Design of welding fixture for sample parts and user manual for Motoman XRC welding robot

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Abstract:

The thesis objective is comprised of two major parts, the first one is to prepare a concise manual for the Motoman XRC arc welding robot, and the second one is design process of a welding fixture for simple joints. The thesis was commissioned by HAMK University of applied sciences in collaboration with Hyria. The key knowledge of welding technology and robotics programming was learned from courses at HAMK. More detailed knowledge of robotics was acquired through self-study and practice. The compact manual could be used as teaching material for students early in their robotics studies. The new fixture will accommodate a robot for welding of various materials of versatile joints and welding types. The new design reduces cycle time and operator effort while enhancing functionality, and allows a smooth welding operation of different joints.

The existing welding set up was thoroughly studied and various back ground literature was used throughout the process. An understanding of robot's movement and operation were learned from the manufacturer's operator manual as well as practicing with robots for a better understanding of improved welding parameters.

The robotic programming and welding parameters were used for the design were based on the Motoman XRC manual and supervisory consultations. The initial findings were used for the primary design. The 3D model of the final design was done with PTC CREO parametric and Autodesk inventor professional 2015.

The thesis will serve as a step by step guide for students to get familiar with robot movements. Moreover, the manual has ready-made programming instructions which can be used to learn to make sample parts. The thesis explains the most popular types of welding as well as arc welding parameters, application methods, and limitations. The new design has dealt with the shortcomings of the previous fixture. The design is versatile, reliable as well as easy to manufacture and repair. Hyria can use the manual as course material, as lab training material and for performing welding operations.

Keywords Welding, robot, Motoman, arc welding, Fixture.

Pages 70 pages + appendix 8 p.

List of Abbreviations:

AWS: American welding Society

ASF: Arc start function

AEF: Arc ending function

AVP: Arc voltage Percentage

DMS: Dead man Switch

HAZ: Heat affected zone

SMAW: Shielded metal arc welding

GTAW: Gas tungsten arc welding

GMAW: Gas metal arc welding

SAW: Submerged arc welding

FCAW: Flux core arc welding

MIG: Metal inert gas

ISO: International standards organizations

CE: Carbon equivalent

DCEP: Direct-Current Electrode Positive

DCEN: Direct-Current Electrode Negative

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1 Introduction

With the advancement of technology, robots and automated systems are going to be significant in our day to day life in the near future. As robots become more technologically advanced, flexible and sophisticated, they can do jobs faster and better than the human counterparts. Their precision, intelligence, and endless energy levels make them the perfect employees even for the simplest job. With the increasing uses of robotics, manufacturers increasingly need to embrace automation to stay competitive.

A robot can be described as a system which can perform mechanical actions through actuators, with sensory feedback from the control system connecting sensing and actions. Robots can be varied from a microchip able to travel through a blood vessel to a gigantic machine in an industrial application. The main types of robots are stationary, virtual, remotely controlled and autonomous robots. A robot has a physical structure, motors, sensors, electric supply and an information processing system.

The earliest robots were being used only for entertainment. Through times, robots have changed the structure of the society and replaced humans in hostile tasks. History of automation dates back to the early Greek civilization. Around 50 A.D., a Greek inventor called Hero developed an automated system that would open a temple door when a priest lit a fire on the temple altar. Despite an early birth of the concept, automation flourished during the Industrial Revolution of the early eighteenth century. Many of the steam-powered devices built by James Watt, Richard Trevithick, Richard Arkwright, Thomas Savery, Thomas Newcomen, and their contemporaries were simple examples of machines capable of taking over the work of humans. (Automation History n.d.)

In advanced welding, a robot is mounted on a motorized positioner that improves access by providing additional motion of axes. A robot carries the torch while part to be welded is fixed in a place. The robot can be taught the positions and paths by a pendant, but many users prefer offline programming. The advanced welding is done in combination with 3D cad model. The Cad model is analyzed by the program to create paths, cycle time as well as simulation. This enables the robot to keep working while next job is developed. (Acieta, n.d.)

The purpose of this study was to prepare an easily understandable guideline for students at Hyria. The instructions needed to be simple and precise to be learnt quickly. Another purpose of the thesis is to design a welding fixture of increased versatility. This will decrease production times compared to existing design.

The background, technology, and welding application are discussed in this thesis first. The second part deals with problems analysis, improvement opportunities, and constraints. After defining the problem, the possible solution has been compared and a final idea has been implemented in the final phase.

The initial part of the thesis introduces the background history of welding, welding processes, joint types, weld transfer mode, shielding gas, filler material as well as welding defects.

One of the most common automated processes in an assembly line is precision welding. The primary benefits of a robotic welding processes are improved quality, productivity, increased output and lower costs associated with labor. The current fixture of Hyria has many drawbacks. It cannot be used effectively for an automated weld. It cannot hold the work piece in a precise location. There are unnecessary metal pieces attached to it. The unwanted parts impede accuracy and tolerance. Moreover, as the fixture does not support any fixed position, the robot has to teach all the coordinates and cycles after the completion of each job. This is time consuming, ineffective and costly. This study was beneficial in developing design guidelines for heights, clearances, grips, and reaches of work pieces and equipment for the purpose of accommodating a fully automated process with the welding fixture at Hyria.

The last part of the thesis addresses the equipment, setup, and workstation in general. It consists of technical information of a robot, a welding unit, shielding gas as well as the working procedure in robot welding.

2 Historical Development of Welding

As one of the modern metal working innovations, welding can trace its notable advancement back to ancient times. The earliest examples originate from the Bronze Age. Small gold circular boxes were made by pressure welding lap joints together. It is estimated that these boxes were made over than 2000 years ago. During the Iron Age the Egyptians and people in the eastern Mediterranean area figured out how to weld pieces of iron together. Many tools were found which were made approximately 1000 B.C. During the middle Ages, the craft of blacksmithing was developed and numerous items of iron were produced which were welded by hammering. It was not until the 19th century that welding, as we know it today was invented. (Cary &Helzer 2005, 4-9)

Edmund Davy of England is credited with the discovery of acetylene in 1836. The production of an arc between two carbon electrodes using a battery is credited to Sir Humphry Davy in 1800. In the mid nineteenth century, the electric generator was invented and arc lighting got to be mainstream. During the late 1800s, gas welding and cutting was developed. Arc welding with the carbon arc and metal arc was developed and resistance welding turned into a realistic joining process. (Cary & Helzer 2005, 4-9)

In the early 1900's, chemical welding found its place in the industries. The resistance welding process were developed, including spot welding, seam welding, projection welding and flash butt welding. Elithu Thompson originated resistance welding .Thermite welding was invented by a German named Goldschmidt in 1903 and was first used to weld railroad rails. (Cary & Helzer 2005, 4-9)

Oxyacetylene welding became the universal method of welding between 1905 to 1930.The electric arc and resistance welding process became established in 1925, start replacing oxyacetylene welding in mass production. Although arc welding development halted by poor quality weld pool. The atmosphere of oxygen and nitrogen in contact with the molten weld metal caused brittle and sometime porous welds, which led to the development of shielding gases. The earliest solution was the covered electrode to produce gases which would protect the molten weld metal from the atmospheric contamination. (Cary & Helzer 2005, 4-9)

Beginning in 1920 Gas tungsten Arc welding (GTAW)is ideal for welding magnesium, stainless steel and aluminum by using helium as inert gas in non-oxidizing atmosphere. The gas shield metal arc welding (GMAW) was successfully developed during Mid 90s. One of the basic changes that made process more usable is tungsten electrode continuously fed through electrode wire enabling use of small diameter electrode wires and the constant power voltage source. But the cost of inert gas was high. Due to need for narrow fusion, low thermal distortion and high quality weld of complex geometry, led to laser welding in recent time. Although initial problem involving short pulses of energy, laser welding was able to generate deeper welding without leaving much splatter .Moreover part remain in ambient temperature which enables low post weld operation time and rapid solidification. (Cornu 1988, 1-8)

3 Design of Weld Joints

A variety of methods used to assemble individual parts into a larger, complex component or assembly. Welds are made at the junction of the components that make up the weldment. The junction of members or edges of members that are to be joined or have joined called as Joint. Structural shapes, hot rolled plates, pipe, castings or forging can be joined to produce a weldment. There are five joint types are used to bring two members together for welding. Meanings of the terms used to portray these joints are like those utilized by various crafts. The relationship between the two members as well as placement of the joint between them are defined as follows: (Cary & Helzer 2005, 494)

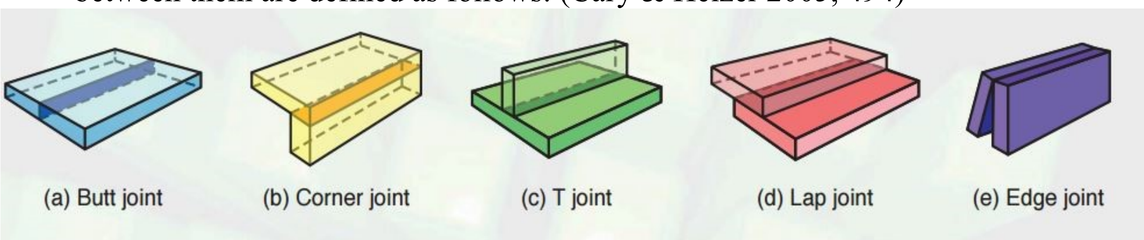

Figure 1 Five basic joint types (Cary & Helzer 2005, 494)

A. Butt joint: A joint between two members aligned approximately in the same plane.

B. Corner Joint: a joint between two members located approximately at right angles to each other in the form of an L.
C. T- joint: A joint between two members located approximately at right angles to each other in the form of a T.
D. Lap joint: a joint between two overlapping members located in parallel.
E. Edge joint: a joint between the edges of two or more parallel or nearly parallel members.(Cary & Helzer 2005,494)

3.1 Weld Types

Welding is a joining process between similar or dissimilar metals involving localized melting and solidification .Welding can be done by melting edges of the members together or letting them fuse together while solidification. Other processes require uses of consumables or non-consumable filler wire. The selection of right types is depends on the base metal, depth of penetration, deposition rate arc speed, application and quantity needed. There are about eight separate and distinct welds, some of which have variation as well as it could be combination of welds. (Cary & Helzer 2005, 494)

The suitability of the processes for welding and joining materials, joint types and components are shown in Table 1.

Table 1: Suitability of the processes for welding and joining materials, joint types and components. (The welding institute, n.d.).

Process	Steel	Stainless	Al	Butt joint	Lap Joint	Plate	Portability	Manual	Automated
Arc	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gas	Yes	Possible	Possible	Yes	Yes	Yes	Yes	Yes	No
Laser	Yes	Yes	Possible	Yes	Yes	Yes	No	No	Yes
Resistance	Yes	Yes	Yes	possible	Yes	Yes	Possible	Yes	Yes
Friction	Yes	Yes	Yes	No	No	Yes	No	No	Yes
Brazing	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Possible
Fasteners	Yes	Yes	Yes	No	Yes	Yes	Possible	Yes	Yes

3.1.1Fillet Weld

Fillet weld is the most commonly used weld. The name comes from cross sectional shape. The fillet is regarded as being on the joint and is defined as a weld of an approximately triangular cross section which joins two surfaces about perpendicular of an angle. The weld is triangular; it could be concave or convex. (Cary & Helzer 2005, 494)

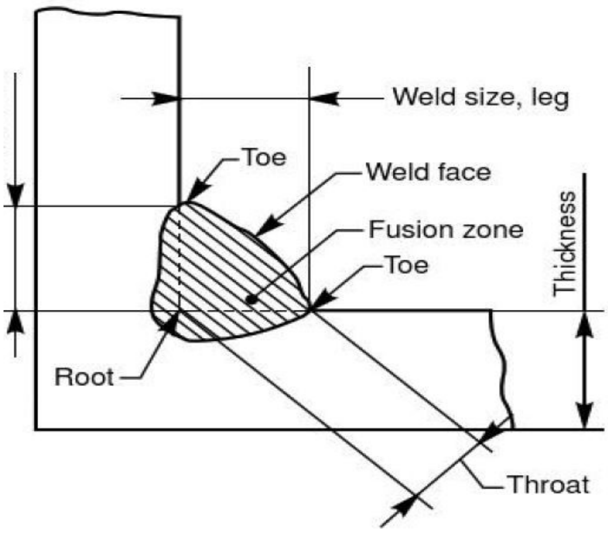

Figure 2: Fillet weld (Narayan, 2006, 161)

Fillet weld consists of five parts as Root, Face, Toe, Leg, and Throat. The symbol of a fillet weld is a triangle. The triangle will lay beneath or above a straight line where an arrow comes of the flat line indicating to the joint. The straight is called as reference line. The side on which the triangle symbol is placed is important because it gives an indication on which side of the joint is to be intersected by the weld. Fillet weld dimensioning can be shown two ways either a (throat thickness) or z (leg length) is always placed in front of the value of the related dimension. (Wikipedia, n.d.)

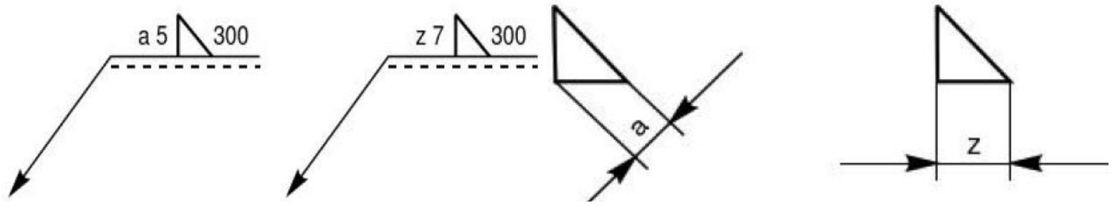

Figure 3: Dimensioning of fillet weld (Narayan, 2006, 161)

3.1.2 Groove Weld

Groove weld is the second most popular weld. The weld is made in the groove

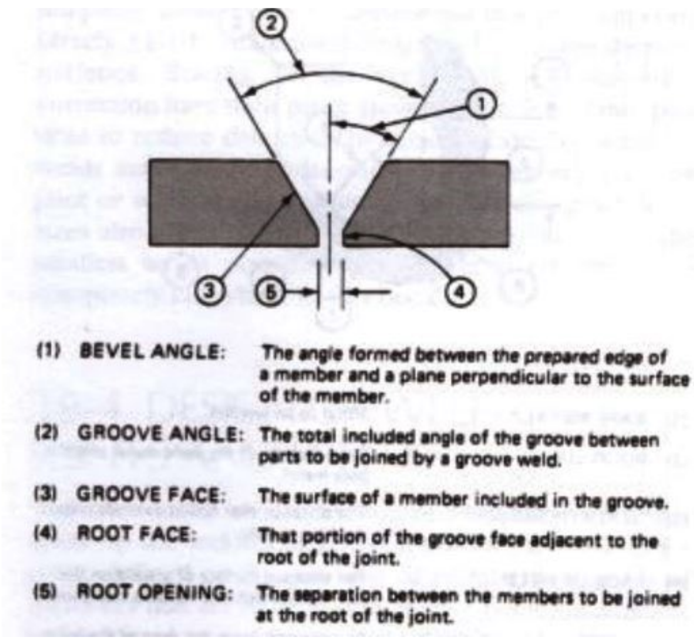

Figure 4: Groove weld (Cary & Helzer2005, 496)

of two members to be joined. The groove weld is regarded as being in the joint. There are 11 types groove weld types which can be single or double. (Cary &Helzer 2005, 496)

3.1.3 Back or Backing Weld

Back welding is done on the back or root side of a previous weld. The root of original weld is gouged, chipped, or grounded to sound metal before the backing weld is made. As a result full penetration is ensured to improve the quality of the joint. Back weld itself, cannot make a joint. (Cary & Helzer 2005, 494)

3.1.4 Plug or Slot Welds

Slots welds are made using prepared holes. They are considered together since the welding to specify them is the same. The important difference is the type of prepared hole in one of the members being joined. If the hole is round, it is plug weld; if it is elongated, it is a slot weld. (Cary & Helzer 2005, 496)

3.1.5 Spot or Projection weld

The resistance of current through the weld piece at the pressure point creates heat. Enough current causes the weld piece to end up distinctly plastic and eventually become molten. The pincer pressure forges the molten material to fuse together. Continued pressure at first after the fusing stage produces the weld into weld nugget .This procedure is also known as single point resistance welding. (Spot track, n.d)

3.1.6 Seam Weld

Resistance seam weld is a procedure that creates a weld at the faying surfaces of two comparative metals. It has a similar cross section of a spot weld. The welding geometry is influenced by the welding process used. Seam welding like spot welding relies on two electrodes, typically produced from copper, to apply pressure and current. The electrodes are disc shaped and rotate as the material passes between them. This permits the electrodes to remain in constant contact with the materials to make long persistent welds. (Wikipedia, n.d.)

4 Weld Symbols on Drawing

Weld symbols have been used for many years and are a simple way of communicating design office details to a number of different industrial shop floor personnel such as welders, supervisors, and inspectors. Subcontractors are often required to interpret weld symbols on engineering drawings, from perhaps the main contractor or client. It is essential that everyone should have a full understanding of weld symbol requirements to ensure that the initial design requirement is met. (The welding institute n.d.)

There are a number of standards which relate to weld symbols including British, European, International and American (American Welding Society) standards. Most of the details are often similar or indeed, the same, but it is essential that everyone concerned knows the standard to be used.

The arrow line can be at any angle (except 180 degrees) and can point up or down. The arrow head must touch the surfaces of the components to be joined and the location of the weld. Any intended edge preparation or weldment is not shown as an actual cross sectional representation, but is replaced by a line. The arrow also points to the component to be prepared with single prepared components. (The welding institute n.d.)

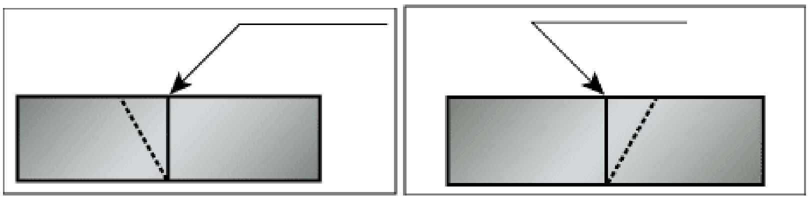

Figure 5: Arrow line and arrow head used in welding drawings. (The welding institute n.d.)

4.1 Types of symbols

The symbols, used in arc and gas welding, are often shown as cross sectional representations of either a joint design or a completed weld. Simple, single edge preparations are shown in *Fig. 6* .For resistance welding, a spot weld and seam weld are shown in Fig. 7:

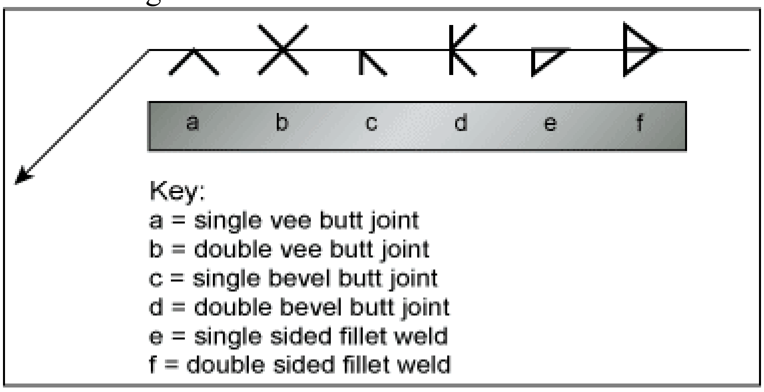

Figure 6: The symbols used in arc and gas welding. (The welding institute n.d.)

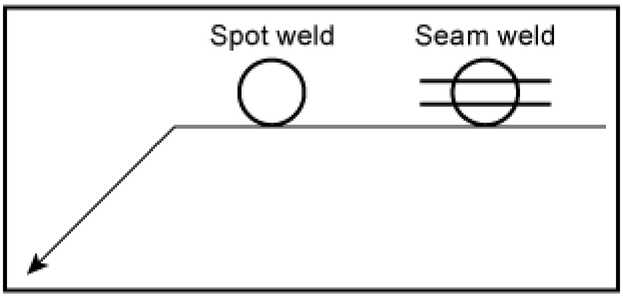

Figure 7: Spot welding symbols. (The welding institute n.d.)

The above examples can be interpreted as either the joint details alone or the completed weld, however, for a finished weld it is normal to find that an appropriate weld shape is specified. Using the examples above, there are a number of options and methods to specify an appropriate weld shape or finish.

Butt welded configurations would normally be shown as a convex profile (Fig.8 'a', 'd' and 'f') or as a dressed-off weld as shown in 'b' and 'c'. Fillet weld symbols are always shown as a 'mitre' fillet weld (a right angled triangle) and a convex or concave profile can be superimposed over the original symbol's mitre shape.

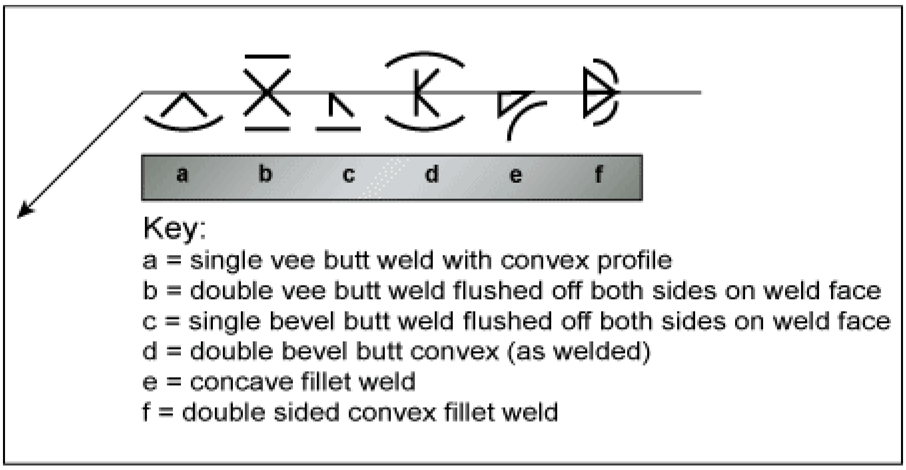

Figure 8: Butt weld shown in a convex profile. (The welding institute n.d.)

5 Types of Welding Processes

Welding is a process of adding material such as metals or thermoplastics in order to seamlessly join them. Though, with the advancement of new technology the welding process has evolved greatly. It can be separated based on the method of energy used to molten the material. The most common processes are discussed below

- Arc welding
- Gas welding

- Energy beam welding
- Resistance welding
- Solid state welding. (Väisänen 2013.)

5.1 Gas Tungsten Arc Welding (GTAW)

GTAW process uses the heat of an arc between a non-consumable tungsten electrode and the base metal. This process is illustrated in Figure 5.The arc develops intense heat of approximately 11,000 F (6,100 C), which melts the surface of the base metal to form a molten pool. No filler material is used when welding thinner materials, edge joints and flange joints. This is called as autogenous welding. (Cary & Helzer 2005, 69)

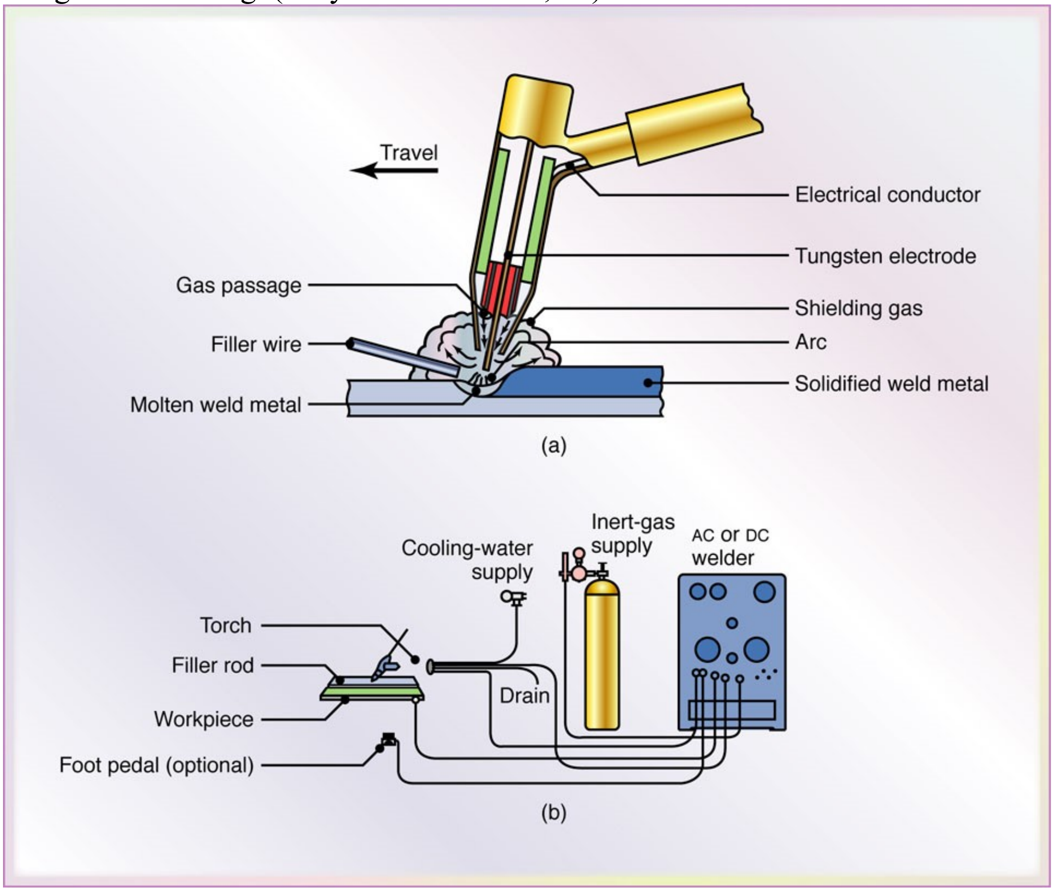

Figure 9: (a) The gas tungsten-arc welding process, formerly known as TIG (for tungsten inert gas) welding. (b) Equipment for gas tungsten-arc welding operations. (Väisänen2013.)

Externally fed or cold filler is used for thicker material. The filler metal is not transferred across the arc but melted by it. The inert shielding gas protect the arc area from the atmospheric oxygen and nitrogen. So that it cannot come in contact with the molten metal or hot tungsten electrode. As the molten metal cools, coalescence occurs and parts are joined. The final weld is smooth, uniform and requires minimum finishing. (Cary & Helzer2005, 69)

Variation of the Process

There are variety of GTAW methods are used based on the application. The most used methods are

- Manual programme
- Pulsed current
- Hot-wire(automatic)
- Dabber welding
- Increased penetration.(Cary & Helzer 2005, 75)

Advantages

The benefits of GTAW methods are

- High quality welds in almost all metals and alloys
- Post weld cleaning is not required
- Filler material is not carried across the arc, so there is very little or no spatter
- Welding can be performed in all positions
- No danger of slag getting trapped in the weld.(Cary & Helzer, 2005, 69-70)

Limitation

GTAW has low productivity. The power source and torch are more expensive than other arc welding processes. Moreover, this method is not suitable to weld of variety of thicknesses and positions as well as material has to be free of rust and dirt. (Cary &Helzer2005, 75)

5.2 Plasma Arc Welding (PAW)

If an electric arc between a tungsten electrode and the work is constricted or reduced in cross sectional area, its temperature increases since it carries the same amount of current. This constricted arc is called a plasma, which is the fourth state of matter. There are two types of operation, the nontransferred arc and transferred arc. In transferred arc the current flow is from the electrode inside the torch to nozzle containing the orifice and back to the power supply. The nontransferred method is generally used for plasma spraying or for generating heat in non-metals. Deep and narrow welds can be made by this process at high welding speeds. (Cary & Helzer, 2005, 77)

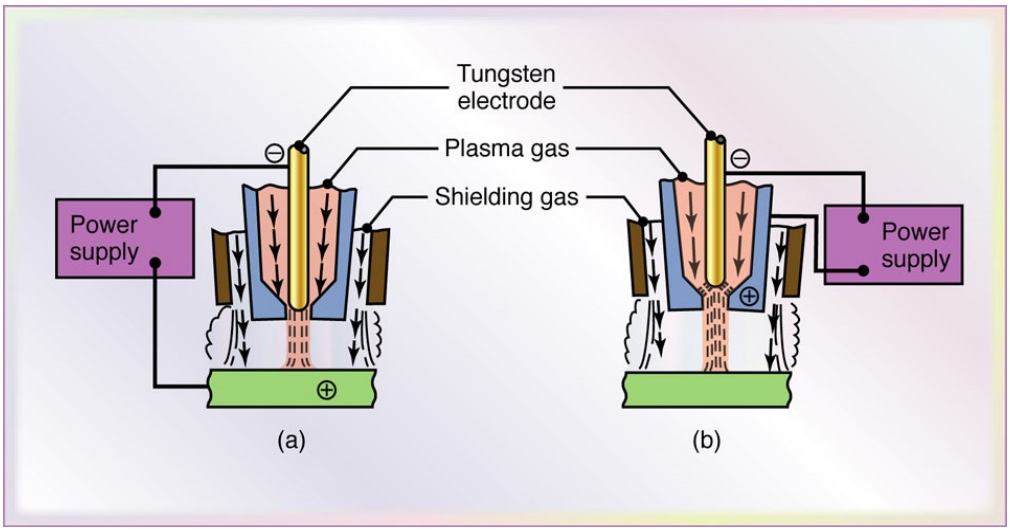

Figure 10: Two types of plasma-arc welding processes: (a) transferred, (b) nontransferred. (Väisänen 2013.)

The plasma is generated by constricting the electric arc passing through the orifice of the nozzle and the hot ionized gases that are forced through the opening. The plasma has a stiff columnar from and is fairly parallel sided so that is does not flare out in the same manner as the gas tungsten arc. When directed toward the work, the high temperature stiff plasma arc will melt the base metal surface and the filler metal may be added to make the weld. In this method, plasma act as an extremely high temperature heat source to form a molten weld pool in the same manner as the GTAW. The high temperature plasma causes this to happen faster. Due to high temperature, high velocity plasma jet provides an increased heat transfer over GTAW at the same current. This results in faster welding speeds and deeper weld penetration. In key hole welding, plasma jet penetrates through the work piece and forms a hole known as a keyhole. Surface tension forces the molten base metal to flow around the keyhole to form the weld. But this method could be used only where the plasma can pass through the joint. (Cary &Helzer2005, 77)

Advantages

- High temperature and high heat concentration of the plasma allow for the keyhole effect, which provides complete penetration, single pass welding of many joints.
- HAZ is smaller and shape of the weld is more desirable. The weld tends to move parallel sides, which reduces angular distortion.
- Faster travel speed result in higher productivity. The plasma arc is more suitable and is not as easily deflected to the closest point of base metal. The weld has deeper penetration and generates a narrower weld.(Cary & Helzer 2005, 79)

Limitations

The limitation of Plasma arc welding are mentioned below

- The torch is more delicate and complex and must be water cooled.
- The current level of the torch cannot be exceeded without damaging the tip.
- The control console adds another piece of equipment, which makes the system more expensive.(Cary & Helzer 2005, 80)

5.3Arc Welding with a Consumable Electrode

The consumable electrode welding arc, also known as a metallic arc, is a sustained high current, low voltage electrical discharge through highly conductive plasma that produces sufficient thermal energy, which is useful for joining metals by fusion. The electrode is continuously fed into the arc and is melted by the heat of the arc. The molten metal of the electrode transfer across the arc gap to the work piece, where it is deposited and upon solidification, becomes the deposited weld metal. The arc welding process that use a consumable electrode are shielded metal arc welding, gas metal arc welding, electro gas or electro slag welding and submerged arc welding.(Cary & Helzer 2005, 94)

5.3.1Modes of Metal Transfer

The forces that cause metal to transfer across the arc are similar to all the consumable electrode arc welding processes. The metal being transferred ranges from small droplets, smaller than the diameter of the electrode, to droplets much larger in diameter than the electrode. The mode of metal transfer across the arc is related to the welding process, the metal involved, the arc atmosphere, size, type, and polarity of the electrode, the characteristics of the power source and the current density and heat output. In gas metal arc welding, reverse polarity (DCEP) is normally employed. For straight polarity (DCEN), an emissive coating is often placed on the electrode surface. Metal transfer can be defined as free – flight transfer mode, which includes spray and globular transfer, or as a contact atmosphere mode, which include short – circuit transfer. (Cary & Helzer 2005, 95-96)

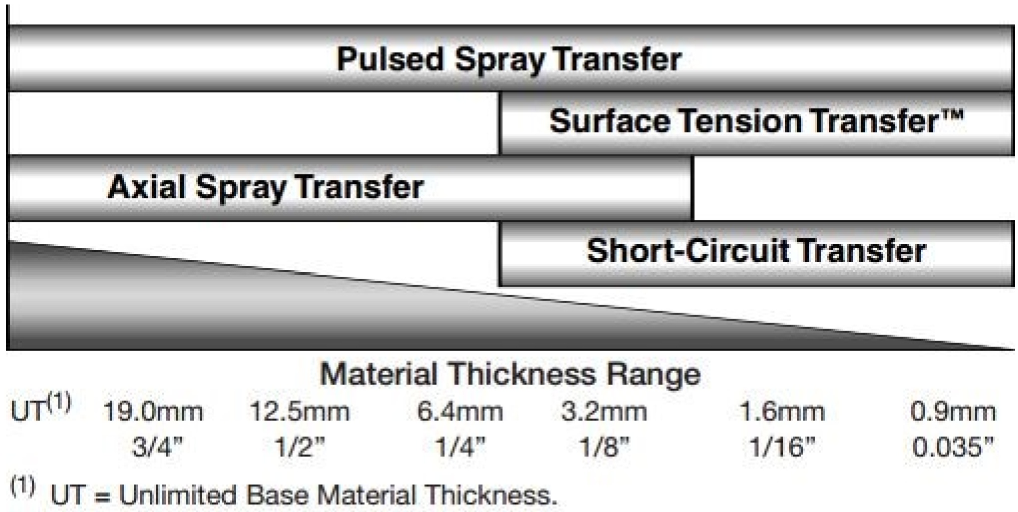

Figure 11: GMAW mode of metal transfer selector (Nadzam, 2014, 9)

5.3.1.1Spray Transfer

Spray transfer, sometimes called axial spray, is a smooth mode of transfer of molten metal droplets from the end of the electrode to the molten weld pool. It was the original type of metal transfer used when gas metal arc welding was initially developed. Spray transfer occurs in an inert gas atmosphere usually with a minimum of 80% Argon shielding gas. The droplets crossing the arc are smaller in diameter than the electrode. It occurs at a relatively high current density and there is a minimum level for each electrode size. As the current increases, the drop size decreases and the frequency of drops increases. The drop have an axial flow, which means that they follow the centerline of the electrode and travel directly to weld pool. There is no short circuit I spray transfer. The electromagnetic forces are the dominant forces due to the high current density. The pinch effect on the molten tip of the electrode physically limits the size of the molten metal droplet that can form. (Cary & Helzer 2005, 96-97)

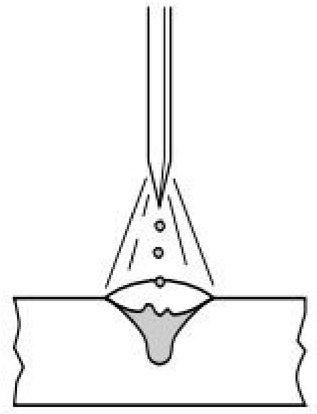

Figure 12: Spray weld metal transfer characteristic (Nadzam, 2014,9)

With spray transfer the deposition rate and efficiency is relatively high. The arc is smooth, stable, and stiff, the weld bead has nice appearance and a good wash into the sides.In spray transfer large amount of heat is involved, which creates a large weld pool with good penetration that can be difficult to control. As current is increased beyond axial spray transfer range, the line of metal drops begins to rotate rapidly about the axis of the electrode, still leaving form the tip of the electrodes. With the increase in current, the diameter of rotation increases and spatter increases. This is known as rotational spray transfer.(Cary & Helzer 2005, 96-97)

5.3.1.2 Globular Transfer

Below the transition level, the metal transfer mode is called globular transfer. It was originally encountered with the development of CO_2 gas shielding welding. Variation of globular transfer include one known as drop transfer, where gravity is the dominant force, and one known as the repelled transfer , where forces due to the plasma jet occur even though gravity force is a factor. Arcs in CO_2 atmosphere are longer than those in an argon atmosphere, resulting in a higher voltage. The cathode jet originates from the work piece (cathode) and actually support the molten drop of metal on the tip of the electrode. The molten globule can grow in size until its diameter reaches 1.5 to 3 times the diameter of the electrode, due to this repelling force .When the globule grows on the tip of the electrode, it takes on unusual shapes and moves around on the tip of the electrode. It separates from the electrode and is transferred across the arc by electromagnetic and gravity forces. The globular transfer across the arc in an irregular path. It changes its irregular shape during flight and sometimes has rotating motion. The irregular shape, motion and flight direction sometimes cause the globule to reconnect with the electrode and touch the work piece as well. This causes a short circuit, which momentarily extinguishes the arc. (Cary & Helzer 2005, 97-98)

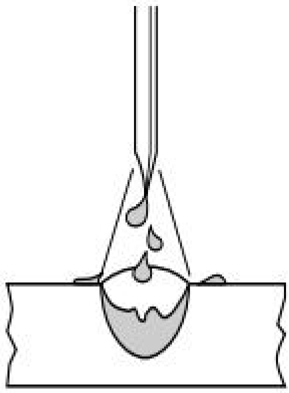

Figure 13: Globular weld metal transfer characteristic (Nadzam, 2014,9)

In this mode, the drop splashes into the weld pool and produces much more spatter than spray transfer. The spatter comes from the violent molten pool as well as from the metal transferring across the arc. The frequency of globular detachment and flight across the arc is random but of relatively low frequency. It takes place at a relatively low current density. The resulting welding is not as smooth as that produced by spray transfer. (Cary & Helzer 2005, 97-98)

5.3.1.3 Short Circuiting Transfer

Out of position welding and thin welding is extremely difficult by using spray or globular metal transfer. In 1950 short circuiting method was introduced for gas metal arc welding of thin and out of position welding. It is also known as short arc and dip transfer. (Cary & Helzer 2005, 98)

The molten tip of the electrode is supported by the cathode jet and may grow to 1.5 times the diameter of the electrode. The electrode is being feed at such a high relative speed that the molten tip will periodically come in contact with the molten weld pool. This short circuit creates a bridge across the gap between the electrode and the molten pool, and the arc is extinguished. Surface tension of the weld pool draws the molten metal of the electrode tip into the molten weld pool. If the electrode touches the weld pool, it will act as fuse and literally explode due to high current density. The explosion reestablishes the arc. This conditions continue at a random frequency. These arc outages occur so rapidly that they are not noticed by naked eye. (Cary & Helzer 2005, 98)

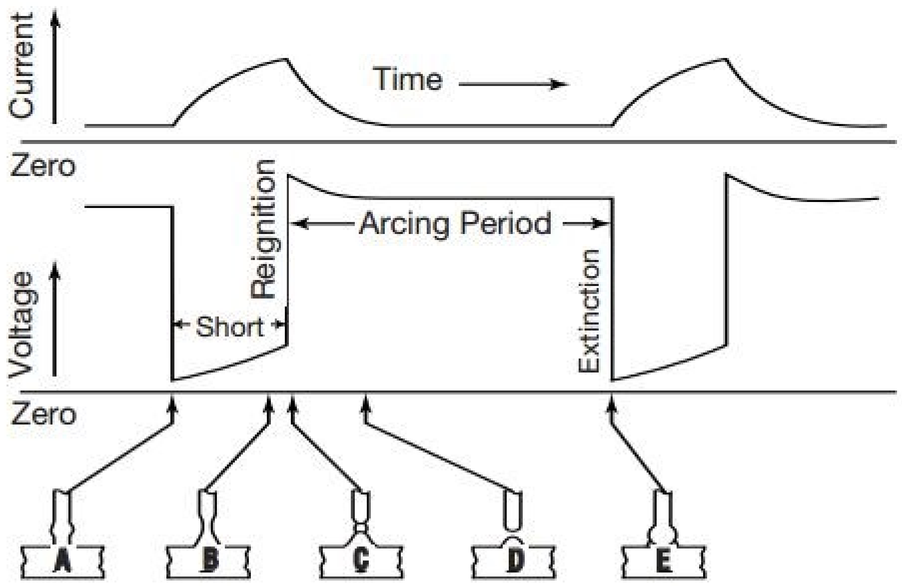

Figure 14: Oscillograms and sketches of short circuiting transfer (Cary & Helzer 2005, 98)

Short circuiting mode is obtained with specific welding parameters normally limited to maximum of 200A DCEP on a 0.035 inch(0.9 mm) steel electrode and CO_2 or 75% argon -25% CO_2 shielding gas. It uses constant voltage (CV) power source with the correct impedance, which provides the proper rate of increase of current during short circuit to maintain a stable arc. This mode of metal transfer will sometimes cause lap defects in the weld and may create undercutting if proper technique is not employed. This method is normally used with CO_2 rich shielding atmosphere and is mainly used on ferrous metals. It is not suitable for non-ferrous metals. (Cary & Helzer 2005, 98)

5.3.1..4 Pulsed spray metal transfer

The spray transfer mode is preferable for many reasons, including smooth bead appearance and minimum spatter. These comes with few disadvantages, which prohibit it from being used for some applications. The transition current is relatively high, which creates a large molten wed pool and deep penetration. Spray transfer could not be used when welding on thin materials and the large weld pool could not be control while welding in the vertical or overhead position. (Cary & Helzer 2005, 98-99)

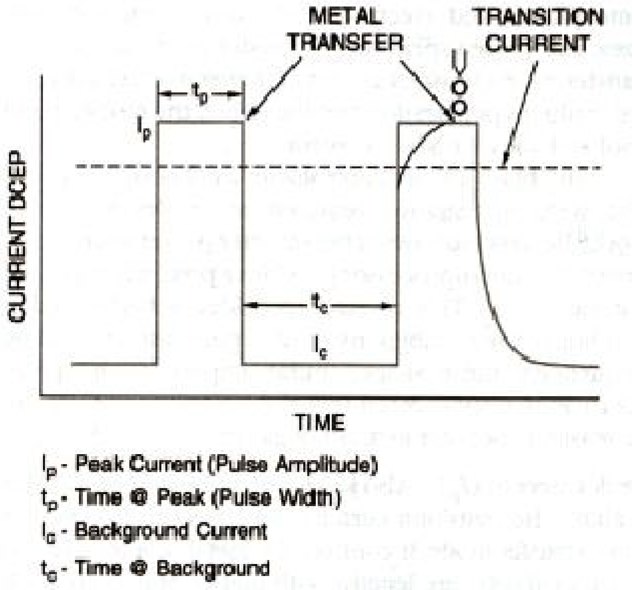

Figure 15: Pulsed arc transfer power source output waveform. (Cary & Helzer 2005, 95-96)

The mechanism of pulsed spray metal transfer is based on a special pulsed waveform of the welding current. The current output is pulsed at high speed from a low to high current peak, known as peak current (I_p), which is above transition current. The time period for the peak current is known as peak time (t_p), sometimes called pulsed width. The current level the remaining time is the background current (I_b), known as low level current. The pulsing waveform continues at a consistent manner at a frequency range of 30 to 400 pulses per second. The pulsed spray mode allows the use of large diameter electrode wire. Thin materials could be welded in all positions using this method. It also can be used to weld most metal. At least 85% to 90% argon rich shielding gas with the mixtures of helium, hydrogen, Oxygen, or CO_2 are used in this transfer mode. It allows the use of 5% to 15% CO2in argon when welding mild steel. It is recommended for high quality precision welding for semiautomatic application or mechanization or when robotic welding is used. (Cary & Helzer 2005, 99)

5.4 Shielded Metal Arc Welding (SMAW)

The shielded metal arc welding process comprises of an arc is started by touching the electrode momentarily to the work piece. The heat of the arc liquefies the surface of the base metal to form a molten pool. The metal melted from the electrode is transferred across the arc into the molten pool. When it solidifies it becomes the deposited weld metal. The molten pool is also called as weld puddle, must be controlled for successful application. The extent of the weld pool and depth of penetration determine the mass of molten metal under the control of the welder. If the current is too high, the depth of penetration will be excessive and the volume of molten metal will become uncontrollable. A higher speed of travel reduces the size of the molten weld pool. If the weld is not in a flat position, the molten metal may run out of the weld pool and create problems. Adjusting the weld variables and manipulating the arc allow the welder to control the molten metal pool properly. The weld metal deposit is covered by slag from the electrode cover. The arc in the immediate arc area is enveloped by an atmosphere of shielding gas produced by disintegration of the electrode coating. A large portion of the electrode core is transferred across the arc, however small particle escape from the weld area as spatter.(Cary & Helzer 2005, 102)

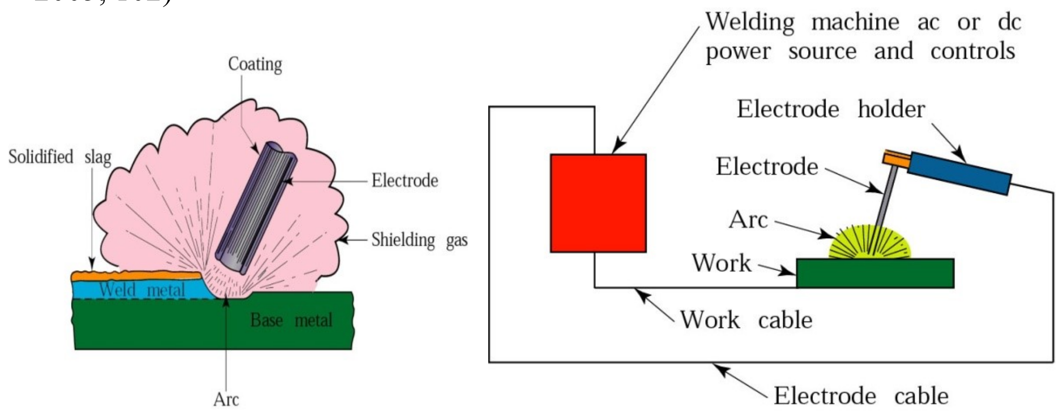

Figure 16: Schematic illustration of the shielded metal-arc welding operations, also known as stick welding, because the electrode is in the shape of a stick. (Väisänen 2013.)

The variation of SMAW processes are

- Gravity welding
- Firecracker welding
- Massive electrode welding
- Arc spot welding(Cary & Helzer 2005, 115)

Welding Conditions

The shielded metal arc welding method is suitable for all positions. Welding in the horizontal, vertical and overhead positions depends on the type and size of the electrode, the welding current and the skill of the welder. It is used for mainly joining steels, including low carbon or mild steels, low-alloy steels, high strength steels, quenched and tempered steels, stainless steel and corrosion resistant steels and for welding cast iron and malleable irons. It can also be used for nickel and nickel based alloys and to lesser degree for welding copper and some copper alloys. (Cary & Helzer 2005, 103-105)

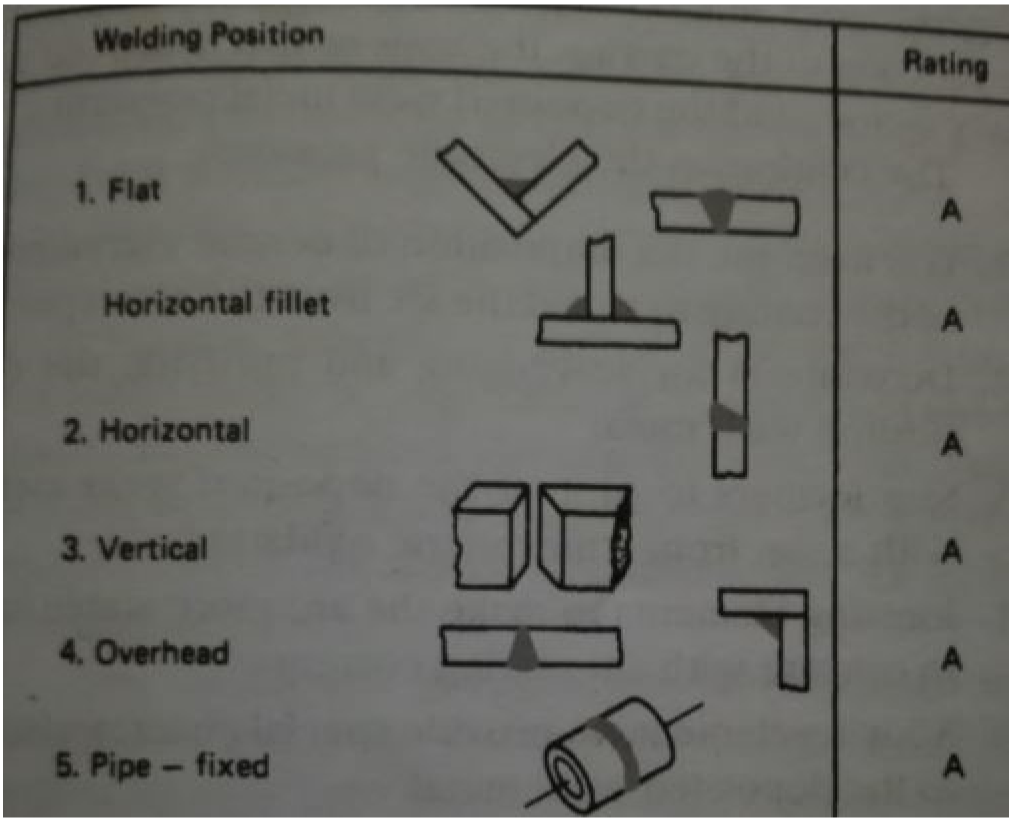

Figure 17: Shielded metal arc welding position capabilities diagram. (Cary &Helzer 2005, 103)

Different weld grove designs are used but fillet is the most common weld made. Space must be available to deposit the weld metal, when welding materials thicker than 3.2 mm.(Cary & Helzer 2005, 103 -105)

Limitations of the Process

The main drawback is built in break. Whenever an electrode is consumed to within 50 mm of its original length, the welder needed to be stopped. Welding cannot proceed because the bare portion of the electrode in the holder should not be used. A new electrode has to be place in the holder as well as chip slag, electrode stub needed to be removed. This happens many times during the process and is controlled by the size and length of the electrode. It prohibits attaining an operator factor or duty cycle much greater than 25%. (Cary & Helzer 2005, 113-115)

5.5 Gas Metal Arc Welding (GMAW)

Gas metal arc welding is an arc welding process that uses an arc between a continuous electrode and the weld pool. It was developed in late 1940's to weld aluminum and also known as metal inert gas (MIG) welding. The heat of arc is used between a continuously fed consumable electrode and the work to be welded. The surface of the base metal and end of electrode is melt by the heat. The metal melted off the electrode is transferred across the arc to the molten pool. The depth of the penetration is controlled by many factors, but the primary one is the welding current. If the penetration is too much, the arc will burn through thinner material and reduce weld quality. When welding other than flat position, the molten metal will run out if molten pool is too large.(Cary & Helzer 2005, 116-117)

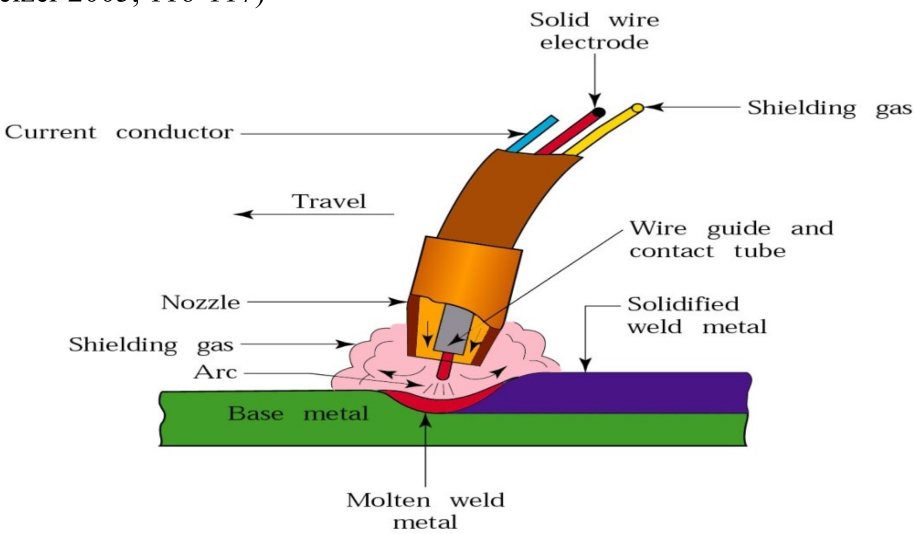

Figure 18: Gas metal arc welding process (Väisänen 2013.)

An envelope of gas fed through the nozzle provides shielding of the molten pool, the arc and the surrounding area. The shielding gas could be inert, active or a mixture. The arc is maintained automatically and travel and guidance can be handled manually or automatically. The work piece dictates the combination of the electrode and shielding gas. The metal transfer mode depends on the type and size of the electrode as well as shielding gas.(Cary & Helzer 2005, 116-117)

Advantages

The major benefit of GMAW are

- High use of filler material, operator factor and deposition rates
- Easy to automate
- Elimination of slag and flux removal
- Reduction in smoke and fumes
- Less skill needed for semi-automatic process than manual shielded metal arc welding.
- It is versatile process with very broad application ability.(Cary & Helzer 2005, 117)

Limitation

- Equipments are more complex and expensive than stick welding process
- Unable to reach inaccessible welding areas with available guns
- Sensitive to impurities and failures
- Wind and drafts affects the efficiency of the gas shielding envelope around the arc area.
- Welding equipments need high maintenance.(Cary & Helzer 2005, 126)

5.6 Flux Core Arc Welding (FCAW)

The FCAW process utilizes the heat of an arc between a continuously fed consumable cored electrode and the work. The heat of the arc melts the surface of the base metal and the end of the electrode. The metal melted of the electrode is transferred across the arc to the work piece, where it becomes the deposited weld metal. This is a variation of GMAW and based on the configuration of the electrode. Additional shielding is obtained from an envelope of gas supplied through a nozzle to the arc. Ingredients within the electrode produce gas for shielding and also provide deoxidizers, ionizers, purifying agents and in some cases alloying elements. These ingredients form a glasslike slag, which is lighter in weight than the deposited weld metal and floats on the surface of the weld as protective cover. The electrode is fed into the arc automatically from a coil.(Cary & Helzer 2005, 126)

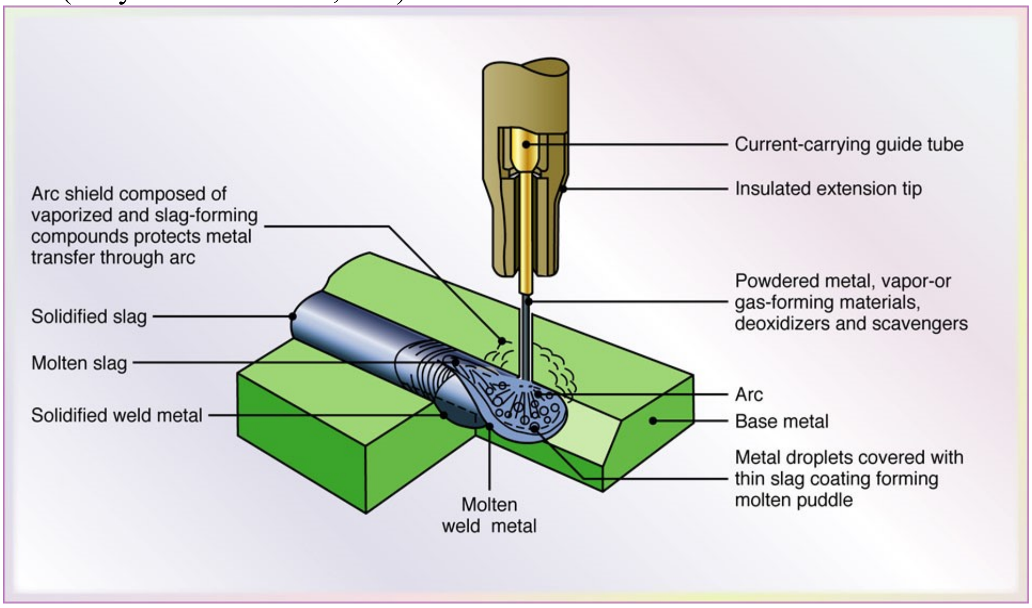

Figure 19: Schematic illustration of the flux-cored arc welding process. (Väisänen 2013.)

There are two variations of the process. One uses externally supplied shielding gas and the second relies entirely on shielding gas generated from the disintegration of the flux within the electrode. The externally supplied shielding gas method uses two distinct types of electrodes. In original flux cored type electrode, materials contained in tubular electrode are primarily fluxing agents. The cored wired electrodes contain alloy elements and powdered iron which enhances productivity with a minimum amount of fluxing material. (Cary & Helzer 2005, 127)

Advantages

- FCAW provides high quality weld at lower cost with less effort than SMAW.
- Excellent weld appearance: smooth , uniform welds
- Excellent contour of horizontal fillet welds
- Welds variety of steels over a wide thickness range
- High operating factor can be achieved from automated process
- Economical engineering joint designs.

- For outdoor welding ,process without shielding gas can be used
- Less preclearing than GMAW
- Reduced distortion over SMAW.(Cary & Helzer 2005, 127)

Limitations of the Process

- It's used mainly for ferrous metals, primarily steels.
- FCAW produces a slag covering that must be removed
- Cored electrode wire is more expensive than solid electrode wires.(Cary & Helzer 2005, 127)

5.7 Submerged Arc Welding (SAW)

This process utilizes the heat of an arc between a continuously fed electrode and the work. The heat of the arc melts the surface of the base metal and the end of the electrode. The metal melted off the electrode is transferred through the arc to the work piece, where it becomes the deposited weld metal. Granular flux provides the shielding, which is laid directly over the weld area. The nearby flux of arc melts and intermixes with the molten weld metal and helps purify and fortify it. The glasslike slag is formed by the flux that is lighter in weight than the deposited weld and floats on the surface as a protective cover. The whole welding process is submerged under this layer of flux and slag, as a result it is known as submerged arc welding. (Cary & Helzer 2005, 136)

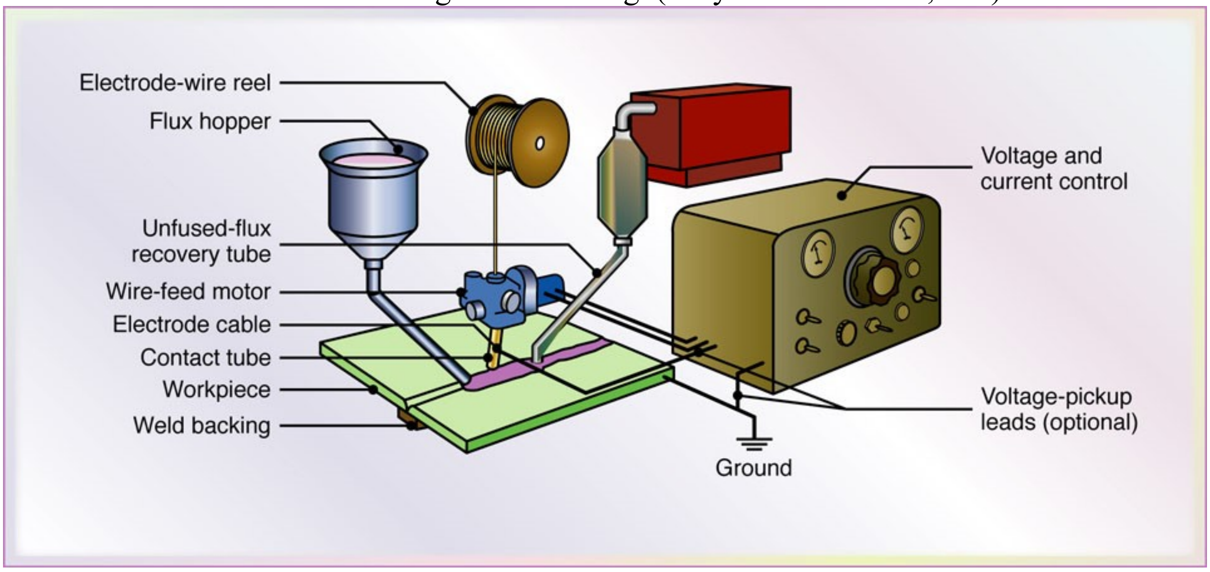

Figure 20: Schematic illustration of the submerged arc welding process and equipment. (Väisänen 2013.)

The arc is covered by the flux and slug, so that it is not visible. Unmelted flux can be reused later. The electrode is fed automatically from a coil. The arc is controlled automatically and travel can be manual or automated. A fuse type start or reversing feed system initiates the arc. The mode of metal transfer is not important in SAW. (Cary & Helzer 2005, 136)

Advantages

- Very high quality and productivity
- Extremely high deposition rate and speed

- Minimal need for protective clothing as no arc flash
- Smooth, uniform finished weld with no spatter
- Electrode wire is highly utilized
- Mainly used for thick plate welding.(Cary & Helzer 2005, 137)

Limitations

- This is a process of limited welding position capability
- The materials can be welded by SAW are limited to steel, stainless steel and nickel.
- High heat input and slow cooling cycle can be problem to weld quenched and tempered steel
- Saw is primarily used for materials that are long and straight or are rotated pipes.
- In the semi-automated process, reaching the root of the groove ,proper filling as well as sizing is not possible due to the process is submerged under the layer of flux and slag .(Cary & Helzer 2005, 137)

6 Electrodes and Filler metals

The materials used to make a weld are generally known as Filler metals. The metals used in welding, brazing or soldering a joint are called filler metals. Generally, a metal and a flux are utilized to bond the two surfaces being welded together. The flux is utilized to prevent contaminates from entering the bead, or the bit of molten metal that will be bonding the two surfaces. They get extremely hot but they do not melt. The filler materials are used or consumed as a part of molten weld pool to complete the weld. It is also a conductor in arc welding and MIG welding. The definition has been extended and also consists of non-consumable electrodes such as tungsten, carbon, and fluxes for brazing, submerged arc welding, and electro-slag welding. Although electrodes for filler metals are not considered as filler metals, nor does it consider studs involved in stud welding. (Cary & Helzer 2005, 336)

A large number of countries issue filler metal specifications. The American welding society has specification covering all filler materials. The European committee for standardization (CEN) is working towards common standardization in Europe. Many of the less industrialized nations use specifications of the industrialized countries or ISO standard. International filler metal specification are provided by AWS which can be cross reference with international filler metal specifications. There are four basic categories of filler metals. (Cary & Helzer 2005, 336)

6.1 Covered Electrodes

The most prominent type of filler metal utilized in arc welding is covered electrode. The formation of electrode determines specification, usage, the composition of the deposited weld metal. The primitive reason for coating was to protect the arc from the nitrogen and oxygen in the atmosphere. Ionizing agents were used to stabilizing the arc and producing alternative arc welding. The introduction of silicate and metal oxide lead to the formation of slag, which improves the weld bead by reacting at the surface of the weld metal. The improve strength and specific weld metal deposit composition was accomplished by the addition of alloying elements.(Cary & Helzer 2005, 339-340)

The covered electrode is comprised of three basic components: the core wire, the chemicals and minerals that form the coating, and the liquid binder that hardens and holds it all together. The core wire for mild steel and low alloy steel electrodes is a low carbon steel with a carbon content of 0.10% carbon, low manganese and silicon content, and the minimum amount of phosphorus and sulfur. The minerals and chemicals are measured definite amount and mixed in dry condition for coating. (Cary & Helzer 2005, 339-340)

The deposition rate depends on the composition of the coating of the electrode. The electrode with iron powder coating provides high deposition rate. The percentage of iron powder varies on the country of origin. In the United States, the percentage of iron powder is 10% to 50%. (Cary & Helzer 2005, 343)

$$\text{\% of iron powder} = \frac{weight\ of\ iron\ powder}{total\ weight\ of\ coating} \times 100 \qquad (1)$$

The percentage are according to AWS specifications. The European method of determining iron powder is based on the weight of deposited weld metal versus the weight of the bare core wire consumed

$$\text{\% of iron powder} = \frac{weight\ of\ deposited\ metal}{weight\ of\ bare\ core\ wire} \times 100 \qquad (2)$$

A general problem in the electrode is finger nailing, which means, the burning off of an electrode faster on one side than on other. No concentricity is the most common reason for the finger nailing. This event is most frequent when direct current is used with the smaller electrode or when low current is used. This condition can be aggravated if the coating is not concentric with the core wire. A quick check for fingernailing during welding is to stop when fingernailing is encountered and rotate the electrode with the holder 180°, continue to weld and see if finger nailing continues on the same side electrode. If it does, the coating is probably off center. (Cary & Helzer 2005, 343)

6.2 Solid Electrode Wires

Oxyfuel gas welding first utilized solid wire as filler material to the joint. These wire were used in straightened lengths approximately (1m) long. It was used in coils for bare wire automatic arc welding, submerged arc, and electro-slag welding. Comparatively small diameter electrode wire is used gas metal arc welding. The production of welding electrodes or rods is similar except the straightening and cut operation is added in welding rod. A thin copper coating is used commonly in solid steel electrode for various reasons. It improves the current pick up between the contact tip and the electrode, aids drawing as well as protects from rusting of the wire when exposed to the atmosphere. In welding shop atmosphere, copper is not desirable and therefore gas metal arc electrode is available with organic coating rather than copper. This organically coated electrode wire is commonly used in electro-slag welding. (Cary & Helzer 2005, 344)

6.3 Cored Electrode Wires

The design of the cored electrode led to the outstanding performance of the flux cored arc welding. This inside -outside electrode made of a metal sheath encompassing a core of fluxing and alloying compounds. The compound in the electrode performs same as the coating on a covered electrode. The cored wire was developed as supplementary for solid electrode wire .it is easier for the welder to utilize tubular wire than the solid wire of the same deposition, especially to weld pipe in fixed position. This production method provides adaptability of composition and is not limited to the analysis of available steel billets. (Cary & Helzer 2005, 346)

6.4 Metal Cored Electrodes

It is a tubular filler metal electrode comprised of a metal sheath and a core of various powdered materials, which produce slag island on the face if the weld bead. Metal core electrode is made of the minor amount of fluxing ingredients or no fluxing ingredients or gas formers. Therefore, the external shielding gas is needed with metal cored electrode. It has a high deposition rate of no less than 95%. This electrode is very desirable to operator because of low spatter, low smoke level and minimum slag coverage .They usually have spray transfer and have good mechanical properties. The shipment of finished cored electrode is sent as a continuous coil, on spools or in round drums.(Cary &Helzer 2005, 347)

6.5 Non Consumable Electrodes

Non-consumable electrode could be made of carbon or tungsten. The carbon based electrodes is a non-filler metal electrode compromised of a carbon graphite rod, which could have copper or other coatings and utilized in arc welding or cutting. The tungsten electrode is likewise a non-filler electrode, made of mainly tungsten as well as used in the similar application. Tungsten electrode can be comprised of pure tungsten or tungsten with the small portion of rare earth elements added to enhance electron emission. (Cary & Helzer 2005, 352)

7 Shielding Gas

Shielding gas shifts the air and does not allow the atmospheric gases to react with the molten metal, electrode, or arc by displacing the air. All the arc welding processes utilize shielding techniques to ensure better weld quality. The disintegration of coating creates gas that protects the molten metal in shielded metal arc welding. In flux- cored arc welding the disintegration of the core material, which may be supplemented by shielding gas, provides shielding from the atmosphere. In Carbon arc welding molten area is protected by the CO_2 gas generated from the slow disintegration of carbon dioxide. Granular flux does the likewise job in submerged arc welding. Shielding gases needed to be supplied and directed around the arc area to provide atmospheric protection in gas metal as well as Gas tungsten arc welding. Moreover, Shielding gas establishes the metal transfer mode and the deposited weld qualities. (Cary & Helzer 2005, 354)

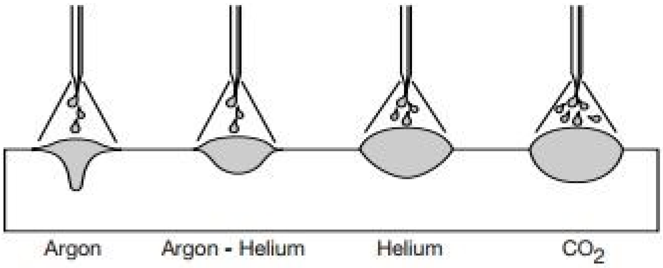

Figure 21: Bead contour and penetration patterns for various shielding gases. (Nadzam 2004, 13)

The efficiency of shielding from the atmosphere, relies on the design of the nozzle, the distance from nozzle to work, the internal diameter, the gas flow rate, side winds, and the purity of the shielding gasses. Inert shielding gasses does not react chemically with other elements. Among the inactive gasses, only helium and argon are adequately available and affordable. The gas tungsten arc welding process requires the utilization of inert shielding gasses and also used in welding of non-ferrous metals with gas metal arc welding. Active gases reacts with molten metal. The oxygen containing gases are called oxidizing gas and oxygen-attracting gases are known as reducing gas. (Cary & Helzer 2005, 355)

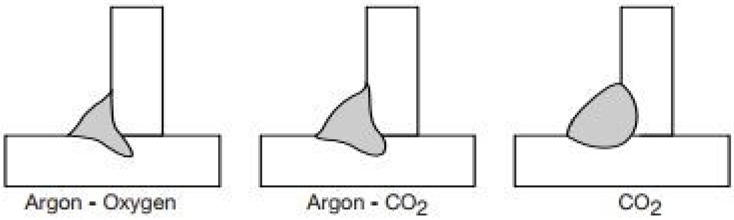

Figure 22 : Relative effect of Oxygen versus CO_2 additions to the argon shield.(Nadzam 2004,13)

Heavier gases will displace air in enclosed area. Lighter gases like helium provides poor shielding as it tends to float away. Thermal conductivity relates to the heat in the arc column. It also indicates the speed of heat flow in the gas. It is easier to start the arc with the gas of lower ionization potential. The higher the ionization potential, the hotter the arc. Purity is the most important characteristic of a shielding gas. (Cary & Helzer 2005, 356)

7.1 Argon

Argon is colourless, odourless, tasteless, and comparatively plentiful than the other inert gases. It can be extracted by liquefying the air under pressure and low temperature. The argon boils off from the liquid at a temperature of 2184°C. The pure argon of approximately 99.99% needed for the welding. It is about 23% heavier than air. Argon shielding is used in gas tungsten arc welding and for gas metal arc welding of nonferrous metals. It has low ionization potential. It provides lower arc voltage than helium in the gas tungsten arc welding. Argon is used in various shielding gas mixture because of its ability to stabilize the welding arc. Although, iron is non- toxic but can cause asphyxiation in confined area by supplanting the air.(Cary &Helzer 2005, 356)

7.2 Helium

Helium is the second lightest gas. It is one seventh as heavy as air. This inert gas is also colourless, odourless, tasteless and nontoxic. It is the only known substance to stay fluid at temperatures close to absolute zero in the liquid state. It can be extracted from natural gas. It is the shielding gas of highest ionizing potential. As a result, gas tungsten arc welding in helium has an extremely high arc voltage. The greater amount of heat is generated from the arc in an atmosphere of helium. It is an inefficient shielding gas as it tends to drift away because of light weight. The Higher flow rate of helium is used to shield the welding area, for example in overhead welding. It is exceptionally costly to weld and is some of the time in rare supply. (Cary & Helzer 2005, 356)

7.3 Carbon Dioxide

Carbon dioxide (CO_2) is a blend of about 27% carbon and 72% oxygen. At normal atmospheric pressure and temperature, it has no colour, nontoxic as well as does not burn. It is about 1.5 times heavier than air and can displace the air in confined space. At elevated temperatures, it will break into carbon monoxide and oxygen. During the welding, disassociation takes place to the extent that 20% to 30% of the gas in the arc area is carbon monoxide and oxygen. Subsequent to leaving the arc territory, carbon monoxide quickly reacts with oxygen to produce CO_2. (Cary & Helzer 2005, 356)

One hundred percent CO_2 shielding produces broad, deep penetration welds, good bead contour and there is no tendency toward undercutting. CO_2 is relatively expensive than inert gas. The arc under CO_2 shielding tends to be somewhat violent, which can lead to spatter and makes thin materials welding difficult.(Cary & Helzer 2005, 356)

Carbon dioxide is released into the air from flue gases, produced by burning of natural gas, fuel oil, or coal. It is also a byproduct of the calcinations operation of lime kilns, from the manufacturing of ammonia, and from the fermentation of alcohol. (Cary & Helzer 2005, 356)

7.4 Argon plus Oxygen

Little addition of less than 1% oxygen, stabilize the arc in GTAW process. Oxygen is used for thin steels, including stainless steels as well as DC electrode negative (DCEN) of aluminium. The arc transfer characteristics significantly influenced by the composition of shielding gas. In mixtures, the required current needed to reach the transition point diminishes as the percentage of CO_2 decreases. The usage of pure argon, results in poor bead contour and penetration pattern. The addition of less than 5% argon, improves the weld quality and provides spray transfer mode. With high oxidizing shielding gas, it is necessary to use an electrode that contains adequate deoxidizers to overcome the loss of silicon, manganese, and aluminium. Additional oxygen will lead to the formation of porosity in the deposit. Oxygen improves penetration pattern by enlarging the deep penetration finger at the center of the weld.In addition, improved bead contour and elimination of undercut at the edge of the weld are provided by the better wetting action.(Cary & Helzer 2005, 357-358)

7.5Argon plus Helium

Argon-helium mixtures is used for welding nonferrous metal in GMAW process. The addition of helium in percentages of 50% to 75% raises the arc voltage and increases the heat in the arc. It is useful for welding heavy thickness of aluminium, magnesium, and copper, and for overhead-position welding. The speed and quality of AC welding of aluminium is proved by the addition of helium. The gas tungsten hot wire variation uses the 25% argon-75% helium mixture. This blend is also used in GMAW of nonferrous metals. (Cary & Helzer 2005, 358)

7.6 Argon plus Hydrogen

Argon with the addition of little amount of hydrogen increases the arc voltage and raises the heat in the arc. Argon mixture of up to 5% hydrogen is used in welding nickel and nickel alloys and for welding heavier sections of authentic stainless steels. Mixtures of argon containing up to 25% hydrogen are used for welding thick metals that have high heat conductivity, such as copper. Hydrogen addition can result in hydrogen pickup for welding of mild or low-alloy steel, aluminium and magnesium. (Cary & Helzer 2005, 358)

7.7 Argon plus Nitrogen

Pure nitrogen is used for GMAW of copper in some countries. Thus, the quality is not as good as expected. For the high quality welding 50% to 75% argon with nitrogen blend is recommended. (Cary & Helzer 2005, 358)

7.8 Argon plus Carbon Dioxide

One of the most popular mixture is 75% argon and 25% CO_2 for GMAW process. It is widely used on thin steel, where less penetration and good bead appearance is needed. It provides better appearance over 100% CO_2 by reducing spatter. This mixture can also be used in out of position welding, thin sheet metal welding and when fit up is poor. (Cary & Helzer 2005, 358)

7.9 Ternary Mixture of Gases

The mixtures of three shielding gases commonly known as tri-mix gas, is becoming popular day by day. Generally, the mixtures use argon with oxygen and CO_2, and sometimes argon, CO_2, and helium. During the liquefaction of argon, the raw argon contains about 2% oxygen before final purification. The impure oxygen is than mixed with CO_2, which provides a tri-mix of 70% argon, 2% oxygen, and reminder CO_2.This mixture is very popular for welding of steel. Another tri-mix uses a small amount of helium to the argon-O_2 mixture. (Cary & Helzer 2005, 358)

For stainless steel applications, three-part mixes are quite common. Helium additions of 55% to 90% are added to argon and 2.5% CO2 for short-circuiting transfer. They are favored for reducing spatter, improving puddle fluidity, and for providing a flatter weld bead shape. (Nadzam 2004)

Various mixture of gases are becoming available that offers specific features. This includes high performance shielding gas mixture that provide higher deposition rates or higher travel speeds. Helium is mostly used in three component mixture of these gases. These mixtures, increases the arc voltage, raises the I^2R heating of the welding electrode beyond tip. The higher voltage and extended electrode wire increase the energy in the arc and increase deposition rates. (Cary & Helzer 2005, 358-359)

7.10 Common Ternary Gas Shielding Blends

90% Helium + 7.5% Argon + 2.5% CO2 — is the most popular of the short-circuiting blends for stainless steel applications. The high thermal conductivity of helium provides a flat bead shape and excellent fusion. This blend has also been adapted for use in pulsed spray transfer applications, but it is limited to stainless or nickel base materials greater than .062" (1.6 mm) thick. It is associated with high travel speeds on stainless steel applications. (Nadzam 2004)

55% Helium + 42.5% Argon + 2.5% CO2 — although less popular than the 90% helium mix discussed above, this blend features a cooler arc for pulsed spray transfer. It also lends itself very well to the short-circuiting mode of metal transfer for stainless and nickel alloy applications. The lower helium concentration permits its use with axial spray transfer. (Nadzam 2004)

38% Helium + 65% Argon + 7% CO2 — this ternary blend is for use with short-circuiting transfer on mild and low alloy steel applications. It can also be used on pipe for open root welding. The high thermal conductivity broadens the penetration profile and reduces the tendency to cold lap. (Nadzam 2004)

90% Argon + 8% CO2 + 2% Oxygen — this ternary mix is applied to short circuiting, pulsed spray, and axial spray modes of metal transfer on carbon steel applications. The high inert gas component reduces spatter. (Nadzam 2004)

Table 2: GMAW shielding gas selection chart. (Nadzam 2004, 15)

Base Material	Mode of metal transfer	Shielding gas blends
Carbon steel	Axial Spray or GMAW-P	82-98% Argon + 2-18% CO2 95-98% Argon + 2-5% Oxygen GMAW-90%Argon+ 7.5% CO2 + 2.5% Oxygen
Low alloy steel	Axial Spray or GMAW-P	95% Argon + 5% CO2

		95-98% Argon + 2-5% Oxygen
Aluminum	Axial Spray or GMAW-P No GMAW-S)	75% Helium + 25% Argon 75% Argon + 25% Helium 100% Helium
Austenitic steel	Axial Spray or GMAW-P	98-99% Argon + 1-2% Oxygen or 98% Argon + 2% CO2 97-99% Argon + 1-3% Hydrogen 55% Helium + 42.5% Argon + 2.5% CO2
Nickel alloys	Axial Spray or GMAW-P	100% Argon 89% Argon + 10.5% helium + .5% CO2 66.1% Argon + 33% Helium + .9% CO2 or 75% Helium + 25% Argon 75% Argon + 25% Helium 97-99% Argon + 1-3% Hydrogen
Copper alloys	Axial Spray or GMAW-P	100% Argon or 75% Argon + 25% Helium 75% Helium + 25% Argon
Silicon Bronze and Brasses	Axial Spray or GMAW-P	100% Argon
Aluminum bronze	Axial Spray or GMAW-P, Limited GMAW-s	100% Argon

8 Welding Problems

8.1 Arc Blow

Arc blow is the deflection of a welding arc from its normal paths due to the interaction of the magnetic field of the welding current with residual magnetic field which may be present in the metal. (Lincoln electric n.d)

When an electric current passes through an electrical conductor, it produces a magnetic flux in circles around the conductor in planes perpendicular to the conductor and with their centers in the conductor, The magnetic flux field tend to stay in the steel because the circular lines of force are distorted and tend to concentrate in the steel where they encounter less resistance than in the air. At the boundary of steel plate and air, magnetic flux lines squeezes, causing deformation in the circular line of forces. This could lead to heavy concentration of flux behind or ahead of a welding arc. As a result arc will move in the direction where it will relieve the squeezing and restore the magnetic field balance. It veers away from the magnetic field concentration. (Lincoln electric n.d)

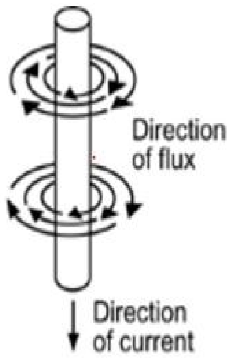

Figure 23: Current through conductor sets up a magnetic field that may be represented by planes of flux lines (Lincoln electric n.d.)

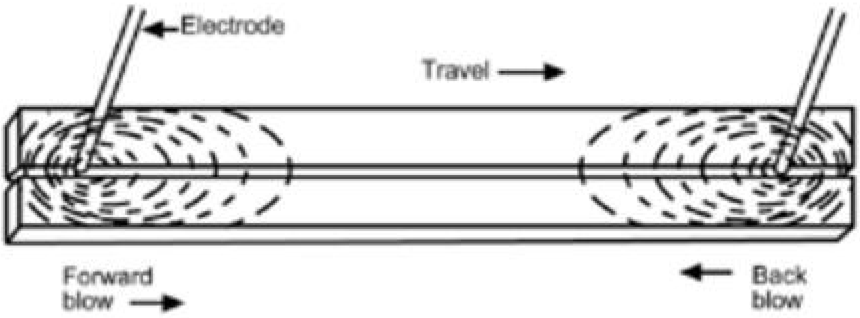

Figure 24: Concentration of magnetic flux behind and ahead of arc. (Lincoln electric n.d.)

These forces will cause the arc to deflect when welding with direct current. The use of AC current significantly reduces the magnitude of the deflection. AC currents sets up other currents that tend to neutralize the magnetic field or greatly reduce its strength. Less arc blows occurs in low current than high currents because the intensity of magnetic field a given distance from the conductor is proportional to the square of the welding current. The steel of 9% Nickel, has high percentage of magnetic permeability and are very easily magnetized by external magnetic field such as power lines. These phenomena makes it difficult to weld due to the arc blow produced by the magnetic field present in the material. . (Lincoln electric n.d)

8.2 Magnetic Arc Blow

To maintain a continuous flow of current in the arc stream, arc requires a hot spot between electrode and plate. As the electrode is advanced along the work, the arc will tend to lag behind. This lag of arc is caused by reluctance of arc to move to the colder plate. The space between the end of the electrode and the hot surface of the molten crater is ionized and, therefore, is a more conductive path than from the electrode to the colder plate. When the welding is done manually, the small amount of "thermal back blow" due to the arc lag is not detrimental, but it may become a problem with the higher speeds of automatic welding or when the thermal back blow is added to magnetic back blow. (Lincoln electric n.d)

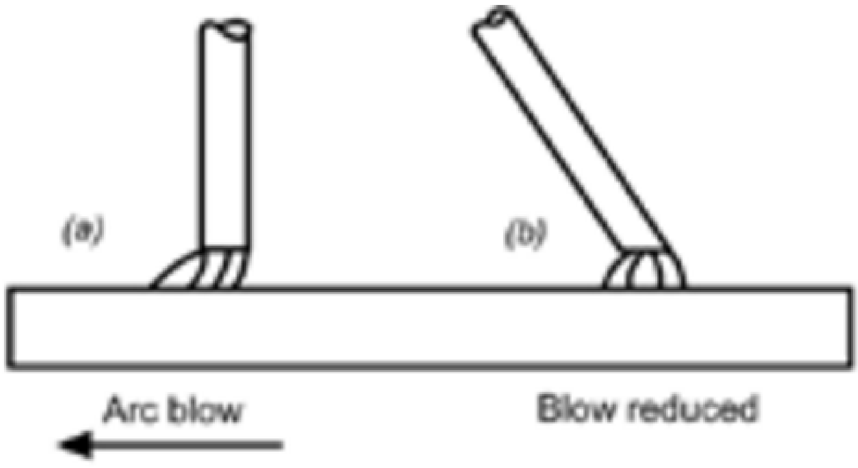

Figure 25 : Arc blow as in (a), can sometimes be corrected by angling the electrode, as in (b). (Lincoln electric n.d)

8.3 Distortion and Warpage

In welding, weld metal and adjacent base metal expands during heating and restrains in cooling process. They are restrained because weld area is a part of large piece of metal. In practice, heating is not uniform across the cross section of a part. There is always restraint, because the parts are not heated or heated to a lesser amount tend to restraint the portion of the same piece is heated to a higher temperature. This differential or nonuniform heating and partial restraint causes thermal distortion and warpage in welding.

While making a weld bead on the plate, the deposited weld metal is momentarily at a temperature of about 3000 F (1649 C), slightly above its melting point. At the point of solidification the molten metal has little strength. As it cools it acquires strength. (Cary & Helzer2005, 600)

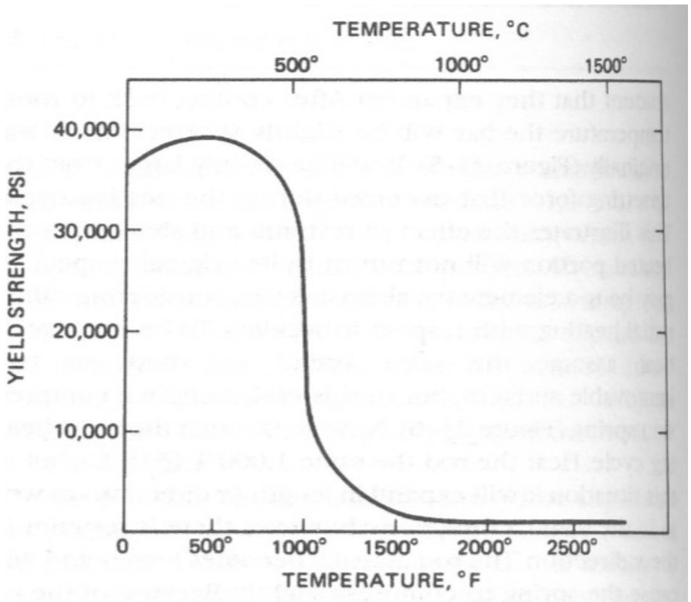

Figure 26: Temperature-yield strength relationship. (Cary & Helzer2005, 600)

With the temperature further reducing and each small increment of heated metal tending to contract, contracting stresses occur and there will be movement in the metal adjacent to the weld. The unheated metal tends to resist the cooling dimension changes based on thermal conductivity. If the metal has high thermal conductivity, the heating differential will be less and change in dimension will be spread over a large area. (Cary & Helzer2005, 601)

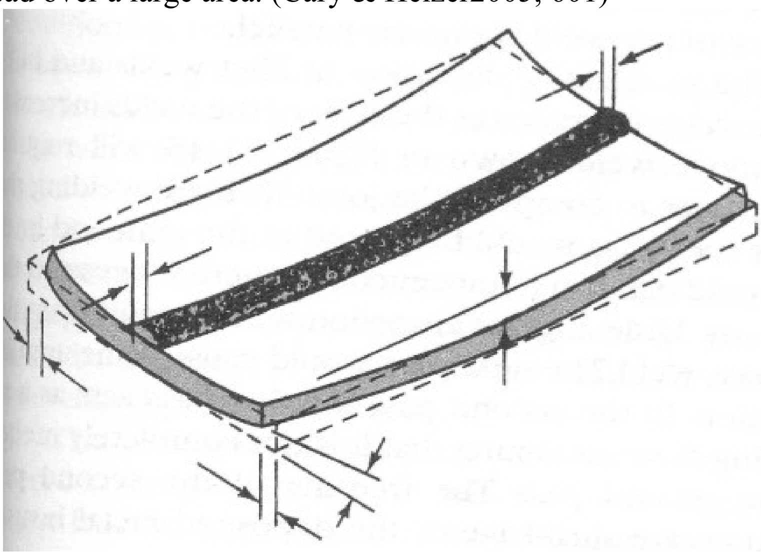

Figure 27: Warpage produced by bead on the plate. (Cary & Helzer2005, 601)

When making a weld joint in two narrow, thin plates, specifically a butt joint, heat input and the travel speed of the welding becomes important. If travel speed is relatively fast, the effect of the arc`s heat will cause expansion of the edges of the plates and they will bow outward and open up the joint. If the travel speed is relatively slow, the effect of arc temperature and the cooling will cause contraction of the edges of the plates and they will bow inward and close up the joint. (Cary & Helzer 2005, 600-605)

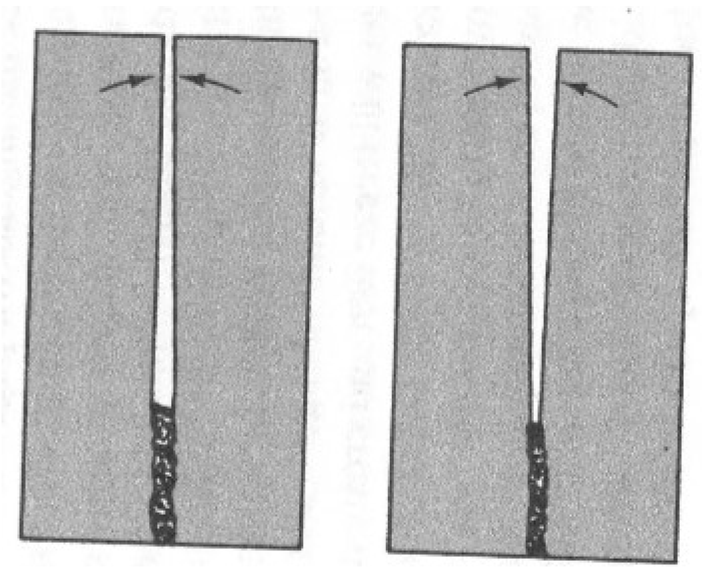

Figure 28: Butt joint showing warpage (Cary &Helzer2005, 601)

8.4 Gas Porosity

Gas porosity can occur on or just below the surface of a weld. Pores are characterized by a rounded or elongated teardrop shape with or without a sharp point. Pores can be uniformly distributed throughout the weld or isolated in small groups. They can also be concentrated at the root or toe of the weld. Porosity in welds is caused by gas entrapment in the molten metal, by too much moisture on the base or filler metal, or by improper cleaning of the joint during preparation for welding. The type of porosity within a weld is usually designated by the amount and distribution of the pores. Types include uniformly scatted porosity, cluster porosity, linear porosity, elongated porosity and wormhole porosity. Radiography is the most widely used non-destructive method for detecting subsurface gas porosity in weldments. (Campbell 2010, 116.)

8.5 Slag Inclusion

Slag inclusions can occur when using welding processes that employ a slag covering for shielding purposes. With other processes, the oxide present on the metal surface before welding may also become entrapped. Slag inclusions can be found near the surface and in the root of a weld (Fig.a), between weld beads in multipass welds (Fig. b), and at the side of a weld near the root (Fig c).

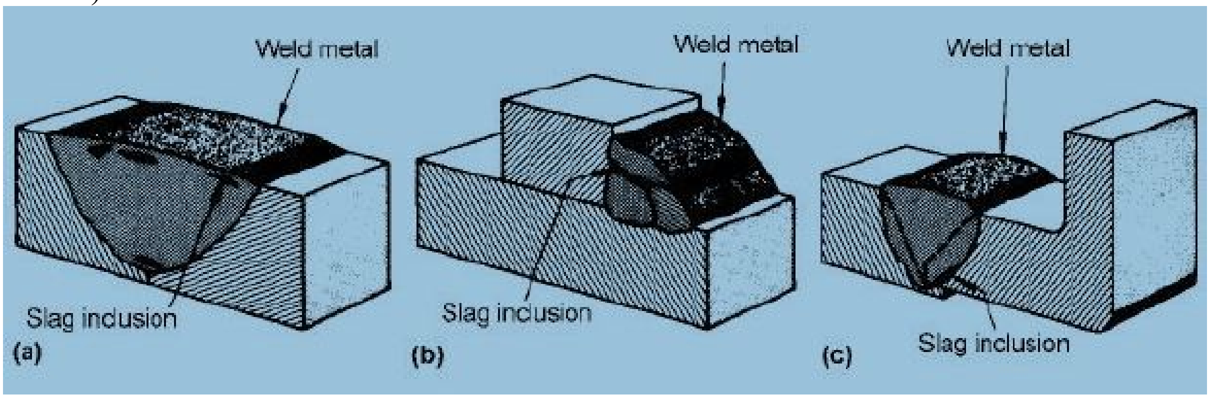

Figure 29: Location of slag inclusion in weld metal (a) near the surface and in the root of a single pass weld (b) between weld beads in a multipass weld and(c) at eh side of a weld near the root. (Campbell 2010, 117.)

During welding slag may spill ahead of the arc and subsequently be covered by the weld pool because of poor joint fit-up, incorrect electrode manipulation or forward arc blow. Radical motion of the electrode, such as wide weaving, may also cause slag entrapment on the sides or near the top of the weld after the slag spills into a portion of the joint that has not been filled by the molten pool. (Campbell 2010, 117.)

8.6 Tungsten Inclusion

Tungsten inclusions are particles found in the weld metal from the non-censurable tungsten electrode used in gas tungsten arc welding. These inclusions are the result of:

- Exceeding the maximum current for a given electrode size or type.
- Letting the tip of the electrode make contact with the molten weld pool.
- Using an excessive electrode extension.
- Inadequate gas shielding or excessive wind drafts that result in oxidation.
- Using improper shielding gases such as argon-oxygen or argon-CO

mixtures which are used for gas metal arc welding. (Campbell 2010, 117.)

Tungsten inclusions, which are not acceptable for high-quality work, can be found only by internal inspection techniques, particularly radio- graphic testing. In general, they must be ground out and repair welded. (Campbell 2010, 117.)

8.7 Heat Forming and Straightening

Welding and other manufacturing processes where heat is introduced will leave stresses in the metal during the subsequent cooling, causing distortion or warping. All metals expands during heating and contracts when cooled. If metal is heated unrestrainedly expands in all directions, but metal is restrained normally due to nonuniform heating. Plastic deformation or upsetting is caused by rapid heating, which leads to dimensional changes upon cooling. Strength of the metal decreases greatly as the temperatures increases. Distortion occurs as a result of forces created by differential heating and restraint. (Bocoline,2009)

Flame straightening is an efficient and long- established method of correcting the distorted parts. In practice, an oxy-acetylene flame is used to rapidly heat a well- defined section of the work piece. Upon cooling, the metal contracts more than it could expand when heated and any resulting distortions can therefore be straightened out. Suitable materials include steel, nickel, copper, brass and aluminium. Although various fuel gases can be used, the highest flame temperatures and intensities for rapid heating are achieved with acetylene and oxygen. (Bocoline 2009)
Components which do not distort or only slightly distort after the welding joint has cooled down are exposed to higher residual welding stresses because the shrinkage stresses have not led to deformation of the component. (Bocoline 2009)

Later, these stresses may be relieved by dynamic loads or by machining. This can then lead to subsequent undesired deformation. Stresses which are relieved after welding, causing deformation, indicate minimal residual welding stresses. The components remain stable. (Bocoline 2009)
During welding, four shrinkage stresses occur which can be seen in the distortion, depending on the level of stiffness. In order to influence residual welding stresses, parameters such as the welding process, seam volume and the energy applied per unit length of weld must be considered. Follow-up plans after welding must be compiled and fulfilled. (Bocoline 2009)

For subsequent stress reduction, the following recommendations should be taken into consideration:

8.7.1 Thermal Processes

The corrective thermal process for distorted parts are:

- Low-stress annealing in a furnace
- Flame heating
- Element heating
- Inductive heating

8.7.2 Mechanical Processes

The mechanical processes used in the treatment of distortion and warping metal parts are

- Non-recurrent mechanical overload
- Vibration relief
- Hammering
- Shot peening
- Flame relief
- Flame straightening

Flame straightening is classified as a mechanical process because the resulting expansion causes external forces to impact on the work piece which then produce stresses in the component. (Bocoline 2009)

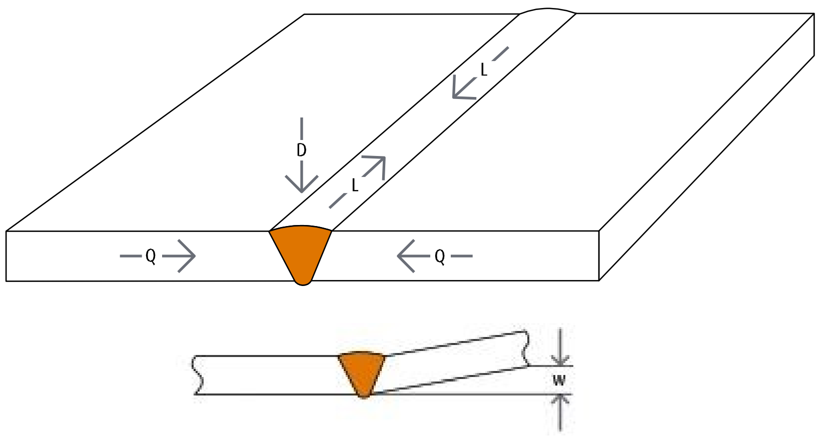

Figure 30:Types of shrinkage during welding.(Bocoline 2009)

Plastic deformation takes place in the work piece above the elastic limit. The result is irreversible deformation.

8.7.2.1 Principle of Flame Straightening:

The component is precisely and locally heated to the material-specific flame straightening temperature at which plastic deformation occurs. As a result of restricted thermal expansion, the deformation remains. During cooling, the work piece is shortened around the deformed portion, leading to the desired change in length or shape. (Bocoline, 2009)

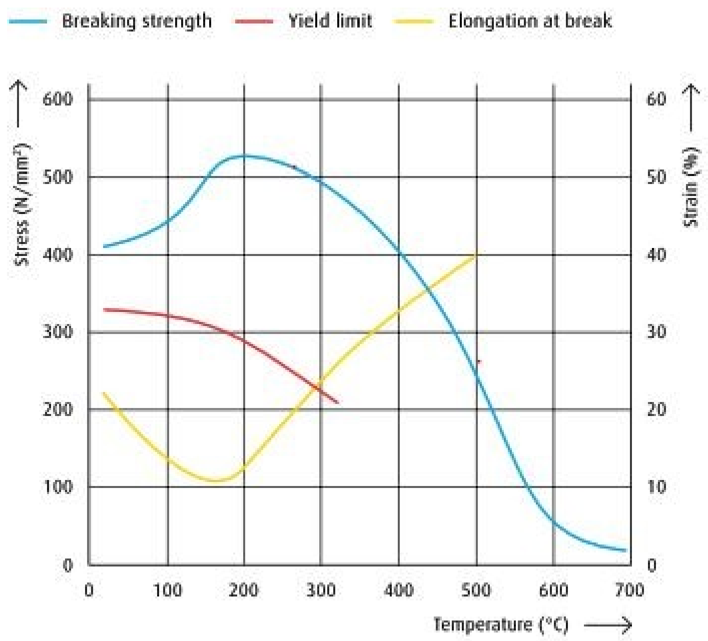

Figure 31: Yield limit and elongation at break for mild steel (S355). (Bocoline2009)

In contrast to mechanical deformation with a press or hammer with which the work piece sections are elongated (lengthened), the use of a flame always leads to the shortening of the heated zone of the component.
All materials are suited to welding can be flame-straightened without difficulty, if the material's specific properties are taken into consideration, as is common practice for welding. The elastic modulus, and therefore also the strength, of every metallic material drops as the temperature increases. In turn, its ductility increases. (Bocoline, 2009)

Using the material S355 as an example in figure 31, it becomes clear that flame straightening temperatures > 650 °C make little sense. An increase by a further 300 °C from 650 °C to 950 °C doubles the heating time and is neither helpful nor necessary. When heating limited sections of the component to a plastic temperature range, the material flows and is upset as a result of restricted expansion. Retrieved 12 December 2016 from (Bocoline, 2009)

9 Weld Stress and Cracking

9.1 Residual Stress

If the metal is not restrained, metal expand and contract the same amount when heat applied and cooled the same amount. The heating and cooling process during welding are not uniform, and there is a temperature difference between the weld spot and area adjacent to the weld. The partial restraint and nonunifrom heating creates stresses in weld area as well as weld metal. If there is more change in temperature happens, the stress will be beyond the yield point of the metal. Yielding will occur so that the retained or residual stress will be at the yield of the metal. This mean that yield point stresses within the weldment may occur in all three directions simultaneously .These internal or remaining stresses are known as residual stress. (Campbell 2010,117.)

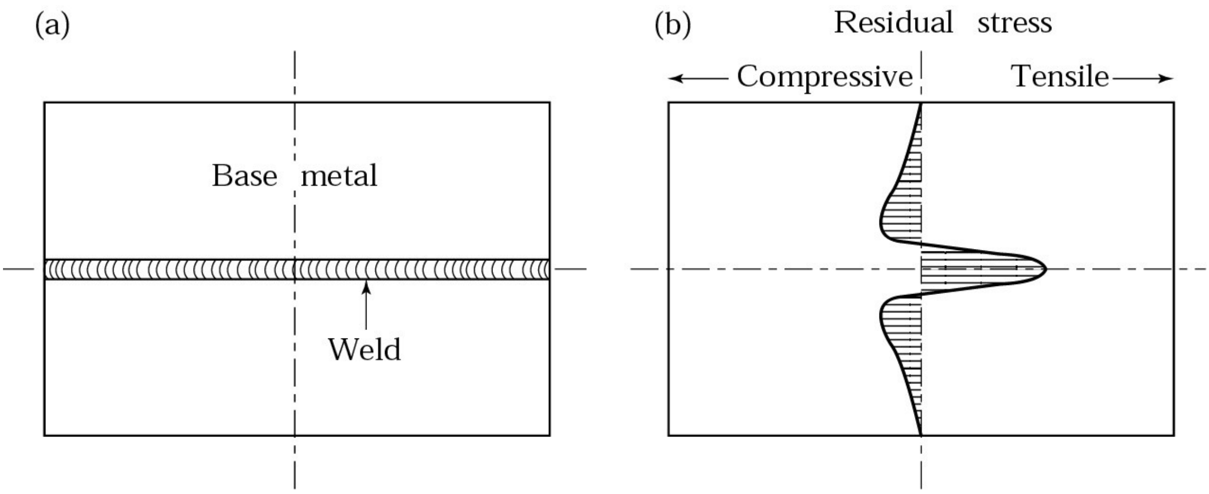

Figure 32: Residual stress developed during welding. (Campbell 2010, 113.)

Residual stresses are normally present in the weldment area, and these can be high and even approach the yield strength. These stresses occur as a result of (a) thermal expansion and contraction during weld, (b) the constraint provided by the fabrication or by the fixtures, and (c) distortion in the structure during fabrication. (Campbell 2010, 126.)

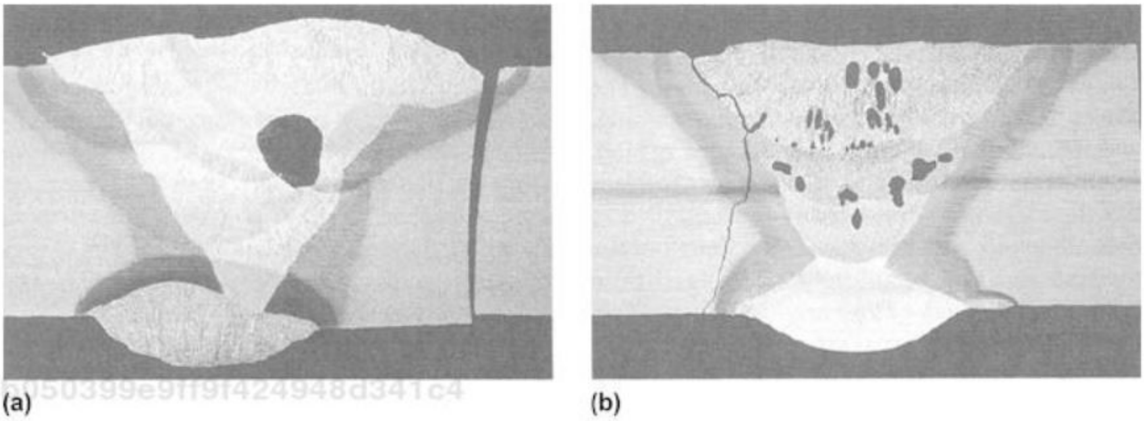

Figure 33: Effect of volumetric defects on fatigue: (a) slag inclusion in the butt weld, and cracking from weld toe; (b) porosity in the butt weld, and cracking from weld toe. (Campbell 2010, 127.)

Residual stresses are not always detrimental. It may have a useful effect on the service life of a part. One of the most common use of residual stress is in the shrink –fit assembly of parts. Shrink-fit assembly is used in shrink fitting of steel tires on wheels for railroad locomotives. The tire is made of relatively high carbon steel. These steel tires are heated and then placed on the locomotive wheel and allowed to cool around the wheel, thus make a very strong mechanical connection. The residual stresses continue to hold the tire on the wheel, even tremendous loads encountered in service. There is no relaxing of the stresses from mechanical working. It seems normal operating loads do not reduce the magnitude of internal residual stresses. (Cary & Helzer 2005, 609)

There are several ways to prevent residual stresses. If the weld is stressed beyond its yield strength, plastic deformation will occur and the stresses will be made more uniform but still at the yield point of the metal. This will not completely eliminate residual stress rather will create more uniform stress pattern. Another way to reduce high or peak residual stresses is by means of loading or stretching the weld by heating adjacent areas, causing them to expand. The heat reduces the yield strength of the weld metal and expansion tends to reduce peak residual stresses within the weld. This technique also makes the stress pattern at the weld area more uniform. The more effective way of reducing high residual stresses is by means of the stress relief heat treatment. The weldment is uniformly heated to an elevated temperature at which yield strength of the metal is greatly reduced. The weldment is then allowed to cool slowly and uniformly, as a result temperature difference between parts is minor and the cooling will be uniform and a uniform low stress pattern will develop within the weldment. (Cary & Helzer 2005, 609)

9.2 Solidification Cracks (Hot Cracking)

Hot cracks are solidification cracks that occur in the fusion zone near the end of solidification. They result from the inability of the semisolid material to accommodate the thermal shrinkage strains associated with weld solidification and cooling. Cracks then form at susceptible sites to relieve the accumulating strain. Susceptible sites are interfaces, such as solidification grain boundaries and interdendritic regions, that are at least partially wetted. (Campbell 2010, 119.)

Solidification cracking requires both a sufficient amount of mechanical restraint (strain) and a susceptible microstructure under conditions of rapid solidification and cooling, the rate of strain accumulation is rapid, leading to an increased cracking susceptibility. Inherently, then, requisite strains for solidification cracking are more likely to be experienced with welding processes that promote rapid solidification and cooling. The use of preheating and controlled heating and cool-down rates helps to prevent cracking.

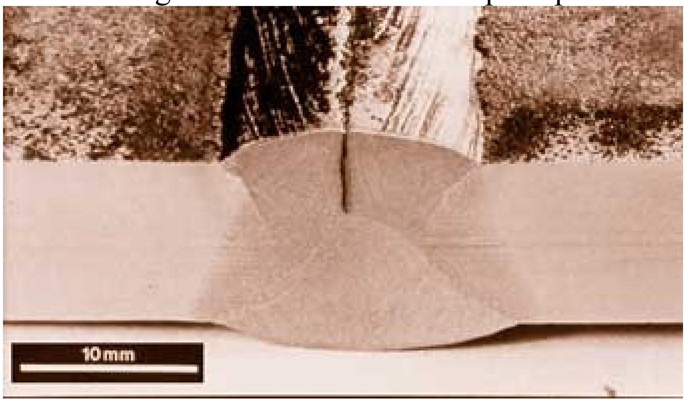

Figure 34: Propagation of solidification crack. (The welding institute 2010.)

A simple way to minimize the restraint on a solidifying weld joint is to keep the joint gap to a minimum by designing hardware with good fit-up. Welding parameters can have a profound influence on the occurrence of solidification cracking. The natural tendency to use high-speed welding to improve productivity can have detrimental effects. Formation of a teardrop-shaped weld pool, which may occur as the weld travel speed increases, can result to centerline solidification cracks. The solidification pattern associated with this type of weld pool is such that solidifying grains meet at the weld centerline, fanning a particularly susceptible site for solidification crack initiation. (Campbell 2010, 119.)

Alloys having a wide solidification temperature range are more susceptible to solidification cracking than are alloys that solidify over a narrow temperature range. This occurs because of accumulated thermal strain is proportional to the temperature range over which a material solidifies. Composition effects in steel alloys that can cause hot cracking include high carbon contents, high alloy contents, and high Sulphur contents. Manganese additions are frequently used to tie up Sulphur in the form of harmless globular MnS particles. (Campbell 2010, 120.)

9.3 Hydrogen Induced Cracking (Cold cracking)

Cold cracks are defects that form as the result of the contamination of the weld microstructure by hydrogen. Whereas solidification cracking and HAZ cracking occur during or soon after the actual welding process. Hydrogen-induced cracking is usually a delayed phenomenon, occurring possibly weeks or even months after the welding operation. The temperature at which these defects tend to form ranges from -50 to 150 °C (---60 to 300 °F) in steels. The fracture can be either intergranular or transgranular cleavage. (Campbell 2010, 122.)

In ideal weld operation, hydrogen induced cracking would be at most minor concern. However, it is extremely difficult exclude hydrogen from structures during welding. Although the primary source of hydrogen in weld metal is considered to be the disassociation of water vapour in the arc and absorption of gaseous or ionized hydrogen into the liquid, other sources are also available. All organic compounds contain hydrogen in their molecular structure, and all may be broken down in the intense thermal environment of a welding heat source. Organic compounds are ubiquitous in the welding environment, from lubricants in assembly areas to body oils on the hands of welding operators. (Campbell 2010,122.)

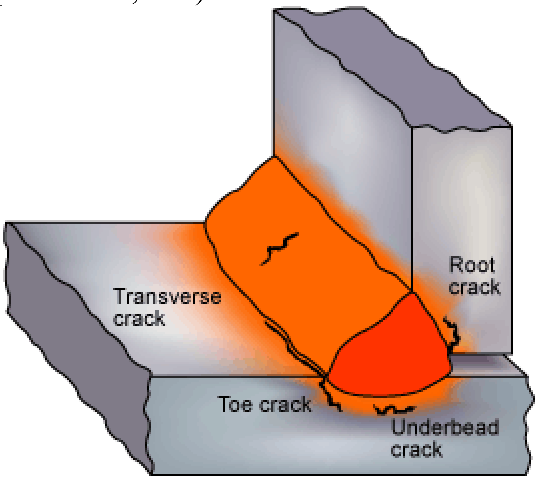

Figure 35: Presence of Hydrogen cracks in weld bead. (The welding institute 2010.)

The most common reason for cold cracking is the presence of existing defect sites in the material-small cracks or discontinuities caused by minor phase particles or inclusions. In the presence of existing stress, these sites may develop high local areas of biaxial or triaxial tensile stress. Hydrogen diffuses preferentially to these sites of dilated lattice structure. As the local hydrogen concentration increases, the cohesive energy and stress of the lattice decrease. When the cohesive stress falls below the local intensified stress level, fracture occurs spontaneously. Hydrogen then evolves in the crack volume, and the process is repeated. (Campbell 2010, 122.)

In steels, where the problem of hydrogen-induced cracking is significant, cracking susceptibility has been correlated both with material hardness and strength and with specific microstructure. Higher-strength steels are more susceptible to hydrogen-induced cracking than are low-strength steels. Steels that transform martensitically are particularly susceptible, especially the higher-carbon alloys with twinned martensitic structures. The desire to avoid martensite formation has driven the development of high strength structural steels for welded applications. Production of the newer high-strength low-alloy (HSLA) steels uses a variety of precisely controlled alloying additions (e.g., aluminium, titanium, vanadium, and niobium) along with meticulous thermomechanical processing to develop a very fine-grained ferrite microstructure possessing substantial strength and fracture toughness with a high degree of resistance to hydrogen induced cracking. (Campbell 2010, 122.)

An effective concept to understand the susceptibility of Carbon and alloy steels to carbon is the Carbon equivalent (CE)

$$CE=\%C+\frac{\%Mn}{6}+\frac{\%Cr+\%Mo+\%V}{5}+\frac{\%Si+\%Ni+\%Cu}{15} \quad (3)$$

Carbon equivalent is related to the development of hydrogen sensitive microstructures. As the CE increases, microstructures are evolved during cooling through the transformation temperature range that are increasingly more susceptible to hydrogen induced cracking. Martensitic structure are expected in high CE value. IF CE exceeds 0.35%, preheats are advisable to minimize hydrogen cracking. At elevated level of CE both preheats and post heat treatment may be required. (Campbell 2010, 122.)

9.4 Lamellar Tearing

Plastically deformed work piece is weaker in its thickness direction than in other directions (anisotropy).Because of shrinkage lamellar tears proceed in the direction of the surface. (Väisänen 2013.)

Lamellar tears are located adjacent to weld, generally outside HAZ area and parallel to the fusion boundary. Lamellar tearing is caused, when base metal is subject to tensile load in the z- direction of the rolled steel. Sometimes the tearing comes to the surface of the metal, but more frequently it remains under the weld and is detectable only by ultrasonic testing. (The welding institute 2010.)

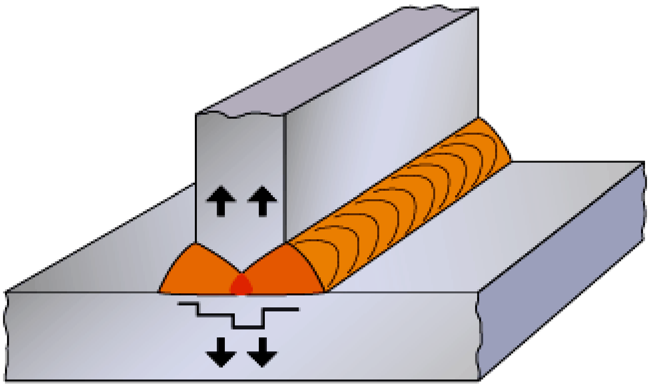

Figure 36: Lamellar tearing in T butt weld. (The welding institute 2010.)

Lamellar tearing occurs when three conditions are simultaneously present:

- Strains develop in the through-direction of the plate. They are caused weld metal shrinkage in the joint and can be increased by residual stresses and by loading.
- The weld orientation is such that the stress acts through the joint across the plate thickness (the z-direction). The fusion line beneath the weld is roughly parallel to the lamellar separation.
- The material has poor ductility in the z-direction (Campbell 2010, 124.)

This problem can be avoided by designing the joint properly. A Lamellar tearing are more likely to appear in T-joints and double fillet welds due to lack of full penetration weld. (Campbell 2010, 124.)

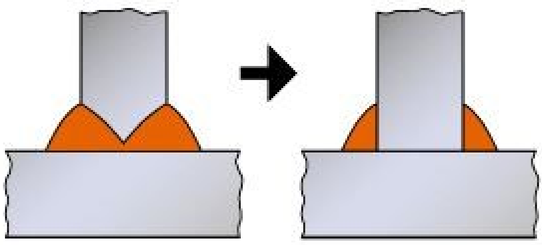

Figure 37: Two fillet weld for T -joint. (The welding institute 2010.)

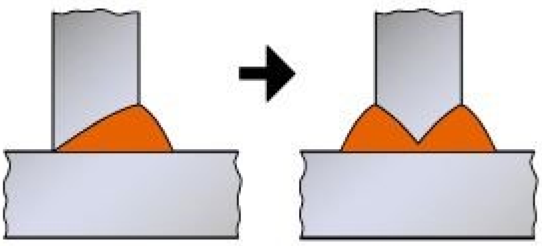

Figure 38: Double-sided welds are less susceptible than large single-sided welds. (The welding institute 2010.)

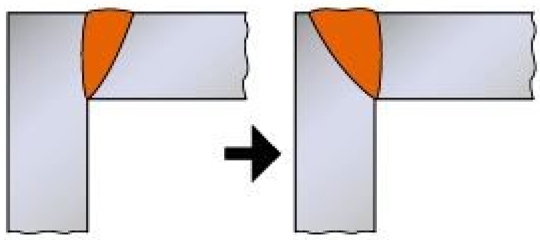

Figure 39: the fusion boundary is more normal to the susceptible plate surface will be particularly effective in reducing the risk. (The welding institute 2010.)

10 Characterization of Welds

The goal of any weld is to create a structure that can meet all the demands of its service environment. In many cases, the best way to assess the performance of a weld is to establish its mechanical properties. In addition to a number of standard material tests, many mechanical tests are directed specifically at determining a weld's capabilities. Mechanical properties typically characterized for welds include yield and tensile strength, ductility, hardness, and impact or fracture toughness. Corrosion testing is often regarded in situations where a welding operation is performed on a corrosion-resistant material or in a structure exposed to a hostile environment. Although absolute corrosion performance is important. A major concern is to ensure that a weld and its heat-affected zone (HAZ) are catholic to the surrounding metal. (Campbell 2010, 131.)

Assessment and characterization of welds may be non-destructive or destructive. Non-destructive techniques incorporate visual, liquid penetrant, magnetic particle, radiographic, and ultrasonic methods. Destructive procedures require the removal of specimens from the weld. The first destructive procedure is microstructural characterization of a segmented weld, including features such as number of passes, weld bead size, shape, and homogeneity; and the orientation of beads in a multipass weld.(Campbell 2010,131.)

10.1 Visual Inspection

A few variables are associated with the quality and performance of the welds are microscopic and naturally visible. The most evident of these are the size, shape, and general appearance of the weld. To a substantial degree, these parameters rely on upon the geometry of the weld joint and the welding process chosen. Various general contemplations apply to most types of welds: (Campbell 2010, 131.)

Size: The measure of the weld ought to be suitable for the part. For instance, a general run for filet welds is that the proportion of leg size to plate thickness ought to be between 3 to 4 and 1 to 1. (Campbell 2010, 131.)

• ***Location:*** An incorrectly found butt weld may not permit the part to function properly. A less extreme illustration is a filet weld with uneven leg lengths, prompting to an uneven stress conveyance and maybe laminar tearing. (Campbell 2010, 131.)

• ***Uniformity:*** Distortion, the likelihood of slag entrapment on multipass welds and consistency of load-conveying capacity all rely upon the relative consistency of the weld. (Campbell 2010, 131.)
• ***Defects:*** Ideally, a weld ought to be free of naturally visible imperfections. Common visual defects incorporate undercutting, lack of fusion, pinhole porosity, also slag capture. (Campbell 2010, 131.)

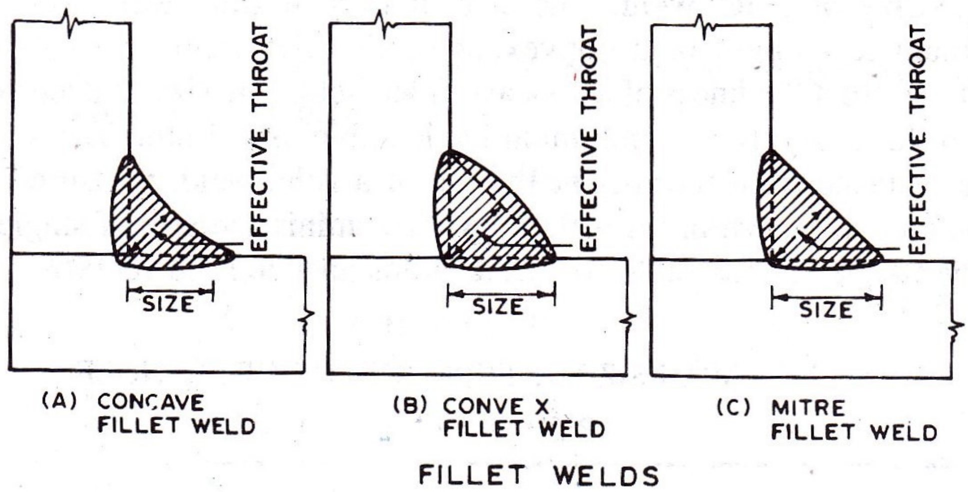

Figure 40: Fillet weld size for checking (Indian council of agricultural research 2013)

• ***Face shape:*** A weld ought to have a relatively flat face. In the event that the weld is too convex, stress will be thought along the toe of the weld. Conversely, a high curved weld face will bring about locally high stresses in the throat region of the weld. (Campbell 2010, 131.)

10.2 Non-Destructive Methods

The most widely recognized of non-destructive methods utilized as assess welds are fluid penetrant inspection, magnetic particle inspection, radiography as well as ultrasonic inspection. The qualities of these non-destructive inspection techniques are given in the table. (Campbell 2010, 132.)

Liquid penetrant inspection includes the use of an indicator liquid that has a surface tension adequately low to be drawn into surface splits too little to be detected visually. The excess colour or fluorescent material is then expelled from the surface but it stays in and highlights the cracks when a developer is applied. (Campbell 2010, 132.)

Table 3: Guidelines for selecting non-destructive testing techniques. (Campbell 2010, 132.)

Technique	Equipment requirements	Defects detected	Advantages	Limitations	Comments
Liquid-penetrant or fluorescent-penetrant inspection	Fluorescent or visible penetration liquids and developers; ultraviolet light for fluorescent dyes	Defects open to the surface only; good for leak detection	Detects small surface imperfections; easy application; inexpensive; use on magnetic or nonmagnetic material	Time-consuming; not permanent	Used on root pass of highly critical pipe welds; indications may be misleading on poorly prepared surfaces
Magnetic particle inspection	Wet or dry iron particles, or fluorescent; special power source; ultraviolet light for fluorescent dyes	Surface and near-surface discontinuities: cracks, porosity, slag	Indicates discontinuities not visible to the naked eye: useful for checking edges before welding: no size limitations	For magnetic materials: surface roughness may distort magnetic field; not permanent	Test from two perpendicular directions to detect any indications parallel to one set of magnetic lines
Radiographic inspection	Equipment for x-ray or γ-ray; film processing and viewing	Most internal discontinuities and flaws; limited by direction of discontinuity	Provides permanent record of surface and internal flaws; applicable to any alloy	Usually not suitable for fillet weld inspection; film exposure and processing critical; slow and expensive	Popular technique for subsurface inspection
Ultrasonic inspection	Ultrasonic units and probes; reference patterns	Can locate all internal flaws located by other methods, as well as small flaws	Extremely sensitive: complex weldments restrict usage: can be used on all materials	Highly skilled interpretor required; not permanent	Required by some specifications and codes

Magnetic particle inspection is a technique for finding surface and subsurface discontinuities in ferromagnetic materials. It relies upon the way that when the material or part under test is magnetized, magnetic discontinuities that lie in a generally transverse to the direction of the magnetic field will cause a leakage field to be formed at and above the surface of the part. The presence of this leakage field and therefore the presence of the discontinuity, is identified by the utilization of finely isolated ferromagnetic particles applied over the surface, with some of the particles being gathered and held by the leakage field. This magnetically held gathering of particles structures a diagram of the discontinuity and generally indicates its area, size, shape, and extent. Magnetic particles are connected over a surface either as dry particles, or as wet particles in a liquid carrier such as water or oil. (Campbell 2010, 132.)

Radiography is utilized to detect internal imperfections, for example, porosity or inclusions. These defects show up because of the difference in x-beam absorption between the matrix and defect materials. In spite of the fact that various variables influence the determination level of radiographic techniques, the minimum size of defects considered in American welding Society (AWS) specification is 0.4 mm (0.0156 in) .In practice this refers to slag entrapment and large inclusion that were present in the starting material. Defect structures are generally measured by comparison with an existing standard, a few of which exist (Campbell 2010, 132.)

10.3 Micro Structural Characterization

Weld microstructures are inspected using standard example removal and preparation techniques, with a few concessions made for their inhomogeneous nature. Additionally, the parameters used to describe the weld microstructures such as grain size, grain morphology, and the amount of the different stages or

micro constituents present, are the same as those used to characterize monolithic materials.
Readily apparent features incorporate the quantity of passes and number of layers, fusion zone area, weld aspect ratio, extent of penetration, face width, and the reinforcement and curvature of the top bead. A transverse section will also demonstrate any gross porosity or substantial inclusions present in a weld and the extent of the HAZ. (Campbell 2010, 134.)

One regular utilization of hardness values in weld specification is as a check for the formation of microstructures that may have low ductility and toughness and thus are prone to cracking. (Campbell 2010, 134.)

10.4 Mechanical Testing

Various mechanical properties are utilized to characterize welds, including strength, ductility, hardness and toughness. In general, the examples and techniques are the same as those used in other areas of metallurgy. However, a prominent concern in regards to the mechanical performance of welds is the direct comparison with the base material. The objective is to guarantee that the weld is not the weakest component of a structure or, if it is, to compensate for this in the design. (Campbell 2010, 134.)

Yield and tensile strength are measured for all-weld-metal examples utilizing a standard tensile test yet with specimens removed from test plates welded according to AWS specification. These tests form the basis for the assignment of yield and extreme quality qualities to welds made utilizing a particular cathode and as indicated by a set methodology. Extra tests are sometimes performed here and there to compare the base metal and weld metal strengths. (Campbell 2010, 134.)

Ductility is another critical weld property. In addition to defects, many welding procedures can deliver hard, brittle microstructures. The standard measures of ductility percent decrease and increase in an area are obtained in a uniaxial tensile test. Another test often specified for welds is a bend test (face bend, root bend, and side bends). In this test, a portion of material containing a weld is deformed around a specified radius and its surface is inspected. The criteria for success or failure are the number and size of defects seen on the external surface of the curve. (Campbell 2010, 135.)

Toughness is the ability of a material to absorb energy during crack. Impact testing is the most pervasive method used to assess weld toughness. To test impact toughness, a sample of specified geometry is subjected to an impact load, and the amount of energy absorbed during fracture is recorded. Usually the specimen is oriented so that the notch and expected plane of fracture run longitudinally through the weld metal. Charpy test do not measure an inherent material property, but they result in a relative measure of impact toughness between materials. A very common use of the Charpy test is to determine a material's ductile-to-brittle transition temperature by performing tests at several different temperatures. (Campbell 2010, 135.)

11 Calculation of Weld Volume and Weight

Deciding the volume of a weld requires some information of fundamental geometrical computations to decide the area of the weld and multiply this figure by its length. With this information, deposition rate of the process, it is possible to determine the time arc is burning and depositing weld metal as well as welding consumables required to fill the joint. These are required to calculate the cost of the weld. (Mathers n.d.).

The initial step is to calculate the cross sectional area of the joint. The computation of fillet weld or a 45°single bevel is relatively simple but the calculations become lengthier as the weld preparation becomes more complex. Fig 41 illustrates simple calculation for an equal length fillet weld; the area of such a weld is half the square of the leg length, Z. It is necessary to keep in mind that welders seldom deposit precisely the size of the weld marked on the drawing or in the welding procedure and that there may be some excess weld metal on the face of the weld.(Mathers, n.d).

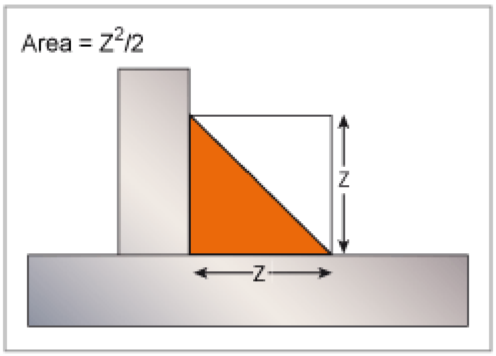

Figure 41: Area of an equal leg length fillet weld. (Mathers n.d.).

The calculation of an asymmetrical fillet weld is a little more difficult. The area of a triangle is given by the base Z_2 times the height Z_1divided by 2 so when a fillet weld is deposited with unequal leg lengths the area can be calculated from multiplying the throat, a, by the length of the face I and divided by 2 as illustrated in Fig.42.(Mathers n.d.).

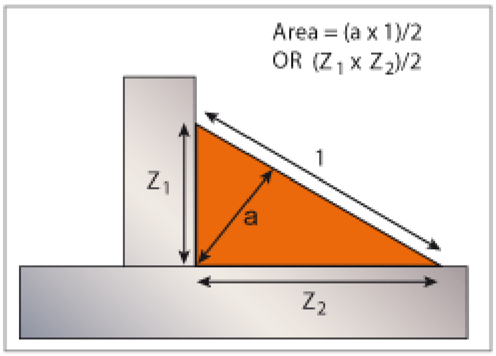

Figure 42: Area of an unequal leg length fillet. (Mathersn.d.).

The three factors determines the volume of the single V butt weld are angle of the bevel, the excess weld metal and the root gap, g .The dimension c is given by (tan b x t); the area of a single red triangle is therefore t(tan b x t)/2. The total area of the two red regions added together can be calculated using the formula 2t (tan b x t)/2 or t (tan b x t) as shown in fig 43.(Mathers n.d.).

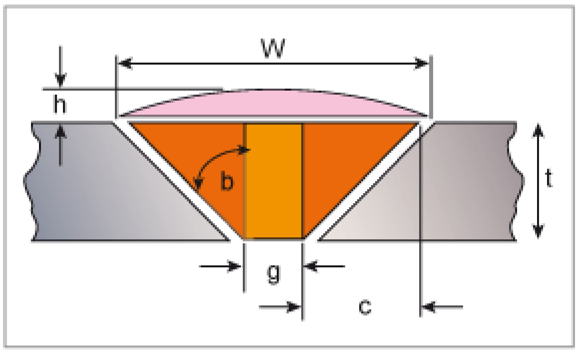

Figure 43: The four area of a single v butt weld.(Mathersn.d.)..

The width of the weld cap, w, is given by W = 2(tan b x t) + g. The area of the excess weld metal is approximated by the formula (W x h)/2.The area provided by the root gap by g x t. (Mathers n.d.).

The bevel angles, b, most often used are 10° = (tan 0.176), 15° = (tan 0.268), 22.5° = (tan 0.414) 32.5° = (tan 0.637) and 45° = (tan 1.00). As will become obvious when the weight is calculated, it is easier to ensure that the decimal point is in the right place if centimetres are used in the calculations rather than millimetres. (Mathers n.d.).

The weight of the weld metal is obtained by multiplying the cross sectional area by the density of the alloy. With some alloys alloying elements can change the density significantly.

Table 4: Densities of some of the more common alloys. (Mathers n.d.).

Alloy	Density (gm/cm^3)
Iron	7.87
0.25% Carbon steel	7.86
12%Cr Steel	7.70
304 Stainless steel	7.92
Nickel	8.90
80/20 Ni.Cr	8.40
Copper	8.94
70/30 Brass	8.53
7% Al,bronze	7.89
Aluminium	2.70
Al 5052	2.65
Al 7075	2.8

A J-preparation adds another area into the equation; that of the half circle at the root of the weld. The formula to calculate c, the area if the two red components and the excess weld metal remain unchanged but the width of the cap must be increased by 2r. There are also the two areas, A and B, to calculate and the two white root radius areas to be added to the total as shown in the fig 44. (Mathers,n.d.).

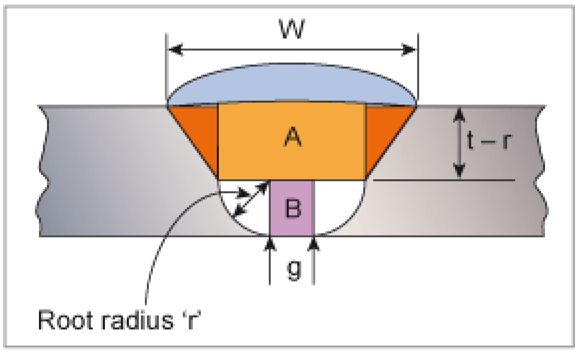

Figure 44: Single U preparation. (Mathers n.d.).

The steps for calculating a J-preparation are thus:

1. The dimension 'c' is given by (tan b x (t-r)); the total area of the two red regions is therefore given by the formula 2((t-r)(tan b x (t-r))/2 or ((t.-r)(tan b x (t-r)).
2. The width of the weld cap, w, is given by w = 2(tan b x (t-r)) + g +2r.
3. The area of the excess weld metal is given by the formula (w x h)/2.
4. The area 'A' is (t-r) x (2r +g).
5. The area 'B' is g x r.
6. The root radius area is (πr^2)/4. (Mathers n.d.).

12 Welding Fixtures

Fixture is a work holding device that holds, supports and locates the workpiece for a specific operation. The main purpose of a fixture is to locate and in some cases hold a work piece during manufacturing process. A jig differs from a fixture in that it guides the tool to its correct position in addition to locating and supporting the work piece.

Fixtures needs to be designed to facilitate the production of articles in large quantities with high degree of accuracy, uniform quality, and interchange ability at a competitive cost. The special characteristics particularly suited to the robotic welding application such as the critical speed of maintain accuracy and part repeatability in an environment exposed to elevated heat and weld spatter.

There are few aspects to keep in mind while designing a fixture

Versatility: It has to adaptive to different multiple welds without the need for multiple setups. The design need to be suitable for different joint types and joining processes. Design will have enough degree of freedom to complete all weld operation.

Productivity: It should be able to process, load, unload and clamp as quickly as possible. Interference with welding process as less as possible. It has to be designed to be effective than previous model. The clamping has to be suitable to reduce distortion.

Cost Efficiency: One of the main aspects of design is to keep the cost as low as possible while ensuring necessary operation requirement is fulfilled. Material cost, operational and maintenance cost need to be considered in designing phase. The higher production rate, scrap reduction and less setup time will ensure to keep unit price at minimal

Material Properties: Generally, the robotic welding are more productive than manual or semiautomatic welding. The level of efficiency depends upon the thoughtful design of the fixture for optimal productivity. The welding can be inefficient and cost prohibitive when simple design considerations are overlooked. The selection of fixture material depends upon the welding applications and processes.

Table 5: Material and Thermal properties. (Lincoln electric n.d.)

	Mild Steel	Tool Steel	Aluminum 6061	Stainless Steel	Copper / Copper Alloys
Material Cost	Low	Medium	Medium	High	High
Wear Resistance	Medium	High	Low	Medium	Low/ High
Electrical Conductivity	Low	Low	Medium	Low	High
Thermal Conductivity	Low	Low	High	Low	High
Thermal Expansion	Low	Low	High	Medium	Medium

The square or rectangular structural steel tubing is used for the frame work to reduce the initial cost. Mild steel, high-carbon steel, aluminum, stainless steel and copper are used generally for designing of fixture. Alloys of the common base materials are available to improve work hardening, and wear resistance properties. Each material has different characteristics that can impact productivity and quality. (Lincoln electric n.d)

From a wear resistance standpoint, fixture hard stops and locating points are often made of alloyed high-carbon tool steel in an effort to resist deformation. Aluminum-bronze alloy, work hardens and is not as prone to residual magnetism when compared to steel. (Lincoln electric n.d.)

Distortion potential by material type

Lowest	Low-carbon steel
↓	High-strength steel
	Nickel-based alloys
	Nickel-copper alloys
	Copper alloys
	Stainless steel
Highest	Aluminum

Figure 45: Distortion potential based on material type. (Nee 2010, 324)

Thermal Properties: Thermal conductivity refer to ability of materials to conduct heat. Copper and aluminum are often used as heat sinks to conduct heat away from work piece and spread the heat over a large surface area to minimize work piece distortion.
A fraction change in length and volume in elevated temperature has significant impact on work piece dimensional accuracy in welding operation. (Lincoln electric n.d.)

Select low-heat input process

Heat Input	Process
High	Gas tungsten-arc welding
↓	Shielded metal-arc welding
	Gas metal-arc welding
	Flux-cored arc welding
	Submerged-arc welding
Low	Laser

Figure 46: Degree of heat input based on process (Nee 2010, 323)

Electrical Conductivity: The Electric circuit is the main driving force in the welding operation. It can easily interfere with productivity, weld quality and equipment service life. Electrical conductivity depends on material conductivity or resistance to allow free flow of current to the circuit. (Bernard, n.d.)

Copper, aluminum and other metals are used in welding equipment because they provide a good balance between cost and conductivity. The copper allows the electric current to flow smoothly. Although, there is the little amount of resistance inherent in the properties of the material, but it is not enough to interfere with the welding operation. Excessive resistance in the circuit, can cause weld defects, reduce productivity and lead to premature equipment failure. (Bernard, n.d.)

If electrons are resisted to continue along the circuit, they convert energy to heat, which is absorbed by the surrounding. As a result, it causes metal components to expand and to contract while cooling, creating mechanical stress. The stress can lead to premature failure of the equipment.(Bernard, n.d.)

Better arranged welding waveforms are needed for optimizing welding circuit to maintain short arc length with less spatter, arc-flare, stubbing, and arc outages, all in an effort to maximize travel speeds. (Bernard,n.d.)

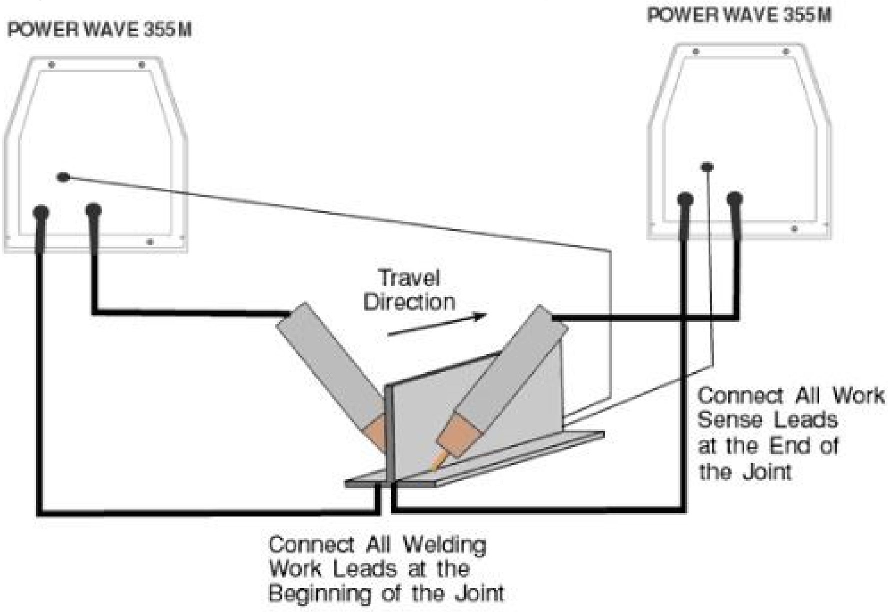

Figure 47: optimized welding circuit. (Lincoln electric n.d)

13 Fixture Design

13.1 Existing Fixture

The current fixture available in Hyria is not possible to fix on the table top. So it can be used as a support to work piece but cannot hold it in the precise position. In addition, it needs additional equipment to balance the parts to be welded together. That makes the fixture very inconvenient and time consuming.

Figure 48: Current fixture used in Hyria

Problems of the current fixtures are:

- It cannot be fixed in a certain position
- There are pieces of metals welded to the fixture
- The set up time for welding is too long and not precise enough
- The robot cannot be instructed to weld based on the pre-existing programme.
- It has to manually guided to the weld area before actual operation
- It is not versatile to make different joint or weld operation.
- The spatter could be scattered during the welding, it is not easy to clean the rough surface.
- Mechanism to attach the fixture to the table top and fixture to the work piece is not available.

13.2 Designing of Model Parts

The work envelope consists of a Motoman XRC robot and Kemppi MIG 3200 welding equipment. The idea of this thesis is to provide the basic understanding of a MIG robotic welding process to the students. The simple joint types and welding operations are considered so that it will be easy to follow the instruction from manual. In addition, it has been provided with sample of the robotic code to practice the robot joint movement and perform particular welding.

MIG welding, creates an arc between a continuously feed consumable electrode and the sheet metal work pieces. Shielding gasses are used to provide protection of both molten metal and arc from the atmosphere. MIG can be used for most metals and alloys. Most commonly weldable materials are carbon steels, low alloy steels, stainless steel and 3000, 5000, and 6000-series aluminum alloys; and magnesium alloys. Other combination of alloys can be MIG –welded through special techniques include 2000 and 7000 –series aluminum alloys, high-zinc copper alloys, and high-strength steels. (Lincoln electric n.d)

This thesis comprises of six joint types

- T –Joint
- Lap joint
- Butt joint
- Lap joint
- Edge joint
- Circular joint

The parts was chosen to show the ability of Motoman XRC to perform various weld operations. Fillet weld, groove weld were used for most part of the study. There is also introductory demonstration of spot welding. The design of the fixture will be discussed in the following section. As well as different joint set up and welding operation will be explained.

13.3 Model Design of Fixture

The final design is a product of the several different ideas and components originally created in the design phase. A better understanding of the best features to incorporate in the final design has been developed after the brainstorming and design formation phases were completed.
The focus of the design was to make it versatile, durable as well as adaptive to the different kind of welding operations. The fixture has to be easily manufacturable and capable of producing the precise joint. It has been designed to replace any broken part easily if needed. The design consists of Base layer, Clamp and Threaded rod.

The vertical plates will be welded to the base plate of 8 mm. The first vertical plate on the both sides are fixed, which work as a support for the second moving vertical plate. The moving vertical plates, can be adjusted through two threaded rods located on the each side. Tooling holes are located along the parts as a part of the design. There are separate holes to position the fixture to the work table as well as to attach the work piece to the precise location. The clamp is also designed to hold the work piece in accurately and easily removable if not needed. There is small gliding mechanism to hold the work piece vertically at various angular positions.

The importance of these features is the cost effectiveness and quality effect they have on the completed item. This is especially true for smaller, close tolerance assemblies. Although the fixture has been designed for MIG welding robot, it can be used in other machining operations, manual and robotic welding such as laser welding, spot welding where parts are needed to be in the precise location.

This design concept takes into consideration the work piece to be mounted in one focal area which guarantees precision and accuracy for the different setups.

Once the work piece is cinched safely, the whole worktable essentially moves to the right area relying upon the welding job. This features permits a few elements to be welded with just a single setup as the worktable can be consequently balanced. It requires less physical work for the operator as the fixture is not bulky and parts are removable.

13.4 Components of the Fixture

The design has focused on simplicity while making it functional. In addition, ease of usage for operator and precision welding has been focused. The design of different parts are explained below

a. Base layer: The base plate has a thickness of approximately 8mm. There are two plates at the both ends of the base. The base plate can be fixed in the desired position on the table top with the screws. Moreover, there are threaded holes for clamp along the plate.

b. Fixed Plate: The plates on the both side are welded. There is a hole on the plate to guide the threaded rod which can be used to move the second plate.

c. Moving plate: The plate can move in the both direction. These plates are controlled by the rod welded to the plate. The distance of the plate movement depends on the length of the threaded rod. Threaded holes are positioned on the plate to clamp work piece in vertical position.

d. Threaded rod: The rod is welded on the second plate, which goes through a threaded hole on the first plate. The rod can be locked into the desired position by a nut. So that the accuracy of the welding operation will be not be compromised.

e. Vertical clamp: The simple clamp with jaw has been designed to hold the work article in 360 positions, where jaws can be adjusted to keep the work in the precise position. The clamp is attachable on the moving plate.

f. Spatter shield: Most of the common causes of spatter are amperage, voltage, and electrical short circuit. Due to the uncontrolled welding operation, spattering can reduce the lifetime of fixture or impact quality greatly. Two spatter shield has been designed to put underneath the work piece which can be removed if damaged. In this way, fixture remains in good condition as well as making it economic and convenient.

13.5 Clamping for Joints

13.5.1 Butt Joint

The work pieces could be fixed by moving the side plates in desired location. Threaded rods will lock the plates in the right place. There is enough space

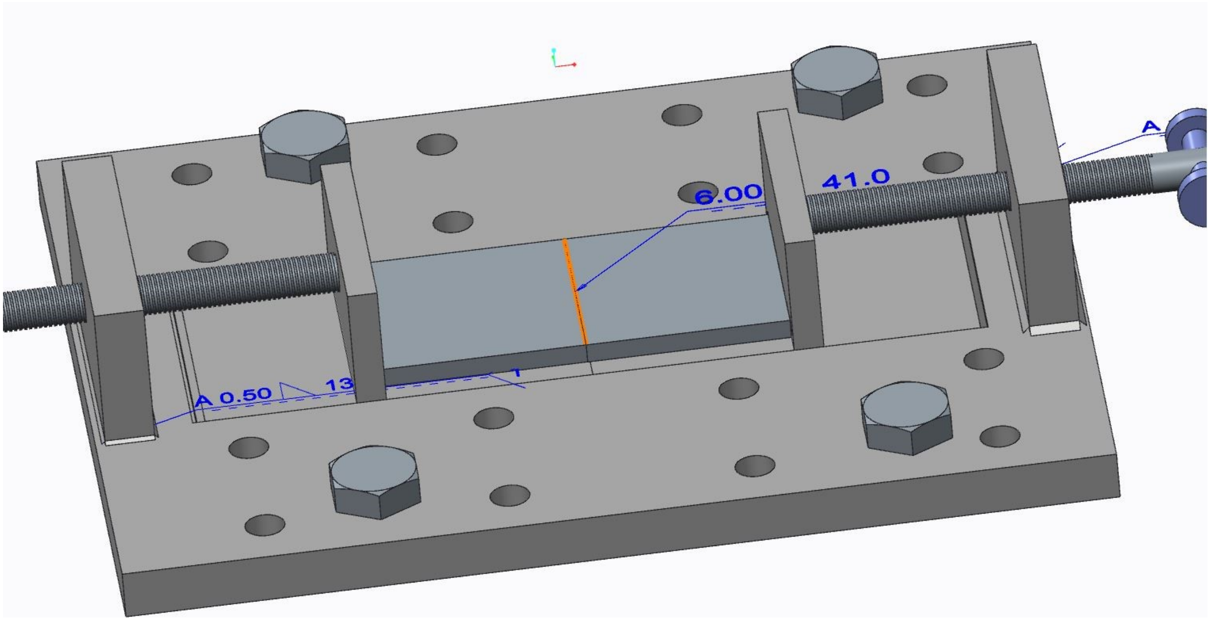

Figure 49: Fixturing for a welding of butt joint on both sides to move the robot freely.

13.5.2 T- Joint

The horizontal plate could be fixed by moving the adjustable plate of the fixture. This position is lockable as like as Butt joint setup. The Vertical work pieces are being held up by the vertical clamp. The vertical clamp is adjustable on the base of the place to make T –joint. This setup gives the freedom to choose any side as welding face for the robot.

The setup postion for corner joint and T –joint is quite identical . As corner joint can be also called as T –joint.

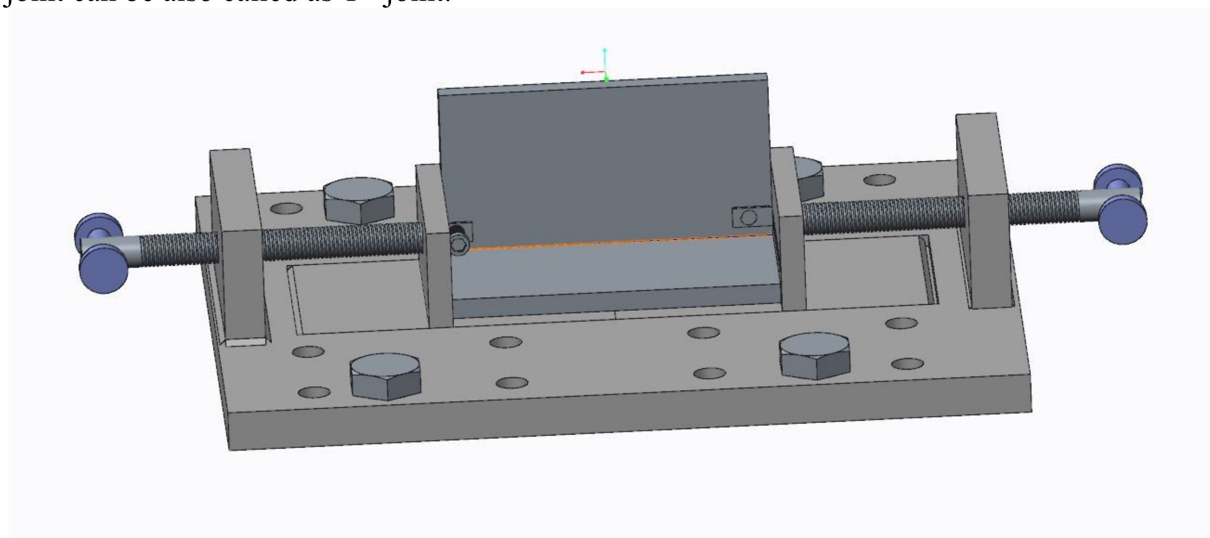

Figure 50: Fixture setup for welding of T –joint in in the corner.

This fixing position is also good for welding of heavier section on the both sides to achieve good penetration.

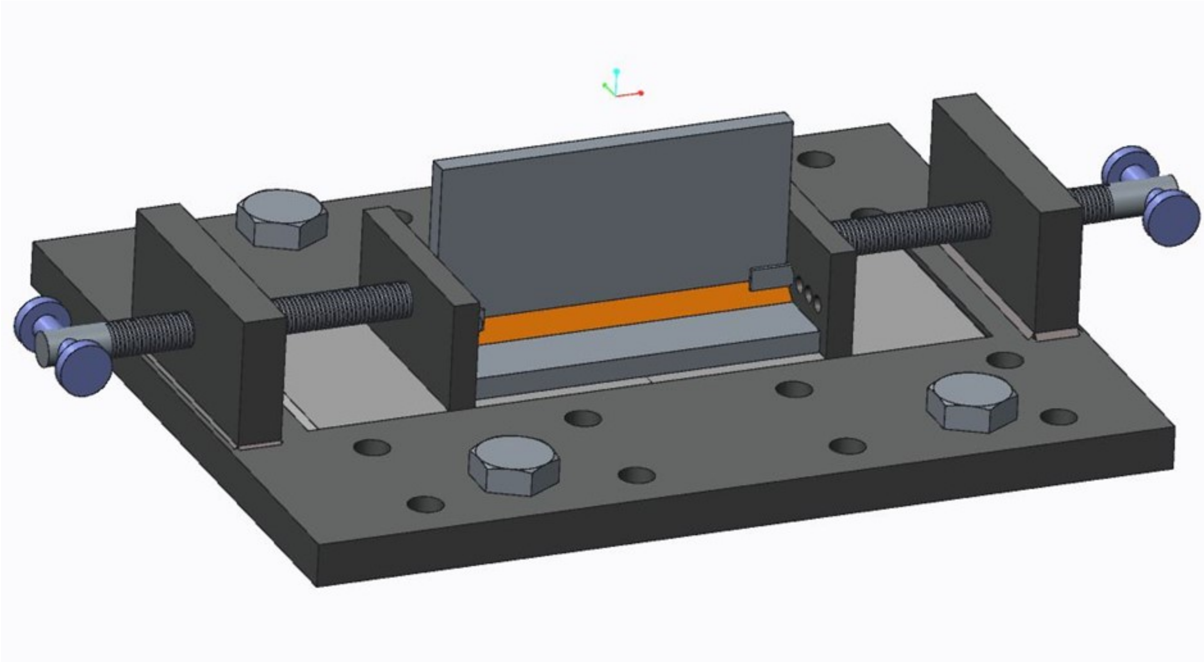

Figure 51: Set up for a T- joint in various positions

13.5.3 Lap Joint

In lap joint base metal overlaps each other as name implies. The weld could be made in one side or both side. An offset lap joint can be done in the natural seem made by the offset. It is normally stronger than a single lap weld.

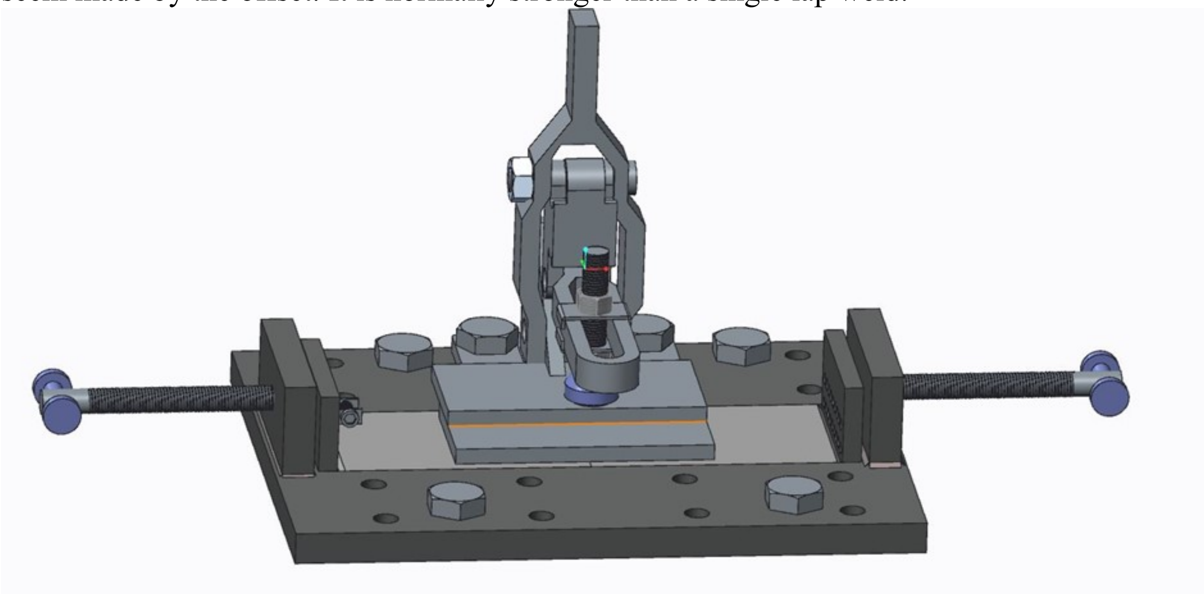

Figure 52: Setup for single or offset lap joint

For a single or an offset joint, the bottom and top parts can be fixed in an exact position with a clamp from either side. Another option would be fixing the bottom part with a moving jaw and the top part with a clamp.

An offset lap joint requires a combination of moving jaws and a clamp. In addition, a plate is needed to support the bottom part.

14 Benefits and Limitations of the Design

Although the proposed design is a definitive improvement to the existing model, it has some drawbacks that need to be work on.

A. Advantages

- It is adjustable and can be used for different types of joints.
- The Parts are easily replaceable
- The Work setup time is minimized.
- The fixture can be used for long term
- Good production rate
- Serial welding is possible
- It provides flexibility while maintaining dimension control
- Light weight design

B. Disadvantages

- The design requires machining, it cannot be built directly from available parts
- Multi axes welding is not possible
- Complex work pieces cannot be easily welded.

15 Design of Clamp

A clamp can come in handy in different welding operations such as butt joints and lap joints. Increasing pressure with minimal cost has increased the need for a shorter set up time. Generally, the setting up time is related to the productivity in welding or other machining operations. The ability to locate the work precisely is decisive to the quality of the output. Secure clamping and exact positioning used in traditional clamping systems contradict the use of fast and efficient clamping.

The clamp can be fixed with screws to the main fixture. It works with basic principle of pressing on one side to generate force on the other .Normally; clamps are used in simple butt joints. With the t joint, corner joint, lap joint, and edge joint as well as the circular joint, the operation can be done as a combination with the jaws of the main fixture.

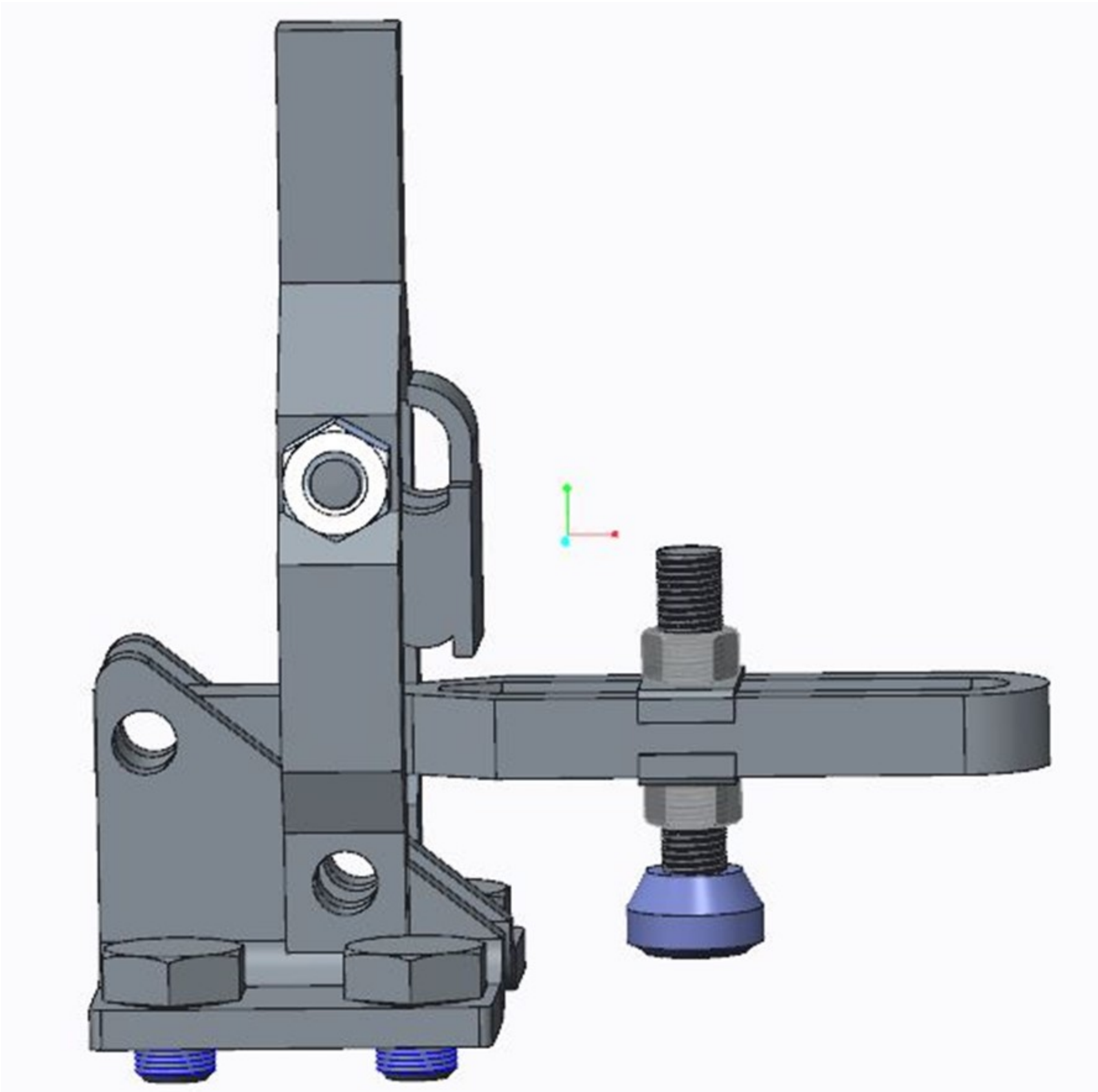

Figure 53: Proposed 3D design of C-clamp

The design of welding clamps depends on the welding processes and applications. A clamp can be locked in a place or movable. Fast release clamps are used if a large volume of tasks has to be done with a quick release. The most commonly used clamps are C-clamps, and W shaped clamps. To choose the right clamp a few things needs to be considered:

- The very high temperatures and forces during welding can cause deformation and distortion of the work piece. The clamping forces has to be able to keep the work piece in precise position.
- The clamp should be easy to use with minimal set up or removal time
- Slide surfaces and screw must threads must be avoided while adding other elements as the spatter will damage and restrict the movement of these elements

- The welding torch need to be moved freely, otherwise, there will be error in the process
- The clamp has to be adjustable to different work pieces as well as welding process
- The material has to be chosen to withstand elevated temperature.

The proposed model is a modified C-clamp. It has a very rigid structure of two 6mm thin plate, which could be attached to the table top or main structure. The vertical movable glider has a j –shape little glider to restrict the movement of vertical arm. This can be useful if similar works are done in bulk amount and needed to be removed quickly. The actual holding arm is a U-shape with blank space inside to slide the clamp screw based on the work type. Thework piece holding stud nut can be fixed in desired position and height with the help of two plate locking it in precise point. The vertical movement of the clamp glider can be controlled by simply moving it with hand vertically.

15.1 Work Table Top Plate

The present round plate is bolted onto the base with three screws which restricts a free movement of the fixture. Moreover, it contains unwanted protrusion on the top. There are some parts welded to the plate either unintentionally or because of faulty welding operations. The design of the plate does not allow for fixing any kind of support or clamping devices to the weld application.

Figure 54: Table top used at Hyria

15.2 Recommended New Design

It is recommended in this thesis that the table top is connected through a screw to the middle of the plate with a translator. The main fixture is bolted on the top of the plate using four bolts. As the table rotates, it can be fixed to the face needed to make weld operations. More threaded holes are also possible to make on the top plate if it is needed to modify the fixture later. These holes can also be used to fix clamping devices while performing simple welding operation where fixture is not needed. This way, a complete new design is not needed if changes in the fixture need to be made.

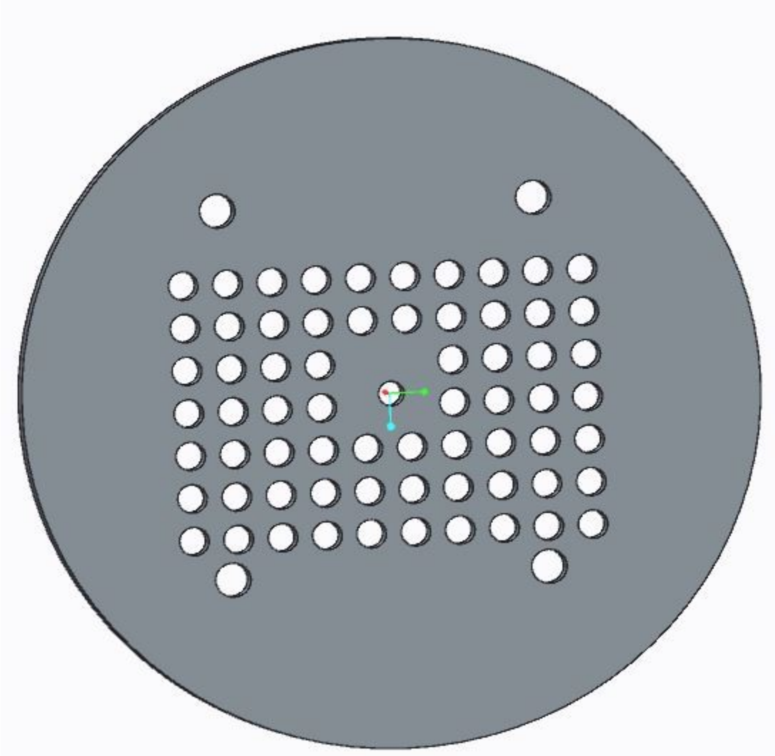

Figure 55: Design of new top plate for working table

16 Description of Equipment

16.1 Motoman XRC

Now a days robots are preferable to human for various reason such as their ability to work seamlessly without any breaks. They bring incredible precision, productivity and flexibility. Moreover, they are capable of working synchronically with humans to further increase flexibility and efficiency.

Motoman XRC is a versatile product released from Yaskawa industry in 1998.It can control up to 27 axes. It is synchronizable to three other robot, it has a programming capacity of 5,000pos and 3,000 instructions. It can handle up to 40 input and 40 output signals. (Yaskawa group, n.d.)

The XRC control system has a Windows oriented interface with directories and folders. There are software for job editing, file transfer or offline programming and simulation. Some exciting features introduced with XRC are Form Cutting (used in laser-, plasma or water cutting), shock sensor functions and the ability to have acceleration/retardation in any point. (Yaskawa group, n.d.)

The technical specifications of the robots are as follows:

Controller	
Configuration	Free-standing, Enclosed type
Dimensions	800(W)x900(H)x650(D) mm
Weight	Approx. 170 kg
Cooling system	Indirect cooling
Ambient temperature	During operation 0° to +45° During transport -10° to +60°
Relative humidity	Max. 90% (non-condensing)
Power supply	3 x 400/415/440V AC, 50/60 Hz
Grounding	Less than 100 ohm
Digital I/O	General signals (standard) 40 inputs and 40 outputs of which 24 inputs and 24 outputs are free 4 direct inputs
Communication	RS-232C and PC-card
Positioning system	Absolute encoder / Serial interface
Drive units	Servopacks for AC servo motor
Accel / Decel	Software servo control
Programming capacity (standard)	5.000 steps and 3.000 instructions 1.500 ladder steps

Safety features	
Personal safety	3-position "dead-man´s handle" Low speed in teaching mode
Teach Lock Mode	Prohibits operation from operator´s panel
Collision proof frames	Doughnut-sector frame, cubic frame
Machine lock	Test-run peripherial device without robot motion
Self-diagnosis	Alarm and error messages displayed together with explanation
User Alarm display	Possible to display alarm messages for peripheral devices

Operator´s panel	
Buttons provided	Mode, Start, Hold, Emergency stop Servo power ON

Programming pendant	
Material	Reinforced thermoplastic enclosure
Dimensions Weight	200(W)x322(H)x65(D) mm 1.2 kg
Display	5.7 inch, 40 characters x 12 lines
Safety feature	3-position "dead-man´s handle"
Interface	RS-232C

Programming functions	
Coordinate system	Joint, rectangular/cylindrical, tool, user coordinates
Robot Motion Control	Joint coordinates, linear/circular, interpolation, tool coordinates
Speed setting	Percentage for joint coordinates, 0.1 mm/s units for interpolations, angular velocity for T.C.P. fixed motion
Program Control Instructions	Jump, call, timer, robot stop, execution of some instructions during robot motion
Modification of teaching point	Adding, deleting, correcting (robot axes and/or external axes)
Position control	Manually forwards and backwards in the job (even circular)
Speed adjustment	Fine adjustment possible
I/O-function	Discrete I/O control, pattern I/O processing
Programming	Interactive programming
Language	Robot language: INFORM II
Display text	English, Swedish, French, Spanish, Italian, Finnish, German
Tool Centre Point	Max. 24 and up to 24 external TCP´s
TCP-calibration	Automatically calibrates parameters for end effectors using master jig

Maintenance functions	
Software time usage meters	Control power-ON time, servo power-ON time, playback time, work time and operation time displayed
Alarm display	Alarm messages and previous alarm records
I/O-diagnosis	Simulated enable/disabled output possible

Options	
Digital I/O	I/O-boards, total max. 256/256 MIO02: 32 inputs and outputs MIO03: 16 inputs and outputs XO102: 40 inputs and outputs
Analogue output	12 channel (MEW/XEW-board)
Memory expansion (up to...)	Max 60.000 points for 6 axes and 20.000 instructions
	3.000 ladder steps
External axis Enclosure classification	Total max. 27 axes IP54, by add on kit

Fig 28: Technical specification of Motoman XRC robot. (Yaskawa group, n.d.)

This figure 28 specifies the Robot's axes, programming control, PC synchronization, safety features, input and output signals, servo motors, operator's panel, maintenance function as well as teach pendant. (Yaskawa group, n.d.)

16.2 Welding Appliances

Kemppi 3200 Mig is a compact device built for industrial application. It has superior arc performance with excellent arc ignition in all situation. It is very smooth to incorporate in an automated process. (Kemppi, 2004)

Power source: The supply voltage of the power source is about 3-230V/400V. The turn switches are used to adjust the voltage of power source up to 40 steps. The ampere meter is imbedded in the system to keep track of voltage or welding current. (Kemppi, 2004)

Figure 29: Kemppi MIG 3200 unit

Wire feeder unit: The feeder unit is four rolled driven unit, which is suitable for air or liquid cooled gas. The unit can be locked or turna ble. It is suitable to use with interconnection cable and push pull gun. The accessory unit KMW timer controls continuous, spot and cycle arc welding.

Figure 30: Filler wire spool

Shielding gas: To ensure weld quality, appearance and reducing post weld cleanup, a combination of 75% Argon and 25% CO_2 is used. This provide arc stability, puddle control and reduced spatter than pure CO_2. This mixture enables the use of spray arc transfer, which can productivity rates and more visually appealing weld. Narrow penetration profile can be achieved by the use of Argon, which is helpful for fillet and butt welds. (Kemppi, 2004)

Electrode: A mild steel tubular electrode is supplied to the welding process by a spool from the rear of the robot. The diameter of electrode is about 1.2 mm

16.3 Workstation

The robot, welding unit and work table are situated in a separate cage. The station is accessible through an automated safety door that does not allow the robot to start working unless the door is closed properly. The main power unit can be turned on from the workshop by the official when needed. The power is cut out when not in use. There are plenty of mechanical tools available in the workshop such as pliers, measuring tapes, scales, and wire cutters. Moreover, the metal pieces can be bent and cut in desired shapes at the bending table. The workshop is decorated with various types of mechanical forming units. Metal sheets of different thicknesses and sizes are available to the need of the welder.

17 Conclusions

The work will be shared between humans and robots in the near future. The automated welding process is becoming alluring for job shops and manufacturers in light of the fact that, the accomplished welders can supervise the outcome more than one mechanical welder at any moment. The Motoman XRC welding robot is a highly effective learning tool to understand the usage of robotics in production processes. One of the benefits of Motoman is that it enables to program and control tasks of a single robot or to coordinate robots. The understanding and hand in approach with Motoman XRC give fundamental knowledge of the welding method, planning for the automated cycle, weld quality, and filler material. It also provides information on mishandled welding processes and ways of ensuring quality joints. This study could serve as a guideline for the students for further studies and employment.

The final design of the fixture will facilitate producing different welding joints seamlessly, repeatedly and accurately. The design satisfies all of the functional requirements and design parameters. The development of this system implanted a realization of the continuous progression cycle in the research and development process. The clamping system can easily be customized according to future needs.

In spite of initial challenges such as proper background information, faulty fixtures, insufficient resources and the long commute from school, the objectives of this thesis project were met. The dedicated approach to study of robot programming languages, careful observations, practical thinking and logical analysis of ideas helped the author to overcome all the adversities. This study could be used as lesson teaching materials, project practical training manual as well as robot programming guide at Hyria.

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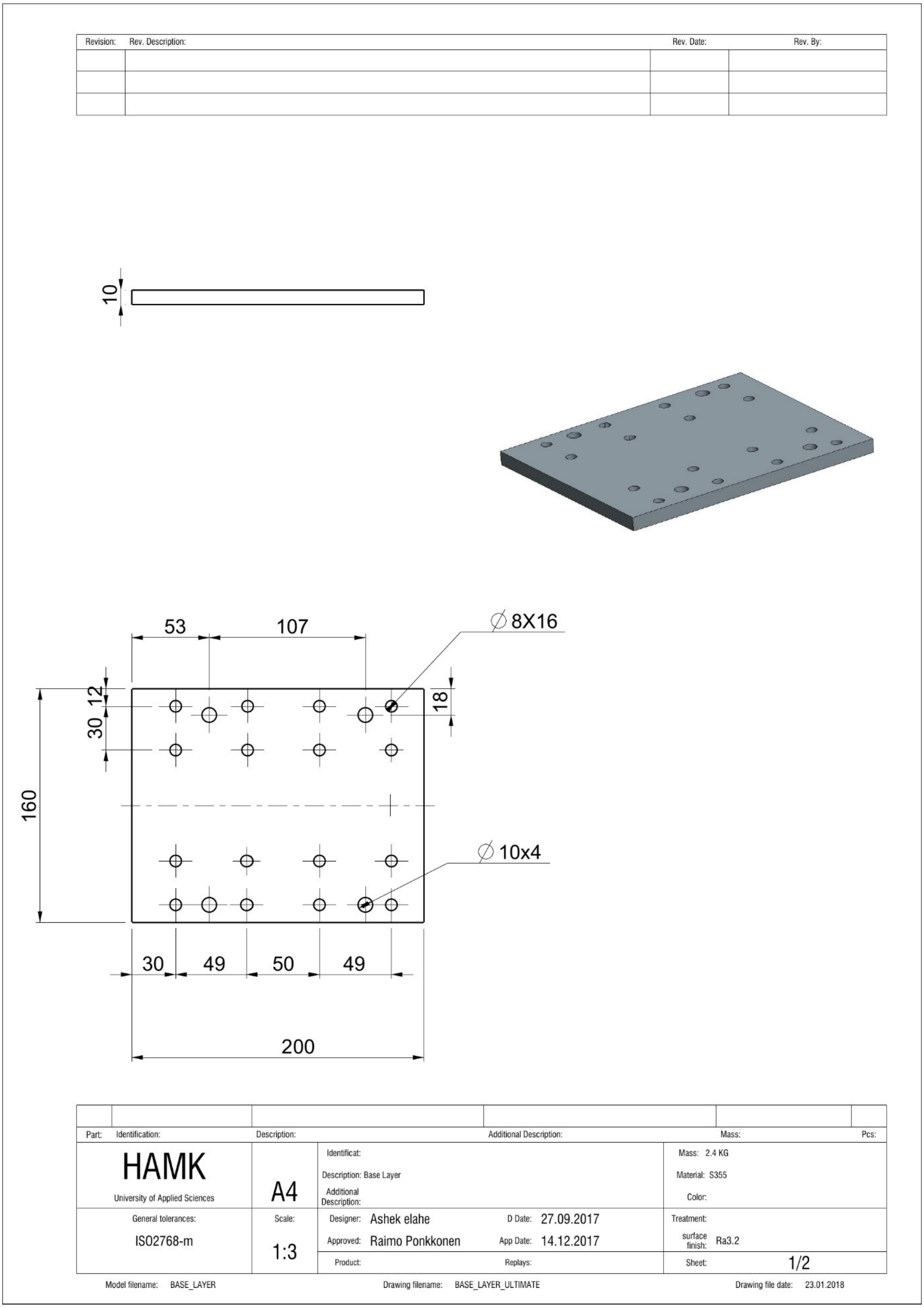
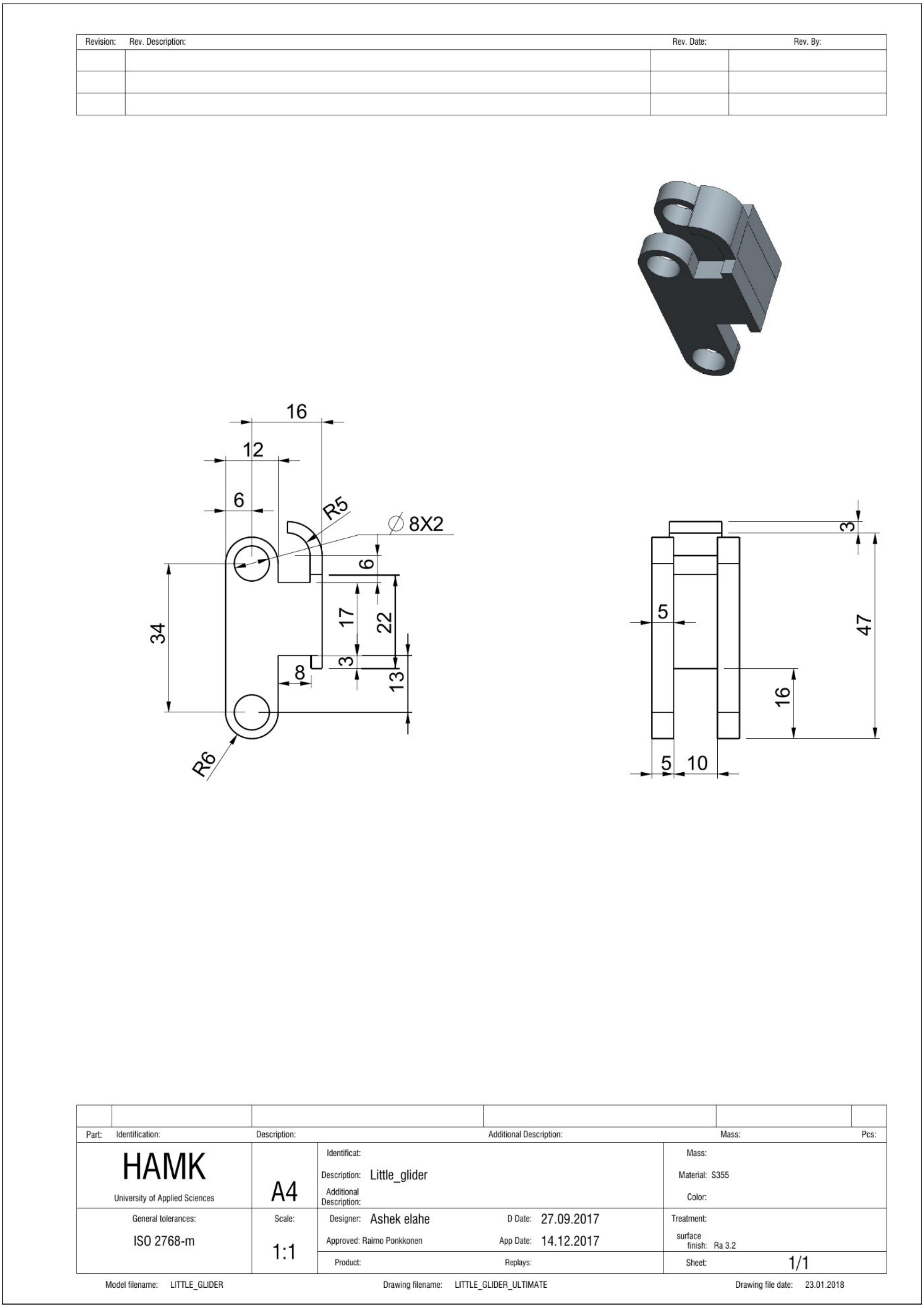
List of Appendices :

Appendix 1: Technical drawing of Base plate



Appendix 2: Technical drawing of clamp glider



Appendix 3: Technical drawing of clamp holder

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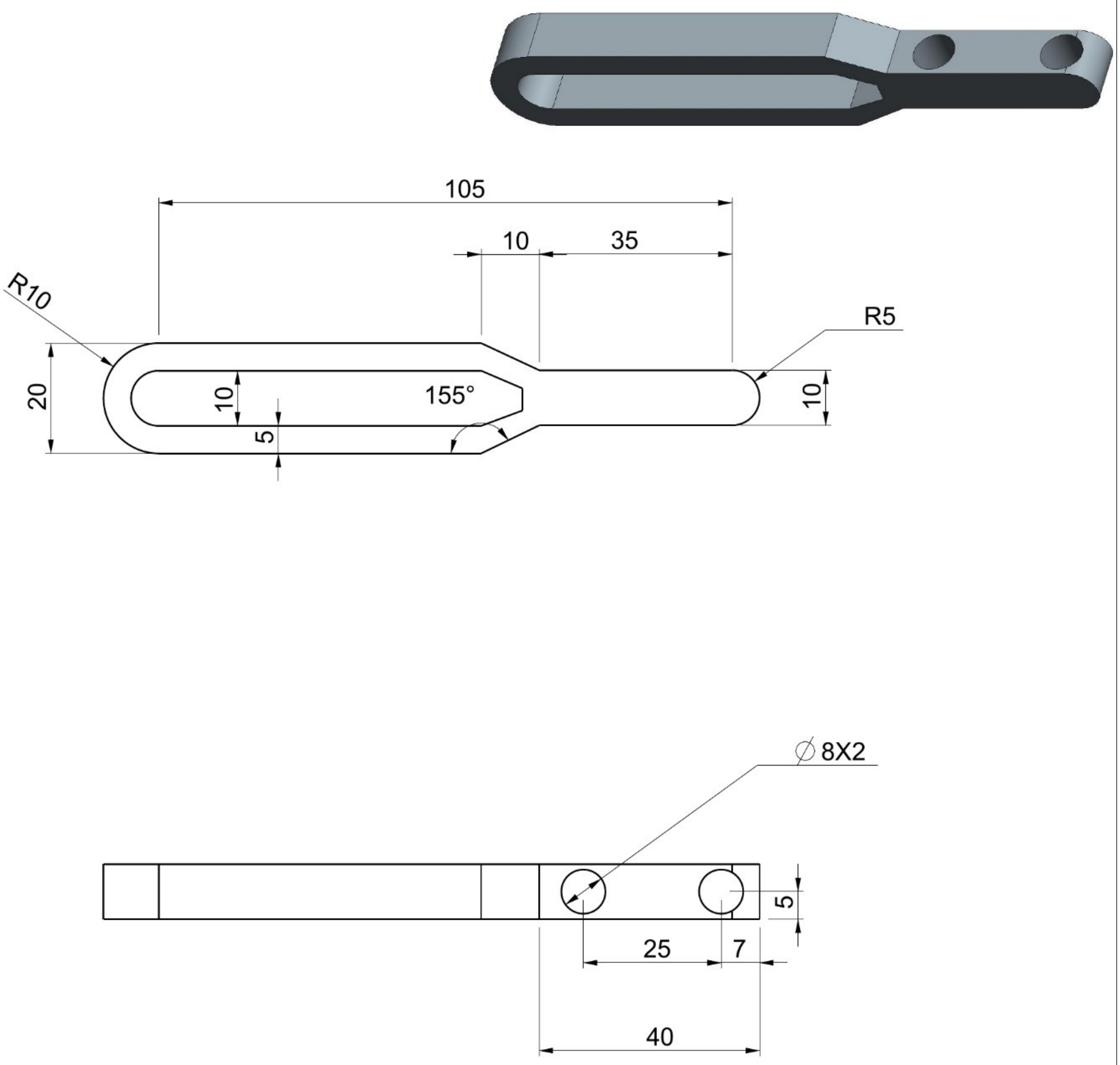

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		Product:	Replays:	Sheet: 1/1

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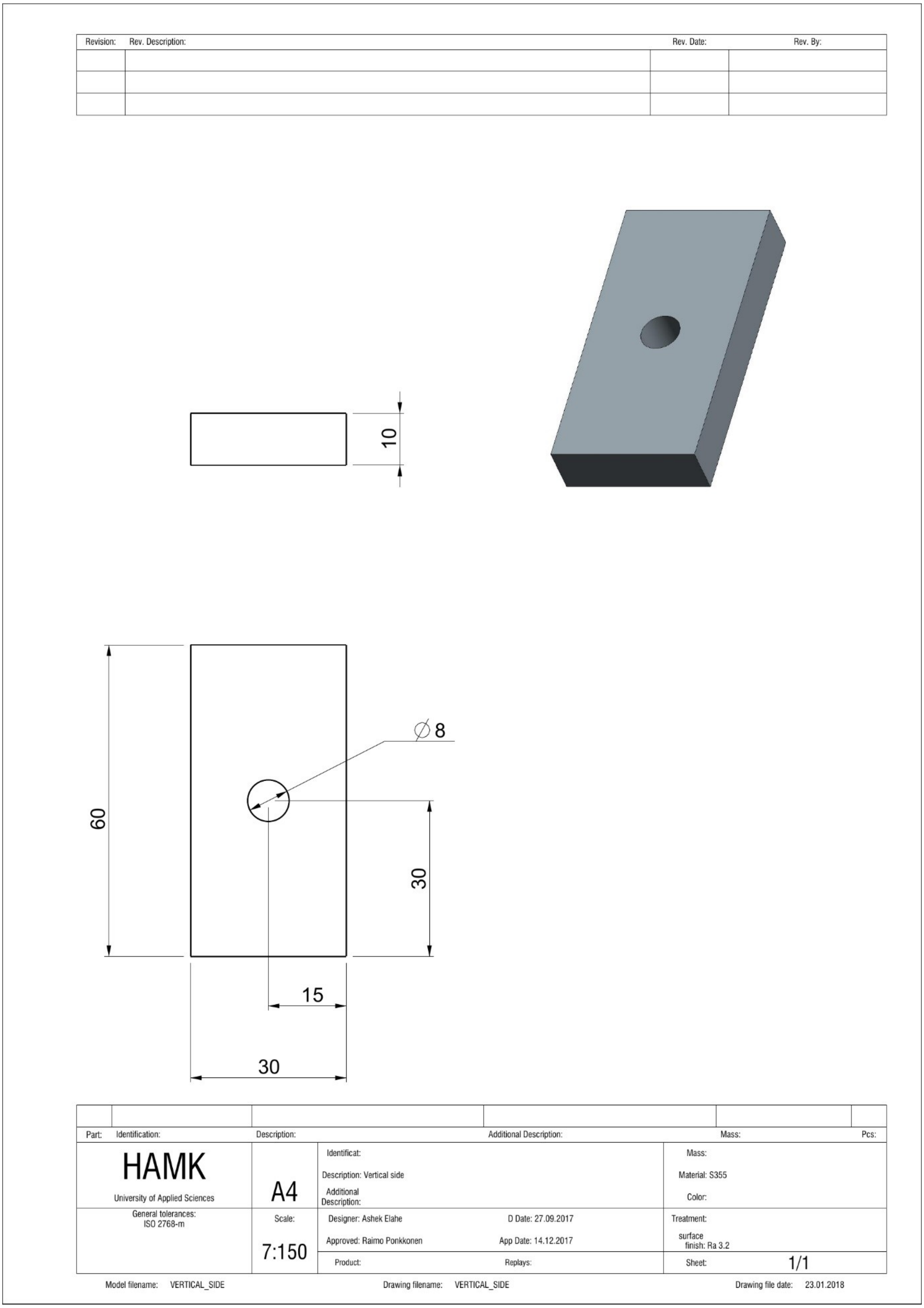
Appendix 4: Technical drawing of Vertical support on the sides



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Appendix 5: Technical drawing of Bracket

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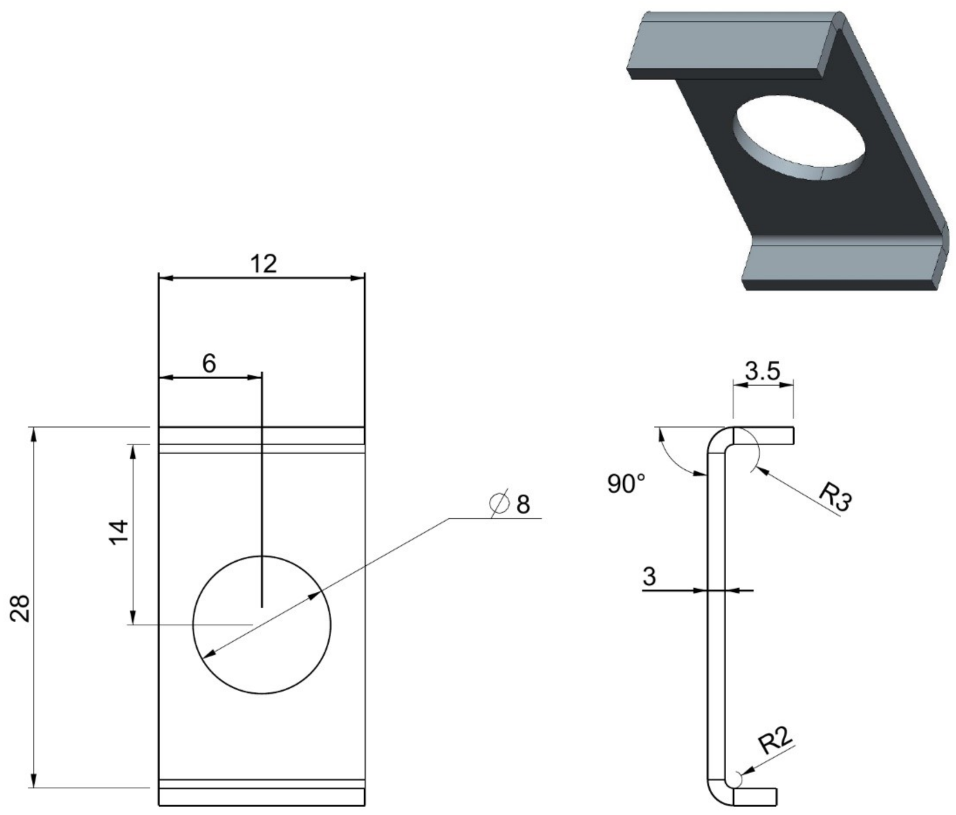

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HAMK
University of Applied Sciences

A4

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Additional Description:

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Color:

General tolerances: ISO 2768-f

Scale: 3:1

Designer: Ashek Elahe
D Date: 27.09.2017
Approved: Raimo Ponkkonen
App Date: 14.12.2017
Product:
Replays:

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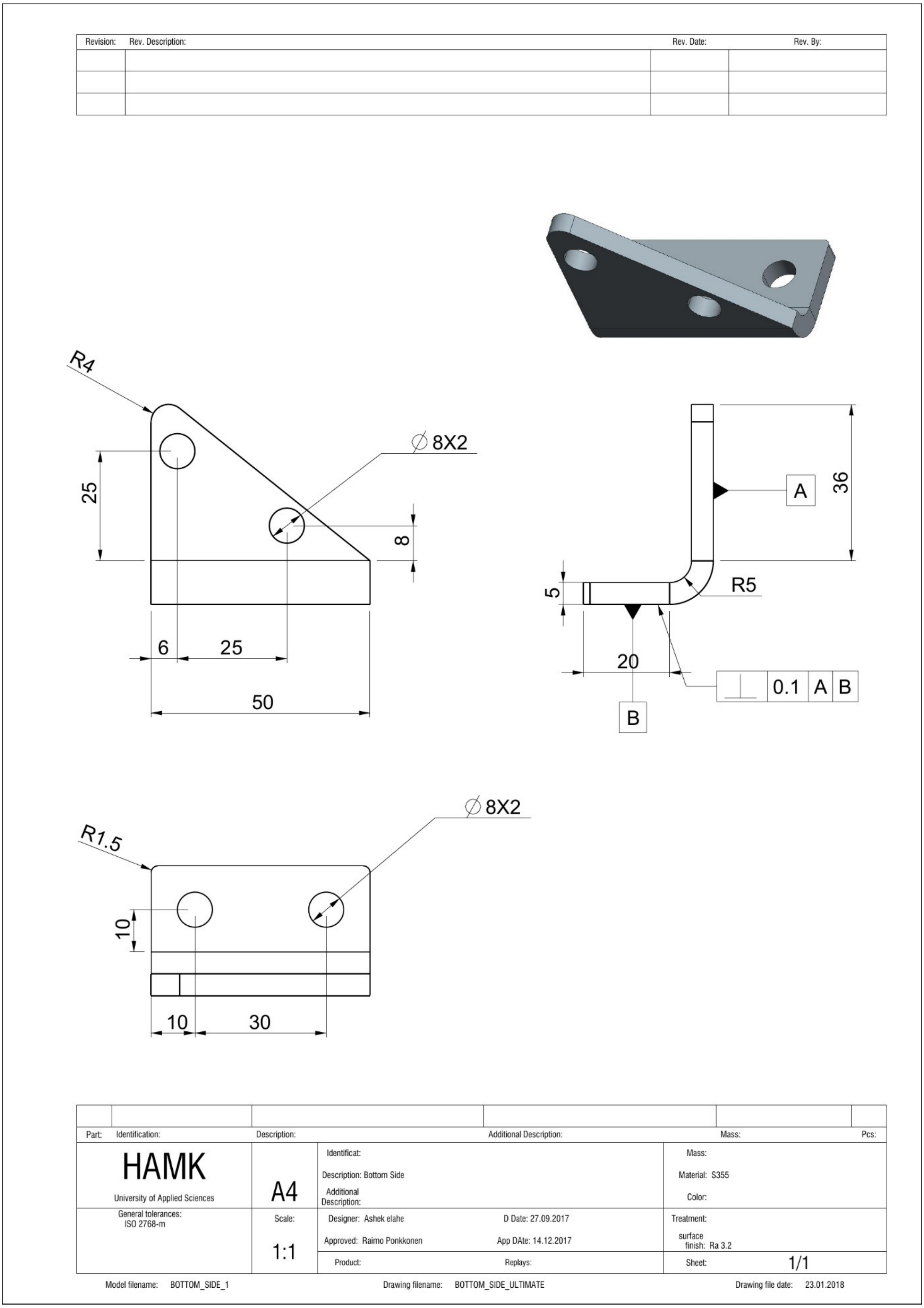
Appendix 6: Technical drawing of Bottom side



Appendix 7: Technical drawing of Base plate screw

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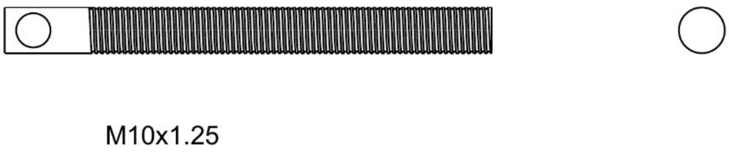

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			Product: Replays:	Sheet: 1/1	

Model filename: BASE_PLATE_SCREW Drawing filename: BASE_PLATE_SCREW_ULTIMATE Drawing file date: 23.01.2018

Appendix 8: Technical drawing of Inside clamp plate