An Experimental Study on Friction Stir Processing of AA-7020 Aluminum Alloy

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ABSTRACT

Friction stir processing (FSP) as a promising thermo mechanical approach aims on altering the microstructural and mechanical properties of material in order to obtain the highest performance (increasing or decreasing of hardness and tensile) in terms of properties, cost and lead time.

This study addresses FSP of AA-7020 aluminum alloy. The effect of variation in the ratio of rotational and translational speeds (i.e., ω/f) is examined on the mechanical properties and microstructure of AA-7020 aluminum alloy. The value of ω/f (ω is rotational speed f is feed rate) is varied from 22 rev/mm to 125 rev/mm. The results show that with increasing ω/f, the grain size decreases. When ω/f (ω is rotational speed f is feed rate) ranges from 22 to 28, average hardness, ultimate strength and yield strength increase from 75 HV to 103 HV, from 313 to 364 MPa and from 173 MPa to 208 MPa, respectively. However, for ω/f ranging from 28 to 125, a reduction has been noticed in these properties. Regarding microstructure, it is found that the size of grain in the processed zone is small and the direction of grain is random. Besides mechanical properties, observations regarding the effect of ω/f on surface quality are also made to show that larger values of ω/f lead to poor surface texture.

Keywords: Friction Stir Processing, Hardness, Impact, Quality, Microstructure, Tensile, AA-7020.

ÖZ

Sürtünme hareketlenme işlemi (FSP) termo mekanik işleme tekniklerini kullanarak malzemelerin mikroyapı ve mekanik özelliklerini değiştiriyor ki bu üretim masraflarını ve zamanı azaltıyor ve yüksek performans elde etmeğe neden oluyor.

Bu çalışmada, Sürtünme hareketlenme işlemi (FSP) soğuk çekilen AA-7020 alaşımı üzerınde kullanılmıştır . Dönme ve öteleme hızı oranı (ω/f), 22 ve 125 (devir/mm) arasında değişmiştir. Adı geçen parameternin mikroyapı ve mekanik özellikler etkilamasi incelenmiştir.Sonuçlarına göre, FSP tanelerin boyunu operasıyon bölgesınde azaltmştır.Nezaman ω/f artmışsa tanelerin boyu azaltmştır. Beli bir aralık için, 0 ile 22 arasında ortalama sertlik artmıştır ve 0 ile 22 aralık için arasında gerilme mukavemeti artmaktadır ki bunlar soğuk çekilen malzemelerin darbe dayanımı ve yumuşaklık azalmasına neden oluyorlar.Halbuki, daha sonra ortalama sertliği 28 ve 125 oranlar arasında ve gerilme mukavemeti 28 ve 125 oranlar arasında ters oluyor.Yukarıdaki parametrenin etkisi yüzey kalitesi nin üzerine görsel olarak gözlenmiştir. Bulunmuştur ki yüzey kalitesi,, ω/f artmasıyla iyileşmektedir. Mikro sonuclarına göre operasıyon bölgesınde tanelerin boyu küçük ve onların yönleri belirsizdir. Beli bir aralık için, 0 ile 22 arasında malzemelerin darbe dayanımı artmıştır Halbuki, daha sonra tekrar azalmıştır.

Anahtar Kelimeler: Sürtünme hareketlenme işlemi,Mikroyapı, Sertlik, Çekme Darbe, Kalite,AA-7020.

To My Parents

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LIST OF SYMBOLS AND ABBREVIATIONS

AA	Aluminum Alloy
AL	Aluminum
ASEM	American Society for Engineering Management
BM	Base Material
CNC	Computer Numerical Control
Cr	Chrome
Cu	Cupper
ECAE	Equal Channel Angular Extrusion
F	Traverse Speed
Fe	Iron
FSP	Friction Stir Processing
GPA	Giga Pascal
H	Hardened
HAZ	Heat Affected Zone
HB	Bernie Hardness
HV	Vickers Hardness
LM	Light Metallography
Mg	Magnesium
Ml	Mill Liter
Mm	Millimeter
Mm/min	Millimeter over Minute
MN	Manganese
MPA	Mega Pascal
OIM	Orientation Imaging Microscope
P	Paper
Rev/mm	Speed over Millimeter
RPM	Rapid Per Minute
SEM	Scanning Electron Microscope
Si	Silicon
TEM	Transmission Electron Microscope
Ti	Titanium
TMAZ	Thermo Mechanical Affected Zone
TWI	Technique Welding Institute
VHN	Vickers Hardness
Zn	Zinc
ω	Rotational Speed (RPM)
ω/f	Rotational Speed over Traverse Speed (rev/mm)
°C	Centigrade
µm	Micro Meter

Chapter 1

INTRODUCTION

1.1 Background

1.1.1 Heat Treatment

The process of altering the physical and in some cases chemical properties of materials for instance metals, by using of heating or chilling and cooling is called “Heat Treatment”. Moreover, heat treatment is applicable in glass industry.

Considering that there is a relationship between the microstructure and properties of material, while heat treatment changes the microstructure, at the same time effects on the mechanical properties of material as well. Therefore, various heating/cooling combinations lead to have a wide range of mechanical properties [1].

1.1.2 Importance of Heat Treatment

Heat treatment modifies the strength of material. The cold working process in heat treatment causes to recover the ductility of material. This issue leads to have improvement in machinability and formability of material.

Employing appropriate heat treatment method leads to get the desired attributes of materials. This notable property has made the head treatment to be a favorable material processing approach in manufacturing, engineering and industry.

1.1.3 Methods of Heat Treatment

1.1.3.1 Normalizing

Normalization is done for the purpose of affording uniformity in the grain size and internal structure of alloy. It is intensity applicable for ferrous alloys which have been faced with austerity and then have been cooled gradually in the open air [1].

The products such as Martensite, Pearlite and Bainite are produced by using normalizing process. Although normalizing effects on hardness of steel which makes it stronger but compared with full annealing on some compositions it leads to have less ductility.

1.1.3.2 Precipitation Hardening

This is a heat treatment technique which is employed to enhance the yield strength of the materials. It relies on hardening metal which is done by motivating the second phase particles in the parent phase of material. Non-ferrous material and some types of stainless steels may have been used in precipitation hardening process [1].

The next step is quenching the material in water to get low temperature until the second phase particles are induced which leads to increase the strength of the metal.

1.1.3.3 Annealing

Annealing is a heat treatment which the temperature of material increases to the specific rate and then decreases with cooling process to a defined rate.

This process alters the microstructure of material. The process of cooling in the annealing normally is performed slowly. The applications of annealing are such as improving the machinability of material, making softer material for some purposes like cold working and altering the properties of material in order to increase the electrical conductivity [1].

1.1.3.4 Carburizing

Carburizing is a heat treatment process with the intent of making the component's surface harder by heating the material with using the diffusion of carbon. The material will be cooled rapidly by quenching and the process continues with tempering the material [1].

1.1.3.5 Stress Relieving

Stress relieving is the procedure of decreasing the internal stress of material which may occur for some reasons such as cold working or non-uniform cooling.

The two phases of relieving the stress of a metal are heating it less than the critical temperature and subsequently making it cool uniformly [1].

1.1.4 Drawbacks of Heat Treatment

Besides of all applications of heat treatment and its usefulness in industry, still it confronts with some problems such as difference in mechanical properties, component's surface decarburization, heavy surface oxidation and cracking.

In addition, the component distortion which is happened during the operations should be recompensed by providing warp age allowance. The allowance used in process causes to have more accurate product but higher product cost.

In fact, the heat treatment is an expensive process since it contains high consumption of energy. Moreover, it requires extended lead times in order to leave metal for heating.

1.1.5 What is FSP (Friction Stir Processing)

As it was mentioned before, there are various thermo mechanical methods. FSP which stands for Friction Stir Processing, inheritances its principles from friction stir welding (FSW) [2]. FSP was invented to alter the internal structure of materials resulting desired mechanical properties with the lowest lead time and cost. It is expected that the total production time and cost in FSP is less than heat treatment method [3] [4]. FSP is a multipurpose method since it has extensive applications such as fabrication, processing, and synthesis of materials.

1.1.6 Advantages of Friction Stir Processing

Choosing a material with suitable attributes and properties is one of the most important parts in lots of industrial applications. Selecting an alloy which has desired properties such as appropriate strength and uniform grain structure is extremely definitive in industries such as aircraft and automotive.

The major purposes which caused to present new material processing methods may are driven from the need of producing a material with small grain size and adequate strength and ductility while the amount of consumed time and cost is acceptable.

There are lots of material processing methods such as FSP and Equal Channel Angular Extrusion (ECAE) which both achieved desired goals. Moreover, these methods strived to improve the conventional processing methods such as the Rockwell and powder metallurgy approaches [5].

Some advantages of FSP which make it distinguished from other metalworking techniques are in following [6][7]:

1. It can be done in a single pass microstructural purification, densifying and homogenizing [8].

2. The behavior of microstructure and mechanical properties of the processed zone can be conducted by tuning the FSP parameters and activating cooling or heating.

3. Adjusting the length of the rotational pin tool provides the possibility of supervision on depth of the processed zone. This ability shows the flexibility of FSP in supporting the several depth ranges from tens of millimeters to hundred micrometers.

4. Since the process of making the input heat is done by using friction and plastic deformation; therefore it is green and energy efficient method. Moreover, the process of FSP does not produce any hurtful gas or radiation and noise.

5. Employing FSP method does not alter the size and shape of the material and keeps them intact.

6. Since FSP process can be performed using any available machines such as conventional milling, and there is no need to any especial facilities and equipment, so it is a reasonable method.

1.1.7 Fundamental of Friction Stir Processing

FSP operation is called as a solid state process since the materials which are used in this process are in the solid form. The rotational tool which is used in FSP is composed of a pin and shoulder with an adequate dimension which is well proportioned with the sheet diameter. The pin is pushed into the surface of the sheet so it can traverse in the defined direction (Figure 1.1). The produced heat through touching the rotational tool and the sheet, moderates the hardness of the material. Moreover, recrystallized grains are obtained when the material inside the processed zone, tolerates extreme plastic deformation.

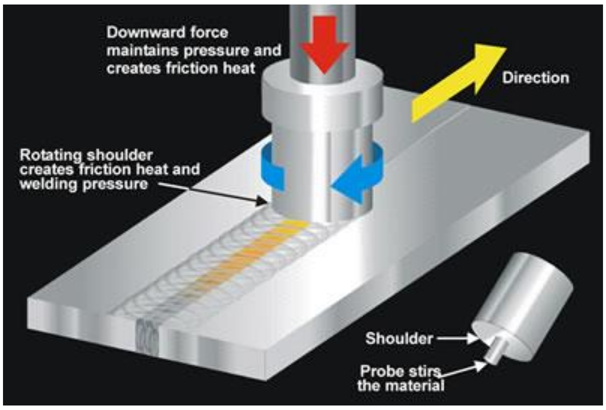


Figure 1.1: The Fundamental of FSP, tool used and traverse direction [4].

1.2 Motivations

According to the mentioned advantages of FSP, it is a highly efficient and adaptable process and is going to be supplanted by the usual property modification techniques. But it is still new. Since it is not employed widely therefore there is a need to enhance the knowledge on different conditions of process. For instance, in commercial usage, for achieving the optimal grain size the value of some tuned parameters like rotational speed (ω) and traverse speed (f) may need to be determined exactly. However, in general they are not constant for all materials.

In this research the sample material used is AA-7020 because of its superiorities properties such as proper machinability, suitable resistance and low cost which have made it a functional material in aircraft, aerospace and automobile industries as well.

1.3 Thesis objectives

The objectives of the current study are mentioned as follow:

1. An investigation on microstructure of the AA-7020 alloy will be done to know the influence of variation ω/f in FSP.

2. Hardness, tensile strength and impact tests which reveal the mechanical behavior of material considering various circumstances such as speed and feed rates will be investigated.

3. Two processed and unprocessed zones will be compared with each other based on their microstructure and mechanical properties.

4. The consequence of altering mentioned parameters on surface quality will be investigated.

1.4 Thesis organization

The following chapters and subjects of this dissertation are: Chapter 2 mentions to the overview of FSP and its applications as well as an exhaustive literature review. In Chapter 3 methodology, experimental setup, procedure and microstructural investigation have been described. Chapter 4 presents the obtained experimental results as well as comparing the properties of processed and unprocessed material. Finally Chapter 5 contains conclusion and future works related to the objectives of the current study.

Chapter 2

LITERATURE REVIEW

2.1 An Overview of Friction Stir Processing

The tool used in FSP is non-consumable cylindrical tool which is composed of a pin and a concentric large diameter shoulder (Figure 2.1).

The tool functions in this way that, firstly with using an appropriate machine to turn the pin it will be pressured into the alloy, then the shoulder goes through the surface to the defined direction. The produced heat through touching the rotational tool and the sheet causes to soften the hardness of the material. It is noticeable that the produced heat during the process does not catch to the melting degree so this process is referred as a solid state process.

As it was mentioned, during the process the pin rotates, the rotation is not exciting action so that cause to plastic deformation instead it produces dynamically-recrystallized grain structure which is the major advantage of this process.

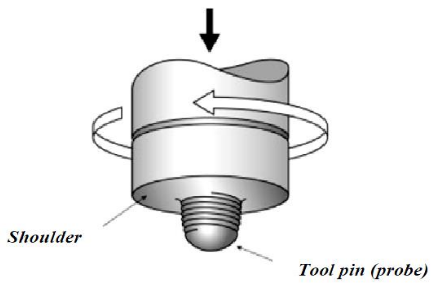


Figure 2.1: The Tool Used [4].

The FSP can be enumerated as a hot working process because of the deformation of the work piece which is generated when the pin and shoulder are rotating. The produced deformation causes to enhance a weld nugget, a heat affected zone (HAZ) and a thermo mechanically affected zone (TMAZ). These three welding zones are shown in Figure 2.2.

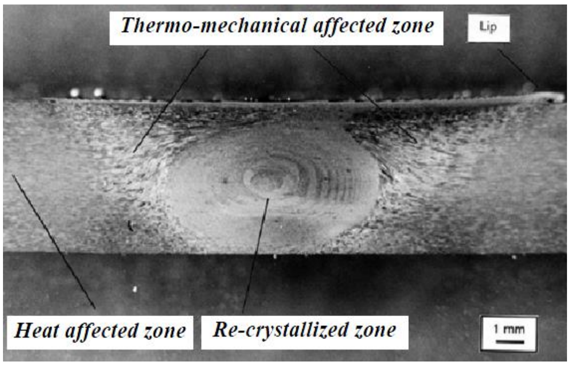


Figure 2.2: The Schematic of Welding Zones

2.2 Major Applications of Friction Stir Processing

FSP is applicable in lots of field in industry such as aircraft, aerospace, shipping and automotive. The major applications of FSP in aerospace industry are fixing battered aircrafts, rivet substituting and assembling [9.10].

Moreover, FSP is applicable in automotive and shipping industries in such a manner that the AL alloy sheets will be attached to each other while provide the minimum weight and fuel consumption and maximum improvement in the speed [3.4].

2.3 Previous Works

Lots of researches have been done in the field of friction stir welding on aluminum alloys. Generally these researches have concentrated on the grain size of weld zone. Moreover, a number of researches have been done on the microstructure temperature distribution of the whole weld zone. Also precipitation phenomenon of precipitants has been studied. Moreover, the microstructure effect of effective parameters on the weld region such as rotational speed, mechanical properties of the friction stir welded joint such tensile strength, hardness are studied. Furthermore, the effect of designing and employing different tools has been studied.

2.4 Related Previous Works in FSP

The major focus of related previous works was on microstructure and mechanical properties of the materials when the effective parameters are adjusted alternately.

Moreover, in the subject of microstructural researches various methods such as Transmission Electron Microscopy (TEM), optical microscopy, Orientation Imaging microscopy (OIM) and scanning Electron Microscopy (SEM) have been investigated. The mechanical tests which have been used in these researches mainly include tensile, hardness, micro hardness and etc.

Bensavides et al studied the friction stir welding on the microstructures of Al 2024 [11]. Moreover, they did more researches on the friction stir welded zone to see how various range of temperature form -30°C to 30°C can affect the size of grains.

The results indicate that in the ordinary temperature (room temperature) there is an increscent in the size of grains of the weld zone. The increscent is from the bottom to the top which means that when the temperature is low, the variation from down to up is smaller. The results in general indicate that there is straight connection between growth of the grains and temperature. The results show that the size of grains varies from 3 and 0.65 μm.

Su et al has investigated the effect of friction stir on the grain size and microstructural properties of commercial 7075 Al alloy [12]. Their results showed that the grain size of the friction stir processed zone did not follow a uniform distribution. On the other hand, the average grain size normally reduced from up to down. Moreover, introducing the Non-uniform plastic deformation which was gained on the recrystallized FS processed grains was one of the major outcomes of this research. This may due to the fact that density of the stir zone is not uniform even if the grain size is equivalent. Generally, multiple overlapping passes is employed when it is desired to work on any size of sheets and obtain extraordinary grained microstructure. Therefore, employing multiple overlapping passes cause to obtain ultrafine grain uniform microstructure.

Liu et al. [13] employed metallography (LM) and transmission electron microscopy (TEM) on Fs welded areas in order to reveal the microstructure behavior and compared the results with the results of same experiments on 6061-T6 Aluminum. They investigated the value of hardness from work zone until the weld zone which there is a micro hardness extension.

Residual hardness varied from 55 to 65 VHN in the weld zone and from 85 to 100VHN in the work piece such that obtained grain size in the weld zone was 10μm whereas this value was 100μm in the work piece.

Itharaju et al. employed FSP on 5052 aluminum sheets and investigated the relation between grain sizes and the force which is produced during the process. Various set of rotational and translational speeds were used. The results indicate that for the mentioned alloy the average grain size varied from 1.5 to 3.5 μm compared with unprocessed sheet which its grain size is 37.5 μm. The results prove the advantage of refinement. Moreover, it becomes obvious that there is a direct relation between rotational speed and pushed force so that increasing the former causes to increase the latter.

The plunge force increases when the rotational speed increases. Increscent of the former is independent from translational speed.

Mishra et al [14] employed FSP to investigate the plasticity of desired Aluminum alloys. Their work presented the effect of nine overlapped passes on friction stir proceed 7075 Aluminum sheets.

They employed a uniform speed punch forming test in order to reveal the strain rate on form modeling.

In addition, in different zones of the friction stir proceeded aluminum sheets, tensile tests were employed. Investigation on microstructure effect of FSP on grains indicates that finer and equiaxed grains will be obtained.

Kwon et al employed the FSP on 1050 aluminum alloy. They have investigated the relation between two mechanical properties hardness and tensile strength with the rotational speed of the tool [15]. They found that they have indirect relation. The results indicate that in the rotational speed of 560 RPM compare with the as-received material, there is an increscent up to 37% and 46% in the hardness and in the tensile strength, respectively. The amount of hardness in the forward side was higher compared with the backward side. The outcome of this research indicates that FSP approach is highly profitable when there is a need to have improvement in the mechanical properties of grain refinement.Salem et al. [16] has done an investigation on maintaining the superplastic behavior in the weld zone. They investigated the effect of fiction stir welded on 2095 sheet.

They got to the result that employing the welding rate of 2.1mm/s at 1000RPM roughs sub grains. This issue causes to decrease superlastic potential.

As the results of high welding rate we can mention to the developing on microstructures. It includes the intertwist structures, tangled disorientated sub grains and increased density translocations. The sheets are deforming up to strains of approximately1.3 when they are welded at 3.2 or 4.2 mm/s.

2.5 Limitations of Friction Stir Processing

Although FSP is one of the more applicable and useful thermo mechanical methods, but still there are some striking limitations. For example its flexibility is less comparing with manual processes. Moreover, there is a need to do rigid clamping on the work piece. In addition, after finishing each pass there will be a keyhole in the work area. It is a backing plate demanded and non-linear process which there some problems with variation in thickness and low traverse rate. Moreover, FSP suffers from having a model which can predict the microstructure properties.

During the work these limitations have been controlled by supervising on probable problems and requirements for each part of the work. For example, rigid clamping has been done on the work piece of each sample by using appropriate clamping tools. For solving the backing plate problem a steel plate was employed. The problem of existing keyhole was solved by extending the samples in order to cut the generated keyhole at the end of the work. We decide to move the used tool linearly in order to deal with the problem of flexibility. Lack of predictive model was solved by adjusting tuning parameters such as rotational speed and feed rate according the obtained results of recent studies.

Chapter 3

METHODOLOGY

3.1 Material, Properties and Application

In this study, 7020 AL alloy was employed regarding its highly usage in industries such as aerospace, aircraft and automotive. Table 3.1 shows the chemical composition of 7020 AL alloy in details.

The major elements of AA-7020 are Zn and Mg.

Table 3.1: AA-7020 Composition

AL	Ti	Zn	Cu	Cr	Fe	Mn	Si	Mg
85.44	0.08	**4.70**	0.10	0.14	0.35	0.24	0.30	**1.30**

Figure 3.1 shows the considered dimensions and rolling direction of samples.

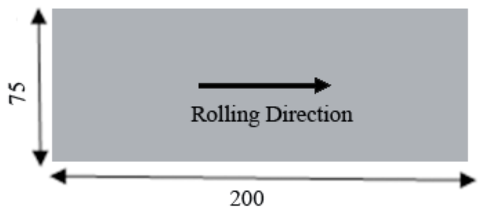


Figure 3.1: The rolling direction and Sample Dimension

The mechanical properties of AL 7020 are presented in Table 3.2. The mechanical properties have been presented in details in the following sections. They are obtained by employing tensile test.

The results of mechanical properties mentioned in this table disclose that AL7020 has high potential to be well forming. Moreover, its powerful ability in corrosion resistance, machine ability and strength in high tempers has made it to a multipurpose alloy [17].

Table 3.2: The Details of Mechanical Properties of AA-7020

Mechanical Properties	Obtained Value
Elongation (%)	10
Tensile Strength (Mpa)	350
Density (1000 g/cm^3)	2.78
Yield Strength (Mpa)	280
Hardness (HV)	75

It should be mentioned that before starting the friction stir process, cold working operation (pre-straining) has been done on all Al sheets.

3.2 Experimental Setup

One of the important advantages of FSP is the need to low-cost tools and availability of its required facilities such as milling machine which is generally available in each workshop. Following sections are allocated to explain more about the experimental setup required for FSP.

3.2.1 The Rotational FSP Tool

In friction stir methods, there is a need to design a suitable and accurate tool [18] [19] [20]. In this case we employ a tool which is manufactured of H13 steel. This selection causes to have improvement in strength and wear resistance during the thermal process. After employing FSP the mechanical properties of tool changed so that its hardness varied from 58 to 61 Rochwell. Figure 3.2 shows the total shape of the rotational tool. The considered pin diameter and length is 5mm and 3.5mm respectively. Moreover, the shoulder diameter is 16mm (Figure 3.3).

Figure 3.2: The Appropriate Tool used in Friction Stir Processing

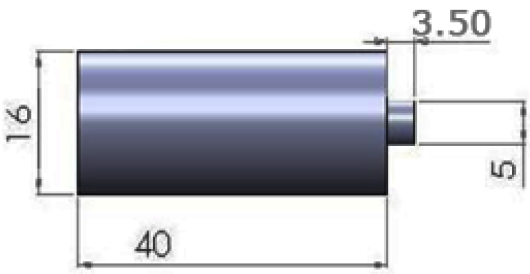


Figure 3.3: The details of size of FSP rotational Tool

3.2.2 Machines Used

As it was mentioned before, FSP utilizes from using available machines. So we employ vertical milling machine (WERNIER 06340) to conduct the process.

Figure 3.4 shows the mentioned machine.

Figure 3.4: A View of Available Machined used in FSP (Vertical Milling Machine)

As it was mentioned in limitation of FSP our solution for clamping problem was using an appropriate rigid clamping tools and backing plate to prevent moving the samples during the process and making them fix (Figure 3.5).

Figure 3.5: The Process of Clamping Samples

3.3 Experimental scheme

We consider dimension 200 *75*8 mm for samples. Moreover, various set of rotation (ω) and translation (f) speed were considered to investigate on each sample.

Table 3.3: Different Combination of ω and f for various Samples

Samples No	Rotational Speed (RPM)	Feed Rate (mm/min)	ω/f (rev/mm)
1	710	25	28.4
2	1000	40	25
3	1400	63	22.22
4	2000	16	125

3.4 Experimental Tests

3.4.1 Hardness

For hardness test we used Vickers hardness tester. We consider a test lost of 60 kg and the delay time of 3 seconds. Various combinations of rotational speed and feed rate were used while the test was employed on several samples and different zones to have accurate experimental results.

Firstly, we divide the operation zone into 7 different areas. Figure 3.6 shows the divided zone. The middle point of divided operation zone with coordinate 100*37.5 mm is named as zone A. Other zones are considered to be placed in two directions longitudinal right and left of zone A. The distance between zones was considered 20 mm.

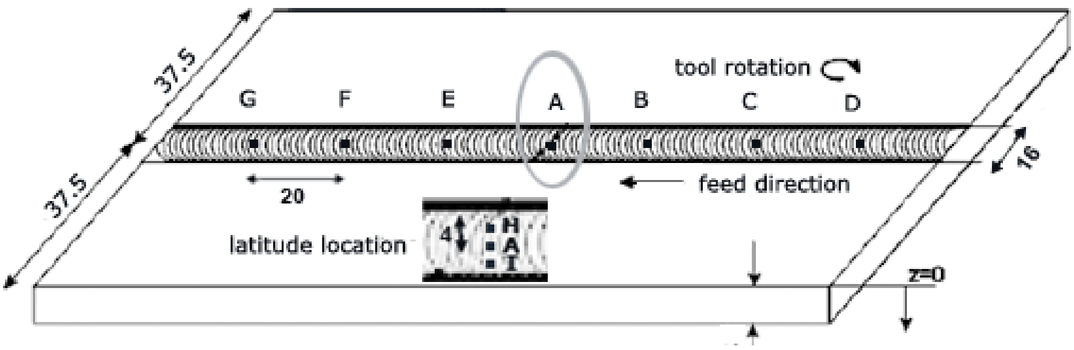


Figure 3.6: A Schematic of Sample with Defined Various Hardness Zones

Secondly, the operation zone was divided into three zones in latitudinal axis to measure the hardness of this axis. Still zone A is at the middle of this division and two other zones are considered at the top and bottom of this zone which are named as zone H and zone I. The distance between these zones is considered 4 mm. The hardness tester machine is shown in Figure 3.7.

Figure 3.7: A View of Hardness Tester Machine used

The applied formulas for measuring the hardness are shown in below:

$$HV = \frac{1.854\ \mathrm{F}}{\mathrm{d}^2} \qquad (3.1)$$

$$\text{Average } d = \frac{d_1 + d_2}{2} \qquad (3.2)$$

The indenter employed in the Vickers test is a square-based pyramid whose opposite sides meet at the apex at an angle of 136º. The diamond is pressed into the surface of the material at loads ranging up to approximately 120 kilograms-force, and the size of the impression (usually no more than 0.5 mm) is measured with the aid of a calibrated microscope. The Vickers number (HV) is calculated using the following formula: with F being the applied load (measured in kilograms-force) and D2 the area of the indentation (measured in square millimeters). The applied load is usually specified when HV is cited.

3.4.2 Tensile Test

ASEME9 standard was used for tensile testing. Figure 3.8 shows the size of samples which have been used in tensile test. Later, the samples will be cut from both proceed and non-proceed zones by using CNC vertical milling machine.shows the CNC machine model DUGARD EAGLE 760. Sand papers (P1000) were used to polish the samples. The cut samples for tensile test have been shown in Figure 3.. These works have been done in order to stop stress focusing and improve the surface quality. The tensile tester machine is shown in Figure .

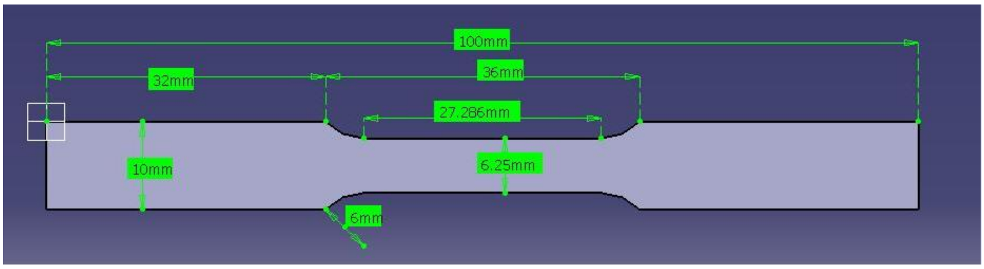


Figure 3.8: Size of Samples used for Tensile Test

Figure 3.9: The Schematic of Vertical CNC Machine used

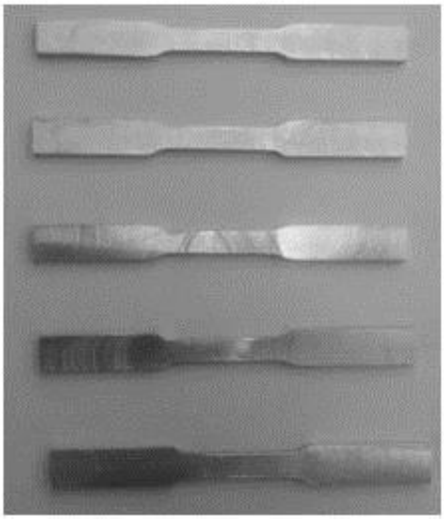


Figure 3.10: Different Cut Samples which are Prepared to Perch in Tensile Machine

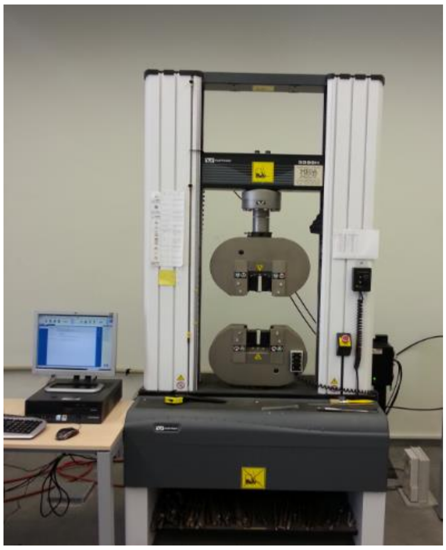


Figure 3.11: A view of Tensile Tester

3.4.3 Impact Test

Longitudinal incisions have been done on all friction stir proceed samples. Figure 3. shows the impact test samples before and after cutting. Thereafter they were transformed by using lathe machine (Harrison M300) to the pins with diameter anlength of 8mm and 45 mm, respectively.

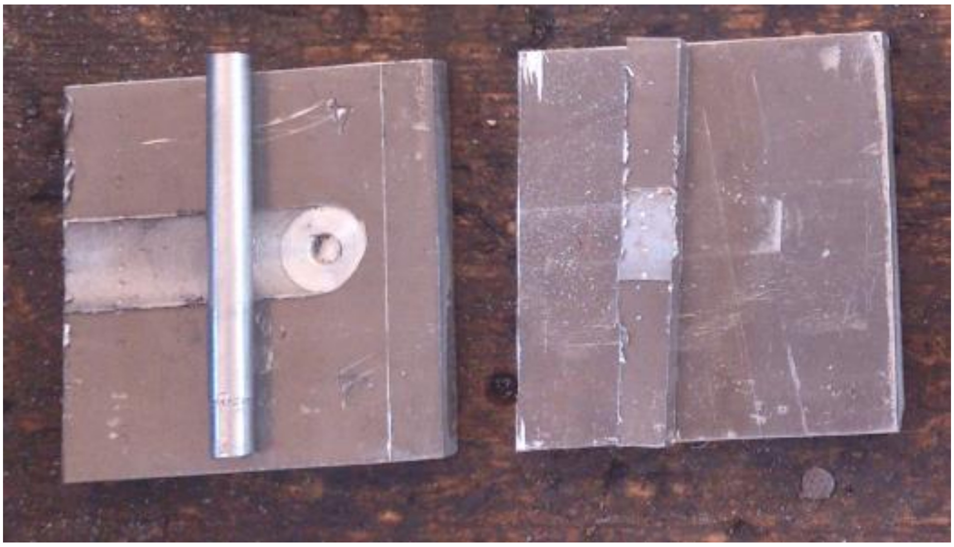


Figure 3.12 Different View of Samples Before and After Cutting


Figure 3.13: A Schematic of Grooved Pin

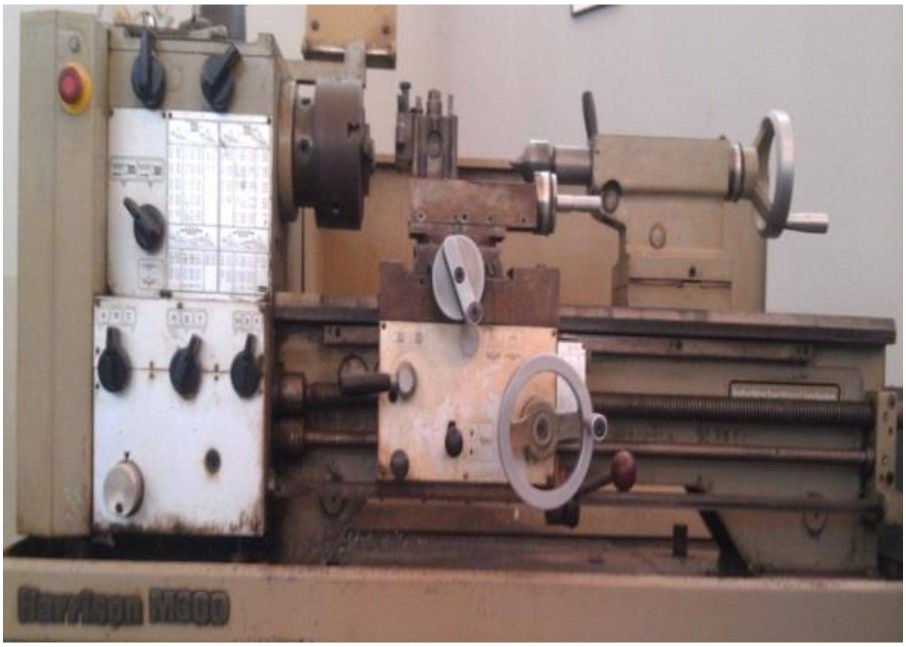


Figure 3.14: A Schematic of the Lathe

Producing a groove over the pins needs to use notching machine which is shown in Figure 3. The groove on the pin was notched in the non-proceed position. In the end for measuring the required force to break each sample, the impact machine which is used in both Figure 3. and Figure 3. was used.

Figure 3.15: The Impact Tester Machine

Figure 3.16: A View of Notching Machine

Figure 3.17: A view of Impact Tester

3.5 Microstructure Investigation

With cooperating the department of material science of Sahand University in Tabriz-Iran the microstructure properties were investigated. Several microscopy methods such as Optical microscopy and Orientation Imaging Microscopy (OIM) were used in order to obtain appropriate quantitative information. For microscopic investigation the samples were grinding by using sand papers (The models P800, P1000, P2000, P3000 and P5000 were used). The microstructure investigation was done on the traverse zone of operation zone. Figure shows the samples for microstructure test.

Moreover, for microscopy investigation various set of rotational and translational speeds were employed on samples.

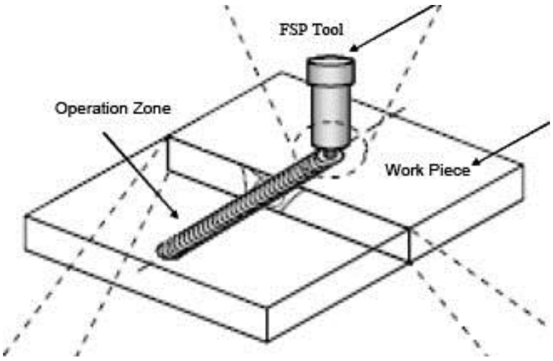


Figure 3.18: A Schematic view of Friction Stir Proceed Samples

After polishing the samples, etching process will be performed in order to investigate the amount of energy saved through the grains borders. The etching solution is made of Keller's which is comprised of 2 ml HF, 3ml HCI, 5ml HNO3 and 190 ml H_2O . Figure shows the Heat Affected Zone (HAZ) on samples which are etched.

Figure 3.19: Etched S

Chapter 4

RESULTS AND DISCUSSION

Recent researches had been focused on two parameters ω and f individually [15] [16] [21]. The parallel change the values of ω and f causes to occur variation in process temperature and cooling rate. Changing these parameters lead to change the microstructure mechanical properties of material. In this study the ω relative to f (ω/f) and its effect on several mechanical properties such as hardness, tensile strength, impact strength and etc. and the microstructure of AA-7020 aluminum alloy have been investigated.

4.1 The performance of variation in (ω/f) on Microstructure

The effect of ω/f on microstructure grain size has been shown in Figure 4.1.whit using this graph it is clear that in general with increasing the value of ω/f, the grain size of the cold worked AA7020 will be decreasing then after the value of 28(rev/mm) it start to increase again. It is due to the fact that the temperature of localized heating which is produced by FSP tools, over goes the recrystallization temperature. [22] [23] [24].

It should be mentioned in recrystallization temperature the size and shape of grains at operation zones is changed.

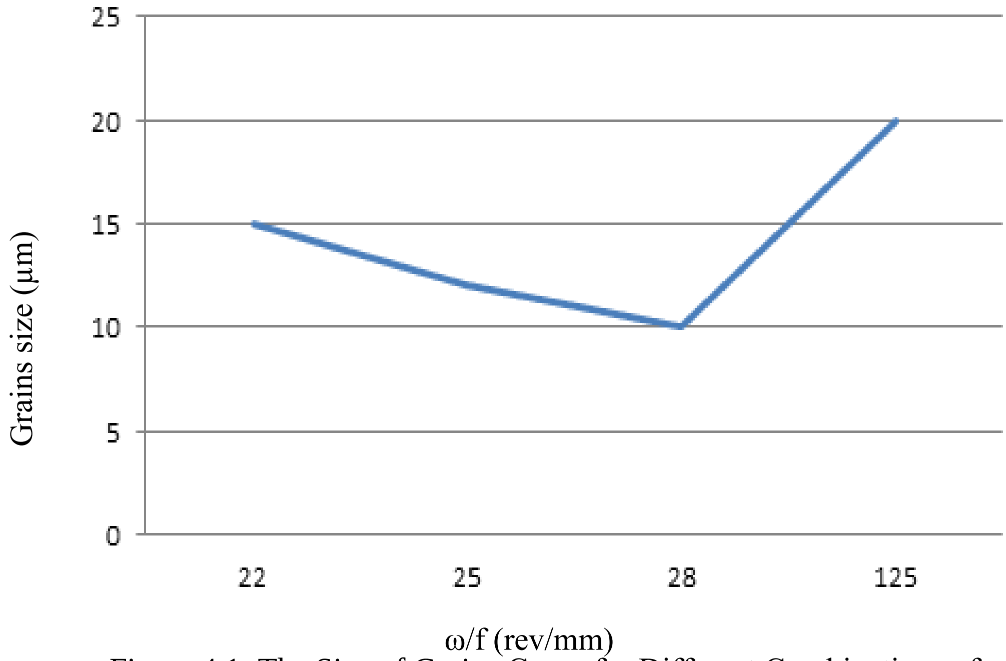


Figure 4.1: The Size of Grains Curve for Different Combinations of ω/f

The deformation zone which has been shown in Figure 4.2 is split up to three sections. These zones are named as heat affected zone (HAZ) which is marked on the top oval, the thermo mechanical affected zone (TMAZ) which is the left oval and the welding zone (Nugget) which is marked in the right oval of Figure 4.2 [25] [26] [27]. Moreover, the microstructure of base material and the direction of rolling are shown in Figure 4.3.

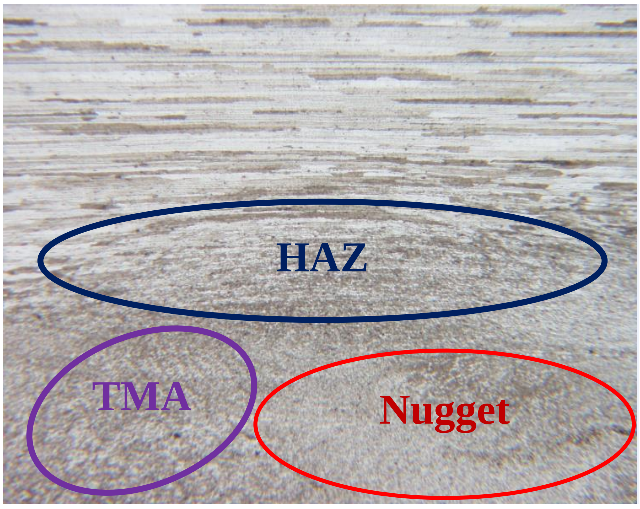


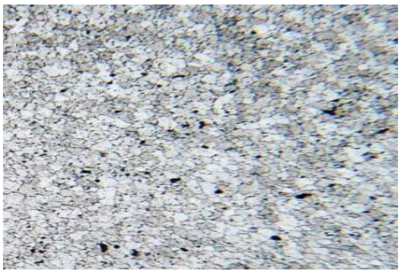
Figure 4.2: A Schematic of Three Welding Zones

Figure 4.3: The Rolling Direction in Base Material

In addition, for each set of values of ω/f in Nugget zone, the corresponded grain size, grain shape and direction have been shown in

Table 4.1. It is completely clear that the grains inside Nugget zones are in order smaller than grains in other zones. Moreover, comparison the grain size between two zones TMAZ and HAZ, it is clear that the grains size in former are less than the latter. Previous researches confirm these results [28] [29] [30] [31].

Table 4.1: The Properties of Grains in a Specified Welding Zone for Various Combination of Rotational Speed over Traverse Speed

Value of ω/f (rev/mm)	Details of Grains in Nugget Zone	
	Size of Grains (μm)	The Schematic of Grains
22.00	10.00	
25.00	7.70	
28.00	6.25	
125.00	Unknown	

In summation, in situations that (ω/f) increases, the temperature of the process and cooling rate increase as well, therefore the grains size is going to be decreased [32] [33].

4.2 The influence of variation in ω/f on Hardness

At first, FSP increases the average hardness of base material. Later, while ω/f increases, hardness starts to decrease which is shown in Figure 4.4.

It is clear that when the ratio of ω and f varies from 0 to 22, the average hardness increases from 75HV to 103 HV. However, with increase in ω/f from 28, to 125, there is reduction in the average hardness from (103HV to 93 HV).

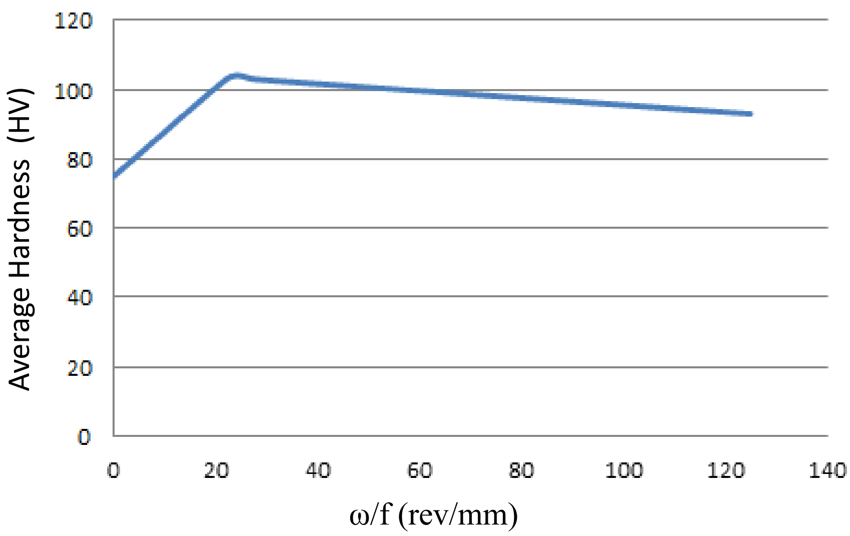


Figure 4.4: Average Hardness Curve for Various Combinations of ω/f

Then we choose the sample which is processed with ω/f=28.4 for investigation the variation of hardness in different distance of operated zone.

It has been divided in 3 different zones which is called A,H,I that A is the middle zone of operation area and H and I are above and below zones of A.the distance between these zones is 4mm.the variation of average hardness in these 3 zones is show in figure 4.5:[34] [35] 36].

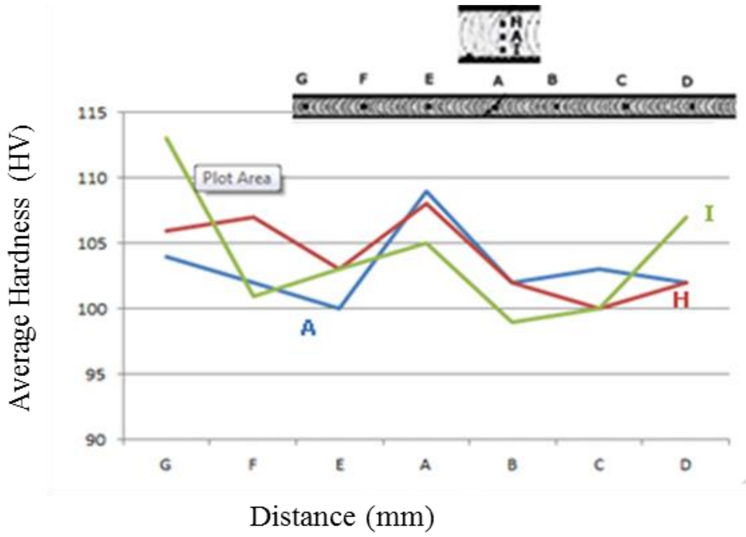


Figure 4.5: The Three Zones Hardness Curves

4.3 The performance of variation in ω/f on Tensile Strength

For both yield strength and ultimate strength at first increasing the ω/f leads to increase both measures but later will decrease them [37] [38] [39] which is shown in Figure 4.6.

It is clear when When the ratio of ω and f varies from 22 to 28, the value of yield strength varies from 173-208 MPa. But when the former varies from 28 to 125, there is reduction in the yield strength from (208- 194 MPa).

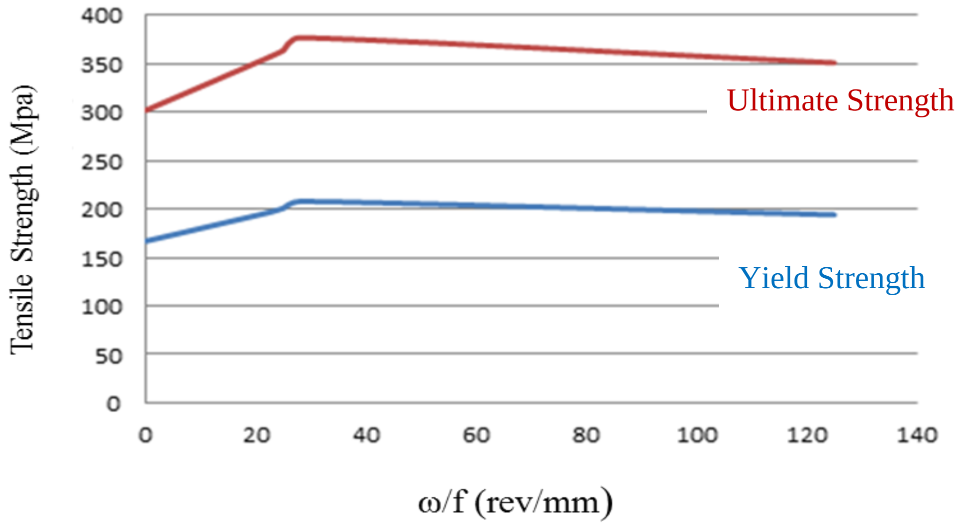


Figure 4.6: The performance of Tensile Strength Test for Different Combinations of ω/f

4.4 The performance of variation in (ω/f) on Impact Strength

The impact strength decreases when ω/f increases [34] (Figure 4.7). It should be mentioned that for base material the impact strength is equal to 9.4.

Whit use of this graph it is clear the impact strength reduces from 14.8MPa to 9.4MPa when ω/f varies from 22 to 125.

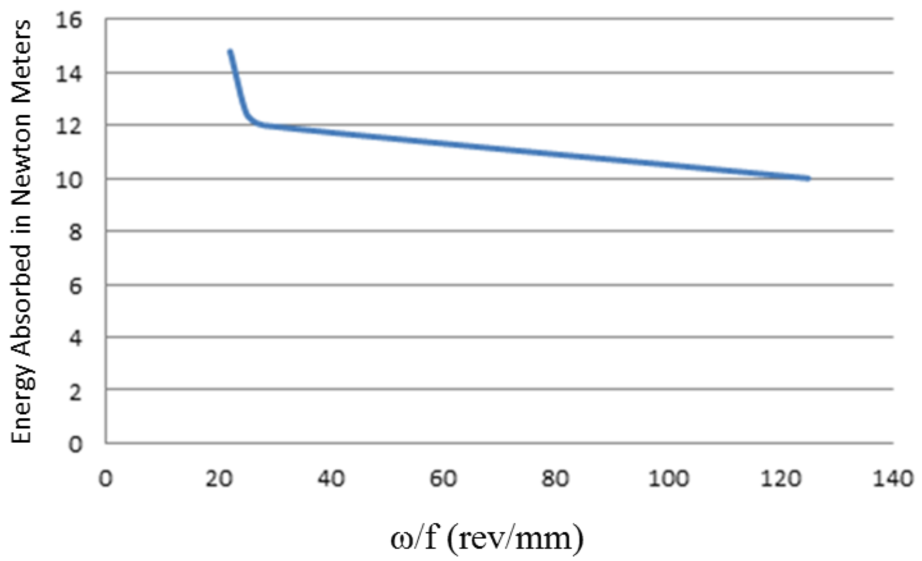


Figure 4.7: The Impact strength Curve for Different Combinations of ω/f

In fact, when impact strength decreases, the ductility of material will be decreased.

4.5 The influance of variation in ω/f on Surface Quality

Due to the fact that adequate increment of ω/f can be effective in improvement the quality of surface but the more increment causes to decrease the quality of surface. Table 4.2 shows the details of surface quality of samples.

Table 4.2: Schematics of Samples for Different Combinations of ω/f and their Corresponded Quality of Surface

Value of ω/f (rev/mm)	Surface Quality (From infront)
28	
25	
22	
125	

Chapter 5

CONCLUSION

This study addressed the performance of FSP on AA-7020 aluminum alloy. The effects of the ratio of rotational and translational speeds on various mechanical properties and the microstructure of AA-7020 aluminum alloy were investigated. The major results are concluded as follows:

1. In general, when there is an increment in the ratio of ω and f, a reduction takes place in the size of grains.

2. When the ratio of ω and f varies from 22 to 28, the value of yield strength varies from 173-208 MPa. But when the former varies from 28 to 125, there is reduction in the yield strength (i.e., from 208- 194 MPa).

3. When the ratio of ω and f varies from 0 to 22, the average hardness increases from 75HV to 103 HV. However, with increase in ω/f from 28, to 125, there is reduction in the average hardness (i.e., from 103HV to 93 HV).

4. The impact strength reduces from 14.8MPa to 9.4MPa when ω/f varies from 22 to 125.

5. When the ratio of ω and f varies from 22 to 28, the ultimate strength increases from 313 MPa to 364 MPa.Hawevery as the ratio of ω and f varies from 28 MPa to 125 MPa, the ultimate strength cantrarily decreases from 364 MPa to 351MPa.

6. The findings of this study can be used as benchmark when there is a need to change the properties of cold worked metals in manufacturing industry like automotive and aerospace industries.

FUTURE WORKS

1. Investigating the effect of tunning parameters on the microstructure of material.
2. Investigating important mechanical properties of material regarding various conditions of tuned parameters such as rotation and traverse speed
3. Investigating the effect of using other tool designing methods
4. Employing cooling rate and pre-heating
5. Investigating the microstructure and mechanical properties of unprocessed material and comparing with processed material
6. Doing all experiments on other series of aluminum alloy in order to compare the results with the current results.

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