Study of ultrasonic waves to stabilize the arc in wet underwater shielded metal arc welding

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I also want to thank my parents for constantly encouraging me to pursue my dream of becoming an Industrial Engineer and always have positive impact on me. This work is dedicated to them

Contents

Nomenclature

MMA	Manual Metal Arc
SMAW	Shield Metallic Arc Welding
FCAW	Flux-cored Arc Welding
GTAW	Gas Tungsten Arc Welding
GMAW	Gas Metal Arc Welding
PAW	Plasma Arc Welding
TIG	Tungsten Arc Welding
MIG	Metal Inert Gas
FW	Friction Welding
H.A.Z.	Heat Affected Zone
k	Kilo
Hz	Hertz
BG	Granular Bainite
AF	Acicular Ferrite
BU	Upper Bainite
M	Martensite
H	Radiation Heights
W	Widmanstätten
SPF	Side plate ferrite
ºC	Degrees Celsius
SEM	Electron microscope (SEM)
SAW	Submerged arc welding (SAW).
σfm	Maximum resistance to traction
N	Force
MPa	Tension
M	Mega

Chapter 1

Introduction

1.1 Motivation

Interest in underwater welding has undergone tremendous growth over the years due to the large range of potential economic and logistical advantage offered by the technique [Levi, 2017]. The appeal of underwater welding is that in enables work to be carried out in ships and offshore structures on-site, eliminating the cost of pulling them out of water. It adapts a very useful method (welding) to an unusual situation, such as underwater conditions.

With the European approach to use more renewable energy the United Kingdom and Germany account for over two thirds of the world's total wind power [Wikipedia, 2018]. The usage of offshore wind farms has become more common for harvesting wind energy to generate electricity. More stable and higher wind speeds are found offshore, increasing the amount of energy produced [BOEM, 2017]. Offshore wind farms have a low global warming potential compared to onshore wind farms as there is a reduction of the emissions of greenhouse gases. [M. Dolores Esteban, J. Javier Diez, Jose S.López, Vicente Negro, 2010]. Therefore the increase of offshore wind farms demands further investigation in underwater welding to improve reparations, safety and life expectancy of the underwater structures.

The economic and technical incentives motivate studies to improve the process of welding underwater. It has been proven that using ultrasounds helps to stabilize the arc and therefore to improve the consistency of the materials being weld using flux cored wires. An improvement in tensile strength and the bending properties was noticed and during tensile testing the fracture occurrence of the weld joint was transferred from the joint in the base metal. [Q.J.Sun, 2016]. We will use the concept behind stabilizing the arc with ultrasounds to stabilize a wet welding process using stick electrodes.

Chapter 2

Background

2.1 Welding

Welding is the process used to joint materials; usually these materials are metals or thermoplastics. The process occurs by fusion, in which both metals with similar compositions and melting points are melted and jointed together [Wikipedia, 2018]. During the welding process a filler material is usually added to increase the cool down of the pool of molten material (weld pool) which helps to produce a stronger joint than the base metal [Wikipedia, 2018].

2.1.1 Electrode

The electrode is used to as an electrical conductor to pass electricity to a nonmetallic part of the circuit. Welding electrodes fuse two pieces together by passing a current through the work piece. For the different processes we use different electrodes. For gas metal arc welding (GMAW) or shield metal arc welding (SMAW) a consumable electrode is used while a non-consumable is used for gas tungsten arc welding (GTAW). For direct current supply the electrode can be a cathode in the case of using a stick or weld rod or an anode in other welding processes. For alternating current the electrode is not considered anode or cathode. [Wikipedia, 2018]

2.1.2 Flux

Flux is a protective agent. In welding flux is used to combat oxygen. At room temperature flux is inactive. But when high temperatures are used to weld the flux is extremely reducing which prevents oxidation of the base and of the filler metal. This happens because the flux dissolves oxides present in the metal surface and it prevents new oxides by acting as a barrier. [Wikipedia, 2018].

2.1.3 Shielded metal arc welding

Shielded metal arc welding is also known as stick welding. The process uses a consumable electrode covered by flux. A direct or alternating current is used to form an electric arc between the electrode and the base metals to join them. The process produces a molten pool that cools to produce the joint. Meanwhile the flux breaks down producing gases which protect and proportionate a layer of slag. Both of these act as protection of the joint from the atmosphere [Wikipedia, 2018].

Some of the reasons to use shielded metal arc welding are: It is a versatile process with respect to locations and environment; it can be done inside or outside of a structure. It can be used for ships, bridges or production lines. It needs simple, inexpensive and portable equipment. No need of auxiliary shielding gas or flux. The process is not very sensitive to wind. It can be also used in areas of limited space. Finally the process is suitable for common metals and alloys [Praxair, 2011].

On the other hand shielded metal arc welding has some limitations. It has low cycles; this makes the cost per deposited weld metal high. It has lower deposition rates compared to other welding processes. Shielded metal arc welding has problems with reactive metals such as titanium, zirconium, tantalum, and columbium. This is because the shielding does not prevent oxygen from contaminating the weld [Praxair, 2011].

2.2 Underwater welding

Underwater welding is commonly done by manual metal arc welding (MMA) or Stick welding using an electric arc as the source of energy. There are two types of environments for underwater welding, wet and dry [Water Welders, 2015]. My research project will concentrate in wet welding but I will explain both for a comprehensive understanding of the experiment.

2.2.1 Dry Welding

Dry welding, commonly known as hyperbaric welding or habitat welding is the most used method. It provides an environment without water for the weld to be joined. It uses a chamber or a partial chamber called ‘Habitat’ for the divers. The chamber’s size can differ from the size of a balloon to the size of a room. Larger habitats are usually more pressurized and circulate air in and out of the chamber to keep Nitrogen and other gases from accumulating. If this is not done the chamber can suffer from risk of fire or explosion. It uses AC/DC power supply and a return load [Water Welders, 2015] [Water Welders, 2016].

The idea is to build a chamber and evacuate the water around the welding zone, thus having the same conditions as welding in air. The other approach is to build an enclosure and fill it with gas (e.g. Helium) under high pressure (hyperbaric) to push the water out. The welder will use a breathing mask and other protective equipment. [Water Welders, 2015] [Water Welders, 2016].

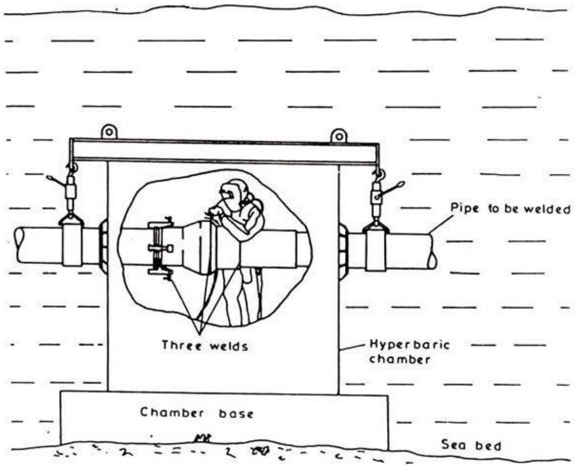

Figure 2.1: Dry underwater welding. [Yourarticlelibrary, 2017]

2.2.1.1 Techniques used in dry welding

The first one is ‘Pressure Welding’, working with one atmosphere unit of pressure, in other words, same pressure at sea level. Secondly is hyperbaric underwater welding (Habitat Welding) that has the same pressure as the surrounding water. The size of the chamber is about a small room’s size. Thirdly ‘Dry Chamber Welding’ which is the same as ‘Habitat Welding’ but with a smaller chamber. It only holds the upper part of the body. Lastly ‘Dry Spot Welding’, the size of the chamber only holds the weld’s site and the welder introduces the electrode inside the chamber, which is completely sealed [Water Welders, 2016].

2.2.1.2 Welds used in dry welding

The common welding techniques used inside the hyperbaric chamber is: Shield metallic arc welding (SMAW), this is the most commonly used weld. Welders use thin, long cylinder (electrode) and an arc. Used for steel, aluminum and others. Flux-cored Arc Welding (FCAW) which has a constant supply of filled metal. Used for nickel-based alloys, cast iron and others. Gas Tungsten Arc Welding (GTAW) also known as Tungsten Arc Welding (TIG). The electrode is made of tungsten, non-consumable; it applies heat and an electric arc. Used for stainless steel, aluminum and others. Gas Metal Arc Welding (GMAW) known as Metal Inert Gas (MIG). It uses a gas to protect the electrode, used for non-ferrous metals, such as, aluminum. Finally we have Plasma Arc Welding (PAW) which uses an electric arc. It combines high arc speed and intense heat to weld. Used for stainless steel, aluminum and others.

[Water Welders, 2016]

In conclusion dry underwater welding is safer for the divers as it offers a more protective space of work due to increased visibility, and still offers a good quality weld with surface monitoring. But it has a much higher cost and a lower accessibility.

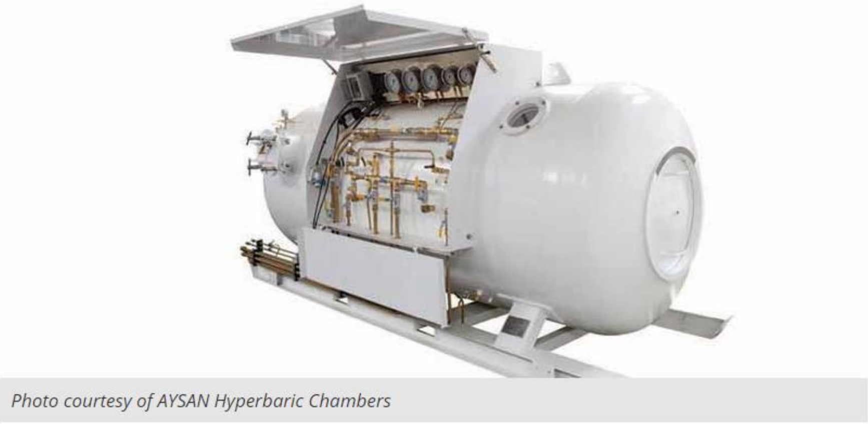

Photo courtesy of AYSAN Hyperbaric Chambers

Figure 2.2: Hyperbaric Chamber used for dry underwater welding.
[Water Welders, 2016]

2.2.2 Wet Welding

Wet welding happens directly in the water and the power supply and cable system is slightly different to the underwater dry welding. The technique employs SMAW with an operating system that consists of double insulated cables with a welding and return aid, knife switch to cut power of the welder, making the diver's job safe because the welding machine it is only on when needed. Only direct current power supply is used and it uses negative polarity.

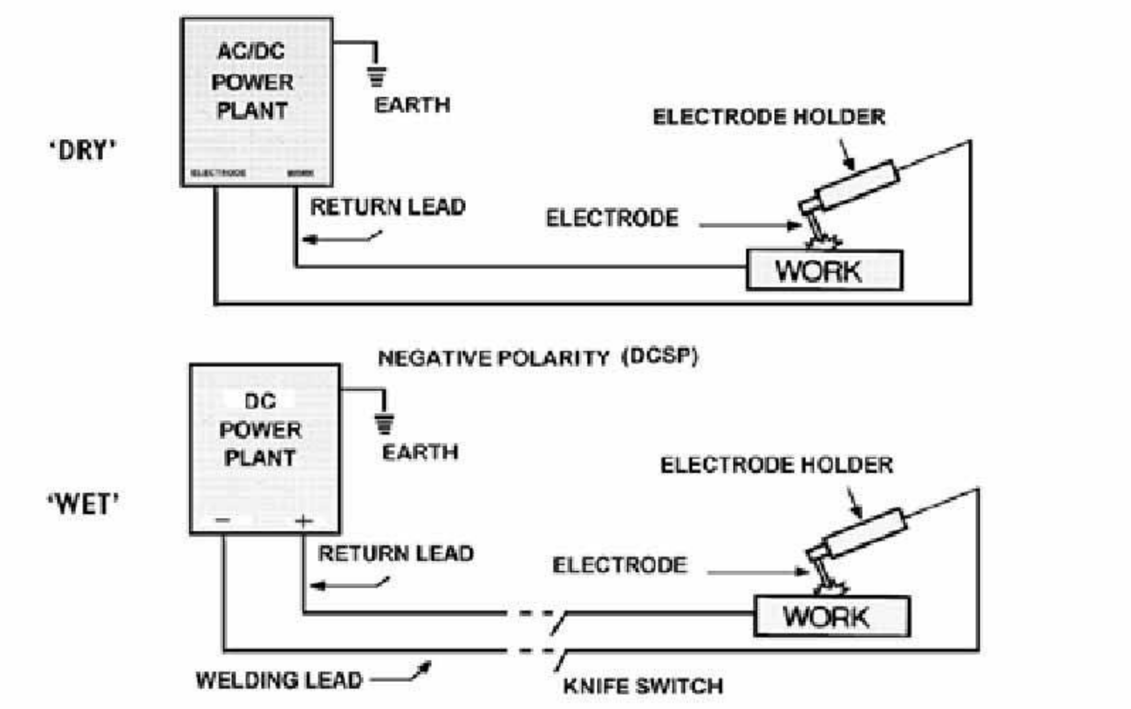

Figure 2.3

Figure 2.3 shows the difference between dry and wet welding. Dry welding uses AC/DC and wet welding just DC. Also the fact that wet welding uses knife switch to disconnect the weld when is not been used. [Water Welders, 2016]

The three primary areas of heat movement are the cathode, anode and plasma. The cathode would be the stick, the anode the metallic work area and the plasma the gaseous cylinder through which the electric arc travels, in other words the path for the electrons. When the welder strikes an arc, the electrons from the cathode travel to the anode and the ions from the anode travel to the cathode (all around the plasma).

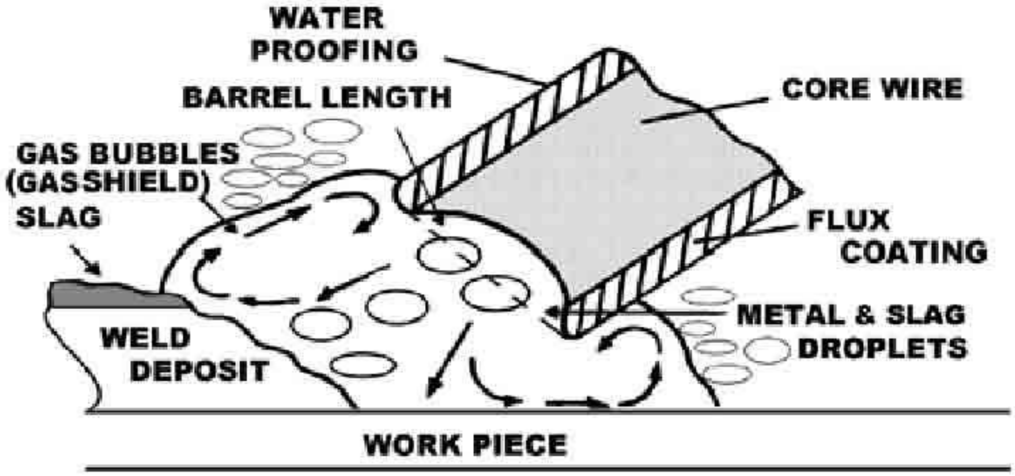

Figure 2.4 [Keats 2004]

A massive amount of energy and heat is generated due to the particle transfer. The arc heats up to 5000ºC. During the process there is a heat distribution, 63% of the heat is transferred to the anode and the other 33% to the cathode's end (without taking in to account heat losses).

When the welder strikes an arc, the welding torch (electrode) creates a surrounding gas bubble that protects the weld from water and corrosive gases, such as oxygen. The bubble is created from the flux in the outside of the electrode, this creates a direct path for electricity, not letting it go to the surrounding waters. The bubble is a mixture of gases which helps melting the metal and joining by guarding the molten material from hydrogen. Further on, the flux produces slag that covers the seam and lets the weld cool slower. Sometimes slag falls on unwanted places, underwater the problem is amplified due to limited visibility and temperature fluctuations. Therefore a more resistant flux has been created which allows the slag to drip evenly and gives a more consistent burn leading to a more controlled situation [Water Welders]. It is also worth mentioning that underwater welding is limited to 400 meters, due to safety risks. [Water Welders]. Some of the risks for the welders are: decompression sickness, hypothermia or even drowning. Also electric shocks or explosions are possible due to equipment failure. Finally people that have worked for years have reported problems hearing, muscle aches or memory problems. [divelawyer, 2013].

The bubble's composition is 70% Hydrogen, 25% CO_2 and 5% CO. One of the main problems of underwater wet welding is the amount of bubbles it produces which affect the visibility of the welder and, even worse, can cause the arc to collapse [Water Welders].

[Water Welders, 2016]

2.2.2.1 Welds used in wet welding

The three types of welding that can be used in wet underwater welding: Shielded metal arc welding (SMAW). Flux-cored arc welding (FCAW) and friction welding (FW). In friction welding (FW) metals are fused with friction and heat. Material melting does not happen [Water Welders, 2016]. Heat is generated by friction between the metals as the metals move relative one to the other. An extra force is applied to plastically displace and fuse the metals, this force is called ‘’upset’’ [Wikipedia, 2018].

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2.2.3 Challenges in wet welding

2.2.3.1 The arc

The heat of the arc dissociates the water. The dissociation of water produces hydrogen and oxygen, which at high quantities can lead to explosions. At room temperature hydrogen does not react with oxygen, but during the welding process the arc provides enough temperature to increase the speed and number of collisions between molecules, reaching the activation energy and therefore breaking the bonds of the reactants (hydrogen and oxygen). New bonds are created between both elements. As the reactants have more energy than the products, this is called an exothermic reaction. The result is an excess of energy which is manifested in the form of heat, light and sound. In order to avoid this, underwater welders should take the following precautions: Stop welding when small popping sounds are hard, look for the areas where the gas can get trapped and weld from the top to the bottom. [H. OZAKI, A Study of Hydrogen Crackin, 1997] [jones, 2015]

2.2.3.2 Hydrogen cracking

Hydrogen cracking is another problem to be dealt with when welding underwater. Hours or days after welding hydrogen can affect the weld and/or the H.A.Z. making the weldment lose its ductility. In his book *“Welding Metallurgy and Weldability*” professor John C. Lippold of the Ohio State university, speaks about the three main risk factors of hydrogen cracking: Threshold level of hydrogen, susceptible microstructure and restrain level. [Electric, 2018]

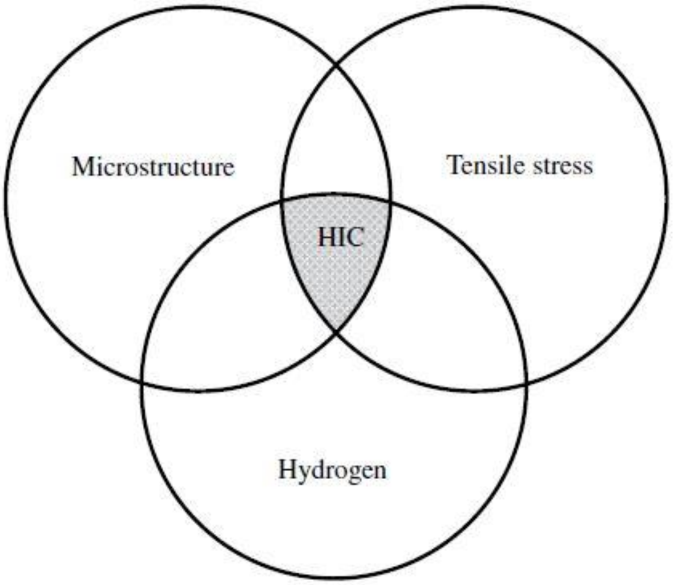


Figure 2.5

Figure 2.5 shows the three factors needed for hydrogen-induced cracking. For the cracking to occur all three of them need to happen. With just two of the three characteristics it would not happen. [Lippold, 2015]

2.2.3.3 Hydrogen

The induced hydrogen comes from the welding process, and it can happen due to moisture in the electrode, flux, shielding gas or environment, decomposition of cellulosic-type electrode coatings and combustion products of oxyfuel gas welding or having on the surface on the material to be weld contaminants with hydrogen. A way to avoid or reduce the HIC is to have a low hydrogen practice. [Lippold, 2015]

2.2.3.4 Pores

The molten pool can get gases trapped inside, such as nitrogen, oxygen or hydrogen. These gases are released during solidification. This can occur for different reasons such as dried electrodes, excessive turbulence or surface paintings. We try to avoid pores because they can lead to cracking. [TWI, 2011]

2.2.3.5 Choosing between Wet or Dry

As seen above in length, wet and dry welding have their advantages and disadvantages, so choosing a procedure over the other is not a linear answer. To pick between them you have to take into account different factors. The key aspects are: welder’s skills, project budget, safety issues, location, depth, and project’s time. Most underwater dry welding occurs at a low depth especially in offshore operations. Wet welding is more versatile and cheaper than dry underwater welding, as no chamber is needed. Furthermore the weld can be reached from more positions, using less equipment and operating at a higher speed. [Water Welders, 2016]

2.3 Ultrasonic Process

2.3.1 Overview

Ultrasounds are acoustic energy in the form of sound waves with frequencies above the human hearing range. Ultrasounds go from 20 kHz to several gigahertz. Ultrasounds are used for many things, such as ultrasound imaging, detection and ranging or acoustic microscopy in medicine. [Wikipedia, Ultrasound, 2018]

2.3.2 Creating ultrasonic waves

In order to produce ultrasonic waves a piezoelectric quartz crystal is used. When the crystal is compressed the crystal charges of electricity, this creates an electric current. The more pressure applied the bigger the current. If the crystal is stretched instead of compressed the current changes direction and when the crystal is stretched and compressed an alternating current is created. If we know apply an alternating current at the natural frequency of the crystal we will produce an ultrasonic wave [Wikipedia, 2018].

2.3.3 Ultrasonic welding

In ultrasonic welding high frequencies to create heat locally and fuse materials together. The materials are placed one on top of the other. The horn gets in contact with the upper material. The horn vibrates transmitting the vibrations through the materials to the joint. The temperature in the joint increases due to the friction until the melting point is reached, materials melt and vibrations stop. The horns stays in its place while the materials cool down and solidify (hold time). Finally the horn pulls back and we are left with a fast, clean and efficient weld [Dukane, 2016].

Metals or plastics are weld only using ultrasounds, it is also important to know that it can only be applied in one point and not in a whole line. AC current (50 to 60 Hz) is increased to (20000-40000Hz) and then transformed into mechanical vibrations using a piezoelectric transducer. The vibrations are transferred to the booster where the amplitude can be changed to optimize the results. Finally the vibrations go to the horn which is in charge of applying it to the welding materials.

The vibrations are transferred to the union point where friction starts to raise the temperature, when the fusion point is reached the vibrations stop allowing to the fusion point to cool done and solidify. The forced applied to the pieces is maintained for some time more in order to allow the two pieces to form molecular bonds. [Flores Esteban, 2014, págs. 2-5]

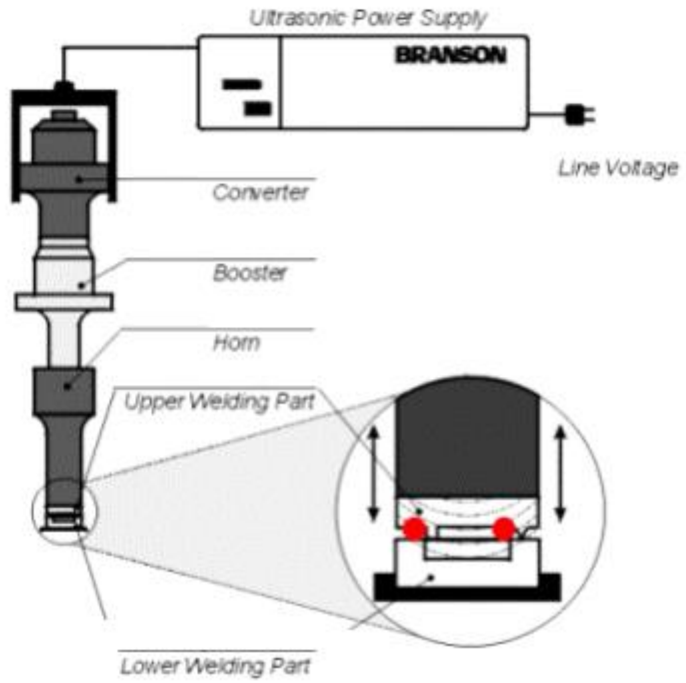


Figure 2.6 Components [Flores Esteban, 2014, págs. 2-5]

For our experiment we are going to use ultrasounds to stabilize the arc improving the welding process and quality in the weld. We can obtain the ultrasounds from mechanical transducers such as piezoelectric or magnetostrictive which is what we will use for our experiment. These techniques can provide the ultrasonic source from different positions. Also there is a new method called; arc with ultrasonic excitation of current which has the ultrasounds incorporated to the arc. Using the arc for thermal energy and as an ultrasonic source. [Bohórquez, Ultrasound in arc welding: A review, 2014]

The piezoelectric transducer consists of a ceramic material (usually Lead Zirconate Titanate) which expands and contracts when a voltage is applied provoking a sound wave. This happens because ceramic is surrounded by electrodes from two metal blocks (aluminum and steel).

The magnetostrictive transducer has a coil of wire with an electric current creating a magnetic field. In the inside of the coli we have a magnetostrictive material (nickel plates arranged in parallel). The magnetic field makes the magnetostrictive material to elongate and contract creating a sound wave.

Piezoelectric transducers are reliable and efficient, have a wider range of frequency and waveform characteristics and better electrical conversion efficiency. Therefore they are most commonly used. [Cleaning Technologies Group, 2004]

2.3.4 Ultrasonic arc welding

In this study, the function of ultrasounds is to stabilize the arc during the welding process. This translates in refined grains. Fine grains help improve the mechanical properties of the weld, like ductility and fracture toughness. They also reduce the probability of solidification cracking during welding.

Wu et al's study 'Microstructure and mechanical properties of ultrasonic assisted underwater wet welding joints' used the arc not only as a thermal source but as an ultrasonic transmitter. The results show how ultrasounds improved the weld and how it affected the different areas.

2.2.5 Usage in wet welding

In underwater welding ultrasounds have been used to stabilize the arc. Sun, Cheng et al used it to assist FCAW underwater. Ultrasonic form an acoustic field between the work piece and the ultrasonic radiator. His results showed an improvement in the arc's stability. Producing more granular bainite (BG) and acicular ferrite (AF) while decreasing the upper bainite (BU) and the martensite (M), the change in structure improved the tensile strength and the bending properties of the sample. [Q.J.Sun, 2016]

2.2.6 Ultrasounds in Sun et Al. experiment

The two main parts of the ultrasonic vibrations equipment are located inside the welding torch. The part at the top is called ultrasonic transducer, its job is to transform electrical signal into ultrasonic vibrations. The second part is the ultrasonic radiator which amplifies the vibrations waves. The ultrasound forms an acoustic field between the work place and the radiator.

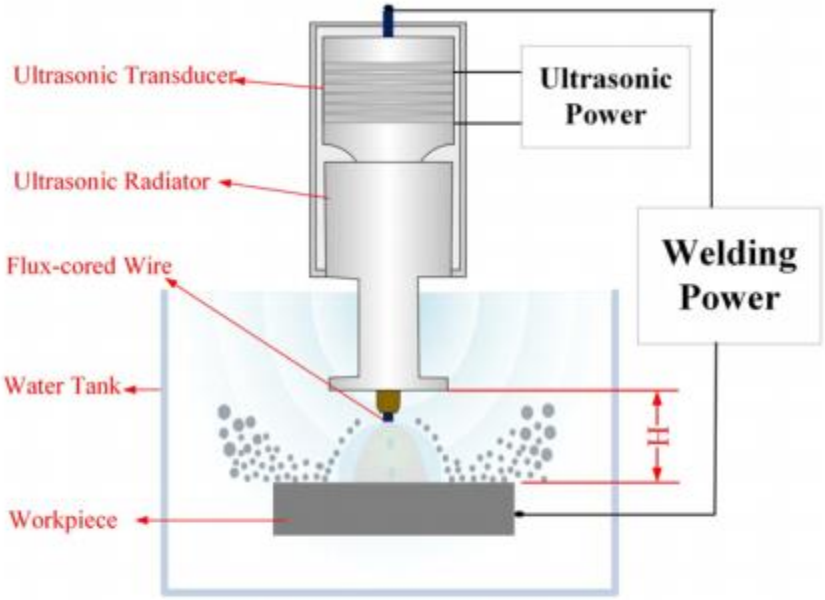


Figure 2.7 [Q.J.Sun, 2016]

2.4 Influence of the ultrasound on the grain structure

2.4.1 Fusion zone

The fusion zone starts and ends in the parts of the materials that have been fused. This section is there after the welding process has happened. Its chemical composition will be a mixture of the substrates been weld and any extra filler material used [Corrosionpedia, 2017]. The microstructure development of the fusion zone depends on the solidification behavior of the weld pool. The parameters that determine the microstructure of zone are; the growth rate, temperature gradient, undercooling and alloy composition. The heat source interacts with the metal during welding, this physical process makes the microstructure development more complicated and remelting, heat and fluid flow, vaporization, dissolution of gases, solidification, subsequent solid state transfer, stresses and distortions affect the weld pool solidification and microstructure. The solidification of the weld is important because it will dictate the grain structure and dendrite growth selection process. The microstructure along the fusion line has a low growth rate and steep temperature gradient, as we approach the weld centerline the growth rate increases and the temperature gradient decreases. This results in a microstructure that varies from the edge to the centerline [S.A. David, S.S. Babu, and J.M. Vitek, 2003].

In Sun et al paper they studied S355J2G3 steel. Without ultrasounds the microstructure was made up of pro-eutectoid ferrite (PF), upper bainite (BU) and martensite (M). BU and M are directional phases which induce degradation of toughness of the weld, this means that the mechanical properties negatively affected. Water quenching increases the cooling rate of the molten metal, where side plate ferrite (SPF) transforms into austenite-ferrite interface. When they used ultrasounds the microstructure was pro-eutectoid ferrite and acicular ferrite. This happens because when ultrasonic waves are applied the austenite grain size grows p and changes the microstructure. Granular pro-eutectoid ferrite (PF) changes to strip pro-eutectoid (PF), the amount of upper bainite (BU) decreases and it is replaced by granular bainite (BG) and martensite (M) disappears meanwhile acicular ferrite (AF) appears. Temperature, when austenite is cooled below 900ºC ferrite nucleates at the austenite grain boundary between 770-680ºC and grows inwards, the ferrite created is called pro-eutectoid ferrite (PF). As temperature continues to decrease (700-650ºC) ferrite is still nucleating inwards, this gives a poor toughness as it has a high density dislocation. Once the temperature is under 500ºC we get acicular ferrite (AF), the problem is that with the increasing cooling rate proportionated by the water quenching instead of getting acicular ferrite (AF), at 550ºC Bainite (B) is formed and Ms and martensite is formed under Ms. Ultrasounds improve the arc stability which means the arc takes longer to extinguish and therefore the cooling rate of the molten pool decreases, transforming the bainite (B) and martensite (M) into acicular ferrite (AF) [Q.J.Sun, 2016].

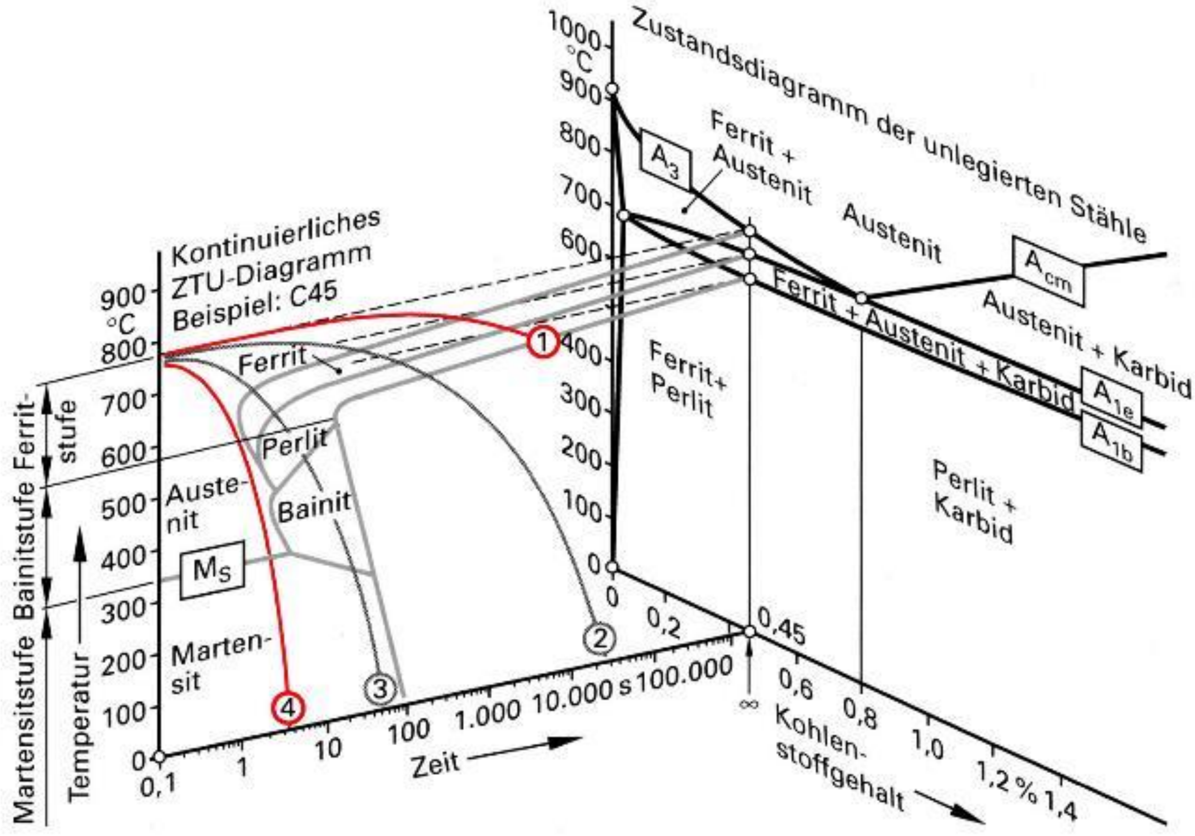


Figure 2.8 [yildiz]

When there are no ultrasonic arc vibrations, more ferrite will be produced (Instead of acicular ferrite), increasing the probability of crack propagation. Acicular ferrite is a microstructure of ferrite characterized by its crystallites, which have the form of needles. We prefer AF to F because its chaotic structure provides us a tougher structure. [Wikipedia, Acicular ferrite, 2018]

In ZHANG O1unlei, WU Minsheng, DU Jinglei experiment ‘Improving Weld Quality by Arc-Excited Ultrasonic Treatment’ the toughness produced by the ultrasonic vibrations was tested using Charpy Unotch test using different modulation frequencies and modulation currents, at room temperature according to ‘G B2650—81’. The results show that for all ultrasonic vibrations the fusion zone toughness was improved between 6% and 12%. The experiment was not done underwater. The experiment was done with submerged arc welding (SAW).

2.4.2 Partially Melted zone

The next zone is the partially melted zone, this zone is the one located right after the fusion zone. The problem is that in this zone we have a peak temperature above 1100ºC but underneath the liquid state. This is dangerous since nearly the whole zone has coarse grains.

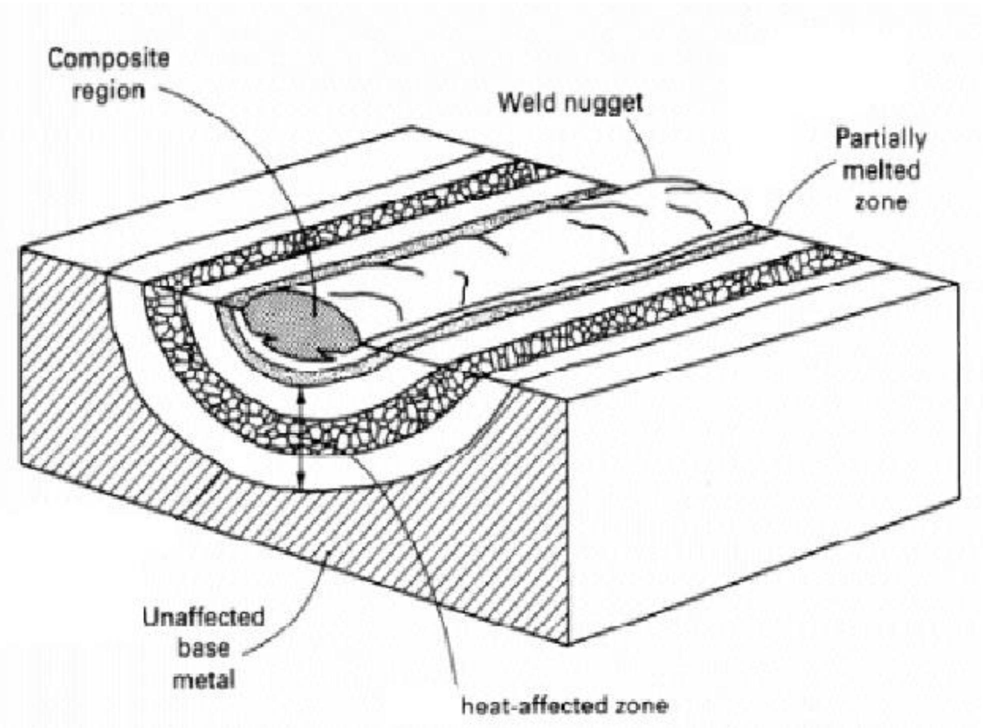


Figure 2.9 [Consulting]

The ultrasonic vibrations help in different ways in this stage. First they improve the grains refinement and decrease their size. As before, vibrations accelerate the heat transmission increasing cooling during solidification. They also break the oxide films (liquid interference during solidification). The oxide films come on the scene due to a redox reaction, as a result of interaction between oxygen and water. Vibrations reinforce the weld pool convections and make the partially melted grains to fall from the base metal. Finally nonlinear pulsation and compression, and surface distortion result in the appearance of impact pulses of pressure and increase the wettability of the solid/liquid interface, which stimulates the generation of new nuclei.
[ZHANG Chunlei, WU Minsheng, DU Jinglei, December 2001]

2.4.3 H.A.Z.

The heat affected zone is the part of the base metal which is not melted but it is affected by the welding process. Therefore the HAZ will undergo a change in microstructure and properties. The property changes are usually not desirable as they lead to residual stress, loss of material strength, or decrease in resistance to corrosion or cracking. Therefore, usually a small HAZ is desired.
[Inspectioneering, 2018]

In the heat affected zone, the vibrations increase the heat conduction. As the vibration propagates through the matrix, the matrix expands and contracts alternately which changes the matrix density. In the compression the volume decreases, leading to higher temperatures. And the opposite happens when it expands, resulting in lower temperatures. The temperature gradient makes the heat go from higher temperature areas to lower temperature areas. This results in accelerated heat transfer, accelerated heat transfer changes the temperature distribution and the change in temperature distribution increases the HAZ.

The HAZ is deepest in the direction of the ultrasounds. As we have said above, a narrowed HAZ is preferred. Ultrasonic enlarges the HAZ but it also produces fine grains giving the HAZ better properties than the matrix. This was researched in ‘‘Ultrasonic-vibration assisted arc-welding of aluminum alloys’ were they used scanning electron microscope (SEM) to observe the grain refinement in the tempered zone.

[ZHANG Chunlei, WU Minsheng, DU Jinglei, December 2001]

2.4.4 Plastics

In plastics ultrasounds have their contact point melted to create a joint between them [Wikipedia, 2018]. This happens because the ultrasonic waves transformed into mechanical energy which is absorbed locally. The mechanical energy creates friction between allowing for the two materials to bond [Dukane IAS, 2016].

Using ultrasounds to joint plastics is a method used all over the world. Some of the industries where it is used are: automotive, electrical, packaging and medical. This is because they all deal with small welding requirements [Wikipedia, 2018].

2.4.5 Support for better grain structure

Fine grains improve mechanical properties of the weld (ductility and toughness) and reduce crack propagation during the solidification process. Ultrasounds are a refining technique.

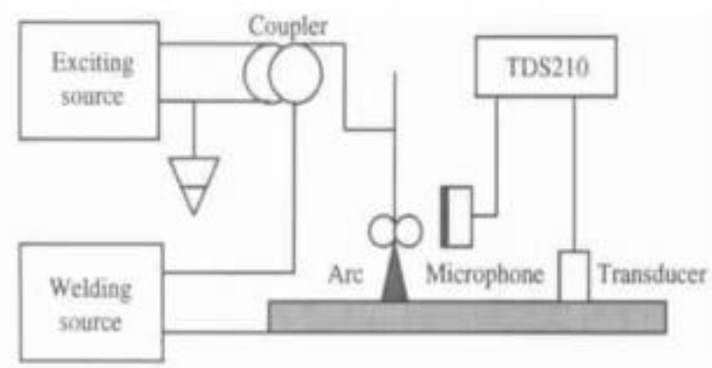


Figure 2.10 Zhang et Al. experimental set up

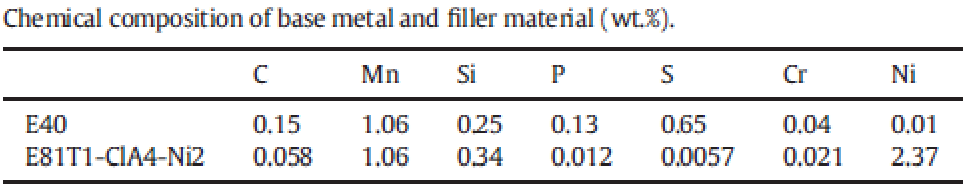
In Zhang et Al. experiment ‘*Improving Weld Quality by Arc-Excited Ultrasonic Treatment*’ where an electronic excitation source was coupled with a conventional welding power supply; submerged arc welding (SAW) and CO2 gas-shielded arc welding. They found out that using ultrasounds improved the fusion zone toughness; this is because the ultrasounds modified the grain structure having more acicular ferrite (AF) and acicular ferrite is responsible for high toughness. Crack propagation is decreased because acicular ferrite has randomly orientated short needles.

2.5 Sun et. Al

Sun, Cheng et al experiment’s aim was to study the use of ultrasonic to assist underwater welding (U-FCAW). They used flux cored arc welding to weld E40 steel. They analysed the tensile and bending strength properties, hardness distribution, stability of the arc and the weld center and the fusion zone microestructures. Since their work was the motivation for my study, I am now going to explain their work more detailled.

2.5.1 Experimental set up

For the experiment they used E40 steel as a base metal with dimensions of 200x50x8mm. A single V weld groove was welded with a 30 degree angle with a 2-mm root face and 2-mm root opening. Filler material was E81T1-ClA4-Ni2 of AWS A5.36, which the diameter is 1.2 mm.



Chemical composition of base metal and filler material (wt.%).

	C	Mn	Si	P	S	Cr	Ni
E40	0.15	1.06	0.25	0.13	0.65	0.04	0.01
E81T1-ClA4-Ni2	0.058	1.06	0.34	0.012	0.0057	0.021	2.37

Table 2.1

The table shows the chemical composition of the base metal and filler metal. [Q.J.Sun, 2016]

The equipment used was a GMA welding system for flux-cored arc welding, an ultrasonic system and a composite welding torch. The ultrasonic transducer, ultrasonic radiator and a wire conductive rod are the three parts of the welding torch. First the ultrasonic transducer transforms electrical signals into ultrasonic vibrations. The ultrasonic radiator amplifies the wavelength. The ultrasonic wave emits from the bottom of the ultrasonic radiator. The welding wire was fed through the wire conductive rod, which is in the axial hole of the ultrasonic transducer and ultrasonic radiator. They used a current of 170A, an arc voltage of 36V and an ultrasonic frequency of 15 kHz. Fresh water was used at a depth of 0.3 meters.

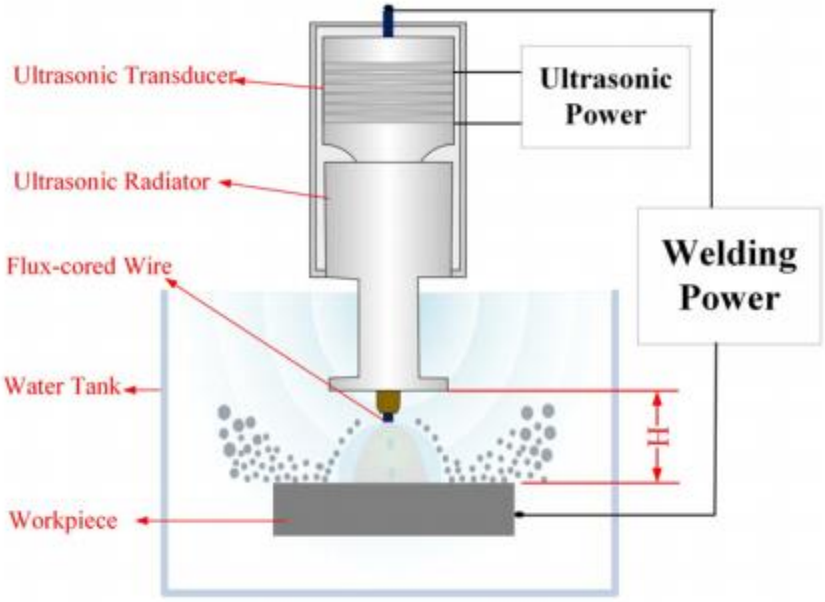


Figure 2.11 [Q.J.Sun, 2016]

For the experiment they used different radiation heights (H) to study the effect on ultrasonic field and the welding quality in air conditions. This was done to obtain the optimum parameters for the arc stability. The radiation height is the distance between the work piece and the ultrasonic radiator.

Finally the equipment used for measuring and analyzing the experiment was a high speed camera (Olympus ISPEED3, Japan) to record the arc. The microstructures were observed using optical microscopy (Olympus GX51, Japan). A universal testing machine (WOW-50, China) with a 30kN capacity was used for measuring the tensile strength and bending. The fracture analysis was done by a scanning electron microscopy (TESCAN VEGA) and finally for the hardness tests a universal testing machine (HVST-1000Z, China) was used.

2.5.2 Results

2.5.2.1 Arc Stability

FCAW welding is an unstable process. Ambient water affected the arc making easy to extinguish, this lead to a ‘serpentine’ weld. Even though, U-FCAW arc becomes more stable for radiation heights (H) between 50mm and 70mm thus the arc size decreases uniformly. The ‘serpentine’ shape in the weld formation dissipates when the radiation height decreases over 70mm height. Weld spattering increases as radiation heights decrease. Underwater wet welding can be secluded by bubbles from water vapor and gas isolating the arc from the neighboring water. The arc burns in the bubble during the welding process. The bubble detaches periodically and rises up, this happens due to the difference between the gas’ and the water’s density. Every time the bubble detaches from the molten pool the arc extinguishes. The ultrasounds provide an additional downward force to help reduce the detachment rate. Instability time also decreases as a result of lower arc extinguish rate. In other words, ultrasounds improve the arc stability and the weld formation improves at a certain height of the radiator.

2.5.2.2 Cross Section Parameters

The effect of ultrasonic radiation height on weld geometry was represented in the diagram.

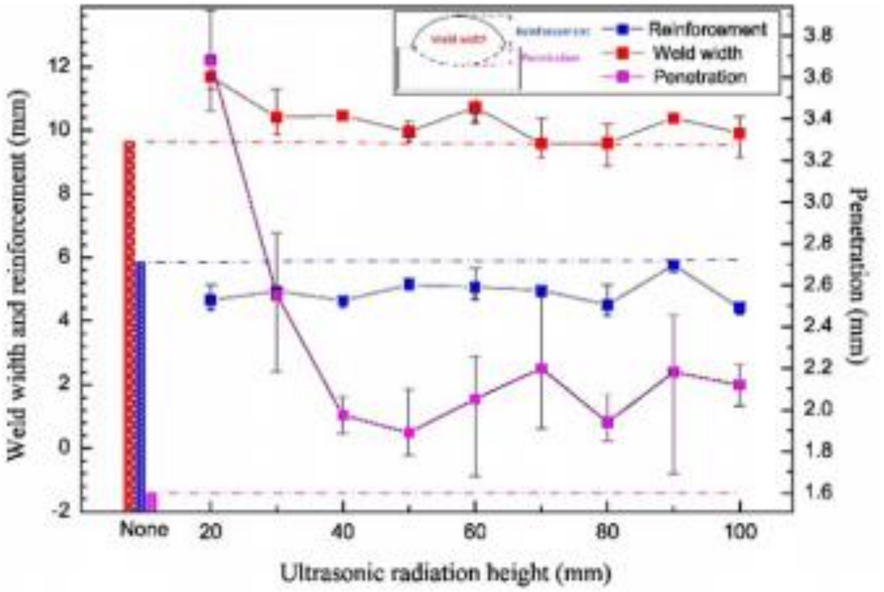


Figure 2.12 [Q.J.Sun, 2016]

The diagram shows the average weld width (Red), reinforcement (Blue) and penetration of FCAW (Pink).

The results show how the use of ultrasounds increased the penetration in underwater weld welding. Having its peak for an H of 20mm where it increased up by 126%. With assisted ultrasounds the arc extinguishing rate decreased this happens due to the downward force provided by the ultrasounds and the increase in heat input, resulting in increased penetration. Weld width increased by 20% using a height of 20mm. Finally the reinforcement of the U-FCAW weld joint decreased by 16% with a value of H of 100mm.

From these results they concluded that the optimum radiation height for satisfying all three parameters was 70mm. 70mm provides maximum arc stability and minimum weld formation.

2.5.2.3 Microstructure

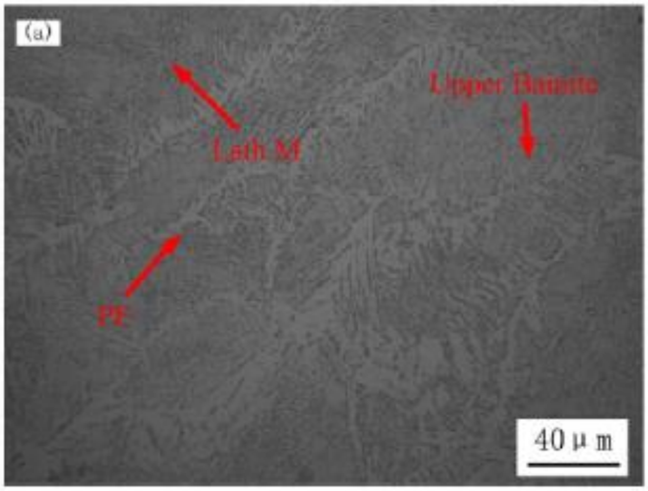


Figure 2.13 [Q.J.Sun, 2016]

Figure 2.13 shows the microstructure of the FCAW welded metal. It is compose by pro-eutectoid ferrite (PF), upper bainite (BU) and martensite (M). Water quenching increases the cooling rate of the molten metal. Some granular pro-eutectoid ferrite is distributed at the boundaries of the austenite-ferrite interface. Plate ferrite (SPF) grows into the austenite-ferrite interface. The parallel ferritic plates combine with the cementite form the upper bainite (BU). Mechanical properties will be deteriorated as the Upper bainite (BU) and martensite (M) are directional phases, which will cause the degradation of toughness of welded metal.

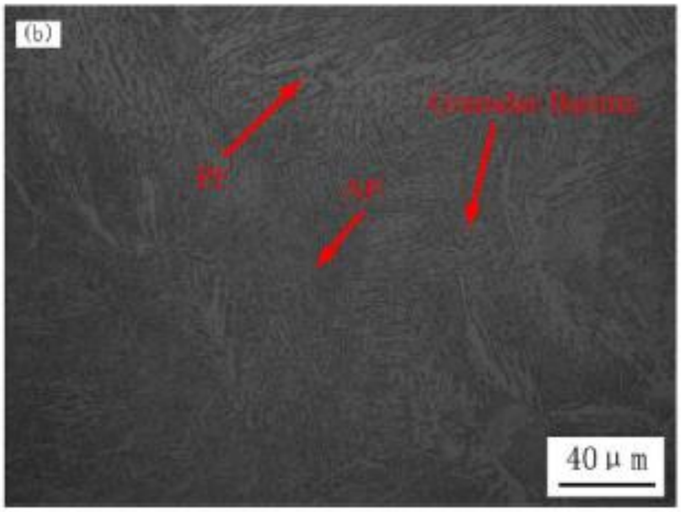


Figure 2.14 [Q.J.Sun, 2016]

Figure 2.14 shows the microstructure of the U-FCAW welded joint. The joint's microstructure changes, as now it is composed by pro-eutectoid ferrite (PF), granular bainite (BG) and acicular ferrite (AF). The ultrasounds increased the size of the austenite, the granular proeutectoid ferrite (PF) changed to strip pro-eutectoid ferrite (PF) with a smaller width. The amount of upper bainite (BU) is reduced and is changed for granular bainite (BG). Acicular ferrite (AF) appears were the lath of martensite (M) was.

Thanks to the ultrasounds the arc extinguishing rate decreases, this leads to an improvement in the arc's stability. As the arc burns for longer the cooling rate of the molten pool decreases having a decrease in bainite and martensite and an increase in transformation of acicular ferrite. Acicular ferrite has fine plasticity and toughness. Also mechanical properties were better than FCAW.

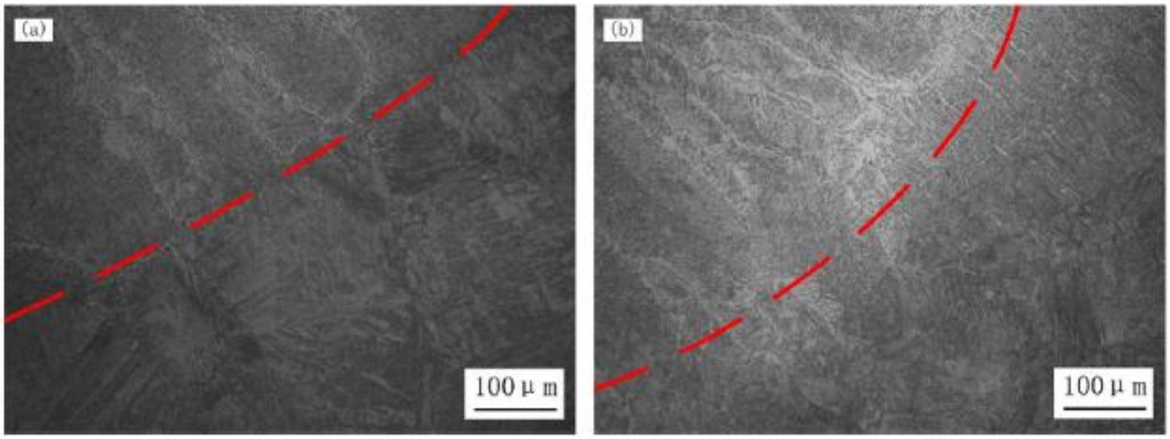


Figure 2.15 [Q.J.Sun, 2016]

Figure 2.15 shows the difference in the weld interface using ultrasounds (b) and without using them (a). The red lines show the weld interface of the joint. When no ultrasounds are used there is primarily martensite (M) and Widmanstätten (W) which proportionate a path for crack growth. Meanwhile using ultrasounds, granular bainite (BG) and acicular ferrite (AF) appear, reducing the trend of crack formation.

2.5.2.4 Mechanical Properties

Tensile strength is very low in FCAW, is very low but with the assistance of ultrasounds it increases thus more granular bainite (BG) and acicular ferrite (AF) are produced. Both of them help blocking crack propagation.

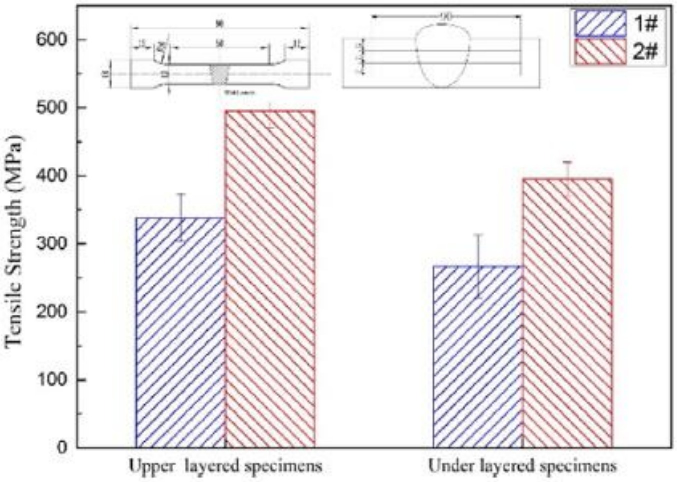


Figure 2.16 [Q.J.Sun, 2016]

As we can see from figure 2.16 tensile strength was improved. Figure 2.17 shows the average tensile strength of the upper and under layers of the FCAW weld (blue) and the UFCAW (red). Without ultrasounds the average tensile strength of the upper layer was 338MPa (approx. 63% of the base metal) and in the under layer the tensile strength was 267MPa (approx. 49% of the base metal). For UFCAW the average tensile strength of the upper layered is 495MPa (approx. 92% of the base metal), and the average tensile strength of under layered is 395MPa (approx. 73% of the base metal).

Bending testing, three bending specimens of the welded joints were tested to measure their bending ductility. The bending angle was increased from 21degrees, which is very poor for bending ductility to 84 degrees by using assisted ultrasounds. This happens because assisted ultrasounds produce granular bainite (BG) and acicular ferrite (AF).

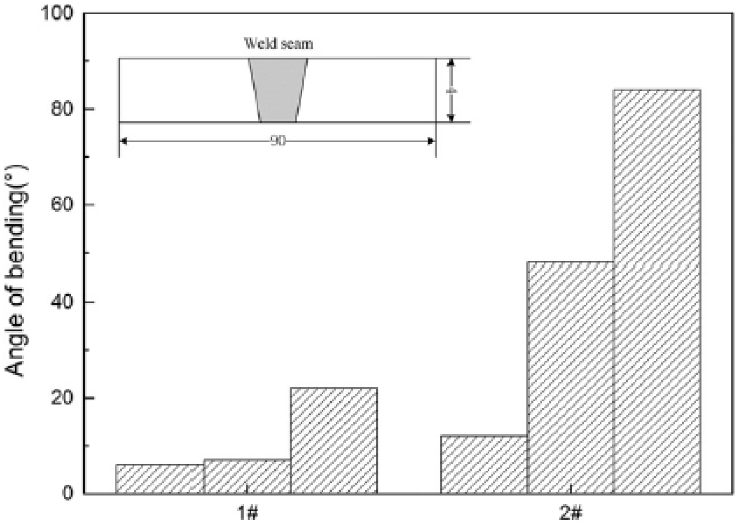


Figure 2.17 Angle of bending (1#) FCAW, (2#) U-FCAW. [Q.J.Sun, 2016]

The hardness of the weld decreased when ultrasounds were applied due to the decrease lath martensite (M) and Widmanstätten (W) structure meanwhile the amount of the granular bainite (BG) and acicular ferrite (AF) increased.

Chapter 3

Material and Methods

3.1 Aim of the project

The aim of this project is to investigate if assisting ultrasonic waves will improve U-SMAW. We will try to incorporate the ultrasonic transducer during the welding process and study how it affects the arc's stability and weld properties.

We will analyze the arc stability, bending strength properties and the weld's center and the fusion zone microestructures.

3.2 Realization

3.2.1 Experimental procedures

The equipment included a power supply, an underwater welding system, an ultrasonic system and a coated electrode automated arc voltage controlled welding torch.

Traditional underwater shield metallic arc welding (SMAW) and ultrasonic assisted underwater SMAW experiments were done with the same welding parameters. The ultrasonic frequency was set up at 40 kHz. Welding current was 150A and a target arc voltage of 28V. The welding speed used was 0.2m/min. The experiment was done in fresh water and its depth was 40cm.

The base metal used for the experiment was S355 steel with dimensions of 210x150x14 mm^3. The plates have a milling v-shape. A single-V weld groove was milled with a 90° angle with a 2-mmroot face and 20 mm root opening. A Nautica 20 electrode was used by voestalpine Böhler, the electrode is a rutile basic steel electrode designed for wet usage, with a diameter of 3.2 mm.

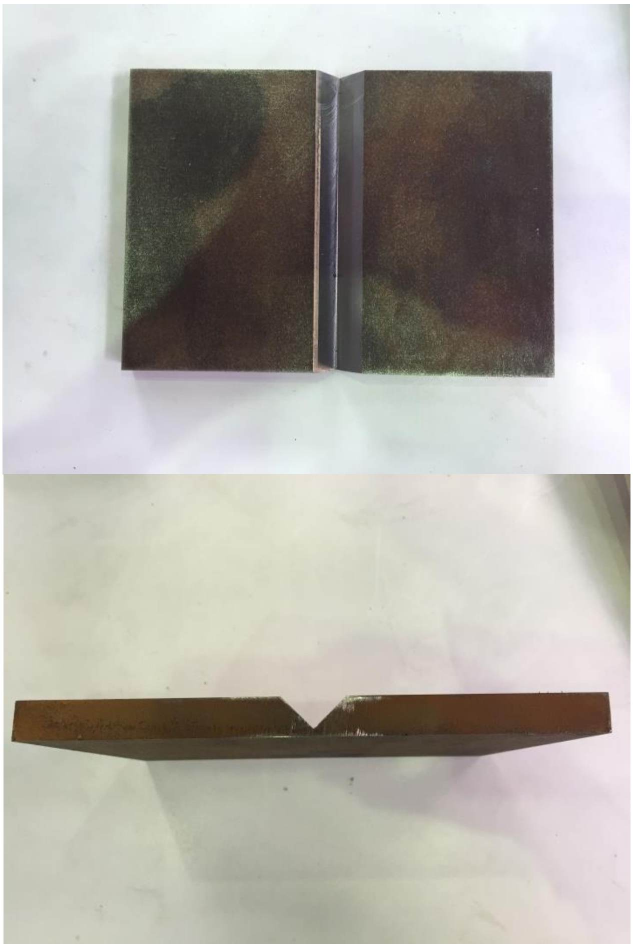


Figure 3.1 Base metal

The experiment consisted of two parts. First we analyzed the arc's stability. We used the high speed camera to compare the arc without ultrasounds and with ultrasounds. We repeated the procedure three times, with and without ultrasounds. In addition we did two more videos decreasing the distance between the welding process and the ultrasonic source. For this part the electrode did not move. For the second part we used the v-shape base metal and the electrode did move. We welded the whole base but only applied ultrasounds to half of the base, it was done four times. We started welding from the part without ultrasounds the first two times and the next two we started from the ultrasonic source. Figure 3.2 shows the equipment used for the experiment having the ultrasonic source at the end.


Figure 3.2 the experimental setup under water

The ultrasonic transducer used was a conventional piezoelectric cleaning transducer (50 watts and 40 kHz). The transducer was not made for underwater use; therefore we had to isolate it with a rubber covering. In figure 3.2 we can see the ultrasonic transducer next to the electrode.

3.3 Testing

3.3.1 Arc

The high speed laser camera was used for the arc. The camera was used to record both welding processes at high speed. We then counted the number of bubbles in each case. The camera was set up at the same level as the electrode and used a laser beam to record at high speed.

3.3.2 Destructive testing of welded material

3-point-bending tests were used to compare the fracture toughness and ductility between the two experiments. The four samples on which we welded were divided into four specimens each. Each specimen was then tested following the ISO 7438 standard for 3-point bending.

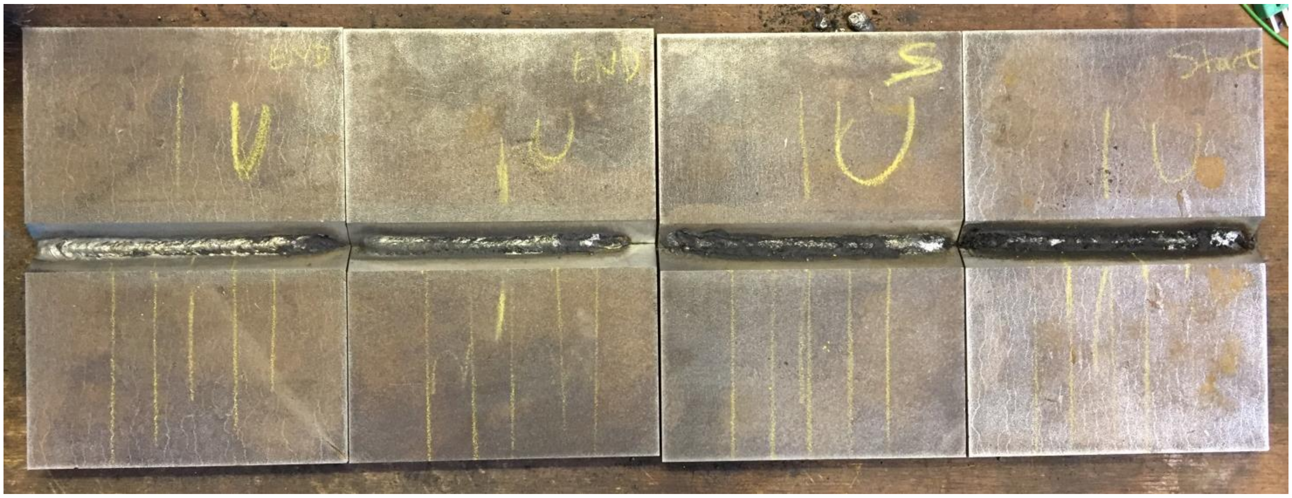


Figure 3.3

Figure 3.3 shows the four bases before being cut for the bending test.

Figure 3.4 Zwick Z 250 Retro Line Traversenwweg

Datum	15.08.2018
Auftrags-Nr.	IWMP18-15082018
Biegeversuch	3 Punkt
Prüfer	Ke
Prüfgeschwindigkeit mm/s	1
Maschinendaten	Zwick Z 250 Retro Line Traversenwweg
Stützweite mm	100
Prüfnorm	In Anlehnung an DINENISO 7438
Bemerkung	Spanien Stützrollendurchmesser/Biegedorndurchmesser= 30 mm

Table 3.1 Bending test parameters

3.3.3 Microstructure

To see the microstructure of the samples we used a microscope. The samples were sanded, polished and etched. We took pictures of the heat affected zone and the base-material of the ultrasound-weld-bead to analyze their microstructures and see if the ultrasounds produced any changes.

Chapter 4

Results

4.1 Arc stability

We used the high speed laser camera to count the time it took the bubble to disengage from the arc. Three videos were recorded without ultrasounds. We took a 0.018968 seconds frame and counted the number of bubbles in each video, we then transformed this time frame to number of bubbles per second, and we got an average of 14.937 bubbles per second. We then repeated the same procedure with the ultrasounds. The average time period was 0.018932 seconds, which we also transformed into a 1 second time period, we got an average of 13.557 bubbles per second. We then did two more tries decreasing the distance of the ultrasonic source to the base metal in each try.

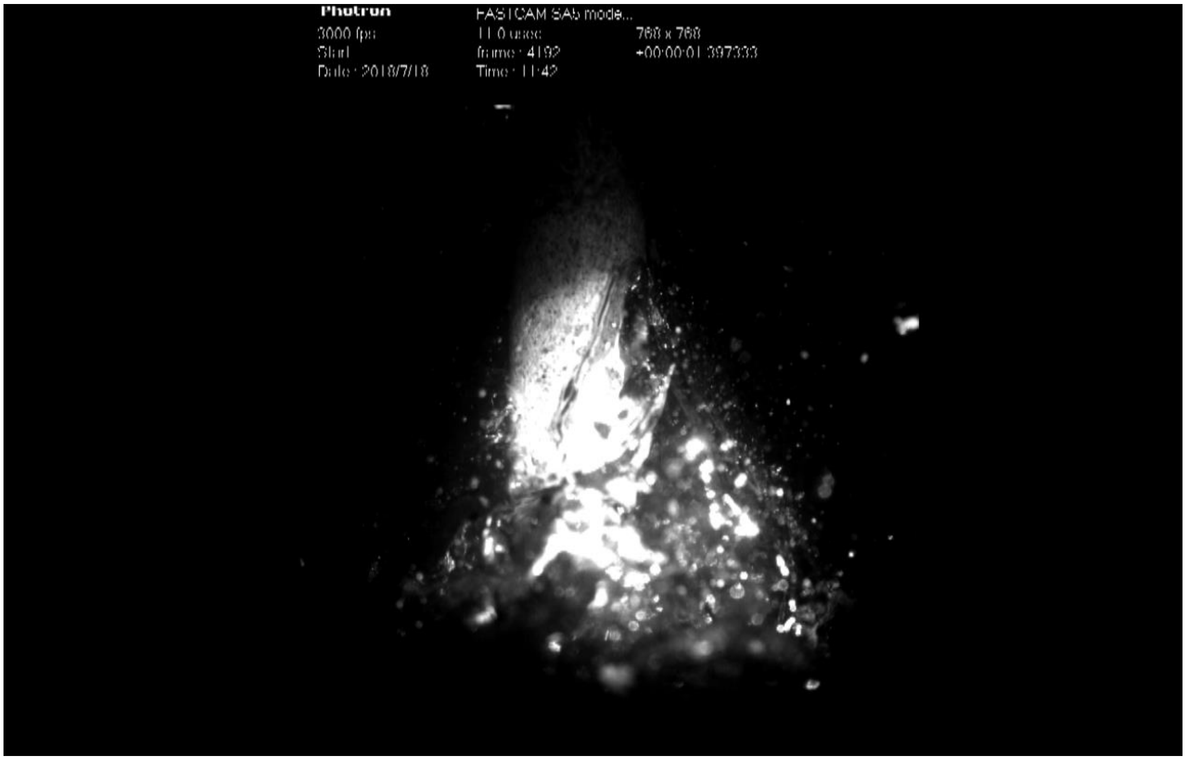


Figure 4.1 Arc disengaging

In figure 4.1 we see what the high speed camera recorded during the experiment. We can see the electrode and the bubble being created and finally leaving the electrode.

Figure 4.2

In figure 4.2 we can see the parameters we used to calculate the number of bubbles per second. Where the arrow is pointing we had the time period. 2 Minutes of real life time was 1.893 seconds in the video. We counted the number of bubbles in that time period and then we used a rule of three to transform it to bubbles per second.

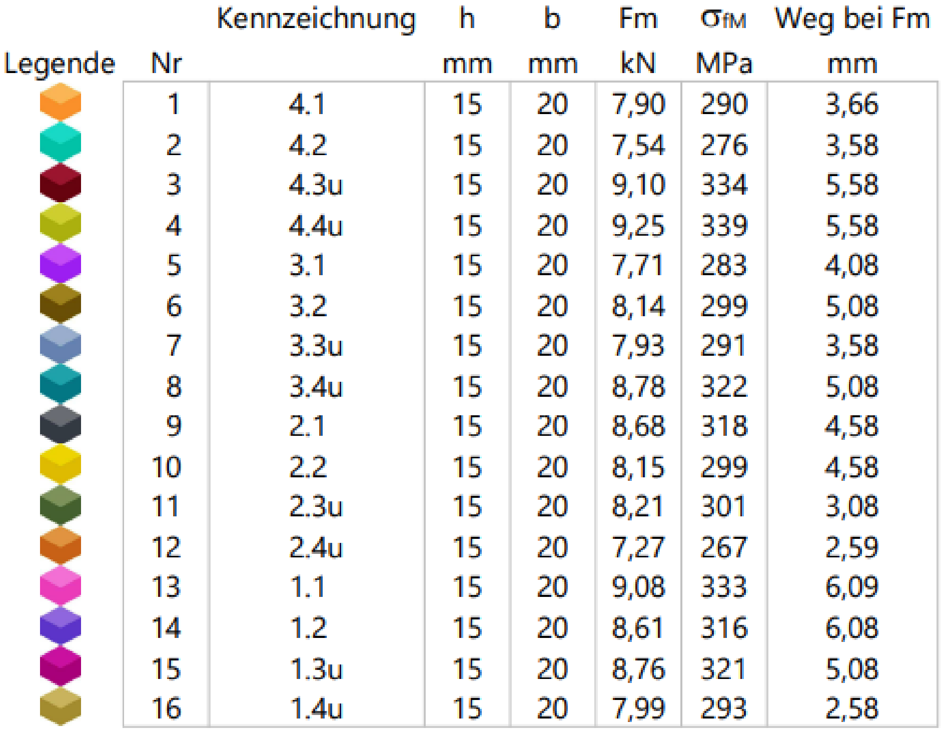
We also calculated the variance in both cases, for the experiment without the ultrasounds the variance was 0.888. This means the results were very close to each other and to the mean. For the experiment with assisted ultrasounds the variance was 3.556. In this case we have a higher variance which means the results are more spread out and further away from the mean.

It is also important to mention that the time between arcs with and without ultrasounds was inconsistent, as no pattern was found in any of the videos.

4.2 Mechanical properties

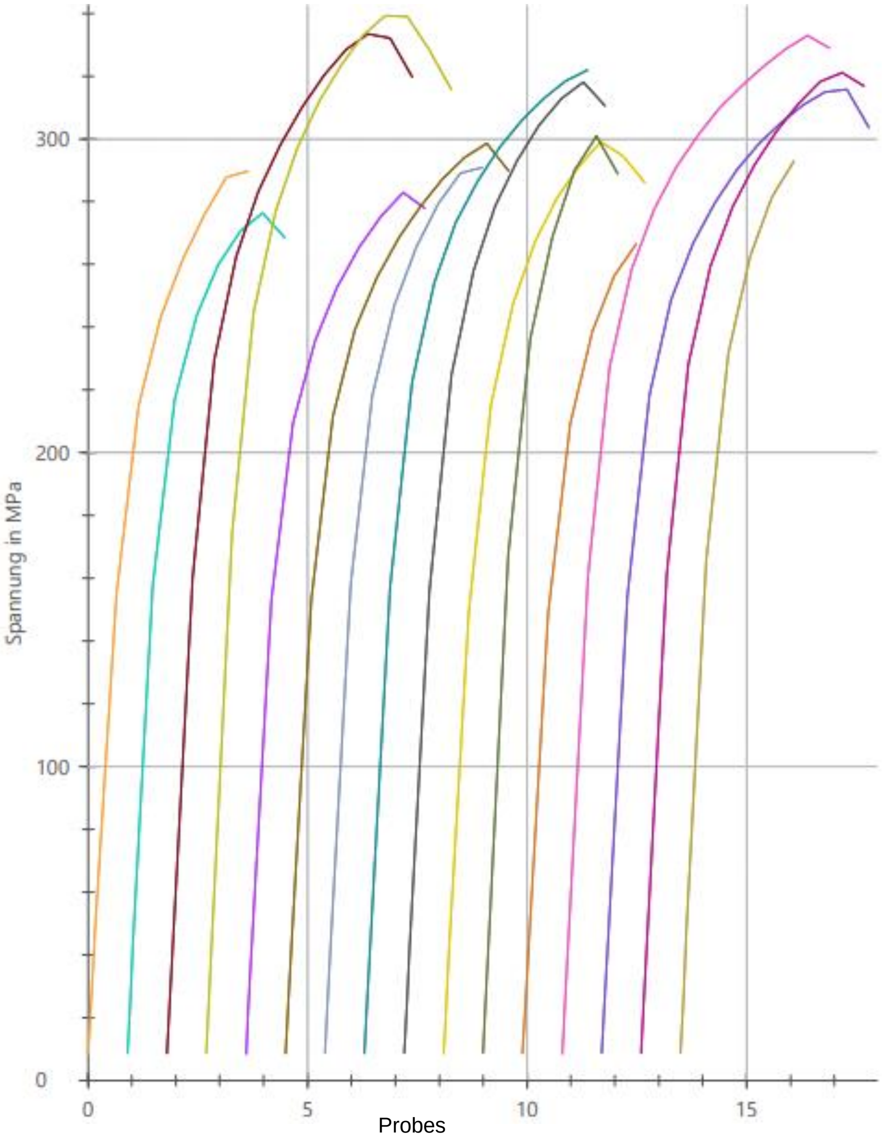
We applied the bending test to the 14 probes, obtaining the force needed to break them (Fm in kN), their maximum resistance to traction (σfm in MPa) and 'weg bei Fm (mm)'. 'Weg bei Fm (mm)' is the distance the bending machine moves downwards to produce the maximum force. Samples with a 'U' had ultrasounds directly applied. Samples 1.3, 1.4, 2.3, 2.4 had ultrasound at the end of the base metal during the experiment and samples 3.3, 3.4, 4.3, 4.4 had the ultrasounds applied at the beginning of the base metal.

Figure 4.3 Bending test probes after the test.



Legende	Nr	Kennzeichnung	h mm	b mm	Fm kN	σ_{fM} MPa	Weg bei Fm mm
🟧	1	4.1	15	20	7,90	290	3,66
🟦	2	4.2	15	20	7,54	276	3,58
🟥	3	4.3u	15	20	9,10	334	5,58
🟨	4	4.4u	15	20	9,25	339	5,58
🟪	5	3.1	15	20	7,71	283	4,08
🟫	6	3.2	15	20	8,14	299	5,08
🟦	7	3.3u	15	20	7,93	291	3,58
🟦	8	3.4u	15	20	8,78	322	5,08
⬛	9	2.1	15	20	8,68	318	4,58
🟨	10	2.2	15	20	8,15	299	4,58
🟩	11	2.3u	15	20	8,21	301	3,08
🟧	12	2.4u	15	20	7,27	267	2,59
🟪	13	1.1	15	20	9,08	333	6,09
🟪	14	1.2	15	20	8,61	316	6,08
🟪	15	1.3u	15	20	8,76	321	5,08
🟫	16	1.4u	15	20	7,99	293	2,58

Table 4.1 Results from bending test



Graph 4.1 Maximum resistances to traction of each probe

As we can see from Table 4.1 and Graph 4.1 the difference between the probes with ultrasounds and the probes without ultrasounds is not very significant.

4.3 Microstructure

The microstructure of the welds depends on the cooling rate. As we can see in figure 4.4 fast cooling rates result in martensite and longer ones in ferrite and perlite.

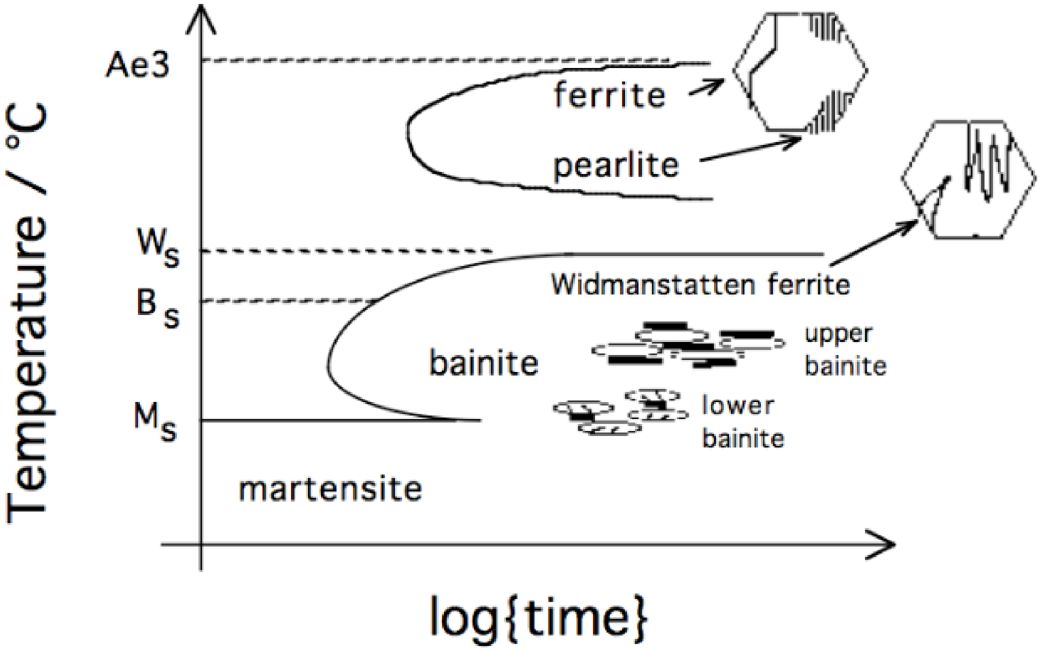


Figure 4.4 Time-temperature-transformation diagram [Bhadeshia, 2005]

Ferrite is an allotropic modification of pure iron with a cubic molecular structure which includes carbon inside the iron structure [Wordpress, 2016].

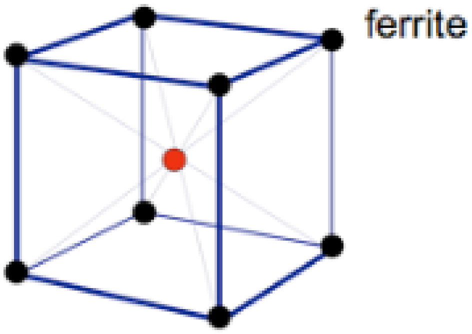


Figure 4.5 Crystal structure of ferrite [Bhadeshia, 2005]

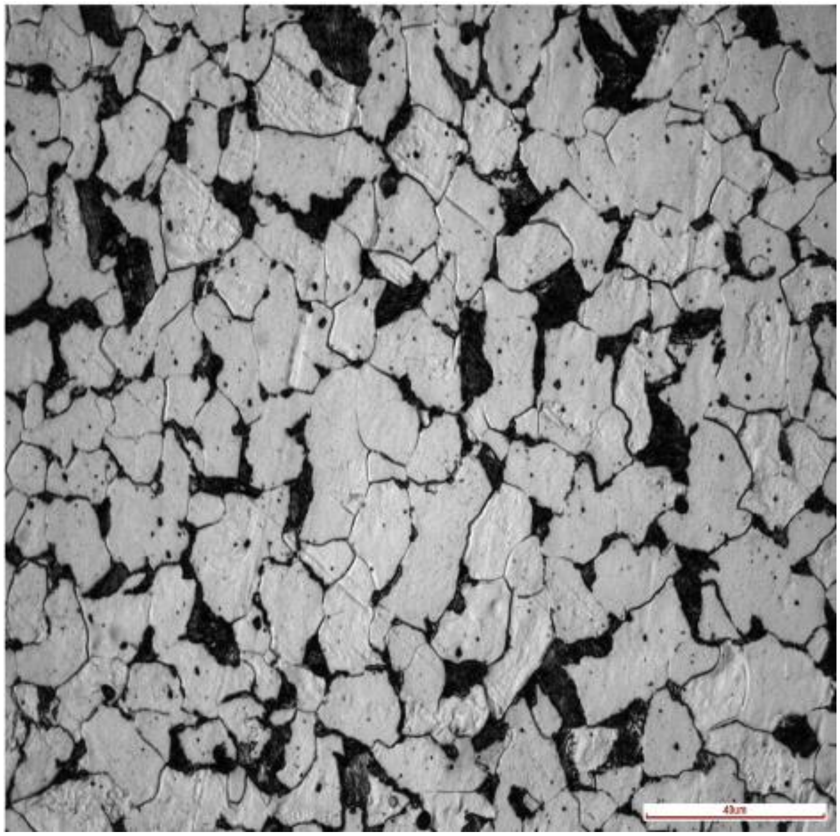


Figure 4.6 Ferrite [Shanhua]

Perlite is formed from sheets of ferrite and cementite. It combines the ductility and softness of the ferrite with the hardness and fragility of the cementite. For every part of carbon it has six of iron. Perlite appears when austenite is slowly cooled, depending of the speeding of the cooling rate the sheets will be closer or further apart. Thick perlite will appear with a slow cooling, normal perlite with cooling in an oven and fine perlite with air cooling. [Wordpress, 2016]

Figure 4.7 Perlite [Wikipedia]

Martensite is the crystalline phase in ferrous alloys. It is created during a phase change, where steel is rapidly cooled down from a very high temperature. During the process there is no diffusion. Steels with martensite are very hard and mechanically resistant but also very fragile and not very ductile. Martensite looks like sheets or needles. [EcuRed, 2018]

Figure 4.8 Martensite [EcuRed, 2018]

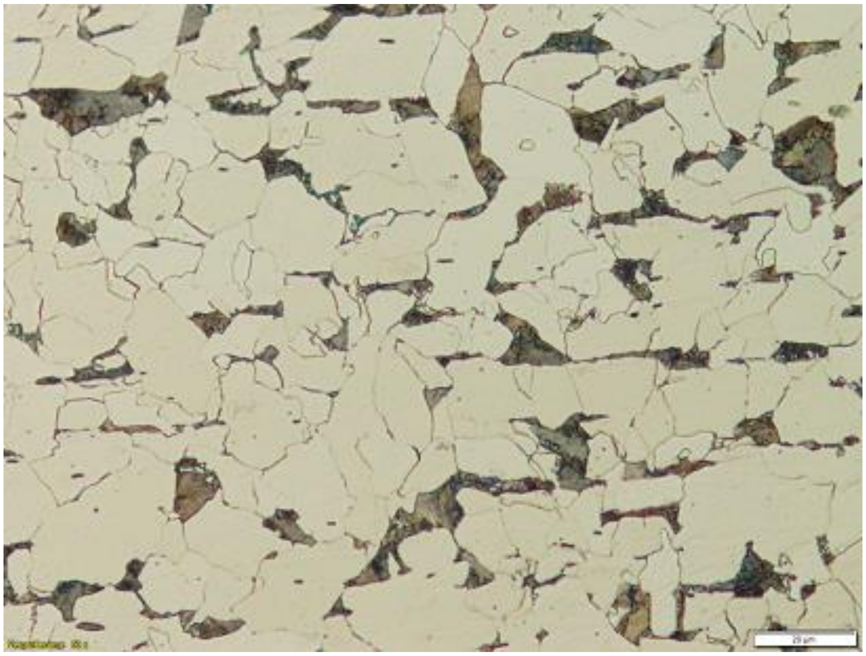


Figure 4.9 Base metal magnification 50x (the white field equals 20 micrometres); Etched with "Beraha 1" etching agent.

Figure 4.10 Base metal magnification 20x (the white field equals 50 micrometres); Etched with "Beraha 1" etching agent.

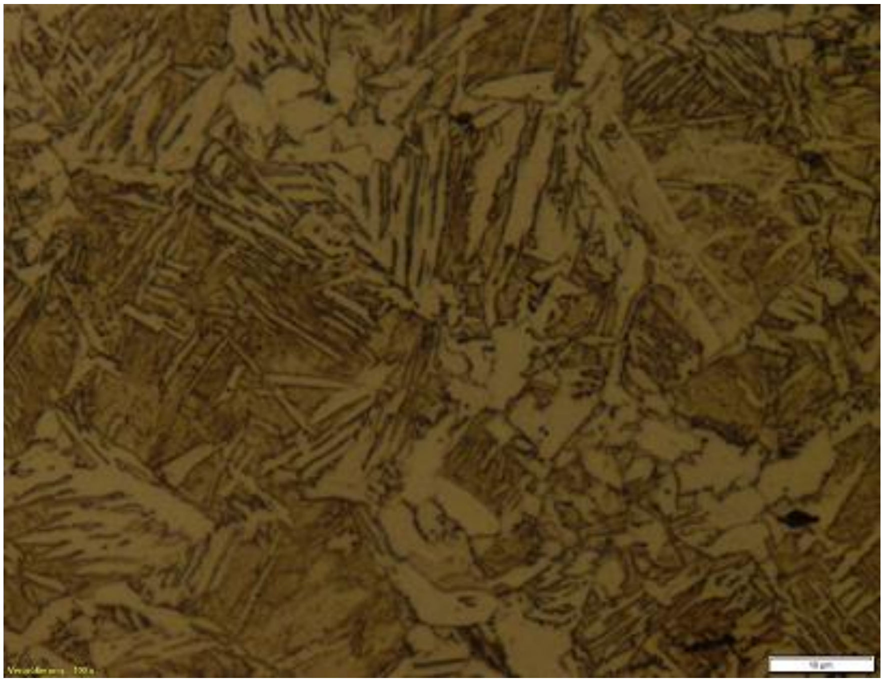


Figure 4.11 H.A.Z. magnification 100x (the white field equals 10 micrometres); Etched with "2%HNO3" etching agent.

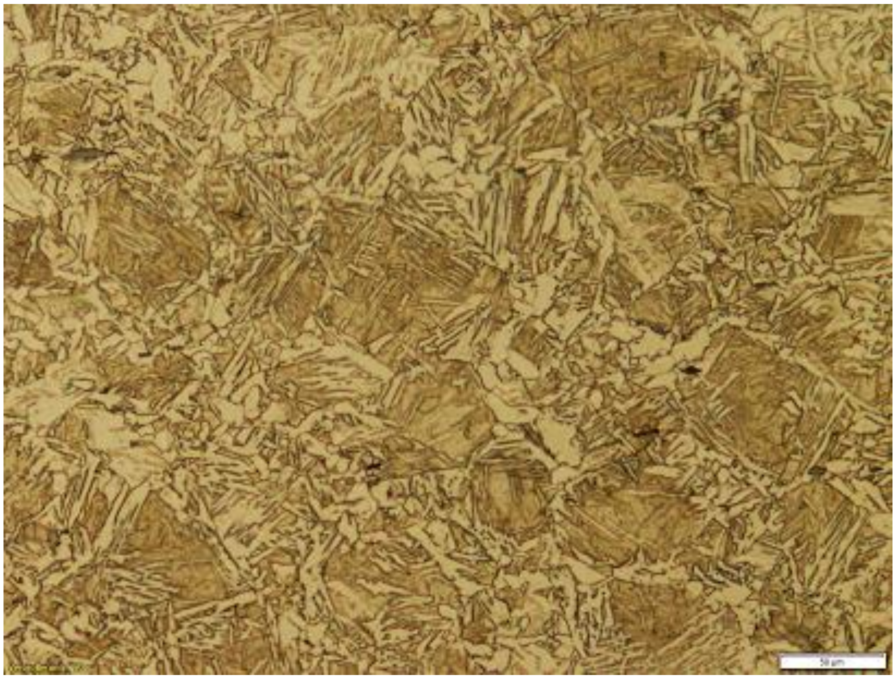


Figure 4.12 H.A.Z. magnification 20x (the white field equals 50 micrometres); Etched with " 2%HNO3" etching agent.

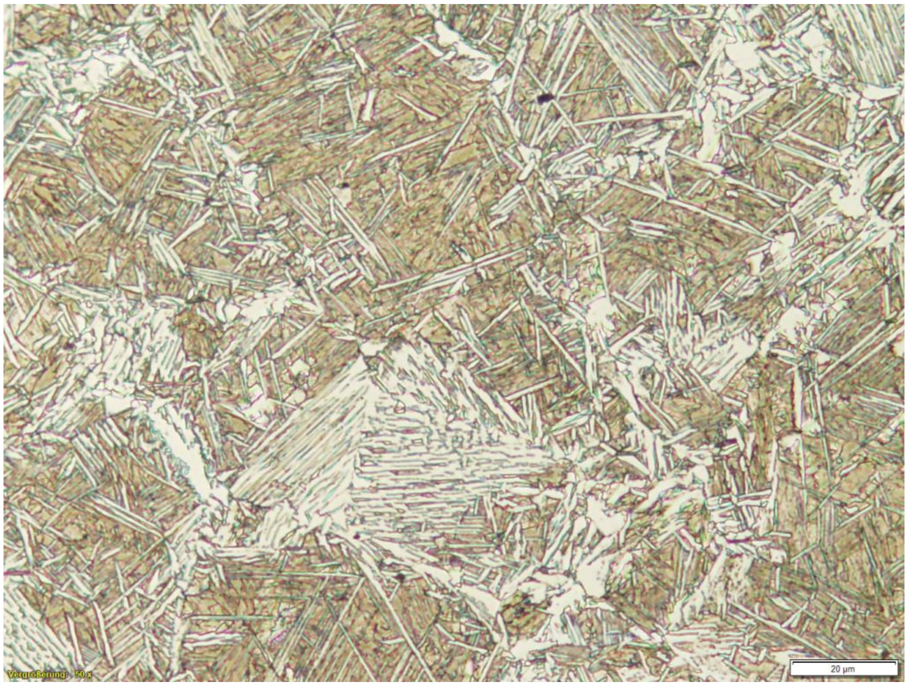


Figure 4.13 H.A.Z. magnification 50x (the white field equals 20 micrometres); Etched with " Beraha 1" etching agent.

Figures 4.9 and 4.10 show the microstructure of the base material of the ultrasound weld bead, we can see that ferrite predominates. Figures 4.11, 4.12 and 4.13 are from the heat affected zone, in the H.A.Z. there is martensite.

Chapter 5

Discussion

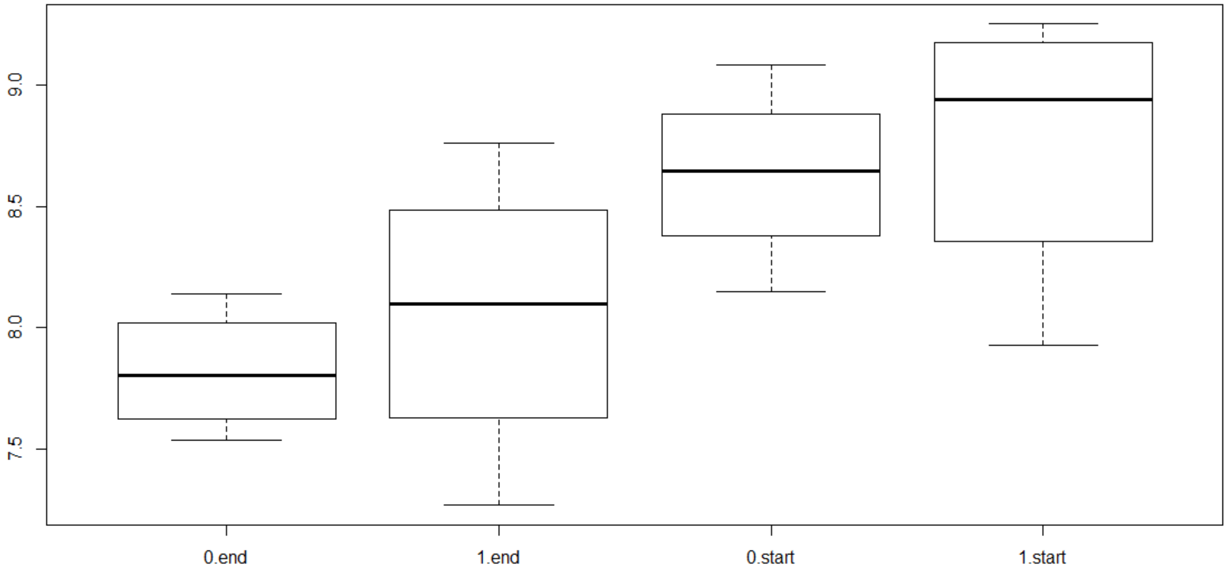
5.1 Arc stability

From the results we got from the videos we found that there was a 9.241% reduction in the number of bubbles. This is a big enough change to say that the ultrasounds had an effect on the arc’s stability but having such a big variance in the results for the experiment with ultrasounds could mean the 9.241% difference is due to an error when reading the results. Therefore we need to see the effect on the microstructure and mechanical properties before concluding the ultrasonic source had an effect on the welding procedure.

5.2 Mechanical properties

		Mean (kN)	Variance
Start	With U	8.765	0.348
	Without U	8.63	0.145
End	With U	8.058	0.380
	Without U	7.823	0.066

Table 5.1 Mean and Variance of the force needed to break the probes



Graph 5.1

From the results in table 5.1 we see that the ‘start’ values are higher than ‘end’ values. Further on the probes with ultrasounds needed higher forces to break. However the values for the variance are too high, as the difference between the highest and the lowest values for ultrasounds been applied at the end of the base metal is of 1.49 kN. Also there are values for the force needed to break the probes which are higher without ultrasounds than with the ultrasonic source been applied. Therefore we conclude that due to the high variance we found no change in the force needed to break the probes when ultrasounds assisted the experiment. Nevertheless we could actually see a difference in toughness between the start and the end of the probes. This difference in toughness could maybe come from the probes not all being completely homogeneous and having a difference in volume between them. Smaller volumes will give higher toughness values for the same energy been applied.

5.3 Microstructure

From our microstructure results we see martensite was produced in the heat affected zone due to rapid water quenching. The ultrasonic source was not able to slow down the cooling rate and therefore no acicular ferrite was produced. Therefore we can conclude that our ultrasonic source had no effect in the on the microstructure.

5.4 Conclusion

In conclusion, we found no improvements when using the ultrasounds in the arc’s stability as although we found a decrease in the number of bubbles per second, the variance was high enough to say there was an error. Further on the mechanical properties results also showed no improvements due to the ultrasonic source, rather an influence of beginning and end of the weldment. Finally we did not achieve the objective of replacing the martensite for acicular ferrite therefore we can conclude the ultrasounds had no effect in our experiment.

5.5 Challenges compared to Sun et Al.

When trying to transfer the principles used by Sun et Al. we had some challenges to deal with.

5.5.1 Electrode

Sun et Al. incorporated the ultrasonic transducer inside the electrode. We could not do this as our ultrasonic transducer did not have the capacity to support the voltage through the electrode. Therefore our ultrasonic transducer was placed besides the electrode instead of inside. Further on they had added shielding gas; this helped to reduce the oxidation produced by oxygen and carbon dioxide. Reducing the oxidation potential helps to maintain the toughness and strength of the weld [Wikipedia, 2018] decreasing the ultrasonic wave’s efficiency. Also the had a constant distance between the electrode and the base metal, in shield metal arc welding the distance from the electrode to the base metal changes as the electrode consumes.

5.5.2 Plate vibrations

The starting idea was to apply the ultrasonic source on the other side from where it was been weld. But the ultrasonic source used was not waterproof and therefore the idea of trying to apply the vibrations directly to the base metal was discarded as the transducer would break. Normal ultrasonic assisted SMAW applies the vibrations directly to the base metal [Bohórquez, 2014]. In figure 5.1 we can see SMAW with assisted ultrasonic waves.

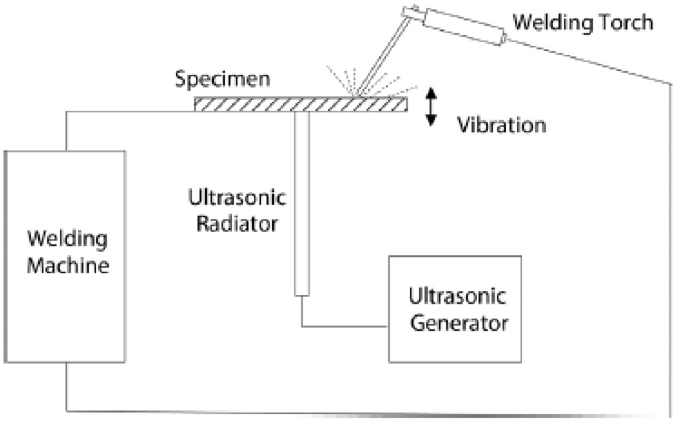


Figure 5.1 [Bohórquez, 2014]

5.5.3 Bubble

The bubble is not constant like it was for Sun et Al. when welding with flux-cored arc welding. This is a problem because it makes it more difficult for the ultrasonic waves to actually help to stabilize the arc, as the bubble form the arc keeps breaking and climbing up and therefore is harder to obtain the extra downward force of the ultrasounds.

5.6 Improvements

During the experiment we had some challenges we had to come through, therefore in other to improve the experiment results here are some improvements I will do to achieve more accurate results. The improvements are based on the challenges we found during the experiment.

First the ultrasonic source, due to issues with time we did not find the most indicated source for our experiment. Instead we used a source that was built for cleaning. The source was not able to support the voltage that went through the electrode so we could not couple the source to the electrode. Also the source was not water proof. I suggest buying an ultrasonic source that can handle high voltages and is water proof as the experiment is underwater. If the source was water proof we could also try to attach it on the other side of the base metal as it is done for shielded metal arc welding in ambient conditions. It will also be interesting to find a source in which frequency could be modify, frequencies from 10 kHz to 100kHz can be used, but it would be interesting to know which is the most efficient.

Chapter 6

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