LAPPEENRANTA – LAHTI UNIVERSITY OF TECHNOLOGY

LUT School of Energy Systems

LUT Mechanical Engineering

Okah Perez Kedzi

COST EVALUATION AND LIFE CYCLE ASSESSMENT OF THICK PLATES USING SAW AND GMAW

Examiners: Professor Harri Eskelinen

Kari Erik Lahti –V.D CEO AB Bayrock

Updated: 21.11.2019

ABSTRACT

Lappeenranta University of Technology

LUT School of Engineering

LUT Mechanical Engineering

Okah Perez Kedzi

Cost Evaluation and Life Cycle Assessment of Thick Plates Using SAW and GMAW

Master's Thesis

2019

(68 pages, 28 figures, 7 tables)

Examiner: Kari Erik Lahti

Keywords: Cost evaluation, welding production, cutting cost, welding cost, life cycle assessment, steel recycling, GaBi life cycle assessment of welding processes, welding high strength steel, welding mild steel.

With the ever-growing demand for steel structures and the rise in environmental awareness, industries are moving towards more sustainable means of producing steel structures, which entails the use of high strength steel instead of mild steel and more sustainable production process. The objective of this thesis is to present a more economical cutting process for thick steel plates based on analytical data. To propose which welding process is more economical and environmentally friendly, and compare the two grades of steels. Justify the move from mild steel to high strength steel base on cost and environmental impact. The objectives are achieved by two sample materials, S355J2 and S690QC, comparing SAW and GMAW, collecting analytical data from online and similar welding experiments with the same parameters. These data were used to calculate the cost of cutting processes and welding processes to evaluate which was economical. For the life cycle assessment, GaBi 6.0 software was used to estimate the environmental burden of each welding process and compared which is more environmentally friendly. The study gives more support to the use of oxyacetylene cutting for steel plates, the use of submerged arc welding process for a more economical and environmentally friendly welding process, and an upgrade to high strength steel from mild steels. Based on the literature and results gotten from both cost and impact categories, this study concludes that for cutting processes, oxyacetylene is the most economical process for cutting steel plates. Submerged arc welding of high strength steel is cheaper than mild steel. Using submerged arc welding is cheaper than gas metal arc welding. The use of high strength steel for structure is more sustainable and environmentally friendly, and the submerged arc welding process has less environmental burden and more environmentally friendly than gas metal arc welding.

ACKNOWLEDGEMENTS

It has been a long and challenging journey which has finally come to an end. Looking back at everything, I couldn't have gone through successfully without the help and support of my family friends and professors.

It is on this regard I would like to give speicail thanks first to God Almight for His grace, blessing and guidance through out my life. He is always leading me to the right people, at the right time for the right reasons.

I would like to thank my professors especially Harri Eskelinen, Mika Lohtander, Juha Varis and Kari Lahti for their guidance and supervision, it was an honor and a privilege learning and working with you. I wish to give a special thanks to Dr. Kah Paul, you have been a model and a mentor through this journey every step of the way, from moral support, to academic and professional advice. I am really grateful for your selfless and unconditional support.

I offer my sincere thanks to my friends especially Dr. Eric Mvola, Francois Njock, Nelson Manjong and Mairam Abdulkareem for your support and guidance through my studies and especially during my thesis. I am grateful for all the efforts and time you dedicated to making my thesis a success.

I can not forget the support and love from my family especially my father; Mr. Okah Solomon Buh, for your love and friendly support, you are my mentor for life and best friend. To my mother; Mrs. Okah Emmerencia Mbong, for you love and encouragement through out my life. I could not have been who I am and where I am today without both you. Last but not the least, a great and special thanks to my siblings; Okah Rita Ndum, Okah Sandra Seng, Okah Afai Chiara and Okah Kai for your understanding, patience and presence throughout my life and stay in Finland, inspite of the distance between use. I am very grateful.

Perez Okah Kedzi

Lappeenranta, November 2019

TABLE OF CONTENT

LIST OF SYMBOLS AND ABBREVIATIONS

A	Cross Sectional Area of Weld
C	Manufacturing Cost
c	System Constant
C	Abrasive Water Cost Per Hour
C’	Abrasive Cutting Cost Per Meter
Ca	Abrasive Cost
ca	Unit Abrasive Cost
Ce	Cost of Electricity
ce	Unit Cost of Electricity
Cec	Cost of Electrode Per Joint
C_{eu}	Unit Cost of Electricity,
C_d	Depreciation Cost,
C_g	Unit of Gas Cost
C_{gc}	Cost of Shielding Gas Used
C_{gt}	Unit Cost of Plasma,
c_{gp}	Unit Cost of Secondary Gas,
Ci	Investment Cost
C_l	Labor Cost
Cm	Manufacturing Cost
Co	Operational Cost
C_{op}	Operational Cost,
Cp	Labor Cost

C_{Total}	Plasma Cutting Cost
Ctotal	Plasma Cutting Cost Per Hour
Cw	Cost of Water
CO_2	Carbon Dioxide
D	Diameter
Do	Orifice Diameter
dm	Mixing Tube Diameter
D_R	Deposition Rate
E	Electricity Consumption,
ε	Machine Efficiency
Ec	Cost of Electrode,
Ep	Electrode Price
fa	Abrasive Factor
F_c	Cost of Flux Used
F_{cf}	Cost of Flux
F_{cr}	Flux Consumption Rate
F_r	Gas Flow Rate
G_t	Plasma Gas Flow Rate,
G_p	Gas Flow Rate of Secondary Gas
Fm	Filler Metal Yield
h	Work Piece Thickness
I	Current
L	Length of Cut,
L_c	Labor Cost
Ma	Abrasive Flow Rate

N	Rotational Speed,
Nm	Machinability Number
OF	Operator Factor
ρ	Density of Material
Pcost	Plasma Cutting Cost Per Meter
Pc	Power Cost
P_R	Power Rate
Pw	Water Pressure
q	Quality Index Level
Qa	Abrasive Consumption
Qw	Water Consumption
t_m	Manufacturing Time,
ν	Cutting Speed,
W	Weld Metal Deposited
W_{pr}	Welder Pay Rate
W_t	Welding Time
V	Voltage
AP	Acidification Potential
BOF	Basic Oxygen Furnace
Cu	Cupper
EAF	Electric Arc Furnace
EP	Eutrophication Potential
GMAW	Gas Metal Arc Welding
GWP	Global Warming Potential

HAZ	Heat Affected Zone
LCA	Life Cycle Assessment
Ni	Nickel
POCP	Photochemical Ozone Creation Potential
SAW	Submerged Arc Welding

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Welding, which all began as a means of maintenance, has become one of the essential methods for both production and construction. It is estimated that about 50% of America's gross national product has welding as its core production method (Howard B. Cary & Scott C., 2005.). Welding can be defined as a process of joining metals or nonmetals, by heating to their required welding temperature, with or without applying pressure and using filler materials. (Howard B. Cary & Scott C., 2005.) Welding is predominantly used to join metal structures and reduce the weight of the structures as compared to using mechanical joints, for example metal construction and automobiles.

There are wide varieties of welding processes, which all depend on the materials, application, and required bond strength. Hence, the type of welding process selected must be appropriate to the desired specification and quality. Joining steel plates often realized from welding processes such as Gas Metal Arc Welding (GMAW) and Submerged Arc Welding (SAW).

1.1. Background History

The aim for researchers has always been to improve the welding processes, making it highly efficient, more economical, and environmentally friendly. Which has led to the development of a wide variety of welding methods. Amongst these methods are GMAW and SAW which are the major welding processes when dealing with steel plates.

GMAW is simply a welding process that uses an arc to join metals, shielding gasses,protects the process from environmental contamination. This welding process, however, was developed back in the 1940s, which was a faster means of welding than the Gas Tungsten Arc welding process, which at the time used non-consumable tungsten electrodes, and process was very slow. It was primarily for welding nonferrous metals, but due to its high deposition rate, it gradually started being used on steels (Howard B. Cary, 2006., pp. 4- 10). Since then, GMAW has had rapid development. Lyubayshkii and Novoshilov incorporated the use of large-diameter steel electrodes, which were shielded with a reactive gas carbon dioxide, in 1950s, this brought high spatter and high heat level. (Universal Technical Institute, 2019.)

This process was further developed using the short circuit transfer, which reduced the heat levels enabling it to be used on thin sections of base materials and all position welding. Later in the 1960s the pulse spray was introduced which brought rapid transition between high-energy peak current to low background current. Hence, metal transfer was clean, spatter free welds with improved fusion at lower heat input. (Howard B. Cary, 1998.) Since then, to the current moment, there has been improvement in GMAW processes to the current era, with the waveform control technology such as GMAW P-waveform, advanced waveform control systems, et cetera (Jeff Nadzam, 2007).

The second welding process, which also trumps in the area of welding steel plates, is submerged arc welding (SAW). This welding process is known to have developed from the military. From the 1920s, the two countries at the forefront of the development where Russia and USA, later in 1955, when japan and Europe became involved and inventors (P. T. Houldcroft, 1992). D. A. Dulczewskij from Russia and B. S. Robinoff from USA filed the first patent of this process in 1929 and 1930 respectively (Dulczewskij, 1929.). Both patents had a unique process as the former used charcoal, sawdust, soot and start as flux for the welding of copper. (Dulczewskij, 1929.) While the later used flux powder, which contained: 63 -76% SiO_2 and 13 – 21% Al_2O_3 (Boris S. Robinoff, 1930). From the first patents, there has been rapid development with some significant development, such as high-speed automatic unshielded electrode welding under a flux layer, which was developed in 1939 at the electric welding institute. This method was characterized by constant filler metal feeding rate independent of welding arc, with a welding rate of 32m/h and was used in the production of 60-tonrain tankers. (Grobosz, 2014.) In 1949, the double arc welding under flux was developed in the electric welding institute which proceeded with the development of semiautomatic SAW and this method was mainly used for shot curvilinear welds and welds in locations inaccessible for automatic welding, due to size of welding machine. (Grobosz, 2014.) With the vast potentials of this welding process for industrial applications, numerous approaches and modifications of SAW were made over subsequent years and decades. Submerged arc welding started being used for surfacing, new approaches to submerged arc welding emerged such as multi-head welding, flux core arc welding, welding with metallic powder addition, welding with strip electrode and with cored strip electrode, welding with hot and cold electrode, narrow gap welding, hybrid laser submerged arc welding et cetera (Grobosz, 2014.)

One of the main materials used in welding is structural steel, which is a standard construction material made from specific steel grades, designed with specific chemical composition and mechanical properties for particular applications. The two structural steel grades highly used are S355 and S690 (S= stands for structural steel, 355 or 690 – stands for minimum yield strength). Some aspects that have made steel so highly used in welding are its wide range of tensile strength, its weldability aspect, and its recycling capabilities.

Steel is said to be one of the materials in the world with endless recycling capabilities and it is the most recycled industrial material in the world with over 500 million tons of scrap recycled annually (Demeri, 2013.) The figure below shows how steel can be recycled endlessly and 100% from its production through usage to recycling.

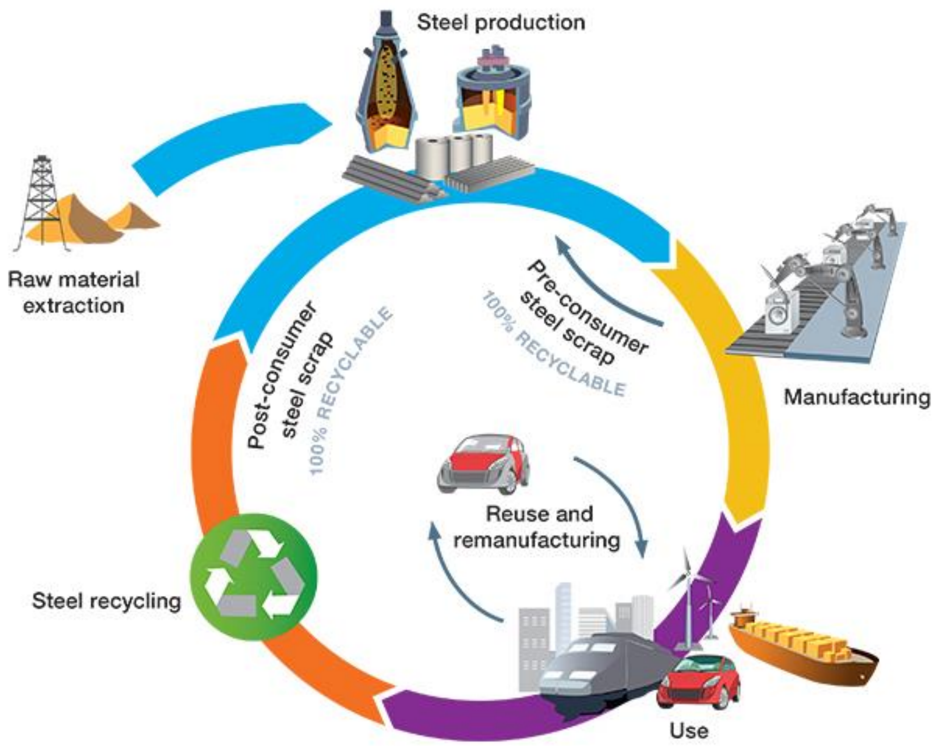


Figure 1.Life cycle of steel (Worldsteel, 2019).

1.2. Objective

- Compare the various cutting processes from mechanical cutting, thermal cutting and non thermal cutting process interms of cost of cut and suggest which is more economical
- Compare with respect to cost the two welding processes gas metal arc welding and submerged arc welding process. propose which is more economical and environmentally friendly
- Compare both steel plates (high strength steel S690QC and mild steel S355J2) which is more economical and environmentally friendly

1.3. Scope

The scope of this thesis will involve the life cycle cost comparison of the two grades (mild steel S355 and high strength steel S690), and how the grades are affected by different welding production process. For the mild steel, we will use a steel plate thickness of 25mm, while for high strength steel will use will be 25mm thick. The welding processes will be gas metal arc welding and submerged arc welding. In evaluating the cost of these processes, deprecition rate will be ignored.

2. WELDING THICK PLATES WITH GAS METAL AND SUBMERGED ARC WELDING

There are a variety of welding processes that exist, each used depending on its application, weld quality, the material used and the environment. While there are also a couple of welding processes that could be used for welding steel plates. Recently there are welding techniques that are most widely used which are: GMAW and SAW for this thick section. This chapter will elaborate general background and operation of the two processes, how they are used, why and its limitations.

2.1. Gas Metal Arc Welding Technique

GMAW is an arc welding process that joins metals together with the use of an external gas mixture supply, which shields the electric arc formed between the workpiece and the consumable electrode from contamination. (Lincoln Electric, 2014.) This electric arc is generated from heat transfer utilizing plasma radiation, conduction, and convection from the plasma, and through electron flow (Belinga, 2017, p. 24)**.** This process can be semiautomatic or automatic, capable of welding most metals such as carbon steel, high strength low allow steel, stainless steel, aluminum, copper in different positions provided the appropriate shielding gasses, electrodes, and welding parameters are chosen. (Lincoln Electric, 2014.)

2.1.1. Principle of Operation

GMAW process is primarily characterized by the following elements: power source, wire feeder unit, welding touch, shielding gas, and electrode source. These elements can be seen in figure 2 (1- welding torch, 2- workpiece, 3- power source, 4- wire feed unit, 5- electrode source, 6- shielding gas supply) alongside with the detailed welding torch. After the operator has the appropriate settings, the power source is switched on when the electric arc touches the base metal; the heat from the arc melts both the surface and the electrode tip, thus creating a molten pool. Depending on the parameters set by the operator, such as wire voltage and current, size of wire, and shielding gas. There are three types of metal transfer that occur are: short-circuiting transfer, globular transfer, and spray transfer (ESAB, 2013).

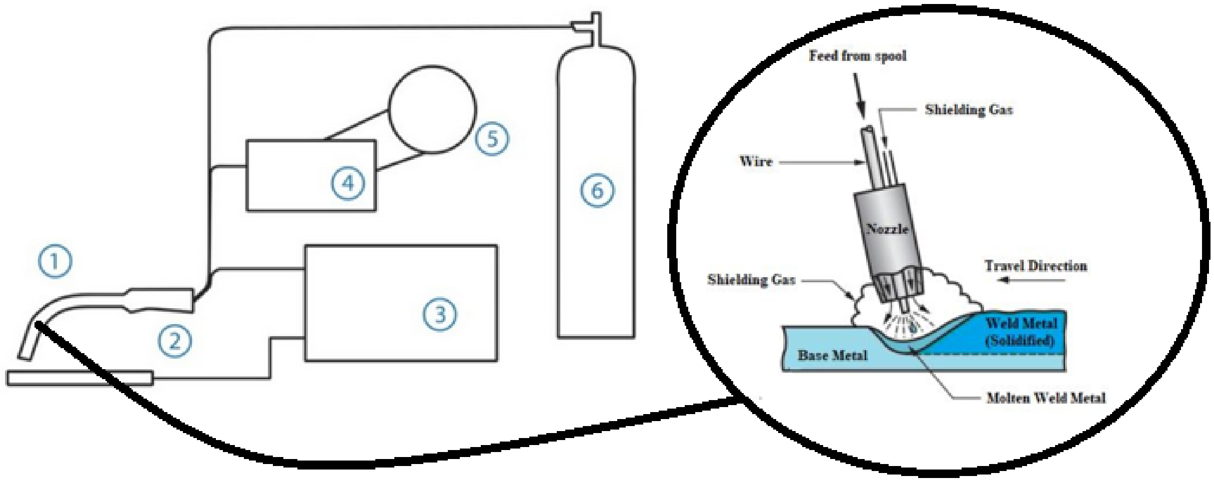


Figure 2. Gas Metal Arc Welding Process (Mod. P.Elango, 2015).

- Short-Circuiting Transfer: This occurs at the lowest range of welding current and electrode diameters. With this type of transfer, a small, fast -freezing weld pool is produced, which is suited for joining thin sections, for out of position welding, and for bridging large openings. The metal transfer is done only during contact between electrode and weld pool, and this contact is made at a rate of 20 to 200 times per second. (Lamet, 1993.) The rate of current is increased by adjusting the power inductance.
- Globular Transfer: This takes place when the current density is relatively low with any shielding gas but mostly used with CO_2 and He (helium). The metal transfer here is characterized by a drop size whose diameter is usually greater than that of the electrode. Due to this phenomenon, the metal transfer is quickly acted upon by gravity hence limiting its operation to flat positions. (Ramesh Singh, 2012, pp. 157-158).
- Spray Transfer: This metal transfer method produces very stable, spatter free transfers with the use of argon as the shielding gas. Due to the discrete drops which accelerated by arc forces to velocities that are able to overcome gravity, this process can be used in any position. Spatter lever is negligible because the drops are separated, hence no short circuits. Almost any metal or alloy could be weld with this mode of transfer, but the thickness factor of the material is to be considered since high current levels are involved. A special power supply was introduced which controls the current output that pulse the welding current from levels below the transition current to levels above it. (Richard L Alley, 1993, pp. 567-574). When welding carbon steels, a standard mixture of 75% argon and 25% CO2 is used which is recomended (Ramesh, 2012, p. 158).

Figure 3 shows the various modes of metal transfer, how each is produced, and affects the joining process. The globular transfer has the wides width but showest depth while spray transfer has the most profound depth and narrowest width.

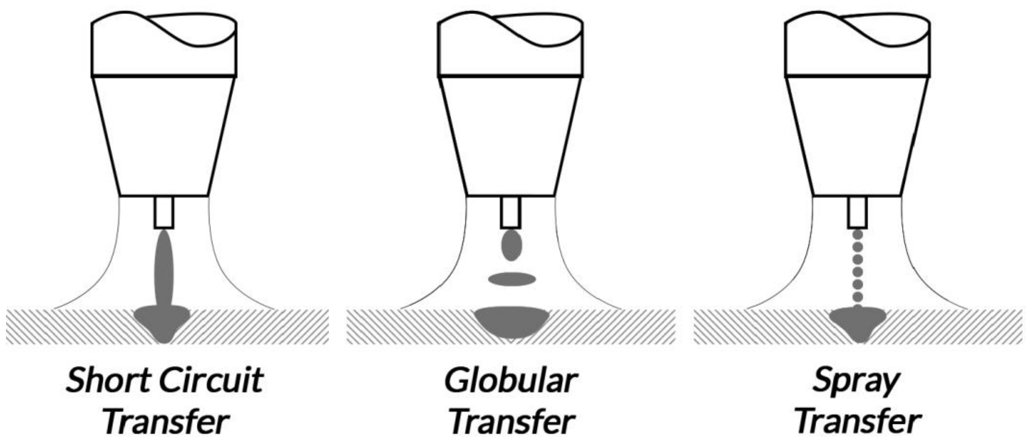


Figure 3. Main modes of metal transfer (Guzman, 2019).

2.1.2. Consumables

In GMAW, there are two main consumables the electrodes and the shielding gas. The electrodes vary in size and chemical composition depending on the base material and the desired weld properties. It is generally designed with extra deoxidizers (silicon is commonly used in steel electrodes) to compensate for reactions with the atmosphere and the base metal. Some physical characteristics such as uniform diameter and smooth surface, finish free of sliver, or scale is required (Richard L Alley, 1993). Shielding gas, which is the other consumable whose primary function is to protect the molten metal from contamination with the surrounding atmosphere, also plays an additional role in the effect of arch characteristics, mode of metal transfer, depth of fusion, weld bead profile, welding speed and cleaning action. When welding steel, CO_2 is one of the shielding gasses, which produces high spatter but allows for deeper penetration, when compared with inert gases (ESAB, 2019.) Hence a compromise is always made between spatter and penetration. Mixtures of CO2 and argon are often used since argon reduced spatter and has less penetration. (Lamet, 1993.) The shielding gasses include hydrogen (H_2), carbon dioxide (CO_2) Oxygen (O_2) helium (He) and argon (Ar) according to the European standards EN ISO 14175 of welding consumables and gases and mixtures for fusion welding and allied processes. (ISO14175, 2008, p. 13). These gases can be used in purely (single) or Binary (a mixture of two gases) or

Ternary (mixture of three gases) or Quaternary (mixture of 4 gases). Figure 4 shows how the pure and binary gasses can affect welding process, CO_2 having the most penetration but a lot of spatter, and He has the least spatter and least penetration.

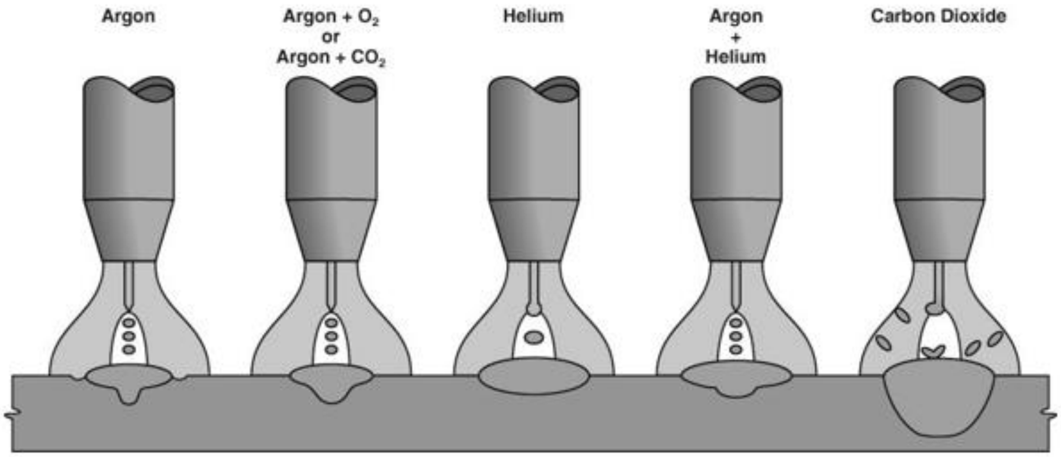


Figure 4. Effect of shielding gas in GMAW (CTS, 2018).

2.1.3. Advantages and Limitations

GMAW has a wide range of applications due to its advantages such as (Welding answers, 2014):

- Being able to weld in all positions with the proper parameters.

-Welding speeds are higher than those of SAW.

- Deposition rates are higher than those obtained by the SMAW process.

- Less operator skill is required as compared to other conventional welding processes.

- Minimal post weld cleaning is required because of the absence of a heavy slag.

All these advantages make the GMAW process weld suited for mass production and automated welding applications. This welding process like any other has its limitations such as:

- The complexity and less portable nature of the equipment is costly.

- Its inability to reach inaccessible welding areas with the welding which is larger.

- The arc must be protected against wind and breeze hence limiting its outdoor use.

- The high levels of heat radiation and arc intensity can make operators reluctant to accept the welding process. (Richard L Alley, 1993)

2.1. Submerged Arc Welding

This is a welding process that joins metals using an arc between the electrode and the weld pool with the help of a blanket of granular and fusible flux, and this conceals the arc and molten metal from the atmospheric contamination.

2.2.1. Principles of Operation

Components of a submerged arc welding machine consist of a power supply (AC or Dc depending on the requirement), electrode wire reel, wire feed motor, unfused flux recovery tube, and a workpiece. Figure 5 shows the setup and process of SAW with a schematic illustration of the welding head.

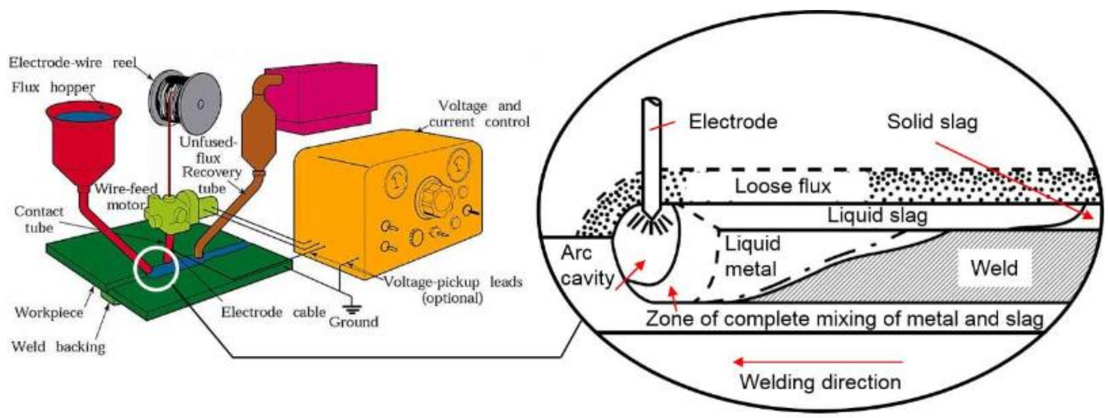


Figure 5. Submerged Arc welding process (Layus, 2017)

This welding process is often fully automated, even though it can be semi-automated. The welding process begins; the arc burns under the layer of flux, which is sufficiently supplied to cover the arc and prevent sparks as the welding is in progress. Slag is formed by the flux, which is closest to the arc melt. The slag protects the molten metal from reacting with O_2 and N_2 in the atmosphere. (Klas Weman, 2012.) SAW has been adapted to suit various demands. for instance, if increase deposition rate or welding speed in needed, a twin arc process is used where two electrodes are fed into same weld pool while sharing a common power source. (Klas Weman, 2012.)

2.2.2. Consumables

There are two main consumables in this welding process which are: filler wire and flux. These two are adjusted to achieve a composition and strength of weld metal like the base material. For the filler wire, its composition primarily affects the mechanical properties of the weld metal. Two important factors are always considered when deciding an appropriate filler wire: for increase strength of the weld metal, it can be alloyed with manganese and silicon and to increase toughness at low temperatures molybdenum and nickel are used as alloy elements. (Klas Weman, 2012.) The Flux aims to form slag and protect the molten weld metal against atmosphere, improve stability of arc and assist ignition, give excellent surface finish to the weld and control the flow of the molten weld metal. There are two types of flux: fused flux and agglomerated flux. Fused flux gives non-hygroscopic high grain strength, but Ci and Ni cannot be used as alloy elements, while agglomerated flux makes it possible for Ci and Ni to be used as alloying elements but has hygroscopic relatively low grain strength. (Klas Weman, 2012., p. 111 &112)

2.2.3. Advantages and Limitations

SAW has its advantages which makes the application-wide, such as (Keen ovens, 2013):

- It is environmentally friendly as the blanket flux eliminates arc flashes, spatter and fumes.
- There is increase penetration due to high current densities hence little need for edge preparation and high deposition rate.
- The flux used has deoxidizers that remove contaminants from the weld pool hence enhances the quality of the weld and its mechanical properties.
- There is little or no waste of flux as the slag can be collected, grounded, and sized for mixing back into new flux.

With these advantages, SAW still has its limitations, such as:

- Only a flat or horizontal position can be used for welding; this is to keep the flux in the joint.
- For multiple passes, the slag has to be removed before subsequent passes.
- Due to the high heat input, this welding process is mostly used to joint steels of thickness greater 6.4mm. (Howard B. Cary & Scott C., 2005.)

3. JOINT PREPARATION: CUTTING PROCESS

The welding process for any given material begins with the Joint preparation, which are steps taken to ensure that the welding performed on the material meets the quality and required standards. A decision is first made in the welding position for the welding process. There are eight welding positions from which the best suited position is selected, which are: Flat welding position(1G & 1F), horizontal welding position(2F & 2G), vertical welding position(3G & 3F) and overhead welding position(4G & 4F) (ISO 6947:2011, 2011, p. 35) . The next step is to determine the type of welding joint suitable for joining the materials. There are about five joint types; Butt joint; between two members allied in same plane. Corner joint; between members at right angles forming L shape. T-joint; between members at right angles in the form of a T. Lap joint between overlapping parallel members. Edge joint; between edge of parallel members (Howard B. Cary and Scott C. Helzer, 2005, p.494). The next step is to determine the type of weld to be performed; there are four types of welds: fillet weld, groove weld, backing weld, and slot weld. For this study, the thickness of the material is 25mm, according to (ISO 9692-1, 2013, p. 15). We will be working with a groove weld, specifically a Double V groove weld for both SAW and GMAW. Both are shown in figure 6 left and right respectively.

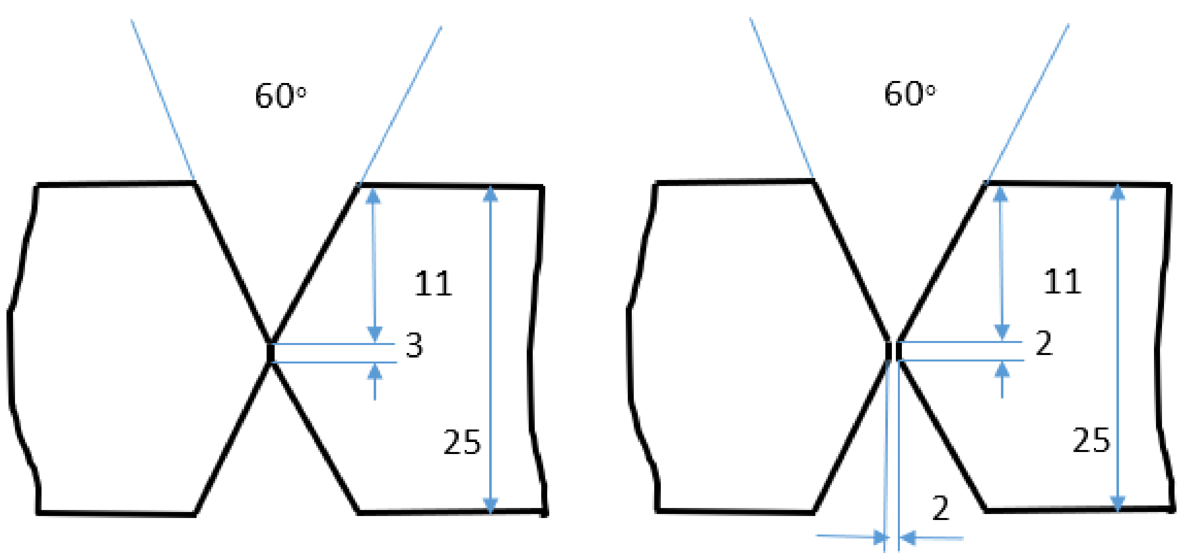


Figure 6. The groove cut for both steel plates

The cutting process is very crucial in welding technology, as each method of cutting will affect the welding process and the material differently. The objective is to select the best method concerning economy and quality, process capabilities and the effect on the material to be cut. In this paper, we will base our interest on the economic aspect of the most used cutting methods. The cutting processes, however, can be divided into three: mechanical cutting, thermal cutting, and non-thermal cutting. Thermal cutting processes principally remove material by localized melting, burning, or vaporization of the workpiece; each process has different applications concerning the material and thickness. The most commonly used methods include laser cutting, plasma cutting, and oxyacetylene gas cutting. Plasma cutting and oxyacetylene cutting will be our focus in this category. For non-thermal cutting, the most used cutting process is the Abrasive water jet cutting, which uses abrasive and water pressure to remove material from the workpiece (Klas Weman, 2012). Highlights on the various cutting processes will be given, but the cost calculations will be done for plasma cutting, machining, and water jet cutting.

3.1. Laser Beam Cutting

Laser cutting is a machining process, which removes material utilizing high intensity laser beam focused on a workpiece, the heat resulting from the laser beam will melt or vaporize or melt through the depth of the workpiece creating a cut. Laser cutting also makes use of pressurized gas jet which enhances material removal by oxidation and melt expulsion. This method of cutting is well used due to its great and precise cutting, its flexibility to be used with a variety of materials, its high cutting speed, and little thermal effect on the material. Cutting can be performed in two ways: Cutting with a CO_2 laser and cutting with neodymium-doped yttrium aluminum garnet (Nd:YAG), these two methods are used depending on the thickness, speed, quality, and material to be used (Klas Weman, 2012).

A high power carbon dioxide laser can cut steel up to 25mm thick, which falls within our desired thickness.

Lasers are most often described in terms of their power from 1kW to about 6kW. The laser power can be defined as the sum of the energy decipated in the form of laser light per second. The higher the power and lesser the area of contact of the laser the higher the intensity of the laser. (Faerber .M, June 2008.) Laser intensity is heats up the material rapidly to ensure little time is left for the heat to dissipate into the soroundings. Hence with high laser intensity the laser is capable of producing high cutting rates and qreat quality cut. The power of the laser also affects the cutting speed of the laser as they are both directly proportional. (Faerber .M, June 2008.)

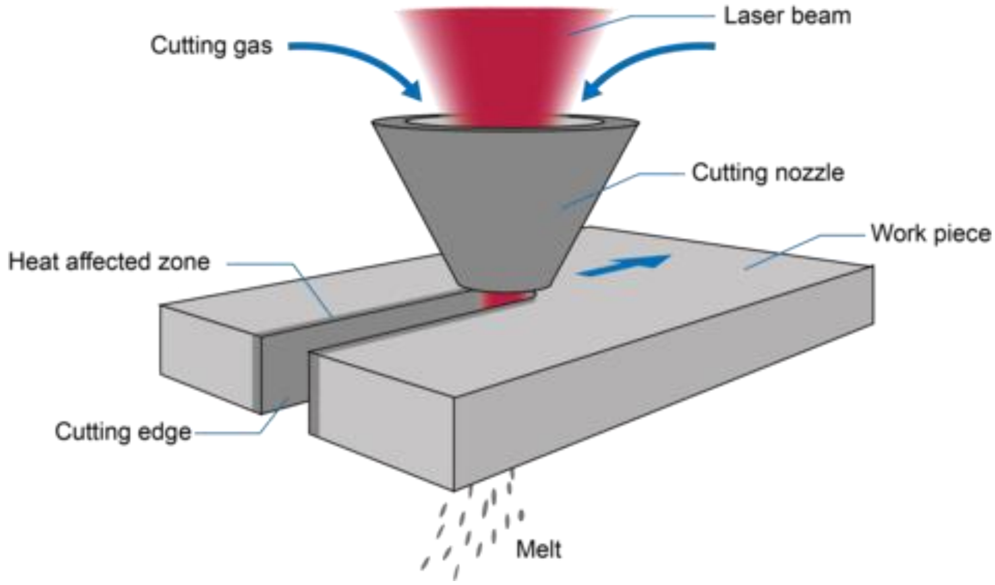


Figure 7. Laser metal cutting process (Laserline GmbH, 2019)

3.2. Oxyacetylene Gas Cutting

This is a thermal cutting process in which chemical reactions are controlled to remove preheated metal by rapid oxidation of pure oxygen. This process is mostly used to cut carbon and low alloy steel plates of any thickness. The cutting process uses flammable gas (mostly acetylene or propane) and burning gas (oxygen), the high-temperature flame produced, preheats the workpiece then a jet of oxygen is released which burns the metal by producing metal oxide in the form of liquid slag and blows it out (Annette O. Brien, 2004). The use of oxygen has three duties: to produce heat with the fuel gas oxidizes the metal to cut and blow of the slag (Annette O. Brien, 2004). The quality of the cut produced by this process depends on a couple of variables, hence due to its complexity, each supplier provides a manual with recommendation of the approximate gas pressure for various sizes, cutting speed, style of cut of cutting torch, thickness of cut, type of gas fuel, quality and angle of cut. The equipment set up for Oxyacetylene gas cutting consists of acetylene and oxygen gas containers, gas regulators, spark lighter, mixing chamber, needle valves, pressure gauges, hoses, torch, and cutting tip.

Figure 8 shows the general equipment assembly for the oxyacetylene cutting machine and a details view of the torch used.

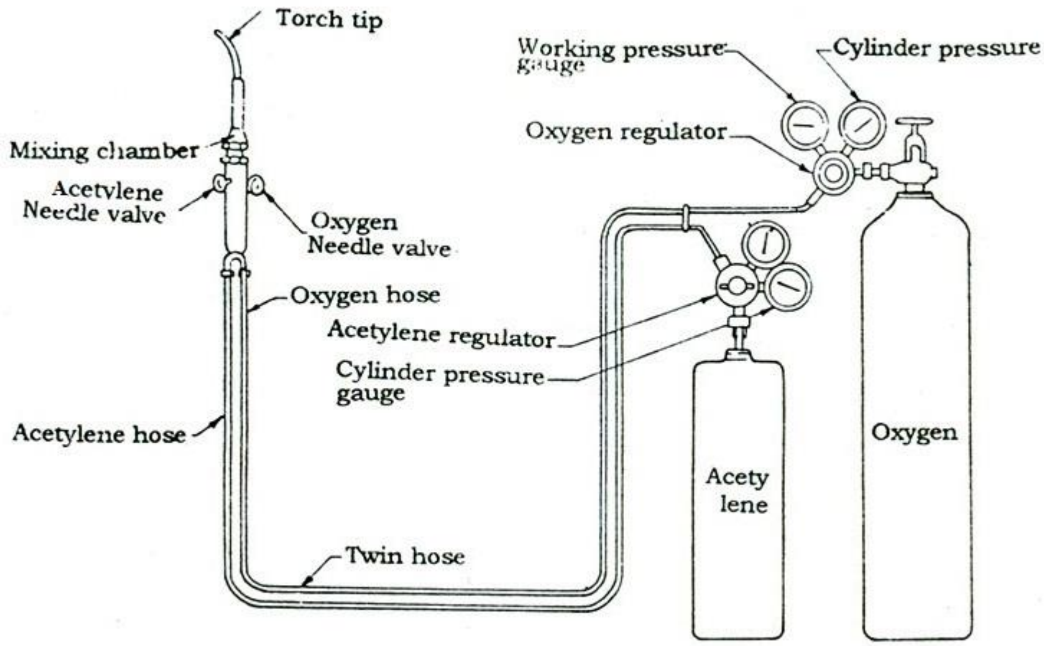


Figure 8. Oxyacetylene Welding Equipment Setup (Workshop Practice, 2012).

Oxyacetylene cutting cost calculation:

For the cost of cutting to be calculated, the two essential parameters to be determined are the cutting time and gas consumption rate for the length of the cut.

i. Cutting Time: the cutting time is given by the formaula:

$T = L/C$ [mm/s] T = cutting time,(s)

L = Length of Cut (mm)

C = cutting speed (mm/s)

ii. Gas Consumption: The two gasses used for the cutting process, as mentioned above, are oxygen and acetylene, which their measurements were taken during several experiments cutting steel of thickness 2.5cm and cut length of 243.8cm. Values for the consumption rate of the gases are taken from the experiments.

Appendix 1 shows the data collected from various experiments to determine the cutting speed and gas consumption of oxyacetylene cutting process with steel thickness ranging from 6mm to 305mm. A comparison was made between manual cutting and machine cutting to get the speed difference and consumption difference (Tyler G. Hicks, 2006, pp. 1645 - 1646)

3.3. Plasma Cutting:

This is a form of thermal cutting in which utilizes an extremely hot, high-velocity plasma jet by an arc, and ionization gas flows through a constricted orifice. This arc plasma is concentrated on a small area of the workpiece, where it melts the metal and forces the molten metal through the kerf and out (Ajan Electronik, 2003). Compressed air is used as plasma gas. An essential aspect of this cutting process is that it can produce lots of noise and smoke hence water is used mostly for two purposed; to supplement the superheat when water is injected into the plasma orifice and used to shroud around the arc hence reducing noise, pollution and arc brilliance (Klas Weman, 2012). Plasma cutting is mostly preferred to oxyacetylene gas cutting because of its higher cutting speed, due to this high speed and narrowly localized heating of the metal. It cuts through carbon steel with no distortion, it also offers a lower HAZ (Larry Jeffus, 2012, pp. 533 - 543).

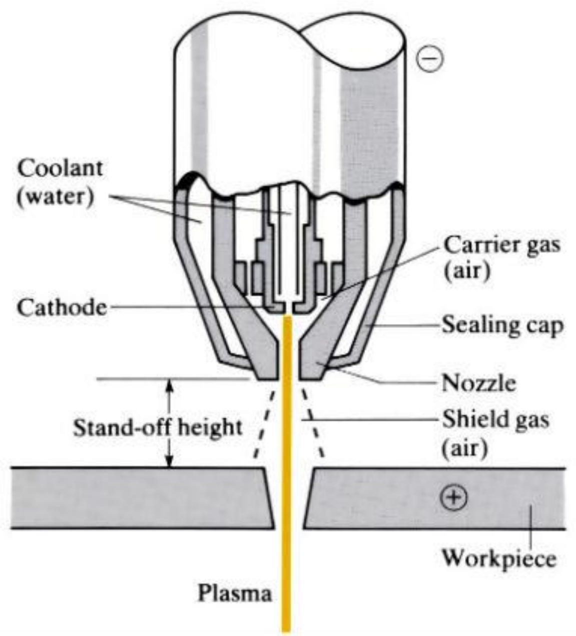


Figure 9. Plasma Cutting Torch *(The Open University, 2019)*

Assumptions:

- Three essential cost influencers; depreciation cost, investment cost and operational cost, and labor cost.
- The calculation will be done to determine the cost of cut for just the specimen to be cut.
- The thickness of the material is 25mm.
- The depreciation cost is neglected.
- The cost of the wear part and maintenance cost is neglected.

- Plasma cost calculation identified categories: depreciation cost, operational cost and labor cost.
  i. Plasma Cutting Cost Per Hour: this is the sum of the three categories

$$C_{Total} = C_d + C_{op} + C_l \quad [Eur/h] \tag{1}$$

C_{Total} = Plasma cutting cost , C_d = depreciation cost, C_{op} = Operational cost,

C_l = Labor cost

  ii. Operational Cost: cost incused during the cutting process

$$C_{op} = C_e + C_{gt} + C_{gp} \tag{2}$$

$$C_e = C_{ue} \times E, \tag{3}$$

$$C_{gt} = c_{gp} \times Gt \tag{4}$$

$$C_{gp} = c_{gp} \times G_p \tag{5}$$

C_e = cost of electricity, C_{gt} = unit cost of plasma, C_{gp} = secondary gas cost

C_{eu} = unit cost of electricity, E = electricity consumption, c_{gp} = unit cost of secondary gas, G_t= plasma gas flow rate, G_p = gas flow rate of secondary gas

  iii. Labor Cost: this is the multiple of the hourly rate of worker and the manufacturing time:

$$t_m = \frac{L}{v} \quad [mins] \tag{6}$$

$$Cl = tm \times \text{hourly pay} \tag{7}$$

t_m = manufacturing time, L = length of cut, ν = cutting speed, Cl= labor cost

  iv. Plasma Cutting Cost per meter:

$$C_{plasma} = C_{Total} / \nu \quad [Eur/m] \tag{8}$$

3.4. Mechanical Cutting:

Mechanical cutting: This is also known as machining, which is a process where a workpiece is being modified to attain a desired geometry or dimension or surface roughness. These aspects are mostly attained through material removal. For a piece of steel to be welded, it can also be machined through the process of milling and or drilling. Each process can be used independently or simultaneously depending on the joint design and what is available in the shop. Our design is a double y groove, which will be joint using SAW process. This grooved design can be easily archived mechanically by either milling or drilling. These processes are briefly explained as follows

3.4.1. Milling Process:

This is a metal cutting technology in which the cutting head is equipped with a multi-edged cutting tool to remove metal material from the workpiece. During the milling process, the tool has generated the cuts and the cutting speed while the workpiece executes the feed motion (Heinz Tschätsch, 2009, pp. 173 - 199). There are about five main milling techniques mostly utilized; these processes can be seen in figure 10 below. Face milling is a suitable technique for the preparation of groove design; the face milling process is further modified to suit the bevel angle.

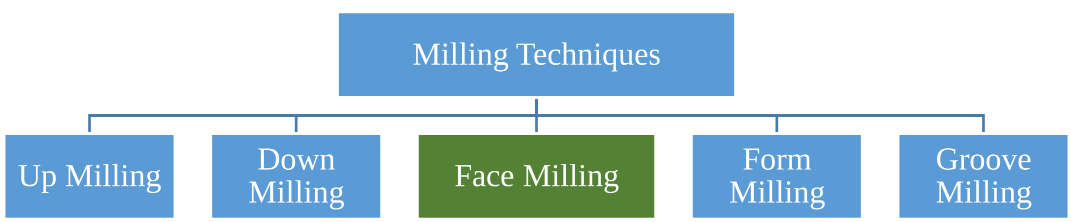


Figure 10.Milling Techniques (with face milling as the suitable technique)

Face Milling: Normally, face milling, also known as facing is done with an Endmill such as two-flute and four-flute end mills, which are often used in milling machines, they are also commonly used when material width is more than 50mm, but our case study material is 25mm. (Arthur R. Meyers, 2001, p. 131). However, due to the desired bevel cut angle needed for our weld joint, facing a vertical milling machine is recommended. This bevel cut can be achieved with a vertical milling machine in two ways. Either by using a single angle cutter in which the milling head is vertical, and the single angle cutter gives the bevel cut with the required angle, or by using an end mill cutter and inclining the head of the vertical milling machine and perform facing on the workpiece. This process is also known as angular face milling. The figures below show a single angle cutter and the angle face milling.

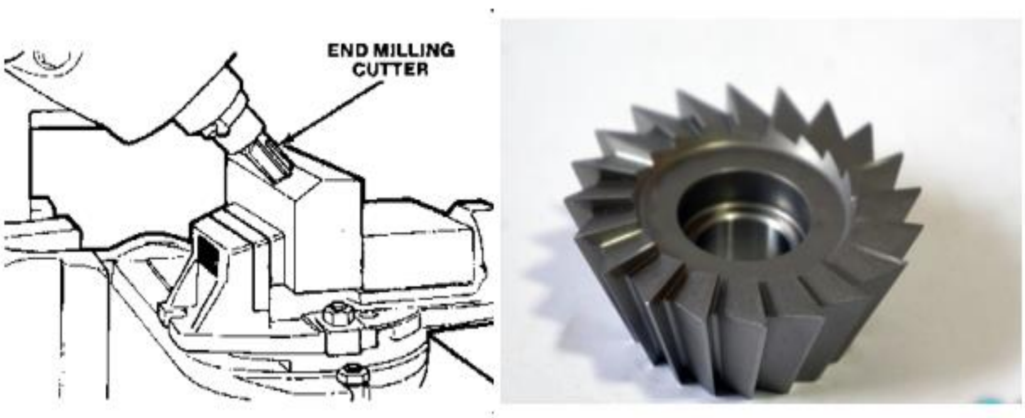


Figure 11. Angular face milling (left) and Single angle Milling head (right).

The cost of producing the bevel cut with the milling machine will be calculated by getting the time it takes for the machining process to complete and multiplying it with the kilowatts per hour to have the cost of machine time; this value will be added to the cost of cutting fluid used during the machining time. This will give us the cost of milling the bevel cut on the workpiece.

i. Rotational Speed (N): this is the number if complete revolution the cutting tool makes in a minute.

$$N = \frac{v}{\pi D} \tag{9}$$

N = rotational speed, ν = cutting speed, D= diameter

ii. Feed Rate (fr): this is the speed at which the cutter advances against the workpiece

$$f_r = N.n_t.f \tag{10}$$

iii. Machine Time (Tm): the time it takes for the milling machine to complete the cut

$$Tm = \frac{L+A+O}{f_r} \tag{11}$$

iv. Cost of Milling :

$$C_m = T_m x \left(\frac{kW}{hr}\right) \tag{12}$$

Cm = 1,85 Euros

3.5. Abrasive Water Jet Cutting:

This is a non-thermal cutting process, which uses a high velocity water jet to cut a wide variety of materials from metallic to non-metallic. This process can be described as follows: an electrically driven hydraulic pump generates an oil pressure of about 20MPa, this high-pressure oil drives the water pump, which produces water pressure of up to 400MPa, and this water pressure is converted to high velocity of about 1000m /s in the jet (Lars Ohlsson, 1995, pp. 12 - 25). The nozzle hole which the high-velocity water passes is about 0.1 to 0.3mm diameter, and this produces a thin hair jet; this is mixed with abrasive (garnet), which produces a cut about 1.5mm (Klas Weman, 2012). There are three types of water jet cutting equipment;

- Standard entrainment: Has an operating pressure of about 70MPa and a nozzle diameter of 3mm.
- Standard entrainment with higher pressures: Operating pressure reaching about 400MPa and a nozzle diameter of 2mm, and this produces the most quality cut and cuts steels of about 100mm.
- Direct entrainment: Operating parameters same as standard entrainment but use a little pressure to mix the abrasive and water hence produces high energy efficiency, high cutting speeds as compared to standard entrainment (Shaw, 1996).

Figure 12 shows the schematic water jet cutting process:

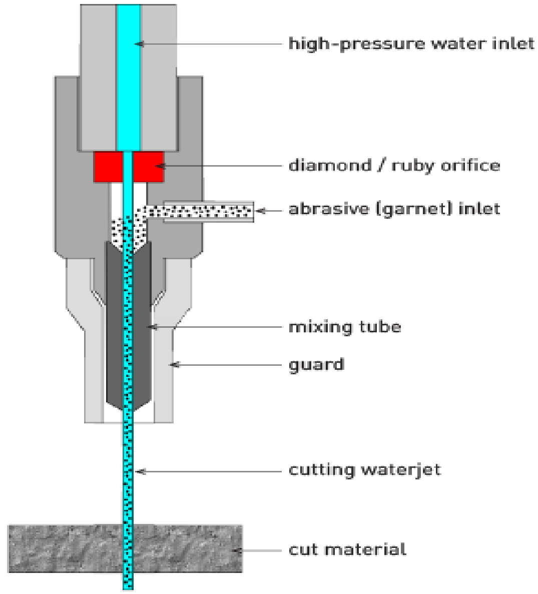


Figure 12. Schematic illustration of Abrasive Water Jet Cutting (AlphaLaser_Cutting, 2019)

Abrasive Water Jet Cutting Calculation: (J. Zeng, 1999).

i. Abrasive Water Jet Cost per hour (C_{ab}): this is the sum of the total cost of the three categories:

$$C_{ab} = C_o + C_p = 40{,}83 \text{ Euros/ hr} \tag{13}$$

C_{ab} = abrasive jet cost per hour, C_o = operational cost, C_p= labor cost

ii. Operational Cost (C_o): cost incurred during the cutting process

$$C_o = C_e + C_w + C_a \tag{14}$$

$$C_e = C_{ue} \; x \; E \quad = 4.2 \; EUR$$

(15)

$$C_w = c_w \; x \; Q_w \quad =0{,}1\text{EUR/hr}$$

(16)

$$Ca = c_a \; x \; Q_a \quad = 23{,}10 \text{ Euros/hr} \qquad (17)$$

Hence C_o = 27,4 Euros

C_e=cost of electricity, C_w= Cost of water, C_a= abrasive cost,

C_{ue}= unit cost of electricity, E= electrical power consumption, c_w=

Q_w= water consumption, c_a = unit abrasive cost, Q_a= abrasive consumption

iii. Manufacturing Cost: hourly pay of worker multiplied by manufacturing time (J. Zeng, 1999).

$$C_m = C_{pay}\ x\ t_m \quad (18)$$

where $$t_m = \frac{L}{v} \quad (19)$$

$$v = [(f_a\ .\ N_m\ .\ P_w^{1.594}\ .\ D_o^{1.374}\ .\ M_a^{\ 0.343}) / (c.q.h.\ d_m^{\ 0.618})\ ]^{1.15} \quad (20)$$

f_a= abrasive factor, N_m= machinability number, P_w= water pressure,

D_o= orifice diameter, M_a= abrasive flow rate, c= system constant,

q= quality index level, h= work piece thickness, d_m=mixing tube diameter

t_m= manufacturing time, C_m= manufacturing cost, C_{pay}= cost of workers

L = cutting length, v= cutting speed

iv. Abrasive Water Jet Cost per meter:

$$C = C_{ab} / v \qquad C = 4{,}39 \text{ Euros /m} \quad (21)$$

C= abrasive jet cost per meter

Appendix 2 give all the variables and their units used for the calcualtion

4. WELDING COST ESTIMATION OF GMAW AND SAW FOR S355 AND S69QL

Recently there has been an increase in the demand and use of high strength steels for structural applications, which means more welding is being performed on this material as the base material. With the shift in use from mild steels to high strength steel, this brings some changes in the use of consumables and welding parameters; these changes, in turn, affect the cost of welding products for the various material. This section brings forth a good cost estimation model for the welding production of both materials, compare the materials and determine which material has higher cost in terms of welding production for SAW. In each of the welding processes, four major categories that significantly affect the welding cost are identified namely: Equipment cost, Consumable cost, Labor cost, and Quality cost.

The materials used for the case study are S355J2 mild steel and S690QL high strength steel. These materials are both structural steels, which mean they are recyclable, has high strength to weight ratio, carbon content between 0.05% to 0.25% (Gilbert, 2012). S355J2 is one of the four variations in the S355 grade steel (S355JR, S355J0, S355J2, and S355K2), Table 1 below shows the chemical composition of S355J2 with its maximum quantity of entities. Appendix 3 gives the additional information for this material.

Table 1. Chemical composition of mild steel S355J2

Chemical compositions and Percentages	C%	Si %	Mn%	P%	S%	N%	Cu%
	0.2	0.55	1.6	0.025	0.025	-	0.55

S690QL is a high strength low alloy structural steel, which has suitable welding and bending properties; this material is mostly used to reduce weight in structures. The table below shows the properties of S690Q. Appendix 4 gives a detailed chemical and mechanical composition of the material.

Table 2. Chemical composition of high strength steel S690QC

Chemical Composition	C %	Si %	Mn %	S %	P %	Cu %	CEV
	0.2	0.5	1.5	0.005	0.02	0.2	0.52

4.1. Welding Cost of GMAW for S355J2 and S690QL

Implementing the four categories: in calculating, the cost of welding production for this material will include:

i. Machine cost (cost of welding equipment and any other equipment to aid the welding process), tooling cost (if there are fixtures concerning the welding process), and Power cost (the number of working hours of the welding machine).
ii. Consumable cost includes material cost (such as filler materials, shielding gasses, Flux).
iii. Labor cost includes the level of skills of the operator, the preparation time and hourly pay of the operator.
iv. Finally, the Quality cost, and technician cost, which is all about the cost to make the weld joint, which will correspond with the required quality and standard.
The sum of all these four categories will represent the total cost of the welding joint by the GMAW process.

All the values used for the calculations for the various cost aspects can be seen in appendix 5. The welding parameters for GMAW can be seen in table below for both materials

Table 3. Welding parameters for both steel plates

Parameters	**S690QL**	**S355J2**
Groove type	Double Y groove	Double Y groove
Filler material	Union NiMoCr, 1.2 mm	Elgamatic 100, 1.2 mm
Shielding gas	M22/Ar+8%CO2	M22/Ar+8%CO2
Power	7.2kW	9.0kW
Number of passes	12	10
Welding speed (mm/s)	12	10
Welding time (s)	25	30
Thickness	25mm	25mm

4.1.1. Consumable Cost:

The rate, at which the consumables are consumed, will depend on the welding position. For our case study, we will be using the flat position 1G, according to AWS. As earlier mentioned this would include all the utilities that are consumed as the welding process is going on:

i. Filler Material: The filler material to be used will depend on the composition of the base metal and required properties of the weldment (where it will be used and the conditions it will be used). The composition of the shielding gas will significantly affect the efficiency of the filler material hence the filler material selected are Union NiMoCr and Elgamatic 100 for S690 and S355 respectively. With this filler wire, the shielding gas combination needed for a great weldment is 80% argon and 20% carbon dioxide. The properties and usage specification of both filler materials are shown in appendix 7. The table below shows the properties of the filler material:

Table 4. Chemical composition of filler materials

Union NiMoCr - Filler material for S690 QL (%)					
C-0.08	Si-0.6	Mn-1.70	Cr-0.2	Mo-0.5	Ni-1.50
Elgamatic 100 - Filler material for S355J2 (%)					
C-0.08	Si-0.85	Mn-1.45	P-0.010	S-0.015	Cu-0.05

The criteria for selecting this filler material is based on the fact that in GMAW the filler material must have yield strength higher than the base material and must make up for some properties the base material lack for the proper functioning. Of the weldment in its required condition (Lincoln Electric, 2014., p. 34)

Appendix 8 gives usage and specification of this filler material.

Studies were done on the relationship between filler diameter and penetration, the higher the diameter, the lesser the penetration (ESAB, 2019.),

Calculations:

Cost of electrode: getting the cost of electrode requires electrode price, weld metal deposited, and filler metal yield percentage. Formula 22 show how it can be calculated (Howard B. Cary, 2006., pp. 520 - 537)

$$Ec = \frac{Ep * W}{Fm} \tag{22}$$

Where: Ec = cost of electrode [€/m] , Ep = electrode price [€/kg]

W = weld metal deposited [kg/m], Fm = filler metal yield % (95%)

$$W = A * \rho \tag{23}$$

Where: A = cross sectional area of weld [m^2], ρ = density of material [kg/m^3]

E_c = 0.39 Euros for S355 and S960 0.34 Euros

4.1.2. Shielding Gasses:

This is another essential consumable in the GMAW. The shielding gas influences the arc and metal transfer, weld penetration, surface shape paten, welding speed and undercut tendencies (Ghazvinloo, Honarbakhsh-Raouf, et al. 2010). The most important aspect to be considered when selecting the shielding gas is its compatibility with the electrode and its penetration reference Welding principles). The compromise between high penetration and less spatter is what every GMAW welding process is faced with, while argon does not produce lots of spatter. It has little penetration, whereas carbon dioxide has lots of spatter and high penetration. This compromise leads to binary shielding gas mixtures. For our welding purpose, selecting the G3SI1 as the filler material, the binary gas mixture percentage recommended is Argon 80% and Carbon dioxide 20%.

Calculation:

Getting the cost of the shielding gas needed will require some variables such as; number of welding passes, gas flow rate, welding time, cost of filler and shielding gas. (Howard B. Cary & Scott C., 2005.)

$$C_{gc} = \frac{C_g * F_r * W_t}{120} \quad (24)$$

C_{gc}= cost of shielding gas used [€], F_r= gas flow rate [m^3/s], C_g= unit of gas cost [€/m3]

W_t = welding time [s]

C_{gc} = 0.100 Euros for S690 and 0.200euros for S355

4.1.3. Equipment Cost:

This section, as earlier mentioned above will consist of machine costs and power costs. These costs are directly related to the operation of the machine.

i. Power Cost: The power consumption will be determined by the quality of the weld required, and this depends on the corresponding parameters for the filler material. With regards to filler material selected for the welding process. Power cost is given by the equation (Howard B. Cary & Scott C., 2005., pp. 525 - 540)

$$P_c = \frac{P_R * V * I * W}{1000 * D_R * OF * \varepsilon} \quad (25)$$

where; Pc = Power cost [€/m], P_R = power rate [€/kWh], V = voltage

I = current, W= weld metal deposited [kg/m], D_R = deposition rate [%]

OF = operator factor [%], ε = machine efficiency [%].

P_c = 0.217 euros for S690 and 0.388 euros for S355

ii. Labor Cost: labor cost and overhead can be considered the same, and they vary from company to company depending on the size of the company and the qualification of the workers. Any welding process is usually determined by the travel speed of the welding, operator factor and the labor rate (payment rate for the operator). This is given by the equation: (Howard B. Cary & Scott C., 2005.)

$$L_c = \frac{W_{pr}}{S * OF * 5}$$

Where: W_{pr} = welder pay rate [€/hr] , L_c = Labor cost [€/m]

L_c = 2.952 euros for S690 and L_c = 2,94 euros for S355

4.2. Welding Cost of Submerged Arc Welding for S355 and S690

This welding had some unique characteristics such as higher metal deposition rate as compared to GMAW, deep weld penetration, high-speed welding and mostly automated**.** The process is slightly different from GMAW in that flux is used in SAW instead of shielding gas. Since both processes fall under the arc-welding category, some formulae used in GMAW will still be adequate to use in SAW, the flux consumption will be calculated as well. Getting the total cost of SAW we will use the four cost evaluation categories as mentioned above in GMAW (machine cost, consumable cost, labor cost, and quality with technician cost). Appendix 6 gives the values used for the calculations.

Parameters for the SAW process is shown in table x below

Table 5. Parameters for SAW process

Parameters	**S690QL**	**S355J2**
groove type	no root gap double Y groove	no root gap double Y groove
Filler wire	Top core 742B, 4 mm	Autrod 12.10, 4 mm
Flux	ST55	OK Flux 10.70
Number of passes	8	6
Welding speed (mm/s)	10	10
Power	20kW	20kW
Thickness	25mm	25mm

4.2.1. Consumable cost:

In submerged arc welding, there are two consumables; feeding wire (electrode wire) and flux. Recently there has an addition of iron powder into the filling runs when welding materials more than 20mm thick. The main reason is to narrow the Heat Affected Zone as compared to regular SAW. The position of welding is still the same 1G (ESAB, 2019.).

i. Flux: The use of flux serves several purposes as earlier mentioned in the introduction, which is: provide a protective cover over the weld, shield and clean the molten, etc. When the flux is poured on to the molten weld, not all of it is used. After the welding is complete, the flux which has not formed slag are collected and reused later. The flux used is OK Flux 10.40. Therefore, the calculation below focuses on the actual amount of flux being used for the welding. Appendix 9 gives the detail composiotn of the flux

Calculation:

Determining the amount of flux used and the cost of the flux will require users to know the amount of weld metal deposited, flux consumption rate and flux cost. flux cost formula gotten from Anoop Desai (Anoop Desai, 2018, p. 159)

$$F_c = W * F_{cr} * F_{cf} * L \qquad (26)$$

where F_c = cost of flux used [€] ,

F_{cr} = flux consumption rate (1) (Anoop Desai, 2018)

F_{cf} = cost of flux [€/kg], W = weld deposition [kg/m]

F_c = € 0.0923 for S690 and 0,080 Euros for S355

ii. Filler Material: the filler material or electrode used is Ok Autrod 12.20 it properties. Same formula as applied to GMAW will be used for SAW filler material. Appendix 10 gives more detail about the filler material.

Calculation:

$$Ec = \frac{Ep * W}{Fm} \qquad (27)$$

Where: Ec = cost of electrode [€/m] , Ep = electrode price [€/kg]

W = weld metal deposited [kg/m], Fm = filler metal yield % (98%)

$$W = A * \rho \qquad (28)$$

Where: A = cross sectional area of weld [m^2], ρ = density of material [kg/m^3]

(36)

E = Deposition efficiency for SAW ranges from 97% to 99% so we will select 98% (Anoop Desai, 2018)

E_c = € 0.14 for S690 and 0,170 for S355

4.2.2. Equipment Cost:

This takes into account any cost that has a direct relation to the operation of the machine during the welding process, these include; machine cost and power cost

i. Power Cost: cost will consist of the energy consumption parameters such as current, voltage, machine efficiency, power cost, etc.

$$P_c = \frac{P_R * V * I * W}{1000 * D_R * OF * \varepsilon} \quad (29)$$

where; Pc = Power cost [€/m], P_R = power rate [€/kWh], V = voltage

I = current, W= weld metal deposited [kg/m], D_R = deposition rate [%]

OF = operator factor [%], ε = machine efficiency [%].

P_c = € 0.38 for S690 and P_c = € 0.24 for S355

ii. Labor Cost: The labor cost for any welding process is usually determined by the travel speed of the welding, operator factor, and the labor rate (payment rate for the operator). This is given by the equation:

$$L_c = \frac{W_{pr}}{S * OF * 5}$$

Where: W_{pr} = welder pay rate [€/hr] , L_c = Labor cost [€/m]

L_c = € 2.90 for S690 and L_c = € 2.86 for S355

5. LIFE CYCLE ASSESSMENT OF A HIGH STRENGTH STEEL STRUCTURE

For the past 20 years, the European Union has had sustainability and sustainable development at the core of its policies and legislation; they have put various strategies in place, such as EU Sustainable Development Strategy, amongst others. The purpose of these strategies is to ensure stability in economic growth and prices, a highly competitive social market economy. Aiming towards full employment and a high level of protection and improvement of the quality of the environment. (European Commision, 2019.) Sustainable manufacturing ensures green products that cut through the three pillars of sustainability: environmental, social and economic. Each product is studied using Life Cycle Assessment (LCA), which is a tool used to know the environmental impact of the processes and the products. (K S Sangwan, 2016, p. 2).

LCA is a process of evaluating all the inputs and outputs entities such as materials and energy, which are related to the product, product system, and production process. These entities are assessed throughout the lifetime of the product (from production to recycling) to know how they influence the environment (ISO 14040, 2006, p. 13). This process has three major impact categories as shown in figure 12. However, some aspects of our work have direct effect on these categories. Hence the environmental assessment which is part of the life cycle assessment will be used.

Green House Effect:
Assesses increased temperature as a result of green house gases (CO_2, CH_4, N_2O etc)

Acidification:
Assesses acidic elements caused by atmospheric polution(SO_2, NO_2, etc)

Eutropicahtion:
Assesses build up of chemical nutrients in the ecosystem (Nitrogen and Phosporus)

Figure 13. Life cycle major impact categories

LCA is generally studied in four phases, as shown in figure 13 below; it also shows the relationship between these four phases. This chapter is made of four topics (Joint preparation assessment, production assessment, product utilization assessment, and recycling assessment); the LCA of each topic will be analyzed using the four LCA phases.

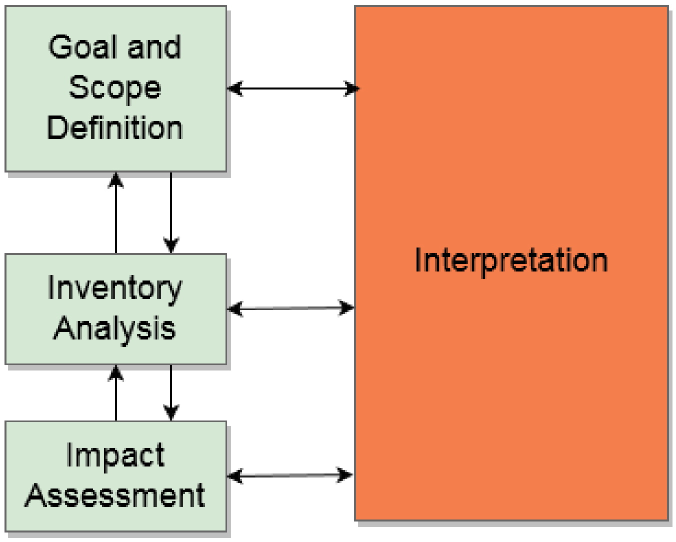


Figure 14. Four phases of LCA (ISO 14040, 2006)

5.1. Joint Preparation Assessment:

For steel to be welded into a structure it goes through the joint preparation which is cutting the steel into a joint design feature. In this section, we will examine milling cutting process which is prominent.

5.1.1. Machining process:

The milling process will be our focus. It is most widely used due to its high achievable tolerances, and high quality surface finish. The four LCA phases will be used to get the LCA of milling process with steel.

- Goal and Scope: The aim is to look at the overview milling process and see how some of its components affect the environment, such as energy and scrap. Furthermore, to see how this process could be improved to reduce its environmental impact.
- Inventory Analysis: These are the various components that make up the milling process. They are divided into input, out and control as shown in figure 15. Input consists of everything that goes into the milling machine. Control consists of the control parameters to get the required finished product, and output consists of everything that goes out of the milling machine during the milling process.

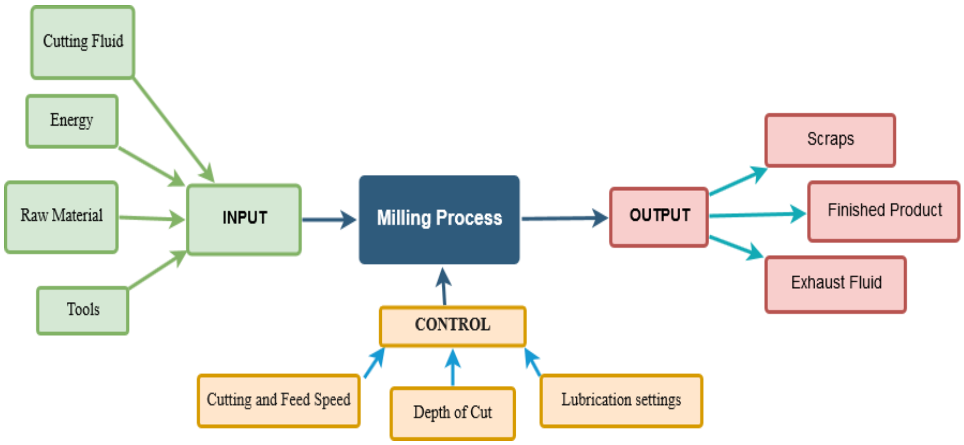


Figure 15. Inventory Analysis of milling process.

Impact Assessment: The environmental impact stems from major identified scenarios: energy and metalworking fluids. For energy, studies have analyzed the exact energy needed for a cut and the total energy needed by the milling machine. The studies done by Gustowski (Gutowski. T, 2005, pp. 1-17) and Kordonowy (Kordonowy, 2002), show the energy required in various milling machines ranging from highly automated to automated machine and manual milling machine, the comparison can be seen in figure 16. The actual energy needed for the milling process decreases with an increase in automation.

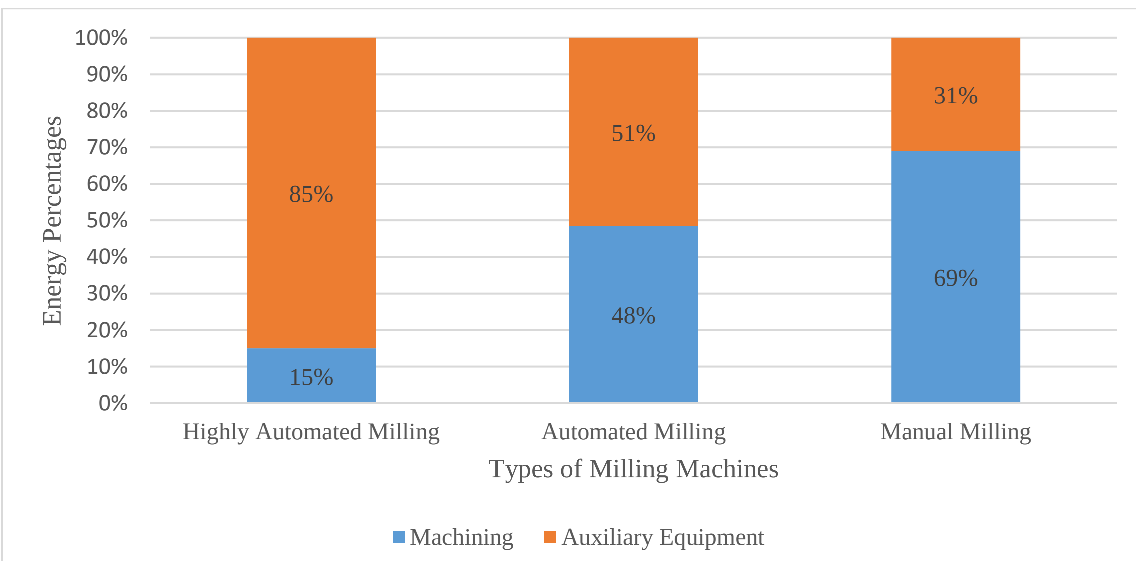


Figure 16. Comparison of milling energy consumption by various milling machines.

For metalworking fluids, there are two distinct ways of applying the fluid during the milling process; flooded or minimal quality liquid. Either way, there is the use of fluid and waste being produced. These fluids will have both environmental and health effects depending on its composition, the material and the machining process. Healthwise, the operator may be in contact with the fluid by evaporation due to high working temperature, or by the rotation of spindle or workpiece, the fluid is dispersed, and finally the high-pressure impact of the fluid on the tool or workpiece causes spatter of the fluid. (Marian Schwarz, 2014, pp. 37-45). With inhalation side effects may range from irritation of throat to nosebleeds, bronchitis, and pneumonitis. While for physical contact, it can cause irritation and allergy. All of these still depend on the chemical composition, metal composition and the individual (Marian Schwarz, 2014, pp. 37-45) (Thompson D., 2005, pp. 153-60). Environmentally the waste from the cutting fluids is approximately ten times higher than the estimated annual consumption of steel, which is more than $2x10^9$ (Marian Schwarz, 2014, p. 42). The waste fluid could be treated aerobically or anaerobically. Chemical oxygen demand (COD) is used to quantify the number of oxidizable pollutants found the effluent. Hence with the two treatment processes, 88% of COD can be removed by aerobic treatment while only 64% can be removed by anaerobic treatment. For non-biodegradable substances in the effluent, 35% was found using anaerobic treatment while a lesser amount was found using aerobic treatment. (Thompson D., 2005)

5.2. Welding Process Assessment:

Welding processes, which are a crucial part of manufacturing, require enormous amount of energy and resources, which bring about metal waste. Hence, environmental assessment of these processes are mostly limited to fumes, greenhouse gasses, and energy emission. (Gunther Sproesser, 2015, p. 46). The problems created by the welding processes can be divided into two parts: environmental and social. For the environmental harms, it can be assessed in four main impact categories: global warming potential, acidification potential, eutrophication potential, and Photochem ozone creation potential. While for the social harm of the welding process could be assessed from three categories; toxicological effect (oral toxicity, eye irritation and dermal irritation), cancer effects (risks of beings exposed to carcinogenic substances) and physical effect (flammability and chemical reactivity) (Yeo S. H, 1997, p. 79)

- Scope and Goal: The goal is to carry out the LCA of the submerged arc welding process. This will be limited to input parameters and the process itself; social impacts will be limited to physical effect and finally environmental impacts.
- Inventory Assessment: Material acquisition, all the various variables, and parameters that are combined to produce the welding process, the wastes after the welding process, and waste management are considered in the inventory assessment. Figure 17 shows a general inventory assessment of a welding process, and it shows the system boundary for the welding process. The focus for this LCA will be on the input, manufacturing process and outputs.

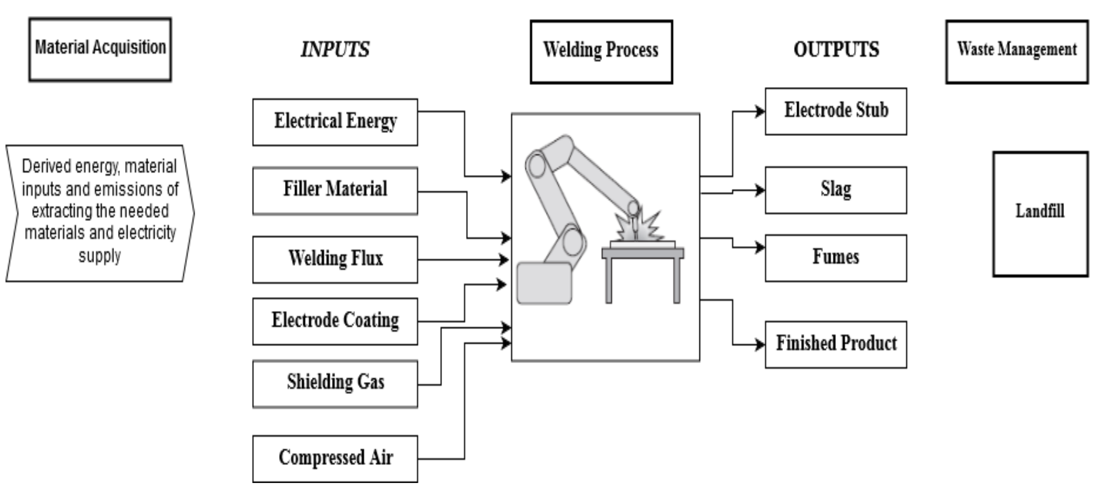


Figure 17. General system boundary of welding processes. (Gunther Sproesser, 2015, p. 48)

LCA software is used to analyze and assess each input variable in the process. For each input product, the software starts analysis its effect from material acquisition phase to the actual product. The sum of the effects of all inputs are calculated and expressed graphically in the four main categories

- Impact Assessment: Depending on the welding process, most of the waste produced are slag, fumes and electrodes stub. Amongst all of these, electrical energy and fumes are known to be affecting both environment and health. Fumes entities produced vary with the welding process, welding parameters, and welding materials. A general constituent of fumes produced by welding processes as shown in figure 18 can be categorized into two; Particles and Gases, which are subdivided into pneumoconiosis and toxic inhalants, primary pulmonary and non-pulmonary respectively.

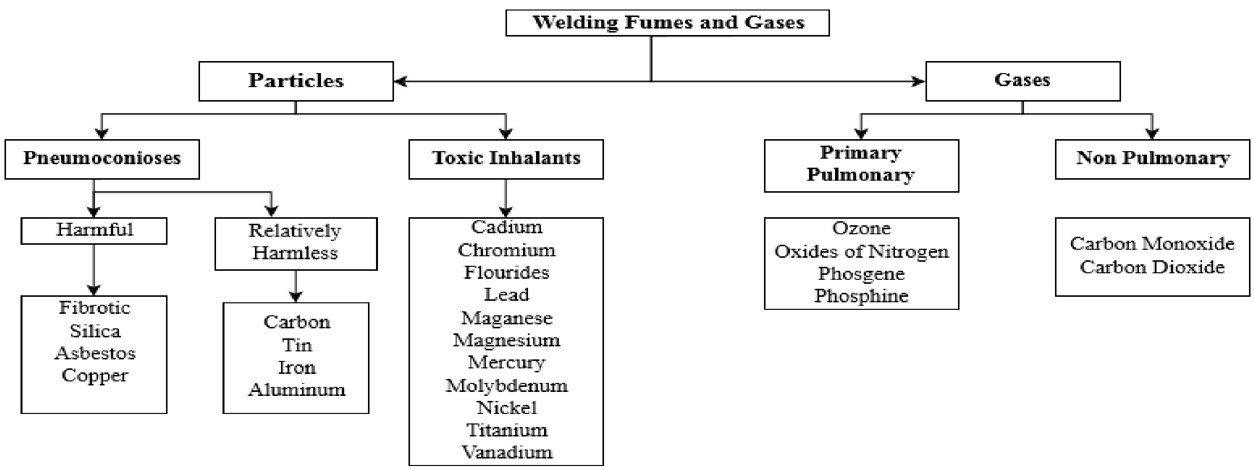


Figure 18. Possible Constituents in Welding Fumes (S.H. Yeo, 1997, p. 82)

Concerning Energy consumptions and environmental impact, three welding processes with the same welding workpiece were studies and analyzed (MMAW, GMAW, and LAHW). Arc welding machines generally have about 80% efficiency as oppose to 30% of LAHW, but LAHW showed the process with the least environmental impact. This is because of its high power density making it possible for least number of passes and weld volume. Its high welding speed means low electricity and gas consumption hence high productivity. Comparing the power consumed and welding time, the low efficiency is overcompensated by saving welding time. (Gunther Sproesser, 2015, p. 51). MMA is said to have the most environment effect, because of its low deposition rate and welding speed, which results in high energy consumption as more energy is needed to melt the weld metal in the subsequent passes. Hence high energy loses due to heat conduction in the base material (J.N. DuPont, 1995, p. 412). For arc welding processes such as MMAW and Submerged arc welding (SAW), when considering material, electricity, fumes flux core and shielding gas, SAW has a lesser environmental impact due to its lower fumes generation (Gunther Sproesser, 2015, p. 47)

5.3. Product Utilization

In this section, the main concern is to evaluate how the two different grades can be used and how they affect the environment during their usage. The general statement commonly used when evaluating the environmental effect of both plates of steel in their use phase is; considering the environmental impact value per ton of steel, the impact increases with an increase in yield strength. However, looking at the long term and overview, less amount of high strength steel is needed to perform same function hence making it more environmentally friendly as compared to mild steels (Göran Andersson, 2013, p. 48). Using the root formula in equation 40, the weight reduction was calculated high strength steel, giving us an approximate of 29% percent of weight reduction from mild steel to high strength steel

$$\frac{\text{weight HS}}{\text{weight MS}} = \sqrt{\frac{\sigma_{MS}}{\sigma_{HS}}} \quad (40)$$

where: σ_{MS} and σ_{HS} are the yield strength coefficient respectively

For getting the environmental impact of steel structures, they are divided into two structures; passive structures and active structures. Passive structures are those, which are fixed at a particular location, perform a particular task with no external assistance examples include; tanks, furniture, shelves, and process systems. While active structures are those such as cars. (Göran Andersson, 2013, p. 55). Passive structures most often have insignificant environmental impact during their utilization phase. However, the environmental benefits for upgrading steel to high strength steel are mainly related to the consumption of lesser amount of steel. Hence lesser amount for transportation. The life cycle of the structure increases with an upgrade of steel strength, also incorporating more corrosion resistant properties of using high corrosion resistant steel my increase the life cycle of the structure (Göran Andersson, 2013, p. 55)

5.4. Recycling of Product

With sustainability at the core of every production, recycling the product is a drive from a linear economy (take, make, consume and dispose of) to a circular economy (take, consume, reused, and or remanufacture). The circular economy significantly reduces the cost in terms of energy, natural resources and reduced pollution (Broadbent, 2016). This means reducing the need for resource extraction and increasing the recycling of end products, which required less energy consumption hence lower emissions and less environmental impacts. Steel, which is the main focus is known to be the metal with the highest quantity usage and also gives the highest environmental impacts annually. The quantity of steel used is about 8 to 9 times greater than the other metals combined. The next five metals, which are manganese, nickel, titanium, cobalt, and chromium, are still incorporated into steel as alloying elements or coating. (Jim Bowyer, 2015)

The steady increase in demand for steel has been a result of the world's population increase, which leads to an increase in consumption of resources. This means more and more steel is needed to meet up with the demand, but there are limited recourses for which the steel can be produced primarily. Hence an increasing need for steel to be produced secondary through recycling. Figure 19 shows the rise in demand for steel from 1950 to 2017. With this demand, there is high need for recycling of steel to meet up with the demand and maintain a sustainable and less polluted environment.

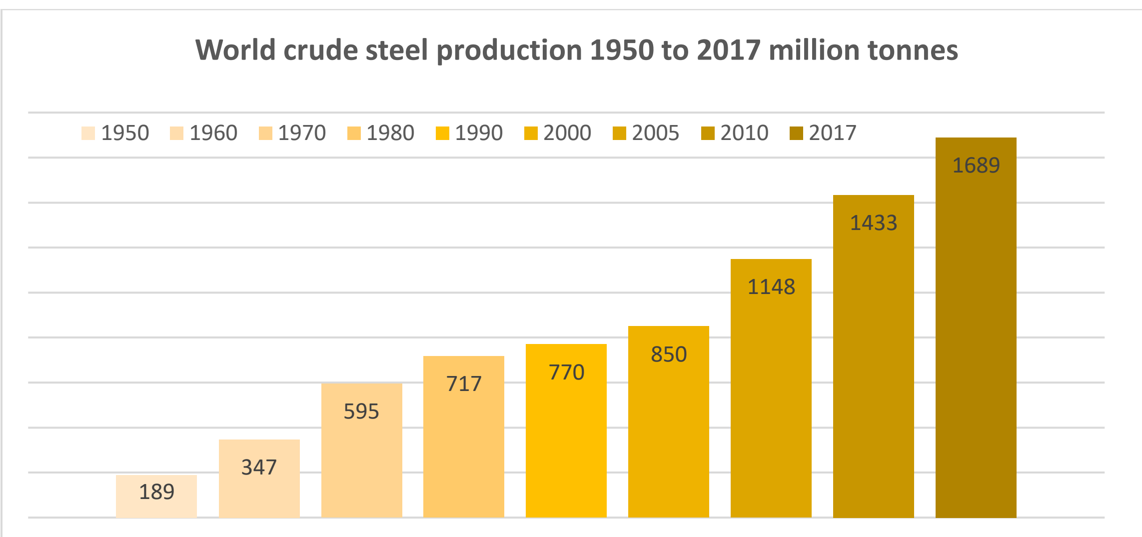


Figure 19. World crude steel production from 1950 to 2017 in million tones (EuRIC, 2018)

5.4.1. Recycling Approach

Currently, there are three approaches to recycling in general; the Cut off approach, the end of life approach, and the 50-50 approach. Amongst these three approaches, the end of life will be our focus. The end of life approach mainly encourages products to be recycled at their end of life, hence reducing pollution in landfills and saves natural resources when creating new products (Broadbent, 2016). Steel is an excellent product that the end of life approach is being applied to because steel is 100% recyclable. This means at each product end of life; the steel can be recycled into another product or same product (WorldSteel_Association, 2019). From the studies done by world steel association in 2017, there has been increased in the percentage of recycled or recovery of steel in every steel usage sector. This is shown in the table below, with the automotive and machinery sectors trumping the recovery rate over construction and electrical appliances.

Table 6. Steel-Recycling Rates by Sectors in 2017 (WorldSteel_Association, 2019)

Sectors	Recycling Percentage
Machinery	90%
Automotive	90%
Construction	85%
Electrical and home appliances	50%

Applying the end of life recycling approach to achieve a circular economy with steel will entail every steel product at the end of its life has to be recycled with little or no virgin material (Iron Ore) added into the system. There are two type of loops in the end of life approach as allocated by ISO 14044: 2006 standards for recycling procedures; open and closed-loop (ISO_14044, 2006). The open-loop recycling describes a product system in which the material is recycled, and the inherent material properties are changed. With regards to steel, an open-loop product system will be one in which the recycled material is made to have different mechanical properties from the original or previous material such as higher yield strength and toughness. Which will be used for a different product (ISO_14044, 2006). The closed-loop recycling describes a product system in which the recycled material is used for the same product type or the inherent properties of the recycled material is not changed. Concerning steel, a closed-loop system will recycle a product material to produce same product with same properties (ISO_14044, 2006). For most parts, steel recycled is regarded as closed-loop because most recycled materials do not have a change in inherent material properties (Broadbent, 2016). Figure 20 shows an illustration of how the circular economy can be achieved with steel, creating a loop.

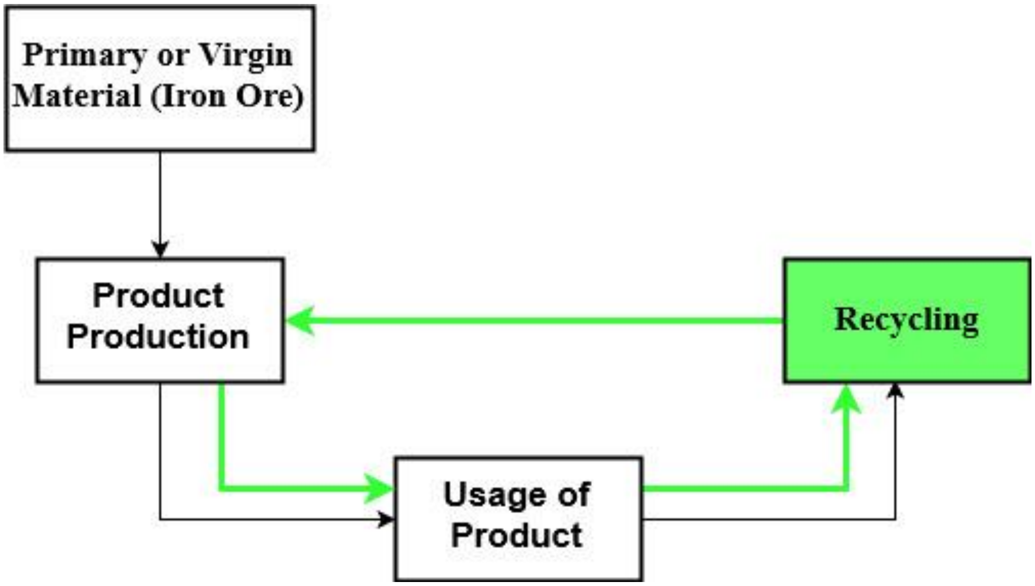


Figure 20. End of Life recycling approach (Anna Nicholson, 2009).

5.4.2. Steel Recycling Process:

Steel production is divided into two categories: Primary steel production, which is the manufacture of iron from iron ore in basic oxygen furnace (BOF), which is then used to make steel. Secondary steel production, which is also referred to as recycling, converts scrap to new steel by re-melting old steel (Broadbent, 2016). There are two processes for recycling steel basic oxygen furnace (BOF) and electric arc furnace (EAF)

- Basic Oxygen Furnace (BOF): This process is mostly used for primary production of steel, but often, about 10 – 30% of scrap is used as iron input in the BOF process. Since there is the use of scrap in the production process of some steel, it is quite acceptable to call the process a steel recycling processes. About 30 – 35% of scrap can be processed in the production of steel (Jim Bowyer, 2015)
- Electric Arc Furnace (EAF): This process is primarily used for the recycling of steel, but however, this process can also be used for primary production of steel. When this process is used for secondary steel production, about 100% of scrap can be used as input for the production of secondary steel (Jim Bowyer, 2015).

  Hence, both processes can be used for the production of primary and secondary steel; the difference is just in the quantity of iron ore and scrap needed to produce primary and secondary steel respectively.

Figure 21 illustrates the size of the arrows concerning the scrap and iron ore, the dominant processes used to produce a steel type. From the figure more scrap is collected processed in EAF process to produce secondary steel, and more iron ore is used to produce primary steel with BOF process.

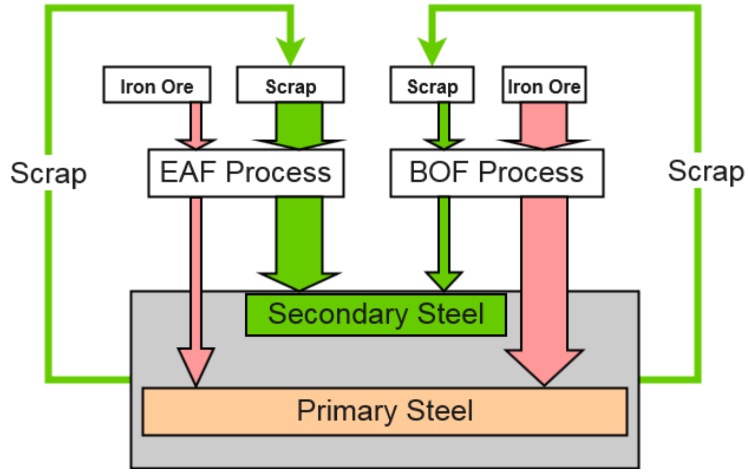


Figure 21. Primary and secondary steel production

Figure 21 gives a general perspective of the various processes, but taking it one step forward is comparing the process numerically, which is done in figure 22. Data was collected from the world steel association. A comparative analysis can be made between the two processes, the average amount of various inputs needed and the average amount of steel produced. For the same amount of crude steel to be produced by both processes, BOF requires more iron ore, limestone and coal than EAF. Whereas more scrap is needed by EAF. Hence EAF is the preferred process for a green and circular economy.

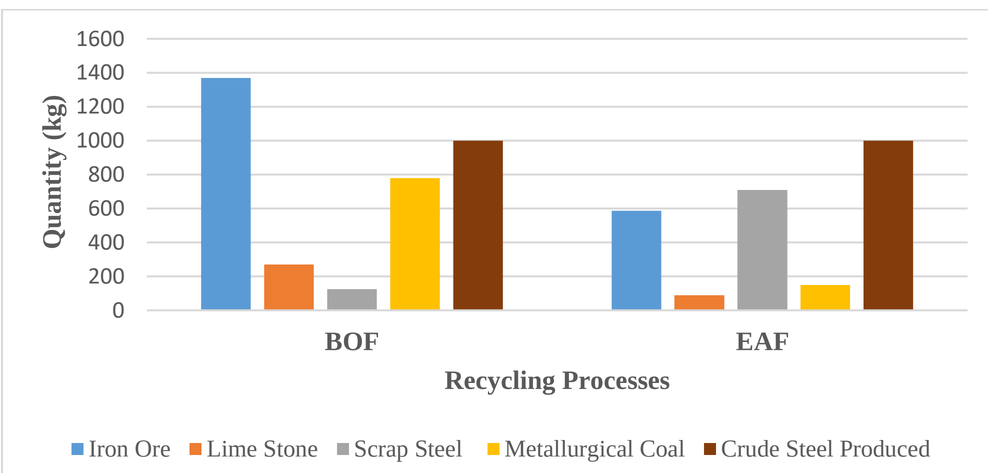


Figure 22. Comparison of the recycling processes

5.5. LCA of welding processes

The LCA of the welding processes is done using the software called GaBi 6.0, and for each welding process, the inputs and output data are collected and simulated to get their corresponding values in the various impact categories we will be analyzing. These impact categories include;

Global warming potential (GWP): this is a category that quantifies the greenhouse effect for substances that have same effect as carbon dioxide in reflecting heat radiation in the lower atmosphere. Global warming potential is quantified and expressed as CO_2 – equivalents (CO_2-eq.). So if a process or substance is simulated to get its global warming potential, this means the software is trying to quantify its equivalence effect on the greenhouse effect as CO_2. This equivalence is usually quantified in a period of about 20, 100 or 500 years. For our case study, 100 years will be use (Heidi K. Standdorf, 2005, p. 40). Substances that contribute to the impact of this category include; CO_2, methane, nitrous oxides including halons and carbon monoxide.

Photochemical ozone creation potential (POCP): this impact categories gives the relative value of the amount of ozone produced from a particular volatile organic compound. This value is obtained by dividing the amount of ozone produced from an equal significant emission of ethene. POCP is what it is refereed in Europe but in America is it Incremental Reactivity (Carter W. P. L, 1995). The unit used for the measurement is grams of ethene equivalence per gram of gas (g C_2H_4/gVOC). Generally ethene has been selected to be the reference gas because it is one of the most potent ozone precursors of all VOCs.

Acidification Potential: this impact category quantifies substances that have the same effect as SO_2 in reflection of acidification. It is expressed as SO_2-equivalence (SO_2 –eq). Hence, each value expressed in the acidification potential is relative to the potential of SO_2.

Eutrophication Potential (EP): eutrophication occurs when there is excess of nutrients in water and soil. These nutrients are mostly nitrogen and phosphorous. Hence EP is the measure of the potential effect a substance has on eutrophication of water and soil. The EP value of the substance is directly proportional to the environmental damage. EP is expressed in kg phosphate equivalence (kg phosphate eq.)

There are other impact categories such as Ecotoxicity, human toxicity, nutrient enrichment, stratospheric ozone depletion, et cetera. However, these will not be covered in this write-up.

5.5.1. Life cycle inventory

Life cycle inventory is a record of the various inputs and their quantities that were used in the GaBi 6.0 software to simulate the environmental impact of the various welding processes

Table 7. Inventory for life cycle assessment

Parameters	**Gas Metal Arc Welding**	**Submerged Arc Welding**
filler material (g)	890	890
Shielding gas (l)	100	-
flux (g)	-	200
Energy consumption (kWh)	2.1	3
slag (g)	-	280

Assumptions:

Titanium oxide was used in the place filler material because this was the closest and also it is same input used for other GaBi welding anaylsis due to the fact welding inputs are limited in GaBi.

Recovered flux was about 80g.

6. RESULTS

Joint preparation for thick plates can be done with various cutting processes. Some cut calculations were done on a sample of steel S690QL and S355. The formulae used in these calculations were one of the different ways of calculating cost. However, these formulae used were most suitable to know the different cost of welding these two plates of steel since there are just little differences in the welding speed, number of passes, voltage, and current. Hence selecting an equation that will incorporate these differences was seen as best option. Calculations where done for plasma cutting, abrasive cutting, oxyacetylene (oxyfuel) cutting, and milling. From the chart shown in figure 23 below, oxyfuel cutting is the most economical means of cutting steel with €0.92 per meter cut of steel.

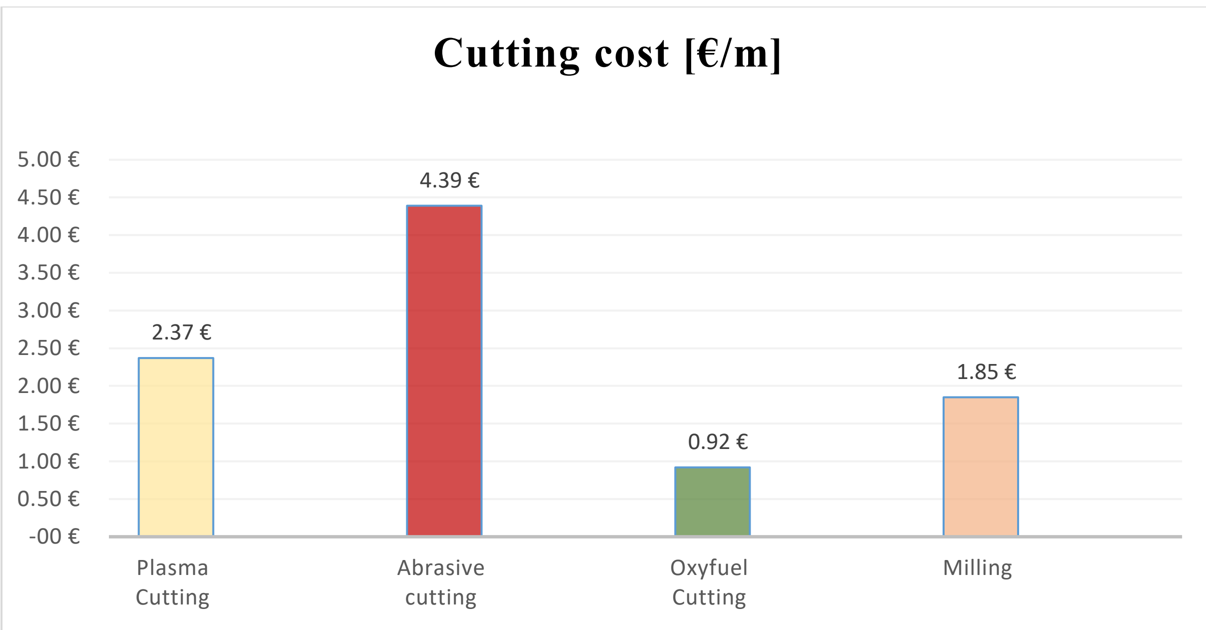


Figure 23. Cutting of Plasma, abrasive water jet, oxyacetylene, and milling

So in comparison to all the cutting processes discussed in this write up, oxyacetylene cutting is most recommended for the cutting of steel but using other cutting processes will be depended on the quality of cut needed, the amounts of cuts per day (say if the company does mass production), and how environmentally conscious the company is. This will mean cutting processes like plasma and laser cutting can be used for high-quality cutting. These processes will also depend on the thickness of material being cut as this limitation makes oxyacetylene cutting highly recommended because it can cut a vast range of thickness. One limiting factor of oxyacetylene cutting is the fact this process uses oxidation as mean process of cutting. Hence limiting its cutting only to ferrous metals. Our cutting profile is a Double V groove, which involves beveling. When using flame cutting, more preheating is required and standard vertical cut. It is because the torch is tilted to the angle required hence, some of the heat bounces off the surface of the material.

Abrasive is the most expensive means of cutting steel with a cost of €4.39 per meter cut. Its thickness of cut ranging from about 50mm to 75mm. Its advantage over other cutting processes is that it can be used to cut any type material from steel to food. One of the aspects that make the cost high is the cost of the abrasive used. There are ongoing research to see how to produce cheaper and better abrasives that will reduce the cost of cut and also the cost of machine is a huge factor.

The cost estimation for the welding processes was centered around filler cost, shielding gas cost, labor cost, power cost, and flux cost. The machine used for the GMAW process for welding the S690 and S355 steel was Kemppi X8 Pulse MIG Welder, with a purchase price of 18 000 €. While the machine used for SAW for S690 and S355 was Power source+ tractor: Pandaweld ASAW630II-CE, with a purchase price of 18 000 €. Full details about the machines can be found in appendix 11.

All calculations were done using the steel samples of same thickness of 25mm, and a welding length of 300mm, welding position 1G was used for both process, welding time for both plates of steel varied depending on the welding speed and voltage used by the machines. Details are found in appendix 5.

For the GMAW process, the total cost was gotten from the sum of labor, shielding gas, electrode, and power cost. Figure 24 shows the cost results and analysis for welding S690 and S355 using GMAW process. Each cost was made for both plates of steel and from the results, the most aspects that cost in the welding process is labor cost, which is about €2,95 for welding the S690 steel and €2,14 for welding the S355 steel. The second costly aspect for the welding process is the cost of electrode required for welding. The sample steels €0,34 for S690 and € 0.44 for S355. This was mainly affected by the cost of electrode per kg which was about €3/kg. Shielding gas was noticed to have a minimal cost in comparison to other aspects. It has got to do with the cost of the shielding per m^3, the efficiency, and gas flow rate of the machine.

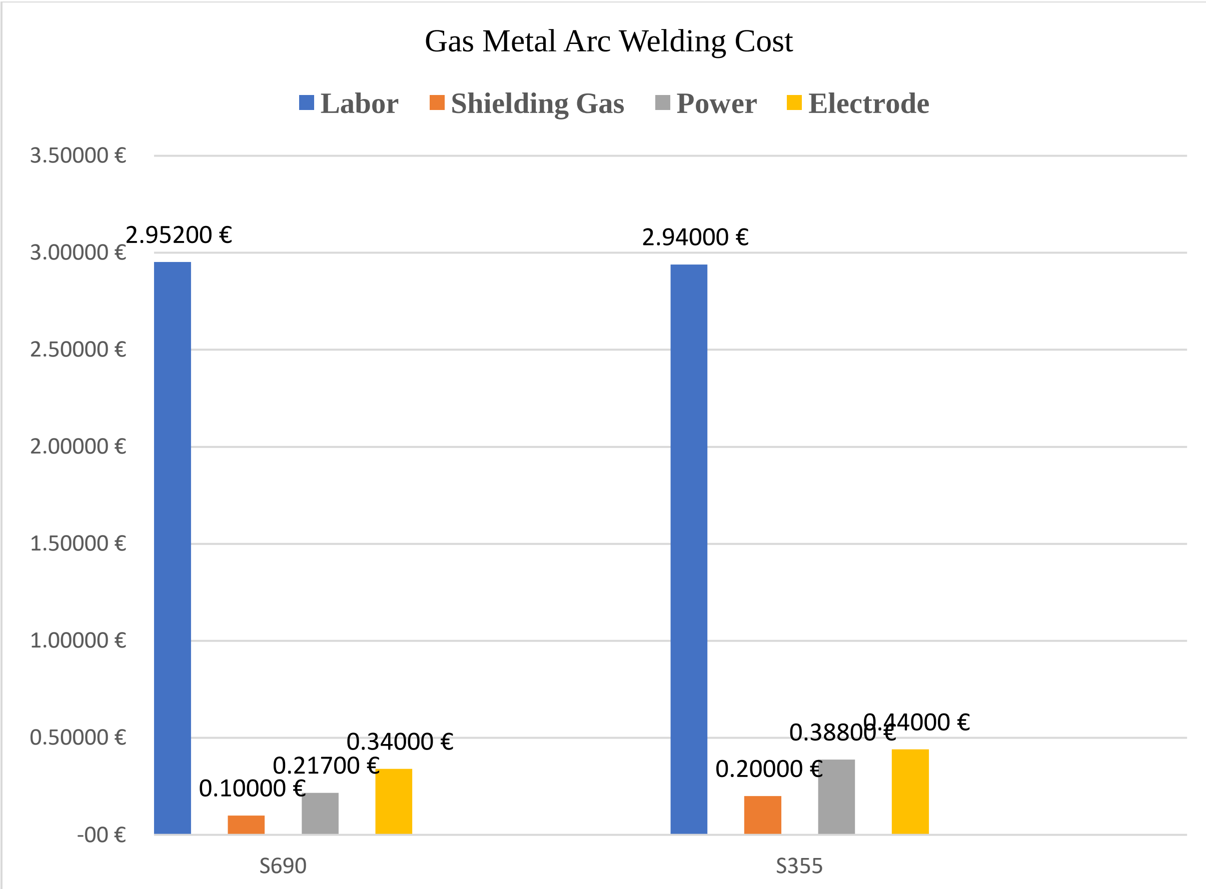


Figure 24. Gas metal arc welding cost for S690 and S355

The total cost for GMAW of S690 was €3,607, and the total cost for S355 is €3,968. This means for the sample material and specifications, welding the 25mm thick plate with 300mm weld length cost €3,607 for S690 and €3,968 for S355. Hence welding S690 of same thickness is cheaper than welding S355.

Percentage-wise figure 25 shows labor occupies the highest percentage in the cost of welding with 82%, 9% for electrode, 6% for power and 3% for shielding gas.

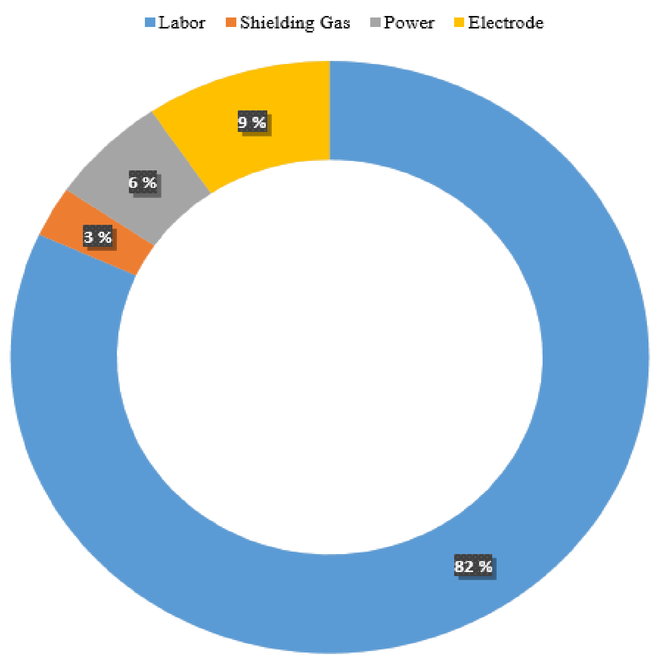


Figure 25. Percentage cost of various categories

For the SAW process, the same aspects for calculating the welding cost were used and showed in figure 26 below. The results show that the total cost for welding S690 steel plate is €3,47/m while the total cost for welding S355 steel plate is €3,60/m. Labor cost is about €2,90, Power cost 0,24, flux cost 0,09 and electrode cost 0,140 for welding S690. for welding S355, labor cost is about 2,87, power cost 0,380 euros, electrode cost 0,17 euros and flux cost 0,080 euros.

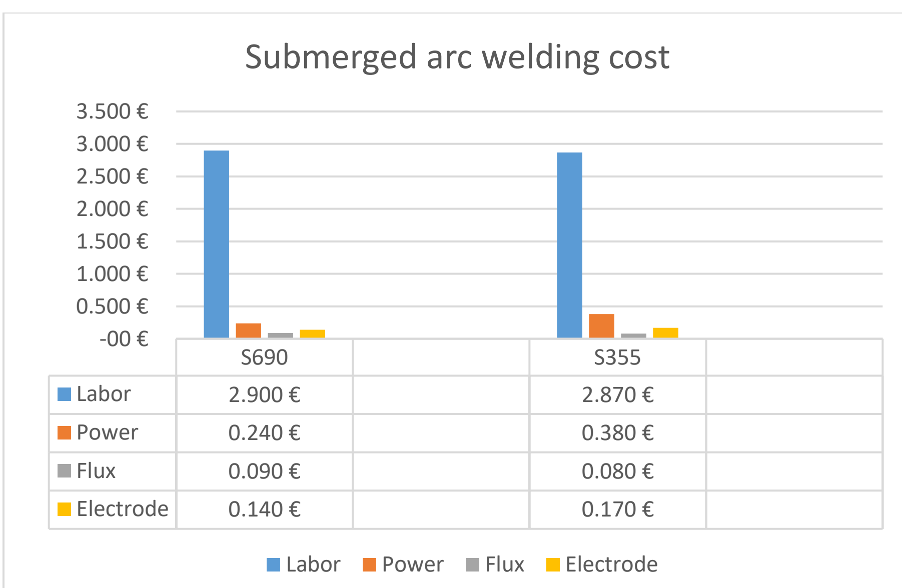


Figure 26. Submerged arc welding cost for S690 and S355.

Percentage wise figure 27 shows labor occupies the greatest for both welding processes with about

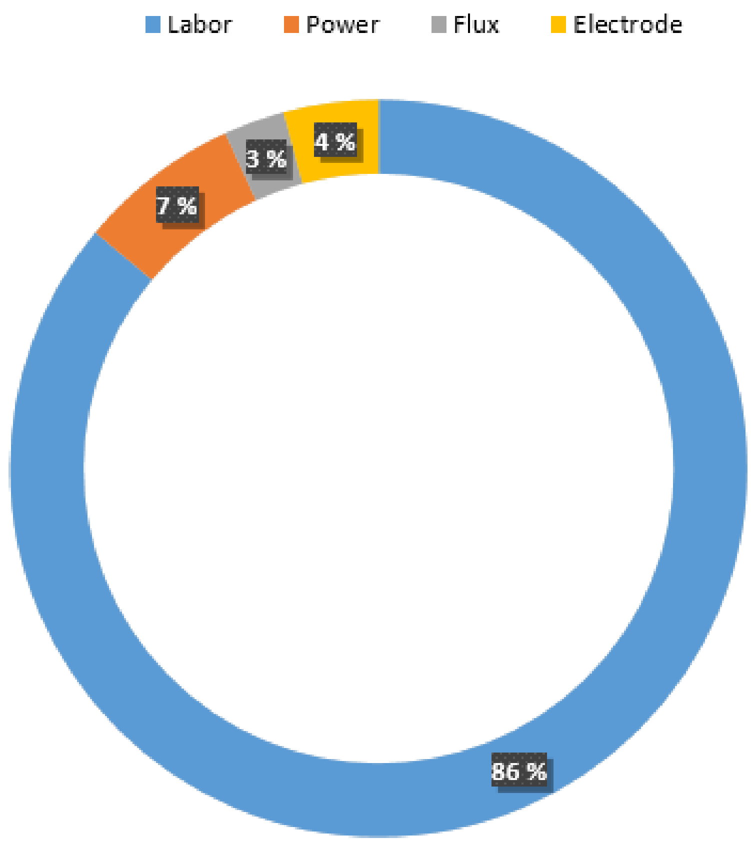


Figure 27. Percentage cost occupied by various categories

Carrying out the life cycle assessment with CML 2001 method, and GaBi 6.0 software, the environmental impact categories; global warming potential (GWP), eutrophication potential (EP), acidification potential (AP) and Photochem ozone creation potential (POCP) were used. The two welding processes where compared to see which has more environmental impact. The results are shown for each impact category.

For global warming potential, filler material used dominates significantly with about 92% for SAW and 91% for GMAW, electricity has 9% for GMAW, and 3% for SAW, flux has about 5% and shielding gas about 0%. Overall, SAW has less impact with regards to global warming. This can be explained by the composition of the filler material as titanium dioxide metal was used as the filler material. Another aspect is the number of passes for welding, 12 passes for GMAW 12 and 8 passes for SAW. Comparing the results obtained with the literature from other GaBi analysis done, the overall trend is the same with filler material dominating the impact followed by electricity and flux; shielding gas usually has very little or sometimes insignificant burdens in the impact categories.

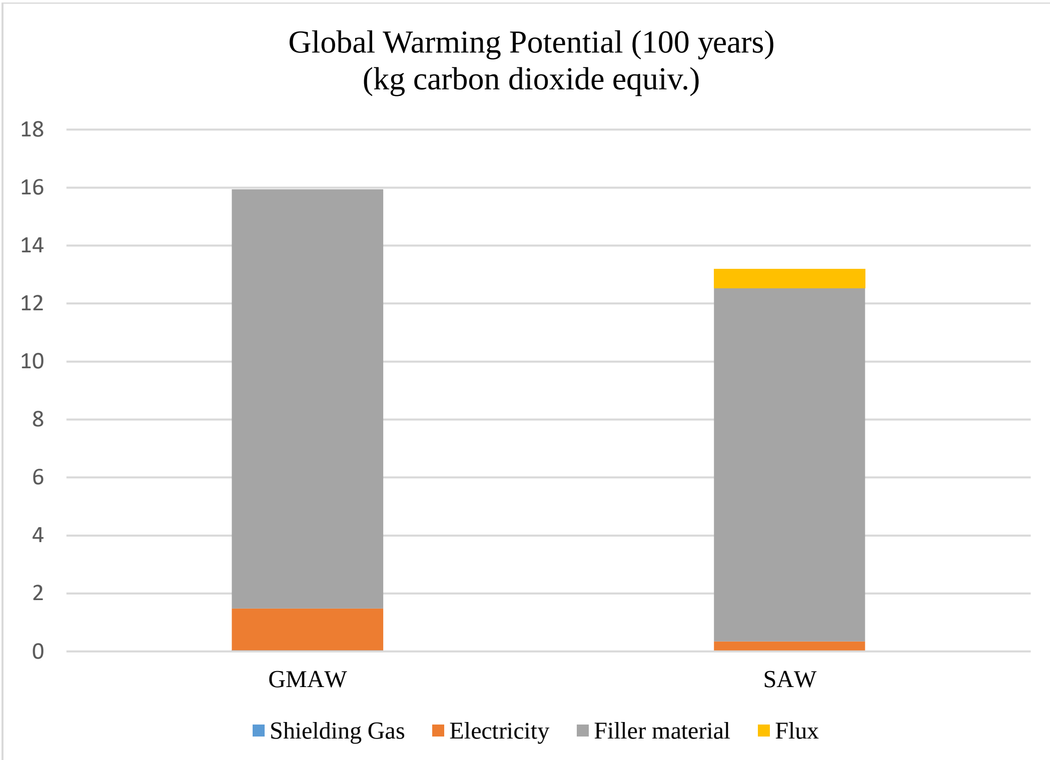


Figure 28. Global warming potential for GMAW and SAW

The results from the global warming chart above show a general trend throughout the other impact categories, with filler material being the most burden, followed by electricity then flux for eutrophication potential, acidification potential, and Photochem ozone creation potential. SAW process is more environmental friendly than GMAW process. This can be seen from the results as GMAW has more burdens in all impact categories as compared to SAW. Detailed graphs analysis can be seen in appendices 12 and 13.

7. CONCLUSION

Estimating the cost of welding is an essential aspect of every manufacturing company. With mild steel and high strength steels being the primary material used for structures, it is paramount to know the cost of welding and particularly which welding process and material is economical. This study estimating the welding cost of GMAW and SAW for S690 and S355, respectively. Both materials have same thickness and same welding length. Data were derived from past lap experiments and the internet. These data were input in cost formula for labor, filler material, flux, shielding gas and power to get their cost estimates. The formulae used were chosen amongst other formulae to be the most suited in comparing welding of both steel plates.

The result from the calculations showed that welding S690 and S355 with SAW cost €2,90 /m and €3,60/m, respectively. Using GMAW to weld both materials S690 and S355 cost €3,60/m and €3,96/m respectively. Hence welding S690 is cheaper than welding S355 with GMAW. This price difference can be accounted for by the fact that; more power is used for S355, the welding speed is lesser. Hence more welding time and more gas consumption, cost of electrode for S355 is more expensive than S690. While using SAW to weld both materials cost €3,51 /m and €3,36/m for S690 and S355, respectively. Hence welding S355 is cheaper than welding S690 with SAW process. The difference in price is accounted for by the fact that both have same welding speed, but S355 welding process has two less welding passes than S690. Also, the prices for electrode and flux for S690 are slightly higher than those for S355.

Comparing the two welding processes SAW and GMAW, it has been shown from the calculations that the SAW process is more economical. The main factor accounting for this is the fact that, flux replaces the shielding gas, and majority of the flux is used to cover the molten filler and material from contamination, which is recovered and is reused for the next welding process. Comparing the two processes considering their environmental impacts with regards to the various impact categories, GWP, EP, AP, and POCP, were estimated. The results showed GMAW as having a higher environmental impact in the impact categories. Generally, shielding gas is the input with the less effect in the impact categories followed by electricity and flux while filler material has the highest effect in the impact categories.

Based on the literature, it can be concluded that when comparing both materials S355 and S690QC for their sustainability and life cycle impact, the high strength steel S690QC is more sustainable and has a lesser environmental impact. This is because High strength steel has higher yield strength, which means a lower amount of high strength steel is needed to replace the mild steel in the same function. Hence less steel weight means less carbon dioxide emission during transportation. A general statement can be made saying: as yield strength of steel material increases, the lesser the environmental impact of its structures.

REFERENCES

Ajan Electronik, S. S. T., 2003. Maintenance manual for ajan precision plasma 260 amper plasma cutting machines. Izmir: s.n.

AlphaLaser_Cutting, 2019. Water Jet cutting. [Online]
Available at: https://alphalasercutting.com/water-jet/
[Accessed 09 10 2019].

American Welding Society, C., 2010. Recommended Procatices for Laser Beam Welding, Cutting and Allied Processes. 2nd ed. s.l.:American National Standard Institute .

Anna Nicholson, E. A. O. J. R. G. R. K., 2009. End of Life LCA allocation methods: Open loop reycling impacts on robustness of material selection decisions. Phoenix , AZ, USA, Institute of Electrical and Electronics Engineers.

Annette O. Brien, 2004. Welding Handbook- Welding Process, Part 1. 9th ed. Maimi: American Wleding Society.

Anoop Desai, A. M., 2018. Production Economics: Evaluating Costs of Operations in Manufacturing and Service Industries. s.l.:CRC Press.

Arthur R. Meyers, a. T. J. S., 2001. Basic Machining Reference Handbook. 2nd ed. New York: Industrial Press Inc..

Belinga, E. M. M., 2017. Effects of Adaptive GMAW Processes: Performance and Dissimilar Weld Quality. 21st June, pp. 25-27.

Boris S. Robinoff, S. E. P., 1930. Method of Welding. United States of America , Patent No. US 1,782,316.

Broadbent, C., 2016. Steel's recyclability: demonstrating the benefits of recycling steel and achieve a circular economy. Life Cycle Assess, Volume 21, p. 1.

Carter W. P. L, P. J. A. L. D. a. M. I. L., 1995. Environmental chamber study of maximum increamental reativities of volativel organic compounds. Atmospheric Environment, 30(2), pp. 181 - 199.

CTS, H., 2018. GMAW/FCAW Shielding gases. [Online]
Available at: http://www.halversoncts.com/711-gmawfcaw-shielding-gases.html
[Accessed 09 10 2019].

Demeri, M. Y., 2013.. Advanced High Strength Steels. Ohio: ASM International.

Dulczewskij, 1929.. Opisanie sposoba dugowoj eleckriczeskoj swarki meidi. USSR, Patent No. 10578.

Elango P., B. S., 2015. Welding parameters for inconel 625 overlay on carbon steel using GMAW. Indian Journal of Science and Tehcnology, 8(31).

ESAB, 2013. Selecting the mode of transfer. [Online]
Available at: https://www.esabna.com/us/en/news/newsletters/july-2013/selecting-the-mode-of-transfer.cfm
[Accessed 2 October 2019].

ESAB, 2019.. ESAB Training and Education. [Online]
Available at: http://soldacentro.com/docs/Submerged-Arc-Welding.pdf
[Accessed 23 October 2019].

ESAB, 2019. What is plasma arc cutting. [Online]
Available at: https://www.esabna.com/us/en/education/blog/what-is-plasma-cutting.cfm
[Accessed 9 October 2019].

EuRIC, 2018. European Recycling Conference 2018- Berlin. [Online]
Available at:
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=7&cad=rja&uact=8&ved=2ahUKEwiCjYvGofjkAhVxxIsKHffGCRUQFjAGegQIBhAC&url=https%3A%2F%2Fwww.euric-aisbl.eu%2Feuropean-recycling-conference-2018%2Fdownload%2F367%2F193%2F32&usg=AOvVaw0X2P2xZX-Mi9BL
[Accessed 30 09 2019].

European Commision, 2019.. Environment. [Online]
Available at: https://ec.europa.eu/environment/sustainable-development/index_en.htm
[Accessed 8 August 2019].

Faerber .M, J. B., June 2008.. Laser cutting. Laserline technical. [Online]
Available at: https://www.boconline.ie/en/images/laser_cutting_tcm674-78872.pdf
[Accessed 1 November 2019].

Grobosz, E. T. &. W., 2014.. Beginnings of Submerged Arc Welding. s.l.:Biuletyn Instytutu Spawalnictwa.

Gunther Sproesser, Y.-J. X. A. P. M. F. M. R., 2015. Life Cycle Assessment of welding technologies for thick metal plate welds. Journal of Cleaner Production, Volume 108, pp. 46-53.

Gutowski. T, C. M. D. A. D. B. B. B. T. P. P. S. J. S. D. T. E. W., 2005. Environmentally benign manufacturing: observations from Japan, Europe and United States. Journal of Cleaner Production, 13(1), pp. 1-17.

Guzman, Z., 2019. MIG Welding Transfer Mode. [Online]
Available at: https://www.aedmotorsport.com/news/mig-welding-transfer-methods
[Accessed 6 05 2019].

Gyasi Emmanuel, A., 2018. On Adaptive Inteligent Welding: Techniques Feasibility in Welding Assurance for Advanced Steels. 28th August, pp. 19-20.

Göran Andersson, 2013. Fabrication of Steel Structures. In: Environmental Evalaution of Steel and Steel Structures. Stockholm: Jernkontoret, pp. 47 - 78.

Heidi K. Standdorf, L. H. A. S., 2005. Impact Categories, normalisation and weighting in LCA. s.l.:Danish Ministry of the environment.

Heinz Tschätsch, 2009. Milling. In: Applied Machining Technology. Dresden: Springer, pp. 173 - 199.

Howard B. Cary & Scott C., 2005.. Modern Welding Technology. 6th Edition ed. Columbus, Ohio: Pearspon.

Howard B. Cary, 1998.. Modern Welding Technology. 4th ed. Columbus, Ohio: Prewntice Hall.

Howard B. Cary, S. C. H., 2006.. Historical Development of Welding. In: Modern Welding Technology. 6th ed. New Jersey: Pearson Prentice Hall, pp. 4 - 10...

ISO 14040, 2006. Environmental Management - Life cyle assessment - Principles and framework. Brussels: Europen Committee for Standardization.

ISO 6947:2011, 2011. Welding and Allied Processes - Welding Positions. s.l.:s.n.

ISO 9692-1, 2013. Welding and Allied Processes - Types of joint preparation - Part 1: Manual metal arc welding, gas-shielded metal arc welding, TIG welding and beam welding of steels. s.l.:s.n.

ISO_14044, 2006. Environmetal Management. Life cycle assessment, riequirements and guide lines. Brussels: CEN.

ISO14175, 2008. Welding Consumables:- Gases and gas mixtures for fussion welding and allied processes. Brussels: Europeon Committee for Standardization.

J. Zeng, J. O. a. C. O., 1999. The Abrasive waterjet as a precision metal cutting tool. Auburn Washington, 10th American Waterjet Conference.

J.N. DuPont, A. M., 1995. Thermal Efficiency of Arc Welding Prcesses. 74(12), pp. 406 - 416.

Jeff Nadzam, L. B. D. K. a. D. M., 2007. Gas Metal Arc Welding - Product and Procdure Selection. [Online]
Available at:
https://m.lincolnelectric.com/assets/global/Products/Consumable_MIGGMAWWires-SuperArc-SuperArcLA-90/c4200.pdf
[Accessed 15 04 2019].

Jim Bowyer, S. B. K. F. M. F. H. G., 2015. Understanding steel recovery and recycling rates and limitations to recycling, s.l.: Research Gate.

K S Sangwan, C. H. P. E. V. B. J. S., 2016. Life Cycle Assessement of Arc Welding and Gas Welding Processes. Braunschweig , ScienceDirect.

Keen ovens, 2013. Submerged arc welding. [Online]
Available at: https://www.keenovens.com/articles/submerged-arc-welding.html
[Accessed 25 September 2019].

Klas Weman, 2012. In: 2nd, ed. Welding Processes Handbook. Oxford: WoodHead Publishing, pp. 143 - 148.

Klas Weman, 2012.. Welding Process Handbook. 2nd Edition ed. Oxford: WoodHead Publising.

Komatsu, A. I., 2016. Twister TFPL Series. [Online]
Available at: http://www.komatsuplasma.com/kai/ctd/en/tfpl/
[Accessed 20 June 2019].

Kordonowy, D. N., 2002. A Power Assessment of Machining Tools,. In: Bachelor of Science Thesis in Mechanical Engineering. Cambridge, Massachusetts: Massachusetts Institute of Technology.

Lamet, B. L. A. W. R. A. J. ,. W. B. C. C. B., 1993.. ASM Handbook - Welding, Brazing and Soldering. ASM International, Volume 6.

Larry Jeffus, 2012. Welding and Metal Fabrication. 1 ed. Clifton Park: Delmar, Cengage Learning.

Lars Ohlsson, 1995. The theory and practicve of abrasive water jet cutting. In: Doctoral Thesis. s.l.:Tekniska Högskolan 1 luleå- Luleå University of Technology, pp. 12 - 25.

LaserLine GmbH, 2019. Laser cutting. [Online]
Available at: https://www.laserline.com/en-int/cutting/
[Accessed 9 10 2019].

Layus, P., 2017. Usability of the Submerged Arc Welding Process for Think High Strength Steel Plates for Artic Shipbuilding Applications. 3rd May, pp. 33-37.

Lincoln Electric, 2014.. Gas Metal Arc Welding - Production and procedure selection. [Online]
Available at:
https://www.lincolnelectric.com/assets/global/Products/Consumable_MIGGMAWWires-SuperArc-SuperArcLA-90/c4200.pdf
[Accessed 17 June 2019].

Marian Schwarz, M. D. R. H. D. V., 2014. Enironmental and Health Aspects of Metalworking Fluid Use. Polish Journal of Environmetal Studies, 24(1), pp. 37-45.

Metal-Art-Press, 2019. Cutting Process - Oxyfuel Cutting. [Online]
Available at: http://www.metalartspress.com/books/chapters/chapter-10-cutting-processes
[Accessed 15 June 2019].

Mohammad S. Alsoufi, 2017. State-of-the-Art in Abrasive Water Jet Cutting Technology and the Promise for Micro-and-Nano- Machining. International Journal of Mechanical Engineering and Applications, 5(1), pp. 1-14.

P. T. Houldcroft, F., 1992. Submerged Arc Welding. Cambridge: Woodhead Pub.

Practice, W., 2012. Gas Weldiing. [Online]
Available at: http://ecoursesonline.iasri.res.in/mod/page/view.php?id=3816
[Accessed 15 September 2019].

Ramesh Singh, 2012. Applied Welding Engineering - Process Codes and Standards. 1st ed. Boston: Butterworth-Heinemann.

Ramesh, S., 2012. Gas metal arc welding - process description. In: Applied Welding Engineering: Processes, Codes and Standards. New York: Elsevier , pp. 157 - 158.

Richard L Alley, 1993. Welding, Brazing and Soldering. Volume 6 ed. s.l.:ASM International.

Shaw, M. C., 1996. Principles of Abrasive Processing. Oxford : Clarendon Press .

Systems, B.-o., 2007. Flame cutting Handbook. Pittsburgh: Weld tooling Corp. .

The Open University, 2019. Plasma arc cutting. [Online]
Available at: https://www.open.edu/openlearn/science-maths-technology/engineering-technology/manupedia/plasma-arc-cutting
[Accessed 20 September 2019].

Thompson D., K. D. Q. M. W. D. E. E., 2005. Occupational Exposure to Metalworking Fluids and Risk of Breast Cancer among Female Autoworkers. American Journal of Industrial Medicine, Volume 47, pp. 153-60.

Tyler G. Hicks, 2006. Hand book of mechanical engineering calculations. 2 ed. s.l.:McGraw-Hill.

Universal Technical Institute, 2019.. Welding history goes back farther than you think. [Online]
Available at: https://www.uti.edu/blog/welding/welding-history-goes-back-farther-than-you-think
[Accessed 17 June 2019].

Welding answers, 2014. Advantages and Limitations of GMAW. [Online]
Available at: http://weldinganswers.com/advantages-and-limitations-of-gmaw/
[Accessed 20 September 2019].

WorldSteel_Association, 2019. Steel Fact Sheets. [Online]
Available at: https://www.worldsteel.org/publications/fact-sheets.html
[Accessed 1 10 2019].

Worldsteel, 2019. Life Cycle Thinking. [Online]
Available at: https://www.worldsteel.org/steel-by-topic/life-cycle-thinking.html
[Accessed 2 08 2019].

Yeo S. H, K. G. N., 1997. Inclusion of environmental performance for decision making of welding processes. Journal of Materials Processing Technology, pp. 78-88.

Oxyfuel cutting gas consumption

PLATE THICKNESS		NOZZLE SIZE		GAS PRESSURES			
				Acetylene		Oxygen	
in.	mm	in.	mm	lbf/in^2	bar	lbf/in^2	bar
Acetylene							
1/8	3·2	1/32	0·75	2	0·14	15	1·05
1/4	6·4	1/32	0·75	2	0·14	25	1·8
1/2	12·5	3/64	1·0	2	0·14	30	2·1
1	25·4	1/16	1·5	2	0·14	35	2·5
2	51	1/16	1·5	2	0·14	45	3·2
3	76	1/16	1·5	2	0·14	50	3·5
4	100	5/64	2·0	2	0·14	60	4·2
6	150	5/64	2·0	2	0·14	75	5·3
Propane							
1/8	3·2	1/32	0·75	3	0·21	25	1·8
1/4	6·4	1/32	0·75	3	0·21	25	1·8
1/2	12·5	3/64	1·0	3	0·21	40	2·8
1	25·4	1/16	1·5	3	0·21	45	3·2
2	51	1/16	1·5	3	0·21	50	3·5
3	76	1/16	1·5	3	0·21	60	4·2
4	100	5/64	2·0	4	0·28	70	4·9
6	150	5/64	2·0	4	0·28	80	5·6
Natural gas							
1/8	3·2	1/32	0·75	Mains	—	25	1·8
1/4	6·4	1/32	0·75	Mains	—	25	1·8
1/2	12·5	3/64	1·0	Mains	—	30	2·1
1	25·4	1/16	1·5	Mains	—	45	3·2
2	51	1/16	1·5	Mains	—	55	3·9
3	76	5/64	2·0	Mains	—	60	4·2
4	100	5/64	2·0	Mains	—	65	4·6
6	150	3/32	2·5	Mains	—	70	4·9

APPENDIX 2

Variables and values used in abrasive calculations

Symbols	*Name*	*Unit*	*Value*
f_a	*abrasive factor*	-	*1*
N_m	*Machinability number*	-	*87.6*
P_w	*water pressure*	*MPa*	*414*
D_o	*orifice diameter*	*mm*	*0.43*
M_a	*abrasive flow rate*	*g/min*	*363*
q	*quality index level*	-	*4*
h	*work piece thickness*	*mm*	*25*
d_m	*mixing tube diameter*	*mm*	*0.76*
c	*system constant*	-	*788*
v	*cutting speed*	*mm/min*	
C_e	*cost of electricity*	*Eur/hr*	*8.92*
C	*abrasive water cost per hour*	*Eur/hr*	
C_w	*cost of water*	*Eur/hr*	*0.12*
C_a	*abrasive cost*	*Eur/hr*	*29.40*
C_m	*manufacturing cost*	*Eur*	
C'	*abrasive cutting cost per meter*	*Eur/m*	
ce	*unit cost of electricity*	*Eur/kWhr*	*0.105*
ca	*unit abrasive cost*	*Eur/kg*	*0.7*
E	*Electric power consumption*	*kW*	*85*
Q_w	*water consumption*	*m3/hr*	*0.24*
Q_a	*abrasive consumption*	*kg/hr*	*42*
t_m	*manufacturing time*	*hr*	
L	*cutting length*	*mm*	*300mm*
C_i	*investment cost*	*Eur/hr*	-
C_o	*operational cost*	*Eur/hr*	
C_p	*Labor cost*	*Eur/hr*	

APPENDIX 3

Data sheet for mild steel S355J2

Chemical composition

Variant	Cast	Weldability		C %	Si %	Mn %	P %	S %	V %
S355J2(M)	CC	CEV 0.5$_{max}$	Min	-	-	-	-	0.020	-
		Pcm 0.3$_{max}$	Max	0.20	0.55	1.60	0.035	0.040	0.150

Mechanical Properties

Variant	Condition	Format	Dimension [mm]	Yield strength min [MPa]	Tensile strength [MPa]	Elongation A_5 [%]	Hardness	Impact (ISO-V) strength$_{min}$
S355J2(M)	+AR	All formats	< 16	355**	490-630	22	150-190 HB	-20 °C 27 J (long)
		All formats	17 < 40	345**	490-630	22	150-190 HB	-20 °C 27 J (long)
		All formats	41 < 63	335**	490-630	21	150-190 HB	-20 °C 27 J (long)
			64 < 80	325**	490-630	30	150-190 HB	-20 °C 27 J (long)

$Rp_{0.2}$ * R_{eh}, ** R_{el}

Transformation temperatures

	Temperature °C
MS	400
AC1	720
AC3	815

APPENDIX 4

Data Sheet for high strength steel S690QL

Chemical Composition for S690QL Steel Plate

Element	Percentage %	Element	Percentage %
C	0.20	Cu	0.50
Si	0.80	Mo	0.70
Mn	1.70	Nb*	0.06
P	0.025	Ni	2.0
S	0.015	Ti*	0.05
N	0.015	V*	0.12
B	0.0050	Zr*	0.15
Cr	1.50		

Mechanical Properties for S690QL Steel Plate

Designation		Mechanical Properties (ambient temperature)						
Steel Name	Steel Number	Min. Yield Strength Reh MPa			Tensile Strength Rm MPa			Min. % elongation after fracture
		Nominal thickness (mm)			Nominal thickness (mm)			
		≥3 ≤50	≥50 ≤100	≥100 ≤150	≥3 ≤50	≥50 ≤100	≥100 ≤150	
S690QL	1.8931	690	650	630	770/940	760/930	710/900	14

S690QL Steel Plate V Notch Impact Testing

Grade	Sample Orientation	@ 0°C	@-20°C	@-40°C	@-60°C
S690QL	**Longitudinal**	50 J	40 J	30 J	¨C¨C
	Traverse	35 J	30 J	27 J	¨C¨C

Maximum CEV Values For S690QL (Ladle)

		Maximum CEV in % for nominal product thickness in mm		
Grade	Steel Number	≤ 50	> 50 ≤ 100	> 100 ≤ 150
S690QL	1.8928	0.65	0.77	0.83

Carbon Equivalent Value CEV = CEV = C+Mn/6+(Cr+Mo+V)/5+(Cu+Ni)/15

APPENDIX 5

GMAW Cost Values

Filler cost

Symbol	Value
Ep	S366 = 0.31, s690 = 0.27
Fm	95%
Ec	S355 = 0.39, S690 = 0.34
A	1.39×10^{-4} m^2
W	1.176

Shielding gas cost Values

Symbol	Value
F_r	48
C_g	0.010
W_t	25 - 30

Labor cost values

Symbol	Value
W_{pr}	26
L_c	2.95
S	S690 = 12, S355 = 10

Power cost values

Symbol	Value
I	600
W	1.117
D_R	0.95
ε	0.8
P_R	0.17
V	60

APPENDIX 6

SAW Cost Values

Electrode cost

symbols	values
A	1.39×10^{-4} m^2
W	1.176 kg/m
F_m	98%
E_p	S690 =0.116, S355 = 0.1416

Flux cost

Symbol	Values
F_{cf}	S690 = 0.268, S355 = 0.22
F_{cr}	1
W	1.176 kg/m
L	300mm

Power cost

I	S690 = 21.7 S355 = 13.72
W	1.176
D_R	98%
V	30
P_R	0.17 €/kWh
ε	1

Labor cost

S	S690 = 8, S355 = 6
W_{pr}	40 €/hr

APPENDIX 7

Data sheet for Union NiMoCr filler material

Union NiMoCr		Solid Wire
Classifications		low-alloyed
EN ISO 16834-A	AWS A5.28	
G 69 6 M21 Mn4Ni1,5CrMo	ER100S-G	

Characteristics and field of use

Medium alloy solid wire electrode for shielded arc welding of quenched and tempered and thermo-mechanically treated fine grained structural steels; for joint welding of wear resistant steels. For use with CO2 and gas mixture. Outstanding toughnesss of the weld metal at low temperatures. For use in crane and vehicle manufacturing.

Base materials

S690QL1 (alform 700 M; aldur 700 QL1; S620QL1, S700MC (alform 700 M)

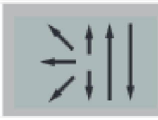
Typical composition of solid wire (Wt-%)

C	Si	Mn	Cr	Mo	Ni
0,08	0,6	1,70	0,2	0,5	1,50

Mechanical properties of all-weld metal

Shielding Gas	*Yield strength 0,2%*	*Tensile strength*	*Elongation (L_0=5d_0)*	*Impact values in J CVN*		
	MPa	*MPa*	*%*	*+20°C:*	*-40°C:*	*-60°C:*
CO_2	680	740	18	80	47	
M21	720	780	16	100		47

Operating data

	Polarity = +	Shielding gas (EN ISO 14175) M21 and C1

Dimensions (mm)

0,8	*1,0*	*1,2*

Approvals and certificates

TÜV (Certificate No. 2760), DB (Reg. form No. 42.132.08), ABS, DNV, BV, GL (6 69S), LR

APPENDIX 8

Data sheet for Elgamatic 100 filler material

Elgamatic 100

GMAW - MIG MAG

Un-alloyed

Date:	2009-04-07
Revision:	11

Description:

Elgamatic 100 is a copper coated, manganese-silicon double deoxidised mild steel wire for use with a CO2 or Ar/CO2 gas shield. The carefully controlled wire metallurgy and surface finish ensure high quality welds and reliable wire feed for mechanised welding systems. Elgamatic 100 is suitable for all general engineering and structural steels.

Welding current:

DC+

Wire composition, wt.%

	C	Si	Mn	P	S	Cu
Min	0,07	0,80	1,40			
Typical	0,08	0,85	1,45	0,010	0,015	0,05
Max	0,12	1,00	1,60	0,025	0,025	0,35

Shielding gas:

C1, CO2, 7-12 l/min

M21, 80% Ar + 20% CO2, 7-12 l/min

Chemical composition, wt.%

	C	Si	Mn
Min			
Typical	0,07	0,8	1,4
Max			

Mechanical properties

	Specified	Typical
Yield strength, Re:	≥ 420 MPa	470 MPa
Tensile Strength, Rm:	≥ 500 MPa	550 MPa
Elongation, A5	≥ 20%	26%
Impact energy, CV:	−20 °C • >47 J	−20 °C • 85 J
	−29 °C • >27 J	−29 °C • 50 J

Classification:

EN ISO 14341-A	G 42 2 (C) M G3Si1
AWS A5.18	ER70S-6

Approvals:

TÜV

DB

MRS

DNV

GL

LR

CE

Note

The typical values are based on M21

Also available in AUTOPAC, a twist-free pay-off pack. For more information about Part no, type of spool and winding, please study the price list.

Data Sheet for Topcore 742B, 4mm

CEWELD®

Topcore 742B

CATEGORIE	SAW Onder poederdek
TYPE	High- basicity flux-cored wire for submerged-arc welding of high tensile steels.
APPLICATIONS	Crane-, rig, plant-, craft-, lifting and steel construction, pipe work, foundries, drilling platforms etc.
PROPERTIES	Remarkable crack resistant weld metal in combination with very low hydrogen content. Therefore, suitable for the economic processing of high-strength and low temperature fine grained structural steels. Excellent welding properties in combination with ST 55 high basic flux even in narrow gabs. Excellent wetting properties compare to solid wires that results in a bigger parameter range and improved deposition rate. To obtain optimum mechanical properties the heat input should be kept below 15 kJ/cm and interpass temperature between 100 and 150ºC.
CLASSIFICATION	AWS A 5.23: F11A8-ECF5-F5 A 5.23M: F76A6-ECF5-F5 EN ISO 26304-A: S 69 6 FB T3Ni2,5CrMo
SUITABLE FOR	StE 690.7 TM, L690M, A 715, StE 690 V, S690QL, A 709, A 515, A 517, EStE 690 VA, S690G1QL1, A 514, A 633, A 709 Naxtra 70, Weldox 700, Dilimax, Optim 700 mc plus, S620Ql1, S690QL1, S600MC, S700MC, Naxtra 63, Naxtra 70, TStE620, TStE690, Weldox 500, Domex 550 MC, Domex 600 MC, Domex 650 MC, Domex 700 MC, Hardox, L480 - L550, X65, X80, X90, X100, Hardox 400, XAR 400, Dilidur 400, 20MnCr65, 28CrMn43, Oceanfit 100, Oceanfit 690
APPROVALS	LLoyds (5Y69), ABS (5Y69), DNV, TUV, BV, CE approved

WELDING POSITIONS:

WELD DEPOSIT ANALYSIS WITH ST55 (WEIGHT %)

C	Mn	Si	Cr	Ni	Mo	P	S
0.08	1,6	0,4	0,5	2,2	0,5	<0.015	<0.015

MECHANICAL PROPERTIES

Heat Treatment	$R_{P0,2}$ (N/mm^2)	Rm (N/mm^2)	A5 (%)	Impact Energy (J) ISO-V -20°C	-40°C	-60°C	Hardness HRc / HV
AW	>690	770-900	>17		>80	>69	

AW: as welded

WELDING PARAMETERS / PACKING

Welding Parameters			Packing		
D (mm)	Voltage (V)	Current (A) DC+	spool type	kg / spool / drum	kg / pallet
2,0	28-34	180-320	K-415 / Drum	25 / 300	
2,4	28-38	250-500	K-415 / Drum	25 / 300	
3,2	28-40	400-800	K-415 / Drum	25 / 300	
4,0	28-40	500-900	K-415 / Drum	25 / 300	

REDRYING TEMPERATURE Not required

APPENDIX 10

Data sheet for SAW flux ST55

ST 55

CATEGORY SAW Arc Submerged

TYPE High basic SAW flux with very low hydrogen content

APPLICATIONS Drilling platforms, crane building, offshore fundamentals, jack ups, narrow gab welding, multi layer welding.

PROPERTIES Neutral high basic flux suitable for a weight range of wire combinations including multi layer welding in high demanding offshore applications because of its low hydrogen content.

Basicity according to Boniszewski: ~3.1
Grain size according DIN EN 760: 2 - 16

CLASSIFICATION EN ISO 14174: SA FB 1 55 AC(D) H5

SUITABLE FOR S355, S420, S460, S690, P500, P550, X65, X70, X80, Weldox 700, Naxtra 70, Hardox 400, Dilimax, P91, P24

APPROVALS DB, LLoyds, DNV, TUV

WELDING POSITIONS:

SiO_2+TiO_2	CaO + MgO	Al_2O_3+ MnO	CaF_2	S	P
15	40	20	25	<0.015	<0.015

MECHANICAL PROPERTIES

with Wire	$R_{P0.2}$ (N/mm^2)	Rm (N/mm^2)	A5 (%)	Impact Energy (J) ISO-V -20°C	-40°C	-60°C	Hardness HRc / HV
SDA D3*	>460	530-680	>20			>47	
Topcore 742B*	>690	770-940	>17		>80	>69	

* For as welded condition and PWHT 580°C / 2hr.

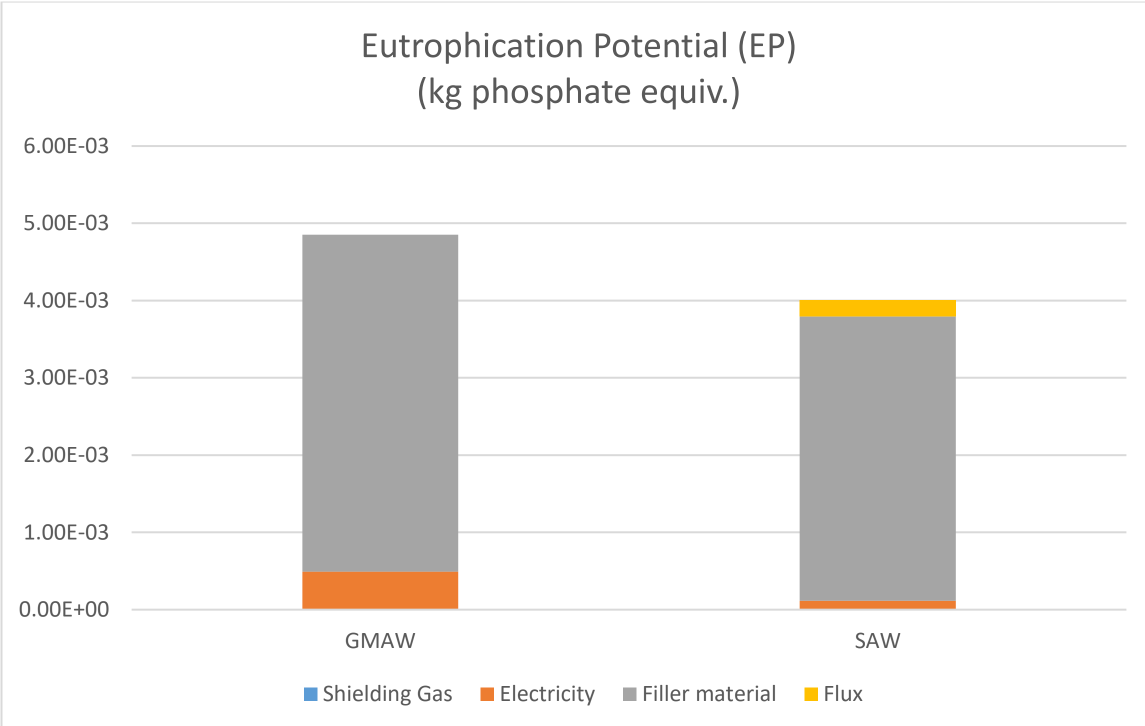
REDRYING TEMPERATURE 300-350°C / 1-2hr

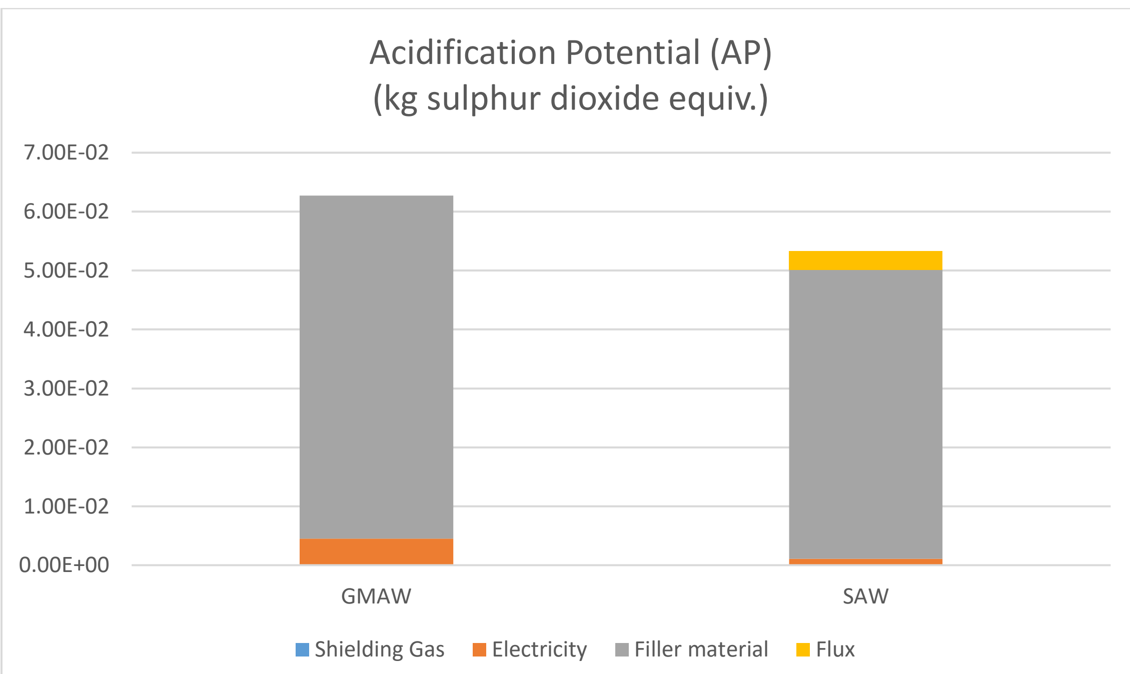
PACKING 25 kg sealed metal buckets / 25 kg bags.

Specifications for machines used in SAW and GMAW

	Pandaweld® 1250	**Pandaweld® 630**
Syöttöjännite:	380-400V, 3-vaihe, 50/60Hz vaihtovirta	
Syöttökaapeli	3 x 25 mm^2 + 16 mm^2	3 x 10 mm^2 + 1 x 6 mm^2
Sulakevaade:	Max. 100A	Max. 63A
Nimellisvirta (hitsaus, DC+)	1250A / 44V / 60% 968 A / 44 V / 100%	630 A / 44V / 60% 488 A / 44 V / 100 %
Virran säätöalue	125…1250 A	50…630
Tyhjäkäynti-jännite:	79 V	75 V
Mitat:	Pituus 79 cm, leveys 66 cm, korkeus 55 cm Paino 115 kg	Pituus 700 mm, leveys 365 mm, korkeus 525 mm, Paino 60 kg
Käyttöympäristö :	Käyttölämpötila -20°C - +40°C Varastointilämpötila -40°C - + 40°C	

Eutrophication potential and acidification potential comparison between GMAW and SAW





APPENDIX 13

Photochem.Ozone creation potential comparison between SAW and GMAW