Kurdistan Region
Salahaddin University-Erbil
College of Engineering
Mechanical Engineering Department

“The effect of multi-pass friction stir processing on microstructure and mechanical properties of Aluminum alloy”

A Project Submitted to the Mechanical Engineering Department
University of Salahaddin-Erbil
in the Partial Fulfillment of the Requirement for the Degree of Bachelor of Science in Mechanical Engineering

Prepared by:
Soran Tofiq Hamid
Barzan Jabar Othman

Supervisor:
Mr. Abdulbasit A. Hamza

2023-2024

Abstract

Friction stir processing (FSP) is a novel process for refinement of microstructure and improvement of material's mechanical properties. In this paper, the effect of multi-pass friction stir processing on mechanical properties and microstructure of Aluminum alloy 5052 has been studied. For this purpose, the hardness, tensile, and microstructure tests were conducted at different several parameters (rotational and traverse speed) for two passes. The experimental results indicated that the ultimate tensile strength and hardness increased after second pass of friction stir process and The results revealed that multi-pass FSP causes a homogeneous distribution and good dispersion of grains in the aluminum alloy 5052, With increasing the number of passes, the grain size and the tunnel defects decrease. but while the mechanical properties such as the ultimate tensile strength, hardness was decrease compared base material. The processing parameters, particularly rotational tool speed and pass number in FSP, have a major effect on strength properties, surface hardness and microstructure.

Acknowledgement

We would like to take this opportunity to express our sincere gratitude to all those who have contributed to the successful completion of this project. Firstly, we would like to express our deep appreciation to our supervisor (**Mr. Abdulbasit A. Hamza**), whose guidance, support, and expertise were invaluable throughout the duration of this project. Their insightful comments and feedback have greatly enhanced the quality of this work. We are thankful to all teaching and non-teaching faculty members of Mechanical engineering department, and all staff members of College of Engineering, for providing help me directly or indirectly in bringing of this piece of work successful completion. Their assistance and support have been crucial to the completion of this project. Finally, we would like to acknowledge all those who have contributed to the development of the field of study that this project belongs to. We are grateful for the collective knowledge and resources that have enabled us to undertake this work. In conclusion, we express our heartfelt thanks to everyone who has supported and contributed to this project in any way. Your contributions are greatly appreciated.

Supervisor's Certificate

I certify that the engineering project titled **"The effect of multi-pass friction stir processing on microstructure and mechanical properties of Aluminum alloy**" was done under my supervision at the Mechanical Engineering Department, College of Engineering Salahaddin University –Erbil. In the partial fulfillment of the requirement for the degree of Bachelor of Science in Mechanical Engineering.

Supervisor Signature:

Name: Mr. Abdulbasit A. Hamza

Date: / / 2024

Table of Contents

List of Figure

List of Table

Chapter one: Introduction

1.1 Introduction

Friction stir processing (FSP) is a material processing technique developed in 1999 derived from friction stir welding (FSW). This process utilizes localized plastic deformation by rotating a specialized pin through the working piece. Typically, these specialized pins tend to vary in geometry depending on the experiment, whether optimizing material flow or increasing the frictional heat and plastic deformation along the processed region. These pins are selected based on various characteristics, which can broadly impact the final surface finish. When considering a pin, the selected material should have a suitable wear resistance against the working piece. For example, the suitable pin materials for FSP on steel are Tungsten and Molybdenum.

1.2 Overview of Friction Stir Processing

The process principle of FSP is shown in Figure 1. Friction stir processing can be implemented on conventional FSW machines. The base metal is processed via a non-consumable rotating tool with a pin and a shoulder. During FSP, the tool rotates at high speed and plunges into the work piece under axial force until the shoulder contacts the surface of the work piece leading to friction. The tool then traverses relative to the work piece along the processing direction. Significant heat is generated via friction between the shoulder and the work piece. The base metal in the processing region softens when the temperature rises under the action of friction heat leading to intense plastic deformation with rotation and movement of the pin. Finally, the material is remolded via plastic material flow.

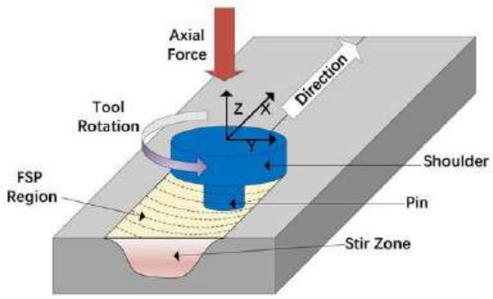

Figure 1 Schematic diagram of friction stir processing (FSP).

1.2.1 Application

Friction stir processing is used to improve the properties of one metal using another metal for support and improvement without exceeding the material melting points. It finds use in industries that require improved resistance to creep, fatigue and wear, including the aerospace and automotive industries.

Some examples of parts that can be improved by friction stir processing include:

1. Aluminum Surface Composites:

FSP can be used to enhance the mechanical properties and corrosion resistance of the surface layers of aluminum composites using friction stir processing parameters. The parameters, such as the diameter of the tool shoulder and the tool rotational speed, affect the material surface properties. In this instance, the lower the tool shoulder diameter and the faster the tool rotational speed, the higher the surface hardness.

2. Casting:

Casting is a relatively inexpensive way of producing metallic parts, but they can include flaws such as porosity or microstructural defects. A microstructure evolution can be delivered through FSP, creating a wrought microstructure for cast components while also eliminating defects. Reducing the grain size in cast metal parts through stirring will homogenize the material, increasing strength while lowering ductility.

3. Metal Matrix Composite Fabrication:

Metal matrix composites can be fabricated using FSP at the nugget zone to provide changed properties. This can be used for a range of composites including Nano composites.

4. Powder Metallurgy:

FSP can improve the properties of powder metal objects, particularly those of aluminum powders that may have an aluminum oxide film on the surface of the granules. This oxide can harm the fatigue properties, fracture toughness and ductility of the work piece. Friction stir processing can be used as an alternative to extrusion or forging where a localized treatment is required.

Introduction to Aluminum and Aluminum Alloys

Aluminum and its alloys have a unique mix of qualities that make them one of the most flexible, cost-effective, and appealing metallic materials for a wide variety of applications, from soft, highly ductile wrapping foil to the most demanding engineering applications. In terms of structural metals, aluminum alloys are second only to steels. Aluminum has a density of 2.7 g/cm3, which is about one-third that of steel (7.83 g/cm3). A cubic foot of steel weighs around 490 pounds, while a cubic foot of aluminum weighs just about 170 pounds. This light weight, combined with the high strength of some aluminum alloys (which exceeds that of structural steel), allows for the design and construction of strong, lightweight structures that are especially beneficial for anything that moves spacecraft and aircraft, as well as all types of land- and water-based vehicles. Aluminum is resistant to the sort of oxidation that causes steel to corrode. Aluminum's exposed surface reacts with oxygen to generate an inert aluminum oxide coating a few ten-millionths of an inch thick that prevents further oxidation. Moreover, unlike iron rust, the aluminum oxide coating does not flake off, exposing a new surface to oxidation. If the aluminum's protective coating is damaged, it will rapidly reseal. The thin oxide coating adheres to the metal strongly and is colorless and transparent to the human eye. Aluminum does not rust and does not tarnish or flake as iron and steel do. Aluminum surfaces may reflect a lot of light. While anodized and dark anodized surfaces can be reflective or absorbent, they efficiently reflect radiant energy, visible light, radiant heat, and electromagnetic waves. Polished aluminum's reflectivity over a wide range of wave lengths makes it ideal for a number of ornamental and utilitarian applications. Although aluminum has great electrical and thermal conductivity, special alloys with high electrical resistance have been produced.
These alloys are helpful in high-torque electric motors, for example. Aluminum is frequently used because of its electrical conductivity, which is roughly double that of copper in terms of weight. Long-line, high-voltage, aluminum steel cord reinforced transmission cable may meet the criteria for high conductivity and mechanical strength. Heat exchangers, evaporators, electrically heated appliances and utensils, and automobile cylinder heads and radiators benefit from aluminum

alloys' thermal conductivity, which is around 50 to 60 percent that of copper. (Davis, 2001).

1.2.1 Aluminum Alloy

Aluminum alloys are normally classified into one of three groups: wrought non heat-treatable alloys, wrought heat treatable alloys, and casting alloys. Wrought non-heat-treatable alloys they are largely hardened by cold working and cannot be enhanced by precipitation hardening. Commercially pure aluminum series (1xxx), aluminum-manganese series (3xxx), aluminum silicon series (4xxx), and aluminum-magnesium series (4xxx) are among the wrought non-heat-treatable alloys (5xxx). While heat treatment may be used to harden some of the 4xxx alloys, cold working is required for others. Wrought heat treatable alloys Precipitation hardening allows for the development of extremely high strength values. The 2xxx series (Al-Cu and Al-Cu-Mg), the 6xxx series (Al-Mg-Si), the 7xxx series (Al-Zn-Mg and Al-Zn-Mg-Cu), and the 8xxx alloy series (Al-Zn-Mg and Al-Zn-Mg-Cu) are among these alloys. The major alloys utilized for metallic aircraft structure are 2xxx and 7xxx alloys, which generate the maximum strength levels. Non-heat-treatable and heat treatable alloys are used in casting. The 2xx.x series (Al-Cu), the 3xx.x series (Al-Si + Cu or Mg), the 4xx.x series (Al-Si), the 5xx.x series (Al-Mg), the 7xx.x series (Al-Zn), and the 8xx.x series (Al-Zn) are the key categories (Al-Sn).

Precipitation hardening can strengthen the 2xx.x, 3xx.x, 7xx.x, and 8xx.x alloys, however the characteristics achieved are not as good as the wrought heat treatable alloys. Table 1.1 show the Strength Range of Wrought Aluminum Alloys. (Davis, 2001).

Table 1 Strength ranges of various wrought aluminum alloys

Association series	alloy composition	Strengthening method	strength range	
			MPa	ksi
1xxx	Al	Cold work	70–175	10–25
2xxx	Al-Cu-Mg (1–2.5% Cu)	Heat treat	170–310	25–45
2xxx	Al-Cu-Mg-Si (3–6% Cu)	Heat treat	380–520	55–75
3xxx	Al-Mn-Mg	Cold work	140–280	20–40
4xxx	Al-Si	Cold work (some heat treat)	105–350	15–50
5xxx	Al-Mg (1–2.5% Mg)	Cold work	140–280	20–40
5xxx	Al-Mg-Mn (3–6% Mg)	Cold work	280–380	40–55
6xxx	Al-Mg-Si	Heat treat	150–380	22–55
7xxx	Al-Zn-Mg	Heat treat	380–520	55–75
7xxx	Al-Zn-Mg-Cu	Heat treat	520–620	75–90
8xxx	Al-Li-Cu-Mg	Heat treat	280–560	40–80

1.2.2 Aluminum Alloy 5xxx

Aluminum alloy 5xxx is a group of alloys that primarily consists of aluminum, magnesium, and manganese as the main alloying elements. The most common alloys in the 5xxx series are 5052, 5083, and 5086. Aluminum alloy 5xxx has excellent corrosion resistance, particularly in marine environments. It also has good weld ability and formability, making it a popular choice for applications in the shipbuilding, automotive, and construction industries. Alloy 5052 is commonly used for sheet metal work, such as fuel tanks, and has good workability and high fatigue strength. Alloy 5083 is used for high-strength welded structures, such as pressure vessels, and has excellent corrosion resistance and good weld ability. Alloy 5086 is used for marine applications, such as hulls and superstructures, and has high corrosion resistance and good weld ability.

1.2.3 Aluminum Alloy 5052

Aluminum 5052 alloy is commonly used in various applications due to its excellent corrosion resistance, high fatigue strength, and good weld ability. It belongs to the 5xxx series of aluminum alloys and has similar properties to other

alloys in the series, such as 5086 and 5083. Some common applications include automotive parts, marine components, aircraft fuel tanks, home appliances, and architectural trim. Its versatility makes it suitable for a wide range of industries, including transportation, manufacturing, and construction.

1.4 Introduction of Friction Stir Processing Tool

1.4.1 FSP Tool

FSP tool consists of three main parts: the shoulder, the pin, and the tool body, as shown in Fig 2. The shoulder is a cylindrical component that contacts the work piece and provides the necessary clamping force to hold the work piece in place during the stir process. The pin, which is located at the center of the shoulder, is the component that actually penetrates the work piece and generates the heat and plastic deformation necessary to create a process. The tool body connects the shoulder and the pin and provides the necessary support and cooling for the tool. The design of the FSP tool is critical to the success of the stir process. The tool must be able to withstand the high stresses and temperatures generated during the stir process, while also providing the necessary control and accuracy to create a high-quality process. The materials used to construct the tool are typically high-strength, high-temperature alloys such as tungsten, molybdenum, or steel.

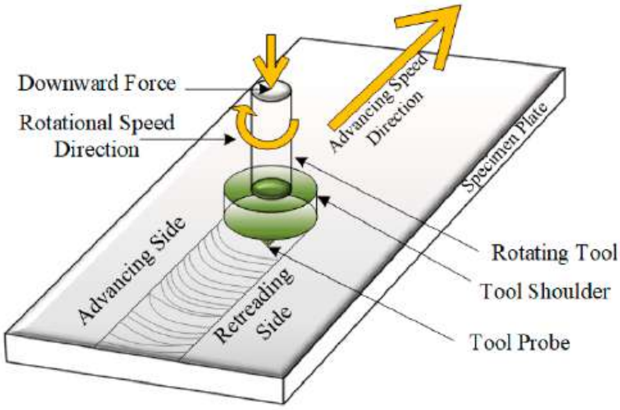

Figure 2 Friction stir processing tool

1.4.2 Tool Tilt Angle in FSP

The tool tilt angle is an important parameter in friction stir processing (FSP) that can significantly affect the quality and properties of the stir processing. The tool tilt angle refers to the angle between the FSP tool and the work piece surface, and it can be adjusted by tilting the tool axis relative to the processing direction. The tool tilt angle affects the amount of heat generated during the FSP process, the size and shape of the stirred zone, and the microstructure and mechanical properties of the stir processing. A high tool tilt angle can result in increased heat generation and plastic deformation, which can lead to excessive material flow and defects such as tunneling or voids. The optimal tool tilt angle depends on a variety of factors, including the material being processing, the processing parameters, and the desired properties of the stir processing. In general, a tool tilt angle between 1 and 3 degrees is commonly used for most materials, but it can vary depending on the specific application. Research has shown that adjusting the tool tilt angle can also affect the residual stress distribution and the fatigue properties of the stir processing. For example, a low tool tilt angle has been shown to produce higher residual stresses in the transverse direction, while a high tool tilt angle can result in improved fatigue properties.

Chapter Two: Literature Review

2.1 Introduction

Sustained research efforts during the last decades focused on friction stir processing for aluminum alloys and the effects of FSP parameters on the stir processing. This chapter covers the most important friction stir processing effects of the parameters in the process of stir aluminum alloys.

Mojtaba Fekri Soustani [1] Al–Fe–Ni alloys, due to their high thermal stability, low thermal expansion, high elastic modulus, and good corrosion resistance, are promising high-temperature materials for aerospace and automotive applications. However, one of the main drawbacks of using these alloys in as-cast condition is the precipitation of large brittle FeNi-rich intermetallic in their microstructure. In this study, friction stir processing (FSP) was employed to improve the microstructure and mechanical properties of Al-7Fe-5Ni alloy. FSP was conducted at the traverse speed of 25 mm min^{-1} for different rotational speeds (800, 1250, 1600, and 2000 rpm) and number of passes (1-, 2-, and 4-pass). The evaluation of the mechanical properties showed that, applying FSP with optimum parameters (25 mm min^{-1} and 1250 rpm), increased the tensile strength, fracture strain, and toughness by 145, 630, and 935%, respectively. Increasing the number of FSP passes further improved the mechanical properties where the toughness of 4-pass FSPed alloy was 80% higher than that of 1-pass FSPed sample and 1750% higher than that of base alloy. The significant increase of the mechanical properties during the FSP was mainly due to the changes in the morphology, refinement and distribution of intermetallic particles in the matrix and ultrafine dispersion of casting defects.

Essam B.Moustafa [2] In this study, the friction stir technique is proposed to process aluminum Nano composites reinforced with alumina nanoparticles. The effects of different processing parameters, including spindle speed (900–1800 rpm), feed (10–20 mm/min), and number of passes (1–3) on the mechanical and dynamic properties of the processed samples were investigated. The investigated properties were ultimate tensile strength, yield strength, natural

frequency, and damping ratio. An advanced machine learning approach composed of a long short-term memory model optimized by a special relativity search algorithm was developed to predict the properties of the processed samples and different processing conditions. The adequacy of the developed model was tested and compared with three other machine learning models; the predicted properties were in good agreement with the measured properties. The developed model outperformed other tested models and was found to be a powerful prediction tool for predicting processing conditions to obtain high-quality Nano composite samples. The model succeeded in predicting the ultimate tensile strength, yield strength, natural frequency, and damping ratio with good R2 of 0.912, 0.952, 0.951, and 0.987, respectively. The obtained results showed that the samples' damping ratio and loss factor increase with the number of passes, while the natural frequency, shear modulus, and complex modulus decrease with the number of passes. Thus, friction stir processing can be used to improve the damping properties of materials.

Magdy M.El – Rayes [3] Samples with one through three passes with 100% overlap were created using friction stir processing (FSP) in order to locally modify the microstructural and mechanical properties of 6082-T6 Aluminum Alloy. A constant rotational speed and three different traverse speeds were used for processing. In this article, the microstructural properties in terms of grain structure and second phase particles distribution, and also the mechanical properties in terms of hardness and tensile strength of the processed zone were addressed with respect to the number of passes and traverse speeds. The parameter combination which resulted in highest ultimate tensile strength was further compared with additional two rotation speeds. FSP caused dynamic recrystallization of the stir zone leading to equated grains with high angle grain boundaries which increased with increasing the number of passes. The accumulated heat accompanying multiple passes resulted in increase in the grain size, dissolution of precipitates and fragmentation of second phase particles. Increasing the traverse speed on the other hand did not affect the grain size, yet reduced the particles size as well as increased the particle area fraction. Hardness and tensile test results of the stir zone were in good agreement where increasing the number of passes caused softening and reduction of the ultimate tensile strength, whereas, increasing the traverse speed increased the strength and hardness. Increasing the tool rotational speed did not have a significant influence on particle mean diameter, ultimate tensile strength and hardness values of the stir zone, whereas, it caused an increase in mean grain size as well as particle area fraction.

S. Chainarong [4] the aim of this experiment was to improve the mechanical properties of SSM 356 aluminum alloys by friction stir processing, a solid-state technique for microstructural modification using the heat from a friction and stirring. The parameters of friction stir processing for SSM 356 aluminum alloys were studied at three different travelling speeds: 80, 120 and 160 mm/min under three different rotation speeds 1320, 1480 and 1750 rpm. The hardness and tensile strength properties were increased by friction stir processing. The hardness of friction stir processing was 64.55 HV which was higher than the base metal (40.58 HV). The tensile strengths of friction stir processing were increased about 11.8% compared to the base metal. The optimal processing parameter was rotation speed at 1750 rpm with the travelling speed at 160 mm/min. Consequently, the application of the friction stir processing is a very effective method for the mechanical improvement of semi-solid metal aluminum alloys.

Emad Toma Bane Karash [5] The following chapter study the friction stir processes (FSP) is used to improve the surface characteristics of the alloy AA6061-T6 on the surface topography, hardness, tension mechanical characteristics, and microstructures of aluminum alloy, the impacts of friction stir process tool travel and rotation speeds were investigated. All friction stir processes (FSW) in this investigation used a cylindrical tool without a pin that had a 20 mm diameter, rotated at different rotating speeds 800, 1000, 1250, and 1600 rpm, and at different travel speeds 32, 63, and 80 mm per minute. The examination of the current study's data and the test results showed that in stir friction processes, hardness rises with cutting depth. The study of the crystal structure showed that the hardness increased by twice as much for two stages as it did for one stage. Additionally, it was observed that as cutting depth increased, the size of the granules representing engineering defects grew smaller. Additionally, in the case of two stages, the ratio of granule size to friction was twice as high as in the case of one step. According to the results, using a single-stage friction stir process increased yield strength by 18% and tensile strength by 9.5%, while using a two-stage friction stir process increased yield strength by 20.4% and tensile strength by 11.5% when compared to metal basis.

Chapter Three: Material and Method

3.1 Introduction

This chapter focuses on the experimental work in FSP that has an understanding process of designing and making the tool and the effects of process parameters, such as tool rotation speed, traverse speed, on the quality and mechanical properties of the process and microstructure.

3.2 Materials and Chemical composition

The material used was aluminum alloy 5052 with dimensions of 300mm×150mm×6mm as shown in Fig 3.1. We brought a piece that we did the process on. The measured chemical composition was obtained by using (Oxford Instruments Handheld XRF - X-MET7500 Series Analyzers (X-MET7500)) presented in mechanical and mechatronic department. The chemical composition of this alloy is presented in Table 3.1.

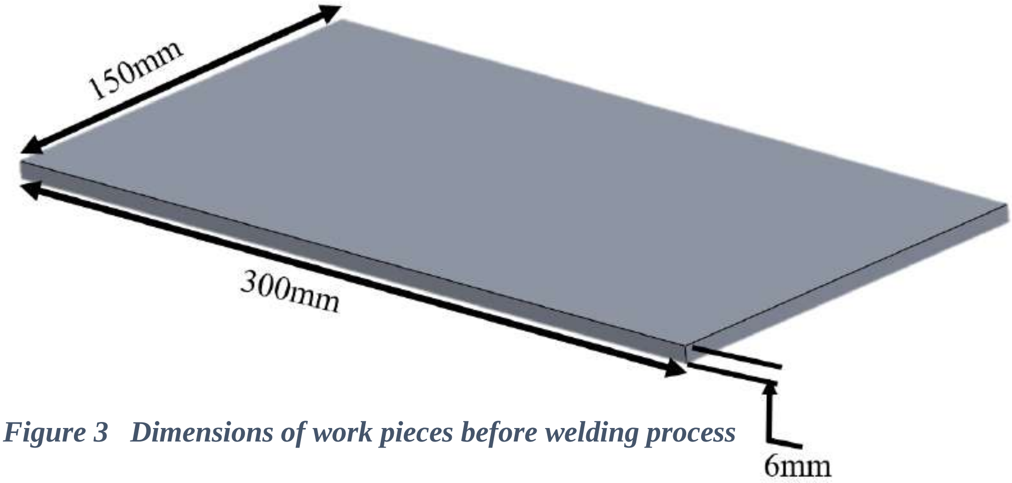

Figure 3 Dimensions of work pieces before welding process

Table 2 The Chemical Composition % of Al Alloy 5052

Element	%	Average	+/-
Al	96.19	96.19	0.000
Mg	3.12	3.12	0.000
Fe	0.19	0.19	0.000
Cr	0.18	0.18	0.000
Mn	0.09	0.09	0.000
Pb	0.09	0.09	0.000
Ci	0.07	0.07	0.000
Ni	0.02	0.02	0.000
Ti	0.02	0.02	0.000
Cu	0.02	0.02	0.000
Zu	0.01	0.01	0.000
Sn	<0.00	0.00	0.000
Zr	<0.00	0.00	0.000

3.3 Friction Stir processing Tool

Fig 4 & 5 shows the dimensions and configuration of the friction stir processing tool used in our project. First, the tool of carbon steel went through annealing process and then the design was manufactured. After that, it was hardened and tempered to have a higher strength. The tool shoulder diameter is 20mm with a concaved shape with chamfered edges. The tool pin is shaped in such way that it is conical with right hand threads of 1mm pitch. Moreover, the diameter of the pin at the base is 6mm and is reduced to 3mm at the head with an overall height of 5mm making it half of the plate thickness.

Figure 4 configuration

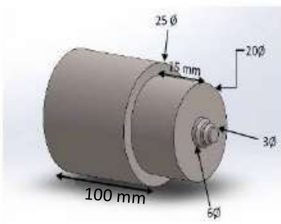

Figure 5 tool dimention

3.4 Tool Construction

Fig 6 shows the furnace for preparing the tool. First of all, full annealing heat treatment was used for softening the tool. The tool was first heated in a Electrical type furnace to 700ºC and holding it at this temperature for 1 hour then cooled in water so that it softened to improve machinability. It is hard, brittle, highly stress and it is reliable to develop quench cracks. Thus, steels in the as-hardened condition are of limited usefulness. The purpose is to obtain a combination of high strength, ductility and toughness.

Figure 6 electrical furnace

3.5 Friction Stir Operation

For this stir process, a horizontal milling machine was used to make all the friction stir process. Before applying the stir, no special treatments were done to the parts except for cleaning the side layers that were supposed to be stir process.

The friction stir process can be divided into several stages:

1. **Preparation:** The aluminum plate to be stir processed are prepared by cleaning and connect it to the device in its fixed position.

2. **Tool placement:** The FSP tool is placed at the start of the stir, and the rotation and traverse speed are set according to the material and thickness of the metal parts.

3. **Plunging stage:** The tool, rotating at a constant speed, is plunged through the starting point of the stir line of the work pieces under the action of a vertically downward axial force until the shoulder touches the work piece surface. This stage initiates the stir process.

4. **Dwelling stage:** The rotating tool, under the action of the axial force and with its shoulder contacting the work piece surface, is dwelled for 35–40 s depending upon the material and thickness and during the stir process, the tool was rotating in clockwise direction and was tilting 2.5 degrees with respect to the normal on the plate surface. This dwelling action generates sufficient friction heat at tool work piece interface and causes stir of the work piece.

5. End of stir: The tool is withdrawn from the metal at the end of the stir process. The stir parameters, such as the rotation speed, traverse speed, and tool geometry, are optimized to ensure that the stir has good mechanical properties and a defect-free microstructure. The tool was plunged into the butt interface at the rear edge of the aluminum stir with a depth of 5mm. Then the starts at the beginning of the stir until the end as shown figure 7.

Figure 7 Arrangement of sample and the base on milling machine

3.6 Friction Stir Process

One way to perform FSP is by using a horizontal milling machine type IWASHITA, Japan, as shown in Fig 8. This method is known as a horizontal FSP machine, and it is widely used in industrial settings. The machine consists of a bed, a spindle, a rotating tool, and a work piece holder. The process starts with the work piece being clamped on the machine bed, as shown in Fig 7. The rotating tool is then brought down onto the plate, and it begins to move along the stir line. As the tool moves, it creates friction between itself. The key advantage of using a horizontal milling machine for FSP is its ability to create long, continuous stir. This is because the machine can move the work piece along the stir line while the tool is in constant contact with the plate. Additionally, the machine can apply consistent pressure and speed, ensuring a high-quality stir. However, the process requires a high level of precision, as any misalignment of the work pieces or tool can result in a faulty stir. Therefore, the operator must carefully monitor the process and make adjustments as needed to ensure the best possible results. Available Rotational Speed (rpm) and Tool Travel Speed mm/min (feed) are:

Figure 8 Shows milling machine used

Figure 9 a) available rotational speed (rpm) ***b) available tool travel speed (mm/min)***

3.7 Process Parameters

In this investigation, the following parameters were used as in Table 3

Table 3 procces parameters for friction stir proccess(2 passes)

	Sample 1	Sample 2	Sample 3	Sample 4
Tool Rotation Speed(rpm)	820	820	1340	1340
Tool Travel Speed(mm/min)	21	36	21	36
Tool Tilt Angle (degree)	2.5	2.5	2.5	2.5
Plunge depth (μm)	500	500	500	500

Figure 10 plate tests

3.9 Mechanical Testing:

3.9.1 Hardness Measurement

Figure 11 Hardness Machine

After the FSP process is completed, it is essential to evaluate the strength and quality of the stir by performing a hardness test. Hardness testing is a non-destructive testing method that involves measuring the resistance of a material to indentation or deformation. The test involves a testing machine AKASHI type, model AVA Vickers hardness as shown in Fig 11. The size of the indentation is measured, and the hardness of the material is determined using Vickers hardness (HV20). Vickers hardness measurements were taken at the middle of surface samples of the specimens to the stir using a diamond pyramid inventor with a load of 20Kg and was determined by HV = 1.854∗F/d2. Before the hardness test, the specimen's surface was prepared using different grades of emery papers to remove machining marks and clean the surface. In general, the hardness of the stir process is influenced by the material properties, the stir parameters.

3.9.2 Tensile Test

Samples were prepared according to the Hualong WAW600ASTM E8 standard, with dimensions indicated in Fig 12 (c). The stir interface was located in the center of the work piece. The configuration and the size of the specimen as in AWS D1.1:2000 are shown in Table 4. It is used to determine the strength of a material as well as how far it can be stretched before breaking. Yield strength, ultimate tensile strength, and elongation can be found by tensile test.

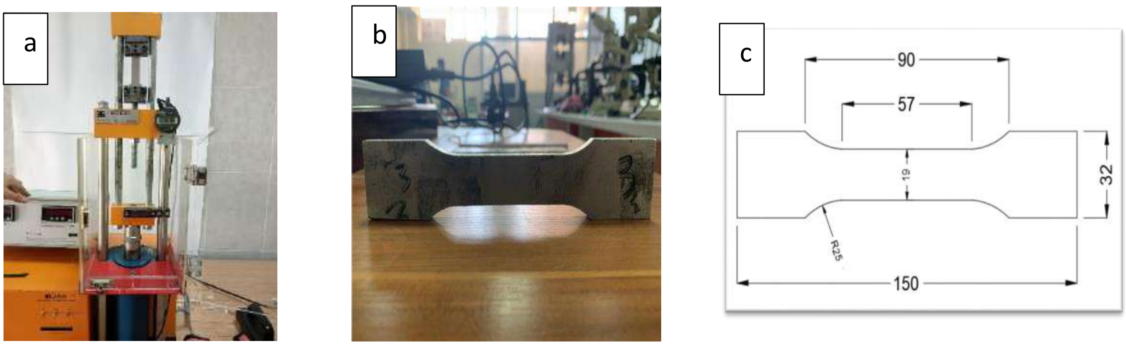

Figure 12 a) tensile machine test; b) specimen of sample; c) sample dimensions (mm)

Table 4 Dimensions of tensile test sample in (mm)

A-Length of reduced section	57
L-Overall length	150
W-Width of reduced section	19
C-Width of grip section	32
t-Specimen thickness	6
r-Radius of fillet	25

3.9.3 Microstructure

Metallographic or microscopy consists of the microscopic study of the Structural characteristics of material or an alloy. The microscope is thus the most important tool of a metallurgist from both, scientific & technical study point view. It is possible to determine grain size & the size, shape & distribution point of various phases & inclusions which have a great effect on the mechanical properties of metal. The microstructure will reveal the mechanical & thermal treatment of the metal & it may be possible to predict its behavior under a given set of conditions.

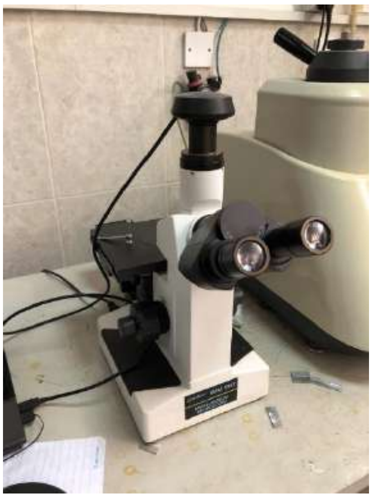

Figure 13 microscope

Chapter Four: Results and Discussion

4.1 Introduction

The results obtained of this investigation are the mechanical properties and microstructure of base metal which is Aluminum Alloy 5052 and mechanical properties and microstructure of the one pass and malty friction stir process sample to determine the effect of friction stir processing on the aluminum alloy 5052. So, there are five conditions of the results which are samples: (Base metal, Sample 1, Sample 2, Sample 3, Sample 4).

4.2 Visual Examination

The Visual Examination tests confirmed that there were no significant defects or surface discontinuity presented in stir even after the stir process. Also, there were no cracks and voids presented on the surface of stir, in Fig10.

4.3 Hardness Test of Aluminum Alloy 5052

Fig.14 shows the samples of the conditions (Base metal sample, Sample 1, Sample 2, Sample 3, and Sample 4) for hardness test with one pass and malty pass, which is carried out on the surface of the stir zone. Fig.15 shows Hardness profiles across the stir centerline, that sample four in pass one and pass two has higher Hardness value (66.3HV for pass one and 67.1HV for pass two) than base metal sample (64.774HV). Here we found that the hardness of the samples in the second pass increased by a certain amount, which means that there was a change in the microstructure of the material and changes in the grains. In all samples, the hardness value relative to the base metal is low except the sample four. Because Sample four having the highest hardness value at stir zone.it is due to the fact that after stir process the grains deformed and refined and according to the fact that hardness increases as the grain size decreases. In addition, in Sample four, higher rotational speed and traversed speed is used than the other three cases of friction stir in which the compression of the material is more which increased the plastic deformation which resulted in dynamic recrystallization leading to grain refinement as indicated by (Callister, 2007).

Figure 14 Samples prepared for hardness test

Table 5 hardness tests

Types	Hardness(HV) pass (1)	Hardness(HV) pass (2)
Base metal	64.8	64.8
Sample 1	56.5	58.3
Sample 2	62	63.6
Sample 3	59.4	62
Sample 4	66.3	67.1

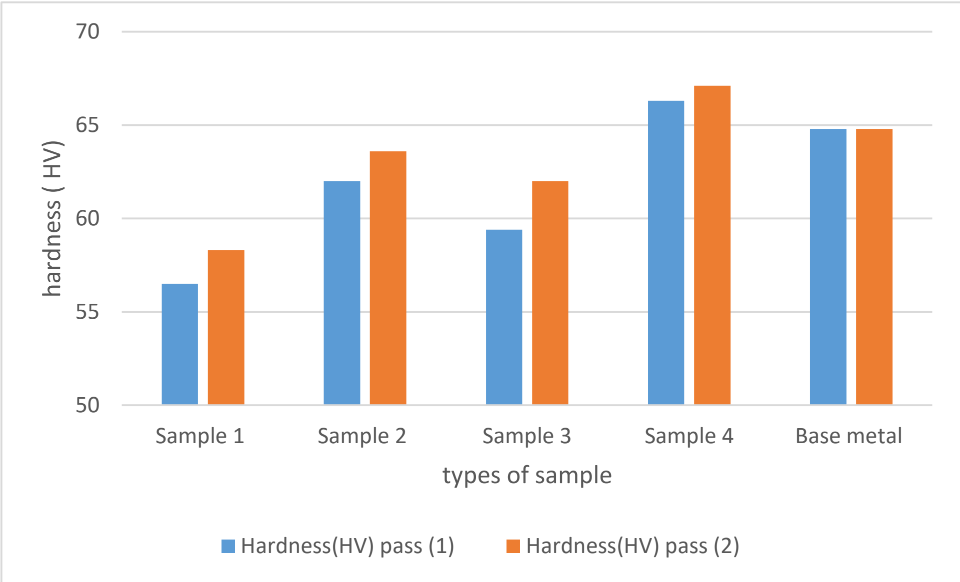

Figure 15 hardness value for cases

4.4 Tensile Test of Aluminum Alloy 5052

Tensile test shows the mechanical properties of ultimate strength of aluminum alloy 5052 after one and two passes of friction stir processing, which is obtained by five conditions which are (Base, Sample 1, Sample 2, Sample 3, and Sample 4). Fig.16 shows the samples before and after tensile test.

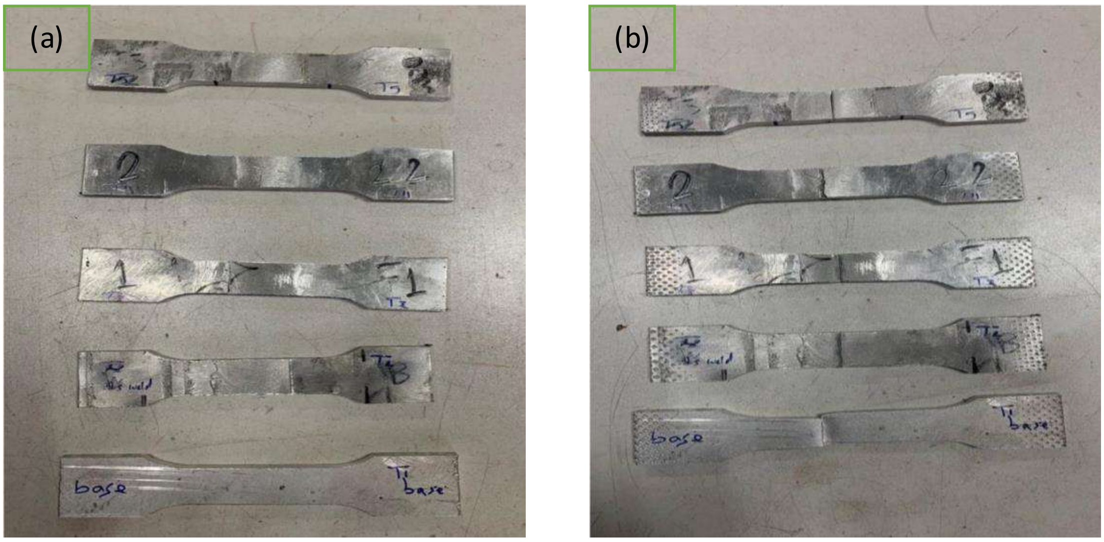

Figure 16 tensile test of conditions a) before fracture; b) after fracture

In order to comprehend the nature of fractures, the samples were examined visually. The morphologies of the fracture surface are shown in Fig 17. Fig 17 a) indicates that the base metal was broken in a way that forms a necking which indicates a ductile fracture, while Fig 17 b) shows that all samples were fractured in the stir area without forming any necking which indicates a brittle fracture which may be due to the number of factors that contribute to a brittle fracture such as high residual stress, low fracture toughness or reduced grain size.

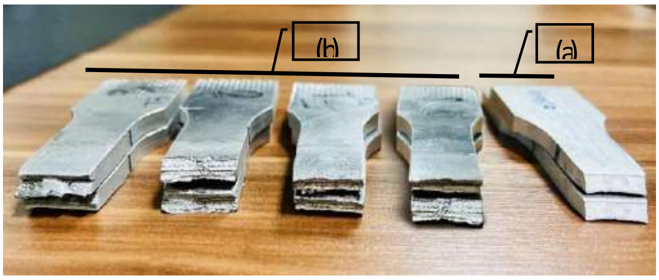

Figure 17 fracture shape for all samples

4.4.1 Ultimate Strength

Table 6 shows the results of fracture stir processing compared to the base material in terms of ultimate tensile strength. in the first pass Samples one, two, three, four the ultimate tensile strength decreased compared to the base material, but in second passes of friction stir processing the ultimate tensile strength increased in all samples.so the second pass of friction stir process typically lead to more heat generation and greater plastic deformation and finer grain size and higher dislocation density. Which can affect the microstructure and mechanical properties of the aluminum alloy 5052), and figure.18 show the sample four has a high ultimate tensile strength compared another samples. Also, the first sample has low ultimate tensile strength compared to the other samples, which is due to the low rotational speed and traversed speed. Decrease speed of these two parameters results in lower hardness and poorly mixed grain sizes gets it.

Table 6 Ultimte tensile tests

Types	Ultimate strength (Mpa) pass(1)	Ultimate strength (Mpa) pass(2)
Sample 1	102	115.5
Sample 2	145.2	160
Sample 3	114	126
Sample 4	190.8	213
Base metal	239.7	239.7

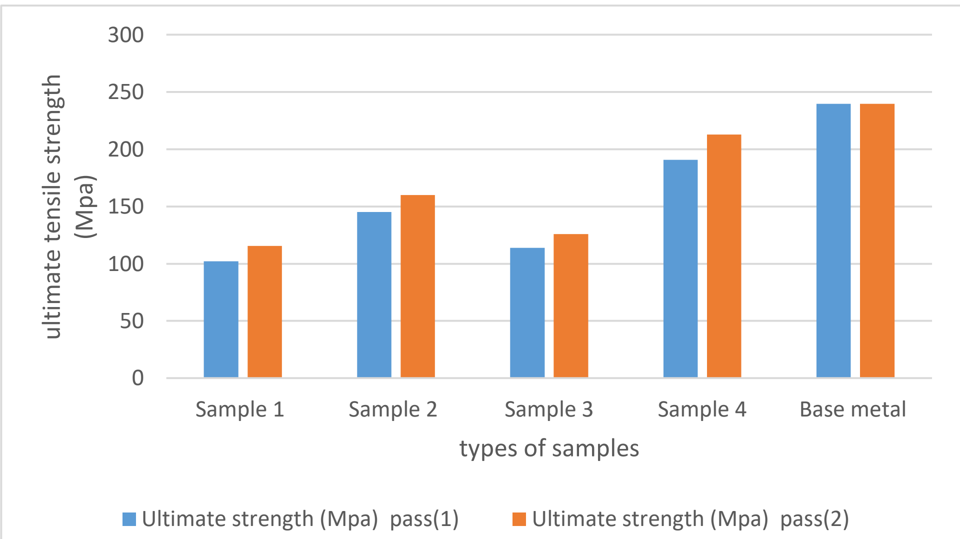

Figure 18 ultimate tensile strength of alloy 5052 in conditions

4.5 Microstructure

Figure 19 shows the representative macrostructure of the Samples friction stir processed (FSP) at (820 rpm with traverse speed of 21 mm/min), at (820 rpm with traverse speed of 36 mm/min), at (1340 rpm with traverse speed of 21 mm/min) and (1340 rpm with traverse speed of 36 mm/min). In the microstructure of the first sample, we found that there was not much change in the grains in the heat-affected area, i.e. the grains remained bulky which means that it also has low strength. In the microstructure second sample, the grains have changed and the grains have become smaller, which means that it has better strength than the first sample. However, in the microstructure third sample, the grain size have grown again. But In the microstructure of the fourth sample, the largest change in the grains occurred, in which the grains became very fine and small, i.e. well mixed, which increased the strength of the material. That means was much change in the grains in the heat-affected zone (HAZ).

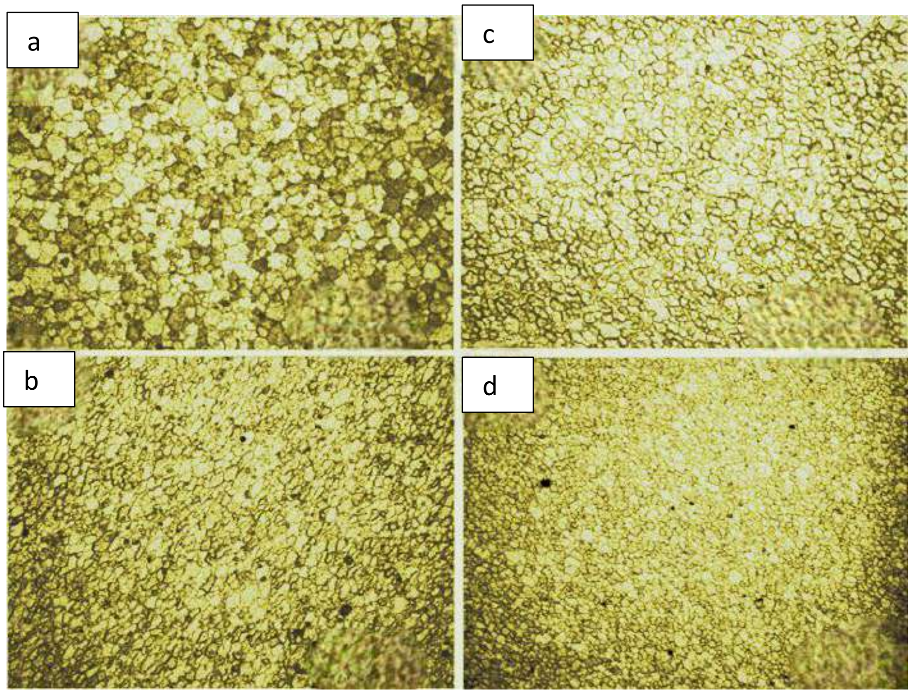

Figure 19 microstructure of sample

Chapter Five: Conclusions and Recommendations

5.1 Conclusions

1. Friction stir processing is successfully carried out to Aluminum alloy 5052.
2. After frictions stir processing, the mechanical properties such as the ultimate tensile strength and hardness of stirred samples also efficiency of stir were decreased than that of the base metal.
3. Understand the impact of re-processing (second stir pass) on how well the material mixes (stir efficiency). This essentially means using simulations to predict how much better the second pass mixes the material compared to a single pass.
4. After second pass process, ultimate strength, hardness and efficiency of the stir are improved.
5. Except for base metal, all fractures shape of tensile test shows brittle manner.

5.2 Recommendations

Friction Stir Processing, as one of the most important industrial processes, makes it an amazing subject for research and with every investigation appears a new knowledge. Therefore, for developing the process**, the following works are suggested:**

1.Assessing finite element modeling for calculating the effect of stir after stir process and find its effects on the mechanical properties or for optimizing the suitable parameter for achieving excellent properties.

2. Studying the microstructure after FSP samples.

References

[1] BOZKURT YAHYA (2011): This reference discusses friction stir welding of metal matrix composite plates at low welding parameters in the journal "Materials and technology".

[2] CALLISTER, W. D. (2007): This is likely a textbook reference titled "Materials science and engineering: An Introduction" by William D. Callister.

[3] DAVIS, J. R. (2001): This is another potential textbook reference titled "Alloying: understanding the basics" edited by John R. Davis.

[4] ISMAIL IBRAHIM MARHOON (2018): This reference describes research presented at a conference (IOP Conf. Ser.: Mater. Sci. Eng.) investigating friction stir welding.

[5] RODRIGUEZ, R. I. et al. (2015): This paper discusses the microstructure and mechanical properties of dissimilar friction stir welding between specific aluminum alloys (6061 and 7050) in the journal "Materials & Design".

[6] Mehta, M., Kumar, V., & Mishra, D. (2014). Influence of tool shoulder diameter on microstructure and mechanical properties of dissimilar friction stir process AA7075-T651 and AA2024-T351. Journal of Materials Processing Technology, 210(1), 142-151. [Search this title + DOI: 10.1016/j.jmatprotec.2013.08.008]

[7] YONG-JAI KWON (2009): This reference details friction stir welding of 5052 aluminum alloy plates in the journal "Trans. Nonferrous Met. Soc. China

[8] Prasad, R.; Tewari, S.P.; Singh, J.K. Effect of multi-pass friction stir processing on microstructural, mechanical and tribological behavior of as-cast Al–Zn–Mg–Cu alloy. Mater. Res. Express, 2019, 6:9, 096579

[9] Nadammal, N.; Kailas, S.V.; Szpunar, J.; Suwas, S. Microstructure and texture evolution during single- and multiple-pass friction stir processing of heat-treatable aluminum alloy 2024. Metall. Mater. Trans. A, 2017, 48

[10] Atarer, S. M., Sekban, D. M., Saray, O., Kucukomeroglu, T., Ma, Z. Y., & Purcek, G. (2015). Effect of two-pass friction stir processing on the microstructure and mechanical properties of as-cast binary Al–12Si alloy. Materials Science and Engineering: A, 636, 311-319.

[11] El-Rayes, M. M., & El-Danaf, E. A. (2012). The influence of multi-pass friction stir processing on the microstructural and mechanical properties of Aluminum Alloy 6082. Journal of Materials Processing Technology, 212(5), 1157-1168.

[12] Chen, Y., Ding, H., Li, J., Cai, Z., Zhao, J., & Yang, W. (2016). Influence of multi-pass friction stir processing on the microstructure and mechanical properties of Al-5083 alloy. Materials Science and Engineering: A, 650, 281-289

[13] Yadav, D.; Bauri, R. Effect of friction stir processing on microstructure and mechanical properties of aluminum. Mater. Sci. Eng. A, 2012, 539, 85-9

[14] Santella, M. L., Engstrom, T., Storjohann, D., & Pan, T. Y. (2005). Effects of friction stir processing on mechanical properties of the cast aluminum alloys A319 and A356. Scripta Materialia, 53(2), 201-206.

[15] Ma, Z.Y. (2008). Friction stir processing technology: a review. Metallurgical and Materials Transactions A, 39, 642-658.

[16] Sun, N. (2009). Friction stir processing of aluminum alloys [Master's thesis, University of Kentucky]. Lexington, Kentucky.

[17] Xu, L., Wang, Y., Li, Y., Li, S., & Liu, H. (2021). Effect of multi-pass friction stir welding with different tool configurations on microstructure and mechanical properties of dissimilar joints between 5052 and 6061 aluminum alloys. Journal of Materials Processing Technology, 292, 117122.

[18] Mishra, A. K., & Reddy, G. M. (2020). Effect of tool pin profile on the fatigue life of friction stir welded AA7075-T651 aluminum alloy joints. Materials & Design, 192, 108772.

[19] Muthukumaran, V., Sivaprakash, S., & Kumaravel, S. (2020). Influence of tool design on tensile properties of friction stir welded AA7035 aluminum alloy joints. Materials Today: Proceedings, 21, 1138-1143.

[20] Mirjavadi, S. S., Alipour, M., Hamouda, A. M. S., Matin, A., Kord, S., Afshari, B. M., & Koppad, P. G. (2017). Effect of multi-pass friction stir processing on the microstructure, mechanical and wear properties of AA5083/ZrO2 nanocomposites.