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MODELING AND SIMULATION OF SEAM WELDING ON ALUMINIUM ALLOY (AA5454) SHEET METALS

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Program: Manufacturing Engineering
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June 2021

Nekemte, Ethiopia

WOLLEGA UNIVERSITY
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STUDIES ON MODELING AND SIMULATION OF SEAM WELDING ON ALUMINUM ALLOY (AA5454) SHEET METALS

A Thesis Submitted to the College of Engineering and Technology in Partial Fulfillment of the Requirements for the Degree of Master of Manufacturing Engineering.

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APPROVAL SHEET FOR SUBMMITTING FINAL THESIS

MODELING AND SIMULATION OF SEAM WELDING ON ALUMINIUM ALLOY (AA5454) SHEET METALS.

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APPROVAL SHEET FOR SUBMITTING FINAL THESIS

As members of the Board of Examining of the Final MSc. thesis open defense, we certify that we have read and evaluated the thesis prepared by Boja Abera under the title "**Modeling and simulation of seam welding on aluminum alloy (AA5454) sheet metals"** and recommend that the thesis be accepted as fulfilling the thesis requirement for the **Degree of Master of Science** in Manufacturing Engineering.

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Certification of the Final Thesis

I hereby certify that all the correction and recommendation suggested by the board of examiners are incorporated into the final thesis entitl **"Modeling and simulation of seam welding on aluminum alloy (AA5454) sheet metals"** by **Boja Abera.**

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THE STATEMENT OF AUTHOR

I **Mr.** Boja Abera hereby declare and affirm that the thesis entitled "modeling and simulation of seam welding on aluminum alloy (AA5454) sheet metals" is my own work conducted under the supervision of Dr. Harish Kumar. I have followed all the ethical principles of scholarship in the preparation, data collection, data analysis and completion of this thesis. All scholarly matter that is included in the thesis has been given recognition through citation. I have adequately cited and referenced all the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and I have not misrepresented, fabricated, or falsified any idea / data / fact / source in my submission. This thesis is submitted in partial fulfillment of the requirement for a degree from the Post Graduate Studies at Wollega University. I further declare that this thesis has not been submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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ACRONYMS AND ABBREVIATIONS

AC: Alternative Current

c_p : specific heat capacity

DC: Direct Current

ERW: Electrical Resistance Welding

FEA: Finite Element Analysis

FEM: Finite Element Method

HAZ: Heat Affected Zone

h: Heat transfer coefficient

JFE: Japan Future Enterprise

k: Thermal conductivity

MMAW: Manual Metal Arc Welding

PDE: Partial Differential Equation

RMS: Root Mean Square

RSW: Resistance Spot Welding

SAE: Society of Automotive Engineers

SMAW: Shielded Metal Arc Welding

2DL: Two dimensional longitudinal cross-sections

2DT: Two dimensional transverse cross-sections

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ABSTRACT

Seam welding method is an inexpensive and efficient which has made it popular in the making of sheet joints. Seam welding process uses the heat generated from the resistance to the flow of current. This heat is used to obtain the weld. Seam welding process requires continuous flow of current. Hence the large current consumption is one of the drawbacks of this process. The objective of this research is to provide new insight about the physical understanding of seam welding on aluminum alloy (AA5454) sheet metals.

This thesis also focuses on the investigation of the thermo-mechanical characteristics of aluminum sheet metal through scientific, structure, and systematic way by using COMSOL software by using finite element method. Finite element method (FEM) is a powerful and efficient way to explore the thermal behavior and effect of input parameters.

The heat energy generated during the seam welding process mainly depends on the resistance between the electrodes, welding current, rotational speed and the geometry of the electrodes. The three dimensional model developed in this paper is a step towards selecting the appropriate welding parameters so as to produce a good welding nugget. The researcher is going to see some properties of aluminum and its properties as well as reveals why AA5454 aluminum sheet alloy is selected. The outcome of this thesis is better understanding about the physics of Seam welding process which serve as a basis for further experimental works.

CHAPTER ONE

INTRODUCTION

Seam welding is a process that produces a weld at the faying surfaces of two similar metals and widely used for joining thin metal sheets in the automobile and power industries. It is also used in the manufacturing of sheet metals in relation to leakage tightness. In all these application leakage is not allowed and thus it is important for reliable welding procedure to be used. The most important factor for maintaining consistency and a good seam weld nugget formation are, the welding force, welding current magnitude, welding speed, electrode shape and the mode of current being supplied(Zhang et al., 2011).

In seam welding electrodes used are in the form of rollers as shown in the Fig, 1.1.The electrode wheels apply a constant force to the work pieces and rotate at a controlled speed. The electrodes are often disc shaped and rotate as the material passes between them. This allows the electrodes to stay in constant contact with the material to make long continuous welds. The electrical current (AC) is passed through the roller shaped electrode, which produces heat at the interface of the sheet which is to be joined. A seam welding process produces a series of nugget at the interface of the aluminum sheets. The parts to be welded are placed between the circular electrodes, which run at a constant velocity in opposite directions and the squeezing force is applied by these electrodes. The current produces a joule heating effect at the contact of the two sheets and the weld nugget is thus formed.

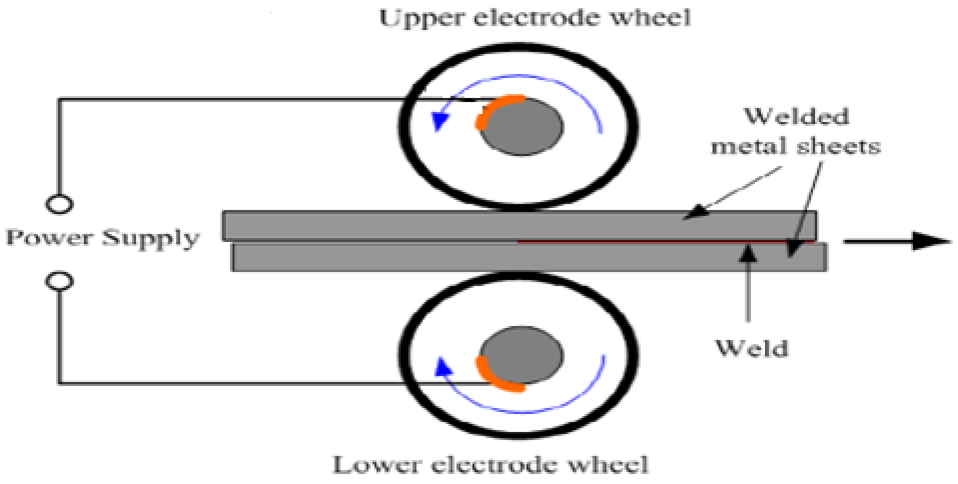


Figure 1.1 working of seam welding (http://www.substech.com) Accessed on 27th December, 2020

In seam welding, the electrodes used are in the form of rollers as shown in Fig. 1.1 the electrical current is passed through the roller shaped electrodes, which produces heat at the interface of the sheets which are to be joined. A seam welding process produces a series of nuggets at the interface of the aluminum sheets. The parts to be welded are placed between the circular electrodes, which run at a constant velocity in opposite directions and the squeeze force is applied by these electrodes. The current produces a joule heating effect at the contact of the two sheets and the weld nugget is thus formed.

1.1. Statement of problem

Welding is a very common operation in many industries and workplaces (El-Batanouny et al., 2009 & National Institute for Occupational Safety and Health, 2002) (NIOSH, 2002). According to American Welding Society, it is defined as “a metal joining process wherein coalescence is produced by heating to suitable temperature with or without the use of filler metal”. (American Welding Society, 2009) (AWS, 2009). There is a variety of welding processes that are used in different working conditions. Worldwide, over five million workers perform welding as a full time or part time duty (Erdely et al., 2012 & Husgafvel-pursiainen et al., 1990). These welders, depending on the conditions, work in outdoor or indoor workplaces, in open or confined spaces, underwater, and above construction sites. The air pollution due to welding leads to certain consequents on humans and environment. Similarly in Ethiopia the familiar and widely used welding technique is manual metal arc welding (shielded metal arc welding). This Shielded Metal

Arc Welding (SMAW) is one of the oldest welding techniques and in which filler material is used and which it's consequence result in more air pollution in Ethiopia. Not only environmental pollution but also this SMAW/MMA is hurt human health directly. Thus, to improve this challenges using resistance seam welding as alternatives is compulsory to keep our planet safe and to reduce global warming.

The finite element model (FEM) is a useful tool for simulating the thermal behavior of the structures during proceeding resistance seam welding techniques. Solving nonlinear equations in an electrical and thermal problem in a time stepping procedure such as for resistance welding requires high computational power. Therefore the solution to such problems requires high computational capabilities.

Progress in computer technology associated with fast computing capabilities, huge memory and flexible communication have made it possible for them to be used in the following fields:

1) Simulating physical phenomena by using numerical analysis;

2) Statistical analysis of experimental data;

3) Real time control manufacturing machines and experimental data.

The computational capability can however, be reduced by making an efficient finite element model of the problem by reducing the dimensions of the model. FEM code for the solution of different problems can be developed by using a general set of subroutines provided by the software. The most popular softwares used to model the resistance welding process are ANSYS, JWRAIN, ABAQUS and COMSOL. About 90% of FEM programs are generic and use similar matrix solvers, quadrature rules and matrix assembly procedures. The seam welding problem is a three dimensional problem. A two dimensional model of a seam welding problem has been developed in order to study the effect of current on the weld nugget formation. Their two dimensional model has been developed from the ax symmetric code developed for the spot welding process. The two dimensional representation of the seam welding process can be analyzed as a transverse cross section (2DT) or as a longitudinal cross section (2DL).The quality of the seam weld joint is mainly dependent on the welding current, the pressure applied between the circular electrode wheels, the motor speed and the width of the welding wheels. Not only these but also knowing the thermal effect during welding is another important issues.

1.2. Objective

Many researchers investigate about seam welding of AA5454 aluminum alloy sheet metals. Most of the time, the detailed process of seam welding not understood well. For this reason, the researcher formulates the following objectives.

1.2.1. General objectives

The general objective of this thesis is to provide new insight about the physical understanding of modeling and simulation of seam welding aluminum alloy (AA5454) by using COMSOL multi-physics software based on finite element method.

1.2.2. Specific objectives

- Investigate simulation on seam welding.
- Study the thermal effects in this welding process.
- To describe temperature distribution during welding.
- Reveal simulation of heat flux, residual stress and temperature distribution.
- Study mathematical modeling.

1.3. Scope of the study

This thesis is limited to aluminum alloy sheet metals (AA5454) wrought aluminum alloy.It involves physical understanding of seam welding process by modeling and simulation using Comsol 5.0 version software.

1.4. Significance of the study

The significance of this thesis will be positive substantial impact on the welding technology of materials specially those which are difficult to weld via convectional welding method and to have well understanding the physics of welding those we didn’t understand via convectional welding.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Seam welding having significant importance in manufacturing gasoline tanks, radiators, heat exchangers, basin sinks due to automated, economical and fast process. Automobile joints require higher load conditions. Following are the literature survey has been done for work:

Tumuluru and Matteson (n.d.) determined procedure development and practice considerations for seam welding process. Peel test and tensile tests was carried out to determine mechanical strength of weld. This paper gives information about seam welding of ferrous materials like low carbon steel, stainless steel. It also described about seam welding of nonferrous materials like Aluminium, Copper, and Bronze etc. They concluded that if the indentation is carefully controlled then tensile strength of 80% to 100% of the parent metal can be achieved of welded joint.

Matteson (n.d.) stated the concept of fundamentals of resistance seam welding. This Paper experimentally showed that if weld force increases under given electrode conditions, there is an improvement in the welding range in speed can be possible. It also leads to control cracking.

Khosravi et al. (2013) experimented that when the current for low welding speeds increases it will lead to decrease in nugget size. When more current is used, it also increases joining zone thickness in each galvanized and electro galvanized sheet. Keeping welding current constant when welding speed increases, results in increase in joining zone thickness and nugget size decreases.

Abdel-Aleem et al. (2005) emphasized that when exhausting pressure increases, there was increase in nugget penetration at an identical welding current. The experimental results of tensile shear testing of joints determined that fracture on the 1050 material always takes place near to the fusion boundary. The hardness at the fusion boundary of 1050Aluminium material increases.

Tomohiro et al. (2013) studied the JFE Steel developed an electric resistance welding (ERW) line pipe technique with a high performance weld seam. The Finite element analysis technique was implemented to construct an analytical model of the ERW weld seam. It can be possible to improve seam mechanical properties by Development of homogeneous heating technology.

Application of Taguchi method for the optimization of resistance spot welding Process (2009) (ATMORSWP, 2009) presents experimental investigation to determine the effect and optimization of process parameters for resistance spot welded SAE 1010 low carbon steel sheets. This paper presents the experimental work conducted under the varying conditions welding current, electrode diameter, electrode force and welding time. Different thickness SAE1010 the steel sheets taken for the experimental work. The effect of input parameters like the tensile shear strength is studied during the work. Level of contribution of the each welding process parameter to the overall improvement of the strength and quality is determined by using ANOVA. This paper concludes that welding current and electrode force were found as the most dominating process parameters and electrode diameter and welding time were least. The results showed that tensile shear strength was increased by 1.20mm and 2.03mm for 1mm and 2mm respectively.

Sahota et al. (2013) investigated significant effect of process parameters on spot welded Austenitic SS 316 material on percentage improvement in material hardness. The experimental studies carried out for the process parameters welding current, electrode force and weld cycles. The result showed that an increase in values of weld current, electrode force and weld time, slight increase in weld nugget diameter and width.

2.2. Residual Stress

Seam weld is made by a combination of heat, pressure and time. The main advantage of seam welding over other joining methods is that it is fast, easy to operate, and adaptable to automation, and is ideal for mass production. Electric welding by resistance is a process of assembly which is significantly used in several industrial fields of manufacture and maintenance (car industry, aerospace and nuclear sectors, electronics and electric industries) (Thrnton et al., 1996; Wan et al., 2014; Zhao et al., 2013; Alizadeh-sh et al., 2014).

This welding process is governed by three essential parameters which are, mechanical (pressure on electrode of welding), electrical (intensity of the current of welding) and electronics (welding duration). In this process, the electrical current crossing sheets to be welded are maintained for a sufficient period to obtain a local fusion at the part interface.

The final mechanical properties of this welding are directly related to the parameters of the process used, knowing the welding pressure, the current intensity and the welding duration.

Increasing restrictions in terms of performance, pollution, safety and energy consumption have resulted in research into the use of new materials and new processes aimed at weight reduction in the production of components. Improvements are obtained through lighter materials, like aluminum alloys and better joining processes, such as resistance seam welding (Pereira et al., 2009).

Residual stresses are stresses that remain in body after all external loads have been removed from that body. Residual stresses resulting from the intense thermal cycling imposed during welding, reduce joint strength. Welding induced residual stresses can significantly increase the fracture driving force in a weldment and also contribute to brittle fracture (Zhang et al., 1999). If the structure is unable to support these stresses, it will either distort or crack. Residual stresses also combine with “in service” loads to create stress fields often very different from those expected (Preston et al., 19999).

Residual stresses due to welding are caused by the application of intense heat or thermal loading at the weld joint, which causes plasticity of the material underneath and immediately surrounding the weld arc, but the nearby cooler material remains elastic and acts to constrain the heated material. The thermal cycle imposed on any welded object causes thermal expansions and contractions to occur which vary with time and location. As this expansion is not uniform, stresses appear when hot regions near the weld are restrained by cooler regions further away. Plastic deformations, occurring as a result of these stresses lead to residual stresses in the object after the temperatures have returned to ambient levels.

There are two common methods including: X-ray diffraction and hole-drilling, to measure residual stresses within the welded materials but, these procedures are time consuming processes and are hard to conduct. This is because, mathematical modeling for prediction of stress field during and after welding, is important to engineers (Ranjbar et al., 2008). Simulation of resistance seam welding processes have been studied and developed by numerous researchers, although their practical methods are different (Deng. n.d.; Cha et al., 2003; Long et al., 2003; Sun & Dong, 2000; Talijiat et al., 1998; Tsai et al., 1992).

Accurate prediction and reduction of welding residual stress and deformation are critical in improving the quality of welded structures. In this study, a computational simulation based on the existing researches (Zhang & Tylor, 2001; Kahraman, 2007; Feuvarch, 2004) is introduced, to study the effects of welding parameters such as applied current, electrode force and welding time on the residual stress in AA5454 aluminum alloy sheets.

Dennison et al. (1997) proposed work on, “Using resistance seam welding for joining aluminum elements in automotive industry”. In this article the comprehensive summary concerning technology of resistance welding of aluminums alloys was presented. The welding schedules, electric parameters of welding, electrodes materials and electrodes life time by resistance seam welding aluminum were described. Few examples directly from automotive industry were presented and advantages of aluminum as a material for some vehicle parts were also discussed.

Sun and Dong (2000) carried out the Finite Element Analysis of resistance seam welding to study nugget formation. This Paper presents the FEA simulation of the RSW process. It requires modeling of complex interactions between electrical, thermal, metallurgical and mechanical phenomena. A 2D axisymmetric FEM model has been developed to analyze the transient thermal behaviors of process using ANSYS software to simulate the thermal characteristics of RSW process. The objective of this analysis is to understand physics of the process and to develop a predictive tool reducing the number of experiments for the optimization of welding parameters. Through the thermal histories and temperature distributions obtained from this analysis, the geometry and dimensions of the nugget can be calculated.

Zhou et al. (2004) worked on Control and process based optimization of Spot Welding in manufacturing systems. The objective of the research was to examine potential mechanisms for improvement of the spot welding process, which is a major component of automotive industry. The paper documents the outcomes of the two techniques and we demonstrate how the significant improvements can be made to the overall spot welding process through the adaptation of such technologies. In particular, both traditional techniques for improving suboptimal parameters in the process and advanced techniques, based upon digital signal processing control of the process were applied to the industrial spot welding test case.

Zhigang et al. (2006) proposed the “Finite-Element Simulation of Resistance Welding Process” in 2011. In this paper, the Resistance Welding is studied and Steel temperature field is gained in this process. The thermal effect of Resistance Welding that specially depends on the electrical and temperature field of it in work-piece is the main key of analysis and optimization of this process, from which the main goal of this paper has been defined. The paper reports the determination of optimum welding conditions (welding intensity and travel speed) for butt joints of Steel Alloys sheets using Resistance Welding. The influence of the welding parameter for each mode on the dimensions and shape of the welds and on their ferrite contents is investigated.

Song et al. (2006) conducted the literature review on “Experimental Investigation of Resistance Spot Welding”. The main emphasis of this review is to study the effect of different input parameter of resistance spot welding on the weld quality. The experimental studies have been conducted under varying welding current and welding time, squeeze and hold time. In this investigation the quality characteristic (tensile strength) has been considered using Grey Relational Analysis Method. Optimal parameters collection of the resistance spot welding operation was obtained via grey relational analysis.

Rahman et al. (2007) carried out “The analysis of spot welding joints of steel sheets with closed profile by ultrasonic method”. The article presents the methodology and the results of non-destructive ultrasonic testing of resistance spot welded joints of thin steel sheet with closed profile. Non-destructive test results were verified on the basis of welded joint area after destructive testing. The obtained results were used to develop an assessment technique for spot welded joints of closed profile with steel sheet, which could be used in factories employing such joints.

Zhang and Lui (2009) investigated the strength of seam weld joint. They also studied its automobile application i.e. vehicle chassis having many seam welds. Analyses of these structures are based on finite element study and experimental study. They have studied the finite element model for seam weld joint under tensile shear load by experimental method. The effect seam weld joint strength is analyzed considering seam weld spacing, edge distance, weld size and thickness using FEA. The conclusion of this study is weld parameters like weld size and thickness are primary factors affecting the strength of the joint of materials.

Ahmet et al. (2011) studied the optimum locations of spot weld and the optimum overlapping length of joined plates. Minimum weld-to-weld and weld-to-edge distance recommended by the industry are considered as side constraints for optimum design of spot weld. They suggest that number of spot welds significantly affects the strength of structure. The distance between two spot welds, arrangement of spot weld and diameter of spot welds, these are the parameters considered for optimum design of spot weld. Spot weld is studied by using FEA and under different loading conditions.

Dipak et al. (2014) conducted a review on Effect of Spot Weld Parameters on Spot Weld Strength. The aim of this study is to find out the effect of spot weld parameters on the strength of spot weld. The effect factors of multiple spot-welded joints strength are analyzed including spot weld arrangement, distance between two spot welds, spot weld diameter and thickness based on finite element analysis (FEA) and experimental results. The study shows that weld diameter and thickness are primary factors affecting the strength of the joints for a given material. From the review conducted, we will interpret the effect of various input parameters on the physical and chemical properties and the primary factors affecting the strength of spot weld joints. The study also helps to understand basics regarding the complicated behaviors of the process which in turn will help one to develop a system to optimize spot welding parameters for maximizing joint strength and efficiency. The study shows that, quantity of heat delivered to the welding spot is dependent upon the duration of current and resistance between the amplitude of electrodes.

2.3. Aluminum and aluminum alloys

2.3.1. General characteristics

The unique combinations of properties provided by aluminum and its alloys make aluminum one of the most versatile, economical, and attractive metallic materials for a broad range of use from soft, highly ductile wrapping foil to the most demanding engineering applications. Aluminum alloys are second only to steels in use as structural metals.

Aluminum has a density of only 2.7 g/cm^3, approximately one-third as much as steel (7.83 g/cm^3). One cubic foot of steel weighs about 490 lb;a cubic foot of aluminum, only about 170 lb. Such light weight, coupled with the high strength of some aluminum alloys (exceeding that of structural steel), permits design and construction of strong, lightweight structures that are particularly advantageous for anything that moves space vehicles and aircraft as well as all types of land and water-borne vehicles.

Aluminum resists the kind of progressive oxidization that causes rust away. The exposed surface of aluminum combines with oxygen to Forman inert aluminum oxide film only a few ten-millionths of an inch thick, which blocks further oxidation. And, unlike iron rust, the aluminum oxide film does not flake off to expose a fresh surface to further oxidation. If the protective layer of aluminum is scratched, it will instantly reseal itself.

The thin oxide layer itself clings tightly to the metal and is colorless and transparent invisible to the naked eye. The discoloration and flaking of iron and steel rust do not occur on aluminum.

Appropriately alloyed and treated, aluminum can resist corrosion by water, salt, and other environmental factors, and by a wide range of other chemical and physical agents. The corrosion characteristics of aluminum alloys are examined in the section “Effects of Alloying on Corrosion Behavior” in this article.

Aluminum surfaces can be highly reflective. Radiant energy, visible light, radiant heat, and electromagnetic waves are efficiently reflected, while anodized and dark anodized surfaces can be reflective or absorbent. The reflectance of polished aluminum, over a broad range of wave lengths, leads to its selection for a variety of decorative and functional uses.

Aluminum typically displays excellent electrical and thermal conductivity, but specific alloys have been developed with high degrees of electrical resistivity. These alloys are useful, for example, in high-torque electric motors. Aluminum is often selected for its electrical conductivity, which is nearly twice that of copper on an equivalent weight basis. The requirements of high conductivity and mechanical strength can be met by use of long-line, high-voltage, and aluminum steel-cored reinforced transmission cable. The thermal conductivity of aluminum alloys, about 50% to 60% that of copper, is advantageous in heat exchangers, evaporators, electrically heated appliances and automotive cylinder heads and radiators.

Aluminum is none ferromagnetic, a property of importance in the electrical and electronics industries. It is none pyrophoric, which is important in applications involving inflammable or explosive-materials handling or exposure. Aluminum is also non-toxic and is routinely used in containers for food and beverages. It has an attractive appearance in its natural finish, which can be soft and lustrous or bright and shiny. It can be virtually any color or texture.

The ease with which aluminum may be fabricated into any form is one of its most important assets. Often it can compete successfully with cheaper materials having a lower degree of workability. The metal can be cast by any method known to foundry-men. It can be rolled to any desired thickness down to foil thinner than paper. Aluminum sheet can be stamped, drawn, spun, or roll formed. The metal also may be hammered or forged. Aluminum wire, drawn from rolled rod, may be stranded into cable of any desired size and type. There is almost no limit to the different profiles (shapes) in which the metal can be extruded.

2.3.2. Mechanical Properties of Aluminum Alloys

The properties of aluminum alloys are compromised at elevated temperatures well before the metal reaches its melting temperature (Kaufman, 1999). For most of the alloys, strengths after significant times at temperatures above 150^{o}C to 200°C (300^{o}F to 400°F) are lower than those at room temperature, and the amount of the strength reduction may increase with both increasing temperature and/ or increasing time at an elevated temperature. As a result, most aluminum alloys are not usually recommended for longtime service at or above these temperatures, but they are widely used in the temperature range from room temperature up to 150 to 200°C. Certain alloys specifically designed to maximize high-temperature resistance.

2.3.3. Physical Properties of Aluminum Alloys

The physical properties of aluminum and its alloys provide some protection when the alloys are near a fire in an adjacent structure and also lessen their increase in temperature in the early stages of a more immediate fire. Those physical properties include the specific heat capacity of aluminum alloys (816 to 1050) J /kg K, which is approximately twice that of steel (377 to 502) J /kg K (Cverna, 2002). This means that it takes twice heat energy as to raise the temperature of aluminum one degree as compared to a similar mass of steel. So in any fire, aluminum members would be relatively slower to heat. This advantage is retained as temperature increases, because the specific heat of aluminum alloys increases with temperature to the melting point (Lundberg, 1994). The thermal conductivity of aluminum and its alloys, which is (88 to 251) W/m K increases with temperature. This is several times the value for steels (11 to 63) W/m K. Thus, heat from a localized source will be distributed along an aluminum structure in a much more efficient manner, enabling it to be radiated off and minimizing hot spots. Also, if the structure is sufficiently massive, the aluminum can act as a heat sink to slow the rate of increase of temperature in the early stages of a fire, increasing the period of serviceability. This might make the difference in prolonging structural endurance in a fire and allowing time to evacuate a burning structure. The reflectivity of aluminum, which is very high 80 to 90 of incident radiation, many times that of bare steel, and reportedly 17 to 19 times greater than the usual painted steel structures (Cverna, 2002). It remains very high, even at high temperatures and even for old and oxidized surfaces. Thus for bare aluminum or aluminum alloys, this high reflectivity also contributes to a slower rise in temperature and longer serviceability than for most structural steels during the early stages of a fire. Reflectivity is decreased if the aluminum surfaces are painted or become coated with soot. The emissivity of aluminum alloys (0.02 to 0.10 for most structural aluminum alloys), which is lower than that of carbon steels (0.10 to 0.80) and stainless steels (0.27) (Cverna, 2002). This also contributes to the ability of aluminum alloys to heat up more slowly than steels in the early stages of a fire, allowing more time for occupants to escape the fire. While emissivity varies greatly depending on surface quality and cleanliness, steel members may heat up approximately four times faster than comparable aluminum alloy members in a non-engulfing fire (Pape & Schmidt, 2009). As noted, these physical properties are the most important if the aluminum components of the structure are nearby or adjacent to the main fire in another structure, but they may also be helpful in the very early stages of a serious configuration in the immediate structure. If the aluminum members become heavily coated with soot, the advantages offered by the physical properties of the original components are diminished or nonexistent.

2.3.4. Categories of aluminum alloy

It is convenient to divide aluminum alloys into two major categories: wrought compositions and cast compositions. A further differentiation for each category is based on the primary mechanism of property development. Many alloys respond to thermal treatment based on phase solubility. These treatments include solution heat treatment, quenching, and precipitation, or Age hardening. For either casting or wrought alloys, such alloys are described as heat treatable. A large number of other wrought compositions rely instead on work hardening through mechanical reduction, usually in combination with various annealing procedures for property enhancement. These alloys are referred to as work-hardening. Some casting alloys are essentially not heat treatable and are used only in as-cast or in thermally modified conditions unrelated to solution or precipitation effects.

Cast and wrought alloy nomenclatures have been developed. The aluminum association system is most widely recognized in the United States. Their alloy identification system employs different nomenclatures for wrought and cast alloys, but divides alloys into families for simplification. For wrought alloys a four-digit system is used to produce a list of wrought composition families as follows:

1*xxx:* Controlled unalloyed (pure) composition, used primarily in the electrical and chemical industries. Aluminum of 99.00% or higher purity has many applications, especially in the electrical and chemical fields. These grades of aluminum are characterized by excellent corrosion resistance, high thermal and electrical conductivities, low mechanical properties, and excellent workability. Moderate increases in strength may be obtained by strain hardening. Iron and silicon are the major impurities.

2*xxx:* Alloys, in which copper is the principal alloying element, although other elements, notably magnesium, may be specified. 2*xxx*series alloys are widely used in aircraft where their high strength (yield strengths as high as 455 MPa, or 66 ksi) is valued. Copper is the principal alloying element in 2*xxx* series alloys, often with magnesium as a secondary addition. These alloys require solution heat treatment to obtain optimum properties; in the solution heat-treated condition, mechanical properties are similar to, and sometimes exceed, those of low-carbon steel. In some instances, precipitation heat treatment (aging) is employed to further increase mechanical properties. This treatment increases yield strength, with attendant loss in elongation; its effect on tensile strength is not as great.

The alloys in the 2*xxx* series do not have as good corrosion resistance as most other aluminum alloys, and under certain conditions they may be subject to intergranular corrosion. Therefore, these alloys in the form of sheet usually are clad with high-purity aluminum, a magnesium-silicon alloy of the 6*xxx* series, or an alloy containing 1% Zn.

The coating, usually from 2 to 5% of the total thickness on each side, provides galvanic protection of the core material and thus greatly increases resistance to corrosion.

Alloys in the 2*xxx* series are particularly well suited for parts and structures requiring high strength-to-weight ratios and are commonly used to make truck and aircraft wheels, truck suspension parts, aircraft fuselage and wing skins, structural parts, and those parts requiring good strength at temperatures up to 150 °C (300 °F). Figure 1 shows the relationships between some of the more commonly used alloys in the 2*xxx* series.

3*xxx*: Alloys, in which manganese is the principal alloying element, used as general-purpose alloys for architectural applications and various products. Manganese is the major alloying element of 3*xxx* series alloys. These alloys generally are non-heat-treatable but have about 20% more strength than 1*xxx* series alloys. Because only a limited percentage of manganese (up to about 1.5%) can be effectively added to aluminum, manganese is used as a major element in only a few alloys. However, one of these, the popular 3003 alloy, is widely used as a general-purpose alloy for moderate-strength applications requiring good workability.

4*xxx*: Alloys in which silicon is the principal alloying element, used in welding rods and brazing sheet. The major alloying element in 4*xxx* series alloys is silicon, which can be added in sufficient quantities (up to 12%) to cause substantial lowering of the melting range without producing brittleness. For this reason, aluminum-silicon alloys are used in welding wire and as brazing alloys for joining aluminum, where a lower melting range than that of the base metal is required. Most alloys in this series are non-heat treatable, but when used in welding heat-treatable alloys, they pick up some of the alloying constituents of the latter and so respond to heat treatment to a limited extent. The alloys containing appreciable amounts of silicon become dark gray to charcoal when anodic oxide finishes are applied and hence are in demand for architectural applications. Alloy 4032 has a low coefficient of thermal expansion and high wear resistance; thus it is well suited to production of forged engine pistons.

5*xxx*: Alloys in which magnesium is the principal alloying element, used in boat hulls, gangplanks, and other products exposed to marine environments. The major alloying element in 5*xxx* series alloys is magnesium. When it is used as a major alloying element or with manganese, the result is a moderate-to-high-strength work-hardenable alloy. Magnesium is considerably more effective than manganese as a hardener, about 0.8% Mg being equal to 1.25% Mn, and it can be added in considerably higher quantities. Alloys in this series possess good welding characteristics and good resistance to corrosion in marine atmospheres. However, certain limitations should be placed on the amount of cold work and the safe operating temperatures permissible for the higher-magnesium alloys (over ~3.5% for operating temperatures above ~65 °C, or 150 °F)to avoid susceptibility to stress-corrosion cracking. Figure 2 shows the relationships between some of the more commonly used alloys in the 5*xxx*series.

6*xxx*: Alloys in which magnesium and silicon are the principal alloying elements, commonly used for architectural extrusions and automotive components. Alloys in the 6*xxx* series contain silicon and magnesium approximately in the proportions required for formation of magnesium silicide (Mg_2Si), thus making them heat treatable. Although not as strong as most 2*xxx* and 7*xxx* alloys, 6*xxx* series alloys have good formability, weldability, machinability, and corrosion resistance, with medium strength. Alloys in this heat-treatable group may be formed in the T4 temper (solution heat treated but not precipitation heat treated) and strengthened after forming to full T6 properties by precipitation heat treatment.

7*xxx*: Alloys in which zinc is the principal alloying element (although other elements, such as copper, magnesium, chromium, and zirconium, may be specified), used in aircraft structural components and other high-strength applications. The 7*xxx* series are the strongest aluminum alloys, with yield strengths ≥500 MPa (≥73 ksi) possible. Zinc, in amounts of 1 to 8%, is the major alloying element in 7*xxx* series alloys, and when couple d with a smaller percentage of magnesium results in heat-treatable alloys of moderate to very high strength. Usually other elements, such as copper and chromium, are added in small quantities. Dilute additions of scandium also improve properties. 7*xxx*series alloys are used in airframe structures, mobile equipment, and other highly stressed parts. Higher strength 7*xxx* alloys exhibit reduced resistance to stress corrosion cracking and are often utilized in a slightly over-aged temper to provide better combinations of strength, corrosion resistance, and fracture toughness.

8*xxx*: Alloys characterizing miscellaneous compositions. The 8*xxx* series alloys may contain appreciable amounts of tin, lithium, and/or iron. Alloys constitute a wide range of chemical compositions. For example, improved elevated-temperature performance is achieved through the use of dispersion-strengthened Al-Fe-Ce alloys (e.g., 8019) or Al-

Fe-V-Si alloys (e.g., 8009) made by powder metallurgy processing. Lower density and higher stiffness can be achieved in lithium-containing alloys (e.g., 8090). The latter alloy, which is precipitation hardenable, has replaced medium-to-high strength 2*xxx* and 7*xxx* alloys in some aircraft/ aerospace applications (e.g., helicopter components).

9*xxx:* Reserved for future use.

Wrought alloys that constitute heat-treatable (precipitation-hardenable) aluminum alloys include the **2*xxx*, 6*xxx*, 7*xxx***, and some of the **8*xxx*** alloys.

Table 1.1. review of some related literatures

Author(s)	**Title**	**Findings**	**Research gap**
Zhang and Lui (2009)	Strength Analysis and Simulation of Multiple Spot Welded Joints	The parameters those affecting the strength of seam welded materials.	Do not give explanation of temperature distribution while we proceed seam welding.
Sun and Dong (2000)	Analysis of aluminum resistance welding process using coupled finite element procedures	Obtain thermal distribution in resistance seam welding by using ANSYS software.	The researcher do not used comsol software.
Zhang et al. (1999)	Residual stress analysis and fracture assessment of weld joints in moment frames.	Welding induced residual stresses can significantly increase the fracture driving force in a weldment and also contribute to brittle fracture.	Do not reveals how this residual stress affect the shape of our working material in this resistance seam welding.
Pereira et al. (2009)	Effect of process parameters on the strength of resistance spot	Improvements are obtained through lighter materials, like aluminum alloys and better joining processes,	Supporting this research by comsol software.

	welds in 6082-T6 aluminum alloy.	such as resistance seam welding.	
Dennison et al. (1997)	Control and process based optimization of Seam Welding in Manufacturing systems	Few examples directly from automotive industry were presented and advantages of aluminum as a material for some vehicle parts were also discussed.	Supporting research with multiphysics software is not stated.

2.4. The research gap observed

Generally, many researches works were carried out on resistance seam welding by using different types of software. But no one attempts the temperature distribution and heat flux condition in seam welding using COMSOL software.

2.5. Applications of seam welding

Figure 1.2 Used for hulls, hull stiffeners, decking and superstructure.

Figure 1.3 The internal hull stiffener structure of the high-speed yacht.

[redacted]

Figure 1.4 Single/ multiple hull high-speed ferries, employ several Al-Mg alloy as sheet and plate.

[redacted]

Figure 1.5 Rugged coal cars are provided by welded 5454 alloy plate construction.

Figure1.6 The Foresmo Bridge in northern Norway is an example of the use of Al-Mg alloys for built up girders systems

Figure1.7 The demands of high-humidity and water exposure in offshore oil rigs are met with Al-Mg alloy welded construction.

Figure1.8 Automotive structures are formed sheet for parts such as internal door stiffeners.

Figure1.9 Automotive structures are formed sheet for parts such as the entire body-in-white.

Figure 1.10 Aluminum can make that one of the largest volume alloys in production

Figure 1.11 Brewery tanks welding

Figure 1.12 Welding of heat exchanger

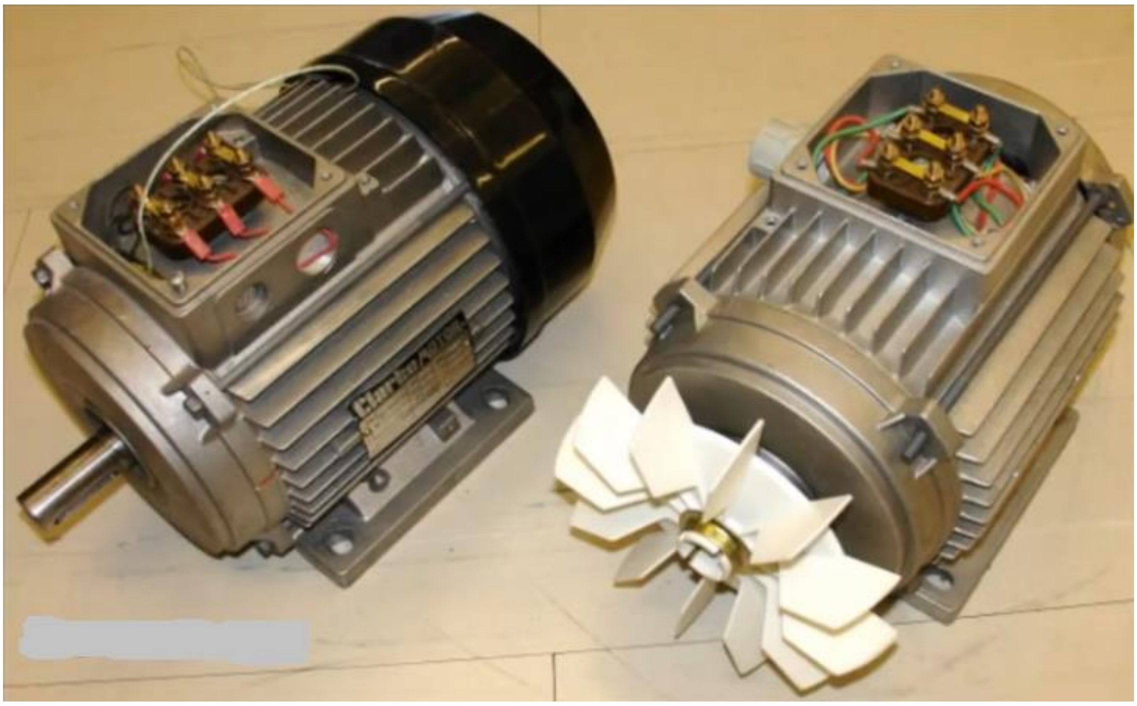


Figure 1.13 Motor cases welding

Figure 1.14 Welding of nuclear components

Figure 1.15 Pressure vessels welding

2.6. Seam welding advantages and disadvantages

2.6.1. Advantages

- This welding is a quicker process.
- It is a continuous welding technique suitable for gas and liquid tight containers.
- Energy is utilized efficiently in this technique.
- This technique is used for making gas or liquid tight vessels.
- It doesn’t need the use of filler material.
- No pollutions like fumes of gases because filler material is not utilized.
- This technique can produce liquid tight and gas tight joints.
- Since the joint is forged due to heat and pressure, a durable weld is formed in seam welding.
- This welding is easy to operate.
- Seam welding gives sturdy design and excellent performance.

2.6.2. Disadvantages

- Higher current is required.
- For harder alloys, high strength welding forces are required.
- The electrode may need to be cleaned after one revolution.
- The mechanized cleaning system is necessary for removal of contaminations.
- This technique is not utilized when the thickness of the sheet metals increases from 3mm.
- If electrodes speed is not controlled efficiently, its performance may be decreased.
- Work-pieces needed to be overlapped to make sure that no overflow of melted metal occurs.
- Its electrodes are motor driven as compared to stationary electrodes.

CHAPTER THREE

THERMAL MODELING OF SEAM WELDING

Seam welding requires models to be studied via simulations evaluate model numerically to estimate model characteristics.

3.1. Thermal modeling

Finite element method is the most commonly used in numerical analysis to obtain approximate solutions for many engineering problems. In present study, finite element program COMSOL multi physics5.0 software is used for numerical simulation of seam welding process. The COMSOL multi physics 5.0 software program has many finite element analysis capabilities. The thermal response of the material during seam welding process is investigated by finite element simulations.

The COMSOL program has many finite element analysis capabilities, ranging from simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis. The COMSOL program has also a comprehensive graphical user interface that gives interactive access to program functions, commands, and documentation and reference materials to users.

A typical COMSOL multi physics analysis has three distinct steps:

- ✓ Build model
- ✓ Apply loads and obtain the solution
- ✓ Review the solution

3.1.1. Assumptions

The following assumptions are made in developing the model;

- o The coefficient of friction is considered with temperature.
- o The material properties are uniform.
- o The heat transfer between work piece and clamp is negligible.

3.1.2. Working material

Seam welding is the process of joining two similar or dissimilar materials at the seam by the use of electric current and pressure. The process is mostly used on metals since they conduct electricity easily and can sustain relatively high pressure. When two sheet metals are pressed together, there will be a slight gap between them due to surface irregularities. In resistance seam welding this gap creates an electrical resistance between the two metals and causes them to heat up at the seam.

3.1.3. Seam welding parameters

The principle of resistance seam welding is the joule heating law where **Q** is generated depending on three basic factors as expressed in the following formula:

$$\mathbf{Q=I^2RT}$$

Where **I**, is the current passing through the metal combination, **R** is the resistance of the base metals and the contact interface, and **T** is the duration/time of current flow.

Heat required for nugget formation

Specific heat of material: 904 J/Kg°C

Density of material: 2700 Kg/m^3

Melting temperature: 660.32 °C

Each sheet thickness, t: 3mm

So, electrode thickness $=\sqrt{t}$ *5 = $\sqrt{3}$ *5 = 8.66mm

Nugget diameter (d) = $\sqrt{t}$ *4 = $\sqrt{3}$ *4 = 6.93mm

Area of nugget = $0.7853*d^2$ = 4.09e-5 m^2

Volume of nugget = Area of nugget * Sheet thickness

=4.09e-5*3e-3

=12.27e-8 m^3

Mass of nugget = Volume of nugget * Density

=12.27e-8 * 2700

= 33.129e-5 Kg

Heat required to make nugget = mass of nugget * specific heat * ΔT

= 33.129e-5 * 904 * 660.32

= 0.198 KJ

Thus, 0.198 KJ is required for 33.129e-5 Kg mass of nugget.

3.1.3.1. Welding current

The welding current is the most important in seam welding which determines the heat generation by power as shown in formula. The size of weld nugget increase rapidly with increasing welding current, but too high current will result in electrode deteriorations. The types of welding current applied in seam welding including the single phase alternating current (AC) that is still the most used in production, the three phase direct current (DC), the compensator discharge (CD), and the newly developed middle frequency inventor DC. Usually the root mean square (RMS) values of the welding current are used in the machine parameter settings and the process controls. It is often the tedious job of the welding engineers to find the optimized welding current and time for each individual welding application.

3.1.3.2. Welding time

The heat generation is directly proportional to the welding time. If the welding current is too low, simply increasing the welding time alone will not produce a weld. When the welding current is high enough, the size of the weld nugget increases with increasing welding time until it reaches a size similar to the electrode tip contact area. If the welding time is pronged, expulsion will occur or in the worst cases the electrode may stick the work-piece.

3.1.3.3. Welding force

The welding force influence the resistance welding process by its effect on the contact resistance at the interface and on the contact area due to deformation of materials. The work-piece must be compressed with a certain force at the weld zone to enable the passage of the current. If the welding force is too low, expulsion may occur immediately after starting the welding current due to fact that the contact resistance is too high, resulting in rapid heat generation. If the welding force is too high, the contact area will be large resulting in low current density and low contact resistance that will reduce heat generation and the size of weld nugget.

3.1.3.4. Contact resistance

The contact resistance at the weld interface is the most influential parameter related to materials. It however has highly dynamic interaction with the process parameters. All metals have rough surfaces in micro scale. When welding force increases, the contact pressure increases thereby the real contact area at the interface increases due to deformation of the rough surface. Therefore, the contact resistance at interface decreases which reduces the heat generation and the size of weld nugget. On the metal surfaces, there are also oxides, water vapor, oil, dirt and other contaminants. When the temperature increases, some of the surface contaminants (mainly water and oil based ones) will be burned off in the first couple of cycles, and the metals will also be softened at high temperatures. Thus the contact resistance generally decreases with increasing temperature. Even though the contact resistance has most significant influence only in the first couple of cycles, it has a decisive influence on the heat distribution due to the initial heat generation and distribution.

3.1.3.5. Material properties

Nearly all material properties change with temperature which adds to the dynamics of the resistance welding process. The resistivity of material influences the heat generation. The thermal conductivity and the heat capacity influence the heat transfer. In metals such as silver and copper with low resistivity and high thermal conductivity, little heat is generated even with high welding current and also quickly transferred away. They are rather difficult to weld with resistance welding. On other hand, they can be good materials for electrodes. Hardness of material also influences the contact resistance. Harder metals (with higher yield stress) will result in higher contact resistance at the same welding force due to the rough surface asperities being more difficult to deform, resulting in a smaller real contact area. Electrode materials have also been used to influence the heat balance in resistance welding, especially for joining light and non-ferrous metals.

3.1.3.6. Surface coating

Most surface coatings are applied for protection of corrosion or as a substrate for further surface treatment. These surface coatings often complicate the welding process. Special process parameter adjustments have to be made according to individual types of the surface coatings. Some surface coatings are strategically selected to bring the heat balance to the weld interface. Most of the surface coatings will be squeezed out during welding some will remain at the weld interface as braze metal.

3.1.3.7. Geometry and dimension

The geometry and dimension of the electrodes and work pieces are very important, since they influence the current density distribution and thus the results of resistance welding.

CHAPTER FOUR

3-DIMENSIONAL FINITE ELEMENT SIMULATION OF SEAM WELDING PROCESS

4.1. Introduction

Resistance seam welding is a widely used process for joining metal sheets in the automobile industry. It is also used in the manufacturing of steel roofs in relation to water tightness. In all these applications leakage is not allowed and thus it is important for reliable welding procedures to be used. The important factors for maintaining consistency and a good seam weld nugget formation are, the welding force, welding current magnitude, welding speed, electrode shape and the mode of the current being supplied.

Inseam welding, the electrodes used are in the form of rollers as shown in Fig. 5.1.A seam welding process produces a series of nuggets at the interface of the Aluminum sheets. The parts to be welded are placed between the circular electrodes, which run at a constant velocity in opposite directions and the squeeze force is applied by these electrodes. The current produces a joule heating effect at the contact of the two sheets and the weld nugget is thus formed. It is common practice in industry that the number of plates to be joined and the thickness of the sheets have a wide variation.

To achieve the optimum weld control system parameters for different thicknesses of the aluminum sheets, repeated welds are made. The finite element model (FEM) is a useful tool for simulating the thermal and mathematical behavior of the structures during welding. Solving nonlinear equations in an electro-thermo-mathematical problem in a time stepping procedure such as for resistance welding requires high computational power. Computer simulation has become an essential part of science and engineering. Digital analysis of components, in particular, is important when developing new products or optimizing designs. Today a broad spectrum of options for simulation is available; researchers use everything from basic programming languages to various high-level packages implementing advanced methods.

When considering what makes software reliable, it’s helpful to remember the goal: you want a model that accurately depicts what happens in the real world. A computer simulation environment is simply a translation of real-world physical laws into their virtual form. How much simplification takes place in the translation process helps to determine the accuracy of the resulting model. It would be ideal, then, to have a simulation environment that included the possibility to add any physical effect to your model. That is what COMSOL is all about. It's a flexible platform that allows even novice users to model all relevant physical aspects of their designs.

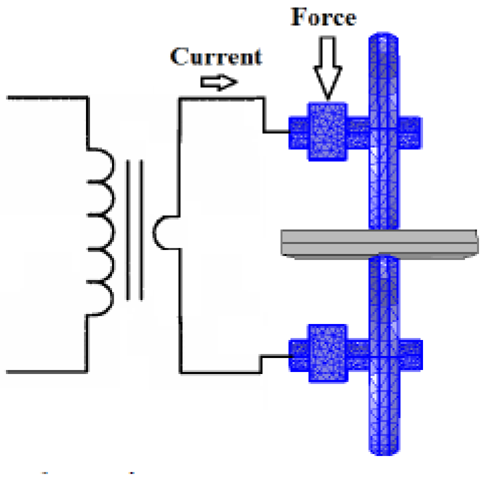


Figure 5.1 Seam welding schematic (https://www.researchgate.net/publication/285445161) Accessed on 17th December, 2020.

FEM code for solution of different problems can be developed by using a general set of subroutines provided by the software. The most popular softwares used to model the resistance welding process are ANSYS (Thakur et al., 2010), JWRAIN (Ninshu et al., 2009) and ABAQUS (Khan et al., 1999).About 90% of FEM programs are generic and use similar matrix solvers, quadrature rules and matrix assembly procedures. The seam welding problem is a three dimensional problem. A two dimensional model of a seam welding problem has been developed in order to study the effect of current on the weld nugget formation. Their two dimensional model has been developed from the axisymmetric code developed for the spot welding process. The two dimensional representation of the seam welding process can be analyzed as a transverse cross-section (2DT) or as a longitudinal cross section (2DL) as shown in Fig. 5.3.

To study the growth of the nugget in the longitudinal direction, a longitudinal model is suitable. The effect of the electrode size and shape on the overall weld can be observed by means of the transverse cross section model.

The quality of the seam weld joint is mainly dependent on the welding current, the pressure applied between the circular electrode wheels, the motor speed and the width of the welding wheels. 50 Hz thyristor controlled machines were previously used in industry, however, with the development of high powered semiconductor switches and DC-DC converter topologies, it is now possible to develop inverter drive resistance welding equipment, which can be operated at frequencies higher than the 50 Hz frequency. The advantage of using high frequencies is in relation to the reduction in the size of the welding transformer. The contact resistance at the faying surface is influenced by the electrode force. A higher pressure between the welding wheels demands a high current in order to achieve the same melting of the weld as compared to that for lower pressure settings. A slow welding speed in the seam welding process results in a wider weld because the welding material has more time to receive the heat generated by the welding current.

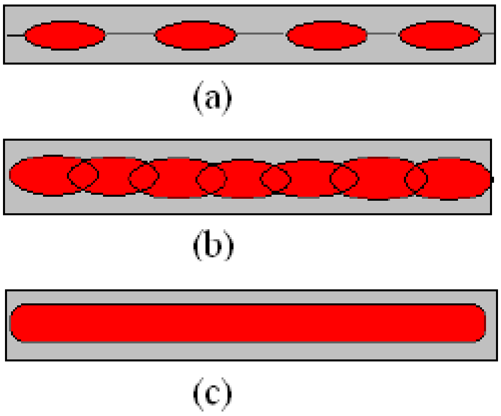


Figure 5.2 Types of seam welding joints

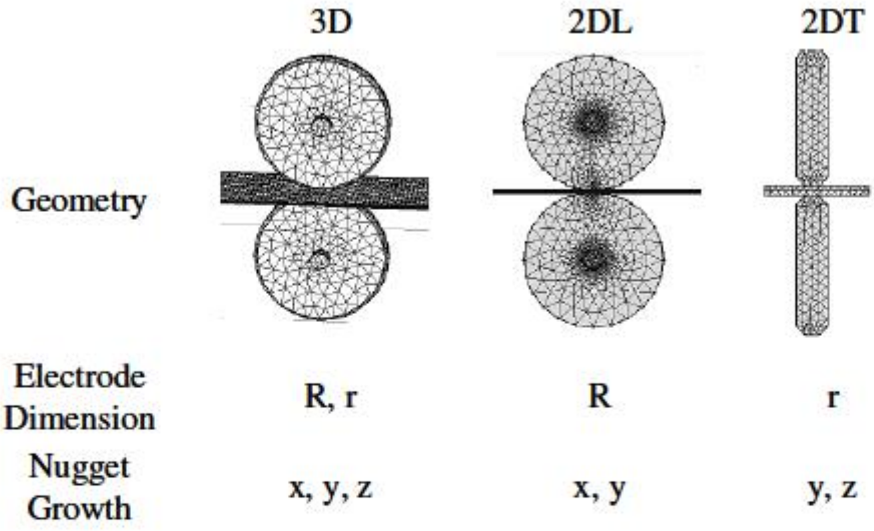


Figure 5.3 Model types (https://www.researchgate.net/publication/285445161) Accessed on 17th December, 2020.

Aluminum alloys contain strong corrosion resistance. These alloys are good low-temperature alloys. Aluminium / Aluminum alloys are sensitive to high temperatures ranging between 200°C and 250°C (392°F and 482°F). The strength of these alloys increases when exposed to subzero temperatures and the strength decreases when exposed to high temperatures.

The following datasheet provides an overview of Aluminium / Aluminum 5454 alloy.

4.2. Chemical Compositions

Table 4.1. the chemical composition of 5454 Aluminum alloys.

Element	Content (%)
Aluminium / Aluminum (Al)	96.3
Magnesium (Mg)	2.7
Chromium (Cr)	0.12
Manganese (Mn)	0.8
Iron (Fe)	0.20
Zinc (Zn)	0.14
Silicon (Sn)	0.12
Chromium (Cr)	0.10
Titanium (Ti)	0.10

Source: (https://www.azom.com/article.aspx?ArticleID=6655) Accessed on July 07, 2021

4.3. Physical Properties

Table 4.2. the physical properties of 5454 Aluminum alloys.

Properties	Metric	Imperial
Density	2.7 g/cm^3	0.0975lb/in^3
Melting point	607°C	1125°F

Source: (https://www.azom.com/article.aspx?ArticleID=6655) Accessed on July 07, 2021

4.4. Mechanical Properties

Table 2.3. the mechanical properties of 5454 Aluminum alloys.

Properties	Metric	Imperial
Elastic modulus	75GPa	10877ksi
Poisson's ratio	0.33	0.33

Source: (https://www.azom.com/article.aspx?ArticleID=6655) Accessed on July 07, 2021

4.5. Thermal Properties

Table 4.4. the thermal properties of 5454 Aluminum alloys.

Table 4.4. the thermal properties of 5454 Aluminum alloys.

Properties		Conditions	
		T (ºC)	Treatment
Thermal conductivity	134 (W/mK)	25	All

Source: (https://www.azom.com/article.aspx?ArticleID=6655) Accessed on July 07, 2021

CHAPTER FIVE

Simulation Results and Discussion

5.1. Simulation Model

Two and three dimensional models for the seam welding process have been developed and analyzed by using COMSOL Multi-physics software. The COMSOL user interface reduces the clutter and redundant tasks, so that attention can be focused on the substance of the design studies, resulting in an increased productivity. COMSOL Multi- physics provides a flexible platform which will even enable a new user to model the different physics involved in the design. The platform is also very adaptable and changing or adding new physics is very easy. It is also possible to readily introduce custom solver sequences and parameterized geometry into the design. Another advantage associated with the use of COMSOL Multi- physics is in relation to the built-in functions that contain a set of predefined routines such as analytical, step, ramp functions etc., which can be useful in applying the input to the system, for example, applying a current to the electrodes. The developed models involve three physics namely, electrical, heat transfer and structural mechanics. The structural mechanics module imposes a force, rotational speed and fixed boundary constrains on the modeled geometry. The electrical module controls the application of the required current to the electrodes. The electrode, work pieces and contact region are assumed to behave elasto-plastically. The heat transfer module governs the joule heat distribution as given in (1)

$$\rho Cp \partial T/\partial t = k\Delta T + Q_T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where CP, ρ, k, QT are the specific heat, density, thermal conductivity, and heat source term per unit volume.

5.2. Material Properties

The materials involved in seam welding, namely the copper electrodes and the aluminum sheets are subjected to a wide range of temperatures. Therefore, temperature dependent material properties are considered in the simulation. The electromechanical properties such as thermal conductivity, coefficient of thermal expansion, specific heat, and resistivity are taken as temperature dependents.

5.3. Structure of geometry and boundary conditions

The finite element modeling approach was used to simulate the coupled thermal effects during seam welding process. In this approach, first the temperature distribution in welding process is determined via steady state heat flow analysis and then using the result of thermal analysis as input, the structural model components, the mechanical elasticity and plastic characteristics such as stress and deformation in weldment is discussed. The work-piece is clamping together and moveable.

5.4. Mesh model

The basic concept is the subdivision of the mathematical model into non-overlapping components called elements. The response of each element is expressed by unknown functions and the response of the whole model is then considered to be approximated by assembling the collection of all elements. Therefore, Finite-element requires discretization of the domain. We do that by meshing it, so that, we would have nodal representation of the geometry and functional representation of the domain. And, FEM is heavily meshing dependent. Refining is needed for two main reasons. One geometrical and other is mathematical.

A three dimensional model of free triangular element was used to mesh the sheet metal. The work-piece was divided into small finite elements and the complete mesh consists of 2656 domain elements, 1960 boundary elements, and 236 edge elements. The convergence is usually achieved by with the tolerance factor of 1E-6.

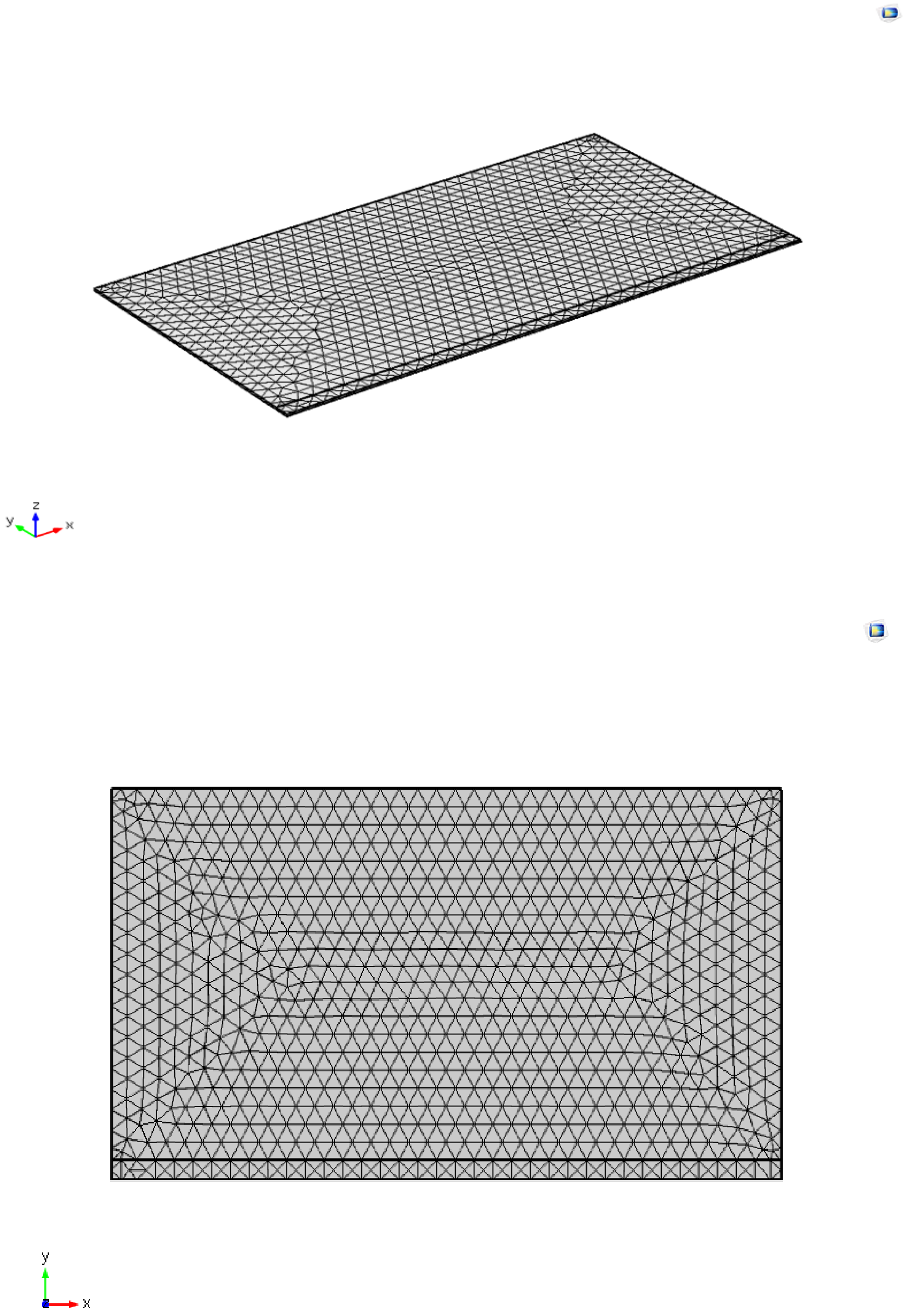
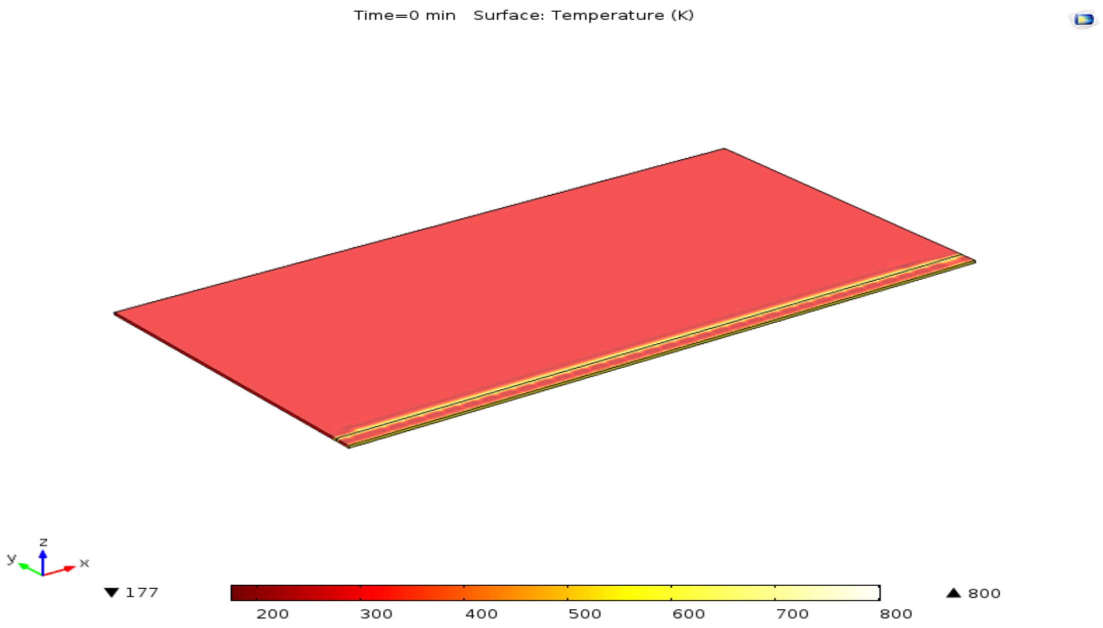


Figure 5.4 mesh work piece used for present study.

The modeling and simulation outcome details of resistance seam welding process for AA5454 sheet metal was described before. The results and their associated discussions obtained from both thermal and structural analysis in this study at different welding conditions are presented in this chapter. The results displayed in this chapter were attained through systematic and structured way to get better understanding of thermal and mathematical performance in welding process.

5.5. Thermal (temperature and heat flux) analysis

During seam welding process the heat induced due to plastic deformation leads to enhance the temperature of the work-piece. The developed model can be utilized to predict this enhance temperature distribution under various welding conditions. The results were calculated through outcome of the temperature distribution on the surface.



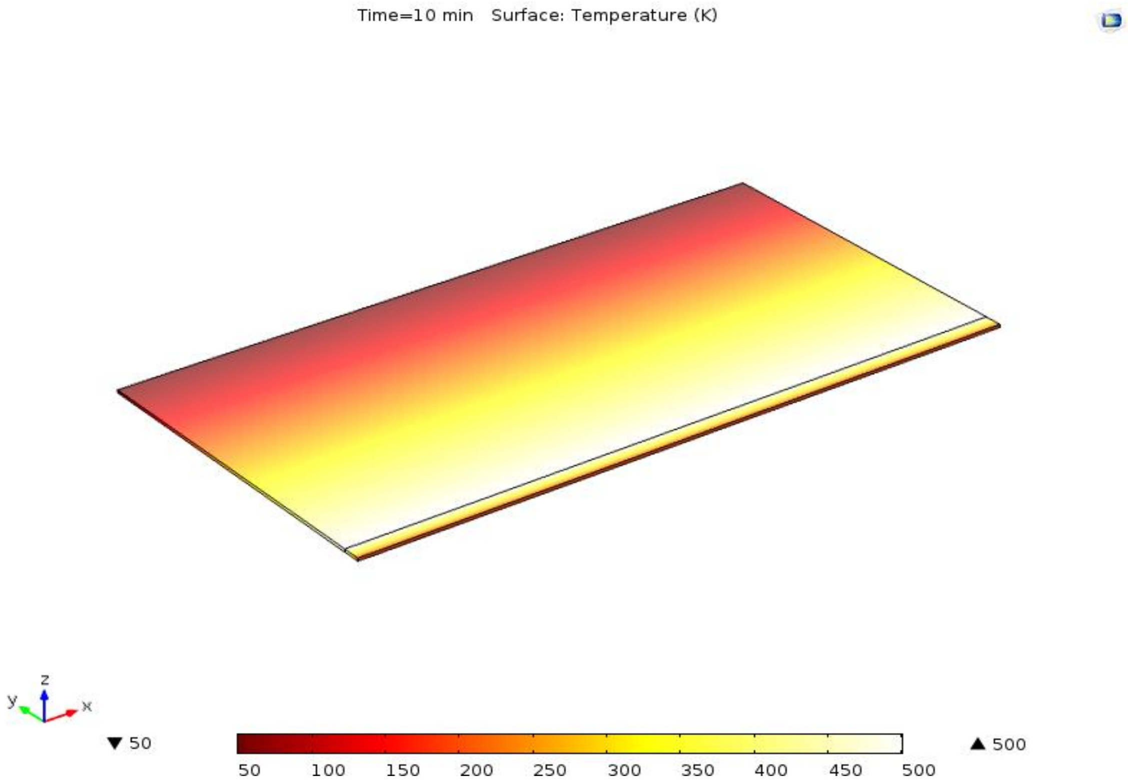


Figure 5.5 the distribution of temperature in work-piece

The above simulation reveal that the simulation of distribution of welding temperature on the surface of the work-piece. At the instant of starting the welding progress (when time is zero second) the temperature is appeared at the line of the welding as shown in fig.5.5 **(a).** As welding operation continuous (when the time is 10 minute) the welding temperature was started to dissipate to the other else surface of our work-piece as shown in fig.5.5 **(b)**

The following simulation again reveals that the dissipation of heat flux and temperature distribution in work-piece contour and it’s result in graphic form.

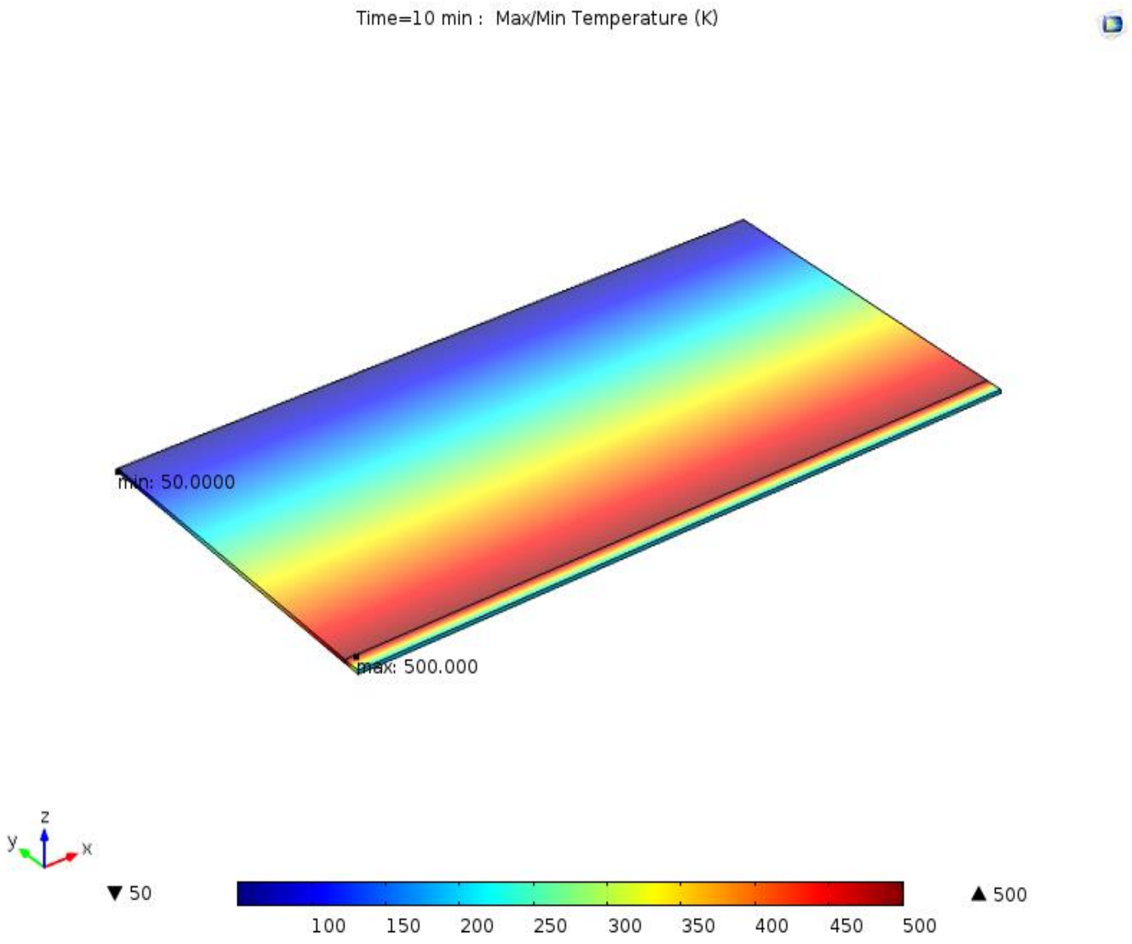
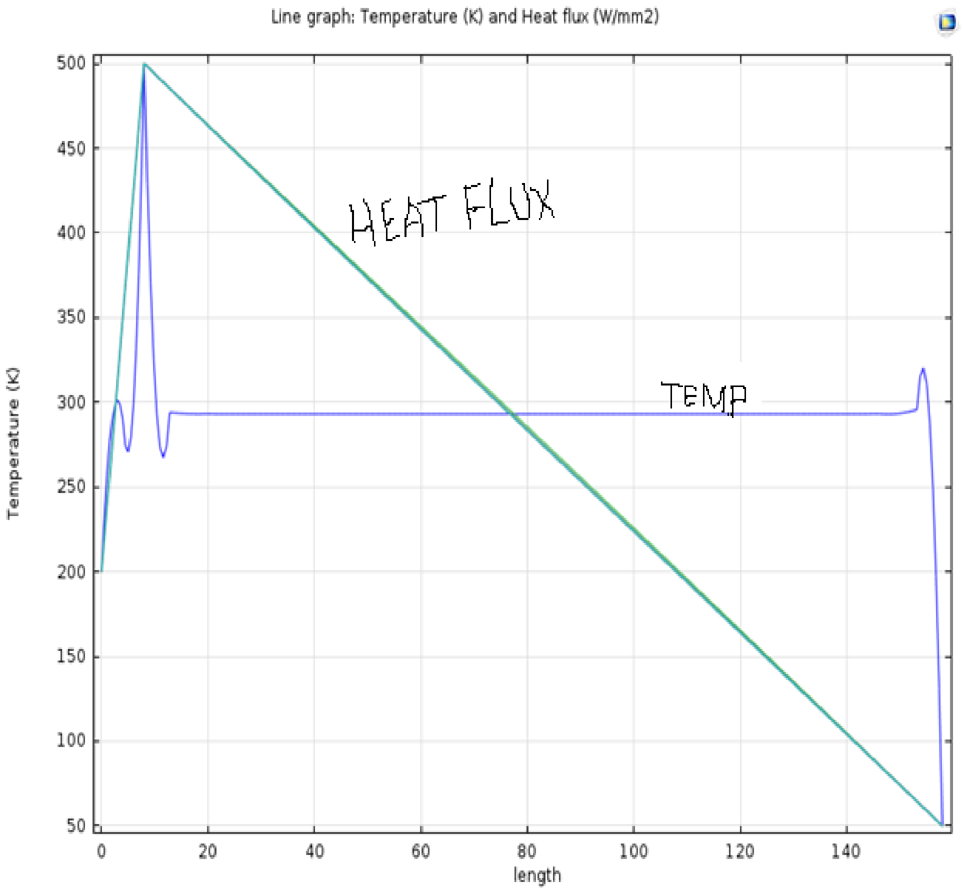


Figure 5.6 Heat flux and temperature indication during welding



If the temperature of the welding supplied to the work-piece is too high it can deteriorate our sheet metals those welded together. From this gaph the welding temperature for our case is 500^0K and the green color represnts the heat flux and the blue black color represents the temperature distribution in our work-piece. For instance, thermal conduction in a rigid solid object is governed by the law of conservation of thermal energy. The rate of change of thermal energy equals the rate at which heat is supplied by sources in the domain plus heat flux through the boundary. From empirical observations, the heat flux in solids is proportional to the temperature gradient and is directed from hotter areas to colder areas.

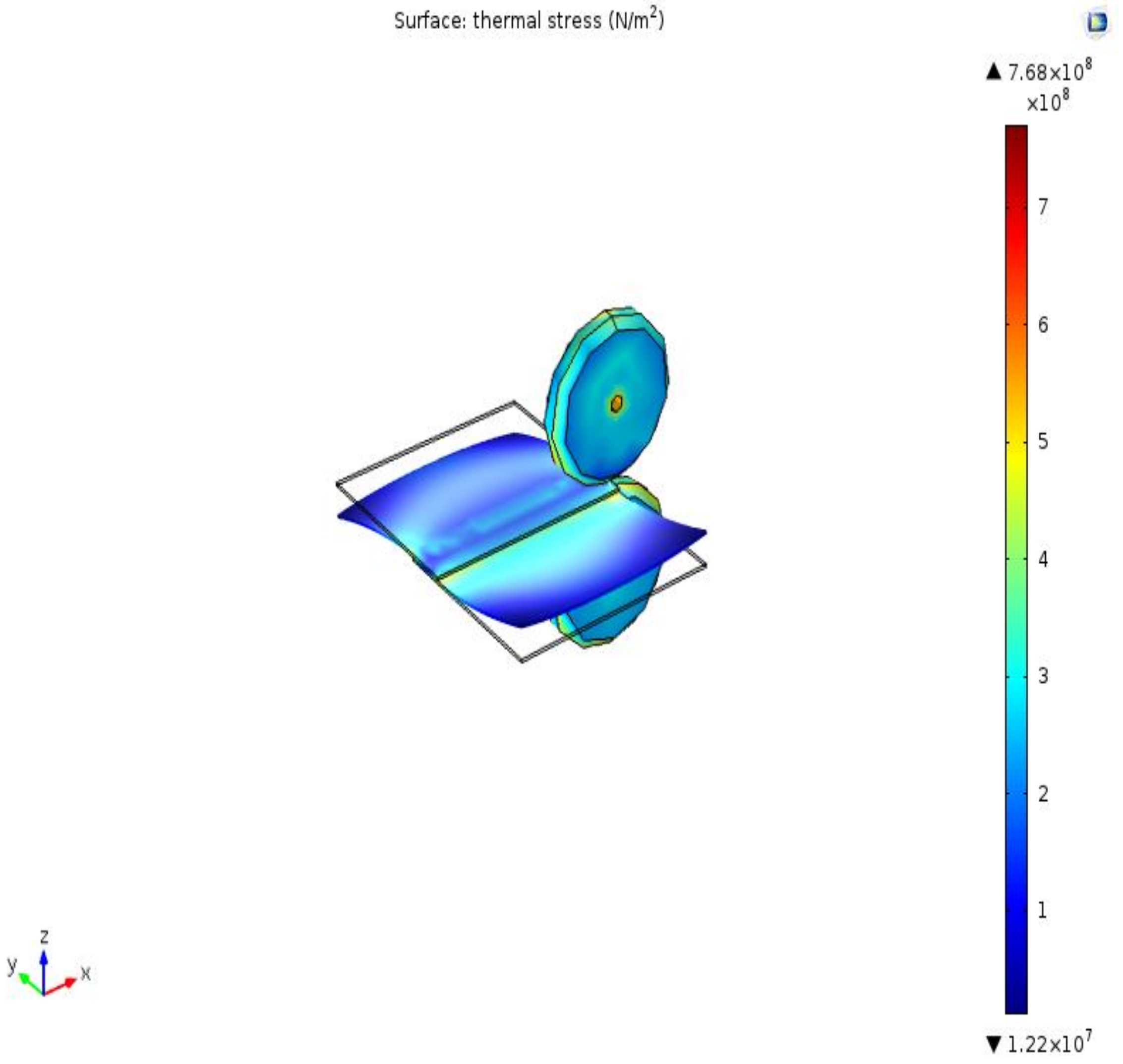
The governing equation to do this resistance welding techniques is given as:

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p \mathbf{u}.\nabla T = \nabla.(k\nabla T) + Q \text{ --(2)}$$

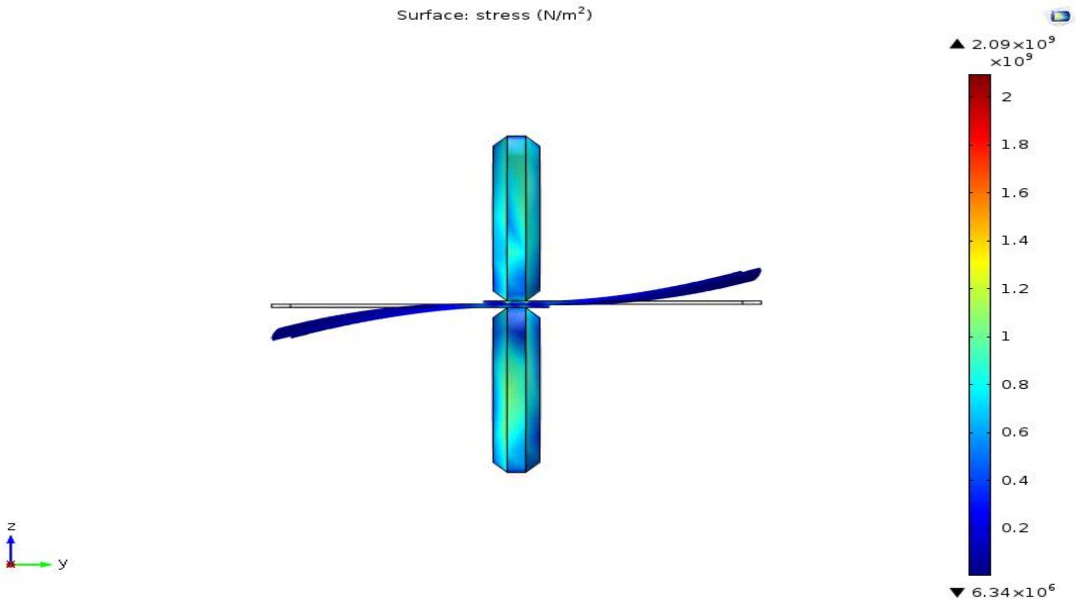
Where, ρ= material (work-piece) density, c_p=specific heat capacity, ∇T = temperature gradient, Q= heat source per unit volume, k= the heat conductivity, U= the velocity vector of the tool. The term $\rho c_p \mathbf{u} \cdot \nabla T$ represents convective term that appears together with the conductive term as a result of using coordinate system on the welding tool.

5.6. Thermal stress analysis

The Thermal Stress multiphysics interface combines a Solid Mechanics interface with a Heat Transfer in Solids interface. The coupling occurs on the domain level, where the temperature from the Heat Transfer interface acts as a thermal load for the Solid mechanic's interface, causing thermal expansion. A Heat Transfer in Solids model is active by default on all domains. All functionality for including other domain types is also available. The temperature equation defined in solid domains corresponds to the differential form of the Fourier's law that may contain additional contributions.



(a)



(b)

Figure 5.7 The effect of thermal stress analysis.

The above figures indicate the effects thermal stress in x, y, z axis on (a) and y, z axis on (b) of the work-piece while we proceeding the resistance welding techniques.

The dependence of **thermal expansion** on temperature, substance, and length is summarized in the equation:

$\Delta L = \alpha L \Delta T$ --- (3)

Where ΔL is the change in length L, ΔT is the change in temperature, and α is the coefficient of expansion, which varies slightly with temperature.

5.7. Mathematical and numerical modeling

Models describe our beliefs about how the world functions. In mathematical modeling we translate those beliefs into the language of mathematics. This has many advantages

1. Mathematics is a very precise language. This helps us to formulate ideas and identify underlying assumptions.

2. Mathematics is a concise language, with well-defined rules for manipulations.

3. All the results that mathematicians have proved over hundreds of years are at our disposal.

4. Computers can be used to perform numerical calculations.

There is a large element of compromise in mathematical modeling. The majority of interacting systems in the real world are far too complicated to model in their entirety. Hence the first level of compromise is to identify the most important parts of the system. These will be included in the model; the rest will be excluded. The second level of compromise concerns the amount of mathematical manipulation which is worthwhile. Although mathematics has the potential to prove general results, these results depend critically on the form of equations used. Small changes in the structure of equations may require enormous changes in the mathematical methods. Using computers to handle the model equations may never lead to elegant results, but it is much more robust against alterations.

What objectives can modeling achieve? Mathematical modeling can be used for a number of different reasons. How well any particular objective is achieved depends on both the state of knowledge about a system and how well the modeling is done. Examples of the range of objectives are:

1. Developing scientific understanding- through quantitative expression of current knowledge of a system (as well as displaying what we know, this may also show up what we do not know);

2. Test the effect of changes in a system;

The processes taking part in the considered system are a complex of interrelated electric, thermal and physicochemical phenomena. The present investigation is based on the analysis of coupled electric and thermal field distributions, studied for several successive time stages, corresponding to the change of contact area, related contact resistance, and reduction of the released power, occurring simultaneously with the creation of contact between the welded work-pieces.

The mathematical formulation of the problem includes determination of the governing equations, boundary conditions, and the field sources corresponding to changes of the contact area dimensions, contact resistance, and released power, depending on the welding time. The modeling of the processes in the considered system is related to determination of coupled field distribution - AC electric field and transient thermal field.

The governing equations for the electric field are:

$J = \gamma E + Je$……………………………………………………………………….…(4)

$E = -\nabla V$

Where **E** is the electric field strength, **J** is the current density, *V* is the scalar electric potential, and γ is the electric conductivity.

In order to take into account the specific changes in the contactarea during the welding process, resulting in changes of the material state and properties, overlapping dimensions, and released power, a corresponding contact resistance has been introduced in the numerical modeling. The layer impedance and relevant overlapping are specified on the basis of preliminary experimental investigations (Darzhanova et al., 2015) and boundary conditions have been introduced accordingly in the model with the given equations below (COMSOL M ultiphysics User's guide, 2015) (CMUG, 2015).

$n.J1 = \gamma s(V1 - V2)/ds$ $n.J2 = \gamma s(V2 - V1)/ds$…………………………………………...(5)

The indices 1 and 2 refer to the two sides of the boundary, γ_s is the contact material conductivity, and d_s is layer thickness (overlapping).

The Ohmic losses determined in the electric field modeling

$Q = J^2/\gamma$,………………………………………………………………………...(6)

are used in the coupled electric-thermal field modeling as a field source in the thermal field analysis.

The transient thermal field is modeled by the equation:

$\rho C \partial T/\partial t + \nabla.(-k\nabla T) = Q$………………………………………………………………...(7)

Where *T* is the temperature, *k* is the thermal conductivity, ρ is the mass density, *C* is the heat capacity at constant pressure, and *Q* is the heat source.

In the field modeling both convection and radiation boundary conditions have been taking into account:

$-k\partial T/\partial n=h(T-Tamb)+\epsilon\sigma SB(T4-T4amb)$…………………………………………….(8)

Where T_{amb} is the temperature far away from the modeled domain, h is the convection heat transfer coefficient, σ_{SB} is the Stefan-Boltzmann constant ($5,67.10^{-8}Wm^{-2}K^{-4}$), and ε is emissivity.

Determination of the field sources, corresponding to the contact area, contact resistance, and released power is based on the previous experimental (Darzhanova et al., 2015) and theoretical (Darzhanova et al., 2017) investigations. Although the theoretical approach (based on electrical analogy of heat transfer) was quite different from that used in the present work, the main assumptions about the dimensions of the affected contact region, corresponding contact resistance, and power change during the welding stages are accepted in the present study.

The driving source thermal power can be calculated as:

$P(t)=RCi^2(t)$,………………………………………………………………………….(9)

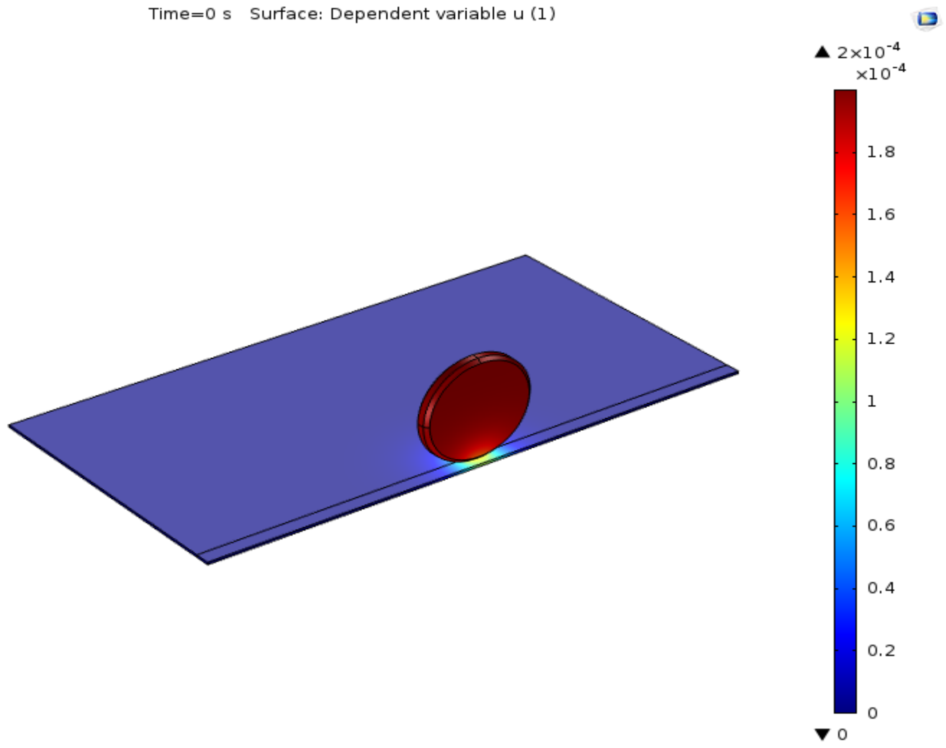
Where $i(t)$ is the source current and R_C is the contact resistance between the two pressed samples. The average initial value for the contact resistance R_C was obtained via preliminary experimental investigations, but, as was noted, because of the material softening, followed by melting and enlarging of the contact zone, this resistance changes significantly.

The Coefficient Form PDE provides a general interface for specifying and solving many well-known PDEs in the coefficient form. Many PDEs originating from physics interfaces and other fields can be cast into a generic form containing derivatives up to second order in both time and space but no mixed derivatives. In COMSOL Multiphysics, you can define a PDE of this type by specifying coefficients for the derivatives of different orders. This results in a coefficient form PDE, which for one dependent variable u reads:

$$e_a\frac{\partial^2 u}{\partial t^2}+d_a\frac{\partial u}{\partial t}+\nabla\cdot(-c\nabla u-\alpha u+\gamma)+\beta\cdot\nabla u+au=f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

The PDE formulations in COMSOL Multiphysics can model a variety of problems, but this guide, as well as the interface, uses descriptive names for the coefficients that fall within the realm of continuum mechanics and mass transfer. For the coefficient form PDE:

- e_a is the mass coefficient.
- d_a is a damping coefficient or mass coefficient.
- c is the diffusion coefficient.
- α is the conservative flux convection coefficient.
- β is the convection coefficient.
- a is the absorption coefficient.
- γ is the conservative flux source term.
- f is the source term.



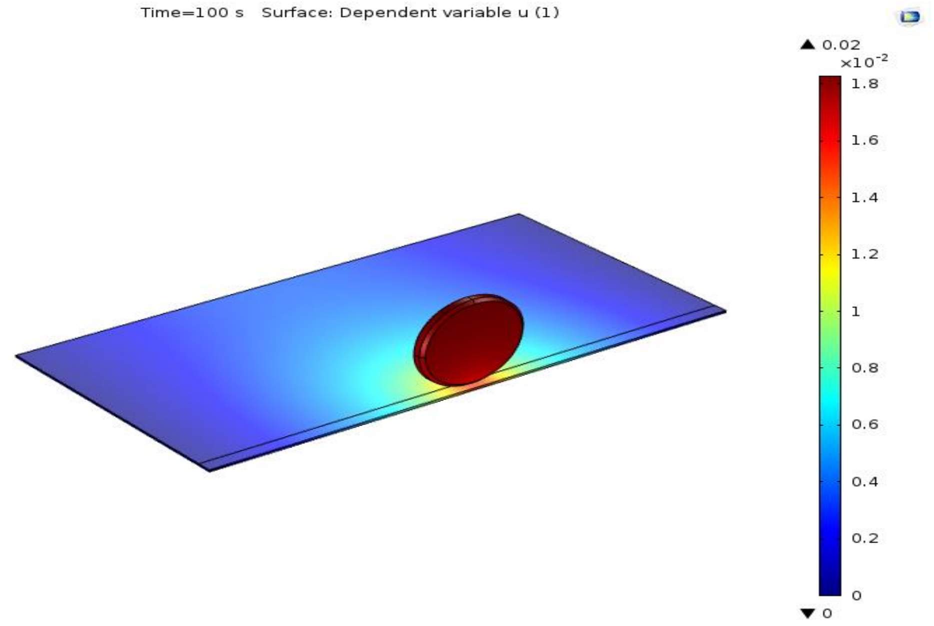
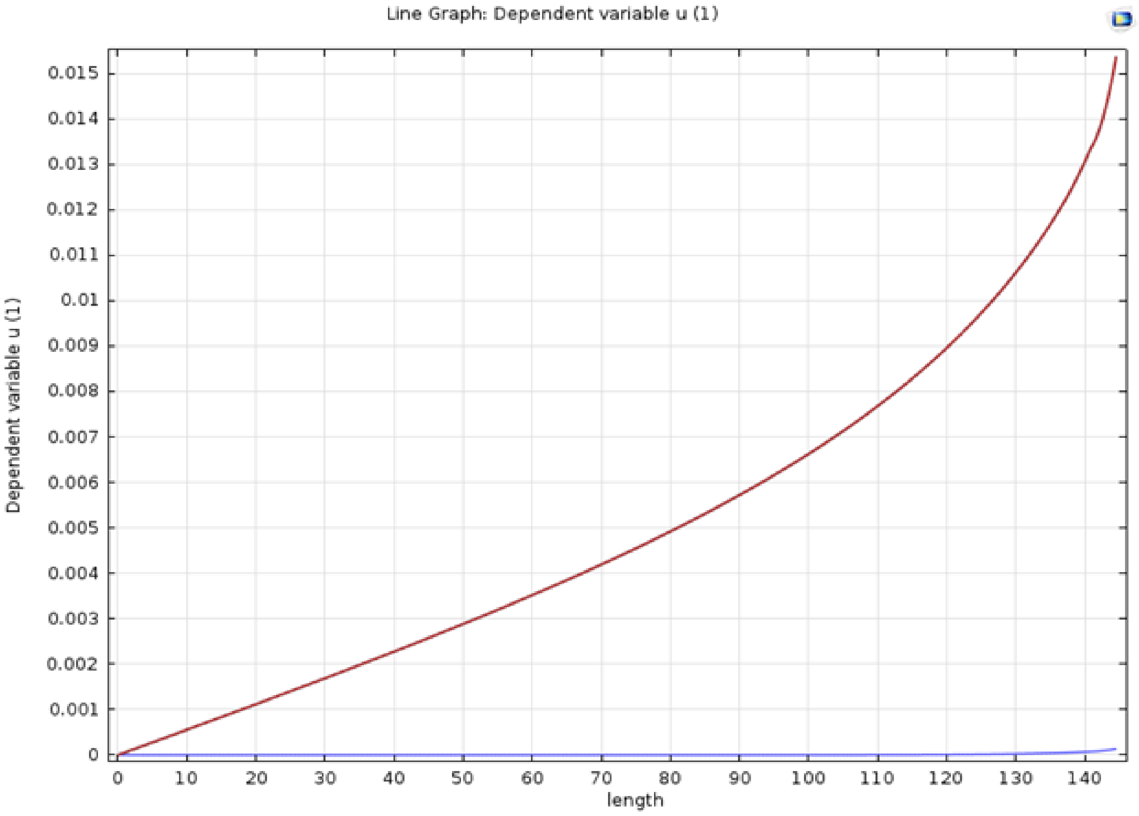


Figure 5.8 the simulation represent accumulation of heat



Partial differential equations are ubiquitous in mathematically-oriented scientific fields, such as physics and engineering. For instance, they are foundational in the modern scientific understanding of sound, heat, diffusion, electrostatics, electrodynamics, fluid dynamics, elasticity, general relativity, and quantum mechanics.

CONCLUSION

In this study the resistance seam welding of three dimensional modeling of thermal and mathematical was developed to investigate the heat transfer process for AA5454 alloys using finite element method through commercially available software which is COMSOL 5.0 multiphysics.

The study is mainly focused on the variation temperature over the work-piece which is made of above mentioned material in this welding technique. The effect of resistance seam welding parameters such as temperature distribution, thermal stress, and heat flux where studied. The result on temperature distribution shows that how heat is dissipated from the line of welding to the other surface of the working sheet metal. While the technique is done on resistance seam welding the thermal stress affect the shape of sheet metals as shown in the study. The other study shows that what heat flux looks like in this resistance seam welding which is difficult to investigate on experimental work rather than using comsol software multiphysics.

Mathematical models are an important component of the final "complete model" of a system which is actually a collection of conceptual, physical, mathematical, visualization, and possibly statistical sub-models. After developing a conceptual model of a physical system it is natural to develop a mathematical model that will allow one to estimate the quantitative behavior of the system. Quantitative results from mathematical models can easily be compared with observational data to identify a model's strengths and weaknesses.

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