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**Simulation Study on The effects of shielded metal arc  
welding on mechanical parts**

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Dedication

I dedicate this humble work to those who have briefed me on  
the wise way

And give me everything that is dear in life with

Immense generosity and thin emotion.

You, my dear mother.

And you, my dear father.

To my family.

To all my friends and colleagues

Everyone who helped me.

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I thank God for giving me health patience and courage

Throughout the work.

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And to all my colleagues.

DAHAAH Saad

# Table of contents

<b>General Introduction</b> .....	1
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## Chapter I

### General information on welding

---

I.1 Introduction .....	5
I.2 Brief History of Welding.....	5
I.3 Definition of welding .....	6
I.4 Welding Processes.....	6
I.5 Fusion welding .....	8
I.5.1 Process definition.....	8
I.5.2 Principle of fusion welding.....	8
I.6 Types of fusion welding .....	9
I.6.1 GAS WELDING.....	9
I.6.1.1 Advantages of gas welding .....	10
I.6.1.2 Disadvantages of gas welding .....	10
I.6.2 ARC WELDING.....	10
I.6.2.1 Shielded metal arc welding (SMAW) .....	10
I.6.2.2 Gas -Tungsten Arc Welding (GTAW) .....	12
I.6.2.3 Gas -Metal arc welding (GMAW) .....	13
I.6.2.4 Plasma arc welding (PAW) .....	14
I.6.2.5 Submerged arc welding (SAW) .....	15
I.6.2.6 Electro slag arc welding (EAW) .....	16
I.6.3 High Energy Beam Welding .....	16
I.6.3.1 Electron Beam Welding (EBW):.....	17
I.6.3.2 Laser Beam Welding (LBW) .....	18
I.7 Fusion welding parameter.....	18
I.7.1 Arc voltage .....	18
I.7.2 Welding current.....	19
I.7.3 Welding speed .....	19
I.7.4 Wire diameter.....	20

I.7.5 Granular flux .....	20
I.7.6 Length of the Arc .....	20
I.7.7 Angle .....	20
I.8 Advantages and Disadvantages.....	21
I.9 Scope of application.....	22

---

## Chapter II

### Shielded Metal Arc welding (SMAW)

II.1 Introduction .....	24
II.2 Principle of the process .....	24
II.3 Equipment .....	25
II.3.1 POWER SOURCES .....	25
II.3.1.1 Machines for SMAW.....	25
II.3.1.2 Types of welding Current .....	28
II.3.1.2.1 Selection of Type of Welding Current .....	28
II.3.1.3 Accessories for SMAW welding .....	29
II.3.1.4 Types of SMAW Electrodes.....	30
II.3.1.4.1 Electrode Size and Coating Factor .....	34
II.3.1.4.2 Storage and drying of electrodes .....	34
II.4 Welding Parameters for SMAW .....	35
II.4.1 Importance of Welding Current.....	35
II.5 Techniques for SMAW welding .....	37
II.5.1 welding conditions.....	37
II.5.2 Edge preparation.....	39
II.5.3 Weld joint .....	39
II.5.4 Types of Weld Joints: .....	40
II.6 SMAW Welding defects .....	41
II.6.1 CLASSIFICATION OF WELD DEFECTS.....	42

---

## Chapter III

### Theoretical studies

---

III.1 Introduction.....	44
III.2 Numerical modelling and limits .....	44
III.2.1 Generalities.....	44
III.2.2 Simulation software and numerical analysis of SMAW process .....	44
III.3 SIMUFACT WELDING.....	46
III.3.1 Software presentation.....	46
III.3.2 Utility of simufact welding .....	46
III.3.3 Advantage of Simufact welding software .....	47
III.4 Modelling steps on simufact welding [27] .....	47
III.4.1 creating a new project .....	47
III.4.2 Importing components.....	50
III.4.3 defining materials.....	52
III.4.4 Defining temperature objects .....	54
III.4.5 Defining the mechanical boundary conditions.....	54
III.4.6 Using node-sets .....	59
III.5 Weld paths and heat sources .....	61
III.5.1 The welding path.....	61
III.5.2 The welding parameters and heat source .....	62
III.6 Configuring robots and weld beads.....	65
III.7 Simulation settings .....	71
III.8 Running the model .....	72

---

## Chapter IV

### Results and discussion

IV.1 Introduction .....	74
IV.2 Discussing results .....	74
IV.2.1.1 Effects of SMAW1-1 (current: 380A; Voltage: 17V) .....	75
IV.2.1.2 Effects of SMAW1-2 (current: 380A; Voltage: 28V) .....	77
IV.2.1.3 Effects of SMAW1-3 (current: 380A; Voltage: 35V) .....	78
IV.2.2.1 Effects of SMAW2-1 (current: 220A; Voltage: 17V) .....	81
IV.2.2.2 Effects of SMAW2-2 (current: 220A; Voltage: 28V) .....	83
IV.2.2.3 Effects of SMAW2-3 (current: 220A; Voltage: 35V) .....	85

IV.2.3.1 Effects of SMAW3-1 (current: 100A; Voltage: 17V) .....	87
IV.2.3.2 Effects of SMAW3-2 (current: 100A; Voltage: 28V) .....	89
IV.2.3.3 Effects of SMAW3-3 (current: 100A; Voltage: 35V) .....	91
IV.3 General Discussion .....	93
IV.4 Conclusion .....	94
<hr/>	
<b>General conclusion</b> .....	96
<b>Bibliographical References</b> .....	98
<b>Abstract</b> .....	101
<hr/>	

# List of Figures

## Chapter I

### General information on welding

<b>Figure I.1</b>	Schematic presentation of the most common welding methods.....	7
<b>Figure I.2</b>	Schematic presentation of Oxyacetylene welding process . .....	9
<b>Figure I.3</b>	Schematic presentation of Oxyacetylene welding process flame types ...	9
<b>Figure I.4</b>	Shielded metal arc welding process (SMAW).....	11
<b>Figure I.5</b>	Tungsten inert gas welding (TIG,GTAW).....	12
<b>Figure I.6</b>	Simple diagram of the gas metal arc welding process.....	13
<b>Figure I.7</b>	Plasma arc welding overall process. ....	14
<b>Figure I.8</b>	Submerged arc welding overall process.....	15
<b>Figure I.9</b>	Electro slag arc welding overall process.....	16
<b>Figure I.10</b>	Electron beam welding overall process .....	17
<b>Figure I.11</b>	Laser beam welding overall process .....	18
<b>Figure I.12</b>	Schematic presentation of Speed of electrode wire relative to work piece is termed as welding speed .....	19
<b>Figure I.13</b>	Schematic presentation of the welding angle.....	20
<b>Figure I.14</b>	Scope of application.....	22

## Chapter II

### Shielded Metal Arc welding (SMAW)

<b>Figure II.1</b>	Equipment for Shielded Metal Arc Welding.....	25
<b>Figure II.2</b>	Diesel Engine Driven Power Source .....	26
<b>Figure II.3</b>	DC Constant Current Portable Welder/Generator .....	26
<b>Figure II.4</b>	AC/DC Single Phase Power Source .....	27
<b>Figure II.5</b>	Three Phase Constant Current Power Source.....	27
<b>Figure II.6</b>	Inverter Power Source for SMAW .....	28
<b>Figure II.7</b>	Schematic showing effect of welding current and polarity .....	29
<b>Figure II.8</b>	Schematic showing effect of type of electrode on mode of metal transfer in SMAW using Acidic and Cellulosic electrodes .....	31



<b>Figure II.9</b> Schematic showing effect of type of electrode on mode of metal transfer in SMAW using Rutile electrode .....	31
<b>Figure II.10</b> Schematic showing effect of type of electrode on mode of metal transfer in SMAW using Basic electrode.....	32
<b>Figure II.11</b> Schematic of electrode showing electrode section size with (D) and without coating (d) and its different components .....	34
<b>Figure II.12</b> Schematic showing effect of welding current on weld bead geometry, e.g. penetration, width and weld area: <b>a</b> plot and <b>b</b> weld joint .....	36
<b>Figure II.13</b> Schematic showing effect of welding speed on weld bead geometry, e.g. penetration, width and weld area .....	36
<b>Figure II.14</b> Schematic showing premature thermal decomposition of electrode coating due to Overheating of core wire .....	37
<b>Figure II.15</b> Weld bead contour when current is too low .....	38
<b>Figure II.16</b> Weld bead contour when current is too high.....	38
<b>Figure II.18</b> Typical edge preparations for SMAW welding.....	39
<b>Figure II.19</b> Distinct zones of Weld Joints .....	39
<b>Figure II.20</b> Schematic showing the only five basic joints. They can, however, be used in combinations.....	40
<b>Figure II.21</b> Schematic showing the Common Types of Welds.....	40
<b>Figure II.22</b> Schematic showing Weld Nomenclature.....	41

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## Chapter III

### Theoretical studies

<b>Figure III.1</b> Mesh of a model on simufact.....	45
<b>Figure III.2</b> Interface of simufact welding. ....	46
<b>Figure III.3</b> Creating a new project. ....	47
<b>Figure III.4</b> Name and location. ....	48
<b>Figure III.5</b> Configuring the simulation- Choosing what will compose the simulation .....	49
<b>Figure III.6</b> Main screen - overview of available interaction areas. ....	49
<b>Figure III.7</b> Importing components. ....	50
<b>Figure III.8</b> Importing with correct length unit. ....	51
<b>Figure III.9</b> Visualization window. ....	52

<b>Figure III.10</b> Material library. ....	52
<b>Figure III.11</b> The material library .....	53
<b>Figure III.12</b> Assigning the material. ....	53
<b>Figure III.13</b> Temperature object. ....	54
<b>Figure III.14</b> Types of boundary conditions.....	55
<b>Figure III.15</b> Creating fixtures. ....	56
<b>Figure III.16</b> Generating geometry.....	56
<b>Figure III.17</b> Selecting reference faces. ....	57
<b>Figure III.18</b> Configuring the geometry.....	58
<b>Figure III.19</b> Placing fixtures. ....	58
<b>Figure III.20</b> Clamping force. ....	59
<b>Figure III.21</b> Node-set creation. ....	60
<b>Figure III.22</b> Node-set creation. ....	60
<b>Figure III.23</b> Creating trajectorye. ....	61
<b>Figure III.24</b> Trajectory from node set.....	62
<b>Figure III.25</b> Welding parameters. ....	62
<b>Figure III.26</b> General properties.....	63
<b>Figure III.27</b> Welding parameters. ....	64
<b>Figure III.28</b> Conventional heat source - Goldak's model for arc welding processes... .....	64
<b>Figure III.29</b> Heat source geometry. ....	65
<b>Figure III.30</b> Assigning trajectories. ....	66
<b>Figure III.31</b> Robot configuration. ....	66
<b>Figure III.32</b> Robot general configuration. ....	67
<b>Figure III.33</b> Trajectory orientation. ....	69
<b>FigureIII.34</b> Schematic view. ....	69
<b>Figure III.35</b> Fillet geometry assignment.....	70
<b>Figure III.36</b> Fillet description. ....	70
<b>Figure III.37</b> Resulting fillet.....	71
<i>Figure III.38</i> Solver settings.....	71
<b>Figure III.39</b> Simulation start. ....	72
<b>Figure III.40</b> Successful completion. ....	72

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## Chapter IV

### Results and discussion

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<b>Figure IV.1</b> SMAW1-1 parameters. ....	75
<b>Figure IV.2</b> Temperature (SMAW1-1).....	75
<b>Figure IV.3</b> Total distortion (SMAW1-1).....	76
<b>Figure IV.4</b> Effective stress (SMAW1-1).....	76
<b>Figure IV.5</b> SMAW1-2 parameters. ....	77
<b>Figure IV.6</b> Temperature (SMAW1-2). ....	77
<b>Figure IV.7</b> Total distortion (SMAW1-2).....	78
<b>Figure IV.8</b> Effective stress (SMAW1-2).....	78
<b>Figure IV.9</b> SMAW1-3 parameters. ....	79
<b>Figure IV.10</b> Temperature (SMAW1-3).....	79
<b>Figure IV.11</b> Total distortion (SMAW1-3).....	80
<b>Figure IV.12</b> Effective stress (SMAW1-3).....	80
<b>Figure IV.13</b> SMAW2-1 parameters. ....	81
<b>Figure IV.14</b> Temperature (SMAW2-1).....	81
<b>Figure IV.15</b> Total distortion (SMAW2-1).....	82
<b>Figure IV.16</b> Effective stress (SMAW2-1).....	82
<b>Figure IV.17</b> SMAW2-2 parameters. ....	83
<b>Figure IV.18</b> Temperature (SMAW2-2).....	83
<b>Figure IV.19</b> Total distortion (SMAW2-2).....	84
<b>Figure IV.20</b> Effective stress (SMAW2-2).....	84
<b>Figure IV.21</b> SMAW2-3 parameters. ....	85
<b>Figure IV.22</b> Temperature (SMAW2-3).....	85
<b>Figure IV.23</b> Total distortion (SMAW2-3).....	86
<b>Figure IV.24</b> Effective stress (SMAW2-3).....	86
<b>Figure IV.25</b> SMAW3-1 parameters. ....	87
<b>Figure IV.26</b> Temperature (SMAW3-1).....	87
<b>Figure IV.27</b> Total distortion (SMAW3-1).....	88
<b>Figure IV.28</b> Effective stress (SMAW3-1).....	88
<b>Figure IV.29</b> SMAW3-2 parameters. ....	89
<b>Figure IV.30</b> Temperature (SMAW3-2).....	89

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<b>Figure IV.31</b> Total distortion (SMAW3-2).....	90
<b>Figure IV.32</b> Effective stress (SMAW3-2).....	90
<b>Figure IV.33</b> SMAW3-3 parameters. ....	91
<b>Figure IV.34</b> Temperature (SMAW3-3).....	91
<b>Figure IV.35</b> Total distortion (SMAW3-3).....	92
<b>Figure IV.36</b> Effective stress (SMAW3-3).....	92
<b>Figure IV.37</b> Results of Effective stress. ....	93
<b>Figure IV.38</b> Results of Distortion. ....	93

# List of Tables

## Chapter I

### General information on welding

<b>Table I.1</b> some reference number of welding methods.....	8
<b>Table II.2</b> Typical leg lengths for various electrode sizes.....	38

## Nomenclatures

Symbol	Unit	Designation
SMAW		Shielded metal arc welding
MMA		Manual metal arc welding
ISO		International Organization for Standardization
MIG		Metal Inert Gas Welding
MAG		Metal Active Gas Welding
TIG		Tungsten Inert Gas Welding
GTAW		Gas Tungsten Arc Welding
SAW		Submerged Arc Welding
PAW		Plasma Arc Welding
ESW		Electro Slag Welding
EBW		Electron Beam Welding
LBW		Laser Beam Welding
HAZ		Heat Affected Zone
CC		Constant Current
DCEN		Direct Current Electrode Negative
DCEP		Direct Current Electrode Positive

BS		British Standard For protective Helmets
OCV		Open Circuit Voltage
IIW		International Institute of Welding
Abaqus		Finite Element analysis software
COMSOL		Multiphysics Simulation Software
FEA		Finite Element analysis
CAD		Computer Aided Design Data
GUI		Graphical User Interface
V	volt	Voltage
A	ampere	Current
S	second	Welding time
D	mm	Electrode Size with coating
D	mm	Electrode Size without coating
K		Potassium
Ca		Calcium
N <sub>2</sub>		Nitrogen Gas
TiO <sub>2</sub>		Titanium Dioxide
CaF <sub>2</sub>		Calcium Fluoride
STKM13A		Carbon steel
G2Si1		Carbon steel wire

**1. General Introduction**

2. Chapter I

3. Chapter II

4. Chapter III

5. Chapter IV

6. General conclusion

7. Bibliographical references

**General  
Introduction**

## **General Introduction**

Shielded Metal Arc Welding (SMAW), commonly known as stick welding, is a widely used welding process in various industries, including manufacturing, construction, and automotive. SMAW involves the creation of an electric arc between a coated electrode and the base metal, resulting in the fusion of metals and the formation of a welded joint. This process offers several advantages, such as simplicity, versatility, and the ability to work in various environments. However, SMAW can also have significant effects on the mechanical properties and performance characteristics of the welded components.

Understanding the effects of SMAW on mechanical parts is crucial for ensuring the structural integrity and functionality of welded assemblies. The mechanical properties of welded joints, including tensile strength, impact resistance, and ductility, can be influenced by various factors such as welding parameters, electrode selection, and post-weld treatments. Additionally, SMAW can introduce residual stresses, distortions, and potential defects, which can affect the overall performance and durability of mechanical parts.

This thesis is divided into four chapters to comprehensively address the research objectives.

The primary objective of this thesis is to comprehensively analyze the effects of SMAW on mechanical parts. The specific objective include: Analyzing the structural integrity of welded components, including weld quality, residual stresses, distortions, and the potential for crack initiation and propagation.

This thesis is divided into four chapters to comprehensively address the research objectives.

Chapter 1 provides a general introduction to welding as a joining process and lays the foundation for the subsequent chapters.

Chapter 2 delves into a detailed explanation of shielded metal arc welding (SMAW),



Chapter 3 focuses on the simulation of nine welding processes using the Simufact Welding software, Chapter 4 presents a comprehensive analysis and conclusion based on the findings from the simulation study.

1. Introduction
2. Chapter I: General information on welding
3. Chapter II
4. Chapter III
5. Chapter IV
6. General conclusion
7. Bibliographical references

# **Chapter I: General information on welding**

## **I.1 Introduction**

Welding is a method that uses heat, pressure, and metallurgical conditions to permanently join two materials. This process plays a crucial role in many industries, such as aerospace, marine, and automotive. For example, welding is extensively used in vehicle manufacturing to create various body parts. In fact, the transportation industry accounted for over one-third of the welding materials market in 2019. The quality of welding technology can significantly impact the performance of industries, as demonstrated by recalls made by “Fiat” and “Ford” due to faulty welding. The welding materials market is also expected to grow from USD 13.6 billion in 2020 to USD 17.3 billion by 2025. Therefore, understanding the welding process is vital for improving the final performance of welded parts across these industries.[1]

## **I.2 Brief History of Welding**

Welding has a rich history dating back thousands of years and has played a crucial role in the development of society. The origins of welding can be traced back to 3000 B.C. with the use of bronze. Over time, humans began working with various metals such as copper, silver, gold, and iron. Examples of welding from ancient times, such as golden boxes from the Bronze Age, have been discovered.

During the middle Ages, blacksmithing and forge welding advanced, and iron became a commonly used material. The publication of "De la pirotechnia" by Italian metallurgist Vannoccio Biringuccio marked an important milestone in metallurgy. In the Renaissance, blacksmithing and forge welding continued to progress.

In the modern era, welding has undergone significant advancements in terms of accuracy, speed, and effectiveness. Today, there are over 90 welding processes, and research in industries such as nuclear, space, transportation, and shipbuilding continues to drive the development of new welding techniques. Safety and quality inspection methods have improved, ensuring higher standards and craftsmanship.

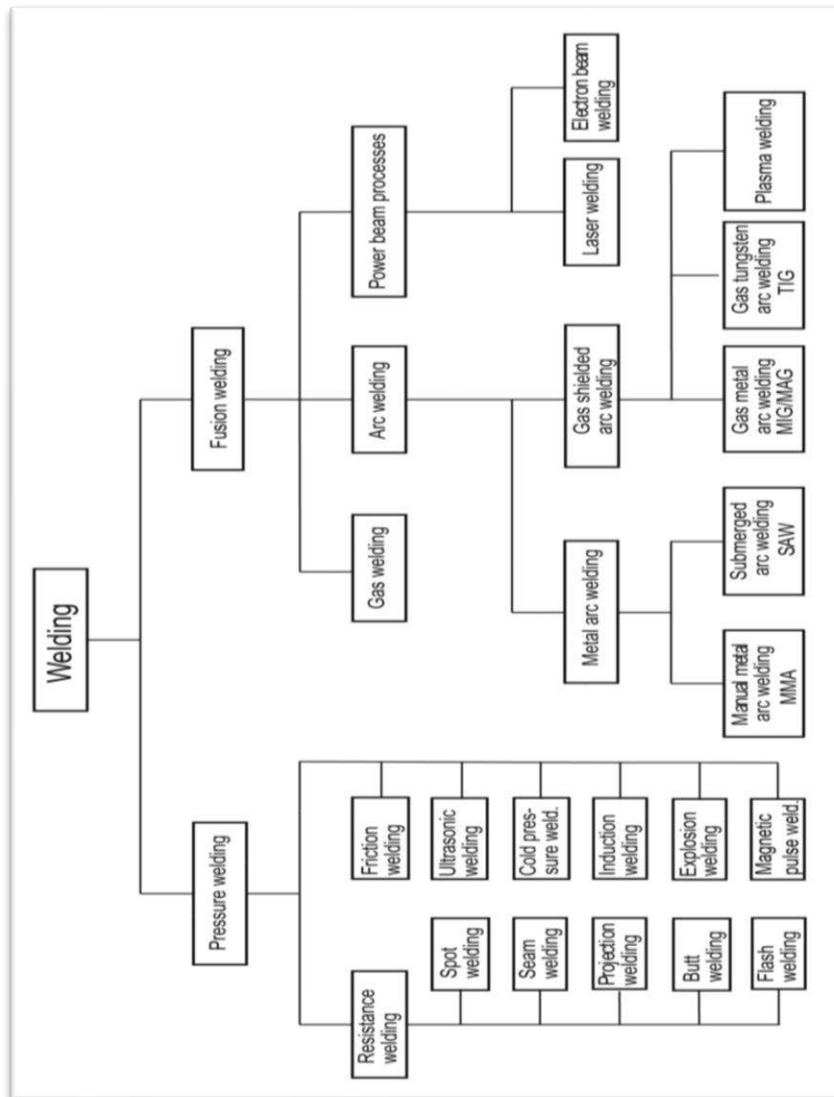
Welding has contributed to the production of various goods, ranging from utensils and jewelry to transportation and weaponry. It remains a vital skill in many industries, constantly evolving with new technologies and research. Welding continues to shape our world with its efficiency, precision, and safety considerations.[2]

### **I.3 Definition of welding**

Welding is a crucial manufacturing process that allows for the fabrication of large and complex products by assembling smaller components. It involves melting the material at the interface of two metals, fusing them together, and solidifying to create a strong joint. Pressure can be applied to facilitate plastic deformation and ensure a tight bond. Filler metals are used to fill the gap between the base metals, providing the same material in a molten state. Fluxes remove impurities and create a protective layer of slag to prevent oxidation. Besides welding, other methods like soldering, brazing, adhesives, and mechanical fasteners are used for joining workpieces. Soldering and brazing are especially useful for joining dissimilar metals without melting the base metal. They involve melting a filler metal to fill gaps and create a strong joint.[3]

### **I.4 Welding Processes**

The processes used to join materials can be broadly classified into four categories: mechanical joining, adhesive bonding, brazing and soldering, and welding. Advances in technology have led to significant developments in adhesive bonding and welding, with improvements to existing processes and the introduction of new methods of joining. In order to provide an overview of the most commonly used joining processes, their applications, and their limitations, a brief description is provided below (Figure 1.1). The “ISO” has established a standardized system for identifying joining processes, known as ISO 4063. The first digit of this code represents the main process grouping, while the second and third digits identify sub-groups.[4]



**Figure I.1** Schematic presentation of the most common welding methods [5].

**Table I.1** some reference number of welding methods [5].

Welding method	Reference number
SMAW welding	111
Flux-cored wire metal-arc welding without gas shield	114
Submerged arc Welding	12
MIG Welding	131
MAG Welding	135
MAG welding with flux-cored wire	136
TIG Welding	14
Plasma arc Welding	15
Oxy-fuel gas Welding	311

## I.5 Fusion welding

### I.5.1 Process definition

Fusion welding is a type of welding process that involves the melting of two or more pieces of metal to create a permanent bond. The process typically involves the use of heat, pressure, or both to melt and join the metal pieces together. The melted metal is allowed to cool and solidify, forming a strong, homogeneous bond between the pieces. Common examples of fusion welding processes include gas welding ,arc welding , high energy beam welding .[6]

### I.5.2 Principle of fusion welding

The welding processes differ in the manner in which temperature and pressure are combined and achieved. The welding process is divided into two major categories:

#### □ Fusion welding

Processes use heat to melt the base metals. In many fusion welding operations, a filler metal is added to the molten pool to facilitate the process and provide bulk and strength to the welded joint.

### □ Solid-state joining welding

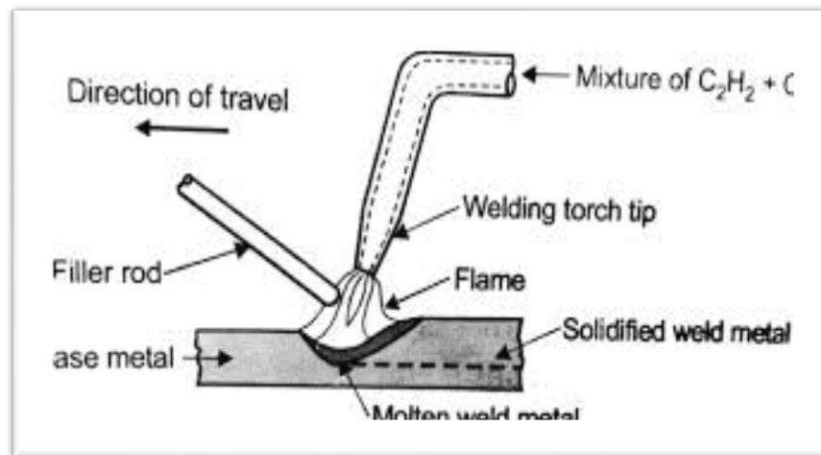
Joining processes in which coalescence results from application of pressure alone or a combination of heat and pressure. [7]

## I.6 Types of fusion welding

### I.6.1 GAS WELDING

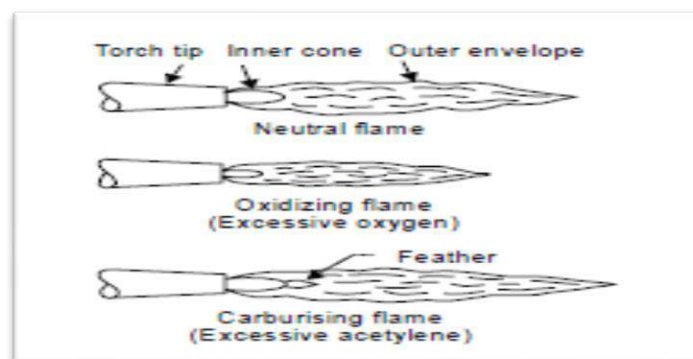
Gas welding is a welding process that melts and joints metals by heating them with a flame caused by a reaction of fuel gas and oxygen. The most commonly used method is oxyacetylene welding, due to its high flame temperature. (Figure.1.2), shows the overall process and welding area of Oxyacetylene

Welding process.[7]



**Figure I.2** Schematic presentation of Oxyacetylene welding process [8].

There are three types of flame in oxyacetylene welding as illustrated in (Figure 1.3).



**Figure I.3** Schematic presentation of Oxyacetylene welding process flame types [9].

**a) Neutral flame**

C<sub>2</sub>H<sub>2</sub> and O<sub>2</sub> are mixed in equal amounts and burn at the tip of the welding torch. The inner cone gives 2/3 of heat whereas the outer envelope provides 1/3 of the energy.

**b) Reducing flame**

The excess amount of acetylene is used, giving a reducing flame. The combustion of acetylene is incomplete (greenish) between the inner cone and the outer envelope. Good for welding aluminum alloys, high carbon steels.

**c) Oxidizing flame**

The excess amount of O<sub>2</sub> is used, giving an oxidizing flame. Good for welding brass.

**I.6.1.1 Advantages of gas welding**

- Simple equipment
- Portable
- Inexpensive
- Easy maintenance & repair

**I.6.1.2 Disadvantages of gas welding**

- Limited power density
- Very low welding speed
- High total heat input per unit length
- Large heat affected zone
- Severe distortion
- Not recommended for welding reactive metals such as titanium and zirconium.

**I.6.2 ARC WELDING**

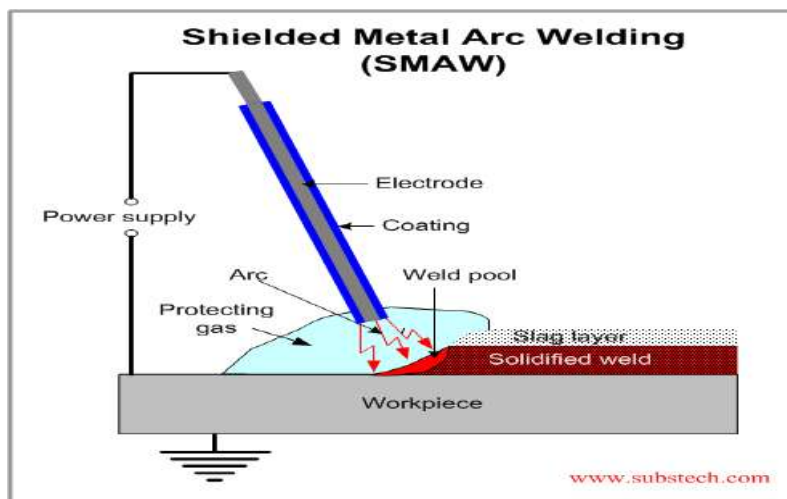
Arc welding is a type of fusion welding that uses a welding power supply to create an electric arc between an electrode and the base material to melt the metals at the welding point. They can use either Direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes. [7]

Arc welding methods can be categorized into the following categories:

**I.6.2.1 Shielded metal arc welding (SMAW)**



The use of an arc as a heat source, along with generated shielding gases and melting slag, has long been a popular method in steel fabrication. It not only melts the parent material but also the electrode core, providing filler material for the joint. The electrode coating can also contribute alloying elements and additional filler material. Moreover, it can create protective layers against wear and corrosion. Although it requires simple equipment and offers a range of consumables, it is labor-intensive and operates at low efficiency.[4] (Figure 1.



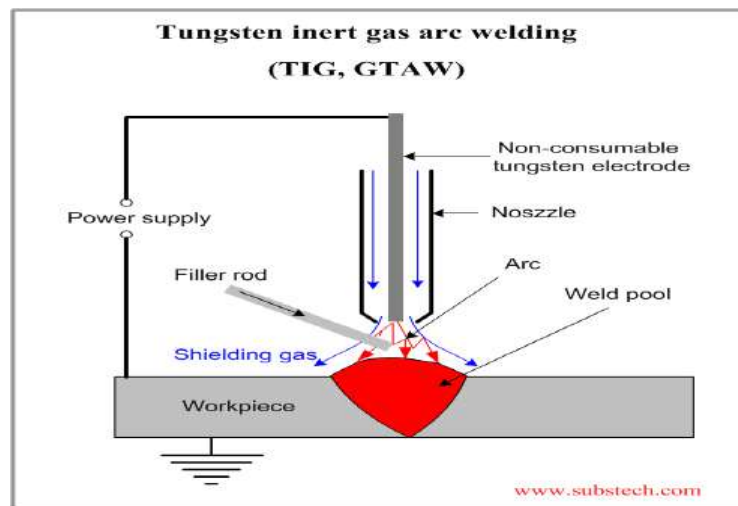
**Figure I.4** Shielded metal arc welding process (SMAW) [10].

#### **Advantages and the disadvantages of (SMAW)**

“SMAW” has both advantages and disadvantages. It offers simplicity, portability, and cost-effectiveness in terms of equipment. It is versatile, suitable for various metals, positions, and electrodes, and can be used outdoors. However, there are drawbacks to SMAW. The process is discontinuous due to limited electrode length, resulting in frequent interruptions and reduced efficiency. Slag inclusions may weaken the weld's strength, and fumes generated during the process can pose health hazards and make control difficult. In conclusion, while SMAW has attractive advantages for welding, it's important to consider its disadvantages when choosing the appropriate technique for a project.[10]

### I.6.2.2 Gas -Tungsten Arc Welding (GTAW)

Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas (TIG) welding involves welding metal parts by creating an electric arc between a non-consumable tungsten electrode and the workpiece. The welding area, tungsten electrode, and molten metal are protected from contamination by inert gases like Argon, which also provide maximum visibility to the welder. Adding hydrogen gas can increase travel speeds.[11]



**Figure I.5** Tungsten inert gas welding (TIG,GTAW) [10].

#### *Advantages of GTAW welding*

Concentrated Arc welding provides excellent control over heat input, making it ideal for welding thin materials. It eliminates the need for flux, reducing slag and improving visibility of the weld pool. This method is safer as it produces no sparks or spatter. It also generates fewer fumes compared to other arc welding methods. However, proper ventilation and safety precautions are still necessary. Concentrated Arc welding is versatile and suitable for various metals and alloys. It is a precise and efficient technique widely used in many industries.[11]

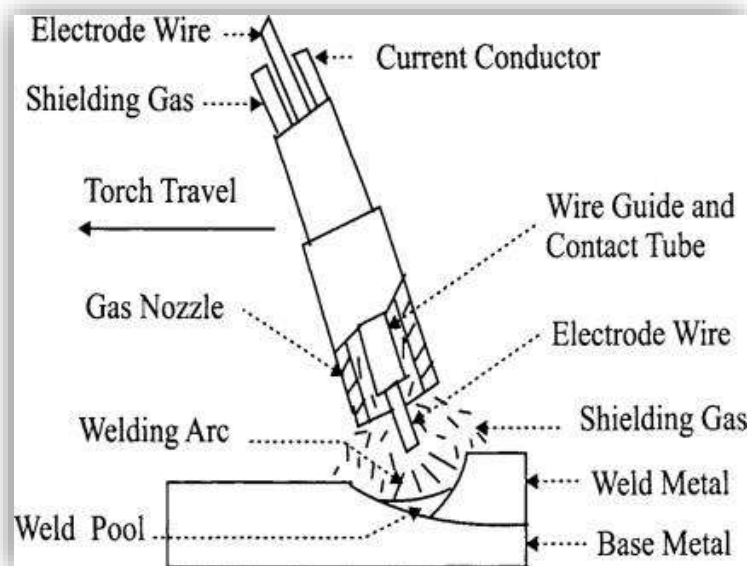
#### **Disadvantages of GTAW welding**

- ❖ Slower travel speeds than other processes.
- ❖ Lower filler metal deposition rates.
- ❖ Hand-eye coordination is a required skill.
- ❖ Brighter UV rays than other processes.

- ❖ Equipment costs can be higher than other processes.
- ❖ Concentrations of shielding gas may build up and displace oxygen when welding in confined areas – ventilate the area and/or use local forced ventilation at the arc to remove welding fumes and gases. If ventilation is poor, wear an approved air-supplied respirator.[11]

### I.6.2.3 Gas -Metal arc welding (GMAW)

Gas Metal Arc Welding (GMAW), also called MIG or MAG welding, melts metals using an electric arc. It involves feeding continuous electrode wire through a welding gun while using shielding gas to protect the arc. GMAW can be done in three ways: semi-automatic, machine, and automatic welding. The basic equipment includes a welding power source, wire feeders, electrode wire, welding gun, and shielding gas cylinder, (Figure 1.6) .[12]



**Figure I.6** Simple diagram of the gas metal arc welding process [13].

#### Advantages of gas metal arc welding

Gas Metal Arc Welding (GMAW) is a versatile process for welding various metals and alloys, including all commercial ones. Unlike submerged metal arc welding, GMAW can be performed in all positions. It offers higher metal deposition rates compared to shielded metal arc welding (SMAW), resulting in faster welding speeds and uninterrupted longer welds. GMAW allows for deeper penetration with spray transfer and eliminates cleaning issues caused by slag. However, GMAW equipment

is more complex, expensive, and less portable than SMAW. Protection against air drafts is necessary, and it produces higher levels of radiated heat and arc intensity.[13]

### Disadvantages of gas metal arc welding

The GMAW gun is quite bulky and difficult to reach small areas or corners.[12]

### I.6.2.4 Plasma arc welding (PAW)

Plasma arc welding (PAW) is an arc welding process that melts and joins metals by heating them with a constricted arc established between a tungsten electrode and the metals as shown in (Figure 1.7). Plasma arc welding is similar to GTAW but an orifice gas and a shielding gas is used. The arc is constricted due to the covering action of the orifice gas nozzle. The tungsten electrode is recessed in the orifice gas nozzle and the arc is initiated by a high frequency generator between the electrode tips and the water-cooled orifice gas nozzle.

The arc is then transferred to between the electrode tip and the Work piece. [10]

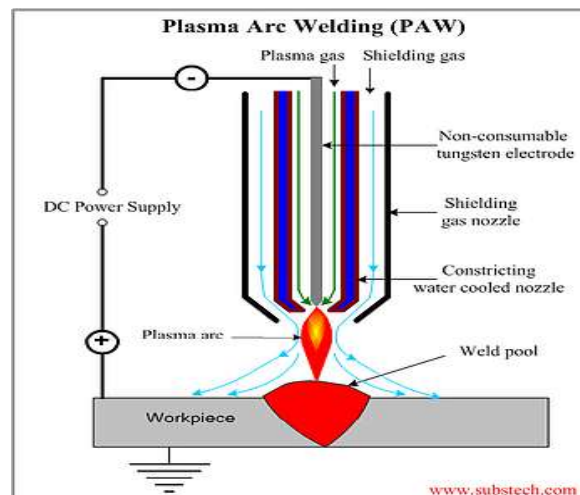


Figure I.7 Plasma arc welding overall process [10].

### Advantages of plasma arc welding

- ❖ The electrode is recessed in the nozzle, so no contamination to the weld metal.
- ❖ Less sensitive to arc length variation.
- ❖ Full penetration.
- ❖ High welding speed.[7]

### Disadvantages of plasma arc welding

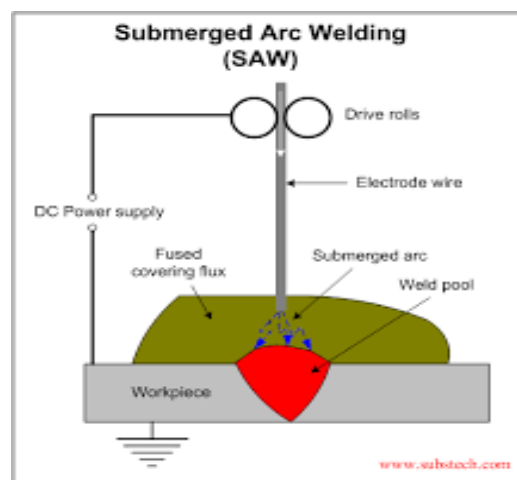
- ❖ More complicated.
- ❖ Require proper electrode tip configuration and Positioning and orifice selection.

- ❖ Equipment is more expensive.[7]

### I.6.2.5 Submerged arc welding (SAW)

Submerged arc welding (SAW) is a process that melts and joins metals by heating them with an arc established between a consumable wire electrode and the metals, with the arc being shielded by a molten slag and granular flux as shown in (Fig.1.8)

In the submerged arc welding, the arc is submerged and invisible. The flux is supplied from a hopper, which travel with the torch. The shielding gas may not be required because the molten metal is separated from the air by the molten slag and granular flux.[7]



**Figure I.8** Submerged arc welding overall process [14].

#### Advantages of submerged arc welding

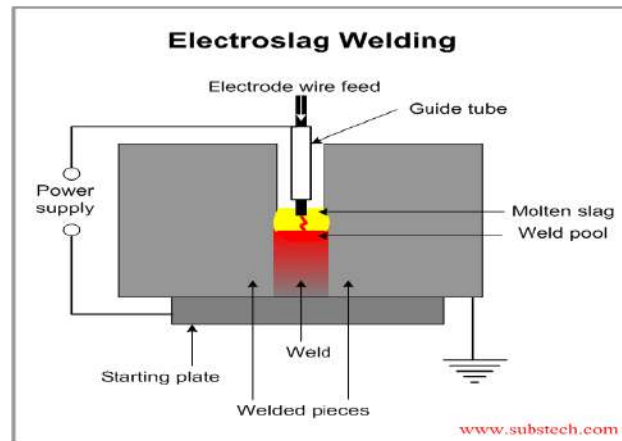
- Clean welds are obtained due to protecting and refining action of the slag.
- At high welding current, spatter and heat loss are eliminated because the arc is submerged.
- Alloying elements and metal powders can be added to the granular flux to control the composition and then increase deposition rate.
- The deposition rate can be increased by using two or more electrodes in tandem.
- Can weld thick section.

#### Disadvantages of submerged arc welding

- ❖ Cannot weld in a flat-position and circumferential (pipe).
- ❖ High heat input can reduce the weld quality and increase distortions.

### I.6.2.6 Electro slag arc welding (EAW)

Electro slag welding (ESW) is a process that melts and joins metals by heating them with a pool of molten slag held between the metals and continuously feeding a filler wire electrode into it as show in (Figure I.8). [7]



**Figure I.9** Electro slag arc welding overall process [15].

In the Electroslag welding process, the weld pool is covered with molten slag and move upward as welding progresses. A pair of water-cooled copper shoes keeps the weld pool and the molten slag from breaking out. The molten slag protects the weld metal from air and refine it. The arc is only used during the initiation process.

#### **Advantages of Electro slag welding**

- Extremely high deposition rate.
- One single pass independent of thickness.
- No angular distortion because the weld is symmetrical with respect to its axis.

#### **Disadvantages of Electro slag welding**

- Very high heat input weld quality could be poor due to coarse grain in the fusion zone or heat affected zone.
- Strict to vertical position due to very large weld pools.

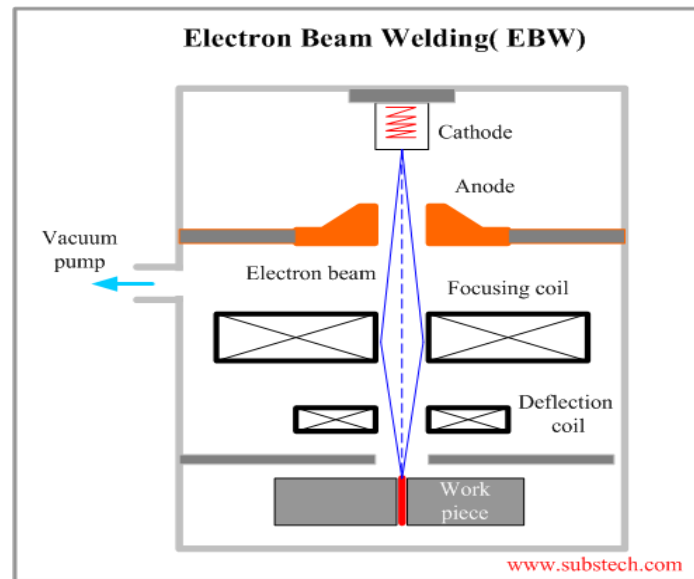
### I.6.3 High Energy Beam Welding

The high-energy beam welding is a fusion welding process that utilizing a heat source, which is Capable of proving extremely high power density, weld input levels. The density of the energy Available from a heat source for welding has more important over the absolute source energy. There Are two main processes of high

energy beam welding: the Electron Beam Welding (EBW) and the Laser Beam Welding (LBW).[7]

### I.6.3.1 Electron Beam Welding (EBW):

Electron beam welding (EBW) is a fusion welding process in which a beam of high velocity electrons is applied to heat and join two materials. The overall process of the electron beam welding is shown in (Figure 1.9). [16]



**Figure I.10** Electron beam welding overall process [16].

#### Advantages of Electron beam welding

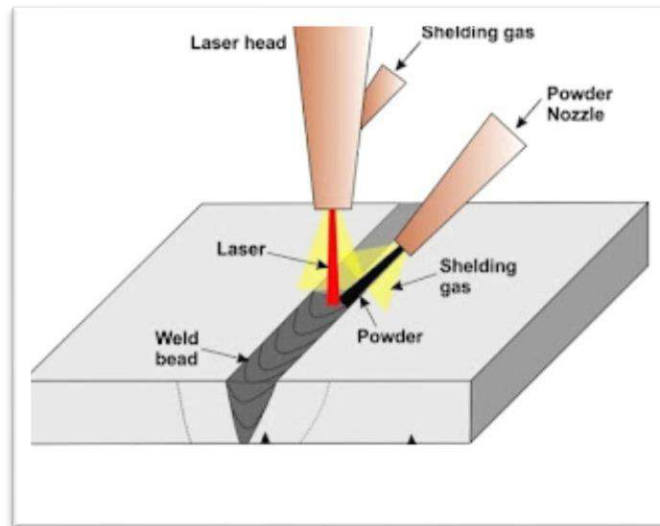
- High power density to produce a full penetration keyhole even in thick specimens.
- Produce a single pass welding at a high welding speed.
- Very narrow heat affected zone (HAZ) and little distortion due to lower heat input per unit length than in arc welding.
- Reactive and refractory metals can be welded in vacuum (no contamination).
- Very rapid cooling can prevent coarse, brittle intermetallic compounds.

#### Disadvantages of Electron beam welding

- Very high equipment cost.
- High vacuum is inconvenient, medium vacuum and non-vacuum (1 atm) EBW have also been developed.
- Precise alignment of the joints and the gun is required due to small beam size.
- Missed jointed of dissimilar metal can be obtained due to beam deflection.

### I.6.3.2 Laser Beam Welding (LBW)

Laser beam welding (LBW) is a process that melts and joins metals by heating them with a laser beam. The overall process of the laser beam welding is shown in (Figure I.10). [7]



**Figure I.11** Laser beam welding overall process [17].

#### Advantages of laser beam welding

- Produce deep and narrow welds at high welding speeds.
- Narrow heat-affected zone.
- Little distortion.
- Can be used for welding dissimilar metals in varying sizes.

#### Disadvantages of laser beam welding

- Very high reflectivity of a laser beam by the metal surface.
- High equipment cost.
- Require precise joint and laser beam alignment.[7]

## I.7 Fusion welding parameter

### I.7.1 Arc voltage

The arc voltage is an important input process parameter in any welding process whether it is arc or any other fusion welding process. It decides the shape and width of the weld. If the arc voltage is more the weld width is generally more. It is also responsible for undercutting and slag formation which is difficult to de-slag.[18]



### I.7.2 Welding current

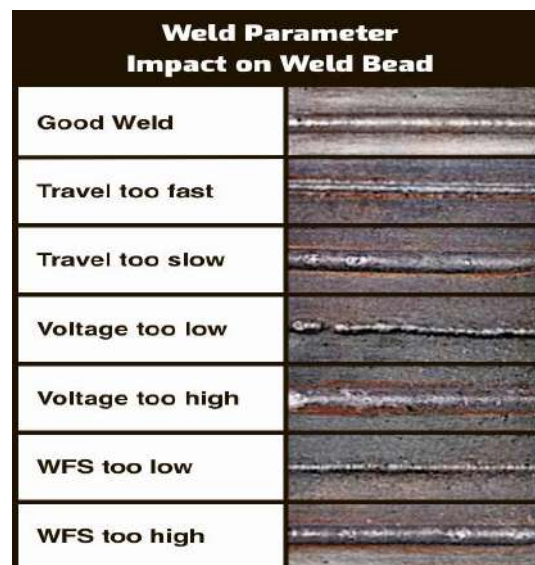
The current provides depth of penetration and so high current can be utilized in case of thick pieces for welding. If the current is very high it can burn the metal and if it is very low it results in incomplete penetration, so proper selection of current for welding is must. [18]

The relationship between welding current, voltage, and power (P) can be expressed as:

$$P = I * V \dots\dots\dots (I.1).$$

### I.7.3 Welding speed

Speed of electrode wire relative to work piece is termed as welding speed. Depth of penetration decreases with increase of speed which results in wider weld width. If the welding speed is very less then opposite effect is also observed as at very low speed the energy transfer to more depth is prevented by the existing molten weld pool and depth of penetration reduces. For maximum required depth of penetration the knowledge of optimum speed is necessary.[18]



**Figure I.12** Schematic presentation of Speed of electrode wire relative to work piece is termed as welding speed [19].

The relationship between travel speed, welding current, and voltage can be expressed as:

$$v = I / (V * efficiency) \dots\dots\dots (I.2).$$

### I.7.4 Wire diameter

Wire diameter is responsible for current density of the electrode. The ratio of current to area of cross section of electrode is known as current density. Current density is reciprocal of square of diameter of the electrode. If wire diameter is very less or very large then there is a strong possibility of unbalanced depth of penetration. So diameter of electrode should be selected properly. [18]

### I.7.5 Granular flux

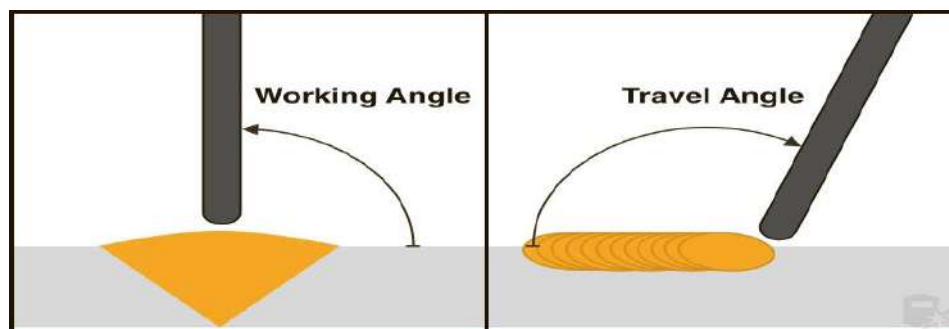
In shielded metal arc welding the coating on stick electrodes is done for shielding of weld but in submerged arc welding case the shielding of weld is achieved by using granular flux. The flux can contain the desired material for weld which may be lost during welding. The fluxes are of 4 types as fused, bonded, agglomerated and mechanically mixed fluxes. To remove moisture hygroscopic fluxes are used. Different types of halides are used to obtain high strength weld.[18]

### I.7.6 Length of the Arc

The distance between the welder's arc and the work plates can have an impact on the amount of heat and current that goes into the joint during welding. When the arc is held closer to the work plates, the heat and current remain high, while holding the arc farther away produces less heat and more spatter. In stick welding, the arc length should match the diameter of the electrode metal, typically 1/8 inch from the joint surface. In wire feed welding, the electrode is held farther away from the joint since the arc is more concentrated and capable of burning through metal.[19]

### I.7.7 Angle

There are two torch angles to remember when welding:[19]



**Figure I.13** Schematic presentation of the welding angle [19].

#### 1. Work angle

The work angle, which is the relationship between the joint and the torch (or rod).

## **2. Travel angle**

The travel angle is the position of the welding torch relative to the direction of travel. By tilting the torch up to 10 degrees in the direction of travel, the welder can see the joint and puddle more clearly. A 90-degree angle allows maximum heat and current into the joint, while a 5-10 degree tilt provides a better view of the puddle. Tilting the torch towards the puddle during dragging helps with penetration and a thick bead, while tilting away from the puddle during pushing limits penetration and heat. Holding the torch perpendicular to the joint is ideal, except for T-joints where the work angle varies between 30 to 50 degrees

## **I.8 Advantages and Disadvantages**

- **Advantages of fusion welding**

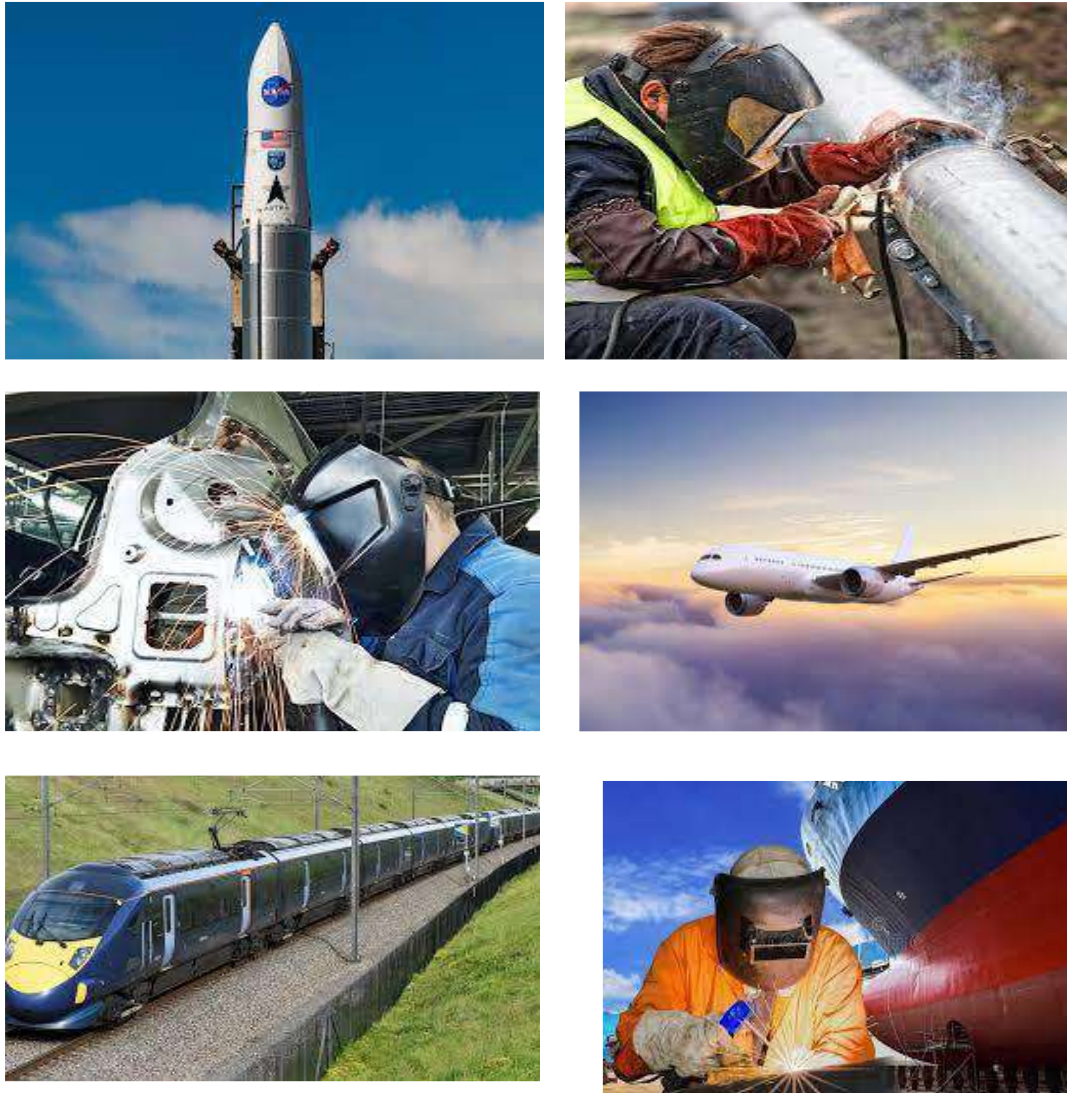
Fusion welding offers several advantages for joining metals. Firstly, it creates strong joints that can withstand high levels of stress, making it suitable for components under heavy loads. Additionally, fusion welding is versatile and can be applied to a variety of metals, including steel, aluminum, and copper. The process also yields high-quality welds with minimal defects, ensuring the strength and reliability of the joints. From an economic standpoint, fusion welding is cost-effective, making it a popular choice in various applications. Furthermore, its potential for automation reduces labor costs and improves overall efficiency in welding operations.

- **Disadvantages of fusion welding**

Fusion welding has certain considerations that need to be taken into account. Skilled labor is required, leading to higher labor costs due to the expertise needed to operate the equipment and handle materials correctly. The high heat input of fusion welding can cause distortion or warping, especially in thin or delicate components. Additionally, there is a potential for hazardous fumes and gases to be generated during fusion welding, necessitating proper safety measures. The limited portability of fusion welding equipment may restrict its use in certain applications. Furthermore, surface preparation is essential for fusion welding, requiring clean and contaminant-

free metal surfaces, which can be time-consuming and increase the overall cost of the welding process.

### I.9 Scope of application



**Figure I.14** Scope of application.

1. Introduction
2. Chapter I
3. Chapter II: Shielded metal arc welding (SMAW)
4. Chapter III
5. Chapter IV
6. General conclusion
7. Bibliographical references

# **Chapter II: Shielded Metal Arc welding (SMAW)**

## II.1 Introduction

Shielded Metal Arc Welding (SMAW), also known as stick welding or stick electrode welding, is a versatile and straightforward welding process where the heat for welding is generated by an electric arc between a covered metal electrode and the workpiece. It can weld both ferrous and nonferrous metals, with thicknesses above 18 gauge in all positions. The welder controls the arc, and the process leaves a slag on the surface of the weld that must be removed. This process is popular for welding mild and low alloy steels, and the equipment is rugged and simple. The electric arc was invented in 1801, and the metal arc welding process began in 1889 when carbon electrodes were replaced by metal rods. The process gained significant popularity during World War I, especially in the shipbuilding industry, and today it remains a widely used welding process.[21]

## II.2 Principle of the process

SMAW is an electric arc welding process that involves heating a consumable electrode and the workpiece by using an electric arc generated by a power source, welding cables, an electrode holder, a work clamp, and a welding electrode. When the electrode is touched briefly to the base metal, an arc is created and the welder guides the electrode to control the direction and speed of the welding process. The heat generated by the arc melts the base metal and the electrode, creating a molten weld puddle that is transferred across the arc to form the deposited weld metal. The deposit is covered by a slag produced by the electrode coating and the arc is surrounded by a gas shield from the same coating. Some spatter and smoke may occur during the process. The heat generated by the welding arc can be calculated using the formula:

$$J = \text{Arc voltage (V)} \times \text{Arc current (A)} \times \text{Welding time (s)} \dots \text{(II.1)}$$

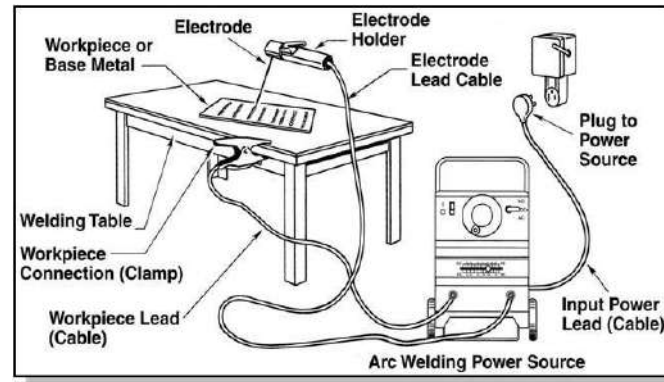
While the net heat input can be determined by:

$$H_{\text{net}} = VI (60)/(S \times 1000) \text{ kJ/mm} \dots \text{(II.2)}$$

If the welding arc is moving at speed S (mm/min). [22]

## II.3 Equipment

Shielded Metal Arc Welding (SMAW), also known as stick welding, and uses a few essential pieces of equipment to perform the welding process. These include: (see Figure II.1)



**Figure II.1** Equipment for Shielded Metal Arc Welding.

### II.3.1 POWER SOURCES

The purpose of the power source or welding machine is to provide the electric power of the proper current and voltage to maintain a welding arc. Many different sizes and Types of power sources are designed for shielded metal arc welding. Most power sources operate on 230 or 460 volt input electric power. Power sources that operate on 200 or 575 volt input power are also available. [21]

### II.3.1 Machines for SMAW

The output characteristics of the power source must be of the constant-current (CC) type. The normal current range is from 25 to 500 amps using conventional size electrodes. The arc voltage is from 15 to 35 volts. [21]

#### ➤ Generator and Alternator Welding Machines

A welding generator is a machine that can be powered by an electric motor or an internal combustion engine, depending on whether it is being used in a shop or in the field. Engine-driven welders can be air-cooled or water-cooled and may provide auxiliary power for other tools or equipment. These machines can provide both AC and DC power for welding. An alternator welding machine is essentially an electric generator that produces AC power through a rotating assembly. These machines are also known as rotating or revolving field machines. Dual control machines typically have a generator where the slope of the output curve can be adjusted, with the fine

adjustment control knob regulating the open circuit voltage and fine welding current during welding (as seen in Figure II.2)



**Figure II.2** Diesel Engine Driven Power Source [21].

➤ **Transformer Welding Machines**

The transformer type welding machine is the least expensive, lightest, and smallest of any of the different types of welders. It produces alternating current for welding. The transformer welder takes power directly from the line, transforms it to the power required for welding, and by means of various magnetic circuits, inductors, etc., provides the volt-ampere characteristics proper for welding. The welding current output of a transformer welder may be adjusted in many different ways.(see Figure II.3).



**Figure II.3** DC Constant Current Portable Welder/Generator [21].

➤ **Transformer-Rectifier Welding Machines**



Transformer welders, as mentioned earlier, deliver alternating current to the welding arc. However, certain types of electrodes require direct current power to operate effectively. To supply direct current power to the arc without relying on a rotating generator, a rectifier can be used. A rectifier is an electrical device that converts alternating current into direct current. By incorporating a rectifier, transformer-rectifier welding machines can operate on single-phase input power. Refer to (Figure II.4) for visualization. [21]



**Figure II.4** AC/DC Single Phase Power Source [21].

### ➤ Three Phase Rectifier Welding Machines

Three phase rectifier welding machines provide DC welding current to the arc. These machines operate on three phase input power. The three phase input helps overcome the line unbalance that occurs with the single phase transformer-rectifier welding machines. ( see figure II.5 ).



**Figure II.5** Three Phase Constant Current Power Source [21].

### ➤ Inverter Power Sources

This power source utilizes an inverter and multiple steps to generate suitable welding power. First, the line power is rectified into pulsed DC. Then, the pulsed DC is transformed into high-voltage and high-frequency AC using a high-frequency oscillator or chopper, typically operating between 5 to 50 kHz. (See Figure II.6). [21]



**Figure II.6** Inverter Power Source for SMAW [21].

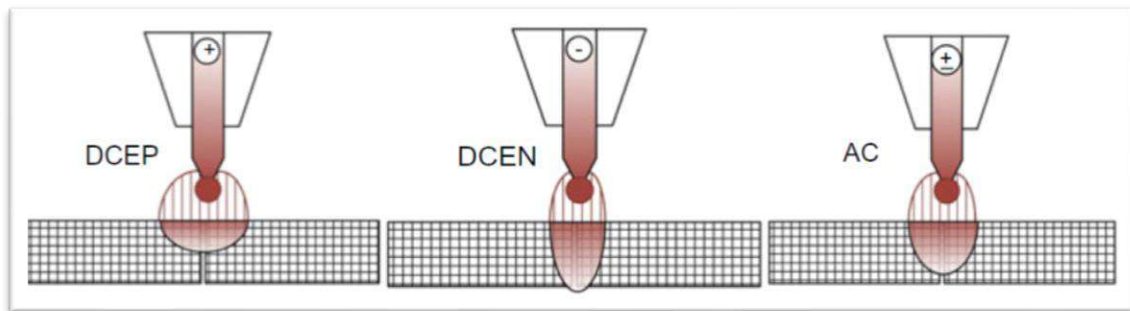
### II.3.2 Types of welding Current

Shielded metal arc welding can be performed with either direct current (DC) or alternating current (AC). Direct current can be used with electrode negative (straight polarity) or electrode positive (reverse polarity). The choice of welding current is typically based on equipment availability and the type of electrode being used. In direct current, the current flows continuously in one direction throughout the welding circuit.[21]

#### II.3.2.1 Selection of Type of Welding Current

When selecting the suitable type of welding current for a specific situation, various aspects need to be considered, including the thickness of the plate/sheet to be welded, cable length required, ease of arc initiation and maintenance, arc blow, odd position welding, and polarity selection for achieving the desired melting rate, penetration, and weld deposition rate. DC is preferred for thin sheet and thickness plates, odd position welding, and polarity selection for controlling the melting rate, penetration, and required deposition rate of the weld metal. AC is preferred for long cables during welding to minimize voltage drop and to overcome arc blow. AC offers penetration

and electrode melting rate somewhat in between that is obtained by DCEN and DCEP. (See Figure II.7) [22].



**Figure II.7** Schematic showing effect of welding current and polarity [22].

### II.3.3 Accessories for SMAW welding

There is a wide range of accessories which a welder requires for either his comfort or safety during welding including:

- ❖ **Helmets:** These are necessary for the protection of eyes and head and incorporate filters to screen out ultra-violet and infra-red radiation and reduce the brightness of the arc. Filters are made in a range of densities to BS 679: 1979 'Filters for use during welding and similar industrial operations'. The higher the welding current the darker the shade. As a protection from damage by spatter a plain cover glass is often fitted in front of the filter.
- ❖ **Electrode holders:** these must be light, easy to hold and grip the electrode securely with the lowest possible electrical resistance. With the passage of several hundred amps even a small resistance can generate considerable heat. Holders should be insulated so that they may be laid on the workpiece without short circuiting the power source.
- ❖ **Welding return clamps:** (also called earth return clamps, or work return clamps) these must make secure and low-resistance contact with the workpiece and are generally made from a copper-based alloy.
- ❖ **Welding cables:** these connect the electrode and the workpiece to the power source and should be of a sufficient size not to overheat. They should be kept as short as possible and any connectors should also offer the minimum electrical resistance.

- ❖ **Chipping hammers and wire brushes:** these items are necessary to remove the slag at the end of a run and clean up the surface.

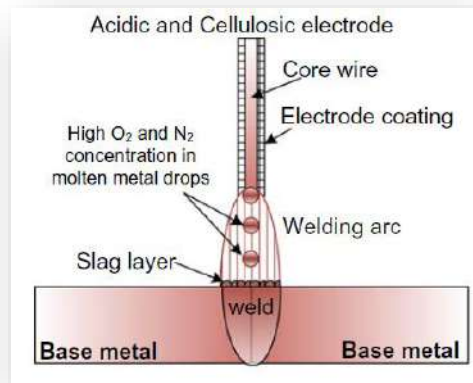
Various items of protective clothing Special clothing is necessary to give protection against heat and hot spatter while safety spectacles are used when chipping off slag.[6]

### **II.3.4 Types of SMAW Electrodes**

Various electrodes with different coatings are available to meet welding requirements. The coating consists of a blend of powdered chemicals and minerals held together by a binder. The coating has multiple functions, including protecting the metal droplets and the weld pool from air reactions, stabilizing the arc, and shaping the upper surface of the weld. Electrodes are categorized into three groups based on the slag composition: acid, rutile, and basic. Other types of electrodes are cellulosic and penetration electrodes. The efficiency of an electrode is calculated as the percentage of weld metal from the electrode compared to the core wire weight. The choice of electrode type depends on various factors summarized in (Table II.1) The efficiency of an electrode can be normal or high.[23]

#### **a) Acid electrodes**

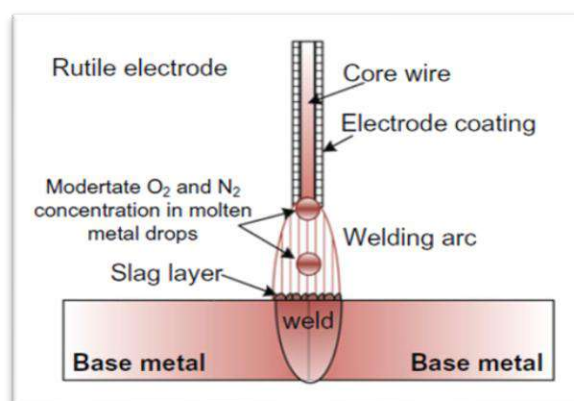
Acid electrodes are coated with iron and manganese oxides, and adding iron powder to the coating improves their efficiency. These electrodes have high productivity and create smooth and shiny weld beads. The resulting slag solidifies slowly, is porous, and can be easily removed. While the weld metal produced by acid electrodes has lower yield strength and ultimate tensile strength than rutile and basic electrodes, it has a higher rupture strain. Acid electrodes are well-suited for horizontal welding and are commonly used for welding low carbon content unalloyed steel. (See Figure II.8). [22].



**Figure II.8** Schematic showing effect of type of electrode on mode of metal transfer in SMAW using Acidic and Cellulosic electrodes [22].

#### b) Rutile electrodes

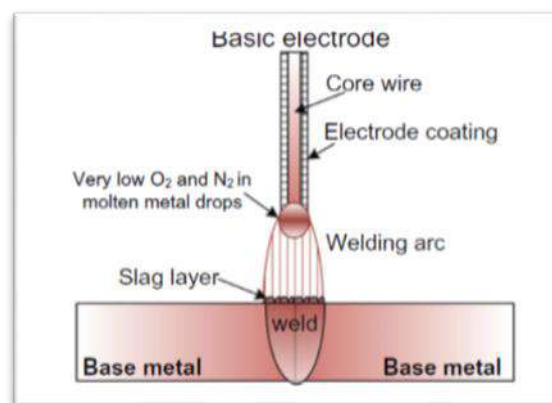
The coating of rutile electrodes typically contains a significant amount (about 25-45%) of the mineral Rutile ( $\text{TiO}_2$ ). Rutile electrodes are known for producing an easily strikable and re-strikable arc, resulting in neat welds with easily removable slag. The weld bead is typically even, resulting in good connection to the base metal at the joint edges and high fatigue strength. However, rutile electrodes have a downside - they tend to produce weld metal with a higher hydrogen content, which increases the risk of hydrogen embrittlement and cracking. As a result, these electrodes are only suitable for welding carbon steel with an ultimate tensile strength of less than 440 Mpa. Rutile electrodes are commonly used for welding standard structural steel and shipbuilding steel. (Refer to Figure II.9). [22]



**Figure II.9** Schematic showing effect of type of electrode on mode of metal transfer in SMAW using Rutile electrode [22].

### c) Basic electrodes

Basic electrodes are coated with calcium fluoride ( $\text{CaF}_2$ ), which reacts as a base, resulting in low oxygen and hydrogen contents in the weld metal. These electrodes produce the strongest and most durable welds and exhibit a higher resistance to hot cracking. Basic electrodes are suitable for welding in all positions and produce a slag with a lower melting point, reducing the risk of slag inclusions. However, they may produce a coarser and rougher weld surface and are hygroscopic, requiring storage in dry conditions. Basic electrodes are well-suited for welding structural, shipbuilding, and pressure-vessel steel. Proper storage and handling are critical to maintaining their quality. (Refer to Figure II.10). [22]



**Figure II.10** Schematic showing effect of type of electrode on mode of metal transfer in SMAW using Basic electrode [22].

### d) Cellulosic electrodes

The coating of cellulosic electrodes contains a relatively high proportion of cellulose substances, intended to produce excellent penetration by providing a high hydrogen content in the arc when welding in any position. The coatings have a high moisture content which means the resulting weld metal contains a high dissolved hydrogen content. It is therefore necessary to employ special methods of welding and to operate at elevated temperatures of  $100\text{--}250^\circ\text{C}$  even when welding relatively thin materials ( $>8\text{--}10\text{ mm}$ ). The principal application of cellulosic electrodes is welding of oil or natural gas pipelines, using the vertical down position. [22] (See Figure II.9).

### e) Penetration electrodes

Penetration electrodes are coated with a thick mixed rutile/acid coating, containing a High proportion of cellulose substances. They produce substantial gas emissions which Increase the arc penetration in the underlying base material. These electrodes are used only in the horizontal position and for welding I-joints (square butt joints).

**TABLE II.1** Factors influencing the choice of welding electrode.

Factor	Rutile electrode	Acid electrode	Basic electrode
Arc stability	++	+	-
Appearance of the weld bead	+	++	-
Striking the arc	++	+	-
Strength of the weld	-	-	++
Different welding positions	+	-	++
Risk of slag inclusions	-	-	++
Resistance to corrosion	+	+	-
Fume formation	++	+	-
Slag removal	+	++	-
Hydrogen content in weld metal	-	-	++

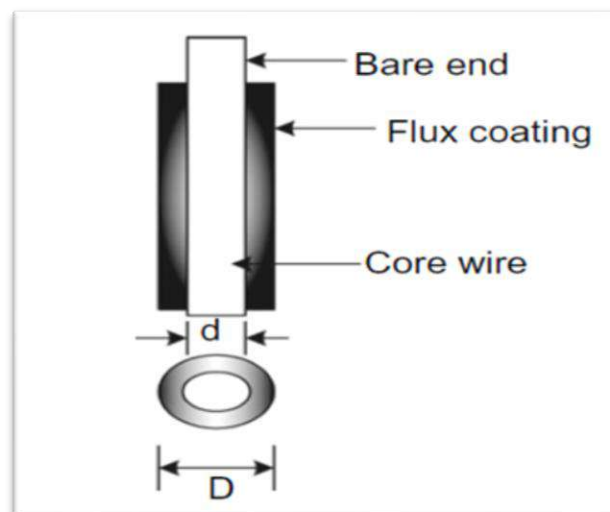
### f) High-yield electrodes:

The productivity (the yield) of an electrode can be substantially improved by mixing iron powder with the coating. The resulting weld metal is produced both by the core electrode wire and the iron powder. One can distinguish between normal-yield

electrodes, having a yield of up to about 130 %, and high-yield electrodes, which have a yield in excess of 130 %, often up to 150-250 %.

### II.3.4.1 Electrode Size and Coating Factor

The diameter of the core wire of an electrode is denoted by  $d$ , while the diameter of the electrode with coating is denoted by  $D$ . The ratio of  $D$  to  $d$  is referred to as the coating factor, which characterizes the thickness of the coating (Figure II.11). Coating factors generally range from (1.2 to 2.2 mm) and are used to group coated electrodes into three categories: light coated coating factor from (1.2 to 1.35 mm), medium coated (coating factor from 1.4 to 1.7 mm), and heavy coated (coating factor from 1.8 to 2.2 mm). Stick electrodes usually come in lengths ranging from (250 to 400 mm). The length of the electrode used during welding is determined by the convenience of the welder to strike the arc, the electrode diameter, and the current carrying capacity of the electrode without causing excessive electric resistive heating of the coating material due to the flow of current through the core wire. The bare end (uncoated portion) of the electrode is used to establish an electrical connection with the power source via appropriate connectors or electrode holders.[22]



**Figure II.11** Schematic of electrode showing electrode section size with ( $D$ ) and without coating ( $d$ ) and its different components [22].

### II.3.4.2 Storage and drying of electrodes

Dampness in some electrode coverings can cause a spatter arc and porosity but its most insidious effect is to introduce hydrogen to the weld and HAZ with the risk of cracking. Users of electrodes should always refer to the manufacturer's literature for the correct procedure to be followed in the storage and drying of electrodes.[6]



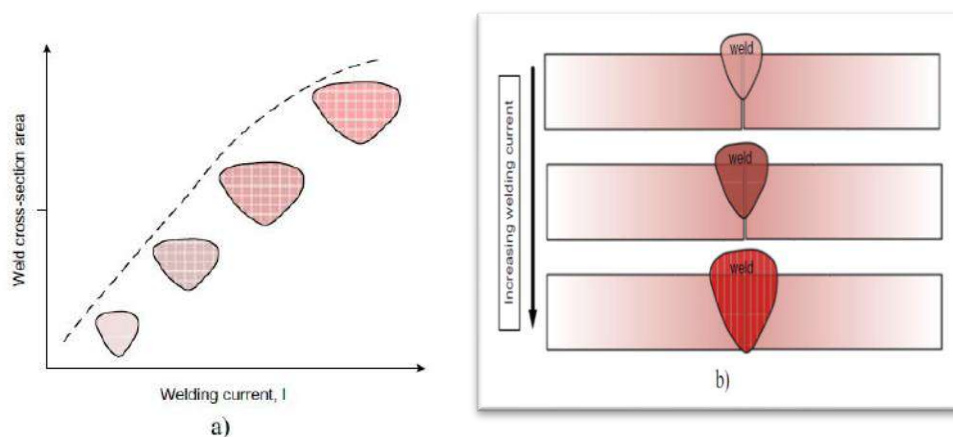
## II.4 Welding Parameters for SMAW

The shielded metal arc welding process typically uses a constant current power source with a welding current ranging from 50 to 600 A and voltage from 20 to 80 V at a 60% duty cycle. Welding transformers (for AC welding) and generators or rectifiers (for DC welding) are commonly used as power sources. For AC welding, the open-circuit voltage (OCV) is usually kept 10-20% higher than DC welding to improve arc stability, as the current magnitude and direction change in every half-cycle in AC welding. OCV requirements are influenced by factors like welding current type and electrode composition, which affect arc stability. Electrodes containing low ionization potential elements like “Ca” and “K” can reduce the OCV required for a stable arc. [22]

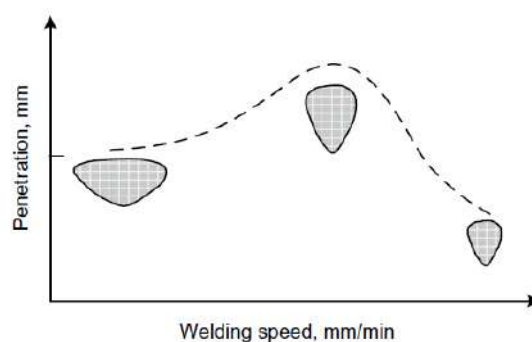
### II.4.1 Importance of Welding Current

The choice of welding current for achieving sound weld joints primarily depends on the thickness of the base metal. Generally, as the thickness increases, more heat input is needed to ensure proper melting, penetration, welding area, and deposition rate (Figure II.12). This increased heat input can be achieved by using higher welding current or slower welding speed. However, there is an optimal welding speed that provides maximum penetration depth, while speeds above or below this optimum reduce penetration depth (Figure II.13). Therefore, adjusting the welding current is the primary method of meeting the heat input requirement. For higher heat input, larger diameter electrodes are required. SMAW electrodes are available in various sizes, typically ranging from (1 to 12.5 mm) in core wire diameter. The upper and lower limits of welding current for SMAW are determined by the tendency of thermal decomposition of the electrode coating material and arc stability, respectively. Generally, the welding current (A) is selected within a range of 40-60 times the electrode core wire diameter (mm). Using excessively high welding current can lead to thermal decomposition of the electrode coating material and turbulence in the arc, resulting in spatter and the entrapment of atmospheric gases. On the other hand, low current leads to an unstable welding arc, poor penetration, and reduced fluidity of the molten weld metal, which can cause discontinuities in the weld joints. In shielded metal arc welding, the lower limit of current is determined by the need for a stable arc, smooth metal transfer, and penetration, while the upper limit is based on the tolerance of the electrode coating to withstand overheating without damage (Figure

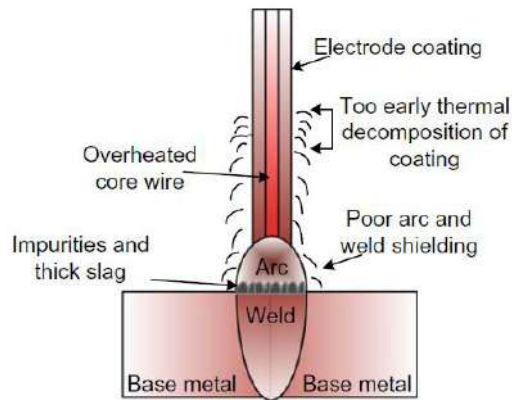
II.14). High current combined with a long electrode extension can cause overheating of the electrode's core wire due to electrical resistive heating. Excessive heating may cause premature combustion or decomposition of the electrode coating, which is essential for providing inactive shielding gases to protect the weld pool and arc. Therefore, larger diameter electrodes are chosen for welding thick sections as they can handle higher welding currents. The increased cross-sectional area of the electrode reduces resistance to current flow, thereby reducing the tendency for electrical resistance heating of the core wire. [22]



**Figure II.12** Schematic showing effect of welding current on weld bead geometry, e.g. penetration, width and weld area: **a** plot and **b** weld joint [22].



**Figure II.13** Schematic showing effect of welding speed on weld bead geometry, e.g. penetration, width and weld area [22].

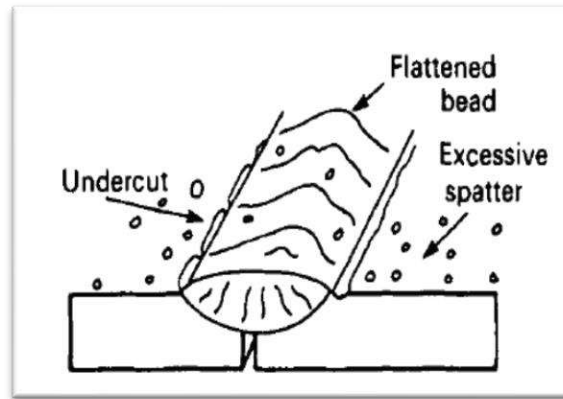


**Figure II.14** Schematic showing premature thermal decomposition of electrode coating due to Overheating of core wire [22].

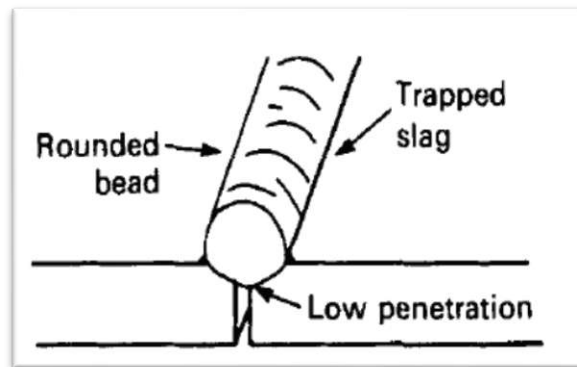
## II.5 Techniques for SMAW welding

### II.5.1 welding conditions

Deviation from the recommended welding current values can significantly impact the behavior of the electrode and the visual quality of the weld. Insufficient welding current (refer to Figure II.15) leads to metal piling up and results in a rough and uneven surface on the weld deposit. Conversely, excessive welding current (refer to Figure II.16) produces a flat deposit with excessive spatter and unnecessary electrode wastage. Maintaining the correct arc length is equally important. If the arc length is too long, the weld metal is deposited in large globules accompanied by explosions that cause spatter and wastage. This results in a slower deposition rate and an irregular weld with an unsightly appearance. The welding speed determines the length of the deposit from each electrode, known as the run-out length. Each electrode has an optimal run length at which it performs best (refer to Figure II.17), which is illustrated specifically for fillet welds.[24]



**Figure II.15** Weld bead contour when current is too low [24].



**Figure II.16** Weld bead contour when current is too high [24].

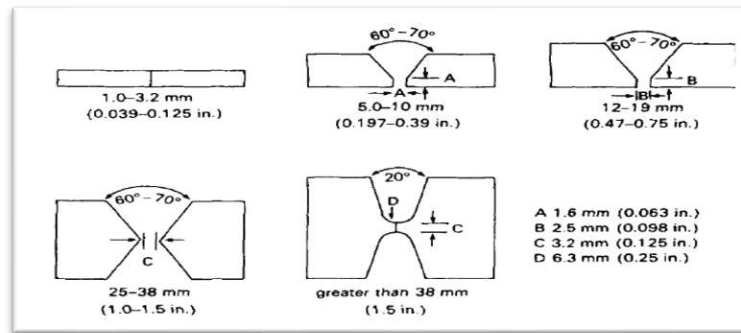
**Table II.2** Typical leg lengths for various electrode sizes [24].

Fillet leg length mm (in.)	Electrode size mm (in.)	Approx. runout length mm (in.)
4.0 (0.16)	3.25 ( $\frac{1}{8}$ )	300 (12)
5.0 (0.20)	4.0 ( $\frac{5}{32}$ )	300 (12)
6.0 (0.24)	5.0 ( $\frac{3}{16}$ )	300 (12)

An excessively long run-out length can result in the electrode moving too quickly, preventing proper fusion from occurring. As a result, the weld metal solidifies rapidly, conversely, a short run-out length causes the arc to linger in one spot, leading to the metal flowing down onto the horizontal plate.

### II.5.2 Edge preparation

Material with a thickness of 1.0-3.2 mm (0.04-0.125 in.) can be welded by butting the two parts together. Above this thickness it is impossible for the molten pool to penetrate to the root of the joint. A groove is therefore necessary and this also accommodates the deposited metal which would otherwise form a pronounced weld bead. Typical edge Preparations for steel plate are shown in (Figure II.18).[24]

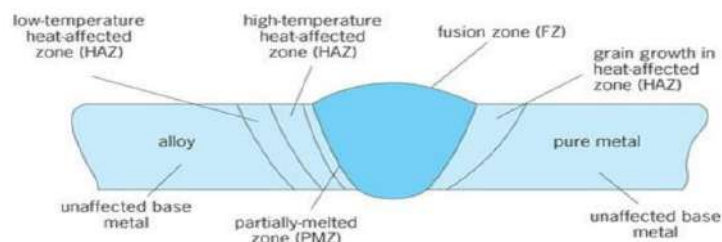


**Figure II.17** Typical edge preparations for SMAW welding [24].

### II.5.3 Weld joint

(Figure II.19) illustrates the presence of three distinct regions within a typical weld joint, which can be categorized as follows: (base metal; heat-affected; zone weld metal).

The characteristics and properties of the second and third regions are significantly influenced by various factors such as the metals being joined, the specific welding process employed, the use of filler metals (if applicable), and the variables associated with the welding heat process. In the absence of a filler metal, a weld joint is referred to as autogenous, and its weld zone comprises the resolidified base metal. Conversely, when a filler metal is utilized, the weld zone contains a central region known as the weld metal, which is a combination of both the base metal and the filler metal.[25]



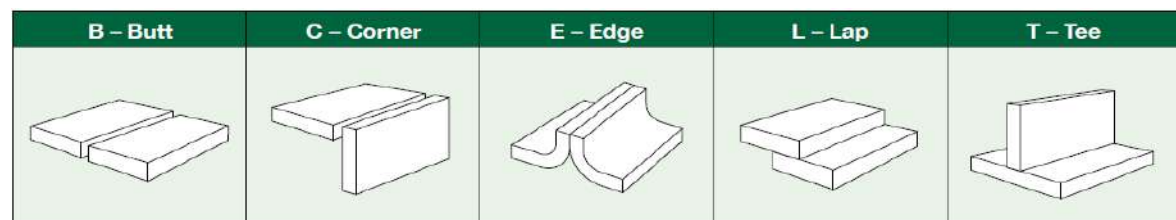
**Figure II.18** Distinct zones of Weld Joints [25].

The heat-affected zone (HAZ) is within the base metal itself. It has a microstructure different from that of the base metal prior to welding, because it has been temporarily subjected to elevated temperatures during welding. The portions of the base metal do not undergo any microstructural changes during welding as they are far enough away from the heat source and far lower temperature to which they are subjected. The properties and microstructure of the HAZ depend on:

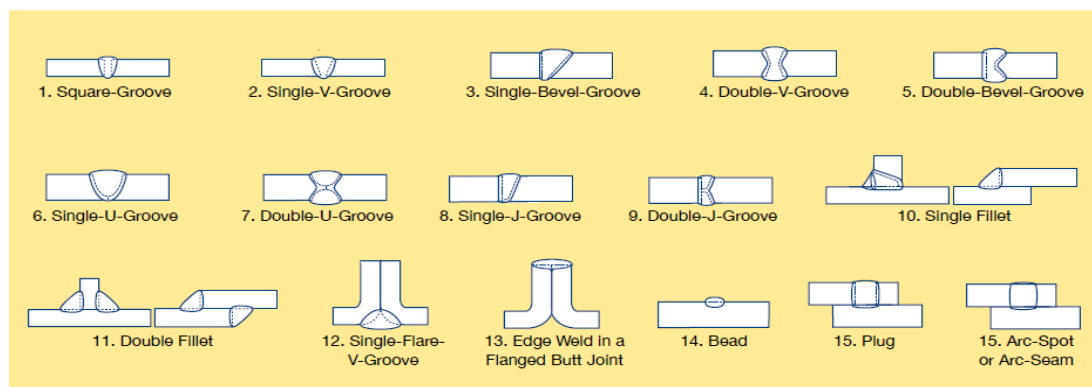
- (a) The rate of heat input and cooling.
- (b) The temperature to which this zone was raised. In addition to metallurgical factors (such as the original grain size, grain orientation, and degree of prior cold work), physical properties influence the size and characteristics of the HAZ. [25]

### II.5.4 Types of Weld Joints:

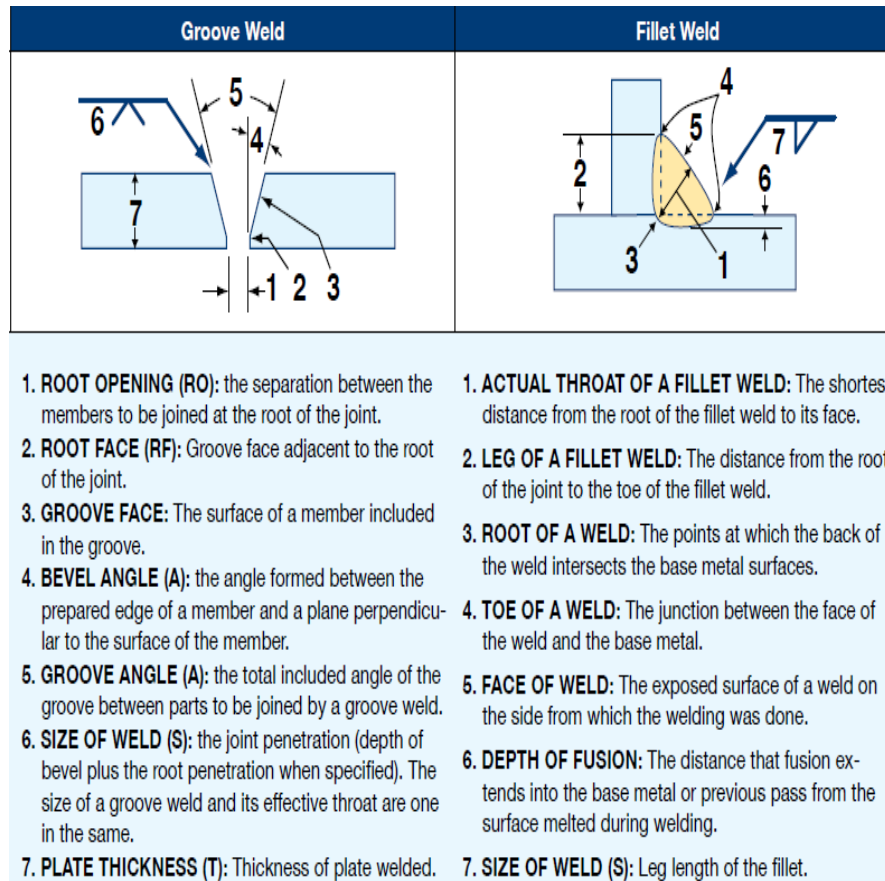
Weld joint design in shielded metal arc welding is influenced by workpiece design, metallurgical considerations, and codes/specifications. Joints are designed for accessibility and cost-effectiveness during construction, which also improves weld quality. There are five basic joint types depicted in (Figure II.20), which can be combined, and various weld types are used based on the joint configuration, see (Figure II.21). Groove and fillet weld nomenclature is depicted in (Figure II.22). [21]



**Figure II.19** Schematic showing the only five basic joints. They can, however, be used in combinations [21].



**Figure II.20** Schematic showing the Common Types of Welds [21].



**Figure II.21** Schematic showing Weld Nomenclature [21].

## II.6 SMAW Welding defects

The quality of welded structures and components is crucial for their performance in service. Weld defects refer to deviations from specified requirements in welded joints or structures. The term "defect" is typically used for faults that have the potential to negatively impact the service life or functioning of the fabricated components, especially in highly stressed areas. In regions of low stress, these faults may be referred to as imperfections, flaws, or discontinuities. The International Institute of Welding (IIW) defines discontinuity as an interruption in the typical structure of a weldment, such as a lack of homogeneity in mechanical, metallurgical, or physical characteristics. Defects weaken the strength of welded joints and can lead to the failure of an entire structure. They are primarily caused by factors such as non-compliance with welding specifications, the use of sub-standard materials, defective welding equipment, or poor welding skills. Weld defects can also be attributed to design or drawing errors by the designer or faults in manufacturing or shop functions, such as material preparation.[26]

### II.6.1 CLASSIFICATION OF WELD DEFECTS

One of the IIW Documents classifies the weld defects into six groups as follows:

- **Cracks:** includes all types of cracks such as crater cracks, hot cracks, cold cracks, etc.
- **Cavities:** including blowholes, porosity, shrinkage, etc.
- **Solid inclusions:** including slag, flux, metal oxides, tungsten, etc.
- **Incomplete fusion or penetration:** including lack of fusion, lack of penetration, suck back, etc.
- **Imperfect shape or Unacceptable contour:** including dimensional deviations, undercut, under fill, overlap, excessive reinforcement, excessive penetration, bead shape, etc.
- **Miscellaneous Defects:** including arc strike, excessive spatter, rough surface, uneven ripples, pock marks, etc.[26]



1. Introduction
2. Chapter I
3. Chapter II
4. Chapter III: Theoretical studies
5. Chapter IV
6. General conclusion
7. Bibliographical references

# Chapter III: Theoretical studies

### **III.1 Introduction**

SMAW welding, like other welding processes, requires a deep understanding of the underlying physics and careful selection of welding parameters to achieve optimal weld performance. Over time, experience with SMAW welding has yielded valuable insights into the process and the factors that affect weld quality. However, testing certain welding conditions may be expensive or impractical, such as using parameters outside the machine's operating range or testing unusual geometries that require specialized setups. Additionally, SMAW welding involves complex interactions between mechanical, electrical, thermal, and metallurgical phenomena, making it challenging to fully comprehend the process. Nonetheless, mastering SMAW welding can lead to high-quality, reliable welds that meet the demands of various industries.

### **III.2 Numerical modelling and limits**

#### **III.2.1 Generalities**

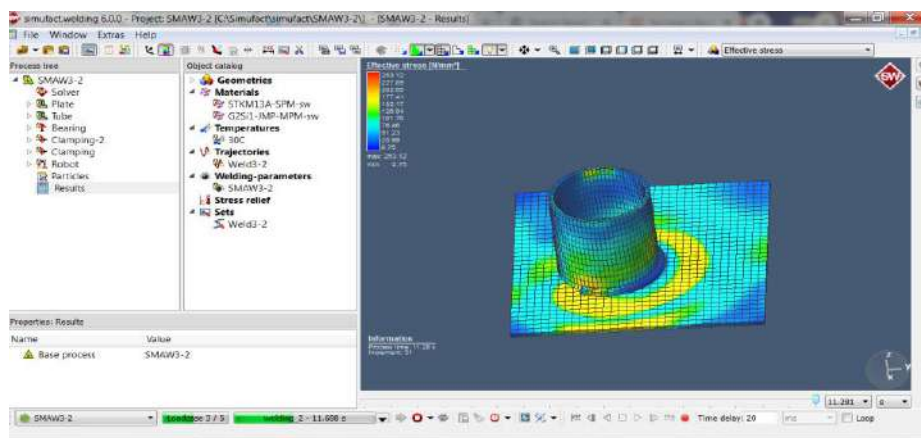
Physical simulation models of the Shielded Metal Arc Welding (SMAW) process can help predict the behavior of the welding process under different welding parameters and conditions, and provide insights into the physical phenomena that occur during the welding process. These models are developed based on fundamental principles of physics and materials science, and can be used to optimize welding parameters to achieve desired weld properties and reduce the likelihood of defects. However, it is important to note that physical simulation models are deterministic and do not account for intrinsic variability in the welding process. Therefore, empirical data and statistical models are also important for understanding and optimizing SMAW welding.

#### **III.2.2 Simulation software and numerical analysis of SMAW process**

Simulation software and numerical analysis of SMAW (Shielded Metal Arc Welding) process are important tools used to optimize welding parameters and predict weld quality. Numerical analysis involves using mathematical equations and computational algorithms to simulate the physical phenomena that occur during the welding process, including heat transfer, fluid flow, and metallurgical transformations. This can help

predict the behavior of the welding process under different conditions and optimize welding parameters for improved weld quality.

There are several software programs available for simulating the SMAW process, including Simufact Welding, ANSYS, Abaqus, and COMSOL Multiphysics. These programs use finite element analysis (FEA) and finite volume methods to simulate the physical phenomena involved in the welding process. FEA divides the welding process into small elements and solves the equations for each element, while finite volume methods discretize the domain into small volumes and solve the equations for each volume.



**Figure III.1** Mesh of a model on simufact.

Finally, software specifically dedicated to resistance welding, which become very easy to use. However, the simplification of these software costs the range of their possibilities; only pre-programmed physical effects can be simulated.

**Note:** the use of simulation software for SMAW process requires a significant amount of time from the operator to input the details of the case to be simulated. However, once the initial case is programmed, other cases with minor modifications can be quickly simulated. The calculation time required to simulate a SMAW process varies depending on the complexity of the physical model chosen. Nonetheless, it is generally longer than the actual welding time due to the highly dynamic nature of the process.

SMAW process involves a range of physical phenomena such as fluid flow, heat transfer, and metallurgical transformations, which requires dynamic models to simulate accurately. The duration of the welding process significantly impacts the calculation time required to simulate it. While static models may be suitable for

simulating rotary welding, most SMAW processes are unsteady and require dynamic models. The availability of high-performance computers has enabled faster computation, but the simulation of SMAW still requires significant computational resources. Nevertheless, numerical analysis and simulation software can provide valuable insights into the behavior of the welding process and optimize welding parameters to enhance weld quality and minimize defects.

### III.3 SIMUFACT WELDING

#### III.3.1 Software presentation

The software Simufact Welding is designed to simulate a variety of thermal joining processes, including arc and beam welding, as well as brazing. In addition, it can model heat treatment processes, variations of cooling and unclamping setups, and mechanical loading of welded structures. The software uses the finite element method, which is well suited for structural welding simulation and calculating elastic-plastic material behavior with hardening. However, complex processes induced by an arc or evaporating metal inside a keyhole are not considered. The software can calculate the effects of heat input from the welding process using a mathematical description of heat flux, but the process stability and weld seam geometry are input parameters, not results of the simulation.[27]

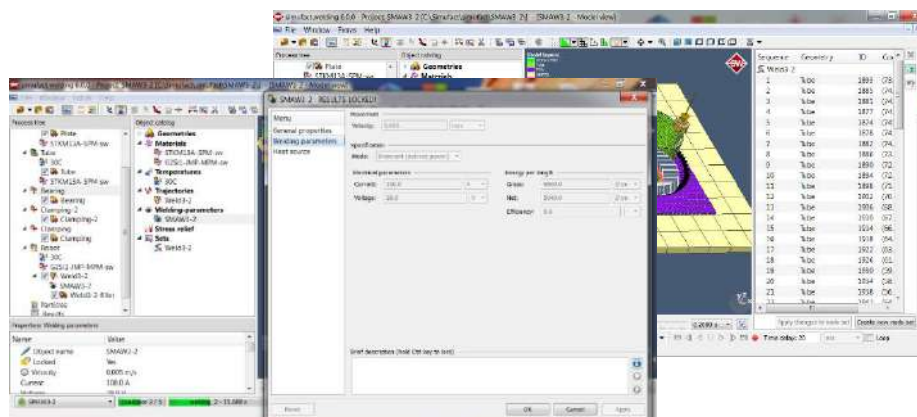


Figure III.2 Interface of simufact welding.

#### III.3.2 Utility of simufact welding

There are various modules provided to enable the simulation of different processes. The primary module, known as the Forming Hub, comes equipped with all the essential features needed to operate and manipulate the simulation software, such as the user interface, solver, and material database. Additionally, the Forming Hub has its own capabilities to simulate cold forming and hot forging. Other than the Forming

Hub, users have the option to select from several supplementary simulation modules, including shaping of sheets, rolling, circular rolling, free forging, heat treatment, and mechanical assembly. Moreover, there are additional modules available for stress analysis in tools and microstructure calculations, performance acceleration, importation of CAD data, customization, and access to material databases. [27]

### III.3.3 Advantage of Simufact welding software

Simufact Welding offers several advantages for engineers, designers, and manufacturers involved in welding processes. Some of the key benefits of using Simufact Welding include process optimization, virtual testing, reduced material waste, improved weld quality, and increased safety. The software enables the optimization of welding parameters such as welding speed, heat input, and welding sequences, resulting in higher welding quality, reduced distortion, and improved productivity. Virtual testing eliminates the need for physical testing, reducing costs, and accelerating the product development process. Simulating the welding process and evaluating the quality of the weld reduces the risk of defects, product failure, and associated costs. Additionally, Simufact Welding can help identify potential safety hazards and measures to reduce the risk of accidents during welding processes. [27]

## III.4 Modelling steps on simufact welding [27]

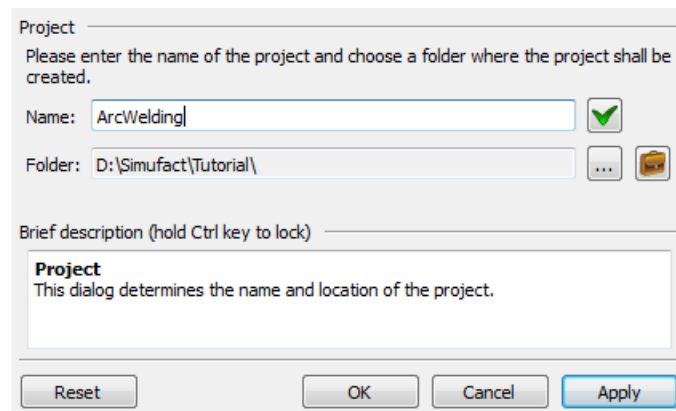
### III.4.1 creating a new project

After launching Simufact.Welding successfully, you will be able to create a new project by clicking **Project - New project** .



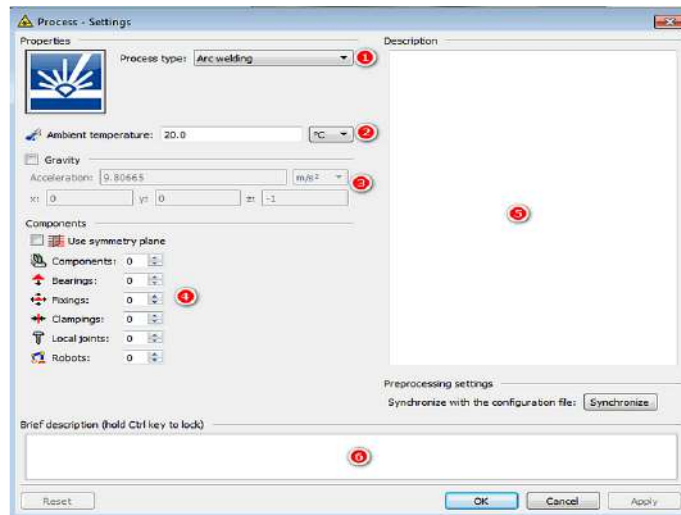
**Figure III.3** Creating a new project.

Give the new project the name SMAW, then we choose a folder path to save and click OK. we need to have sufficient rights (read & write) in this folder.



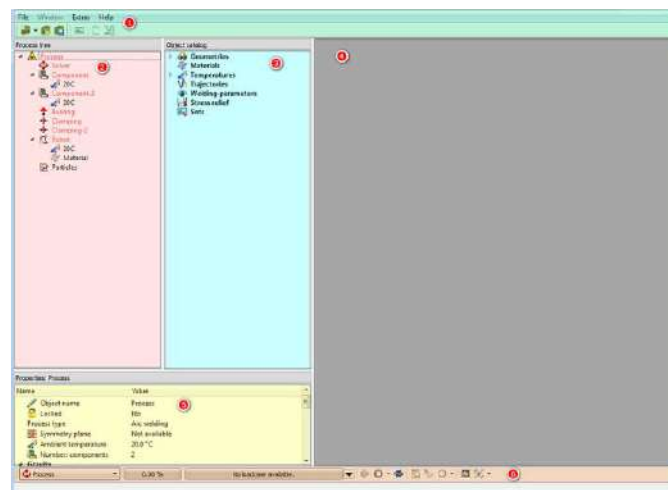
**Figure III.4** Name and location.

When we accessed the next screen, we were able to initiate the configuration of our model. Here, we had the opportunity to provide details regarding the number of components, bearings, fixings, clamps, robots, and other settings that were pertinent to our project. Firstly, we needed to choose the appropriate welding process type that best suited our needs. In this instance, we selected "SMAW1-1" as our preferred process type. Once we had chosen our process type, we were able to determine the ambient temperature, which was a universal value applied to the entire model and regulated the level of heat losses to the environment (2). We were also able to specify the direction of gravity (3) and preselect the numbers of components, robots, and boundary conditions in our model (4). It was recommended that we provide a meaningful description of the process (5). It was worth noting that all of these settings could be modified later on, so it wasn't a concern if we found that we required additional clamping tools or robots than originally defined. In the text field (6) located at the bottom of the window, we could access supplementary information by hovering our mouse pointer over certain input fields. This text field was present in most of the GUI's setting windows. [27]



**Figure III.5** Configuring the simulation- Choosing what will compose the simulation. We make sure we have the following configuration before clicking *OK*:

( **Process type** - Arc welding ,**Ambient temperature** - 30 Celsius degrees, **Use symmetry plane** - Not used, leave unmarked, **Components** - 2 components, **Bearings** - 1 bearing, **Fixings** - 0 fixing, **Clamping** - 2 clamps, **Local joints** - 0 local joint ,**Robots** - 1 robot.)



**Figure III.6** Main screen - overview of available interaction areas.

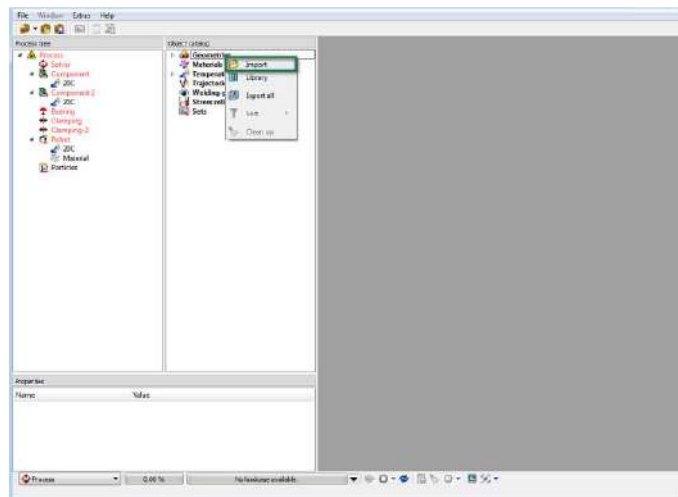
This interface is divided into six sections, each of which serves a distinct purpose:

1. The main menus/toolbar provide access to general actions, such as save, open, and close.
2. The process tree displays all participating objects in the current project, which may include multiple processes.
3. The object catalog contains all available data from different sources.

4. The visualization window allows you to view the 3D-model and results, and perform actions such as panning, rotating, zooming, and picking.
5. The properties window displays the properties of the selected item.
6. The status/control bar provides information about the simulation's current status and enables control through start/stop buttons. [27]

### III.4.2 Importing components

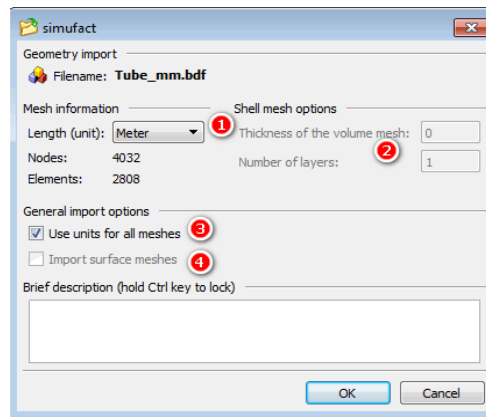
To import any number of components, we can right-click on **Geometries** in the Catalog area, select **Import**, and navigate to the corresponding directory.



**Figure III.7** Importing components.

As the next step after defining the initial configuration of the project, we need to import meshes of components. Components are the foundation of the simulation and provide guidance for clamp positioning and trajectory generation. For this thesis, we will use Plate.bdf and Tube.bdf files located in the geometry library folder <installation path>\simufact\welding<version>\lib\geometries\tutorial. A window will appear displaying the following information:



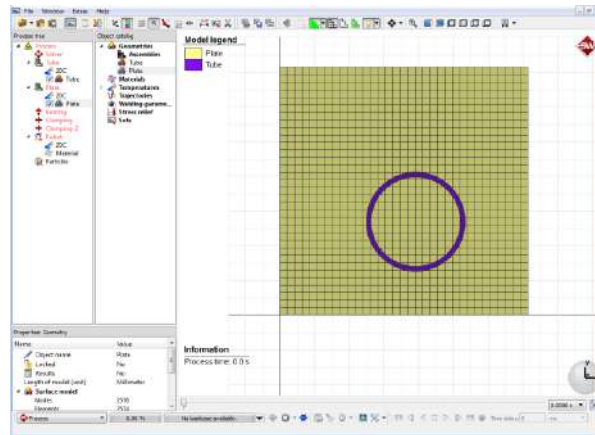


**Figure III.8** Importing with correct length unit.

We should choose the unit system that matches the one in which the geometry was originally created, either on the CAD system or from the mesher software. If we select the wrong unit system, Simufact.welding will scale it incorrectly and interpret it wrongly. We can mark the check-box (3) when all selected geometries use the same unit system. As the mesh contains only numbers, no imported information regarding unit, material or load type will be available. For this thesis, we prepared the geometries in millimeters, so we should select Millimeter in the list (1) and check the Use for all geometries box (3).

The import window also has some additional functionalities. If we import surface meshes, we can check the Import surface meshes (4) box to import all surface meshes we selected for the import as they are, and they can be used for tools such as clamps, fixings, and bearings. If we don't check the box, we can expand 2D-meshes into a 3D-structure, especially for sheets. In this case, the fields under Shell mesh options (2) will be activated. We can enter the thickness of the sheet in millimeters and the number of layers in the extrusion direction. However, we should be careful, even if the mesh is not suitable for the extrusion, as activating these settings might result in a 3D-mesh that is not useful in the simulation.

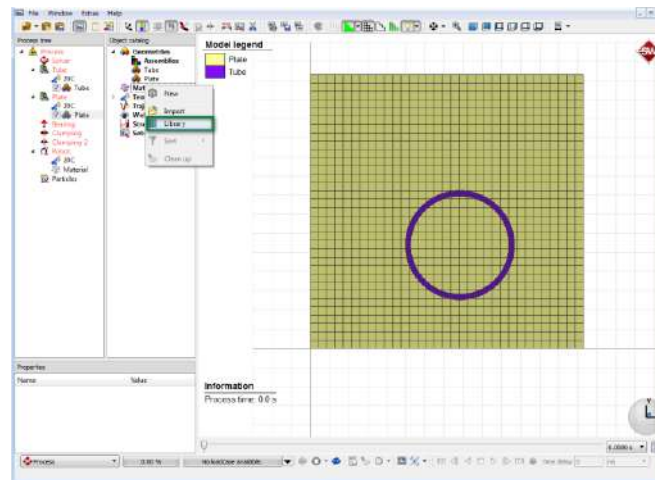
The imported components will appear under Geometries in the Object catalog area. To assign these geometries to a process, we should drag and drop each one into a Component object type. Doing so, the Visualization area will update and show the participating components.



**Figure III.9** Visualization window.

### III.4.3 defining materials

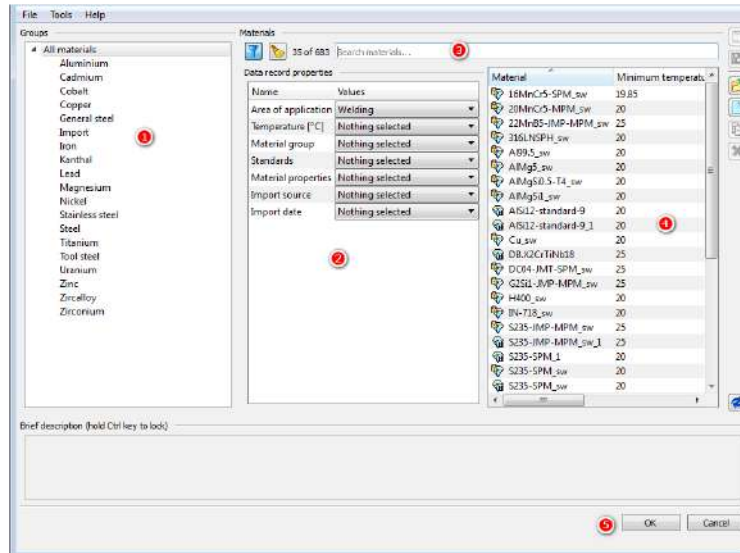
To access the material library, we can right-click on Materials in the Catalog area and select Library. The material library contains all the important mechanical, thermal, and electrical properties of materials, which can be readily loaded into Simufact.welding. If we need to use a special material type or a customized input, we can use the graphical support provided by the software.



**Figure III.10** Material library.

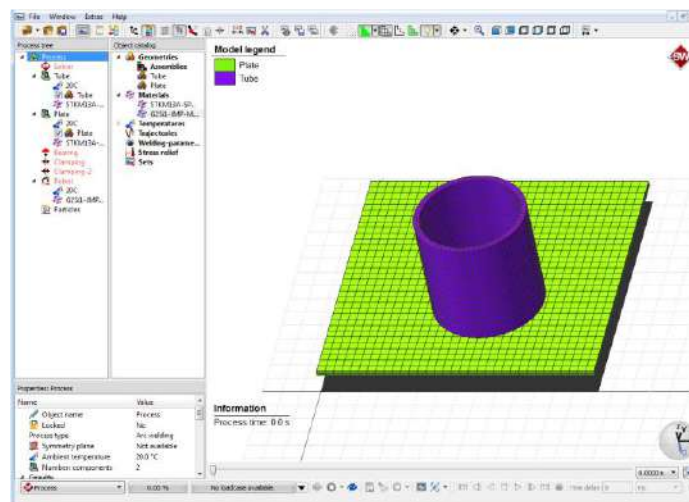
We can select the material Group (Area 1) in the Simufact.material GUI. Additionally or alternatively, we may use more powerful filters (2) or start typing the material name directly (3). We can then select the material from the resulting filtered list (4). It is important to note that it is not recommended to use any material in a welding simulation that does not belong to the Welding area of application.

For this purpose, we will use **STKM13A** for the components and **G2Si1** for filler material (weld bead). We can select both and click **OK** (5). After importing all required data, both materials will appear under Materials on the Catalog area.



**Figure III.11** The material library

We need to drag and drop **STKM13A** on each component (Tube and Plate), as well as **G2Si1** on the Robot. It is important to ensure that our Process tree and Object catalog match the configuration shown in the image below.



**Figure III.12** Assigning the material.

### III.4.4 Defining temperature objects

We may have noticed during the definition of components that they already have a temperature object assigned. A temperature object in Simufact.welding describes thermal initial and boundary conditions. While there is a default object present, we may want to change the settings or create new objects. With this object, we can set the initial temperature of a component or robot to which the object is assigned (1). Furthermore, we can define the convective heat transfer coefficient to the environment (2) via a constant value or a predefined table. The same can be done for contact heat transfer between different bodies in the model (3). In this case, we can also use automatic calculation of the contact heat transfer coefficient. The emission coefficient (4) must be set as a constant value, governing the radiation heat losses.

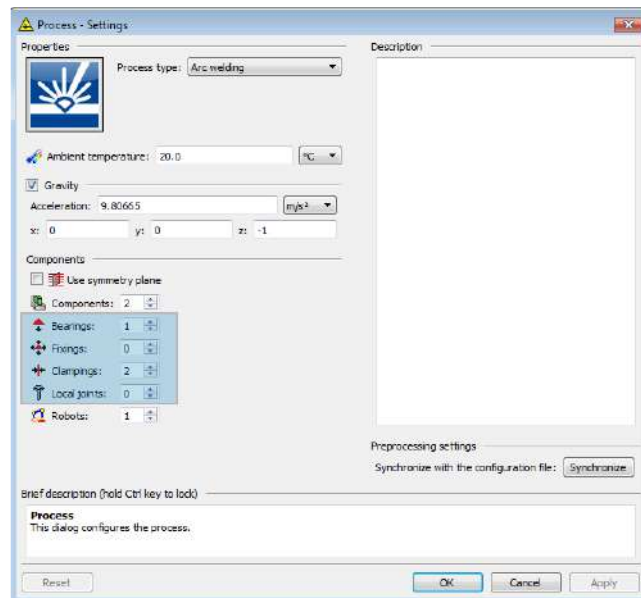


**Figure III.13** Temperature object.

### III.4.5 Defining the mechanical boundary conditions

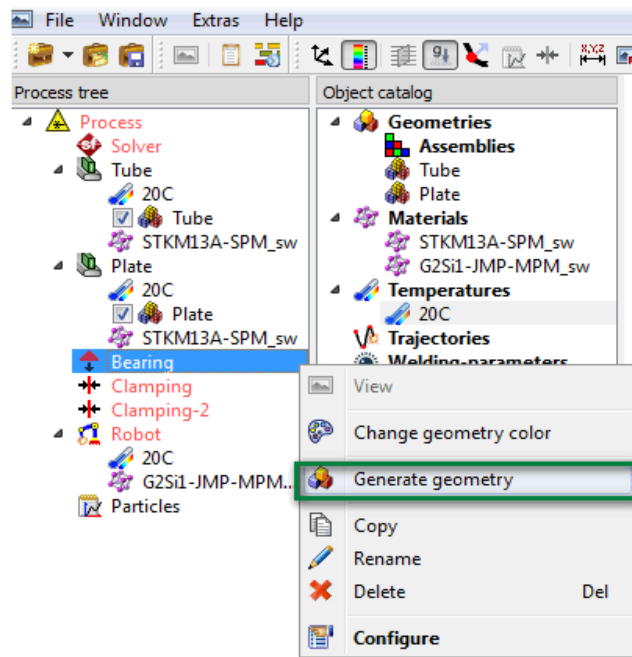
In order for a model to be properly set up, it is necessary to define mechanical boundary conditions. These boundary conditions serve two main purposes. Firstly, they prevent the rigid body motion of components during simulation, ensuring that they stay in place. Secondly, during welding, components are often fixed in place by being mounted on tables, clamped with tools, or fixed at certain positions.

In Simufact.welding, there are three main types of boundary conditions that are considered: bearings, fixings, and clamps. Additionally, there are local joints that connect components with each other. While local joints are not technically considered a boundary condition, they serve a similar purpose in connecting components together.



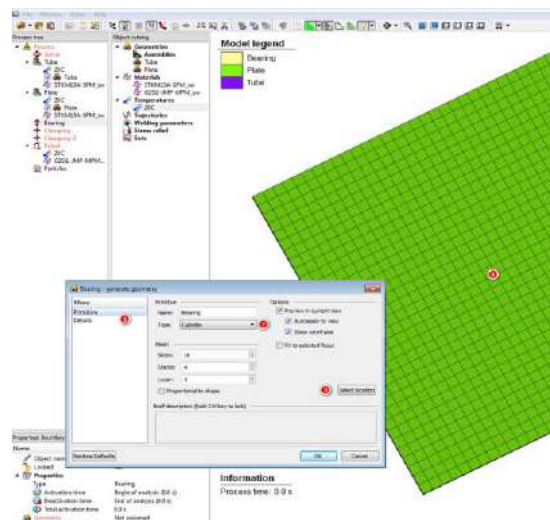
**Figure III.14** Types of boundary conditions.

The text explains the three main types of boundary conditions used in Simufact.welding and how they are used. Bearings allow for movement on the same plane of contact, fixings restrain all six degrees of freedom, and clamps are used to apply force. Local joints keep referred nodes and their defined sphere of influence tied and can be used to simplify tack welds or spot welds. The text also notes that all types of boundary conditions except for local joints can be imported or created using Simufact.welding tools, and that to create them using these tools, the user should right-click on the fixture name in the Process tree and select "Generate geometry."



**Figure III.15** Creating fixtures.

To place the geometry on the model, we can click and drag to select the desired region and use the "Select location" button.

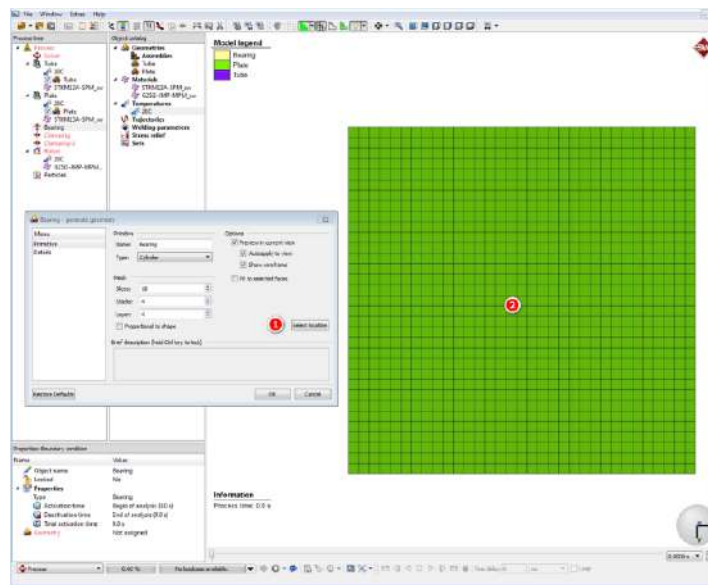


**Figure III.16** Generating geometry.

For this thesis, we will create three boundary conditions: one bearing-type acting as a table and two clamping-

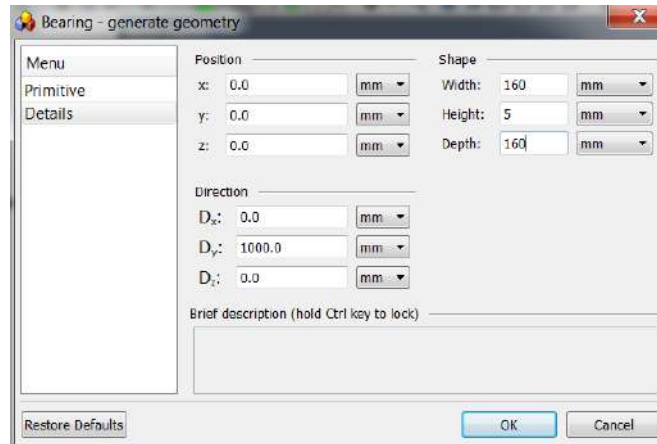
Type to act as holders. Following the steps bellow will create the necessary geometries for defining the model.

• **Bearing** - To add a bearing to the model, we need to change the current view to Bottom view by using the View tool bar and zoom out a bit to see the entire bottom plate. Then, we should right-click on **Bearing** in the Process tree and select **Generate geometry**. We should make sure **Cuboid** type is selected, and then click on **Select location** button. After that, we should go back to the Visualization area and click and drag on the center of the plate to create the geometry.



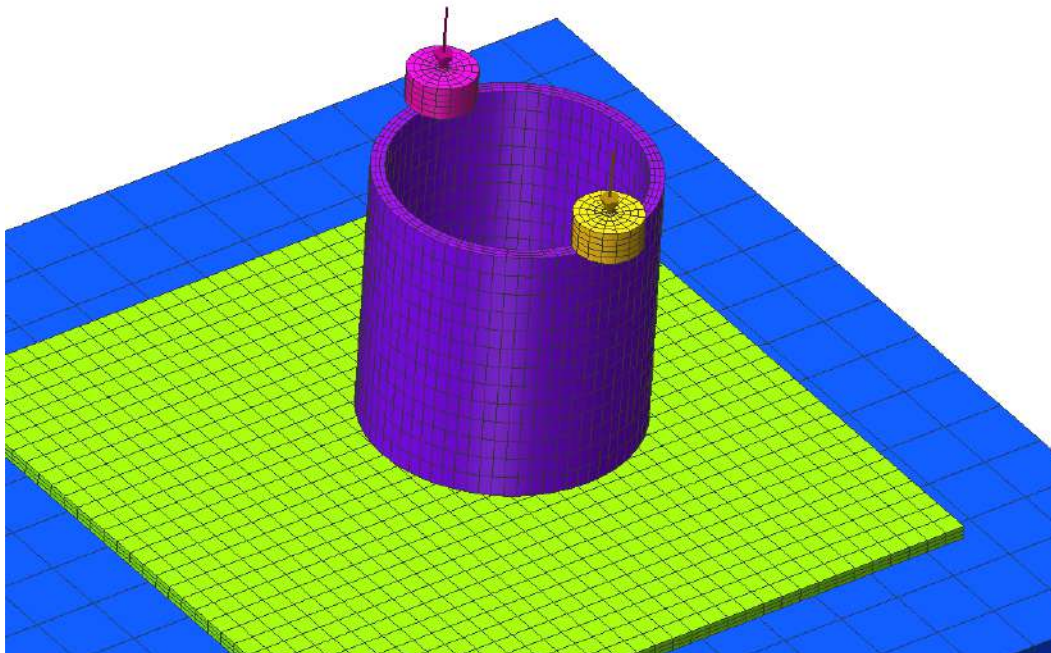
**Figure III.17** Selecting reference faces.

After creating the cuboid, we should go to the Details tab and change the Height value to 5 mm. We should also change the Width and Depth to 160 mm each and position the bearing in the middle of the component. If needed, we can also adjust the surface mesh by going back to the Primitive page of geometry creation dialog. After making all the necessary adjustments, we should click OK and the new geometry will be created. It's worth noting that besides being assigned to the Bearing boundary condition, the newly created geometry will also appear under the Geometries section on the Catalog.



**Figure III.18** Configuring the geometry.

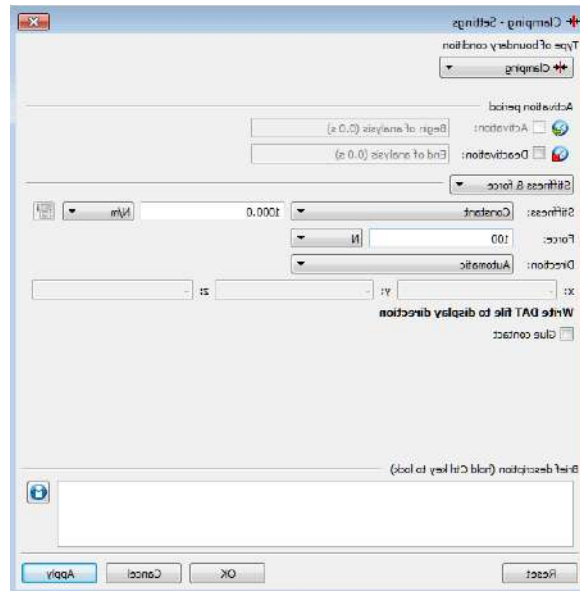
To create the missing two clamps, we can follow the same procedure but using cylinders and set Radius and Height to 5 mm each. We should change to Top view before picking the region. After doing it properly, the result should be very similar to the following picture



**Figure III.19** Placing fixtures.

After creating the clamps, we need to configure the force they will exert on the rounded component against the bearing to keep the two components together during welding. To do this, we can double-click on the Clamping in the Process tree, and the configuration window will appear. We can then change the behavior to Stiffness & Force, set the holding force to 100 N, and click OK. It's also possible to enter the stiffness as a table as a function of elongation





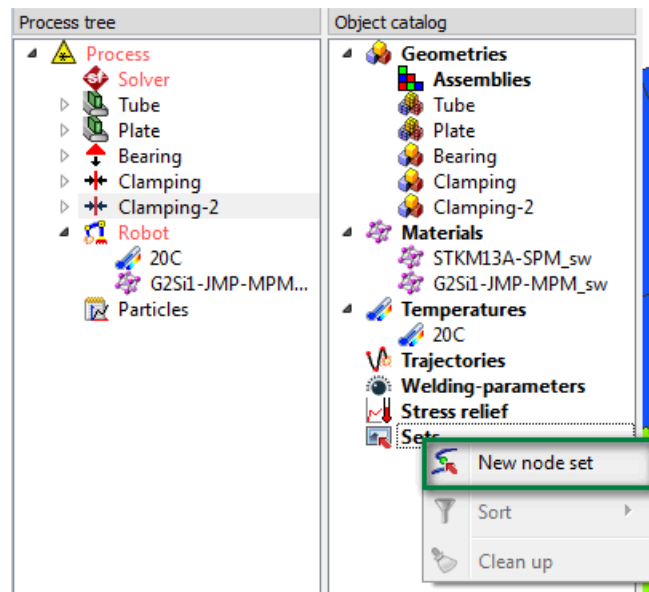
**Figure III.20** Clamping force.

We should do the same for the second boundary condition, Clamping-2, in order to complete the clamp setup for this project. At this stage, we will notice that the name of the process, as well as the Robot and Solver, are displayed in red in the Process tree, indicating that some definition is missing to run the process. The following steps will focus on defining the elements for the robot's actions.

### III.4.6 Using node-sets

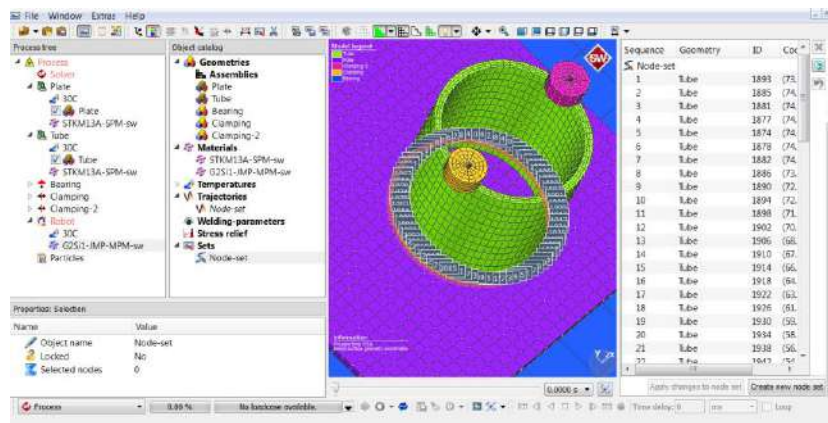
According to Simufact.welding terminology, a node-set refers to a cluster of points with defined X/Y/Z coordinates in relation to the global coordinate system, and its position is determined by the FE mesh. The order of the nodeset group is essential since it can be utilized as a welding path by the trajectory object. To define a group of points, we have two options: either directly selecting them from the model using the Visualization area or importing them from a CSV file. However, note that picking points on the screen is restricted by the mesh resolution (element size) and may result in a distorted path if the mesh is too coarse. To achieve a smooth transition, enough points should be selected for linear interpolation between two points. If a node set was used to generate a weld path, the weld path's coordinates can be altered independently of the node position.

To create a node set, we can right-click on Sets (Catalog area) and select New node set. We can then select nodes from the models on the screen to construct the set



**Figure III.21** Node-set creation.

To select the desired points, we can use a left mouse click to make the node selectable. For this thesis, we need to pick 72 points from the cylinder's base to establish the first node set that will be used as a welding path later. Once all 72 points have been selected, we can click on "Apply changes to node set"



**Figure III.22** Node-set creation.

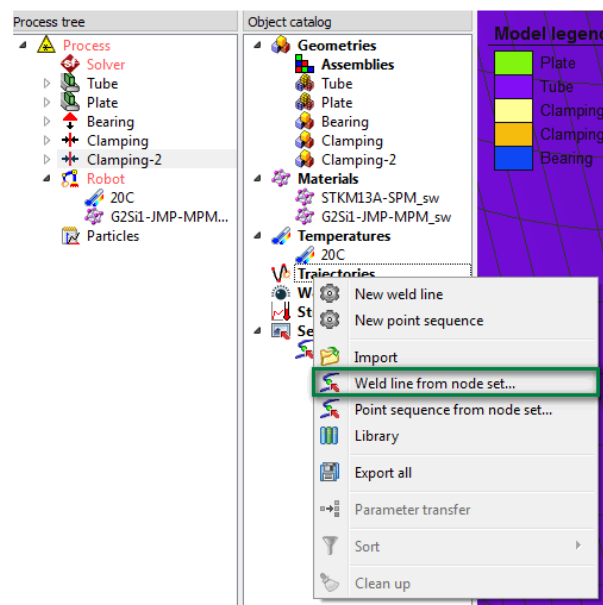
The node-set description window contains comprehensive information about the selected points, including:

- **Sequence:** The sequence is crucial because it determines the welding path for subsequent steps.

- **Geometry:** This displays the geometry from which the points were selected and is useful when dealing with numerous components in close proximity to each other.
- **ID:** This indicates the node number that was selected on the geometry.
- **Coordinates:** This shows the selected nodes' location with respect to the absolute axis system.

### III.5 Weld paths and heat sources

Trajectories are paths with additional information to become weld lines. Regardless of welding process to be simulated, the steps up to this point are the same. We will fill-up the information as to be concise with a real arc welding process. To create and define a trajectory, **RMC** on Trajectories and a context menu will show the options.



**Figure III.23** Creating trajectory.

#### III.5.1 The welding path

We can drag and drop the node-set on the **Trajectories** catalog entry. we can just drag and drop the Node-set on a robot.

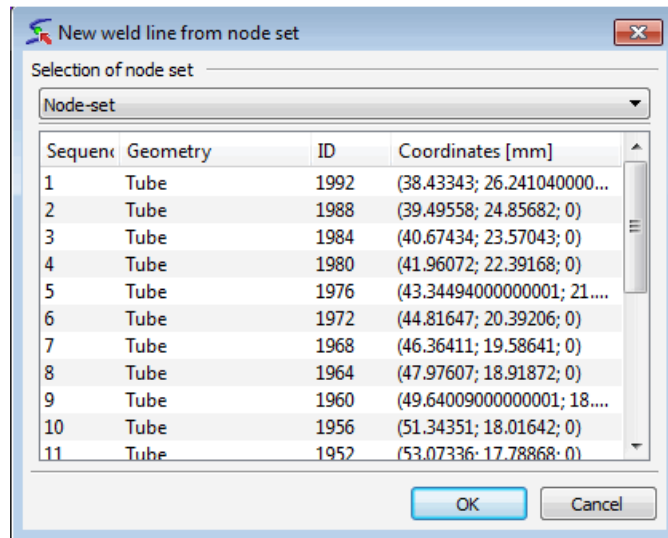


Figure III.24 Trajectory from node set

### III.5.2 The welding parameters and heat source

To create a new welding parameter object, **RMC** over Welding-parameter section on the Catalog then we select **New welding parameter**.

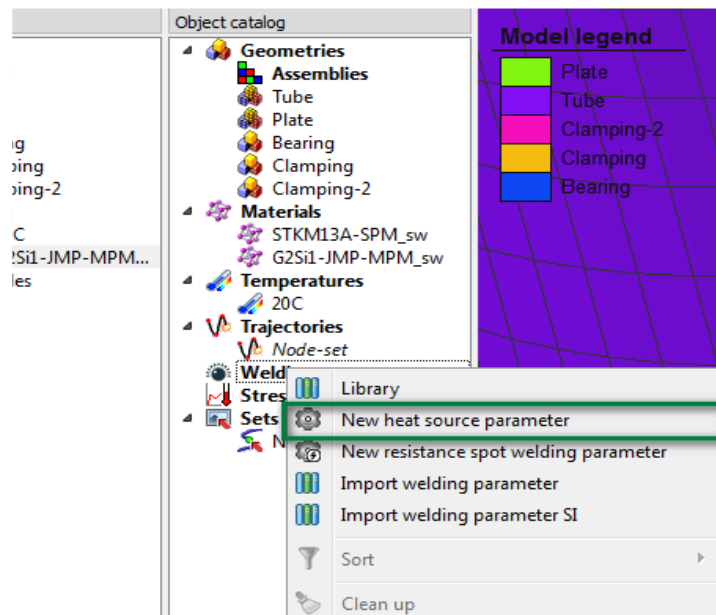
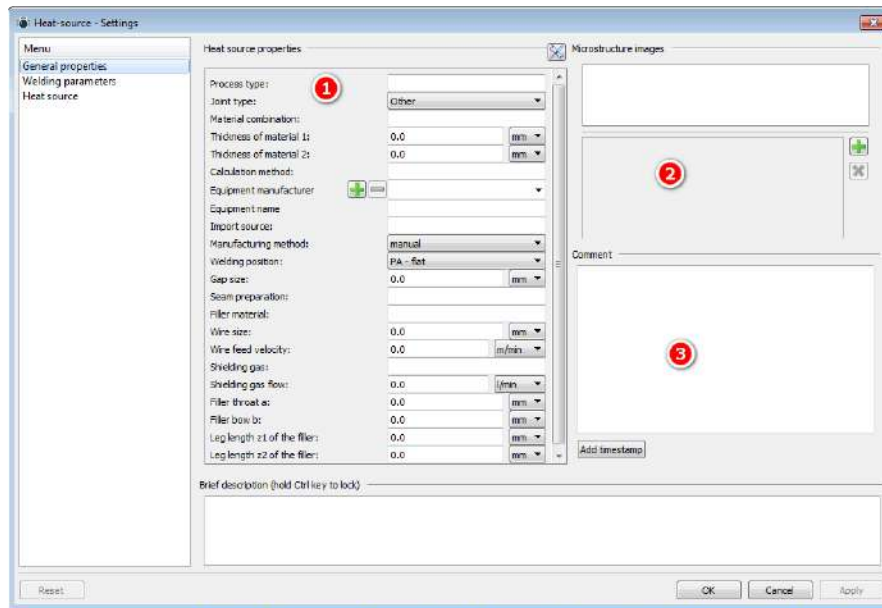


Figure III.25 Welding parameters.

When we open a new window, we will be prompted to input the necessary data. The window will contain a section called "General Properties" where we can describe the process from which the welding parameters are derived. This section is for informational purposes only and does not affect simulations. We can provide a process description in (1), insert images in (2), and add comments in (3). This information can be used as a filter in the Welding Parameter library.

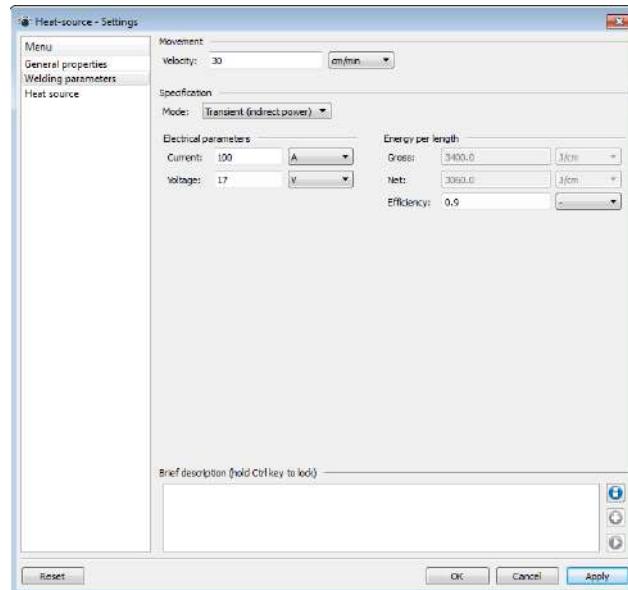


**Figure III.26** General properties.

In order to define the welding parameters and calculation method, we need to access the Welding Parameters tab. From there, we have the option to choose between Transient (Indirect power), Transient (Direct power), and Thermal cycle. For the purposes of this thesis, we will be using the indirect power method, which requires us to provide the following input values:

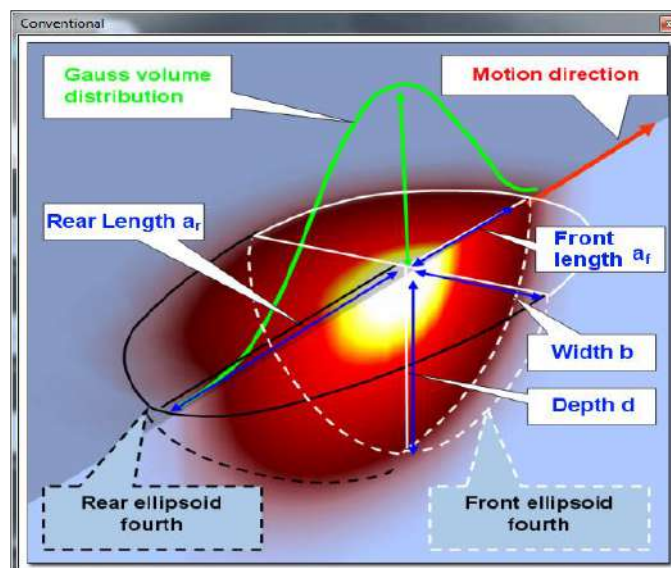
- Velocity: 30cm/min
- Current: 100A
- Voltage: 17V
- Efficiency: 0.9.

Note: this values are fore the last SMAW process of this thesis.



**Figure III.27** Welding parameters.

In the Heat source tab, we have the option to choose between a conventional heat source (arc welding) or a highly focused laser heat source. we have selected Conventional, which is a Goldak's double ellipsoid model. This approach is a good choice for most arc welding processes.

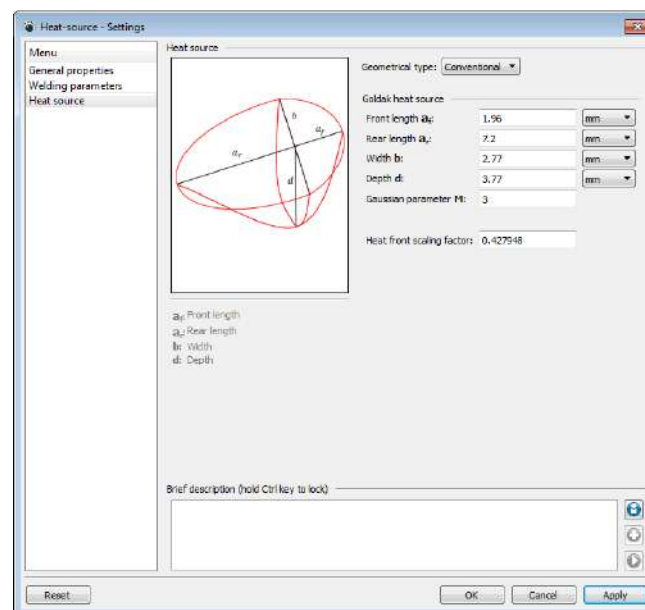


**Figure III.28** Conventional heat source - Goldak's model for arc welding processes.

We configure the parameters (dimensions) of the heat source to match the real heat source geometry of a welding process, which can be obtained from a macrographic test of a weld bead cross-section. However, we also provide approximation formulas

in Simufact.welding for designing new welding processes based on expected weld bead formation. For the first process, we input the following values:

- Front length  $a_f$ : 1.96 mm
- Rear length  $a_r$ : 7.20 mm
- Width  $b$ : 2.77 mm
- Depth  $d$ : 3.77 mm
- Gaussian parameter  $M$ : 3.

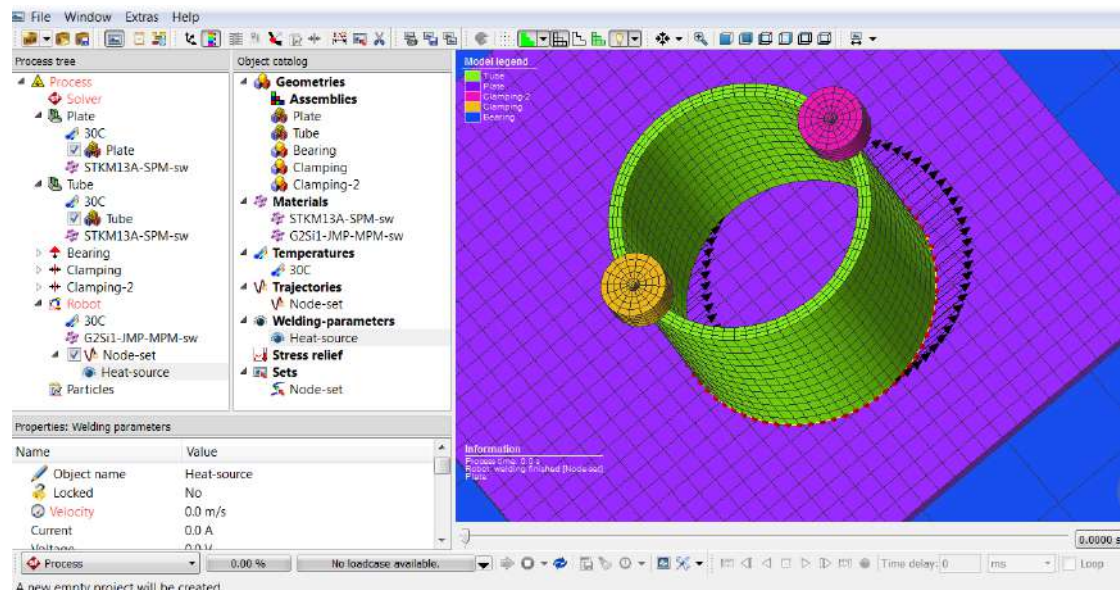


**Figure III.29** Heat source geometry.

### III.6 Configuring robots and weld beads

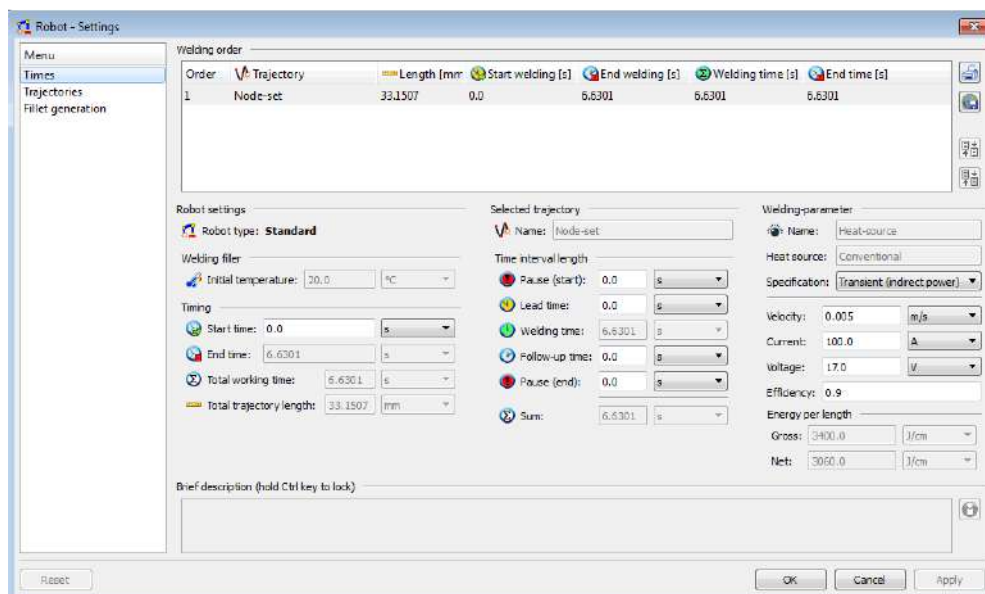
We need to assign four types of objects to robots for performing the welding process simulation, namely temperature, material, trajectory, and welding parameter. The robot configuration window is where we generate or assign weld beads from externally imported meshes. To begin, we can drag and drop the created trajectory into the Robot object on the Process tree and then drag and drop the welding parameter onto the trajectory. By doing this, the Visualization area will update, displaying the trajectory and heat source. If a robot has more than one trajectory assigned to it, we can also drag and drop the welding parameter to the robot itself. In this case, we have the option to assign the welding parameter to all trajectories except

those that already have a welding parameter assigned, or to completely overwrite all assignments and assign the welding parameter to all trajectories.



**Figure III.30** Assigning trajectories.

**Double click** on the Robot object and its configuration window will appear:



**Figure III.31** Robot configuration.

In the first tab, we can see all trajectories assigned to the robot and their order. In this case, there is only one trajectory. The Welding order area displays all the trajectories assigned, and we can change the order by dragging and dropping them or reversing them by clicking on the buttons on the right.



This tab also has three sections with some configurable parameters:



**Figure III.32** Robot general configuration.

In the first tab, we can see all trajectories assigned to the robot and their order. In this case, there is only one trajectory. The Welding order area shows all the trajectories assigned, and we can change the order by drag and drop or reverse them by clicking on the buttons on the right.

This tab has three sections with configurable parameters:

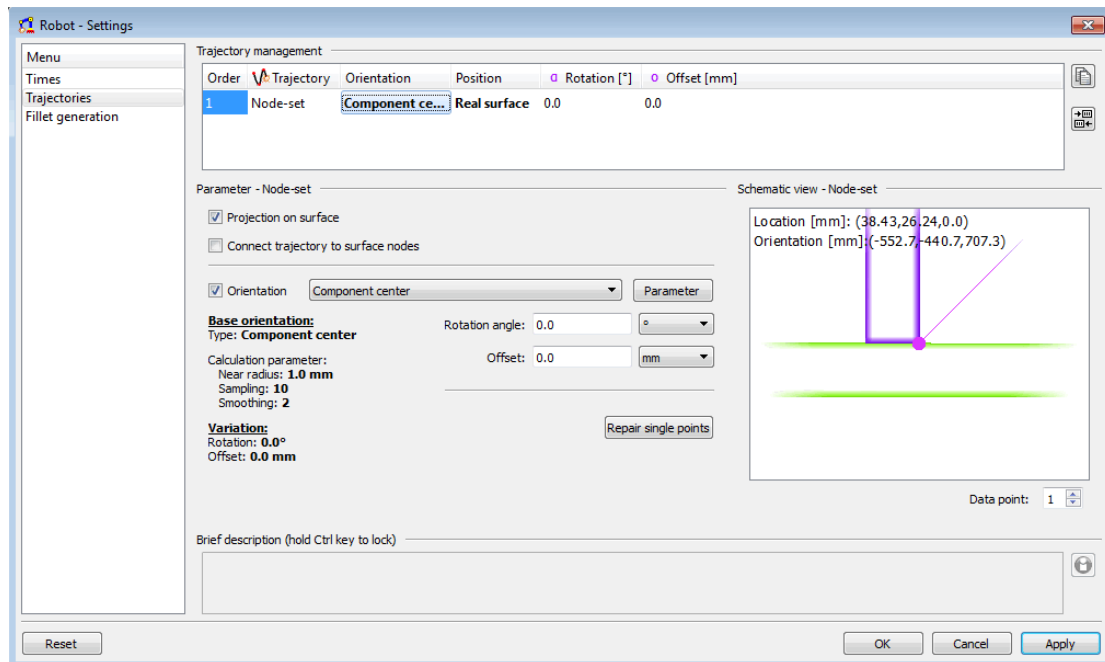
- Robot settings - We can define the start time manually for the robot, which has a direct impact on delaying all trajectories (1).
- Selected trajectory (2)
- Pause (start): Within this time interval, there is no heat input despite already initiating the trajectory (similar to pre-gas timing).
- Lead time: During the lead time, the robot has an arc opened, heat input starts but there is no movement (similar to the keyhole opening procedure).
- Follow-up time: During the follow-up time, the robot still has an open arc but ceases movement (similar to crater-filling).
- Pause (end): Within this time frame, there is no heat input and no movement, and is the last step of a welding trajectory (similar to post-gas timing).
- Welding parameter (3)

- Specification - Calculation method
- Velocity - Welding speed
- Current - Welding current
- Voltage - Welding voltage
- Efficiency - Process estimated efficiency All non-open arc time frames will mainly act like a small 'cooling phase,' and depending on the number of trajectories, they can have a major impact on the final result.

For this thesis, we should configure the parameters as follows:

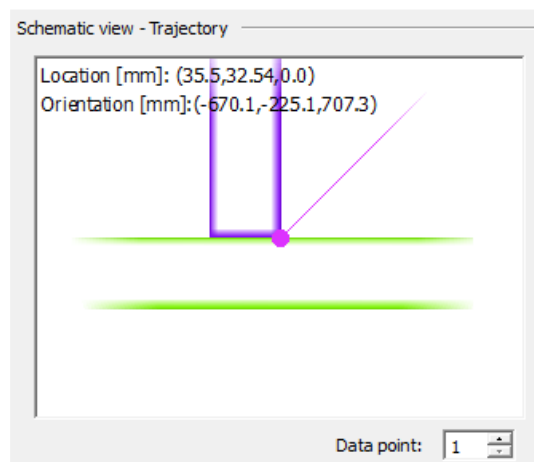
- Start time: 0s
- Pause (start): 0.2s
- Lead time: 0.1s
- Welding time: grayed out (not directly configurable)
- Follow-up time: 0.1s
- Pause (end): 0.2s

In the second tab, we can configure the alignment of the 'torch' and perform trajectory reversal using the icons on the right side. This area is where all angular positions are set and it heavily relies on the quality of the underlying meshed components. If the normal vector of a given component is misaligned, it will impact the orientation of the trajectory. In this case, we carefully generated the meshes and double-checked their quality. The "Connect trajectory to surface nodes" is useful if we expect a lot of deformation in the model, so that the heat source, which is defined in global coordinates, might miss the defined path. However, to use this option, we should define the trajectory directly on the nodes in question; otherwise, the GUI will map the trajectory as defined on the nearest surface nodes, which might result in the wrong path. The more sampling points we have, the better the result will be in this case.



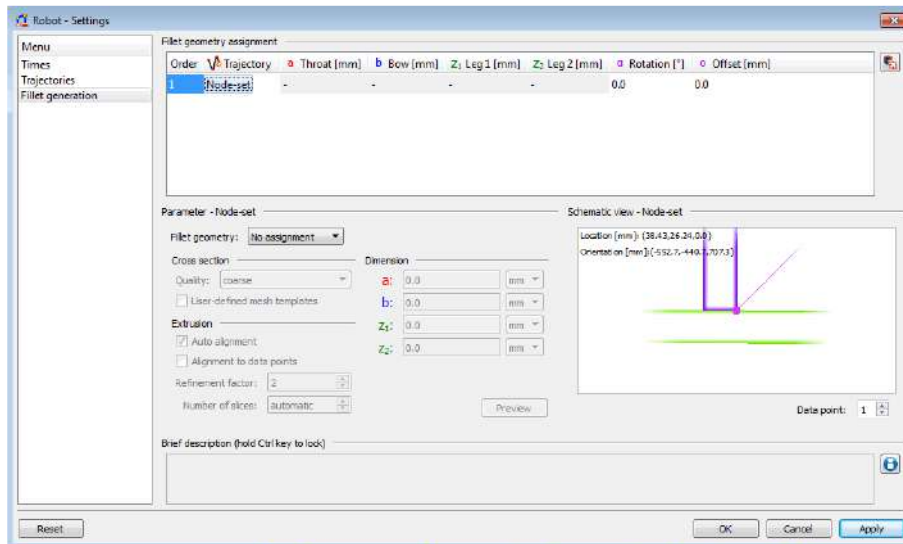
**Figure III.33** Trajectory orientation.

The Schematic view - Trajectory window provides helpful insight for the currently selected data point regarding its orientation with respect to other components. We use this window as a local reference when aligning or correcting the orientation.



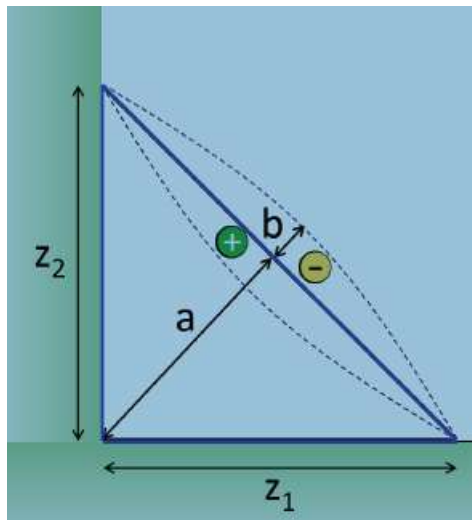
**Figure III.34** Schematic view.

Fillet geometry creation for processes with filler metal (non-autogenous processes) can be done. we will generate the weld bead instead of importing it.



**Figure III.35** Fillet geometry assignment.

When generating fillets inside Simufact.welding the dimensioning parameters are:

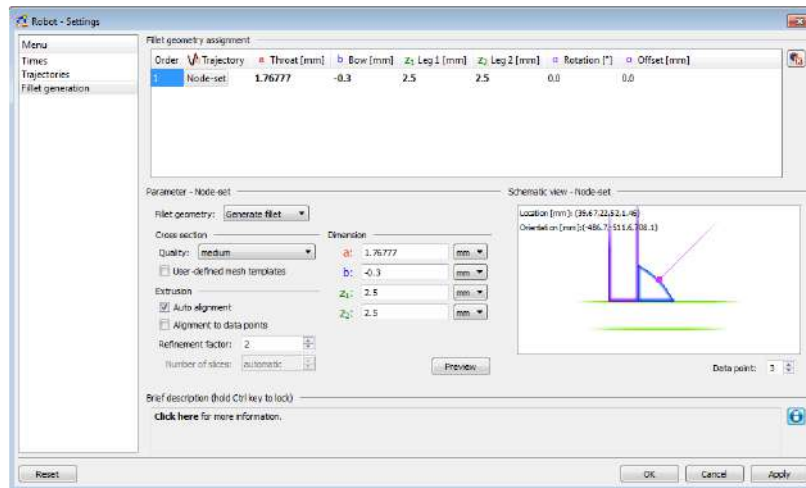


**Figure III.36** Fillet description.

To generate a fillet for the trajectory, we need to select >Generate fillet< from the Fillet geometry menu and change the Quality to medium. Then we need to input the following values:

- Throat a: The 'height' of the cross-section (automatic)
- Bow b: The concavity of the fillet, set to -0.3mm
- Leg z1: Leg of the fillet, set to 2.5mm
- Toe z2: Toe of the fillet, set to 2.5mm

After that, we need to click on Preview and we should get the following result:



**Figure III.37** Resulting fillet.

### III.7 Simulation settings

To configure the simulation settings, we need to double-click on the Solver object in the Process tree



**Figure III.38** Solver settings.

We can configure some settings to change the way the simulation is handled. To access these parameters, we need to double-click on the Solver object on the Process tree. We have the option to enable multiprocessing capabilities and a technology called Domain Decomposition Method (DDM) to speed up the simulation and reduce wall-time, allowing us to get results faster. However, for this to work, the Intel™ MPI Library must be installed and running properly. Additionally, each core needs to have a license to run the solver thread.

In the next tab, called "Time Control," we can configure the duration of the simulation. To do this, we need to set the "End Time" parameter to 30 seconds and the result output frequency to 1. After that, we can click "OK" to confirm the changes. It's important to note that we should leave the other parameters untouched for now.

### III.8 Running the model

We now have all the necessary settings to run the welding simulation. We will click on the scope icon to bring up Simufact.monitor so that we can monitor the execution. Then, we can click on the green arrow on the analysis control tool bar to start the simulation. After clicking the green arrow, we will have the option to edit the input file before running the simulation. However, in our case, we can just press OK. If desired, we can turn off this window in the Simufact settings.

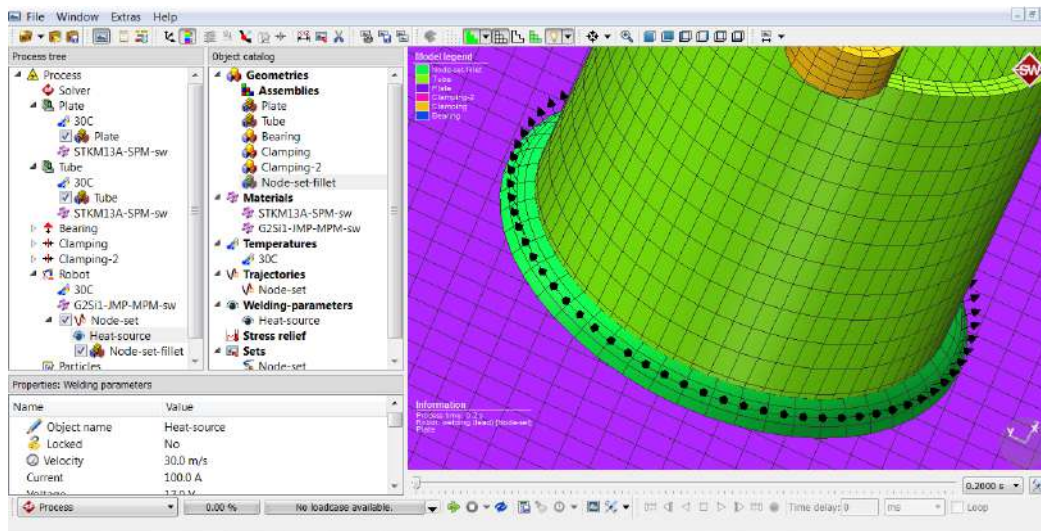


Figure III.39 Simulation start.

After some time the simulation will finish and reach the following state:



Figure III.40 Successful completion.

1. Introduction

2. Chapter I

3. Chapter II

4. Chapter III

**5. Chapter IV: Results and discussion**

6. General conclusion

7. Bibliographical references

# **Chapter IV: Results and discussion**

## **IV.1 Introduction**

Shielded Metal Arc Welding (SMAW) is a commonly used welding technique in industry to join metal pieces together. During the welding process, high heat and pressure are applied to the metal pieces, causing them to melt and fuse together. However, the welding process can also have significant effects on the mechanical properties of the welded pieces, including changes in strength, toughness, and residual stress. To better understand these effects, simulation software such as Simufact Welding can be used to model the welding process and predict the resulting changes in the mechanical properties of the welded pieces. In this chapter, we present the results of a simulation study using Simufact Welding to investigate the effects of SMAW on mechanical pieces. Specifically, we focus on the changes in temperature, distortion, and residual stress of the welded pieces under different welding conditions, including heat input, welding speed, and current, voltage.

## **IV.2 Discussing results**

We conducted a study on the effects of Shielded Metal Arc Welding (SMAW) on mechanical parts using the Simufact Welding software. We chose to vary the electrical parameters, specifically the current and voltage, while keeping other parameters constant. We selected three ranges of current: 100A, 220A, and 380A. For each current range, we tested three values of voltage: 17V, 28V, and 35V. The components we focused on were a tube and a plate. We applied boundary conditions of one bearing and two clamping, along with the involvement of a robot in the welding process. The temperature during the welding process was set at 30°C, and other parameters included a welding velocity of 30 cm/min and an efficiency of 0.9. We provided the results for each process, including maximum and minimum values for temperature, distortion, and stress. Welding time was 30s.



### IV.2.1.1 Effects of SMAW1-1 (current: 380A; Voltage: 17V)

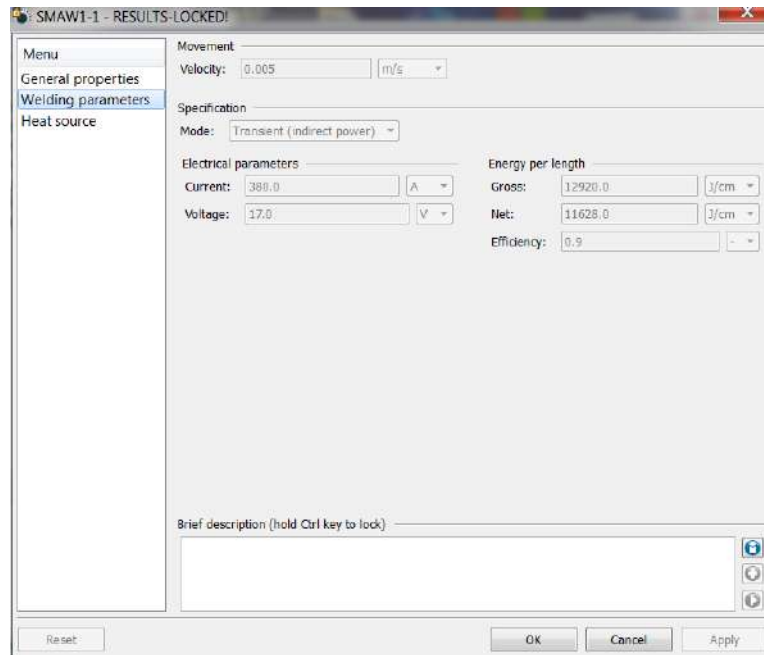


Figure IV.1 SMAW1-1 parameters.

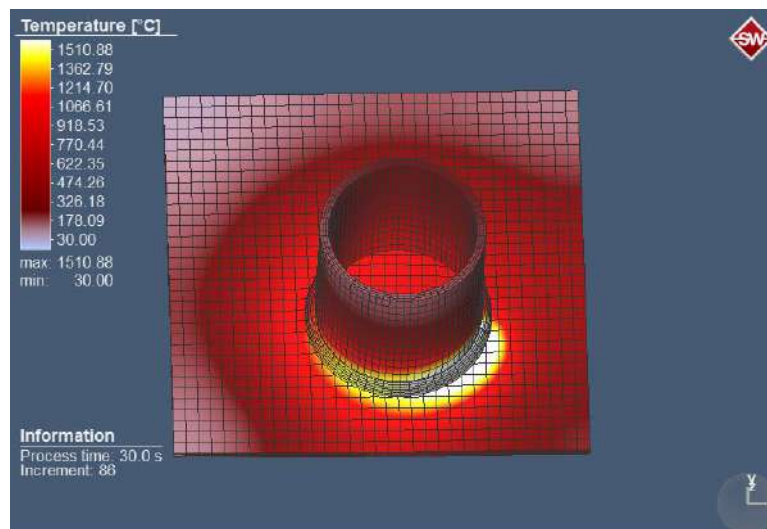
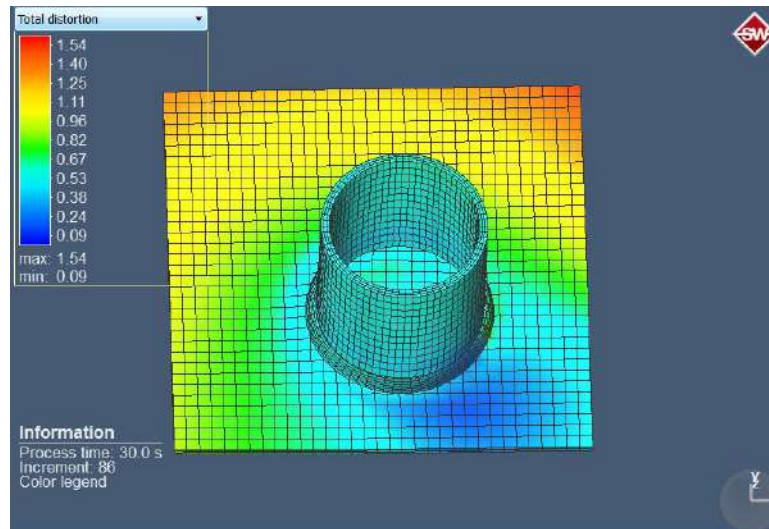
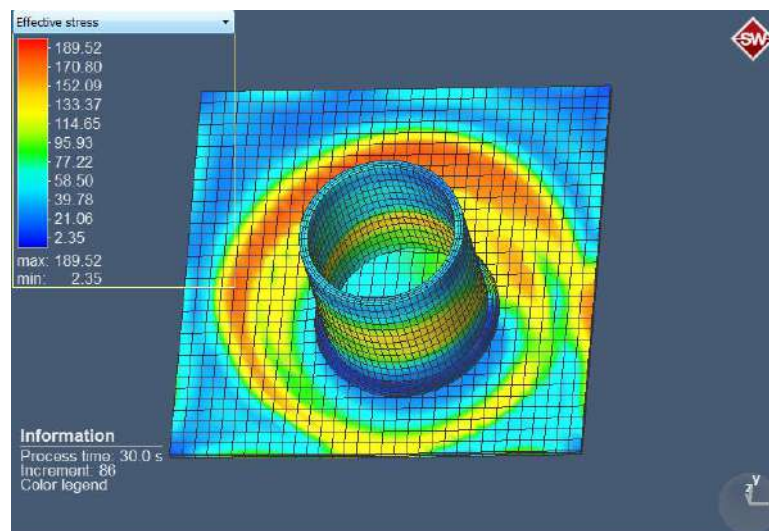


Figure IV.2 Temperature (SMAW1-1).



**Figure IV.3** Total distortion (SMAW1-1).



**Figure IV.4** Effective stress (SMAW1-1).

SMAW1-1 (380A, 17V):

- Temperature: Maximum temperature reached was 1510.88°C, while the minimum temperature was 30°C.
- Distortion: Maximum distortion observed was 1.54mm, and the minimum distortion was 0.09mm.
- Stress: Maximum stress recorded was 189.52 N/mm<sup>2</sup>, and the minimum stress was 2.35 N/mm<sup>2</sup>.

### IV.2.1.2 Effects of SMAW1-2 (current: 380A; Voltage: 28V)

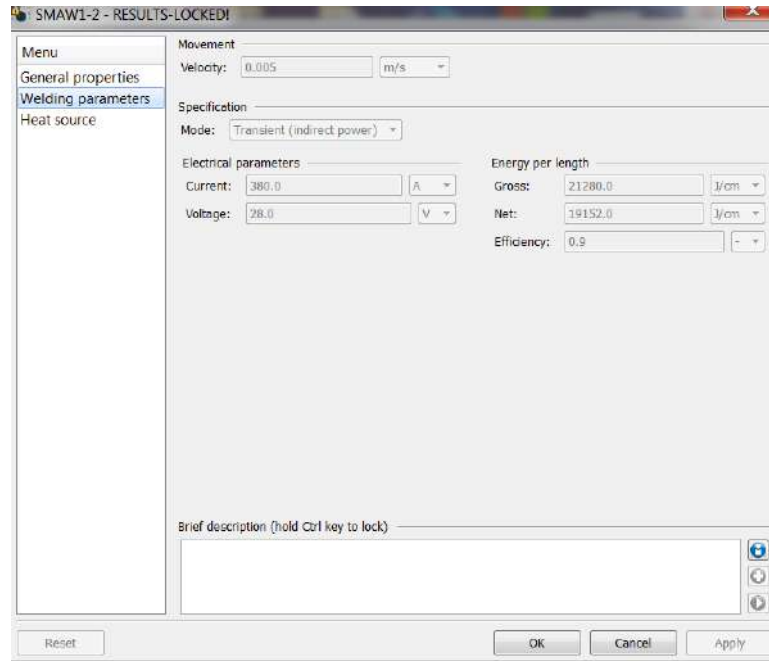


Figure IV.5 SMAW1-2 parameters.

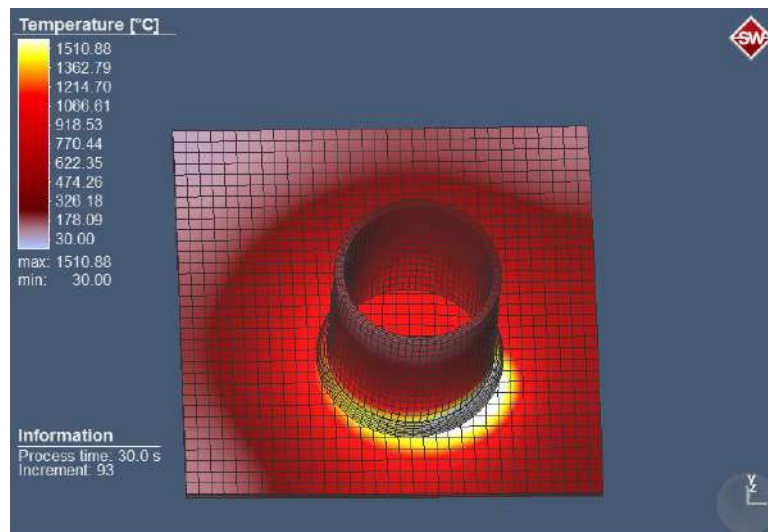
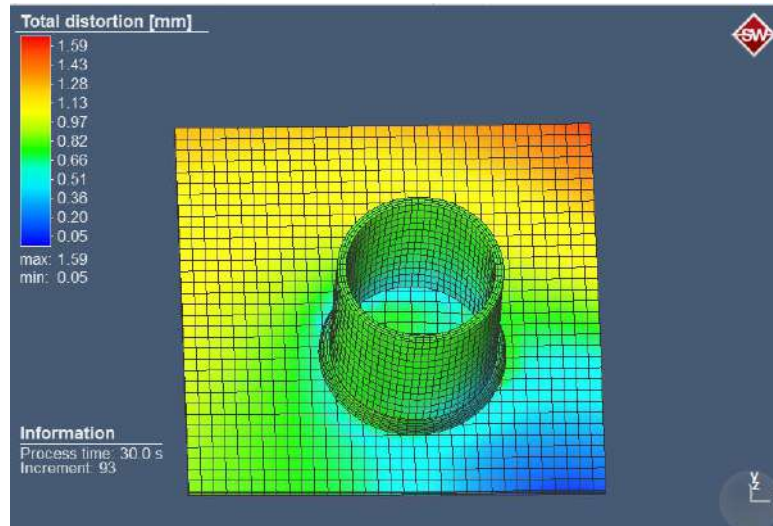
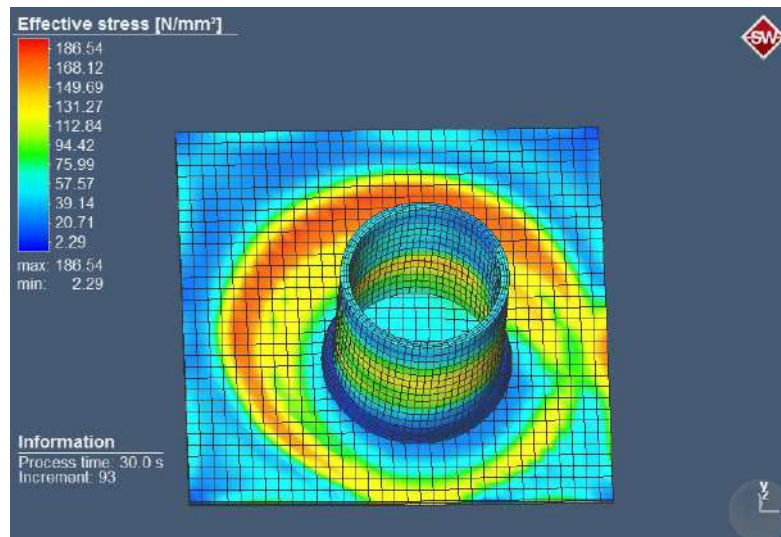


Figure IV.6 Temperature (SMAW1-2).



**Figure IV.7** Total distortion (SMAW1-2).

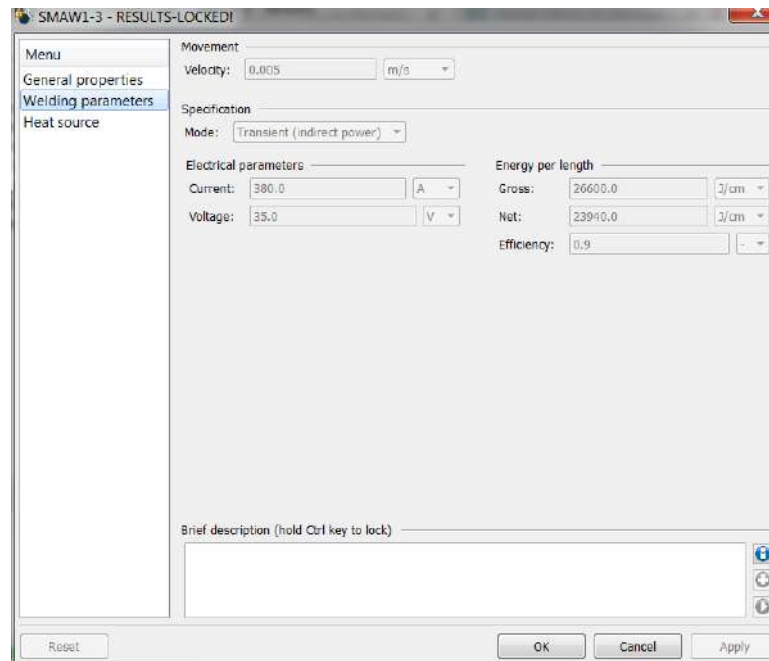


**Figure IV.8** Effective stress (SMAW1-2).

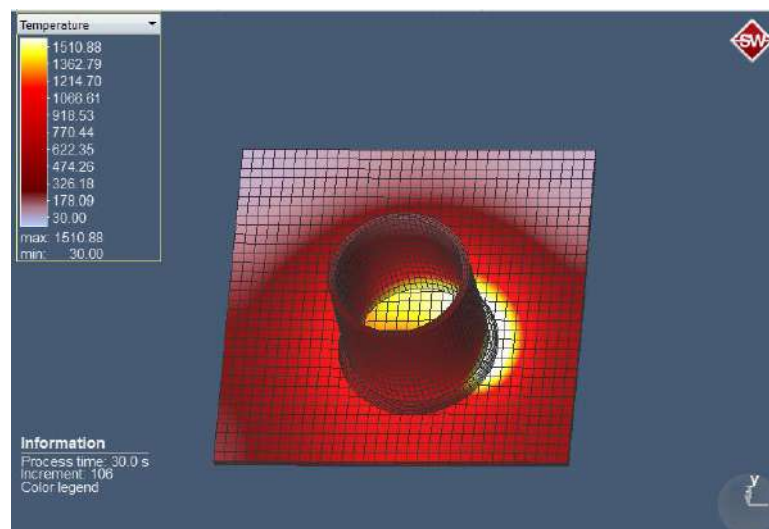
SMAW1-2 (380A, 28V):

- Temperature: Same as SMAW1-1, with a maximum of 1510.88°C and a minimum of 30°C.
- Distortion: Maximum distortion was 1.59mm, and the minimum distortion was 0.05mm.
- Stress: Maximum stress reached 186.54 N/mm<sup>2</sup>, while the minimum stress was 2.29 N/mm<sup>2</sup>.

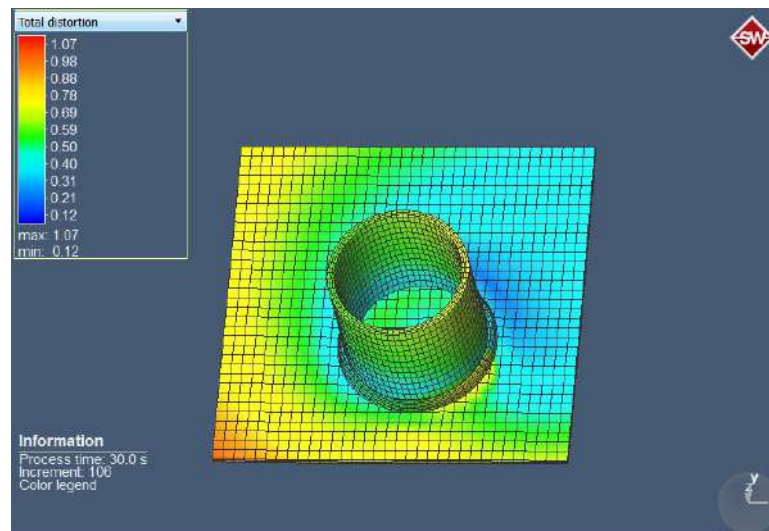
#### IV.2.1.3 Effects of SMAW1-3 (current: 380A; Voltage: 35V)



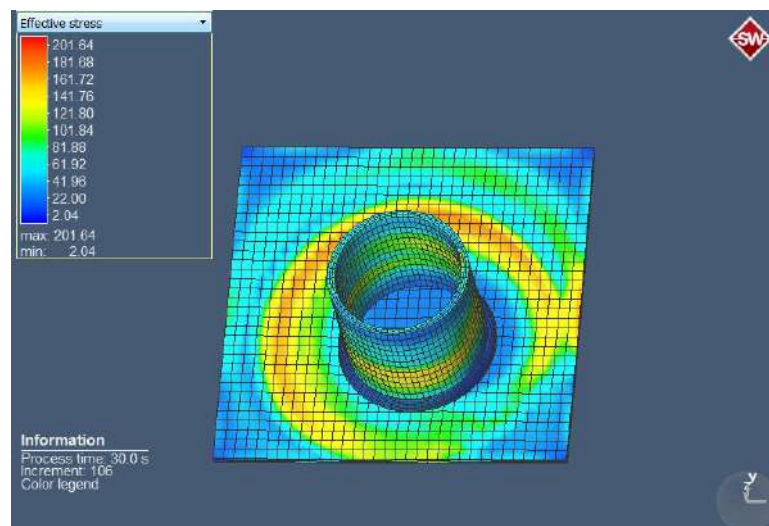
**Figure IV.9** SMAW1-3 parameters.



**Figure IV.10** Temperature (SMAW1-3).



**Figure IV.11** Total distortion (SMAW1-3).



**Figure IV.12** Effective stress (SMAW1-3).

SMAW1-3 (380A, 35V):

- Temperature: Maximum temperature remained consistent at 1510.88°C, and the minimum temperature was 30°C.
- Distortion: Maximum distortion observed was 1.07mm, while the minimum distortion was 0.12mm.
- Stress: Maximum stress recorded was 201.64 N/mm<sup>2</sup>, and the minimum stress was 2.04 N/mm<sup>2</sup>.

### IV.2.2.1 Effects of SMAW2-1 (current: 220A; Voltage: 17V)

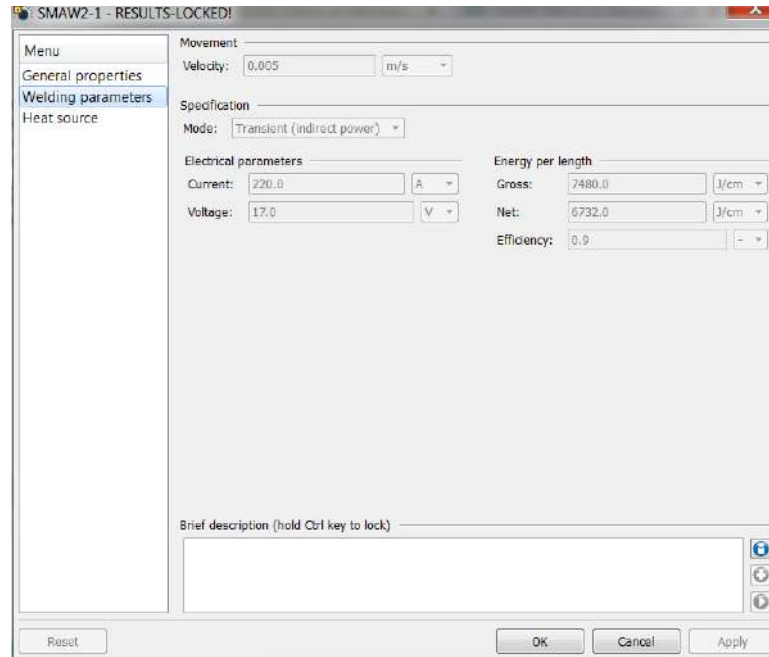


Figure IV.13 SMAW2-1 parameters.

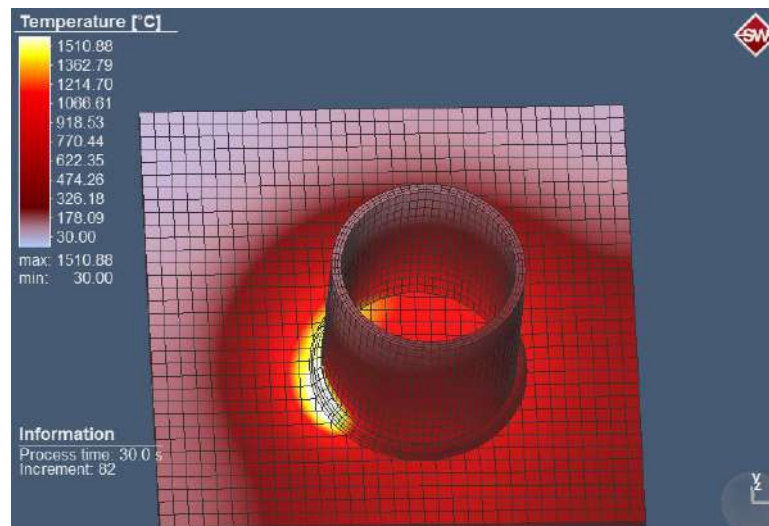
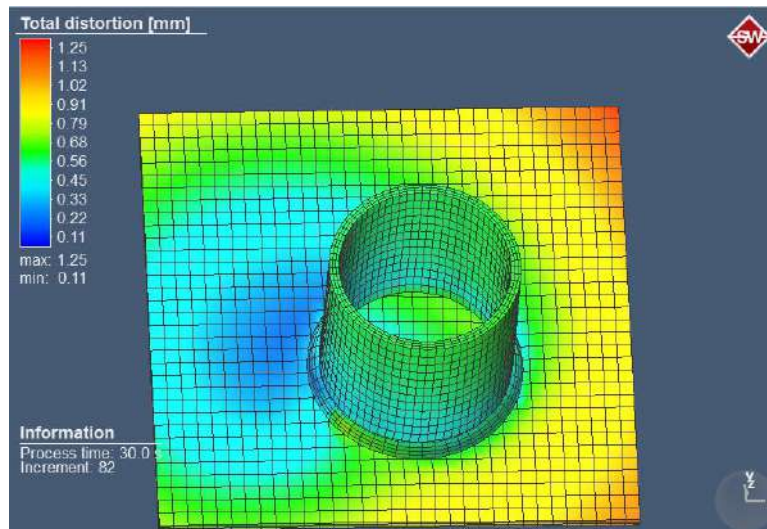
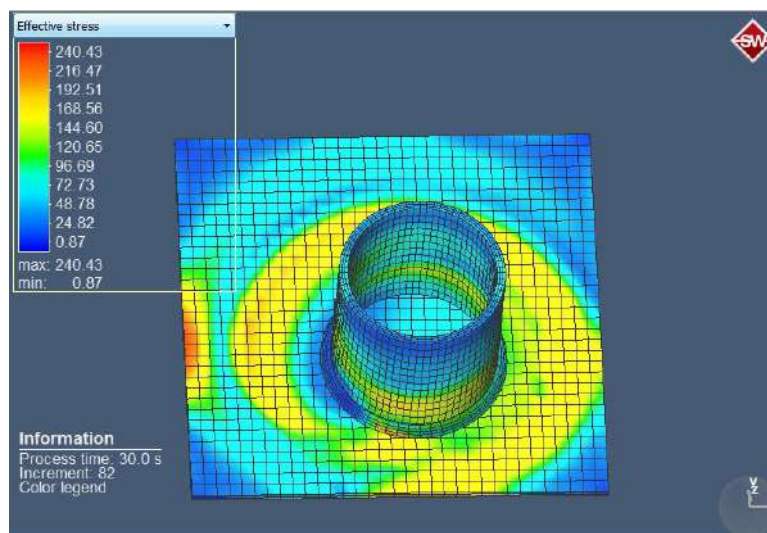


Figure IV.14 Temperature (SMAW2-1).



**Figure IV.15** Total distortion (SMAW2-1).



**Figure IV.16** Effective stress (SMAW2-1).

SMAW2-1 (220A, 17V):

- Temperature: Maximum temperature reached 1510.88°C, while the minimum temperature was 30°C.
- Distortion: Maximum distortion observed was 1.25mm, and the minimum distortion was 0.11mm.
- Stress: Maximum stress recorded was 240.43 N/mm<sup>2</sup>, and the minimum stress was 0.87 N/mm<sup>2</sup>.



### IV.2.2.2 Effects of SMAW2-2 (current: 220A; Voltage: 28V)

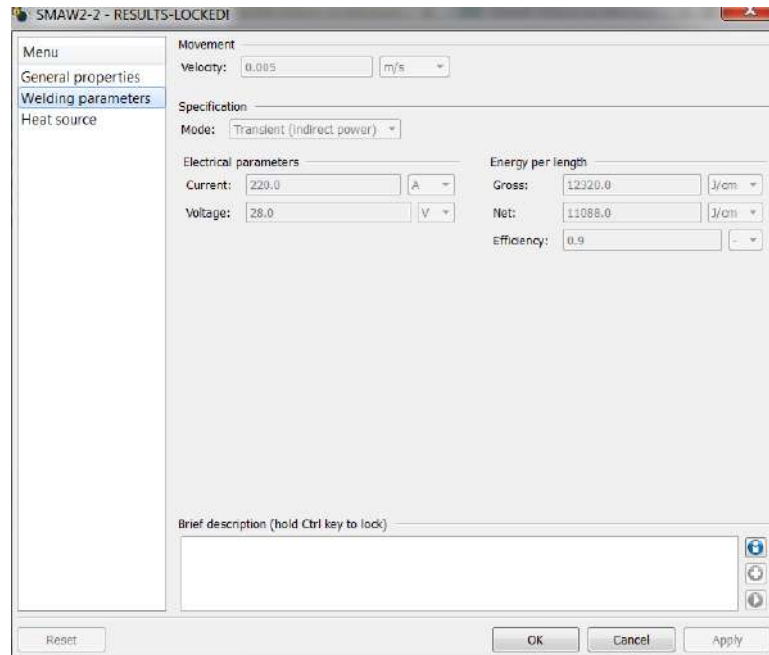


Figure IV.17 SMAW2-2 parameters.

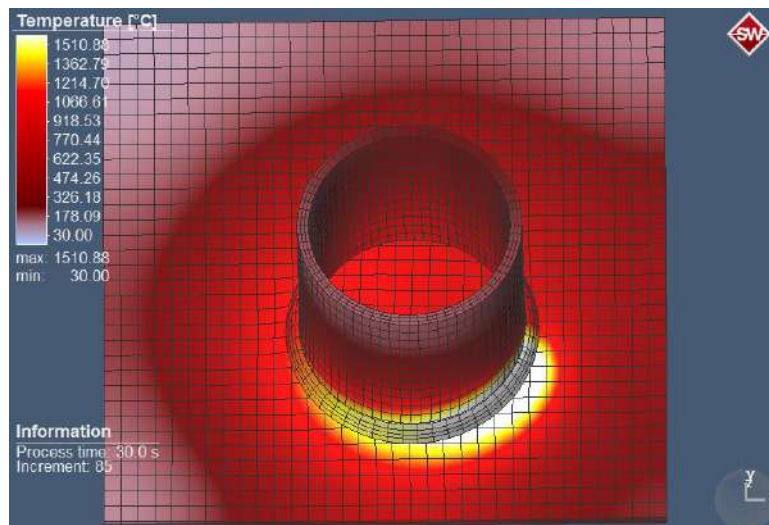
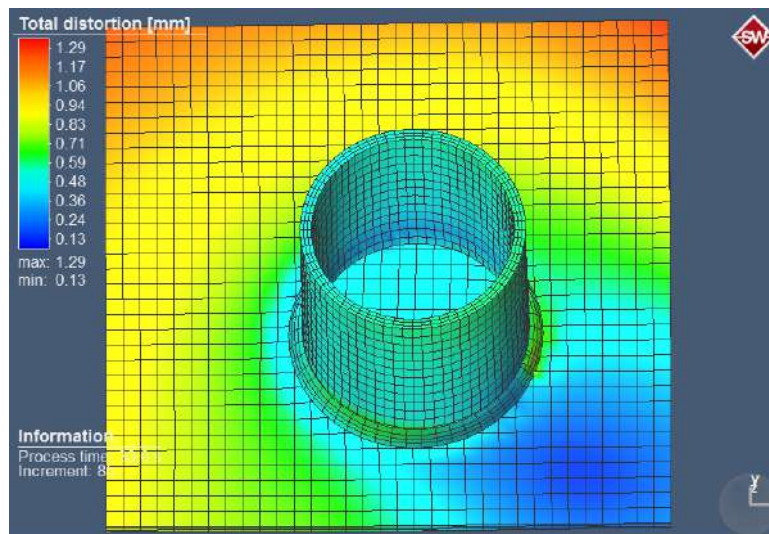
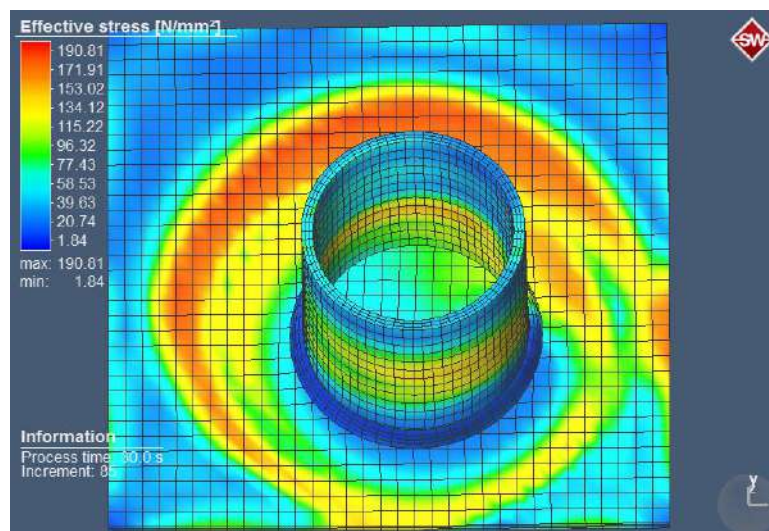


Figure IV.18 Temperature (SMAW2-2).



**Figure IV.19** Total distortion (SMAW2-2).



**Figure IV.20** Effective stress (SMAW2-2).

SMAW2-2 (220A, 28V):

- Temperature: Same as SMAW2-1, with a maximum of 1510.88°C and a minimum of 30°C.
- Distortion: Maximum distortion was 1.22mm, and the minimum distortion was 0.13mm.
- Stress: Maximum stress reached 190.81 N/mm<sup>2</sup>, while the minimum stress was 1.84 N/mm<sup>2</sup>.

### IV.2.2.3 Effects of SMAW2-3 (current: 220A; Voltage: 35V)

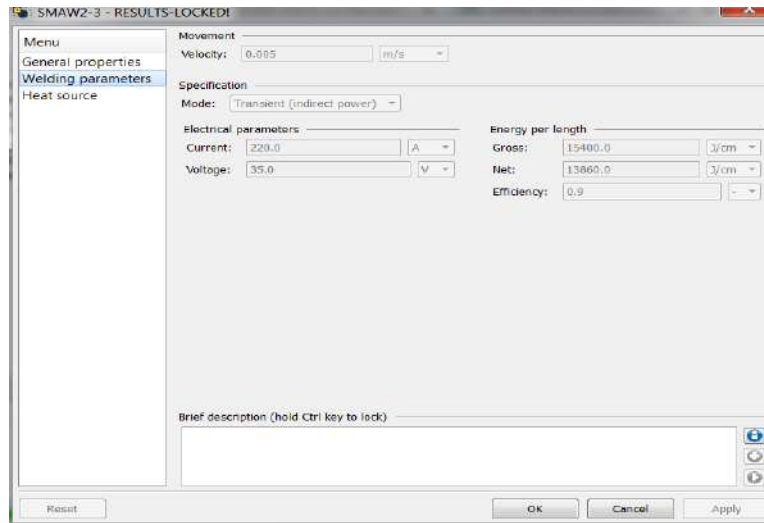


Figure IV.21 SMAW2-3 parameters.

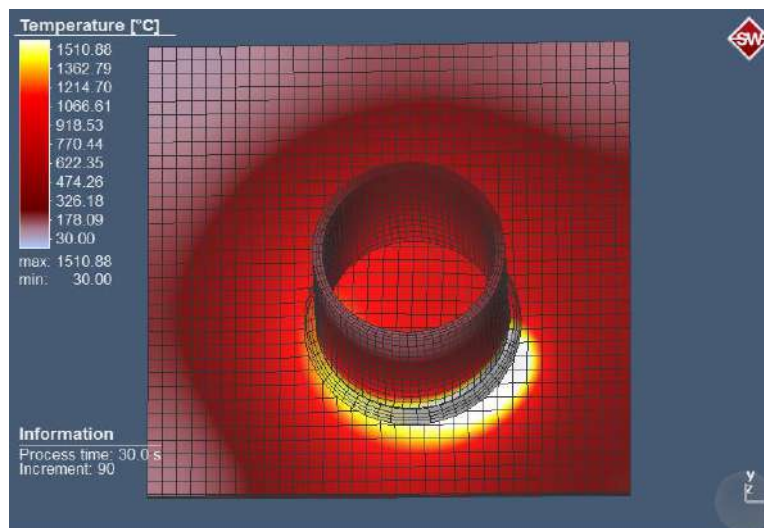
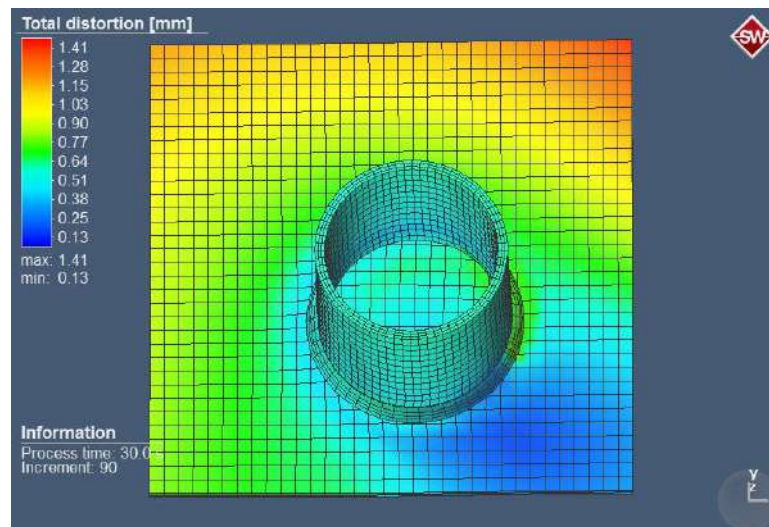
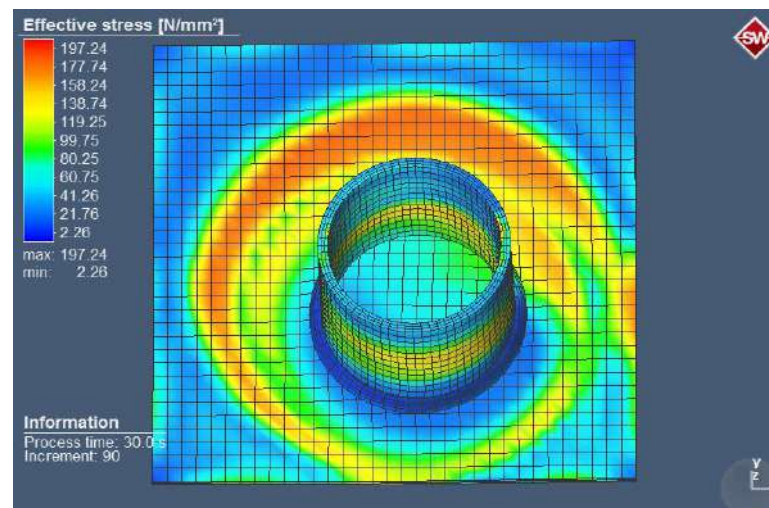


Figure IV.22 Temperature (SMAW2-3).



**Figure IV.23** Total distortion (SMAW2-3).



**Figure IV.24** Effective stress (SMAW2-3).

SMAW2-3 (220A, 35V):

- Temperature: Maximum temperature remained consistent at 1510.88°C, and the minimum temperature was 30°C.
- Distortion: Maximum distortion observed was 1.41mm, while the minimum distortion was 0.13mm.
- Stress: Maximum stress recorded was 197.24 N/mm<sup>2</sup>, and the minimum stress was 2.26 N/mm<sup>2</sup>.

### IV.2.3.1 Effects of SMAW3-1 (current: 100A; Voltage: 17V)

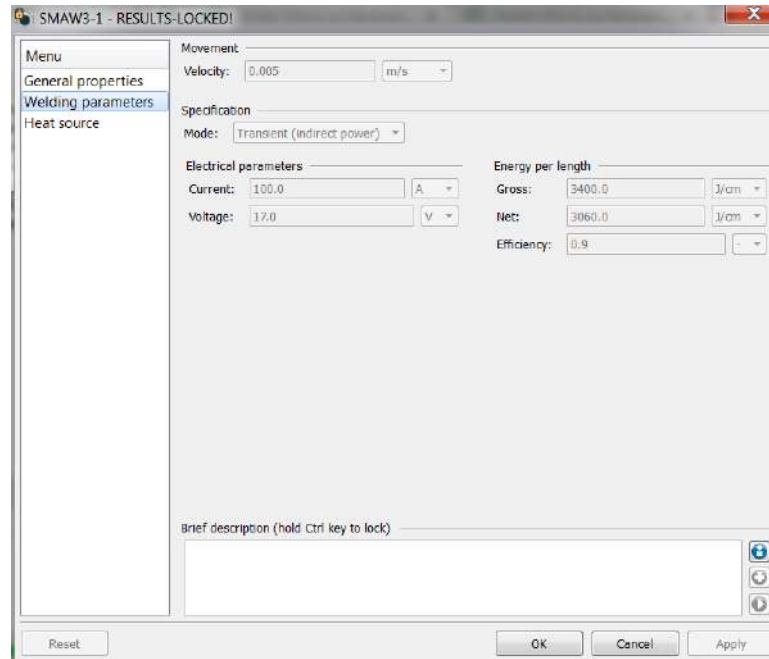


Figure IV.25 SMAW3-1 parameters.

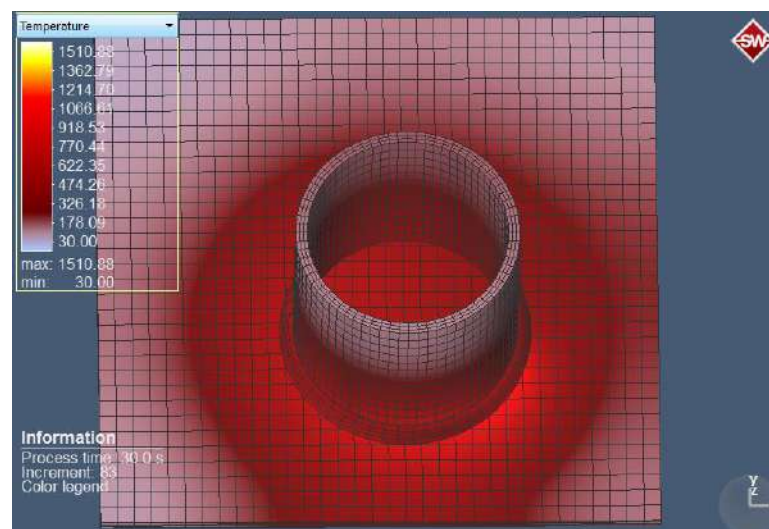
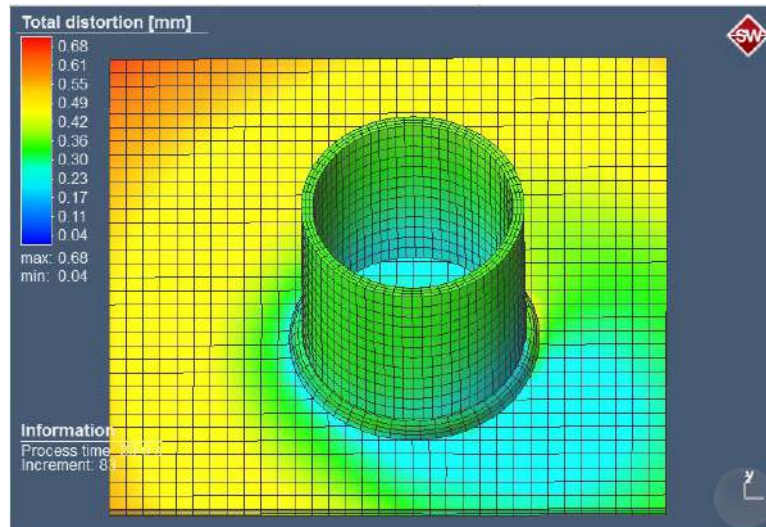
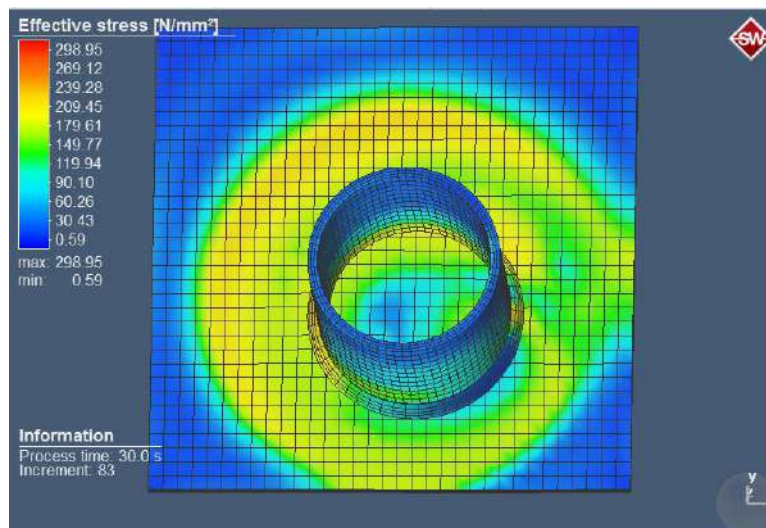


Figure IV.26 Temperature (SMAW3-1).



**Figure IV.27** Total distortion (SMAW3-1).



**Figure IV.28** Effective stress (SMAW3-1).

SMAW3-1 (100A, 17V):

- Temperature: Maximum temperature reached 1510.88°C, while the minimum temperature was 30°C.
- Distortion: Maximum distortion observed was 0.68mm, and the minimum distortion was 0.04mm.
- Stress: Maximum stress recorded was 298.95 N/mm<sup>2</sup>, and the minimum stress was 0.59 N/mm<sup>2</sup>.

### IV.2.3.2 Effects of SMAW3-2 (current: 100A; Voltage: 28V)

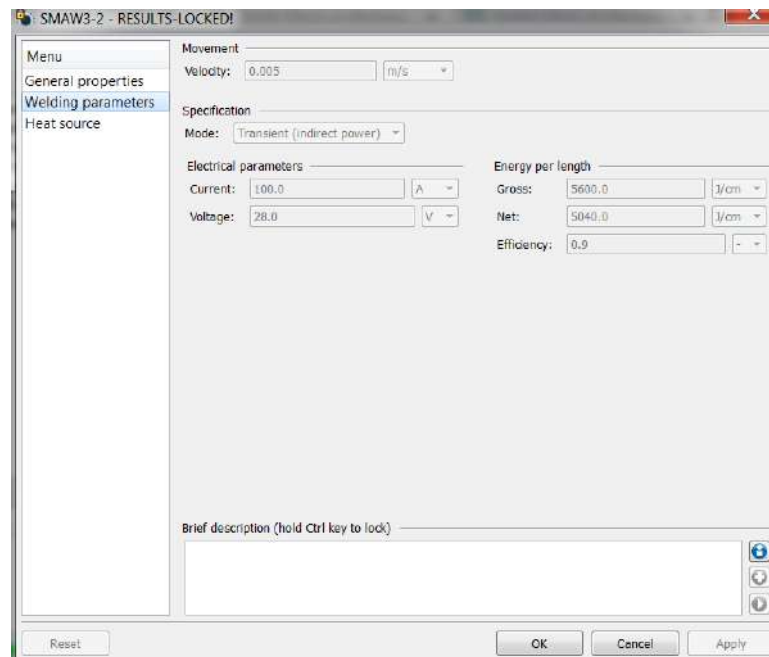


Figure IV.29 SMAW3-2 parameters.

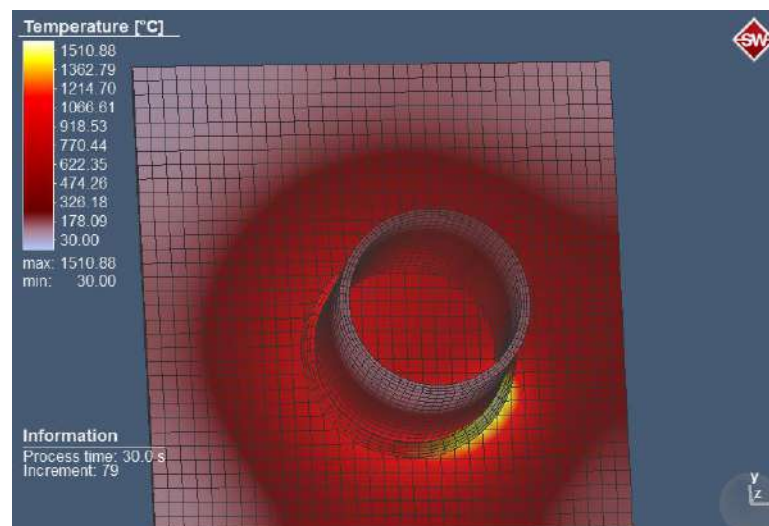
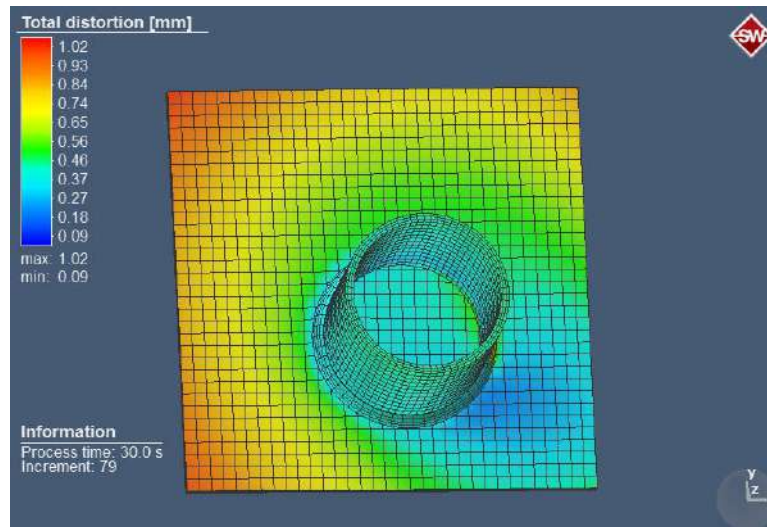
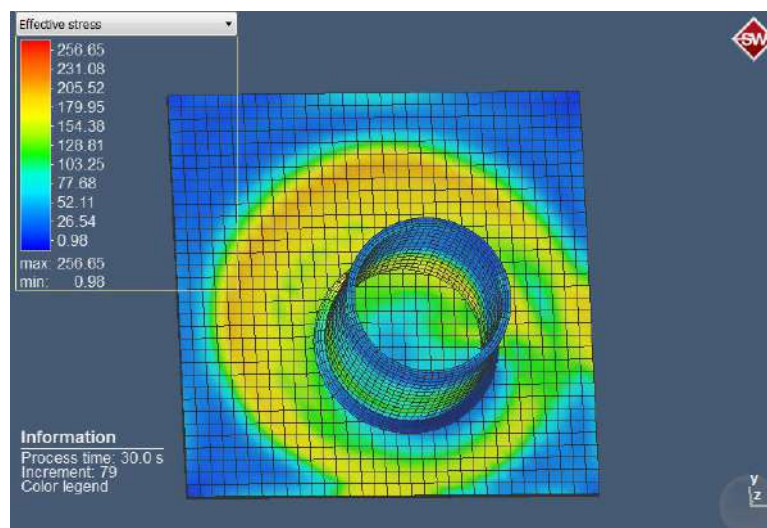


Figure IV.30 Temperature (SMAW3-2).



**Figure IV.31** Total distortion (SMAW3-2).



**Figure IV.32** Effective stress (SMAW3-2).

SMAW3-2 (100A, 28V):

- Temperature: Same as SMAW3-1, with a maximum of 1510.88°C and a minimum of 30°C.
- Distortion: Maximum distortion was 1.02mm, and the minimum distortion was 0.09mm.
- Stress: Maximum stress reached 256.65 N/mm<sup>2</sup>, while the minimum stress was 0.98 N/mm<sup>2</sup>.



### IV.2.3.3 Effects of SMAW3-3 (current: 100A; Voltage: 35V)

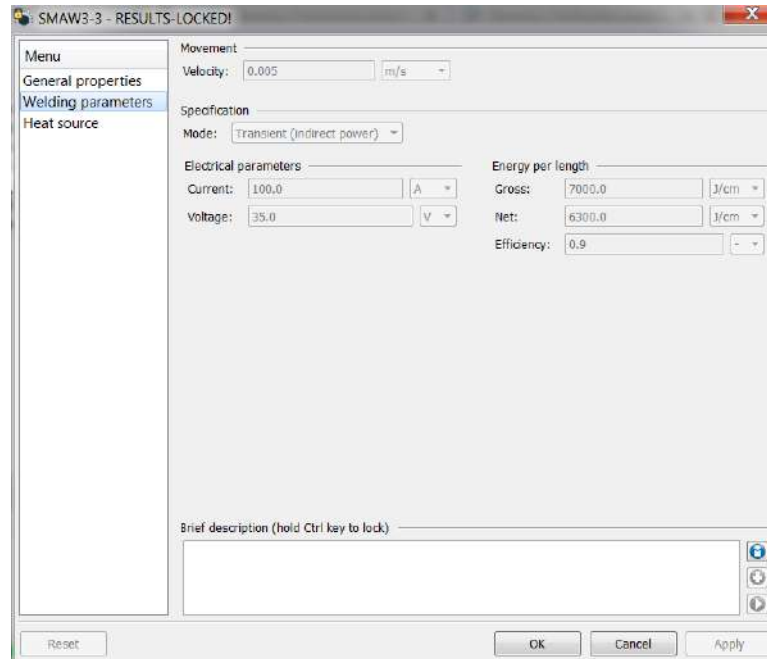


Figure IV.33 SMAW3-3 parameters.

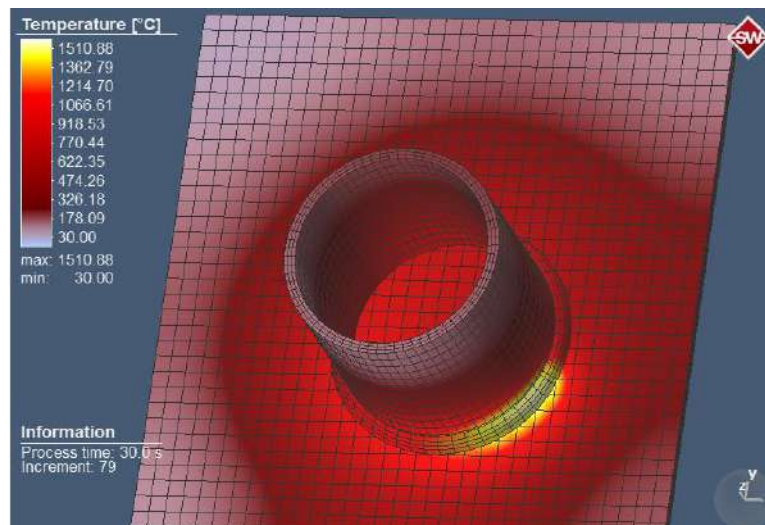
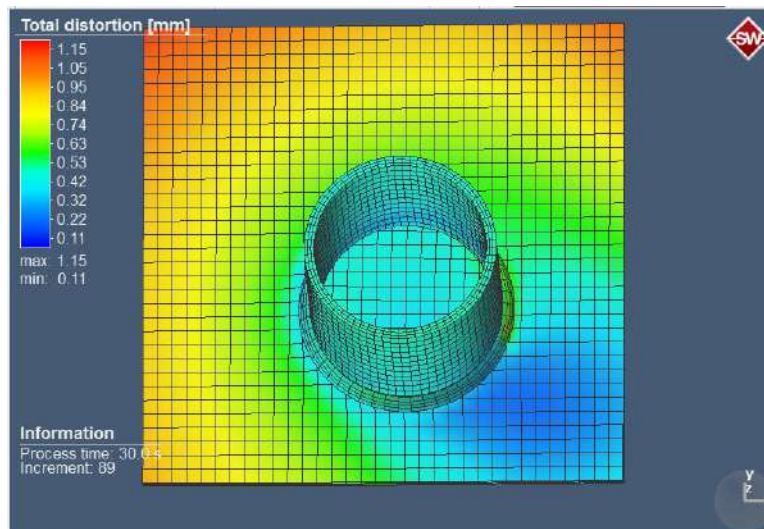
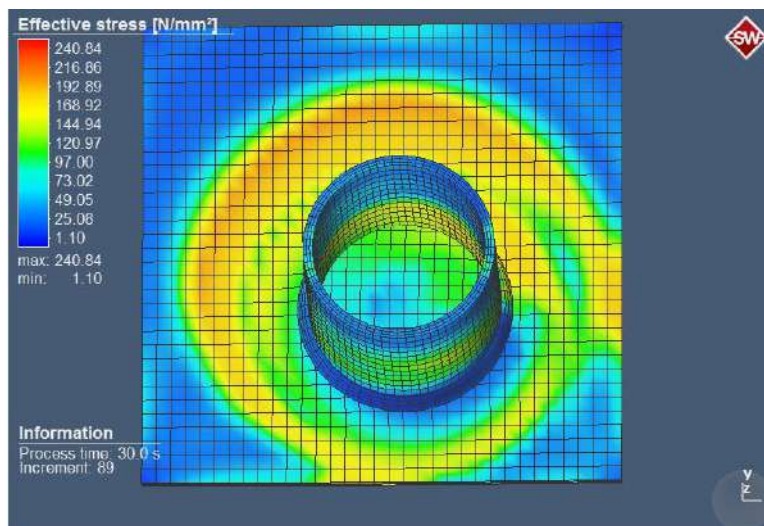


Figure IV.34 Temperature (SMAW3-3).



**Figure IV.35** Total distortion (SMAW3-3).



**Figure IV.36** Effective stress (SMAW3-3).

SMAW3-3 (100A, 35V):

- Temperature: Same as SMAW3-2, with a maximum of 1510.88°C and a minimum of 30°C.
- Distortion: Maximum distortion was 1.15mm, and the minimum distortion was 0.11mm.
- Stress: Maximum stress reached 240.84 N/mm<sup>2</sup>, while the minimum stress was 1.10 N/mm<sup>2</sup>.

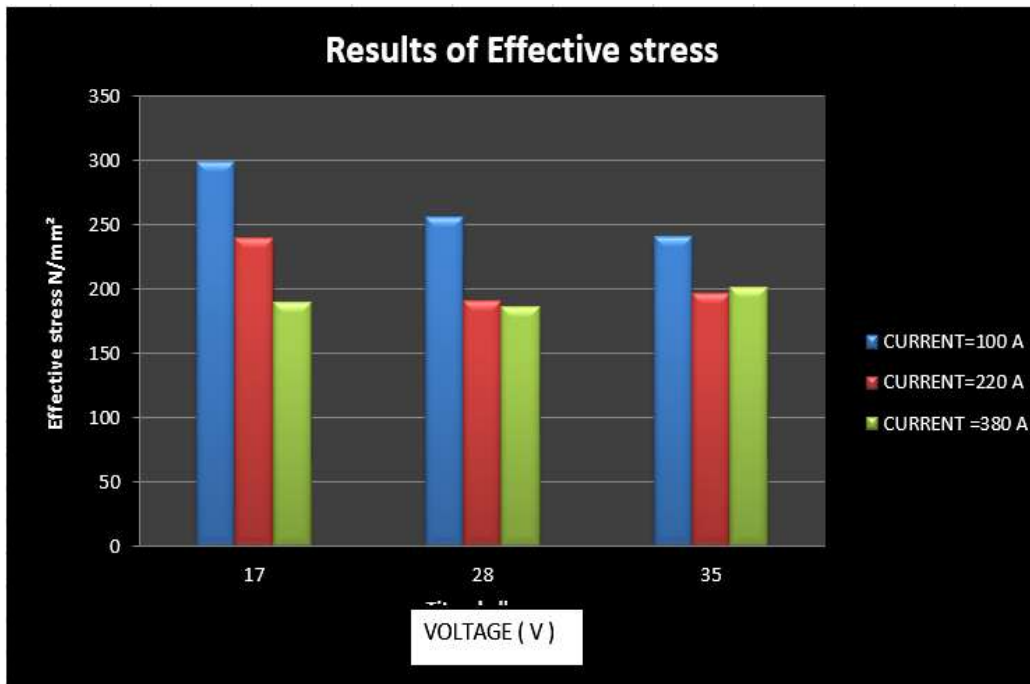


Figure IV.37 Results of Effective stress.

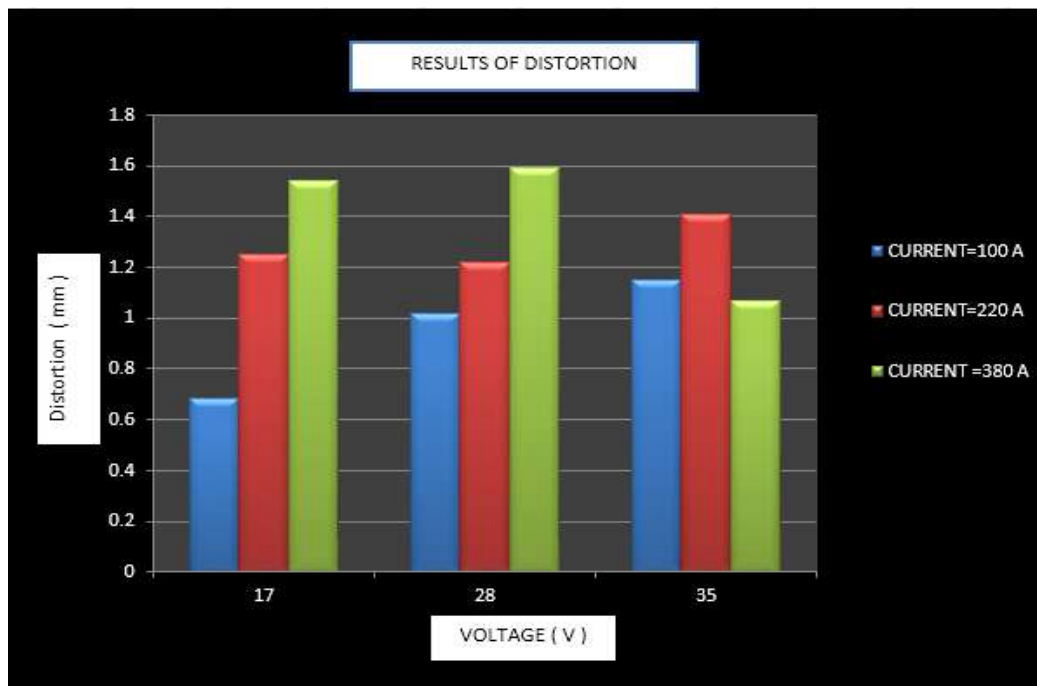


Figure IV.38 Results of Distortion.

### IV.3 General Discussion

1. Temperature: The maximum temperature reached during welding in all cases was extremely high, exceeding 1500°C. This highlights the intense heat generated during the SMAW process. Such high temperatures can have

implications for the microstructure and mechanical properties of the welded parts, as well as potential issues with thermal distortion and residual stresses.

2. Distortion: The distortion of the welded parts varied with different current and voltage combinations. Generally, higher current and voltage values led to greater distortion. This can be attributed to the increased heat input and resulting thermal expansion and contraction effects. Controlling distortion is essential for maintaining dimensional accuracy and ensuring proper fit and function of the welded components.
3. Stress: Stress levels observed in welded parts were affected by current and voltage settings. High current and voltage values have generally led to lower stresses. Excessive stress levels can lead to structural safety concerns, such as deformation, cracking or reducing fatigue life.

#### **IV.4 Conclusion**

This study examined the effect of uneven current and voltage in protective metal arc welding (SMAW) on temperature, distortion and stress in mechanical parts. Nine different processes were analyzed, including three bands of current (100A, 220A, 380A) and three voltage values (17V, 28V, 35V). The results revealed many important ideas. Firstly, regardless of current and voltage fixtures, the maximum welding temperature exceeded 1500 ° C, indicating high heat inputs associated with SMAW and its effects on the precise structure of the welded part and mechanical properties. Second, the deformation was affected by current and voltage at their higher value resulting in greater deformation due to thermal expansion and shrinkage effects. Deformation management is critical for dimensional accuracy and functional proportionality of welded components. Third, stress levels varied based on current and voltage settings, as higher values generally led to lower pressures. Controlling stress concentrations is necessary to avoid structural safety problems.

The study results provide valuable insights for welders and engineers in selecting the right parameters for SMAW. In general, this study enhances our understanding of the effects of current and voltage differences in SMAW, contributing to the field of welding and mechanical engineering.

1. Introduction
2. Chapter I
3. Chapter II
4. Chapter III
5. Chapter IV
6. **General conclusion**
7. Bibliographical references

# General conclusion

## **General conclusion**

This thesis provides a comprehensive exploration of Shielded Metal Arc Welding (SMAW) and its effects on mechanical parts. It's aims to advance our understanding of the effects of shielded metal arc welding through simulation. By employing advanced computational techniques, we strive to provide valuable insights into the thermal behavior, metallurgical transformations, and residual stress distribution associated with SMAW.

We can conclude that Regardless of current and voltage fixtures, the maximum welding temperature exceeded 1500 ° C, indicating high heat inputs associated with SMAW and its effects on the precise structure of the welded part and mechanical properties.

The deformation (Distortion) was affected by current and voltage at their higher value resulting in greater deformation due to thermal expansion and shrinkage effects. Deformation management is critical for dimensional accuracy and functional proportionality of welded components.

In this study stress levels varied based on current and voltage settings, as higher values generally led to lower pressures. Controlling stress concentrations is necessary to avoid structural safety problems.

The study results provide valuable insights for welders and engineers in selecting the right parameters for SMAW.

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2. Chapter I
3. Chapter II
4. Chapter III
5. Chapter IV
6. General conclusion
7. Bibliographical references

# Bibliographical References

## Bibliographical References

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**Abstract**

This thesis presents a study on the process of shielded metal arc welding using Simufact Welding software. The study aimed to investigate the impact of varying welding parameters, such as current and voltage, on the temperature, distortion, and stress in welded joints. The welding process was simulated using the software, and the results were analyzed and discussed. The study revealed that increasing the current and voltage leads to an increase in temperature and distortion, while causing a decrease in stress in the welded joints. The research also concluded that controlling the welding parameters is crucial for achieving high-quality welded joints with minimal distortion and stress.

Keywords: Shielded Metal Arc Welding (SMAW), Simufact Welding, welding parameters, current, voltage, temperature, distortion, and stress.

**Résumé**

Ce these présente une étude sur le processus de soudage à l'arc avec électrode enrobée en utilisant le logiciel Simufact Welding. L'étude avait pour objectif d'examiner l'impact de la variation des paramètres de soudage, tels que le courant et la tension, sur la température, la déformation et les contraintes dans les joints soudés. Le processus de soudage a été simulé à l'aide du logiciel, et les résultats ont été analysés et discutés. L'étude a révélé qu'une augmentation du courant et de la tension entraîne une augmentation de la température et de la déformation, tout en provoquant une diminution des contraintes dans les joints soudés. La recherche a également conclu que le contrôle des paramètres de soudage est essentiel pour obtenir des joints soudés de haute qualité avec une déformation et des contraintes minimales.

Mots-clés : Soudage à l'arc avec électrode enrobée (SMAW), Simufact Welding, paramètres de soudage, courant, tension, température, déformation, contraintes.

**ملخص**

تقدم هذه الرسالة دراسة حول عملية اللحام بالقوس المعدني المحمي باستخدام برنامج Simufact Welding. هدفت الدراسة إلى التحقيق في تأثير تغيير معالمات اللحام، مثل التيار والجهد، على درجة الحرارة والتشوه والتوتر في المفاصل الملحومة. تم نمذجة عملية اللحام بالقوس المعدني المحمي باستخدام البرنامج، وتم تحليل ومناقشة النتائج. أظهرت الدراسة أن زيادة التيار والجهد يؤدي إلى زيادة في درجة الحرارة والتشوه ونقص في

درجة التوتر في المفاصل الملحومة. خلصت البحث أيضاً إلى أن التحكم في معلمات اللحام أمر حاسم لتحقيق مفصل ملحوم عالي الجودة مع تشوه وتوتر أدنى.