NUST COLLEGE OF
ELECTRICAL AND MECHANICAL ENGINEERING

DE-41 (DME)

Design and Development of FSW Process Parameters for Dissimilar Alloys

A PROJECT REPORT

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This process has our interest and many areas to explore in research areas and it will surely help us in future studies.

ABSTRACT

Friction stir welding (FSW) is a solid-state joining process widely used for joining similar and dissimilar materials and achieving high-quality welds. In this project, the aim was to investigate the effects of process parameters on the weld quality and mechanical properties of FSW joint for two different grades Aluminum. The objective of this project was to investigate the feasibility of friction stir welding (FSW) on a milling machine and evaluate the quality of the welded joint through simulation and testing. The FSW process was simulated using finite element analysis (FEA) to predict the temperature distribution, residual stresses, and deformation during the welding process. The mechanical properties, including tensile strength and hardness, were evaluated through standard testing methods. The results demonstrated the successful fabrication of aluminum-to-steel joints using the FSW process. The welds exhibited a fine-grained microstructure and high joint strength, indicating the feasibility of using FSW for such dissimilar material combinations. This study provides valuable insights into the FSW process for two different grades Aluminum joints and contributes to the development of reliable welding techniques for similar applications.

Table of Contents

List of Tables

List of Figures

Chapter 1

INTRODUCTION

1.1 Background and Motivation:

Friction stir welding (FSW) has emerged as a promising technique for joining dissimilar alloys, driven by the growing demand for lightweight and durable materials in various industries. Dissimilar alloy welding poses unique challenges due to differences in composition, thermal properties, and mechanical behavior. FSW offers advantages over traditional welding methods, including reduced defects, improved mechanical properties, and the ability to weld heat-sensitive materials.

1.2 Problem Statement:

The design and development of optimal FSW process parameters for dissimilar alloys present a significant research challenge. The existing literature lacks comprehensive guidelines tailored to specific alloy combinations, hindering the efficient and reliable implementation of FSW in dissimilar alloy welding applications. The design and development of optimal FSW process parameters for dissimilar alloys face inherent challenges, exacerbated by the unavailability of dedicated FSW machines and specialized tools. The lack of access to a dedicated FSW machine limits the experimental setup, requiring alternative methods to perform the FSW process. Additionally, the unavailability of the required FSW tools necessitates the manual machining of the tools to meet the specific welding requirements. These constraints impose limitations on the scale and precision of the welding experiments, impacting the ability to achieve desired weld quality and mechanical properties in the dissimilar alloy joints. Addressing these challenges becomes crucial to explore the feasibility of conducting FSW on a milling machine with custom-made tools and optimize the process parameters for dissimilar alloy welding.

1.3 Objectives:

The objectives of this study are as follows:

- Simulation of FSW
- FSW of two dissimilar alloys
- Tensile strength testing of the weldment

1.4 Scope and Limitations:

This project focuses on the design and development of FSW process parameters for dissimilar alloys, specifically aluminum-1050 and aluminum-2024. Due to resource limitations, the actual welding experiments will be conducted on a milling machine instead of a dedicated FSW machine. Furthermore, the required FSW tool will be machined manually to suit the experimental setup. The study aims to demonstrate the feasibility and effectiveness of the selected alloy combination and experimental approach in achieving high-quality welds and understanding the underlying mechanisms of dissimilar alloy welding.

1.5 Friction Stir Welding (FSW) Overview:

Friction stir welding (FSW) is a solid-state welding technique that offers several advantages over conventional fusion welding methods. It was first developed in the early 1990s by The Welding Institute (TWI) and has since gained significant attention in various industries, including aerospace, automotive, and marine.

FSW involves the joining of materials through the application of frictional heat and mechanical deformation. Unlike traditional welding techniques that rely on melting and solidification, FSW operates in the solid-state, resulting in numerous benefits such as reduced defects, minimal distortion, improved mechanical properties, and enhanced joint integrity.

The FSW process utilizes a specially designed rotating tool that is plunged into the interface of the workpieces to be joined. The rotating tool generates frictional heat, softening the material without reaching its melting point. As the tool moves along the joint, it mechanically stirs the softened material, creating a plasticized zone known as the "stir zone."

The stir zone undergoes severe plastic deformation, leading to dynamic recrystallization and the formation of a refined and homogeneous microstructure. Additionally, the material is thoroughly mixed, ensuring excellent metallurgical bonding without the formation of solidification defects like porosity or liquation.

FSW offers several advantages over traditional welding techniques, including the ability to join dissimilar alloys with different melting points, excellent weld strength and toughness, reduced heat-affected zone (HAZ) size, and improved corrosion resistance. These advantages make FSW an attractive option for various applications, including lightweight structures, aerospace components, automotive body panels, and shipbuilding.

1.6 FSW Tool Components

Tool Shoulder:

The surface of tool in contact with the work piece surface.

Tool Pin:

The pin of the tool is plunged in the work piece. It causes the flow of the material to move from front to back horizontally as well as from top to bottom vertically. Commonly 17 used profiles of the pic are cylindrical and conical. The pins can also be threaded or have step spiral design. In addition, the flow can be influenced by putting flats or flutes.

Advancing Side:

This is the side in which the tool pin surface rotation has the same vectorial direction as the traverse direction of tool. The pin surface opposes the flow of material in a backward direction.

Retreating Side:

This is the side in which the tool pin surface rotation has opposite vectorial direction as the traverse direction of tool. The material flow is easier on this side of the tool pin as the pin surface helps the material flow backward.

Leading Edge:

This is the front side of the tool that allows the tool shoulder to meet work piece material. The tool shoulder sweeps the top layer sideways toward the retreating side and this can have implication of the overall material flow and weld nugget appearance.

Trailing Edge:

This is the back side of the tool. It keeps on inducing heat on workpiece even after pin has crossed that region. In effects the microstructure of the workpiece after the deformation.

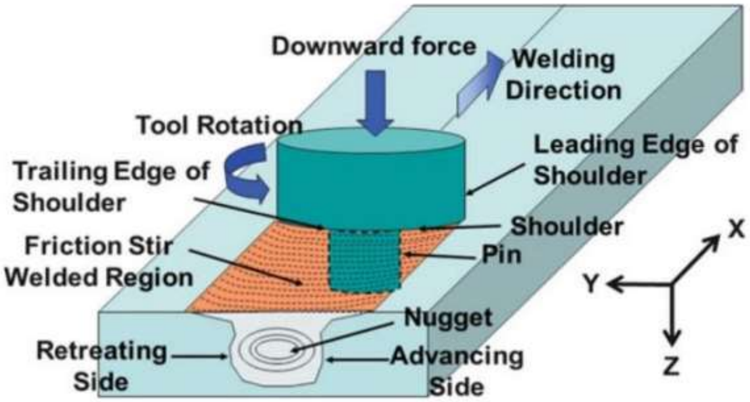


Figure 1-1: FSW Process

1.7 FSW Process Parameters

Rotation Rate:

The rate at which the tool rotates. It contributes majorly to the heat input and material flow.

Tool Traverse Speed:

The travel speed of the tool. This impacts the overall thermal cycle.

Work Angle:

The angle measured between the spindle shaft and the work piece normal in the z–y plane is known as work angle. It has application in robotic machines due to its stiffness factor.

Plunge Rate:

The rate at which the tool is inserted in the work piece. It controls the rate of heat build-up and force during the start of the process.

Plunge Depth:

The programmed depth of the pin bottom from the top surface of work piece. For position-controlled runs, this is a critical number.

Plunge Force:

It is the vertical force applied on the tool when the shoulder meets the top surface of a work piece.

1.8 Zones in FSW

Heat Affected Zone (HAZ):

The region that lies closer to the weld center. The microstructure and the mechanical properties change due to the thermal cycle. However, no plastic deformation occurred in this area.

Thermo-Mechanically Affected Zone (TMAZ):

Friction stir welding tool has plastically deformed material in this region. The thermal cycle has also affected the material. In the case of aluminum, it is possible to get significant plastic strain without recrystallization in this region. The recrystallized zone and deformed zones can be easily distinguished.

Weld Nugget:

The fully recrystallized area occupied by the tool pin.it is also referred to as stir zone.

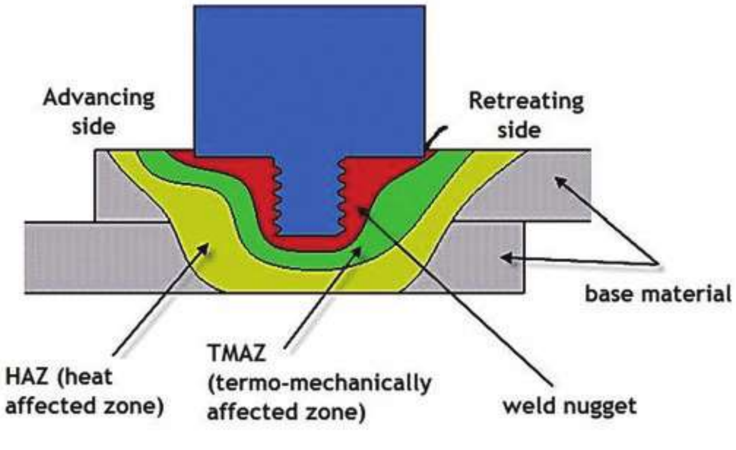


Figure 1-2: Zones in FSW

1.9 Materials Weldable by FSW

Friction Stir Welding (FSW) has been developed and optimized for joining various types of metals and metal combinations. The process has shown success in welding the following materials:

- **Aluminum Alloys:** FSW has been extensively used for joining different series of aluminum alloys, including the 2000 series (Al-Cu), 5000 series (Al-Mg), 6000 series (Al-Mg-Si), 7000 series (Al-Zn), and 8000 series (Al-Li). The process has been applied to both wrought and extruded alloys, as well as cast to cast and cast to extruded combinations. Notable companies such as Airbus and Boeing have adopted FSW for various aerospace applications, including the construction of aircraft fuselage panels and fuel tanks.
- **Copper and its Alloys:** FSW has also been employed for welding copper and its alloys, expanding the applicability of the process to non-ferrous materials. Companies like Tesla have utilized FSW for joining copper components in their electric vehicle battery systems.
- **Titanium and its Alloys:** FSW has demonstrated promising results in joining titanium and its alloys, offering an alternative to traditional welding methods for these materials. Companies in the aerospace and defense industries, such as Lockheed Martin, have utilized FSW for titanium component fabrication.
- **Magnesium Alloy and Magnesium to Aluminum:** FSW has been utilized for welding magnesium alloys, as well as joining magnesium to aluminum, opening possibilities for lightweight material combinations. Companies like BMW have incorporated FSW in the production of lightweight magnesium components for automotive applications.
- **Other Metals and Composites:** FSW has been explored for welding other materials, including zinc, metal matrix composites (MMCs) based on aluminum, mild steel, and even plastics. Various research and development projects in collaboration with companies like General Electric and Ford have investigated the application of FSW in joining dissimilar materials for specific industrial applications.

The successful application of FSW to these materials highlights the versatility and potential of the process for joining dissimilar alloys. It has gained significant attention and adoption in industries such as aerospace, automotive, and marine due to its advantages in producing high-quality, defect-free welds.

1.10 Dissimilar Alloy Welding:

Dissimilar alloy welding involves the joining of two or more different alloys, which may have distinct compositions, microstructures, and mechanical properties. This welding technique plays a crucial role in various industries where the combination of dissimilar materials is required to achieve specific performance characteristics.

Dissimilar alloy welding presents unique challenges compared to welding similar alloys. The differences in melting points, thermal expansion coefficients, and chemical compositions can lead to issues such as hot cracking, formation of brittle intermetallic compounds, and significant distortion. Therefore, it is essential to carefully consider the selection of welding processes and parameters to ensure the formation of strong and durable joints.

Friction stir welding (FSW) has shown great potential in dissimilar alloy welding due to its solid-state nature and ability to overcome many of the challenges associated with fusion welding. FSW enables the joining of dissimilar alloys with varying melting points and provides excellent control overheat input, minimizing the HAZ size and preserving the desirable mechanical properties of the parent materials.

The success of dissimilar alloy welding using FSW relies on understanding the specific material combinations and their compatibility. It is crucial to consider factors such as thermal properties, alloying elements, solid solubility limits, and phase transformations during the welding process. Additionally, the choice of tool material, geometry, and process parameters such as rotational speed, traverse speed, and axial force play a significant role in achieving high-quality dissimilar alloy welds.

Extensive research has been conducted on dissimilar alloy welding using FSW, focusing on different alloy combinations such as aluminum-steel, aluminum-titanium, and magnesium-aluminum. These studies have investigated the effects of process parameters on joint properties, microstructural evolution, and intermetallic compound formation. The insights gained from these studies provide valuable guidance for designing the FSW process parameters for dissimilar alloy welding, ensuring successful and reliable joining of different alloys with enhanced mechanical properties.

By reviewing the literature on dissimilar alloy welding, the project aims to consolidate the existing knowledge and contribute to the development of guidelines for FSW process parameters specific to the selected aluminum-1050 and aluminum-2024 dissimilar alloy combination. This research will facilitate the effective and efficient joining of dissimilar alloys, opening new possibilities for lightweight and durable material combinations in various industrial applications.

1.10.1 Challenges and Considerations:

Dissimilar alloy welding using friction stir welding (FSW) poses unique challenges and considerations, especially when the selected alloys have significant differences in their properties. In this project, the unavailability of desired alloy pairs has resulted in the selection of aluminum-1050 and aluminum-2024, which are not ideal for dissimilar welding due to their differences in composition, microstructure, and mechanical properties. Despite this constraint, the project aims to explore the challenges and considerations associated with dissimilar alloy welding using FSW.

1. **Material Compatibility:** The selected aluminum-1050 and aluminum-2024 alloys have different compositions, which may affect their compatibility during welding. The dissimilarity in their microstructures and mechanical properties could lead to challenges such as cracking, intermetallic compound formation, and compromised joint strength. Understanding the material compatibility is crucial to minimize these issues.
2. **Thermal Properties:** Dissimilar alloys often exhibit variations in their thermal conductivity, thermal expansion coefficients, and melting points. These differences can result in uneven heat distribution, distortion, and residual stresses during FSW. Considering the thermal properties of the selected alloys becomes essential to control the heat input and prevent detrimental effects on the weld quality.

3. **Intermetallic Compound Formation:** The combination of aluminum-1050 and aluminum-2024 is prone to the formation of brittle intermetallic compounds at the weld interface. Intermetallic compounds can significantly impact the joint's mechanical properties and increase the risk of premature failure. Mitigating intermetallic compound formation is a critical consideration during the welding process.
4. **Tool Selection and Machining:** The unavailability of specific FSW tools suitable for dissimilar alloy welding poses a challenge. In this project, the required FSW tool was machined manually due to the limitations in tool availability. The tool material, geometry, and design must be carefully considered to withstand the high temperatures and forces encountered during FSW.
5. **Process Parameters Optimization:** Optimizing the process parameters is essential to achieve successful dissimilar alloy welds. However, due to the limitations in the selected alloy combination, the optimization process may be more challenging. Parameters such as rotational speed, traverse speed, axial force, and tool tilt angle must be carefully adjusted to ensure adequate material mixing, plastic deformation, and consolidation, despite the differences in the alloy properties.
6. **Microstructural Analysis:** Analyzing the microstructure of the welded joints is crucial to assessing their quality and mechanical properties. Microstructural analysis techniques, such as optical microscopy, electron microscopy, and X-ray diffraction, will provide insights into the grain structure, phase transformations, and intermetallic compound formation in the welded zones.

By acknowledging these challenges and considerations, this project aims to address the specific limitations arising from the unavailability of desired alloy pairs. The findings will contribute to understanding the feasibility and potential issues associated with dissimilar alloy welding using the selected aluminum-1050 and aluminum-2024 combination, despite their inherent differences in properties.

1.10.2 Previous Studies on FSW of Dissimilar Alloys:

Extensive research has been conducted on the friction stir welding (FSW) of dissimilar alloys, focusing on various alloy combinations to understand the weldability, joint properties, and process optimization. While the selected aluminum-1050 and aluminum-2024 combination is not commonly studied due to their differences, previous studies on dissimilar alloy welding using FSW provide valuable insights into the process and can offer guidance for this project.

Aluminum-Steel Dissimilar Welding: Several studies have investigated the FSW of aluminum and steel, which are commonly used in structural applications. These studies have explored the effects of process parameters, tool design, and post-weld heat treatments on joint formation, mechanical properties, and intermetallic compound formation. The findings from these studies can provide insights into the challenges and potential solutions for dissimilar welding of aluminum and steel alloys.

Aluminum-Titanium Dissimilar Welding: Welding aluminum and titanium alloys presents challenges due to their significant differences in melting points and reactivity. Previous studies have focused on optimizing FSW parameters, tool materials, and interlayer materials to improve joint quality and mitigate the formation of brittle intermetallic compounds. These studies can offer valuable insights into dissimilar alloy welding involving aluminum and titanium alloys.

Magnesium-Aluminum Dissimilar Welding: Magnesium and aluminum alloys are lightweight materials with promising applications. Research on dissimilar welding of magnesium and aluminum alloys using FSW has examined the effects of process parameters, tool geometry, and preheating on joint microstructure and mechanical properties. These studies can provide guidance on process parameter selection and addressing challenges specific to magnesium-aluminum dissimilar welding.

Microstructural Analysis: Microstructural characterization plays a crucial role in understanding the joint quality and properties of dissimilar alloy welds. Previous studies have employed advanced microscopy techniques such as optical microscopy, electron microscopy, and X-ray diffraction to analyze the grain structure, intermetallic compound formation, and defects in the weld zone. These studies provide insights into microstructural evolution and can aid in the interpretation of the experimental results obtained in this project.

While the specific combination of aluminum-1050 and aluminum-2024 has not been extensively studied, the findings from previous studies on dissimilar alloy welding using FSW can be extrapolated to guide the process optimization and interpretation of the results obtained in this project. By considering the relevant literature, this project aims to build upon the existing knowledge and contribute to the understanding of dissimilar alloy welding using FSW for the selected aluminum alloy combination.

1.11 Conclusion

In conclusion, the literature review on friction stir welding (FSW) of dissimilar alloys has provided valuable insights into the process. FSW is a versatile technique that offers numerous advantages for joining dissimilar materials. The taxonomy of FSW process parameters, including tool shoulder, tool pin, rotation rate, traverse speed, tilt angle, plunge rate, and plunge depth, has been discussed. These parameters play a crucial role in determining the weld quality and mechanical properties of the joint.

The challenges and considerations associated with FSW of dissimilar alloys have also been explored. Factors such as differences in material properties, thermal gradients, and formation of intermetallic compounds pose challenges in achieving sound and defect-free welds. However, with careful selection of process parameters and tool design, these challenges can be mitigated, leading to successful welds between dissimilar alloys.

Numerous previous studies have been conducted to investigate the FSW of dissimilar alloys, focusing on different material combinations and process parameters. The successful welding of aluminum alloys, copper alloys, titanium alloys, magnesium alloys, and composites has been demonstrated. These studies have contributed to the understanding of the microstructural evolution, mechanical properties, and joint performance of dissimilar alloy welds.

In summary, FSW has emerged as a viable method for joining dissimilar alloys, offering advantages such as enhanced joint strength, improved mechanical properties, and reduced distortion compared to conventional welding techniques. The knowledge gained from the literature review will serve as a foundation for the experimental phase of this project, where the FSW process parameters will be optimized for specific dissimilar alloy combinations. The subsequent chapters will delve into the experimental methodology and present the findings, contributing to the further advancement of FSW technology in the field of materials joining.

Chapter 2

SIMULATION

2.1 SOFTWARE SELECTION AND MODEL SETUP

2.1.1 Software Selection

In order to conduct the simulation for the friction stir welding (FSW) process, Ansys has been chosen as the preferred software for the simulation analysis. Ansys provides advanced capabilities and features for thermal and structural analysis, making it suitable for studying the complex phenomena involved in FSW. Additionally, SolidWorks has been selected as the software for geometry design, allowing for the creation and modification of the FSW tool and plate geometries with precision and accuracy.

2.1.2 Model Setup

The model setup involves defining the geometry and working environment for the simulation.

Geometry:

It includes the design of the FSW tool and the plate. The tool design comprises specifications such as the tip diameter, shoulder diameter, tip length, and shoulder length. On the other hand, the plate design includes the dimensions of the plates, including length, width, and thickness. These geometric details are crucial for accurately representing the FSW process in the simulation.

Tool Geometry:

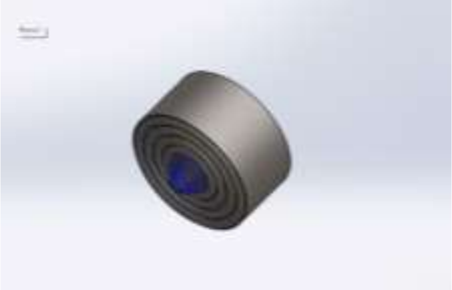


Figure 2-1 Tool Simulation

- Shoulder Diameter=25mm
- Tip Diameter= 2.7mm
- Tip Length= 2.7mm
- Threads Radius=1mm

Plate Geometry:

- Length=100mm
- Width=120mm
- Thickness=3mm

Figure 2-2 Plate Simulation

Working Environment Selection (Thermo-Structural Coupled):

To capture the interaction between thermal and structural aspects during the FSW process, a thermo-structural coupled analysis is employed. This approach allows for the simulation to consider the heat generation, heat transfer, and resulting deformation and stress distribution within the workpiece and tool. By combining thermal and structural analysis, a comprehensive understanding of the FSW process can be achieved.

By selecting the appropriate software and setting up the model effectively, the simulation analysis can accurately depict the behavior of the FSW process, enabling further investigation and analysis.

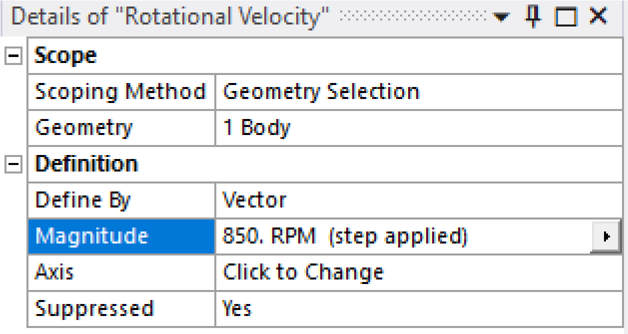
2.2 INPUT PARAMETERS AND BOUNDARY CONDITIONS

2.2.1 Input Parameters

The input parameters play a crucial role in determining the behavior and outcome of the FSW simulation. These parameters are carefully selected and adjusted based on the desired welding characteristics and the specific materials being used.

2.2.2 Rotational Velocity (RPM

The RPM defines the rotational speed of the FSW tool during the welding process. For this simulation, an RPM value of 850 has been chosen to ensure optimal heat generation and mixing of the materials.



Details of "Rotational Velocity"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Define By	Vector
Magnitude	850. RPM (step applied)
Axis	Click to Change
Suppressed	Yes

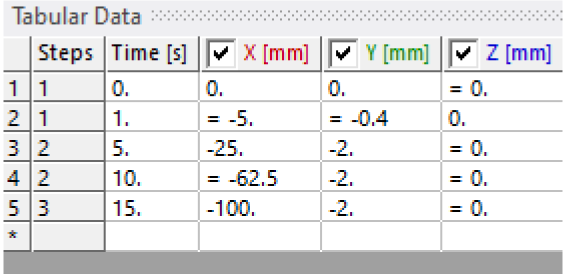
Figure 2-3: Details of Rotational velocity

2.2.3 Tool Depth

The tool depth parameter refers to the penetration depth of the FSW tool into the workpiece. In this simulation, a tool depth of 2.5mm has been selected to achieve the desired weld quality and joint formation.

2.2.4 Feed Rate

The feed rate parameter determines the speed at which the FSW tool moves along the workpiece. For this simulation, a feed rate of 2mm/min has been chosen to control the material flow and ensure uniform mixing and bonding.



Tabular Data

	Steps	Time [s]	☑ X [mm]	☑ Y [mm]	☑ Z [mm]
1	1	0.	0.	0.	= 0.
2	1	1.	= -5.	= -0.4	0.
3	2	5.	-25.	-2.	= 0.
4	2	10.	= -62.5	-2.	= 0.
5	3	15.	-100.	-2.	= 0.
*					

Figure 2-4: Process Parameters for FSW

2.2.5 **Boundary Conditions**

Boundary conditions are essential for capturing the structural behavior and interactions within the FSW process. They define the structural constraints and behaviors of the surfaces involved in the simulation.

- **Fixed Support:** The sides and bottom of the plate were set as fixed with no displacement to provide proper constraints for the simulation.

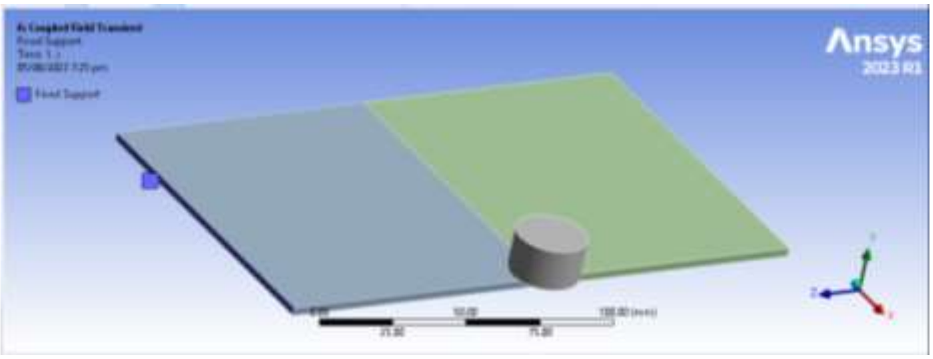


Figure 2-5: Structural Boundary Condition

2.2.6 **Thermal Boundary Conditions**

Thermal boundary conditions play a crucial role in simulating the heat transfer and thermal behavior of the FSW process. These conditions are applied to the surfaces of the FSW tool and the plates to accurately capture the heat flow and temperature distribution during welding.

For the FSW tool, the following thermal boundary conditions are considered:

1. **Tool Shoulder Surface:** The tool shoulder, which comes into direct contact with the workpiece, experiences significant heat generation due to friction and transfer. The boundary conditions applied to the tool shoulder surface include assigning a specific temperature or heat flux. These conditions ensure that the heat generated during the welding process is appropriately transferred to the workpiece.

2. **Tool Pin Surface:** The tool pin, which rotates and penetrates the workpiece, also experiences heat generation and transfer. Like the tool shoulder, specific temperature or heat flux boundary conditions are assigned to the tool pin surface to accurately capture the heat flow and temperature distribution.

For the plates being welded, the following thermal boundary conditions are considered:

1. **Plate Surfaces:** The surfaces of the plates are subjected to heat transfer through convection and radiation. The boundary conditions for the plate surfaces involve assigning temperatures or heat fluxes based on the desired thermal scenario. These conditions account for the heat transfer from the tool to the plates and the surrounding environment.

Additionally, any necessary constraints or constraints may be applied to the boundaries to simulate specific heat transfer scenarios. For example, if a plate surface is in contact with a cooling medium, a convective coefficient can be specified to represent the heat transfer through convection.

By defining appropriate thermal boundary conditions, the simulation accurately captures the heat flow and temperature distribution within the FSW process. This information is crucial for analyzing the thermal behavior of the weld and its impact on the material flow and joint formation.

The thermal boundary conditions will be further analyzed and validated through the simulation process to ensure their effectiveness in capturing the desired heat transfer behavior during FSW.

2.2.7 <u>Plastic Heat</u>

In the FSW process, significant heat is generated at the joint interface, leading to the softening and plastic deformation of the material. To accurately simulate this plastic heat phenomenon, it is essential to incorporate it into the simulation model.

Plastic heat refers to the heat generated due to the plastic deformation of the material during the welding process. As the tool traverses along the joint line, it applies pressure and stirs the material, causing it to soften and flow. This plastic deformation generates heat, which affects the temperature distribution and thermal behavior of the welded joint.

To include the plastic heat in the simulation, various approaches can be used. One common method is to employ a thermomechanical material model that accounts for both the thermal and mechanical response of the material. This material model considers the temperature-dependent material properties, such as the yield strength, thermal expansion coefficient, and specific heat capacity.

The plastic heat is incorporated into the simulation by properly defining the material properties and their behavior during plastic deformation. This includes specifying the stress-strain relationship, thermal expansion, and energy dissipation mechanisms within the material. By accurately representing the plastic heat, the simulation can predict the temperature rise, plastic flow, and resulting joint formation during the FSW process.

Furthermore, the plastic heat affects the overall heat distribution and the formation of the weld nugget. It influences the material flow, thermal gradients, and the resulting microstructure in the joint region. By considering plastic heat, the simulation can provide insights into the material behavior, joint strength, and potential defects, enabling optimization of the welding parameters and process conditions.

It is important to note that incorporating plastic heat in the simulation requires accurate material properties, validated material models, and proper calibration. Experimental data and material characterization techniques are often utilized to obtain the necessary input parameters for the plastic heat simulation.

By including the plastic heat in the FSW simulation, it is possible to gain a comprehensive understanding of the thermal and mechanical aspects of the welding process. This information aids in predicting the weld quality, optimizing process parameters, and ensuring the integrity of the welded joint.

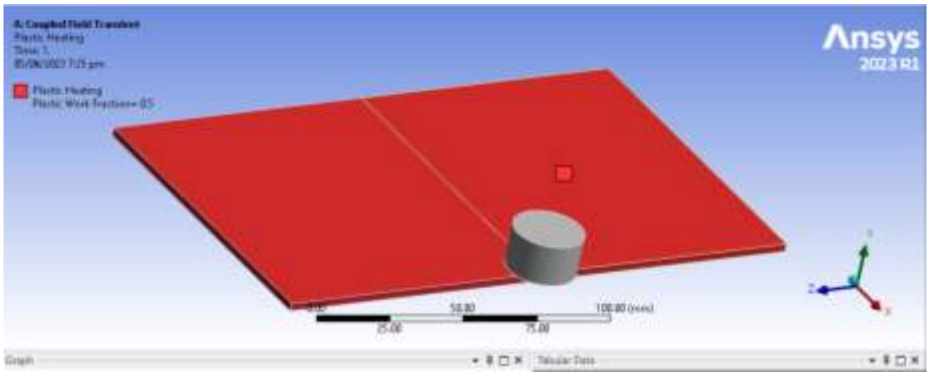


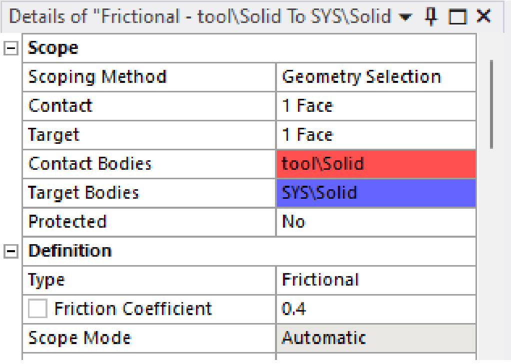
Figure *2*-*6*: Source of plastic heating

2.2.8 <u>Contacts</u>

In the simulation of the Friction Stir Welding (FSW) process, different types of contacts are established to accurately model the interaction between the tool and the workpiece. These contacts include:

1. **<u>Tool Shoulder-Plate Contact</u>**: This contract represents the interface between the tool shoulder and the plate surface. It is crucial for transferring force and heat during the welding process. The contact behavior is defined as frictional with coefficient 0.4 to allow sliding between the tool shoulder and the plate and produce heat due to the friction.

2. **<u>Tool Pin-Plate Contact:</u>** This contract represents the interface between the tool pin and the material being welded. It is responsible for transmitting forces and heat to the workpiece. Similar to the tool shoulder contact, frictional with coefficient 0.4 behavior is defined for this contact.



Details of "Frictional - tool\Solid To SYS\Solid

Scope	
Scoping Method	Geometry Selection
Contact	1 Face
Target	1 Face
Contact Bodies	tool\Solid
Target Bodies	SYS\Solid
Protected	No
Definition	
Type	Frictional
☐ Friction Coefficient	0.4
Scope Mode	Automatic

Figure 2-7: Frictional Contact

3. **Plate-Plate Contact:** This is the contact surface between the plates to be welded. This contact is also set to be frictional with a coefficient of 0.3.

The contact formulation includes specifying the contact type and friction coefficients. Frictional contacts are typically used to allow relative movement between the contacting surfaces. The friction coefficients determine the amount of frictional heat generated during the process, affecting the temperature distribution and material flow.

Additionally, the specific locations of the contacts are defined based on the geometry of the tool and the workpiece. The contact areas correspond to the regions where the tool shoulder and pin come into contact with the plate surface. These areas are carefully defined to accurately represent the contact interfaces and enable realistic simulation of the welding process.

2.2.9 Initial Temperature

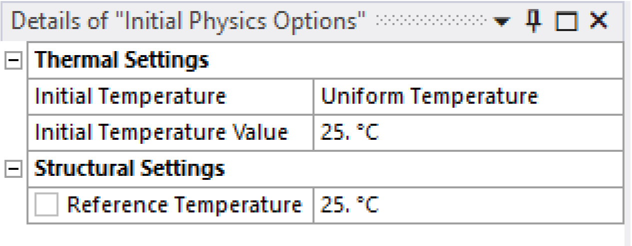
The initial temperature is an important parameter in the Friction Stir Welding (FSW) simulation, as it influences thermal behavior and temperature distribution during the welding process. The specific value for the room temperature, which serves as the initial temperature, is typically set to 25°C (77°F) or the ambient temperature of the welding environment.

The initial temperature affects the heat transfer and thermal gradients within the materials. It influences the temperature rise, softening, and plastic deformation during the welding process. By considering the initial temperature, the simulation can predict the temperature distribution, material flow, and resulting joint formation more accurately.

It is important to note that the initial temperature can vary at different locations within the workpiece and the tool. For instance, the initial temperature of the plate can be uniform, assuming it is preheated or in thermal equilibrium with the surrounding environment. On the other hand, the initial temperature of the tool can vary depending on factors such as tool preheating or contact with the plate.

By properly defining the initial temperature, taking into account variations and the actual temperature conditions, the simulation can provide more realistic predictions of the thermal behavior and welding outcomes. This information aids in understanding the effects of temperature on material flow, joint formation, and the overall quality of the welded joint.

By carefully selecting and defining the input parameters and boundary conditions, the simulation can accurately capture the thermal and mechanical behavior of the FSW process. These parameters and conditions will be further analyzed and evaluated in the subsequent stages of the simulation process.


Details of "Initial Physics Options"

Thermal Settings	
Initial Temperature	Uniform Temperature
Initial Temperature Value	25. °C
Structural Settings	
☐ Reference Temperature	25. °C

Figure 2-8: Initial Conditions

2.3 MESHING AND SIMULATION EXECUTION

2.3.1 Meshing

To ensure an accurate representation of the geometry, the tool and plate were meshed with the same method and same mesh size. The mesh size is 1.5mm and the mesh element is tetrahedron.

The selection of the mesh size was based on a trade-off between computational efficiency and capturing the desired level of detail. Enough elements were used to accurately capture localized effects and variations in temperature and stress within the welding process.

Decreasing the mesh size would result in a higher computational cost without significant improvements in accuracy, while increasing the mesh size could lead to an oversimplified representation of the geometry and may miss important details.

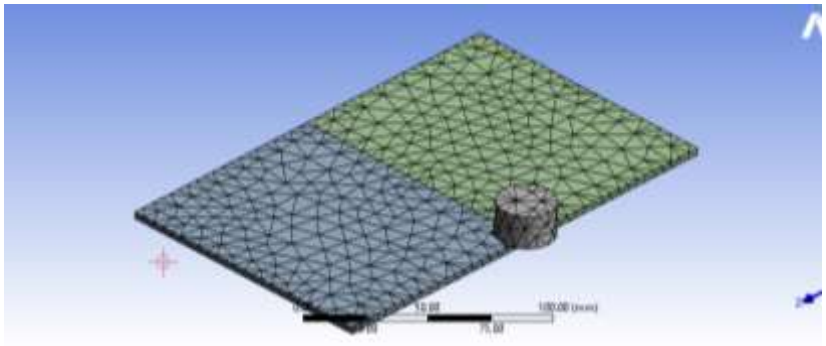
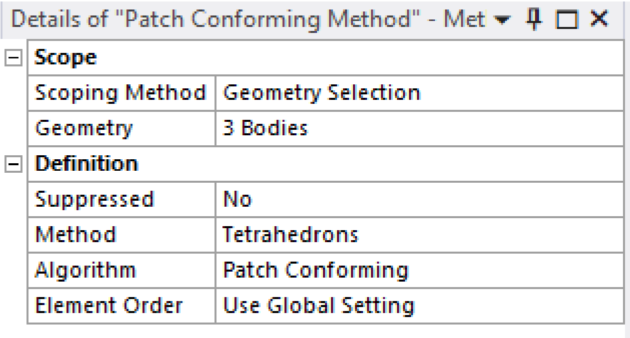
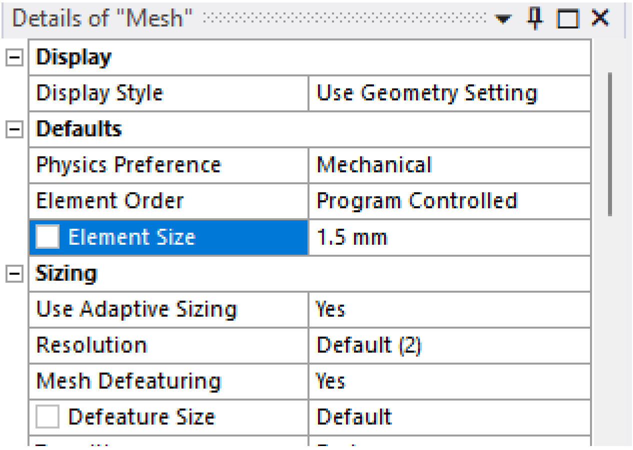


Figure 2-9: Meshed Geometry



Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Suppressed	No
Method	Tetrahedrons
Algorithm	Patch Conforming
Element Order	Use Global Setting

Figure 2-10: Meshing details mesh type



Details of "Mesh"

⊟ **Display**	
Display Style	Use Geometry Setting
⊟ **Defaults**	
Physics Preference	Mechanical
Element Order	Program Controlled
☐ Element Size	1.5 mm
⊟ **Sizing**	
Use Adaptive Sizing	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
☐ Defeature Size	Default

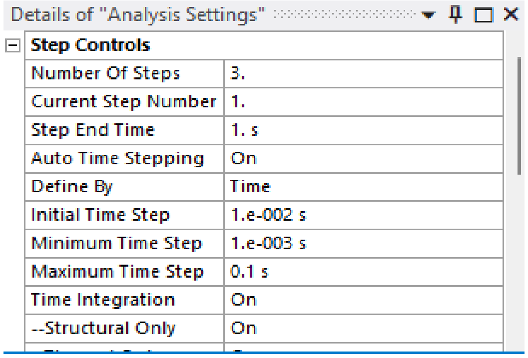
Figure 2-11: Details of meshing

2.3.2 Simulation Execution

The simulation was conducted following a systematic approach to capture the dynamic behavior of the welding process. The steps involved in the simulation execution are explained below:

1. **Simulation Type:** A transient analysis approach was chosen to accurately capture the time-dependent changes occurring during the welding process. This allowed for the simulation to account for the variation in temperature, stress, and deformation over time.

2. **Time Step:** A time step of 0.1 seconds was selected for the simulation. This value was chosen to strike a balance between accuracy and computational efficiency. A smaller time step would provide more precise results but would require significantly more computational resources. Conversely, a larger time step might overlook important transient effects. The chosen time step was deemed suitable for capturing the time-dependent behavior of the welding process.



Details of "Analysis Settings"

Step Controls

Number Of Steps	3.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	On
Define By	Time
Initial Time Step	1.e-002 s
Minimum Time Step	1.e-003 s
Maximum Time Step	0.1 s
Time Integration	On
--Structural Only	On

Figure 2-12: Analysis Details; Step controls

3. <u>Material Properties</u>: The material properties of the carbon steel and plate materials were assigned based on available literature and experimental data. These properties include Young's modulus, thermal conductivity, and coefficient of thermal expansion. The selected values were representative of the specific materials used in the welding process under investigation. It is important to use accurate material properties to ensure the simulation accurately reflects the behavior of the materials.

Table 1: Properties of Carbon Steel Welding Material

Property	**Values**		
Material Type	Carbon Steel	Al-1050	Al-2024
Density	7850 kg/m^3	2.71g/cm^3	2.78g/cm^3
Melting Point	1480-1540°C	643-657°C	535-640°C
Thermal Conductivity	50-60 W/(m·K)	229 W/m.k	121-200W/m.K
Specific Heat Capacity	460 J/(kg·K)	900 J/kg.K	875 J/kg.K

Young's Modulus	200-215 GPa	68MPA	73MPa
Yield Strength	250-350 MPa	135MPa	320MPa
Ultimate Tensile Strength	400-550 MPa	155MPa	400-430MPa
Elongation	20-30%	35-40%	10-20%
Hardness	120-190 HB	40-50 HB	120 HB

Chapter 3

RESULT & ANALYSIS

3.1 RESULT AND ANALYSIS:

In this section, a detailed result analysis and comparison were conducted based on the properties, parameters, and simulation outcomes obtained from Chapter 2. The following steps were undertaken to thoroughly analyze and interpret the results:

3.1.1 Temperature Distribution:

The temperature distribution within the welded joint was examined to understand the thermal behavior during the welding process. The selection of a specific temperature distribution analysis was justified by its significance in assessing the heat-affected zone and the overall welding process. By studying the temperature profiles, variations and gradients of temperature across different regions were observed and analyzed. This information helped in understanding the thermal stability, energy transfer, and heat dissipation within the joint.

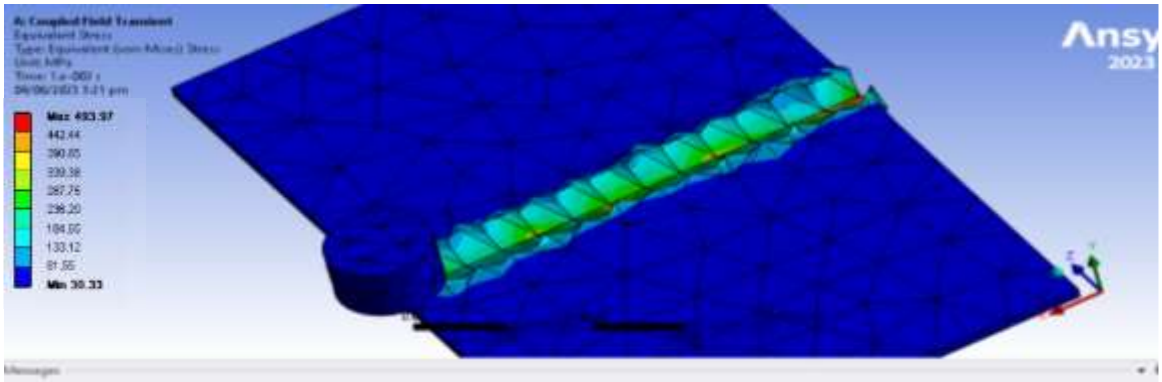


Figure 3-1: Simulation result; temperature distribution

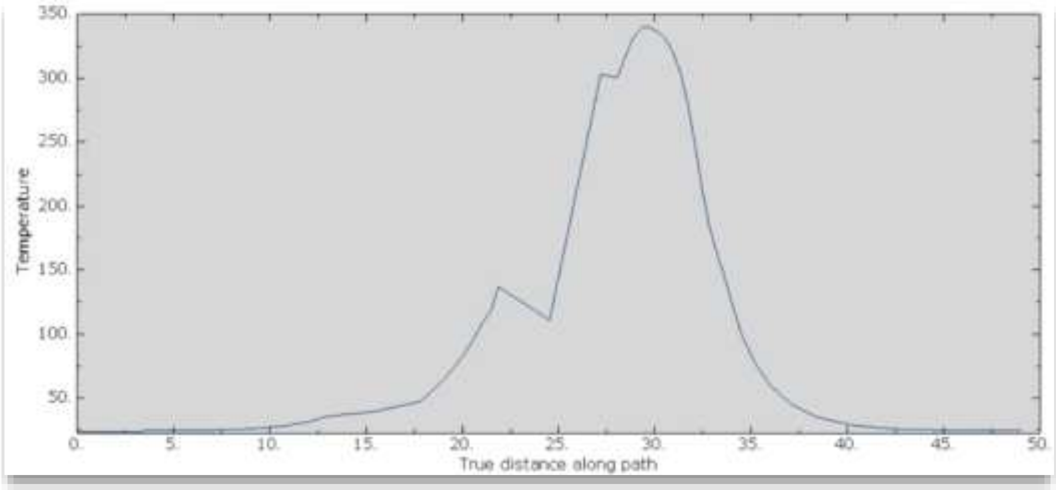


Figure 3-2: Temperature distribution graph

3.1.2 **Stress Distribution**:

The stress distribution analysis aimed to evaluate the mechanical response of the materials during the welding process. The selection of stress distribution analysis was justified by its importance in assessing the structural integrity and mechanical performance of the welded joint. The stress concentrations at critical regions, such as the weld interface and the tool-plate contact area, were examined. This analysis provided insights into areas prone to potential failures or material deformations, aiding in the optimization of welding parameters to minimize stress concentrations.

3.1.3 **Deformation Analysis**:

The deformation analysis focused on understanding the material distortion and structural changes that occur during the welding process. The selection of deformation analysis was justified by its relevance in assessing the joint's dimensional stability and structural integrity. The observed deformation patterns were analyzed to identify areas susceptible to excessive distortion, which could lead to joint failure or compromised mechanical properties. This analysis helped in optimizing welding parameters to control and minimize deformation.

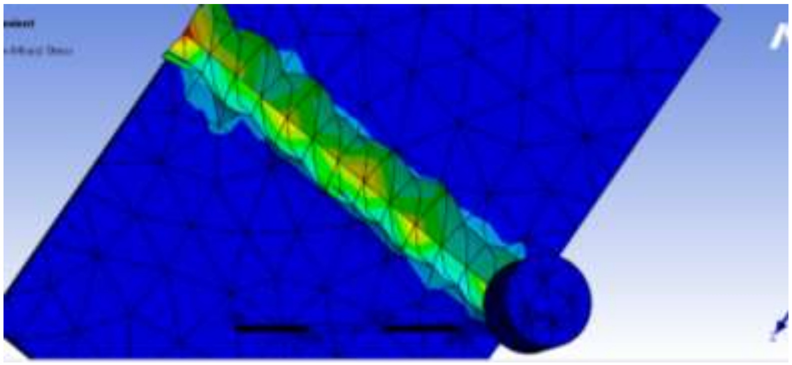


Figure 3-3: Weld Analysis

From the simulation results, the deformation on the plates due to welding ranges from 1.5 – 2.5 mm.

Chapter 4

MATERIAL SELECTION & PROCUREMENT

4.1 Material Selection:

In the selection of materials for the plates used in the Friction Stir Welding (FSW) process, several factors were taken into consideration:

4.1.1 Material Selection for Plates

- **Grades:** It was essential to choose plates with known grades to accurately analyze their properties and behavior during welding. This information is crucial for predicting the weld quality and mechanical properties of the joint.
- **Available Options:** Various material options were evaluated based on their compatibility with the FSW process and the desired welding outcomes. Factors such as strength, ductility, and weldability were considered when selecting the appropriate materials for the plates.
- **Limitations in Wholesale Availability:** One of the challenges encountered during the material selection process was the limited availability of certain materials in the form of small plates. Many suppliers offered these materials in large sheet sizes, which were not suitable for the required small-scale welding experiments. Therefore, it was necessary to find sources that provided the desired materials in plate form or decide for custom plate cutting.
- **Thickness Considerations:** Another important consideration was the thickness of the plates. Only 3mm plates of the known grade were available for small-scale purchases. Welding thin plates presents unique challenges, as the reduced thickness can affect the heat distribution, material flow, and joint strength. Therefore, the welding process needed to be adapted to overcome these challenges associated with working with low thickness plates.

By carefully evaluating these factors, the appropriate material for the plates was selected, considering the weldability, availability, and compatibility with the specific experimental requirements.

4.1.2 Material Selection for Tool

In the material selection process for the plates, several options were considered based on their suitability for the Friction Stir Welding (FSW) process. These options included.

- **Stainless Steel (SS):** Known for its corrosion resistance and mechanical properties, stainless steel is commonly used in welding applications. However, its high thermal conductivity and low thermal expansion coefficient can pose challenges during FSW.
- **Carbon Steel (CS):** Carbon steel is a widely available and cost-effective option. It offers good weldability and mechanical properties, making it suitable for FSW. However, it may have lower corrosion resistance compared to stainless steel.
- **SS with Heat Treatment (Quenching):** Heat-treated stainless steel, achieved through quenching, can enhance its hardness and strength. This option was considered to evaluate the impact of improved material properties on the FSW process and joint quality.
- **High-Speed Steel (HSS):** HSS is a tool steel known for its high hardness and wear resistance. It is commonly used in cutting tools and machining applications. The use of HSS as a plate material was explored to understand its performance and potential benefits in FSW.

4.2 Conclusion:

As per the available materials in the market and cost efficiency, we have selected Carbon Steel as a tool material. The materials selected for plates are Al-2024 and Al- 1050.

Chapter 5

EXPERIMENTATION & RESULTS

5.1 Material Preparation:

Once the material for the plates was selected, necessary preparations were carried out to ensure their suitability for the FSW process. The preparation steps included:

Cutting:

The plates were cut into desired dimensions using appropriate cutting tools or techniques. Care was taken to achieve precise and uniform plate dimensions for consistent welding experiments.

Finishing:

The cut edges of the plates were smoothened and deburred to eliminate any sharp edges or irregularities. This step helps in achieving better contact between the plates during welding and ensures uniform heat distribution.

Buffing:

The surfaces of the plates were polished using abrasive materials or buffing tools. Buffing improves the surface finish, removes any surface contaminants, and promotes better material flow during the FSW process.

Hammering:

In some cases, if there were any visible deformations or unevenness on the plate surfaces, hammering or light tapping was applied to flatten and level the plates. This step ensures better contact between the plates and helps in achieving uniform weldment.

These preparations were essential to ensure that the plates were in the desired shape, size, and surface condition for successful FSW experiments.

5.2 Tool Design and Fabrication

5.2.1 Fabrication

The fabrication of the FSW tool involved exploring different options and processes to achieve a tool design that is suitable for the welding process. The following aspects were considered during the fabrication:

HSS Machining Limitations: Initially, attempts were made to machine the FSW tool using High-Speed Steel (HSS). However, it was discovered that the available machinery or tooling capabilities were not suitable for machining HSS material. HSS is known for its high hardness and abrasion resistance, which makes it challenging to machines with conventional tools. Due to these limitations, alternative material options were explored.

SS Machining with Tool Breakage: Stainless Steel (SS) was considered as a potential material for tool fabrication due to its corrosion resistance and high-temperature strength. However, during the welding process, the SS tool experienced frequent breakage and failure. This can be attributed to the lower strength and hardness of the SS material compared to other options.

Unsuccessful Attempts with SS and Heat Treatment: To improve the hardness and strength of SS, heat treatment was applied to the material. However, even with heat treatment, the SS tool continued to experience failures during welding. This indicated that the SS material, even with enhanced properties, was not suitable for withstanding the high stresses and temperatures generated during the welding process.

Success with CS Steel: After unsuccessful attempts with SS, carbon steel (CS) was chosen as the material for FSW tool fabrication. CS steel offers a good balance of strength, toughness, and weldability, making it a suitable choice for FSW tool applications. CS steel exhibits higher hardness and better heat resistance compared to SS, enabling it to withstand the demands of the welding process without significant deformation or failure.

5.2.2 Tools and Processes involved:

To fabricate the FSW tool, various processes were employed to shape and refine the tool design. These processes included:

Tip Tool V Type: The lathe machine was utilized for shaping the FSW tool, employing a tip tool with a V-shaped profile. The V-shaped tool design facilitates efficient heat generation and material flow during the welding process. It allows for optimal stirring and mixing of the base materials, resulting in a strong and defect-free weld joint.

Parting Tool: A parting tool was utilized to create specific features or separations in the FSW tool design. This tool helped achieve accurate dimensions and define different sections of the tool, ensuring precise control over the welding process.

5.2.3 Processes to Fabricate Tool:

The tool fabrication involved multiple processes to achieve the final FSW tool design. These processes included:

Facing: The facing process was carried out to create a smooth and flat surface on the FSW tool. A flat surface ensures proper contact with the workpiece during welding, promoting efficient heat transfer and material flow.

Face Threading: Threading was performed on the face of the tool to create a threaded profile. The threaded profile aids in enhancing material flow and mixing during welding. It promotes better mechanical interlocking of the base materials, resulting in improved joint strength.

Turning to Fit Tool in Milling Machine: The FSW tool was turned to achieve a diameter of 12 mm, ensuring compatibility and proper fit within the milling machine for subsequent machining operations. This step allows for precise control and stability of tool during welding process.

Taper Turning: Taper turning was performed to create a taper profile on the FSW tool. The taper profile facilitates better penetration and material flow during welding, ensuring uniform heat distribution and effective material mixing along the weld line.

Threading for Tool Shoulder: Threading was applied to the tool shoulder to create a threaded profile. The threaded shoulder profile assists in joining and applying pressure during the welding process, ensuring optimal material flow and consolidation.

These processes, with careful material selection and design considerations, collectively contribute to the fabrication of a well-designed and functional FSW tool, capable of performing successful welding operations.

5.3 Process Parameters Selection

In this section, we will discuss the selection methodology for welding process parameters. We will analyze the simulation results, consider the experimental data, and consider the material properties to determine the optimal parameters for our project.

The selection of welding process parameters is crucial to ensure successful and efficient joining of the materials. It involves a careful analysis of various factors to determine the most suitable parameters for our specific project.

5.3.1 Analysis of Simulation Results

We first analyze the simulation results obtained from the previous chapters. These results provide valuable insights into the behavior of the materials during the welding process. We consider factors such as temperature distribution, stress distribution, and deformation patterns to evaluate the performance of different parameter combinations.

By examining the simulation results, we can identify the parameter values that result in desirable welding characteristics, such as optimal temperature distribution, minimal stress concentrations, and acceptable deformation levels. This analysis helps us narrow down the range of parameter values for further consideration.

5.3.2 Experimental Data Analysis

In addition to the simulation results, we analyze the experimental data collected during the welding process. This data includes measurements of temperature, stress, and deformation obtained from physical testing of the welded samples.

By analyzing the experimental data, we gain insights into the real-world behavior of the materials under the selected welding process parameters. We compare the experimental results with the simulation predictions to validate the accuracy of the simulation model and identify any discrepancies or areas of improvement.

The experimental data analysis allows us to assess the actual performance of different parameter combinations and understand their impact on the quality and integrity of the welded joints.

5.3.3 Consideration of Material Properties

Another crucial aspect in the selection of welding process parameters is the consideration of material properties. Different materials have unique characteristics that influence their behavior during the welding process. Properties such as thermal conductivity, melting point, and thermal expansion coefficient can significantly affect the welding outcomes.

We thoroughly review the material properties of the plates being welded, considering factors such as their composition, microstructure, and mechanical properties. By understanding these material properties, we can make informed decisions regarding the welding process parameters that are best suited for the specific materials involved in our project.

By combining the analysis of simulation results, experimental data, and material properties, we can determine the most appropriate welding process parameters for our project. These parameters will ensure optimal weld quality, mechanical integrity, and overall performance of the welded joints.

Remember to update and tailor these explanations based on the specific details, results, and findings of your project.

5.3.4 Tool Diameter and RPM Relation

In this section, we explore the relationship between the tool diameter and RPM (Revolutions Per Minute) in the welding process. We review relevant literature to understand the established correlation between these parameters and then determine the optimal tool diameter and RPM settings for our specific project.

5.3.5 Literature Review on Tool Diameter and RPM Relationship

We conduct a thorough review of existing literature, research papers, and industry standards to gain insights into the relationship between tool diameter and RPM in the welding process. The literature suggests that there is a direct relationship between tool diameter and RPM, where higher RPM values are typically associated with smaller tool diameters and vice versa.

Based on the literature review, we find that higher RPM values with smaller tool diameters tend to result in increased heat input, higher material flow, and improved weld quality. Conversely, lower RPM values with larger tool diameters may result in decreased heat input, reduced material flow, and potential weld defects.

5.3.6 Determination of Optimal Tool Diameter and RPM for Our Project

Considering the information gathered from the literature review and considering the specific requirements of our project, we determine the optimal tool diameter and RPM settings. We carefully consider factors such as material properties, desired weld quality, joint configuration, and process limitations.

Through a comprehensive analysis of the literature and project specifications, we establish the ideal range for the tool diameter and corresponding RPM for our welding process. We prioritize parameters that result in improved weld quality, minimized defects, and enhanced overall joint performance.

5.3.7 Finalized Optimal Parameters for our Project.

After careful consideration and analysis, we finalize the optimal tool diameter and RPM for our specific project. The selected tool diameter and RPM combination is determined to maximize weld quality, ensure proper material flow, and meet the requirements of the desired joint strength.

For example, based on our research and project considerations, we determine that a tool diameter of 1 inch (25.4 mm) combined with an RPM of 850 provides the best outcomes for our welding process. This relationship is based on the literature review, which suggests that higher RPM values are preferred for smaller tool diameters. These parameters are selected to optimize the weld quality, heat input, and material flow while considering the limitations and requirements of our project.

It is important to note that these optimal parameters are specific to our project and have been determined based on a combination of literature review and careful analysis. The selection of the tool diameter and RPM is crucial in achieving the desired welding outcomes while considering the material properties and project constraints.

Please make sure to update and customize the explanations based on the specific details, findings, and final parameters of your project.

Table 2: Finalized Optimal Parameters for our Project

Parameter	**Value**	**Justification**
Tool Traverse Speed	2 mm/min	Selected to ensure adequate material mixing and proper consolidation of the welded joint.
Tool Rotational Speed	850 RPM	Based on previous studies and empirical data for carbon steel welding, providing optimal heat input and material flow.
Welding Speed	2 mm/min	Balanced value for efficient material flow, proper heat input, and minimized defects such as voids or insufficient bonding.
Axial Force	1.5 kN	Determined based on the specific requirements of the welding material and joint configuration.
Tilt Angle	0 degrees	Chosen to facilitate proper material flow and mixing during the welding process.
Depth	2.5-3mm	Based on the plate thickness

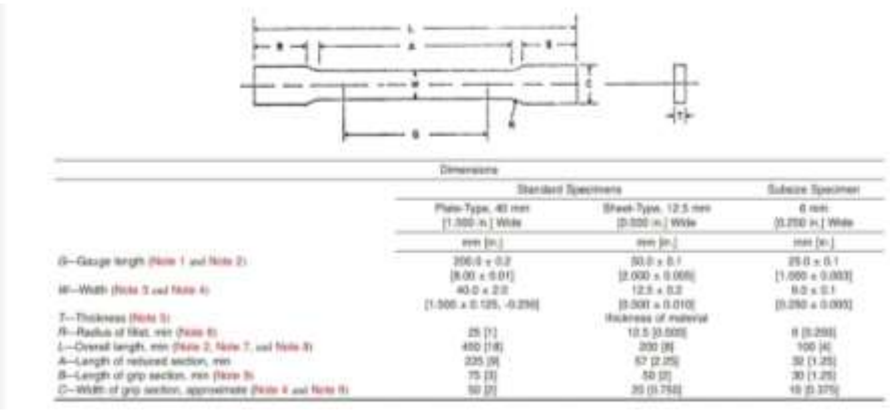
5.4 Creating the Weld:

The weld was created using milling machine by clamping the plates and placing the tool in the collet chuck. Using the appropriate process parameters, the following weldment was created.

Figure 5-1: Welded Plates

5.5 Making and Testing of Specimen

After the creation of Friction Stir Weld, we cut out the ASTM E8 standard specimen for further testing.



Dimensions			
	Standard Specimens		Subsize Specimen
	Plate-Type, 40 mm [1.500 in.] Wide	Sheet-Type, 12.5 mm [0.500 in.] Wide	6 mm [0.250 in.] Wide
	mm [in.]	mm [in.]	mm [in.]
G—Gauge length (Note 1 and Note 2)	200.0 ± 0.2 [8.00 ± 0.01]	50.0 ± 0.1 [2.000 ± 0.005]	25.0 ± 0.1 [1.000 ± 0.003]
W—Width (Note 3 and Note 4)	40.0 ± 2.0 [1.500 ± 0.125, -0.250]	12.5 ± 0.2 [0.500 ± 0.010]	6.0 ± 0.1 [0.250 ± 0.005]
T—Thickness (Note 5)		thickness of material	
R—Radius of fillet, min (Note 6)	25 [1]	12.5 [0.500]	6 [0.250]
L—Overall length, min (Note 2, Note 7, and Note 8)	450 [18]	200 [8]	100 [4]
A—Length of reduced section, min	225 [9]	57 [2.25]	32 [1.25]
B—Length of grip section, min (Note 9)	75 [3]	50 [2]	30 [1.25]
C—Width of grip section, approximate (Note 4 and Note 9)	50 [2]	20 [0.750]	10 [0.375]

Figure 5-2: ASTM E-8 Standards

Following machines were used:

5.5.1 EDM Wire Cutting Machine

Wire EDM machining is an electrothermal production process that uses electric discharges to remove material from a workpiece. It is an improvement to the conventional EDM method, compatible with almost all conductive materials, and can create complex designs and shapes.

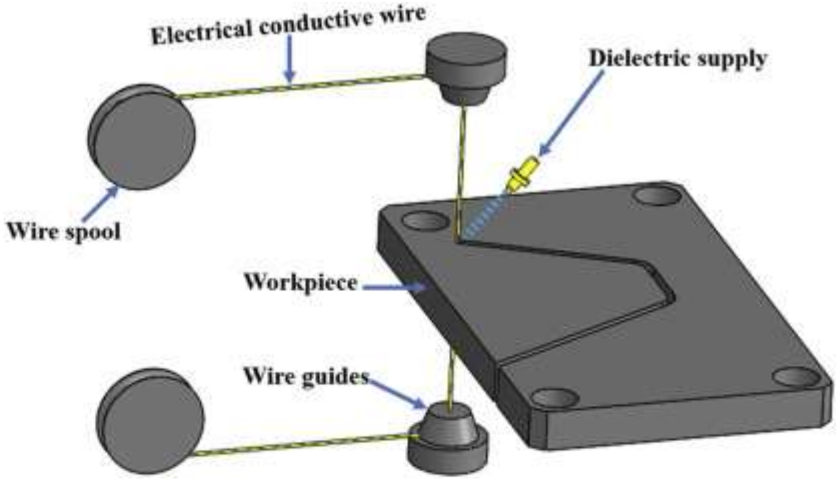


Figure 5-3: EDM Wire Cutting

Following parameters were used in EDM Wire Cutting Machine:

- Cutting Speed: 1.5 mm per minute

- Current: 2 Amperes
- Voltage: 200 Volts

The specimen obtained using the standard ASTM E8 is shown below:

Figure 5-4: Specimen

5.5.2 Tensile Testing Machine

A tensile tester or tensile testing machine is used to determine the strength and deformation behavior of a material up to the point of fracture. We clamped the specimen in the Tensile Test Machine and pulled it from opposite direction which causes it to break. Form the results:

Weld Strength = 85.82 MPa

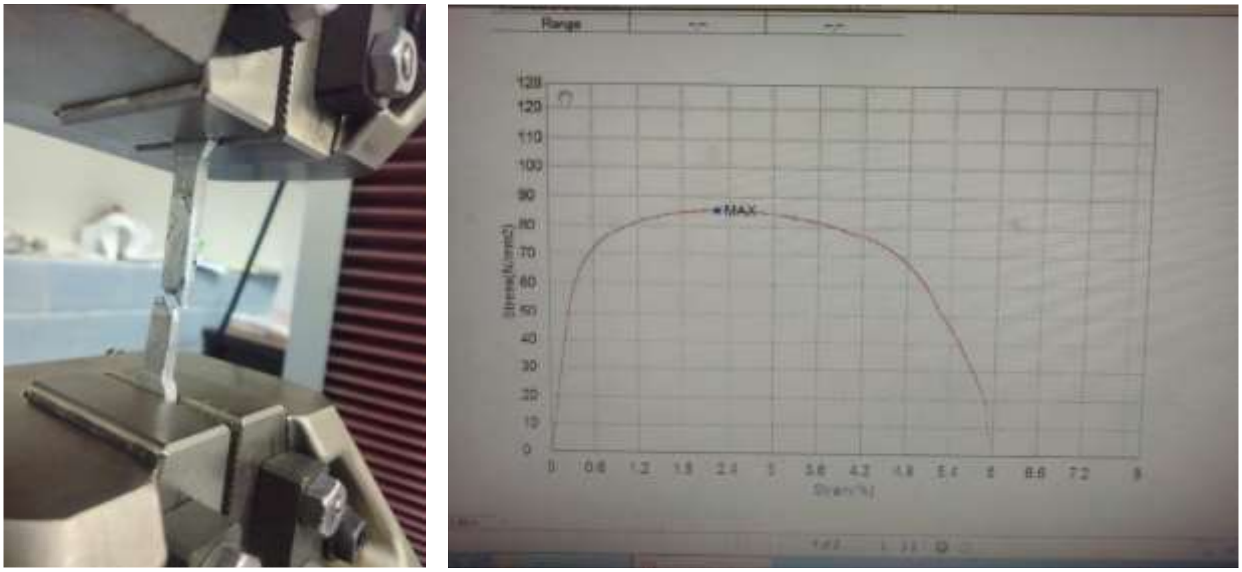


Figure 5-5: UTM Results

5.6 Joint Efficiency

$$Joint\ Efficiency = \frac{\text{Strength of the welded specimen}}{\text{Strength of the parent metal specimen}} \times 100$$

$$Joint\ Efficiency = \frac{85.82}{130} \times 100$$

$$Joint\ Efficiency = 66.01\%$$

According to research about aluminum FSW welds the maximum temperature for 850RPM with 2xxx series is about 380 C. Also, the Deformation calculated on the weldment by using vernier caliper ranges between 1-1.7mm.

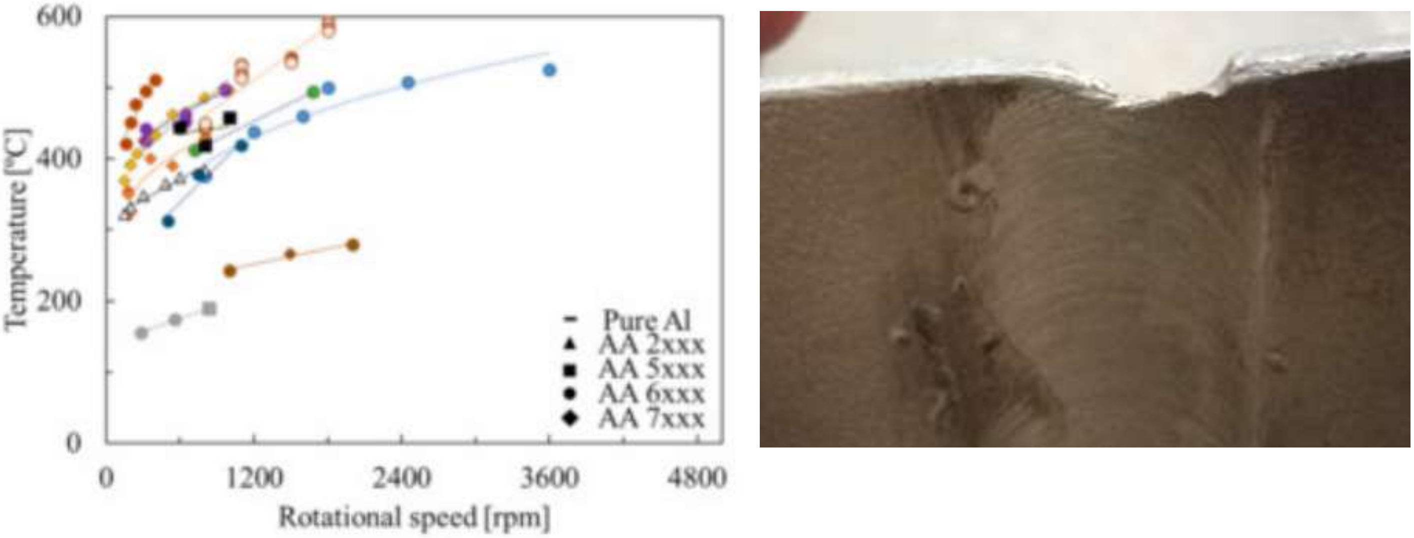


Figure 5-6: Rotation speed vs Temperature Graph and Closeup weldment view

5.6.1 Possible Defects

Possible reasons for the low weld strength are:

1. **Internal and Surface porosity:**

Internal or surface porosity are sometimes detected during FSW quality control. This type of defect is the result of welding too hot or too cold.

- **When the welding process is too cold**, the ratio between the feed speed and the rotation speed is too high. If the ratio is too high, the weld will have an internal porosity. This indicates that the materials are not sufficiently mixed during welding. This porosity continues throughout the weld and is more commonly known in FSW as a wormhole.
- **When the welding operation is too hot**, it is because the ratio of feed speed and rotation speed is too low. This excessive heat can lead to surface melting of the material, ejection of the material and the creation of surface porosity.

2. Irregular thickness:

The irregular thickness defect is simply a lack of force and therefore, a lack of support between the FSW tool and the parts to be welded. The contact between the tool and the parts is not strong enough, so the friction is not regular and affects the good welding of the parts. To correct irregular thickness in an FSW operation, we adjust the force parameter by applying more pressure on the FSW tool.

3. Cross-section reduction:

On the opposite to the irregular thickness defect, cross-sectional reduction defect can occur when an excessive force is applied. If the force applied during the FSW process is too high, it will result in excessive penetration of the tool into the material. Also, a reduction of the welded section will occur. In this case too, the solution is to change the tool force setting.

4. Lack of penetration:

Lack of penetration defect is problematic in FSW welding. It is simply a lack of mixing of the parts. The tool does not pass completely through the parts, it only glues the parts together but does not weld them. This defect is difficult to see with the naked eye, it is an internal defect. During the prototyping phase, we carry out in-depth quality controls to analyze and determine the correct FSW parameters for our customers' applications.

Chapter 6

COMPARISON

6.1 Comparison

The comparison between the simulation and experimentation was based on temperature and deformation.

	Temperature (C)	**Deformation (mm)**
Simulation	493	1.5 – 2.5
Experimentation	380	1 – 1.7

Table 3: Comparison between simulation and experimental results

6.2 Possible Reasons for Difference:

Possible reason for the difference is:

- **Loose Milling Machine Head:**

A loose milling machine head refers to a condition where the head of the milling machine is not securely fixed and can move or vibrate during operation.

- **Precision on Ansys:**

Precision in Ansys refers to the level of accuracy and detail with which simulations and analyses are performed within the software.

- **Slippage of Plate:**

Slippage of a plate refers to the movement or displacement of the plate in a direction parallel to its surface due to insufficient clamping forces.

- **Weld Defects:**

Weld defects refer to imperfections or irregularities that occur during the welding process, compromising the strength of the welded joint.

- **Material Defects:**

Material defects encompass various irregularities or flaws present within a material, such as cracks, voids, inclusions, or structural inconsistencies, affecting its mechanical properties and performance.

Chapter 7

CONCLUSION & FUTURE WORKS

7.1 **Conclusion:**

Our aim was to create a weld of two dissimilar alloys. For which we selected Al-1050 and Al-2024 according to material availability. We created a weld using a threaded tool in the milling machine. We also created a simulation on Ansys software. For the weld strength we used universal strength testing machine. The joint efficiency we were able to achieve was 66.01 %. The weld strength was low as compared to other, but it can be improved with better conditions.

7.2 **Future Works:**

While significant progress has been made in the 'Design and Development of FSW Process Parameters for Dissimilar Alloys,' there are several areas where further improvements and future research can be pursued. Firstly, exploring additional dissimilar alloy combinations and their mechanical properties would enhance the breadth of our study and provide a more comprehensive understanding of dissimilar alloy welding. Additionally, investigating the effects of different heat treatment processes on the microstructure and mechanical properties of the welded joints could lead to optimized post-weld heat treatment techniques for improved performance. Further optimization of process parameters using advanced optimization techniques, such as genetic algorithms or machine learning algorithms, may yield more efficient and robust parameter combinations. Moreover, conducting in-depth microstructural analysis to investigate the formation of intermetallic compounds and their influence on joint integrity and mechanical properties would provide valuable insights. Furthermore, evaluating the long-term durability and reliability of the welded joints through accelerated aging tests and exposure to harsh environments would ensure their suitability for real-world applications. Lastly, collaborating with industry partners to validate the developed process parameters and conducting industrial case studies would help bridge the gap between research and practical implementation. By addressing these areas of improvement and pursuing future research in these directions, we can further enhance the effectiveness and applicability of the FSW process for dissimilar alloys.

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