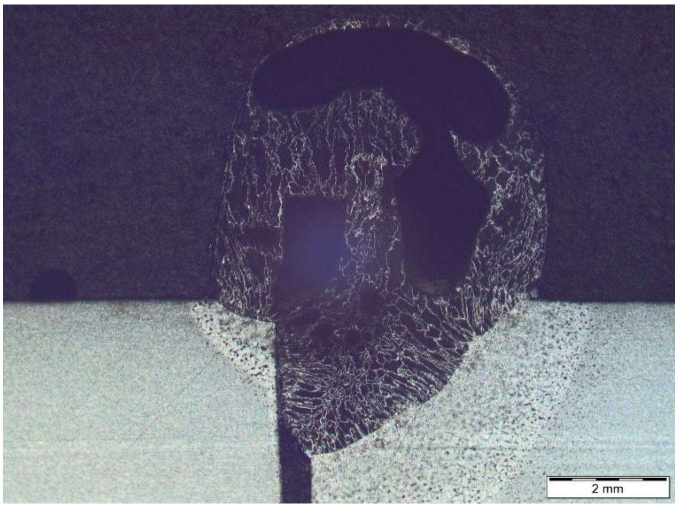


Figure 55: Group 1, Worst Practical Test
Source: self-made

Figure 56: Group 2, Worst Practical Test
Source: self-made

Making a conclusion in this paragraph can be finalized about the correct evaluation of all works and clearly demonstrate the coordinate differences in the quality of the weld.

9.1.4 Comparing of Resources Consumptions and Costs

Group 1: SOLDAMATIC + Workshop

Each participant in this group receives 10 hours of training, of which 6 hours with SOLDAMATIC welding simulator and 4 hours in the workshop. These are the values from table below (Tab.9) will be useful for calculating the consumption of various resources. In the workshop, as previously mentioned, two different welding machines are used: EWM and Rehm. These two machines have slightly different gas and wire consumption. That's why half of the group worked on the EWM machine and the other half on the Rehm machine.

Group 1 – SOLDAMATIC Training	Gas, [L]	Wire, [m]	Metal, [g]
Participant 1	2880	1200	9928
Participant 2	2880	1200	9743
Participant 3	2880	1200	6452
Participant 4	2880	1200	7274
Participant 5	2880	1200	9120
Participant 6	4320	816	10293
Participant 7	4320	816	6759
Participant 8	4320	816	9188
Participant 9	4320	816	6660
Participant 10	4320	816	8474
Total Value	36 000 L	10 080 m	83 891 g

Table 9: Spent resources by Group 1 at Hochschule Esslingen
Source: self-developed based on Results at Hochschule Esslingen

- Gas

For information about gas consumption per hour, see chapter 6.11.2

$$G_{EWM} = 1080\frac{L}{h} * 4h = 4320 \text{ L spent in 4 hours by one participant on EWM welder}$$

$$G_{Rehm} = 720\frac{L}{h} * 4h = 2880 \text{ L spent in 4 hours by one participant on Rehm welder}$$

The final result is a value of 36 000 liters in gaseous state spent by the 10 participants in the training. Hochschule Esslingen uses 20-liter (max. 12 000 L in gas state) ArCO2 gas cylinders. After the gas is converted from liquid to gaseous state, about 12 000 liters should be obtained. During the experiment, 3 bottles of gas were spent, so the verification calculation to make sure that the information is correct made below. Also, a correction factor of 83% needs to be considered, each participant worked about 83% on the welder.

$$\text{Bottle filling in liters} = \frac{36\,000 \text{ L} * 0{,}83}{3} = 9\,960 \text{ L from each bottle in gas state}$$

The resulting number confirms the fact that the information is reliable. The amount of gas consumed in the liquid state is 60 liters.

The cost per bottle of ArCO2 is 35 Euro. The corresponding 3 bottles cost 105 Euro.

- Wire

For information about wire consumption per hour, see chapter 6.11.2

One coil of wire weighs 15 kg and to measure the amount of meters of wire on one new coil requires measuring how many grams weigh one meter of wire. After the measurement have that 1m of wire is 3.6 g. In this case one coil is 4166 m of welding wire.

$$W_{EWM} = 204\frac{m}{h} * 4h = 816\text{ m spent in 4 hours by one participant on EWM welder}$$

$$W_{Rehm} = 300\frac{m}{h} * 4h = 1200\text{ m spent in 4 hours by one participant on Rehm welder}$$

During the experiment 10 080 m of wire were spent and, in this case, it can be calculated how many coils were consumed in the end.

$$\text{Amount of coils} = \frac{10\ 080\text{ m} * 0{,}83}{4166\text{ m}} = 2\text{ coils}$$

The price of one coil is 45 Euro, respectively, obtaining 90 Euro for the two coils spent during the experiment.

- Metal – Carbon Steel S355J2

In the experiment at Hochschule Esslingen, carbon steel S355J2 with a thickness of 5 mm and sheets with a size of 1000x200 mm were used and cut to size. A total of 83.9 kg of metal was used for Group 1. In order to calculate the cost of spent metal, it is necessary to understand how many sheets were used, and specifically to calculate the weight of one sheet. To do this using the elementary formula: m=V*ρ, where V-volume, ρ-density of steel (7870 kg/m^3).

$$m = V * \rho, \text{where m} - \text{mass, V} - \text{volume, } \rho - \text{density}$$

$$m = V * \rho = (0{,}005\text{ m} * 0{,}2\text{ m} * 1\text{ m}) * 7870\frac{kg}{m^3} = 7.87\text{ kg}$$

Thus, obtained that the weight of a sheet of 1000x200 mm is 7.87 kg, so now enough data to calculate how many sheets were spent and the cost.

$$\text{Amount of Spent Metal Sheets} = \frac{\text{Total spent metal, [kg]}}{\text{One sheet metal, [kg]}} = \frac{83.9\text{ kg}}{7.87\text{ kg}} = 11\text{ Metal Sheets}$$

$$\text{Cost of spent Metal} = 11\ \text{Sheets} * 31.4\ \text{Euro} = 345\ \text{Euro}$$

- Electricity

As already described in chapter 6.10.1, the power consumption of the SOLDAMATIC simulator is 0.196 kWh per hour. In this case there are 10 participants, and each of them worked on the welding simulator for 6 hours.

$$P_{Soldamatic} = 0.196\ \text{kWh} * 6\text{h} * 10\ \text{participants} = 11.76\ \text{kWh in total}$$

It is also required to take into account the electricity consumed during the actual welding process for 4 hours by each participant. It is obligatory to take into account the factor 83% (details are described in chapter 6.11.1)

$$P_{welder} = P_{fin} * t * \text{Part.} * 83\%, \text{where } P_{fin} - \text{electricity consumption per 1 hour [kWh]},$$
$$t - \text{time [h]}, \text{Part.} - \text{amount of participants}, 83\% - \text{correction factor},$$
$$P_{welder} - \text{total consumption during actual welding process.}$$

$$P_{welder} = P_{fin} * t * \text{Part.} * 83\% = 13{,}1\ \text{kWh} * 4\text{h} * 10 * 0.83 = 435\ \text{kWh spent 10 participants}$$

The final value of electricity consumed by group 1, as well as the cost:

$$P = P_{Soldamatic} + P_{welder} = 11.76\ \text{kWh} + 435\ \text{kWh} = 447\ \text{kWh}$$
$$\text{Cost of Electricity} = P\ [\text{kWh}] * \text{Cost of 1 kWh [Euro]} = 447\ \text{kWh} * 0.225\ \text{Euro} = 101\ \text{Euro}$$

(globalpetrolprices 2022)

- CO_2

From paragraph 6.12 understand the ratio of CO_2 emissions in the atmosphere in relation to metal and electricity. In this calculation, the total CO_2 emissions are calculated.

CO_2 emissions from Metal production:

$$1.85\ \text{kg}\ CO_2 = 1\ \text{kg Metal}$$

$$CO_{2\ metal} = m_{total}[\text{kg}] * 1.85\ [CO_2] = 83.9\ \text{kg} * 1.85\ \text{kg}\ CO_2 = 155.2\ \text{kg}\ CO_2$$

CO_2 emissions from Electricity production:

$$0.45\ \text{kg}\ CO_2 = 1\ \text{kWh Electricity}$$

$$CO_{2\ electricity} = P\ [\text{kWh}] * 0.45\ [CO_2] = 447\ \text{kWh} * 0.45\ \text{kg}\ CO_2 = 201.2\ \text{kg}\ CO_2$$

Total Emissions of CO2 in the Atmosphere:

$$CO_{2\ total} = CO_{2\ metal} + CO_{2\ electricity} = 155.2\ kg\ CO_2 + 201.2\ kg\ CO_2 = 356.4\ kg\ CO_2$$

Group 2: Workshop

Group 2 also had 10 participants, all working exclusively with welding machines without studying on SOLDAMATIC. The training course lasted 10 hours (Tab.10).

Group 2 – Traditional Training	Gas, [L]	Wire, [m]	Metal, [g]
Participant 1	7200	3000	35475
Participant 2	7200	3000	30745
Participant 3	7200	3000	31323
Participant 4	7200	3000	30724
Participant 5	7200	3000	20496
Participant 6	10800	2040	32358
Participant 7	10800	2040	35029
Participant 8	10800	2040	19434
Participant 9	10800	2040	34305
Participant 10	10800	2040	24169
Total Value	90 000 L	25 200 m	284 058 g

Table 10: Spent resources by Group 2 at Hochschule Esslingen

Source: self-developed based on Results at Hochschule Esslingen

To compare resource consumption and costs, calculations are made as for group 1 above (see above for detailed explanations and calculations)

- Gas

For information about gas consumption per hour, see chapter 6.11.2

$$G_{EWM} = 1080 \frac{L}{h} * 10h = 10\ 800\ L \text{ spent in 10 hours by one participant on EWM welder}$$

$$G_{Rehm} = 720 \frac{L}{h} * 10h = 7\ 200\ L \text{ spent in 10 hours by one participant on Rehm welder}$$

During the course of the experiment, this group consumed 7 bottles of $ArCO_2$ (90 000 L in gas state or 140 L liquid state)

$$\text{Bottle filling in liters} = \frac{90\,000\ \text{L} * 0{,}83}{7} = 10\,671\ \text{L from each bottle in gas state}$$

The cost of full bottle is 35 Euro. The corresponding 7 bottles cost 245 Euro.

- Wire

$$\text{W}_{\text{EWM}} = 204\frac{\text{m}}{\text{h}} * 10\text{h} = 2\,040\ \text{m spent in 10 hours by one participant on EWM welder}$$

$$W_{Rehm} = 300\frac{m}{h} * 10h = 3\,000\ m\ \text{spent in 10 hours by one participant on Rehm welder}$$

Group 2 spent 25 200m of fusing electrode during the full training.

$$\text{Amount of coils} = \frac{25\,200\ \text{m} * 0{,}83}{4166\ \text{m}} = 5\ \text{coils}$$

The price of one coil is 45 euros, respectively, obtaining 225 Euro for 5 coils spent during the experiment.

- Metal – Carbon Steel S355J2

Metal for this group was used exactly the same as for group 1: 1000x200x5 mm. The total consumption for the training was 284 kg.

$$\text{Amount of Spent Metal Sheets} = \frac{\text{Total spent metal, [kg]}}{\text{One sheet metal, [kg]}} = \frac{284\ \text{kg}}{7.87\ \text{kg}} = 36\ \text{Metal Sheets}$$

$$\text{Cost of spent Metal} = 36\ \text{Sheets} * 31.4\ \text{Euro} = 1130\ \text{Euro}$$

- Electricity

For this calculation take the data from chapter 6.11.1. It is obligatory to take into account the factor 83%.

$$\text{P}_{\text{welder}} = \text{P}_{\text{fin}} * \text{t} * \text{Part.} * 83\%, \text{where P}_{\text{fin}} - \text{electricity consumption per 1 hour [kWh]},$$
$$\text{t} - \text{time [h], Part.} - \text{amount of participants}, 83\% - \text{correction factor},$$
$$\text{P}_{\text{welder}} - \text{total consumption during actual welding process.}$$

$$\text{P}_{\text{welder}} = \text{P}_{\text{fin}} * \text{t} * \text{Part.} * 83\% = 13{,}1\ \text{kWh} * 10\ \text{h} * 10 * 0.83 = 1087{,}3\ \text{kWh spent 10 participants}$$

Cost of Electricity for Group 2:

$$\text{Cost of Electricity} = \text{P [kWh]} * \text{Cost of 1 kWh [Euro]} = 1087{,}3\ \text{kWh} * 0.225\ \text{Euro} = 245\ \text{Euro}$$

(globalpetrolprices 2022)

- CO_2

From paragraph 6.12 understand the ratio of CO_2 emissions in the atmosphere in relation to metal and electricity. In this calculation, the total CO_2 emissions are calculated.

CO_2 emissions from Metal production:

$$1.85 \text{ kg } CO_2 = 1 \text{ kg Metal}$$

$$CO_{2\,metal} = m_{total}[\text{kg}] * 1.85\,[CO_2] = 284 \text{ kg} * 1.85 \text{ kg } CO_2 = 525.4 \text{ kg } CO_2$$

CO_2 emissions from Electricity production:

$$0.45 \text{ kg } CO_2 = 1 \text{ kWh Electricity}$$

$$CO_{2\,electricity} = P\,[\text{kWh}] * 0.45\,[CO_2] = 1087.3 \text{ kWh} * 0.45 \text{ kg } CO_2 = 489.3 \text{ kg } CO_2$$

Total Emissions of CO2 in the Atmosphere:

$$CO_{2\,total} = CO_{2\,metal} + CO_{2\,electricity} = 525.4 \text{ kg } CO_2 + 489.3 \text{ kg } CO_2 = 1014.7 \text{ kg } CO_2$$

Table comparing resources spent and costs (Tab.11):

Resource	Group 1 – SOLDAMATIC Training		Group 2 – Traditional Welding Training		Consumption of SOLDAMATIC
Gas	60 L	105 €	140 L	245 €	2.4 times less
Wire	10 080 m	90 €	25 200 m	225 €	2.5 times less
Metal	83.9 kg	345 €	284 kg	1130 €	3.4 times less
Electricity	447 kWh	101 €	1 087,3 kWh	245 €	2.4 times less
CO_2	356.4 kg CO_2	-	1 014.7 kg CO_2	-	2.8 times less
Total costs	641 €		1845 €		2.9 times less

Table 11: The final values of the amount of spent resources and money at Hochschule Esslingen
Source: self-developed based on Results at Hochschule Esslingen

To summarize, 2 486 Euro were spent on research at Hochschule Esslingen, of which 1 845 Euro went to Group 2. Group 1 spent only 641 Euro, which is 2.9 times less. Also, with the modern type of training was spent: 2.4 times less gas, 2.5 times less wire, 3.4 times less metal, 2.4 times less electricity and 2.8 times less CO_2 emissions into the atmosphere.

9.1.5 Analysis of Questionaries of Group 1

During the course, two surveys were conducted with survey participants about their past experiences, equipment use, and satisfaction, the main results of which will be analyzed below. Ten people aged 21-32 took part in the survey. The average age of this group is 26.5 years.

Analyzing the results of the following question about past experience with welding it was found that only 30% of the participants have ever tried to use welding, that is, most of the participants did not have any experience in welding metals (Fig.57).

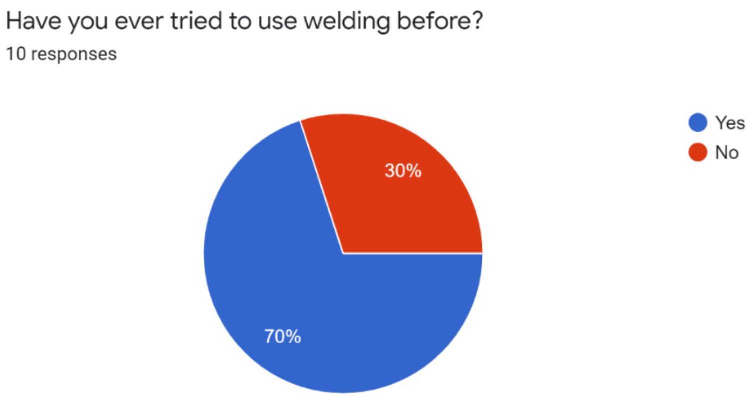


Figure 57: Chart for the question: Have you ever tried to use welding before?
Source: Google Forms

Thus, the next question assessed the skill in consequence of the existing experience of the students (Fig.58): What are your welding skills?

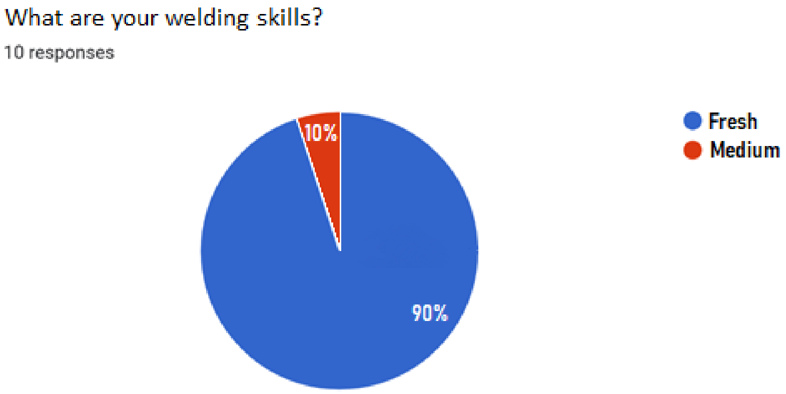


Figure 58: Chart for the question: What are your welding skills?
Source: Google Forms

There were three possible answers for this question: Fresh/Medium/Expert. Thus, it was found that 90% of the participants had a beginner's skill level before taking the course. Comparing the two questions, it is possible to say that participants did not have any skills at the beginning of the study.

The next and one of the important questions is: How would you rate your experience with SOLDAMATIC? The participants were given the opportunity to evaluate the SOLDAMATIC simulator in terms of working with it on a scale of 1 to 10 (Fig.59). As a result, the level of satisfaction with SOLDAMATIC is 6.7.

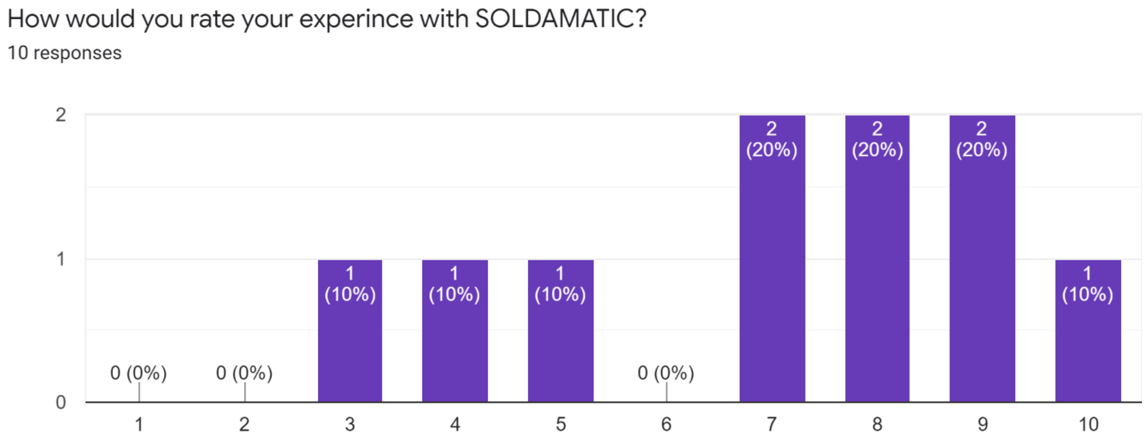


Figure 59: Chart for the question: How would you rate your experience with SOLDAMATIC?
Source: Google Forms

Do you know of any other simulators? The answers of all participants to this question came to a consensus. No student knows of any other simulators except SOLDAMATIC.

For a complete understanding of the participants satisfaction with SOLDAMATIC, there was a follow-up question: Would you recommend SOLDAMATIC to a colleague? 80% of the people answered that they would recommend this simulator for welding training to their friends and colleagues (Fig.60).

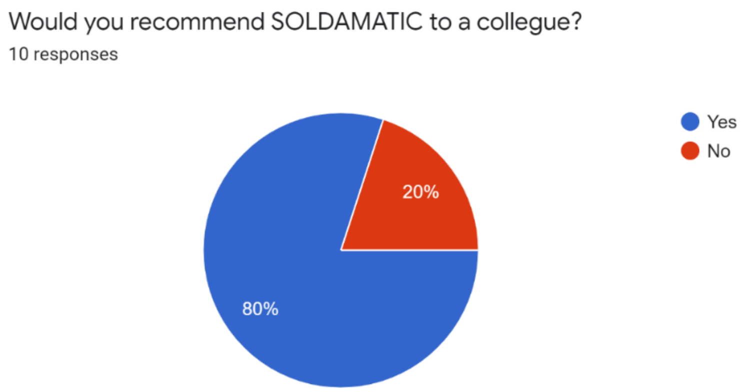


Figure 60: Chart for the question: Would you recommend SOLDAMATIC to a colleague?
Source: Google Forms

The following is the analysis of the answers to the free-choice questions. Conclusions are based on the main points of the provided answers.

The most attractive aspects of the SOLDAMATIC welding simulator were the safety training and the clear, easy-to-understand guidelines, such as the adjustment of the hand position during work. But also, participants indicated what they did not like, this is a problem with Augmented Reality, uncomfortable helmet and lack of physical feedback.

Also, a comparison of two types of welding training, virtual and real, was made. The students were asked: What advantages do you think digital training has over traditional training? The main answers to the question were the arguments that this type is safer and resource consumption is much less than for traditional training. However, the participants also pointed out the main disadvantage of training with augmented reality simulator, namely that it cannot fully replace the work with a real welding machine and the feeling of welding.

9.1.6 Analysis of Questionaries of Group 2

This paragraph analyzes the answers to the questions by the participants of the second Group.

The first question was: What is your age? All of the answers are shown in the chart below. The age range was 20-33 years old and the average age for this group was 26 years old (Fig.61).

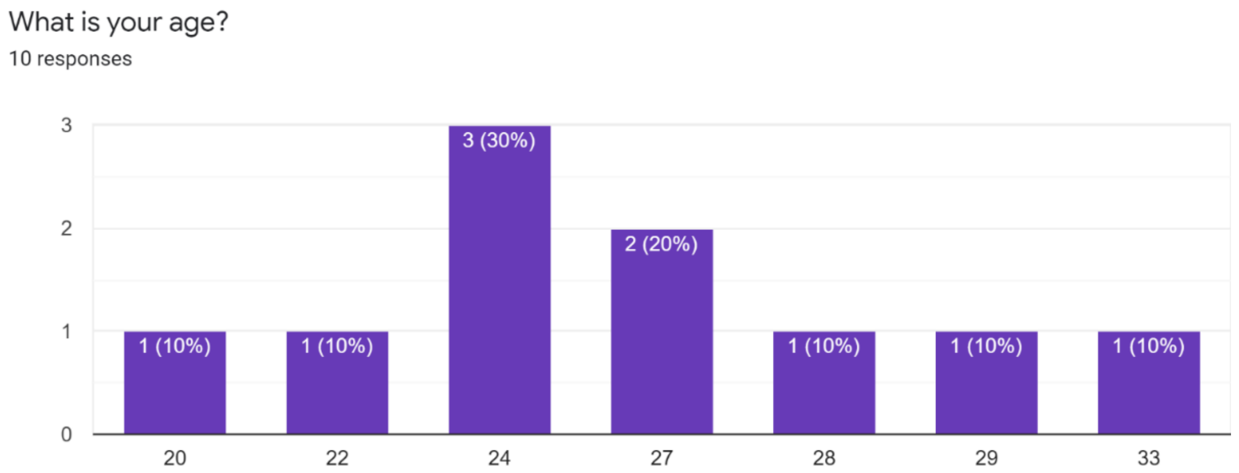


Figure 61: Chart for the question: What is your age?

Source: Google Forms

The next and one of the most interesting questions for this study was the question of existing experience in welding. According to the results of the survey it was found that 50% of the participants already had some experience in this area (Fig.62).

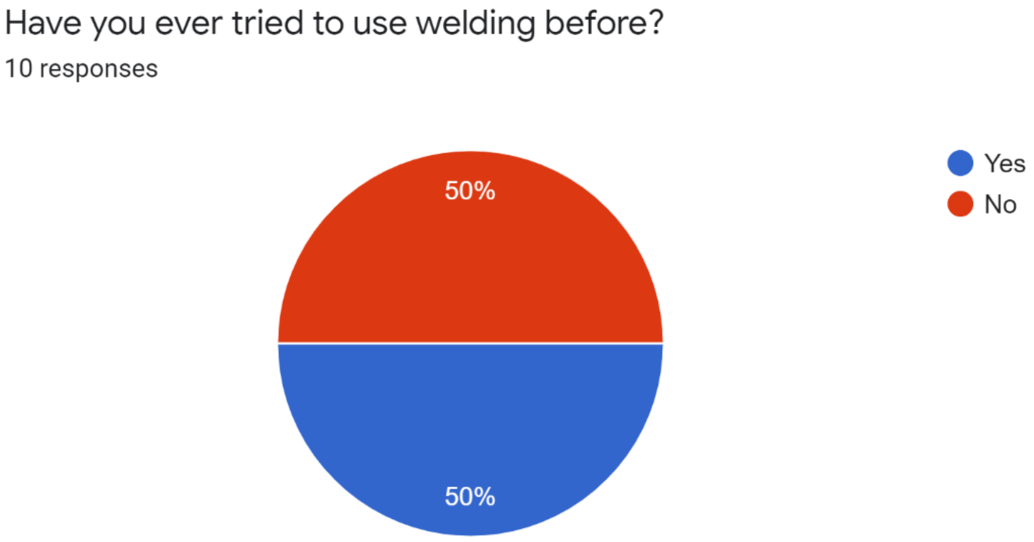


Figure 62: Chart for the question: Have you ever tried to use welding before?

Source: Google Forms

The next question was aimed at a specific understanding of which type of welding the participant has experience in (Fig.63). The chart below shows that only 20% of the participants had experience with MIG/MAG welding, which is a good sign for this research.

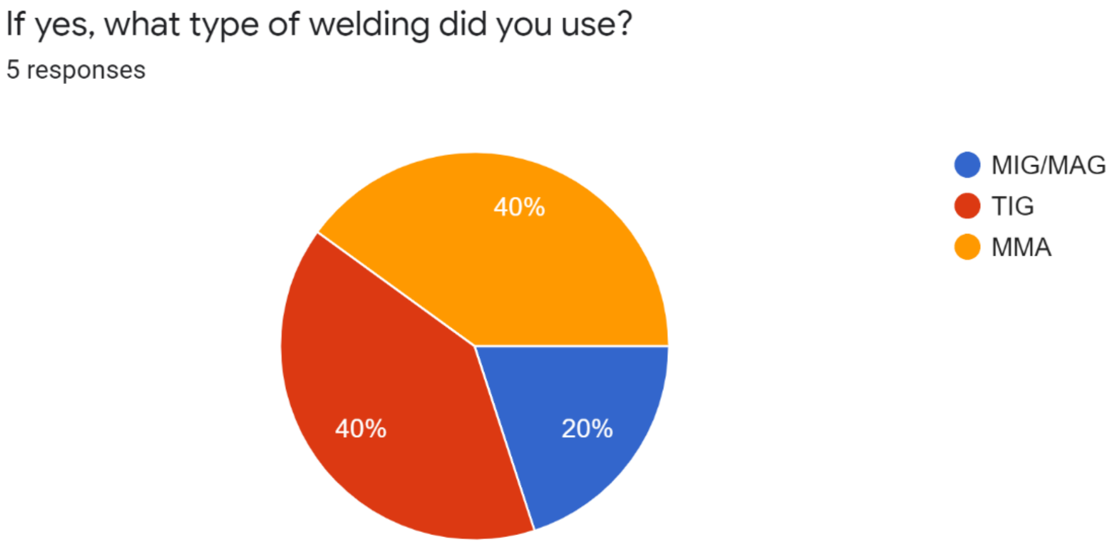


Figure 63: Chart for the question: what type of welding did you use?

Source: Google Forms

Would you like to have SOLDAMATIC training in the future? - was asked of each of the participants (Fig.64). The vast majority responded that they would like to have an augmented reality simulator training experience in the future.

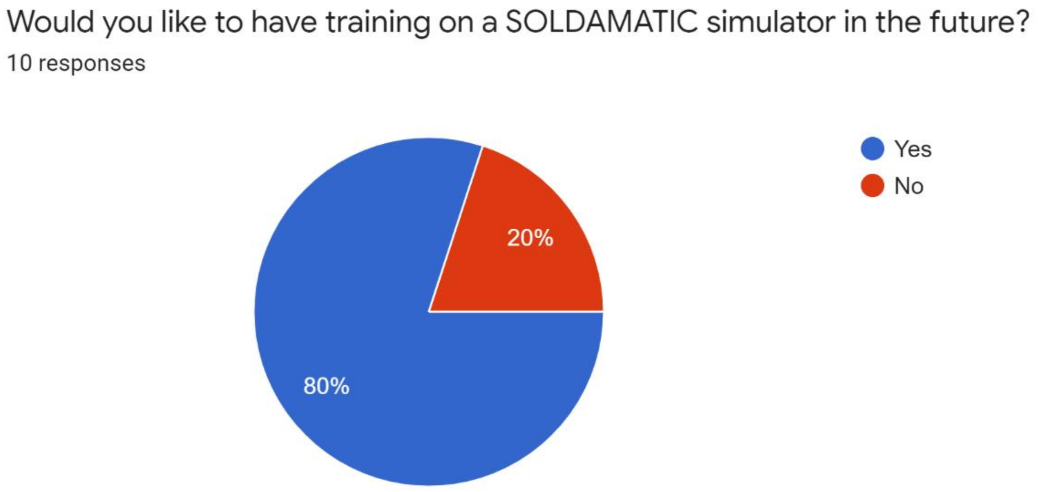


Figure 64: Chart for the question: Would you like to have training on a SOLDAMATIC simulator in the future?

Source: Google Forms

This questionnaire also included a series of other questions about feedback on the welding machines in the workshop, but these questions were not included in the research due to their inappropriateness.

9.2 Analysis of Welding Training in AUDI

9.2.1 Comparing of Theoretical Results

In this paragraph the results of theoretical tests made by two groups in AUDI will be discussed as well as a comparison of the data obtained. The content of the theoretical test is the same as in the part of the university research (Tab.12).

Group 1 – SOLDAMATIC Training	Theoretical Test Results	Group 2 – Traditional Training	Theoretical Test Results
Participant 1	53%	Participant 1	71%
Participant 2	76%	Participant 2	71%
Participant 3	65%	Participant 3	59%
Participant 4	47%	Participant 4	71%
Participant 5	30%	Participant 5	47%
		Participant 6	77%
Mean Value	54%	Mean Value	66%

Table 12: Results of Theoretical Tests Group 1 and Group 2 at AUDI

Source: self-developed based on Results at AUDI

The table above (Tab.12) shows the test results for the theory of the two groups. Group 2 completed this test at 66% (group average) of 100% possible, which is 12% more successful than Group 1, which scored 54%. As already described in section 8.1.1, this proves once again that learning theory from the printed version is a better way to understand any material than reading electronically. This phenomenon does not refute the usefulness of the E-Learning platform because the research described in 8.1.1 explains human psychology. Thus, in the future, it will be possible to use the method of learning theory by combining a printed source of information with the E-Learning platform, which will improve the quality of learning.

9.2.2 Comparing of Practical Results

This chapter analyzes the results of the practical tests and then compare the two groups of participants from the company AUDI AG.

Grading system: max. 50 points

- Butt Weld – 10 points
- Overlap – 10 points
- T-joint – 10 points
- AUDI Plate – 20 points

After scoring each participant's work, add up the three results and divide by 0.5 to get this result as a percentage. An example is shown below:

Participant Y got 12 points for the first test (Overlap), 8 points for the second (T-joint), 3 points in third test (Butt weld) and 18 points for the last test (AUDI Plate).

$$\text{Grade} = \frac{12 + 8 + 3 + 18}{0.5} = 82\%$$

Grading Criteria:

- Butt weld: Visual inspection of the accuracy of the work, the welding line must run evenly along the weld, visual inspection of the back side of the weld to see if there was enough penetration during welding. The best and worst work from both groups will be examined with a microscope to show the differences in joint quality.
- Overlap: Visual inspection of the accuracy of the work, the welding line must run evenly along the weld, visual inspection of the back side of the weld to see if there was enough penetration during welding. The best and worst work from both groups will be examined with a microscope to show the differences in joint quality.

- T-joint: Visual inspection of the accuracy of the work, the welding line must run evenly along the weld, visual inspection of the back side of the weld to see if there was enough penetration during welding. The best and worst work from both groups will be examined with a microscope to show the differences in joint quality.
- AUDI Plate: Visual inspection of the accuracy of the work, the welding line must be between the engraved contours.

Practical tests for AUDI results are evaluated using this grading system.

In the table below (Tab.13) the results of both groups can be seen in the AUDI part of the research with detailed points for each test.

Group 1 – SOLDAMATIC Training	Butt Weld	Overlap	T-joint	AUDI Plate	Practical Test Results
Participant 1	4	6	9	14	66%
Participant 2	4	7	9	10	60%
Participant 3	5	5	7	8	50%
Participant 4	9	8	9	14	80%
Participant 5	3	3	6	8	40%
Mean Value					59%
Group 2 – Traditional Training	Butt Weld	Overlap	T-joint	AUDI Plate	Practical Test Results
Participant 1	7	8	5	6	52%
Participant 2	7	8	6	12	66%
Participant 3	8	7	6	14	70%
Participant 4	10	9	6	18	86%
Participant 5	10	7	7	10	68%
Participant 6	6	6	6	6	48%
Mean Value					65%

Table 13: Results of Practical Tests Group 1 and Group 2 at AUDI

Source: self-developed based on Results at AUDI

Figure 65: Practical Tests of Group 1 at AUDI

Source: self-made

Figure 66: Practical Tests of Group 2 at AUDI

Source: self-made

In the AUDI part of the research, Group 1, which used SOLDAMATIC simulator to learn welding skills, performed 59% out of 100% possible (group mean) and Group 2 performed the test at 65%. The difference between the two groups was 6%, which is not a coordinate difference. Just as in the Hochschule Esslingen study (point 8.1.2) various factors, both psychological and motivation of each participant in the group, could have influenced such a small difference, since this training was not specialized for the profession of Mechatronics. Also due to unforeseen circumstances in Group 2 there was one more participant, which also may have affected the difference in the results between the two groups.

9.2.3 Comparing of Welding Specimens under the Microscope

In this section the best and worst work done by the participants in the AUDI experiment are compared and clearly explained. Below are pictures taken with an OLYMPUS microscope in the laboratory of the Hochschule Esslingen.

In the picture below (Fig.67) shows the best work that was done by the participants of the two groups during the research. The quality of these welds is good: no porosity, no cavities, no cracks, good penetration inside the weld.

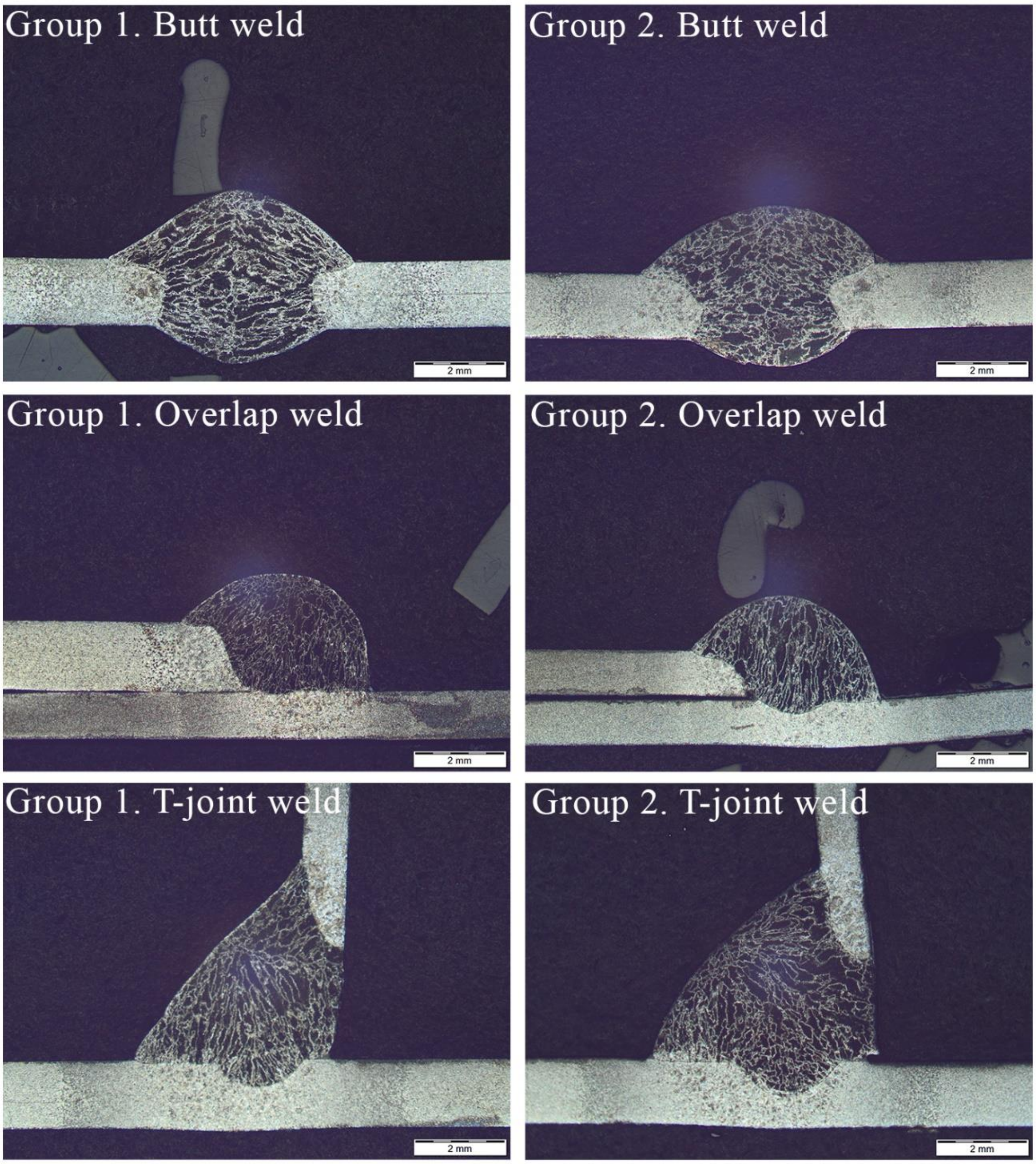


Figure 67: Best works of Group 1 and Group 2 at AUDI
Source: self-made

On the other hand, the following picture (Fig.68) shows the worst versions of the participants work. The first line can be seen Butt welds which do not have a quality weld because there is not enough penetration and also the weld lies, on the surface of the metal. On the second line there are mistakes in Overlap welds, the participants made some mistakes in technique and as a result did not get the proper quality: insufficient penetration, cavities in the weld. On the third line, everyone can see with the naked eye that, again, no mistakes in technique were made and the weld is not exactly on the joint line, there is not enough penetration to get a good quality weld. Thus, it can be assumed that these welded joints will not last long in real conditions.

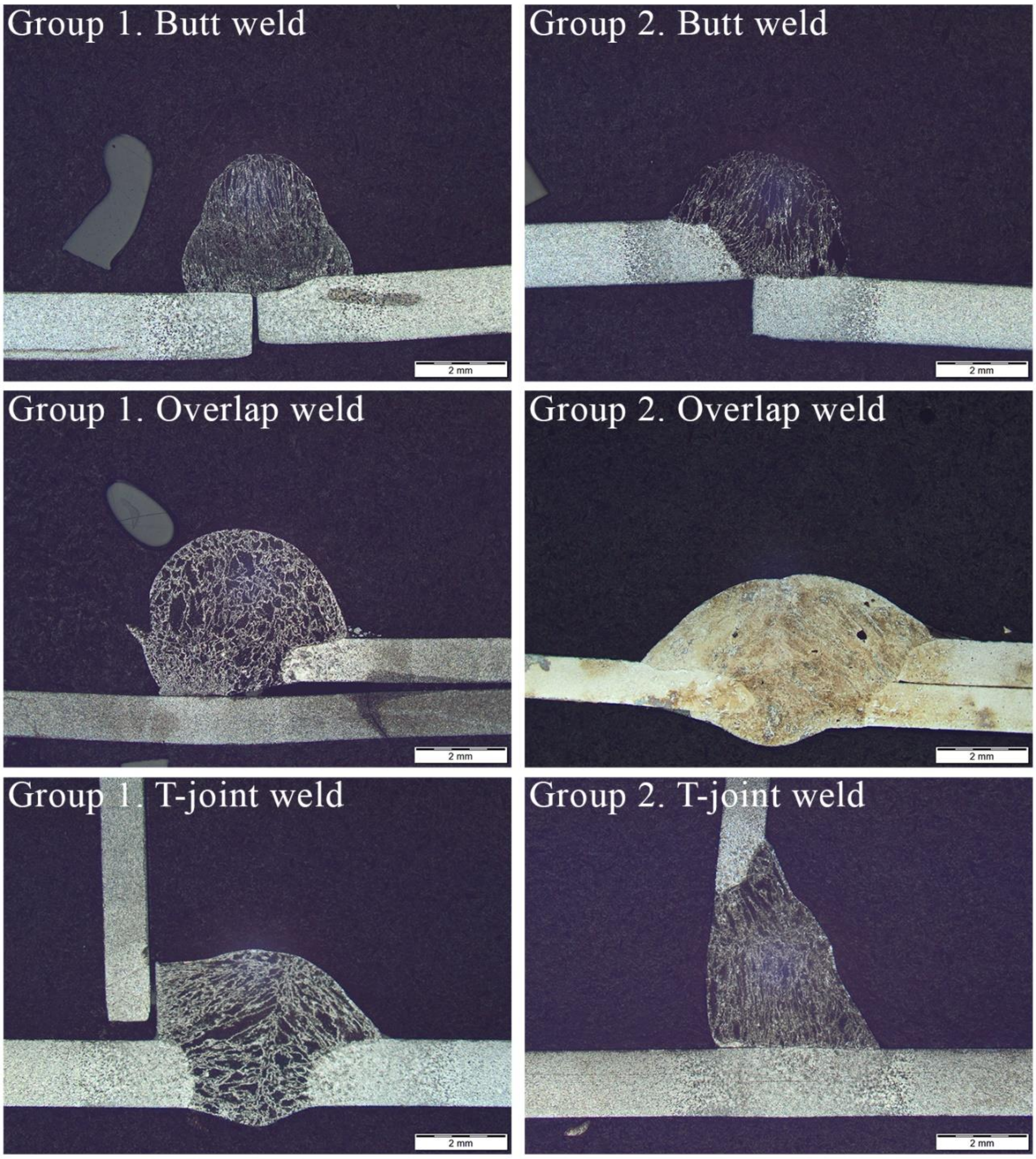


Figure 68: Worst works of Group 1 and Group 2 at AUDI
Source: self-made

To summarize this point, the evaluation of the results of the practical tests in point 8.2.2 is clearly confirmed by photos and analysis.

9.2.4 Comparing of Resources Consumptions and Costs

AUDI Group 1: SOLDAMATIC + Workshop

The second part of this experiment was a research at AUDI AG. The training for group 1 was divided into two parts just like in the university research, the first part was the SOLDAMATIC for 21 hours, then the workshop which lasted 14 hours and each participant work on welding machine LORCH. Below is a table (Tab.14) with the data on which will be more accurate calculation in the following steps. This calculation is done using the same methods and logic as in 8.1.4, where the resources and their capacities were calculated during the university research.

Group 1 – SOLDAMATIC Training	Gas, [L]	Wire, [m]	Metal, [g]
Participant 1	8400	3052	11400
Participant 2	8400	3052	12750
Participant 3	8400	3052	7330
Participant 4	8400	3052	9290
Participant 5	8400	3052	19840
Total Value	42 000 L	15 260 m	60 610 g

Table 14: Spent resources by Group 1 at AUDI
Source: self-developed based on Results at AUDI

- Gas

The gas consumption during the experiment was 10 L/min on each welding machine.

$$G_{Lorch} = 10\frac{L}{min} = 600\frac{\mathrm{L}}{\mathrm{h}} * 14\mathrm{h} = 8400\ \mathrm{L\ spent\ in\ 14\ hours\ by\ one\ participant\ on\ LORCH\ welder}$$

In order to calculate the cost of gas it is necessary to find out how many bottles of gas were consumed. Since AUDI does not use bottled gas but has a centralized $ArCO_2$ gas supply system with pipes, this answer is not obvious. Based on the data in 8.1.4, it can be assumed that one cylinder with $ArCO_2$ gas in gaseous state is filled to 9 960 L. Below the calculation of the number of used 20 L bottles of gas and their cost will be made. Also, in this calculation it is necessary to take into account the factor 83%, which corrects the time of work, because each of the participants did not spend 100% of the time on the welding process (detailed information about this factor is shown in paragraph 6.11.2).

$$\text{Amount of spent bottles ArCO}_2 = \frac{42\ 000\ \text{L} * 0.83}{9\ 960\ \text{L}} = 3.5\ \text{Bottles}$$

3.5 bottles mean 70 L of gas in liquid state.

The cost of one bottle of $ArCO_2$ welding gas is 35 Euro.

$$\text{Final cost of ArCO}_2 = 3.5\ \text{Bottles} * 35\ \text{Euro} = 122.5\ \text{Euro}$$

- Wire

One coil of wire weighs 15 kg and contains 4166 m. The cost, as described in point 8.1.4, is 45 Euro. The consumption of each welding machine averaged 3.63 m/min.

$$\text{W}_{\text{Lorch}} = 3.63\frac{m}{min} = 218\frac{\text{m}}{\text{h}} * 14\text{h} = 3052\ \text{m spent in 14 hours by one participant on Lorch welder}$$

During the experiment 15 260 m of wire were spent and, in this case, it can be calculated how many coils were consumed in the end.

$$\text{Amount of coils} = \frac{15\ 260\ \text{m} * 0{,}83}{4166\ \text{m}} = 3\ \text{coils}$$

The price of one coil is 45 euros, respectively, obtaining 135 Euro for the 3 coils spent during the experiment.

- Metal – Carbon Steel S355J2

In the experiment in AUDI AG, carbon steel S355J2 with a thickness of 1.5 mm and sheets with a size of 1000x2000 mm were used and cut to size. The first Group spent 60.6 kg of metal. The calculation is made in accordance with paragraph 8.1.4.

Formula for mass: m=V*ρ, where V-volume, ρ-density of steel (7870 kg/m^3).

$$\text{m} = \text{V} * \rho, \text{where m} - \text{mass}, \text{V} - \text{volume}, \rho - \text{density}$$

$$\text{m} = \text{V} * \rho = (0{,}0015\ \text{m} * 1\ \text{m} * 2\ \text{m}) * 7870\frac{\text{kg}}{\text{m}^3} = 23.61\ \text{kg}$$

The weight of a sheet of 1000x2000 mm is 23.61 kg, so now enough data to calculate how many sheets were spent and the cost.

$$\text{Amount of Spent Metal Sheets} = \frac{\text{Total spent metal, [kg]}}{\text{One sheet metal, [kg]}} = \frac{60.6\text{ kg}}{23.61\text{ kg}} = 2.6\text{ Metal Sheets}$$

$$\text{Cost of spent Metal} = 2.6\text{ Sheets} * 60\text{ Euro} = 156\text{ Euro}$$

- Electricity

It was not possible to measure the electricity consumption in AUDI, so in this chapter the values from paragraph 6.10 are used.

The power consumption of the SOLDAMATIC AR welding simulator is 0.196 kWh per hour.

$$P_{\text{Soldamatic}} = 0.196\text{ kWh} * 21\text{h} * 5\text{ participants} = 20.58\text{ kWh in total}$$

It is obligatory to take into account the factor 83% for calculation of Electricity consumption by actual welder (details are described in chapter 6.11.1).

$$P_{\text{welder}} = P_{\text{fin}} * t * \text{Part.} * 83\%, \text{ where } P_{\text{fin}} - \text{electricity consumption per 1 hour [kWh]},$$
$$t - \text{time [h], Part.} - \text{amount of participants, } 83\% - \text{correction factor,}$$
$$P_{\text{welder}} - \text{total consumption during actual welding process.}$$

$$P_{\text{welder}} = P_{\text{fin}} * t * \text{Part.} * 83\% = 13{,}1\text{ kWh} * 14\text{h} * 5 * 0.83 = 761.1\text{ kWh spent 5 participants}$$

The final values of electricity and cost:

$$P = P_{\text{Soldamatic}} + P_{\text{welder}} = 20.58\text{ kWh} + 761.1\text{ kWh} = 781.7\text{ kWh}$$

$$\text{Cost of Electricity} = P\text{ [kWh]} * \text{Cost of 1 kWh [Euro]} = 781.7\text{ kWh} * 0.225\text{ Euro} = 176\text{ Euro}$$

(globalpetrolprices 2022)

- CO_2

In this calculation, the total CO_2 emissions are calculated (all information in paragraph 6.12).

CO_2 emissions from Metal production:

$$1.85\text{ kg } CO_2 = 1\text{ kg Metal}$$

$$CO_{2\text{ metal}} = m_{\text{total}}[\text{kg}] * 1.85\ [CO_2] = 60.6\text{ kg} * 1.85\text{ kg } CO_2 = 112.1\text{ kg } CO_2$$

CO_2 emissions from Electricity production:

$$0.45\text{ kg } CO_2 = 1\text{ kWh Electricity}$$

$$CO_{2\ electricity} = P\ [kWh] * 0.45\ [CO_2] = 781.7\ kWh * 0.45\ kg\ CO_2 = 351.8\ kg\ CO_2$$

Total Emissions of CO2 in the Atmosphere:

$$CO_{2\ total} = CO_{2\ metal} + CO_{2\ electricity} = 112.1\ kg\ CO_2 + 351.8\ kg\ CO_2 = 464\ kg\ CO_2$$

AUDI Group 2: Workshop

In part of the research at AUDI, Group 2 worked in a workshop for 35 hours on LORCH welding machines like Group 1 (Tab.15).

Group 2 – Traditional Training	Gas, [L]	Wire, [m]	Metal, [g]
Participant 1	21000	7630	23490
Participant 2	21000	7630	9500
Participant 3	21000	7630	23100
Participant 4	21000	7630	23020
Participant 5	21000	7630	22990
Participant 6	21000	7630	25280
Total Value	126 000 L	45 780 m	127 380 g

Table 15: Spent resources by Group 2 at AUDI
Source: self-developed based on Results at AUDI

All calculations are made as in chapter 8.1.4 in point: Group 2: Workshop.

- Gas

$$G_{Lorch} = 10\frac{L}{min} = 600\frac{\mathrm{L}}{\mathrm{h}} * 35\mathrm{h} = 21\ 000\ \mathrm{L}\ \text{spent in 35 hours by one participant on LORCH welder}$$

$$\text{Amount of spent bottles } ArCO_2 = \frac{126\ 000\ \mathrm{L} * 0.83}{10\ 671\ \mathrm{L}} = 9.8\ \text{Bottles}$$

196 L of $ArCO_2$ in liquid state.

The cost of one bottle of $ArCO_2$ welding gas is 35 Euro.

$$\text{Final cost of } ArCO_2 = 9.8\ \text{Bottles} * 35\ \text{Euro} = 343\ \text{Euro}$$

- Wire

$$W_{Lorch} = 3.63\frac{m}{min} = 218\frac{\mathrm{m}}{\mathrm{h}} * 35\mathrm{h} = 7630\ \mathrm{m}\ \text{spent in 35 hours by one participant on Lorch welder}$$

In experiment 45 780 m of wire were spent and, in this case, it can be calculated how many coils were consumed in the end.

$$\text{Amount of coils} = \frac{45\ 780\ \mathrm{m} * 0{,}83}{4166\ \mathrm{m}} = 9\ \text{coils}$$

The price of one coil is 45 euros, it is mean that 405 Euro for the 9 coils spent during the experiment.

- Metal – Carbon Steel S355J2

Second Group spent 127.4 kg of metal. The calculation is made in accordance with paragraph 8.1.4.

$$\mathrm{m} = \mathrm{V} * \rho = (0{,}0015\ \mathrm{m} * 1\ \mathrm{m} * 2\ \mathrm{m}) * 7870\frac{\mathrm{kg}}{\mathrm{m}^3} = 23.61\ \mathrm{kg}$$

The weight of a sheet of 1000x2000x1.5 mm is 23.61 kg, so now enough data to calculate how many sheets were spent and the cost.

$$\text{Amount of Spent Metal Sheets} = \frac{\text{Total spent metal, [kg]}}{\text{One sheet metal, [kg]}} = \frac{127.4\ \mathrm{kg}}{23.61\ \mathrm{kg}} = 5.4\ \text{Metal Sheets}$$

$$\text{Cost of spent Metal} = 5.4\ \text{Sheets} * 60\ \text{Euro} = 324\ \text{Euro}$$

- Electricity

$$\mathrm{P_{welder}} = \mathrm{P_{fin}} * \mathrm{t} * \text{Part.} * 83\%, \text{where } \mathrm{P_{fin}} - \text{electricity consumption per 1 hour [kWh]},$$
$$\mathrm{t} - \text{time [h], Part.} - \text{amount of participants}, 83\% - \text{correction factor},$$
$$\mathrm{P_{welder}} - \text{total consumption during actual welding process.}$$

$$\mathrm{P_{welder}} = \mathrm{P_{fin}} * \mathrm{t} * \text{Part.} * 83\% = 13{,}1\ \mathrm{kWh} * 35\ \mathrm{h} * 6 * 0.83 = 2283{,}3\ \mathrm{kWh}\ \text{spent 6 participants}$$

$$\text{Cost of Electricity} = \mathrm{P\ [kWh]} * \text{Cost of 1 kWh [Euro]} = 2283{,}3\ \mathrm{kWh} * 0.225\ \text{Euro} = 514\ \text{Euro}$$

(globalpetrolprices 2022)

- CO_2

From paragraph 6.12 understand the ratio of CO_2 emissions in the atmosphere in relation to metal and electricity. In this calculation, the total CO_2 emissions are calculated.

CO_2 emissions from Metal production:

$$1.85 \text{ kg } CO_2 = 1 \text{ kg Metal}$$

$$CO_{2\,metal} = m_{total}[kg] * 1.85\,[CO_2] = 127.4 \text{ kg} * 1.85 \text{ kg } CO_2 = 235.7 \text{ kg } CO_2$$

CO_2 emissions from Electricity production:

$$0.45 \text{ kg } CO_2 = 1 \text{ kWh Electricity}$$

$$CO_{2\,electricity} = P\,[kWh] * 0.45\,[CO_2] = 2283.3 \text{ kWh} * 0.45 \text{ kg } CO_2 = 1027.5 \text{ kg } CO_2$$

Total Emissions of CO2 in the Atmosphere:

$$CO_{2\,total} = CO_{2\,metal} + CO_{2\,electricity} = 235.7 \text{ kg } CO_2 + 1027.5 \text{ kg } CO_2 = 1263.2 \text{ kg } CO_2$$

Table comparing resources spent and costs (Tab.16):

Resource	AUDI Group 1 – SOLDAMATIC Training		AUDI Group 2 – Traditional Welding Training		Consumption of SOLDAMATIC
Gas	70 L	122.5 €	196 L	343 €	2.8 times less
Wire	15 260 m	135 €	45 780 m	405 €	3 times less
Metal	60.6 kg	156 €	127.4	324 €	2.1 times less
Electricity	781.7 kWh	176 €	2283.3 kWh	514 €	2.9 times less
CO_2	464 kg CO_2	-	1263.2 kg CO_2	-	2.7 times less
Total costs	590 €		1586 €		2.7 times less

Table 16: The final values of the amount of spent resources and money at AUDI
Source: self-developed based on Results at AUDI

Thus, in the research at AUDI the following results were obtained. A total of 2 176 Euro were spent on the study, of which 1 586 Euro went to Group 2, which worked all 35 hours in the workshop. Group 1 using SOLDAMATIC spent only 590 Euro which is 2.7 times less. Also, the training way with SOLDAMATIC was more economical in terms of resources: 2.8 times less gas was used, 3 times less wire, 2.1 times less metal, 2.9 times less electricity. In addition, one of the most important indicators is the CO_2 emissions into the atmosphere, using the augmented reality simulator emissions are 2.7 times less, which is an impressive difference in the amount of pollution.

9.2.5 Analysis of Questionaries of AUDI Group 1

In this chapter the results of the Group 1 survey at AUDI will be reviewed and analyzed. The 5 participants who spent 60% of the training time working on the augmented reality simulator answered a number of questions that can further help in the development of both the current training path and the development of the simulator itself.

As shown in the chart below (Fig.69), the age category of Group 1 participants was 16 to 18 years old. The average age in the group is 17 years old.

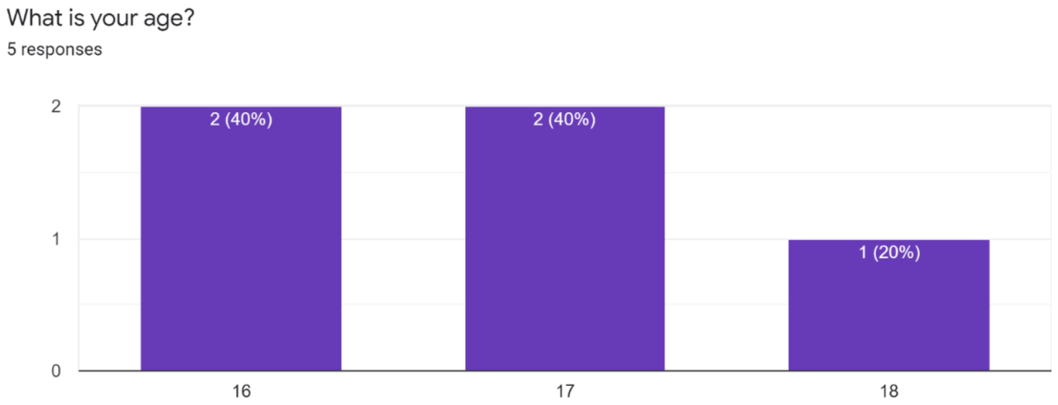


Figure 69: Chart for the question for Group 1 at AUDI: What is your age?

Source: Google Forms

The next question asked each participant about his or her experience in metal welding (Fig.70). The following two graphs show that only 1 out of 5 persons had experience in MIG/MAG welding. Although the author of the research did not notice any special welding skills in any of the participants in this group at the beginning of the training. In this case, it can be assumed that no one had any experience before this training.

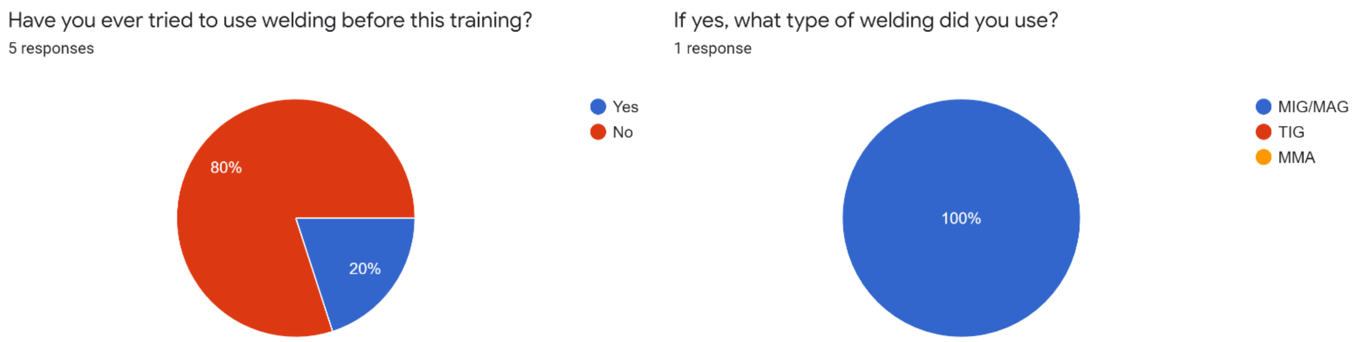


Figure 70: Chart for the question for Group 1 at AUDI about Previous Experience

Source: Google Forms

In the question about the experience with SOLDAMATIC simulator all participants agreed in a very positive opinion of the simulator, which leads to the conclusion that this technical idea of the company Seabery has proven itself in the work with Group 1 (Fig.71). Moreover, 100% of the participants would recommend SOLDAMATIC training to their colleagues (Fig.72).

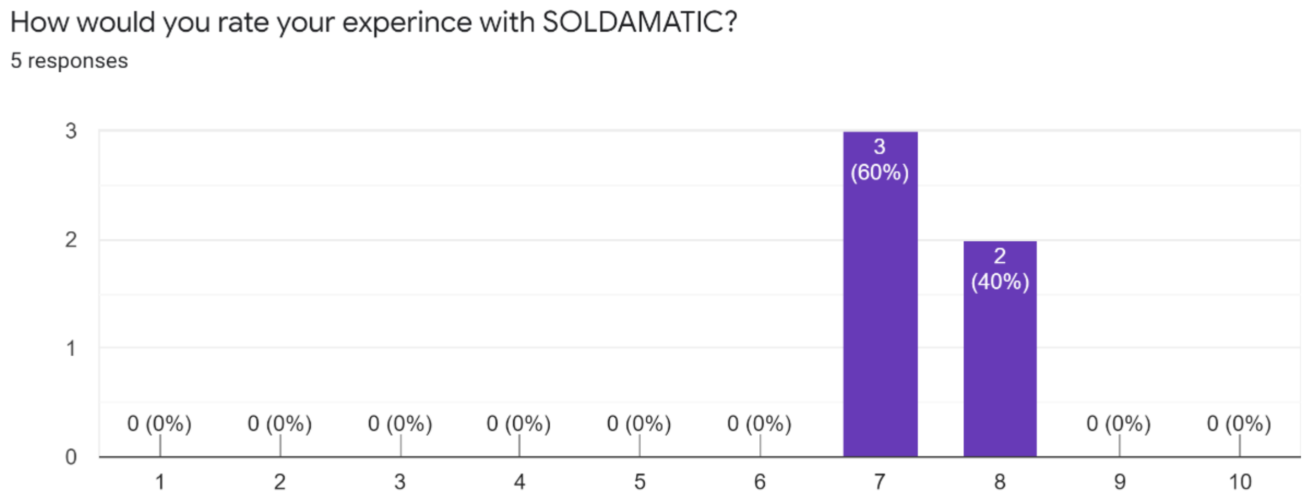


Figure 71: Chart for the question for Group 1 at AUDI: How would you rate your experience with SOLDAMATIC?

Source: Google Forms

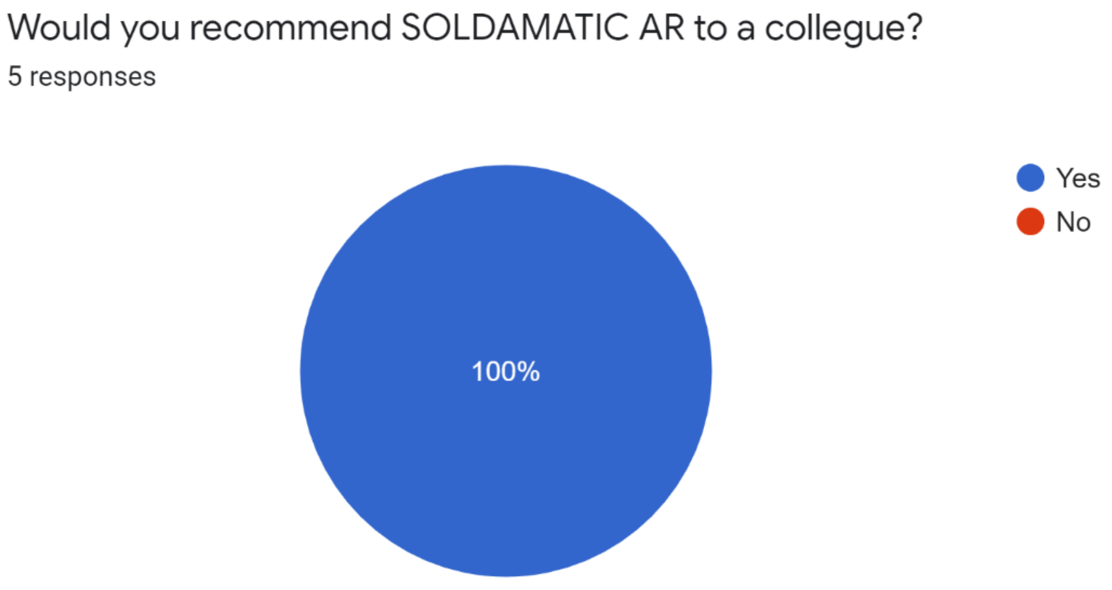


Figure 72: Chart for the question for Group 1 at AUDI: Would you recommend SOLDAMATIC Augmented Reality to a colleague?

Source: Google Forms

The next two questions were free-response, so the analyzed data are given without the diagrams.

- What did you like the most in work with SOLDAMATIC? - Everyone answered that this type of training is good because it does not require a lot of resources and is good for learning welding techniques with markers that are always in front of your eyes while working on the Augmented Reality simulator.
- What did you like the least in work with SOLDAMATIC? - To this question almost every participant answered that the welding helmet for this simulator is very uncomfortable and heavy, sometimes there are Augmented Reality errors.

9.2.6 Analysis of Questionaries of AUDI Group 2

During the research at AUDI AG, Group 2 was interviewed as well as Group 1, and an analysis of this survey will be presented below.

The chart below (Fig.73) shows the age of the participants, so Group 2 was 15-20 years old and the average age of the group was 17 years.

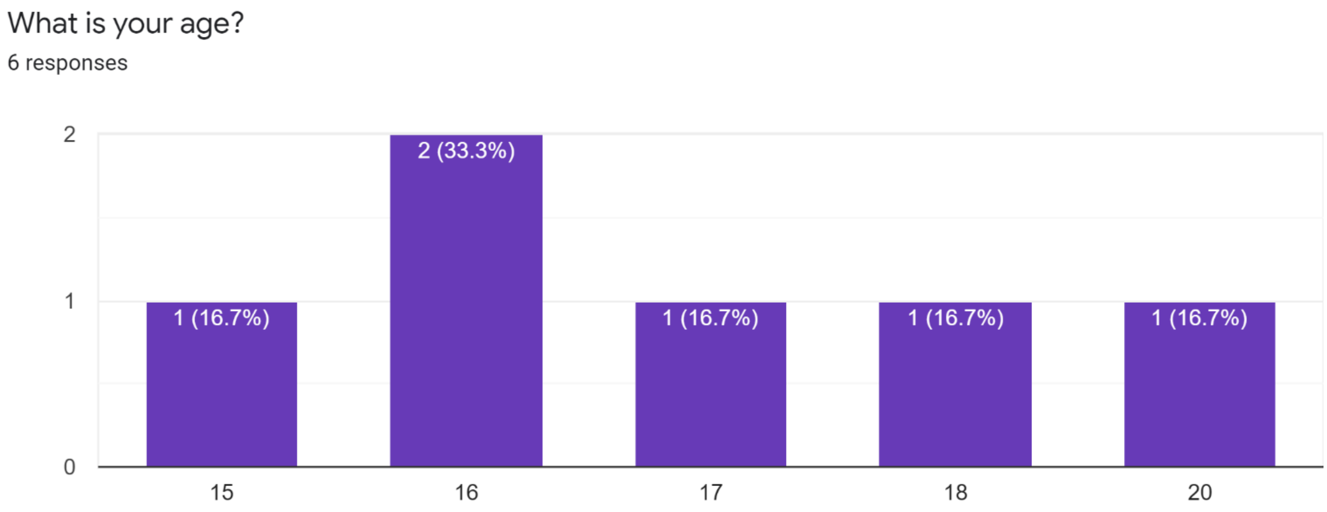


Figure 73: Chart for the question for Group 2 at AUDI: What is your age?
Source: Google Forms

Judging by the data obtained from the survey, 1 out of 6 participants in this group has already had experience using MIG/MAG welding in his/her life (Fig.74). As in point 8.2.5 the author of the research did not notice any special welding skills in Group 2, so let's assume that all participants did not have any experience in this area before the training.

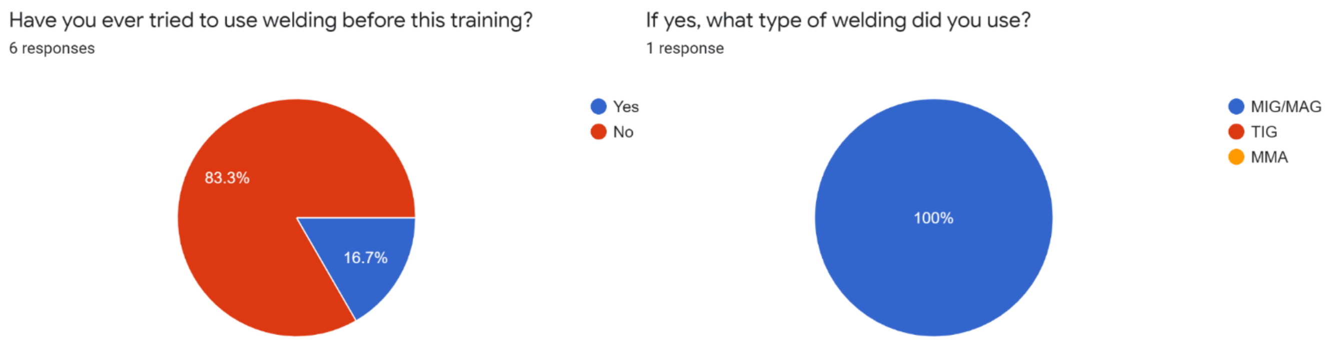


Figure 74: Chart for the question for Group 2 at AUDI about Previous Experience

Source: Google Forms

The questionnaire also contained a set of other questions for participants, but these questions are not presented in the research because they are not relevant.

10. Results

An overview table with all the results of the research is shown below (Tab.17).

Organization	Hochschule Esslingen		AUDI AG	
Group №	Group 1	Group 2	Group 1	Group 2
Theoretical Results, [%]	62 %	75 %	54 %	66 %
Practical Results, [%]	51 %	55 %	59 %	65 %
Gas spent, [L]	60 L	140 L	70 L	196 L
Wire spent, [m]	10 080 m	25 200 m	15 260 m	45 780 m
Metal spent, [kg]	83.9 kg	284 kg	60.6 kg	127.4 kg
Electricity spent, [kWh]	447 kWh	1 087.3 kWh	781.7 kWh	2 283.3 kWh
CO_2 emissions, [kg CO_2]	356.4 kg CO_2	1014.7 kg CO_2	464 kg CO_2	1263.4 kg CO_2
Money spent, [€]	641 €	1 845 €	590 €	1 586 €

Table 17: Overview table with results

Source: self-developed based on Research Results

Several major findings emerged from this research in the following areas.

1. In terms of **theoretical results**, it was found that the most effective way to learn theory is the paper format.

Results from Hochschule Esslingen:

- The quality of print-based learning is 13% better than digital learning

Results from AUDI:

- The quality of print-based learning is 12% better than digital learning

Also, it was assumed that if to combine two kinds of training namely a paper carrier and digital platform E-Learning it can positively influence training.

2. The **practical results** showed that regardless of the path of mastering welding skills, approximately the same level of mastery was achieved by both groups in both parts of the research

Results from Hochschule Esslingen:

- The quality of training with the SOLDAMATIC Augmented Reality Simulator is about equal to the quality of training in the traditional way. The difference in 4% is not significant and could be due to human factors

Results from AUDI:

- The quality of training with the SOLDAMATIC Augmented Reality Simulator is about equal to the quality of training in the traditional way. The difference in 6% is not significant and could be due to human factors

3. One of the significant findings of this research is the **consumption of resources** by two different learning pathways

In a research at Hochschule Esslingen the group that used the augmented reality simulator SOLDAMATIC spent:

- 2.4 times of Gas less than group with traditional way of training
- 2.5 times of Wire less than group with traditional way of training
- 3.4 times of Metal less than group with traditional way of training
- 2.4 times of Electricity less than group with traditional way of training
- 2.9 times of Money less than group with traditional way of training
- 2.8 times less CO_2 was emitted into the atmosphere

In a research at AUDI the group that used the augmented reality simulator SOLDAMATIC spent:

- 2.8 times of Gas less than group with traditional way of training
- 3 times of Wire less than group with traditional way of training
- 2.1 times of Metal less than group with traditional way of training
- 2.9 times of Electricity less than group with traditional way of training
- 2.7 times of Money less than group with traditional way of training
- 2.7 times less CO_2 was emitted into the atmosphere

4. According to a **survey** conducted at Hochschule Esslingen, 70% of the participants liked the augmented reality simulator SOLDAMATIC and 80% would recommend this type of training to

their colleagues. At AUDI, 100% of participants responded that they enjoyed working on the simulator and moreover 100% would recommend the training to colleagues, which is a good sign.

5. The SOLDAMATIC augmented reality simulator is a safe device for users who have never done welding before. During the actual welding process there are a number of hazards such as burns, electric shock, harmful fumes to the respiratory system, etc. In the case of the welding simulator these hazards do not exist.
6. Also, another positive feature of the simulator should be highlighted - the use of SOLDAMATIC in unprepared place. The Seabery device can be used in a normal classroom or company office and does not require a specially prepared room with special expensive workstations.

11. Limitations

This chapter describes the factors to which the research may have been limited.

These factors are:

- Time: This research was time-limited, as 5.5 months were allocated between October 15, 2021 and March 31, 2022.
- Theoretical information: Also, this research is limited to the theoretical volume of information as it is not possible to rely on all the existing information in this area, as a result it turns out that the investigation is limited to those sources that were directly included in the theoretical part of the research.
- Student sample: Since part of the research at the Hochschule Esslingen was conducted on a voluntary basis, there was not an extensive selection of candidates and as a consequence a large volume of participants in the research. In the AUDI part of the research, participants completed mandatory training for their work.
- Use of one type of welding – MAG: Initially, this study was limited to one kind of welding, namely MAG, which is also a kind of limitation because other types of welding are not considered.
- Conditions of research process: The conditions of the study were also limited by the equipment and software provided by the university, in particular one SOLDAMATIC unit and two welding machines.
- Judgments, assessments, conclusions: Limitations in these three directions are also inherent in the research, as any judgments, assessments and conclusions are subjective.
- Motivation of participants: Since the selection of participants for the research at the university was conducted on a voluntary basis, all students had different motivation in the learning process (some people learned the welding skills for themselves and others for professional activities in the future). In the AUDI part of the research this course was not profile for workers in the field of mechatronics.

12. Recommendations and Development Prospects

No less important point in this work is to determine what Seabery needs to improve in its product, namely the SOLDAMATIC augmented reality simulator and the E-Learning digital platform. This paragraph may be one of the most important for the engineering department of this company. Below are listed and explained a number of errors and deficiencies that are worth fixing.

Recommendations for improvement:

<u>Augmented Reality simulator SOLDAMATIC:</u>

- Augmented Reality Errors: During the entire course of the research, each of the participants sometimes had Augmented Reality errors that interfered with or sometimes slowed down the process of learning how to weld. This was due to factors such as light and, more often than not, there was no explanation for this error. Also, head movements caused the simulator to indicate an incorrect hand position. When changing the head position without changing the hand position with the welding gun, the markers that helped the welder in learning the technique would light up green (correct position).
- Freezing and Video Device Problems: Also, in the process of work there were cases of freezing devices, this happened after turning on a new practical exercise, after which it was necessary to restart the unit and an error appeared associated with video devices (Fig.75). The solution to this problem was to restart the unit 3-4 times in a row.

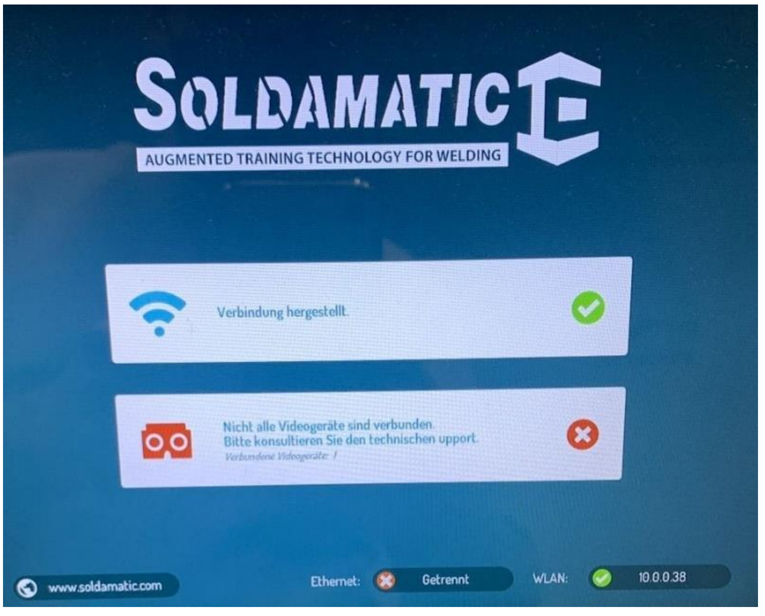


Figure 75: Video Devices Error in SOLDAMATIC welding simulator
Source: self-made

- License Errors: This type of errors constantly appeared during work with “DVS-Media Grundkurs MAG”. The solution was to restart the device, but sometimes this error was not solved in this way.
- Heavy Helmet: Most participants in the survey (paragraphs 8.1.5 and 8.2.5) reported that the welding helmet on the simulator was uncomfortable and heavy, as well as some participants were uncomfortable with the short and hard wire from the simulator to the helmet. The real welding helmet and the helmet from the simulator were weighed to confirm this fact. The weight of the real helmet was 486 g and the weight of the helmet from the Augmented Reality simulator was 939 g, which is almost twice as much. A solution to this problem could be Bluetooth technology.
- Screen: Most people these days use smartphones and tablets with Touchscreen technology on a daily basis, which is a very convenient feature. During the research participants who worked on SOLDAMATIC tried to click on the simulator screen and did not get any response from this device. In the future it would be good to see an Augmented Reality simulator with Touchscreen technology.
- Software Update: In the future it would be a big advantage if the software on the SOLDAMATIC Augmented Reality Simulator could be updated automatically and free of charge, because this feature allows us to provide a quality service to customers with the possibility of fixing bugs during the updates.

Digital Platform E-Learning:

- WPS from E-Learning platform: As already described in point 6.5.2, E-Learning platform does not allow the possibility to make the Welding Procedure Specification as a PDF file and download it to a computer for further use. This feature could have been very handy in the training process.

13. Conclusion and Outlook

The Spanish company Seabery, which produces the SOLDAMATIC simulator, has made it possible to train people in welding skills in an innovative and sustainable way using Augmented Reality technology. In order to prove the ability to achieve decent results in the SOLDAMATIC training process, this research has been organized. Based on the results obtained, it can be said with confidence that the research was successful and all the necessary information was obtained, proving that welding training using augmented reality technology, SOLDAMATIC simulator and E-Learning platform is competitive. Under the same conditions of the research, the participants achieved almost the same level of proficiency with both the SOLDAMATIC simulator and the actual welding equipment. The traditional method of welding training, however, consumed considerably more resources and generated several times as many CO2 emissions as the SOLDAMATIC training. Thus, if all comments about the shortcomings of this simulator are taken into account the technology has a great potential for better training and more productive results than the traditional method of training.

After the improvements of the SOLDAMATIC Augmented Reality Simulator and the E-Learning platform, it is worth to repeat this research in order to confirm the superiority of this type of training in welding technology.

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