Fabrication of hexagonal bar from aluminum alloy AA6063 scrap by frictional stir back extrusion on milling machine

A thesis submitted by

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ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIAL ENGINEERING

DEPARTMENT OF MECHANICAL DESIGN AND MANUFACTURING ENGINEERING

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Declaration

I hereby declare that the work which is being presented in thesis entitled "**Fabrication of hexagonal bar from aluminum alloy scrap by frictional stir back extrusion on milling machine**." In partial fulfilment of the requirement for the award of the degree of Masters of Science in Manufacturing Engineering is my own work carried out September to June 2018 under the supervision of **Dr. Habtamu Beri and Dr. Perumalla Janaki Ramulu,** program of Mechanical Design and Manufacturing Engineering, Adama Science and Technology University, Adama, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis has been duly acknowledge.

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This is to certify that the above declaration made by the candidate is corrected to the best of my knowledge and belief. This thesis has been submitted for examination with our approval.

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Acknowledgement.

Frist of all I would like to thank the almighty God for giving me this a golden chance, time and health. Next this thesis was made possible due to the masterly guidance of **Dr Habtamu Beri** (former Dean of School of Mechanical, Chemical and Material Engineering). I was nourished profoundly from your erudite knowledge, dedication to work and spirit of always seek truth from facts. You set a good example of researcher and solution maker to any problem by technical way. Those countless brainstorm enlightens me to think critically and deeply, today and tomorrow. Your methodology and advises are still guiding me find the right path. I thank you very much that you gave me perfect advices whenever I faced serious problems, you made me feel hopeful to finish this thesis.

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Abstract

Friction stir back extrusion (FSBE) is a novel and an efficient method of manufacturing sounded products by using specialized tool in one step (without melting of scrap). It can be saved about 40% of material, 26-31% of energy consumption, and 16-60% of labor costs compared with conventional extrusion. The objective of this research was to fabricate a hexagonal bar from aluminum alloy scrap by FSBE. The material used for this study was AA6063 as a scrap and H-13 tool steel as a die. The sampling method is, simply extruded out the hexagonal shaped bar at the center of die hole by using friction formed between scrap die interface. The depth of extrusion land to form a shape of sample bar was 2mm. After 2mm, the diameter of die hole increased into 14mm in order to decrease the friction force between hole of die and bar surface. The length of extruded sample was 260mm, 100mm, 70mm, 210mm, and 270mm (from 630rpm to 200rpm) and the same 6mm inscribed diameter thickness. The considered parameters were chamber rotational speed and vertical die transverse speed as major parameter. Aluminum hexagonal shaped bar is used as a supporter in medical and marine industry, as a raw material to the mass production of hexagonal head aluminum nut and bolt, Allen wrenches etc. The microstructural investigation was performed by using optical microscopy. Extruded bar was defect free, non-blurred grain boundary and clear surface than the base material. The hardness and compression test were done by using Vickers hardness tester and universal testing machine (UTM). The hardness value of base material is less than the sample extruded at 200, 400 and 500rpm and also greater than the other extrudes. The result showed that the compression strength of extruded sample was higher than the base material by 5%. This work has proved the feasibility to extrude hexagonal-shaped bar by using FSBE by fixed die and rotated chamber. The optimum rotational speed of chamber to produce sample bar with the minimum twist angle is 250rpm and transverse speed 6.25mm/min. if the rotational speed increases twist angle also increased.

***Keywords**:* Hexagonal Bar; Friction Stir Back Extrusion Process; Aluminum Alloy Scrap; H-13 Tool Steel Die and Chamber.

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Acronyms and abbreviation

FSBE	Friction Stir Back Extrusion.
FSW	Friction Stir Welding
OM	Optical Microscopy
FSE	Friction Stir Extrusion
FSFE	Friction Stir Forward Extrusion
FE	Friction Extrusion
HV	Hardness Vickers
RPM	Revolution per Minute
UTM	Universal Test Machine
RCH	Rockwell Hardness
EDM	Electron Discharge Machine
P	Power
ω	Omega
CNC	Computer Numerical Control
ASME	American Society Mechanical Engineering
T_m	Temperature of Melting
AISI	American Iron and Steel Institute

CHAPTER ONE: INTRODUCTION AND BACKGROUND

1.1 Background of the study

Friction stir extrusion (FE) was developed at The Welding Institute (Cambridge, UK) in the early 1990's. It was the first time derived from friction stir processing as a process of forming or reforming ceramic/metal composite material (Thomas *et al*. (1993)). Over the past two decades, significant amount of work had done on multiple aspect of friction stir process. Gronostajski *et al*. (1996), produced composite materials from aluminum alloy chips (AlCu4) with addition of tungsten powders by frictional extrusion**.** And also (Charity (2003)) applied this technology to produce a high strain super plastic and fine grain microstructure of commercial aluminum alloy AA2024. Mishra et al (2003) developed surface metal-matrix composite from Al-Sic with different volume fraction of particle. The surface composites have excellent bonding with the aluminum alloy substrate. The thickness of the surface composite layer ranged from 50 to 200 mm and have excellent bonding with the aluminum alloy substrate. The micro hardness of the surface composite reinforced with 27vol.%SiC of 0.7 mm average particle size was ~173 HV, almost double of the 5083Al alloy substrate (85 HV). Kwon *et al* (2004)**,** improved the mechanical properties of aluminum alloy AA1050 specimen by grain refining by using friction stir process. Sherafat *et al.* (2009) mixed the Al powder (90% to 40%) with AA7075 (10% to 60%) chips by using hot-extrusion at 500°C. Tang *et al*. (2010)**,** produced a fully consolidated and sounded wires from aluminum alloy AA2195 and aluminum alloy AA2050 machining chips by using the frictional stir extrusion process and many more. So, still now friction stir extrusion is considered as an efficient manufacturing technology because of its a near-net shape manufacturing method by without environment pollution.

1.2 Introduction

Along with the rapid development of automotive, aerospace and manufacturing industry in recent years, novel technologies like near-net shape manufacturing, additive manufacturing, solar energy jet and fuel cell battery plays a critical role in producing safe, economical and durable products. Friction stir extrusion process can meet this need as an innovative and economical material processing method as it directly converts metal wastes without melting to useful products. Compared with traditional manufacturing processes, it has more efficient, green, energy saving and environmental friendly technologies (Li et al. (2016)).

Friction stir extrusion is divided into two major processes such as, frictional stir back and frictional stir forward extrusion. If the finished product extruded through opposite side of the applied force direction or movement of die the extrusion process is called frictional stir back extrusion but inverse forward extrusion. Friction stir back extrusion (FSBE) is one of the recent developments based on FSW (frictional stir welding) to produce wire, tube, cylindrical rod, square bar etc. The technique uses a rotating non-consumable tool to weld two sheets or plates together by "stirring" the material surrounding the parting line (Farha (2012)).

Friction stir extrusion relies on extensive plastic deformation and basic frictional heating generated by method to stir, consolidate, and extrude the small block, chips and scrap directly into functional form. And also it was developed into a recycling process for various metals and alloys and eliminate the energy and labor intensive processes of melting and casting. Generally, there are two types of recycling methods, conventional recycling and direct recycling. The conventional recycling methods involve melting of metal wastes and pass multiple steps. However, the direct recycling methods don't involve melting and have less steps. In comparison with conventional recycling method; direct recycling (frictional stir back extrusion)have high advantages, such as less material loss due to absence of melting, low energy consumption and thus environmental friendly and considerable labor savings. For example direct recycling aluminum can save about 40% of material, 26-31% of energy consumption, and 16-60% of labor costs. The friction extrusion process falls into the category of direct recycling methods and it has all the advantages (Hosseini, *et al*. (2012)).

Aluminum and its alloys have received much attention in aerospace, automobile, and construction industries; due to their high strength-to-weight ratio, good formability, excellent corrosion resistance, low maintenance, good toughness and high strength to weight ratio (Behnagh, *et al*. (2014)). Aluminum is also known for the diversity of its alloys, but not all of them are suitable for extrusion. There are three classes of aluminum alloys commonly used for extrusion. These are the 1000 series, 6000 series, and 7000 series. The 6000 series recognized for excellent extrudability and among them aluminum alloy6063 was the most popular one used for extrusion. This alloy properties were formed into complex shapes with very smooth surfaces and commonly used to produce hexagonal bar, square bar, pipe, tube and aluminum furniture (Camero, *et al*. (2006)).

The application of aluminum hexagonal bar is to produce nuts, bolts, connecter and fasteners in varieties of production such as, electrical, plumbing and marine and also a many industrial application such as medical assembly, air craft construction, structural component and commercial transportation due to light weight, corrosion resistance, and excellent machinability. The working principle of friction stir extrusion process is, the die moves down or the ram goes up to compress the precursor in the chamber. Then the die rotates in order to generate frictional heat at the die/precursor interface. Under high pressure and continued frictional heating, the precursor (such as machining chips and metal scrap) in the chamber will be extruded out through the extrusion hole after experiencing softening but not melting and severe deformation (Li, *et al*. (2016)).
To concluded that, FSBE is a branch of friction stir process that used to produce hexagonal shaped bar by using specialized tool (chamber and die) by one step fabrication without melting of material.

1.3 Statements of the Problem

To produce hexagonal shaped bar the input raw material was not only direct metal billet but also the recycled metal scrap, chips and small blocks. It was not favorable due to a significant metal loss in melting step and low density compacted chips enhances losses through oxidation. There were a further losses on each stages caused only 54% of the metal was recovered but in friction extrusion 95%of scrap material recovered. During the conventional recycling of aluminum alloy scrap and manufacturing of hexagonal bar about 45% of metal lost. Those losses impacted to costs rising in labor, energy and expenditures for environmental protection.

The demands of aluminum alloy hexagonal bar have increased rapidly in the automobile, air craft and ship building industry to make Allen wrench, bolt, nut and aluminum supporter due to high strength to weight ratio, excellent corrosion resistance and good formability. By the conventional extrusion it was not recommended because of high amount of metals waste during recycling.
The grain size of extrudes produced by friction stir extrusion is very fine related with the base metal**.** This grain refinement and homogenization of processed materials enhancing the mechanical properties. In this case any product fabricated by friction stir back extrusion is high strength than the conventional extrudes.

1.4 Objective

1.4.1 General Objective

The main objective of this study was, fabricating a hexagonal shaped bar from aluminum alloy 6063 scrap by frictional stir back extrusion on milling machine.

1.4.2 Specific Objectives

The specific objectives this thesis are as follows.

- Designing and fabricate the die and chamber
- Selecting the required bolt, nut, clamp and fixtures from the international standard.
- Test the chemical composition of aluminum alloy scrap.
- Analyzing the mechanical properties of hexagonal shaped sample bar fabricated by friction stir back extrusion like a hardness test and compression test.
- Investigating the microstructural properties of sample bar that produced by friction stir back extrusion by using optical microscopy.

1.5 Scope of the study

This study is limited up to the geometrical design of dies and chamber and manufacturing of hexagonal bar from aluminum alloy 6063 scrap through frictional stir back extrusion process. And also mechanical properties namely hardness and compression strength were investigated. In addition to this microstructure was analyzed by using optical microscopy. The maximum inscribed diameter of hexagonal sample bar that fabricated by FSBE is 6mm.

1.6 Significance of Study

The outcome of this study is believed to provide a great contribution for manufactures to achieve the green development without environmental pollution by one steps fabrication of aluminum product. Addition to this, the other main significance of study was as follows:

- ❖ Fabrication of hexagonal shaped bar by FSBE can save about 40% of material, 26-31% of energy consumption, and 16-60% of labor costs. And 95% of material reutilize and recover during recycling of scrap.
- ❖ It was partially fulfilled the demand of automotive, maritime aircraft spare parts such as, bolts, nuts and Allen wrench by efficient manner.
- ❖ The study spreading the concept of FSBE techniques to produce other shapes.

- No melting and solidification on the material during recycling process.

1.7 Thesis Layout

(1) Chapter one presents the background of friction stir extrusion and brief introduction of FSBE, advantages of friction stir extrusion compared with conventional extrusion, application of aluminum hexagonal shaped bar. Objectives, scope, significance and limitation also explained.

(2) Chapter two reviews the previous works done by friction extrusion and find out research gap.

(3) Chapter three focus on methodology and materials. The following aspects are mainly discussed: (A) Geometrical design and fabrication of die and chamber, (B) describe specification of the required materials, machines and accessory, (C) sample fabrication and setup preparation, and (D) mechanical and microstructural test procedure.

(4) Chapter four includes result and discussion on (A) Fabricated die, chamber and extruded samples, (B) Twist angle analysis, composition of AA6063 and its effect, (C) Microstructural, hardness and compression test.

(5) Chapter five conclusion and recommendation.

1.8 Limitation of the Thesis

The thesis on the Fabrication of hexagonal bar from aluminum alloy 6063 scraps is limited due to different challenging problem. The main problem are as follows.

1) During the experimentation; sometimes the electric power connected with milling machine was interrupted by unknown cause of main source problem.
2) Unavailability of functional EDM machine resulted made hexagonal shape by manually file. This manual operation was impossible to made proper shape and required depth of hexagonal land.
3) Unavailability of precision UTM test machine in Ethiopia to clamp small length and size samples hexagonal bar to test tensile strength.
4) In addition to this the consequence of the unavailability of the proper chemicals for etchant resulted in not shows detail image of microstructure and grain boundaries.

CHAPTER TWO - LITERATURE REVIEW

2.1 Previous Works on Friction Stir Extrusion Process

FE is a friction based extrusion method for producing high quality wire, rod and other form of shapes from low-cost precursors (e.g. scrap and chips). Tang (2010), applied this technology to produced fully consolidated wires from aluminum alloy AA2050 and AA2195 machining chips. As fig.2.1 shown below the rotation of die face perpendicular to chamber which compacted with chips. Hardness tests and bending tests were performed and the results were related to experimental parameters. Extrusion rate was simply related to the power input and die rotational speed. And also, they determined that the FSE process was limited by extrusion temperature which, if too low and high, resulted in cold crack (Fig. 2.2 A) and hot crack (Fig. 2.2 C). From Fig. 2.1 B, it observed that the wire surface was structurally sound at the rotation speed of 160 rpm. But they, neither the trend of compression properties nor hardness test has been discovered.

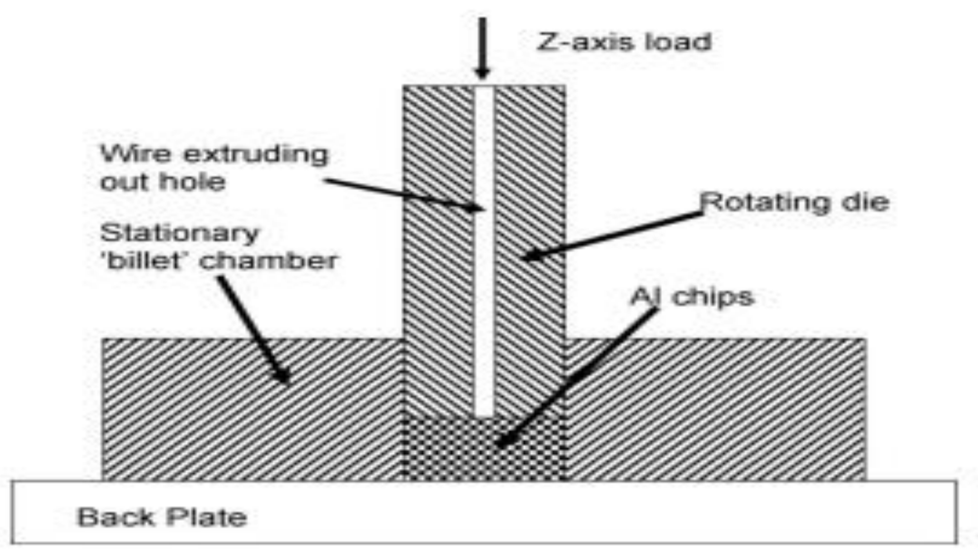


Figure.2. 1 Friction stir wire extrusion setup (Tang (2010)).

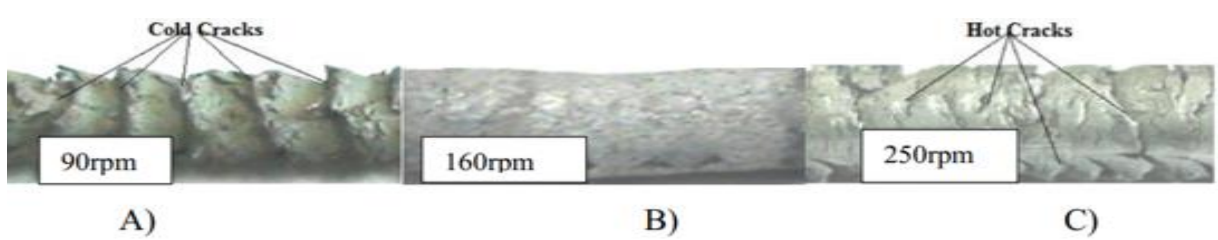


Figure.2. 2 Extruded wires with different rotational speeds (Tang (2010)).

Kwon *et al* (2004) were produced Ultra-fine grained 1050 Al alloy specimens through only a single pass of the friction stir process (FSP) at tool rotation speeds ranging from 560 to 1840 min^{-1}. The influence of the tool rotation speed on the microstructure and mechanical properties of the friction stir processed 1050 Al alloy was experimentally investigated in detail. The average hardness of the friction stir processed zone exhibited the nearly equal value in all the cross-sections which were perpendicular or parallel to the tool traverse direction or parallel to the work piece surface, respectively. In addition to it was significantly increased to even about 37% greater than that of the unprocessed zone by the Hall-Petch hardening with decreasing the tool rotation speed, i.e. with decreasing the grain size. The average ultimate tensile strength of the friction stir processed materials was increased by the Hall-Petch strengthening with decreasing the tool rotation speed, with decreasing the grain size. As a result, it reached a level about 46% greater than of the cold-rolled 1050 Al alloy. The friction stir processed (FSPed) zone and the unprocessed zone are labeled FZ and UZ, respectively as shown below fig.2.3. X, Z and Y represent the tool traverse direction, the tool rotation axis and the rolling direction of the work piece material (cold-rolled 1050 Al alloy), respectively.

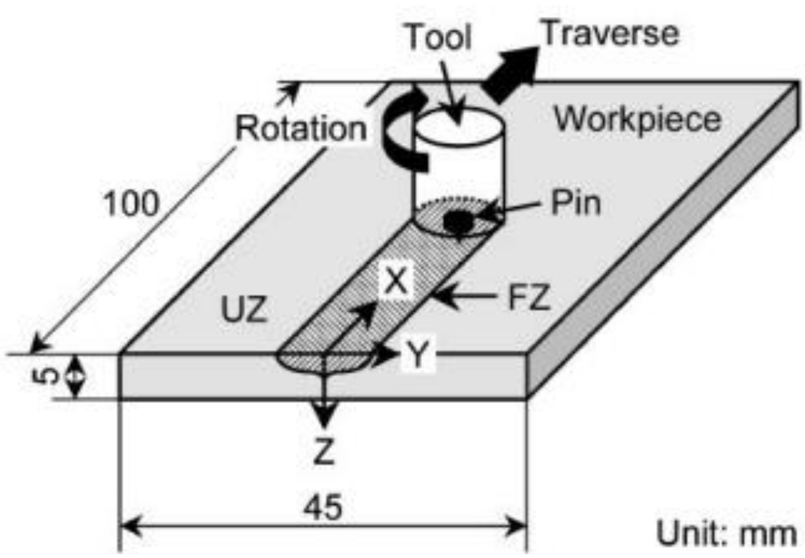


Figure.2. 3 Schematic illustration of the friction stir process (FSP) (Kown *et al.* 2004)

The dimensions of the work piece were 45 mm wide x 100 mm long x 5 mm thick and a specially designed tool was composed of a cylindrical shoulder and a sub conical pin.

South wire Company, (2011) examined on the feasibility and potential capability of a highly energy efficient solid-state metal scraps recycling and synthesizing process by using friction stir extrusion process. Their research determined the procedure and materials parameters for producing extruded product forms by direct conversion of recyclable materials. The materials can be scrap or other recyclable feedstock through mechanical alloying and thermo mechanical processing in a single step by using frictional heat. Process parameters were further optimized for plunge forces, die design and rotational speed. Deferent aluminium alloys including 6082, 5052, and 1350 were successfully extruded. Both slugs and metal chips were used as feed stock material. A comparative analysis of the wires produced through regular melting, casting and drawing vs. friction stir extrusion revealed that the mechanical/electrical properties of the extruded products were comparable. From microstructural point of view, the samples contained both coarse and fine grains; important to the decision that further optimization of the process is essential to get a homogeneous structure. They determined that, the potential feasibility of friction stir processing (FSP) to produce new alloys by coextruding different alloys, like aluminium alloys, 6201 and 1350 with nano-Al2O3 (alumina) particles, 5052/1350 and 6061/1350 were successfully coextruded.

Farha (2012), also applied the derivative of FE which is called frictional stir back extrusion to produce sounded, defect free aluminum alloy AA6063-T52 tube. A rotating tool is plunged into aluminum round bar specimens at a selected feed rate, forcing the processed material radially outwards and thus forming tubes as shows below Fig 2.4. Microstructural examination shows fine grained refinement within the stirring zone and some recrystallization was observed in the formed tubes due to the heat generated by the process. But not investigated any mechanical test of sample.

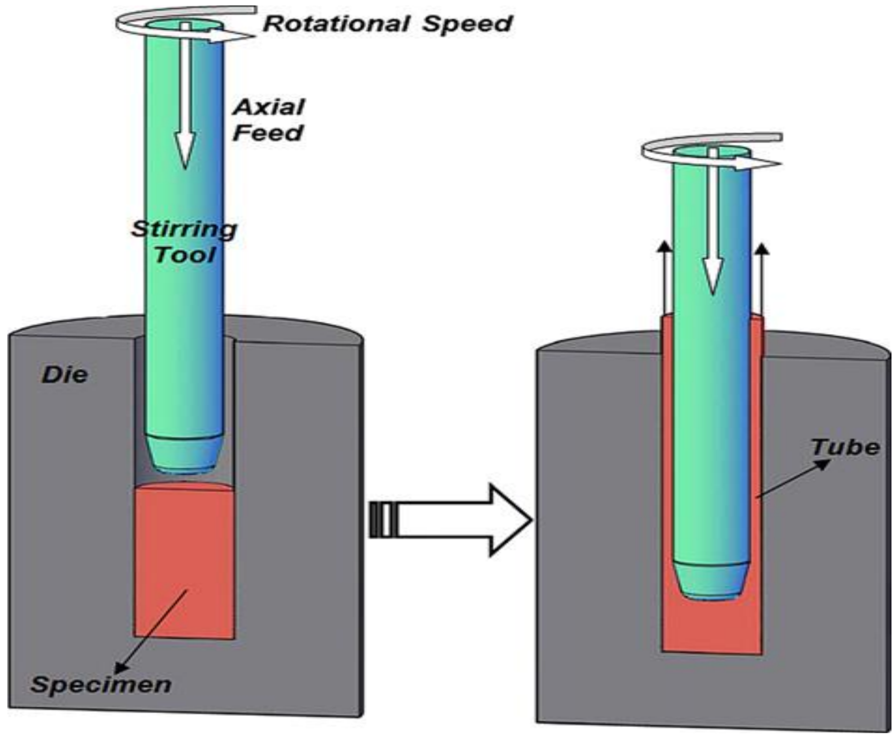
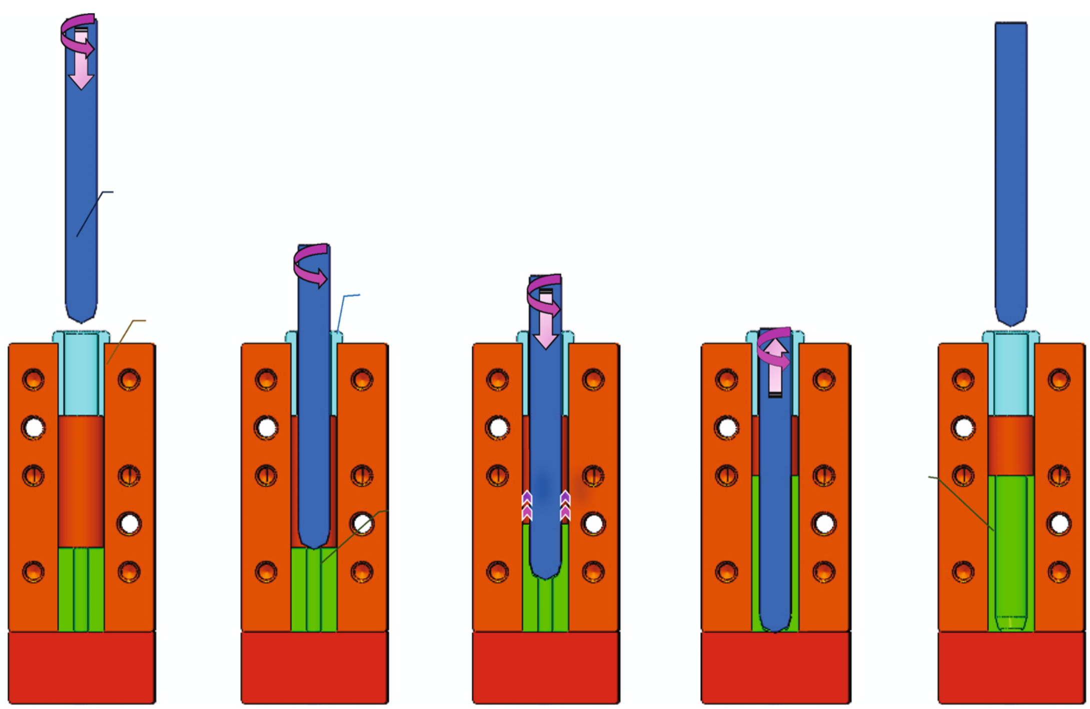


Figure.2. 4 Schematic demonstration of the several friction string processes of tube (Farha 2012)

By the same method (Dinaharan (2014)), produced pure copper tube and examined microstructure across the extruded tubes. The tool was rotated at 1500rpm with an axial feed of 0.5mm/s. an axial force of tool was 10Kn and extrusion ratio 4:1. The specimen was polished by using silicon carbide emery paper from 240-1200grit size and fine polished by diamond paste of various (10-1µm). The etchants were 20g chromic acid, 2g sodium sulfate, 1.7 ml HCl (35%) in 100ml distilled water. The microstructure of the produced tube was studied by using optical microscopy. Homogeneous and coarsened grain along the tube wall due to trapped heat. Adequate heat dissipation is required during (FSBE). The tool and die made from double tempered high carbon high chromium steel (HCHCr). The end of tool was tapered to an angle of 10^0 to facilitate the extrusion process and the taper angle can be considered equivalent to the extrusion angle in a conventional extrusion process. The grain size was approximately 1.5 times higher compared to the grain size of copper bar**.** Neither the die nor the cylinder preheated. The parameters where chosen based on trial experiment. But not include other mechanical test and other material applied.

Ahmadkhanbeigi *et al*. (2016), produced fine-grained tubes based on friction stir back extrusion by a four different production step as Fig 2.5. (A) placing the tube specimen in the die, (B) rubbing the upper edge of the tube specimen by the tool, (C) plunging of tool, (D) attaining the end of the process, (E) removing of the tool Tubular aluminum alloy specimen whose inner diameter was less than the diameter of the rotating tool, was placed on a cylindrical die and penetrated by a rotating tool. They investigate the mechanical and microstructure properties of processed tube. Micro structural evolution of the formed tube showed significant grain refinement at various locations, particularly in its inner wall. The grain size decreased to 39 µm from the initial value of 100 µm at this part of processed tube. The variation of grain size on processed tube due to effect of strain gradient and non-uniform heat. The ultimate strength and the elongation of processed tube were increased from the initial value of 183–225 MPa and 19–22 %, respectively.



(a) (b) (c) (d) (e)

Figure.2. 5 Schematic of the Friction stir tube extrusion process, (Ahmadkhanbeigi, *et al*. (2016))

Khorrami and Movahedi (2014), Fabricated Aluminum tubes successfully by using a novel process of friction stir back extrusion. And also investigated the details micro structural evolution as well as the mechanical properties of the formed tube. For conducting the process, first the initial round bar with a height of 50 mm was inserted into the die cavity. Then, stirring tool with rotation speed of 1600 rpm was driven downwards against the specimen with axial feed rate of 40 mm/min. They observed that the extruded base metal showed a higher hardness and ultimate tensile stress compared to the formed tube. It was found that the process is capable to form a tube with a

significant fine grained structure resulting from dynamic recrystallization phenomenon in the stirred area. Moreover, the rate of strain hardening was relatively higher for the starting material than that for the formed tube due to the more dislocation density of the extruded base metal. Conclude that it is worthy to note that the rotation speed was chosen high enough that the material could be soften easily. The higher rotation speed can make material flow easier as a result of more heat input applied during FSBE process; but it should be considered that this can lead to the more grain growth and decrease in the mechanical properties of the formed tube in addition to the sticking between the material and the processing tool Not include any test other than hardness.
With a similar concepts, (Joshi et al. (2014)) proposed a method of torsional shear assisted indirect extrusion process by uses a rotating ram as opposed to the axially fed ram used in the conventional indirect extrusion process. This work has shown that by using optimized high shear deformation and second phase particles of Mg2Si and MgxZnZrythe energy absorption of the extrusions can exceed that of AA6061. It also demonstrated significant promise with regards to tailoring the microstructure and is readily scalable to produce large parts relevant to automotive applications.

Behnagh *et al*. (2014), Produced fully consolidated wires from aluminum alloy AA7277 machining chips by the friction-stir extrusion. Components were stationary cartridge and a rotating plunger with a scroll-faced head. Investigated microstructure by optical microscopy and hardness of sample by Vickers micro hardness tester. The variation of rotation speed leads to the change in extrusion temperature that, if too high, results is hot cracking, and too low, cold tearing. Micro structure is characterized by equiaxis and recrystallized grains in the center of specimen. The hardness of the center was lower than that of the parent metal. The highest value of hardness existing in the zone near the outer surface of the wire was much higher than that of the parent metal. Sounded wire produced by optimum rotational speed was 160rpm. The fig 2.6 shows blow was rotational direction extrusion direction. But he was not tried other shape like tube, bar shape etc.

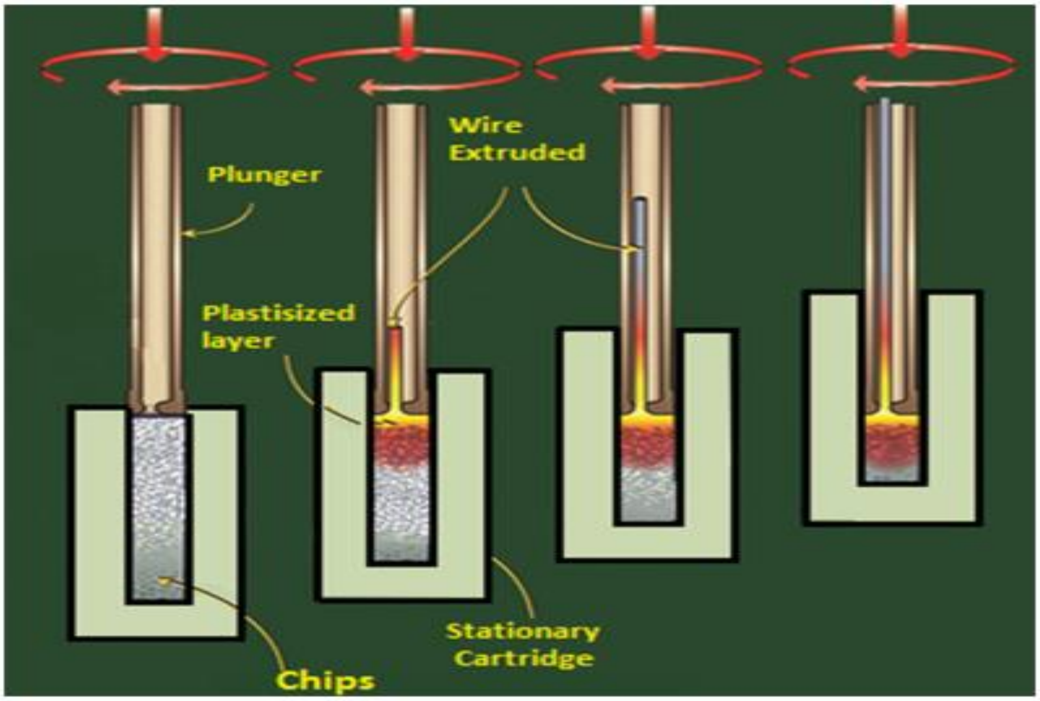


Figure.2. 6 Schematic representation of friction-stir extrusion process (Behnagh *et al*. 2014)

Ramesh Babu *et al* (2014), Investigated the effect of friction stir processing on the superplastic forming of magnesium alloy (AZ32B). Friction stir processing was performed by varying the process parameters, such as tool axial force, tool traversing speed and tool rotational speed. The process parameter that produced equiaxed grains in the stirred zone with a grain size less than 10 µm is selected. Magnesium alloy exhibits superplastic forming characteristics at elevated temperatures and the strain rate sensitivity lies in the range of 0.3–0.35. The temperatures of the superplastic flow for magnesium alloy were identified as 350^0C and 400^0C. Beyond 400^0C, the oxidation occurred on the apparatuses. The temperature and pressure increase up to a certain point, the strain rate sensitivity increases and then decreases. The forming pressure was identified as 0.4 MPa at temperatures of 350^0C, and 400^0C, with the maximum strain rate sensitivity of 0.35 for non-friction stir processed material. Finally the increased strain rate sensitivity index was due to the decrease in the grain size in the friction stir processed zone. The maximum strain rate sensitivity at a temperature equal to (0.5) Tm and beyond that the strain rate sensitivity value decreases. The studies focused only super plasticity behaviors but not touch any mechanical properties.

Sharifzadeh *et al* (2015), was applied friction stir extrusion process to produce a sounded wire from pure Mg chips. The experiments was performed under the tool rotational speed of 150, 250 and 355rev/min and at a constant plunge rate of 20mm/min. the target was microstructural evolution, tribological behavior and corrosion resistance with reference specimen and the frictional extrudes. Microstructural characteristics of the specimens were investigated by optical microscopy (OM) and scanning electron microscopy (SEM). The polishing was done with a 1000 grit Al2O3 paper and final polish by colloidal silica with 40 nm in diameter. The specimens were etched by acetic picral (5 mL acetic acid, 6 g picric acid, 10 mL water and 100 mL ethanol) at room temperature. Mechanical properties include micro hardness and dry sliding wear test cared out by Vickers micro hardness and the average hardness value approximately HV 25 by 1kgf (one kilo-gram force). They related grain size and evolution of microstructure with the corrosion behavior of the friction stir extruded samples. Finally the wear resistance of the pure Mg chips significantly enhanced by the friction stir extrusion due to the intensive grain refinement during the process. An infrared thermometer was used to monitor the temperature changes during the process. The measured value indicates the maximum temperature during the process is 0.8Tm with the rotation speed of 355 r/min, where Tm is the melting temperature. The schematic representation of component of FSE process is shown in Fig.2.7. The face plunger inserted into cavities of container.

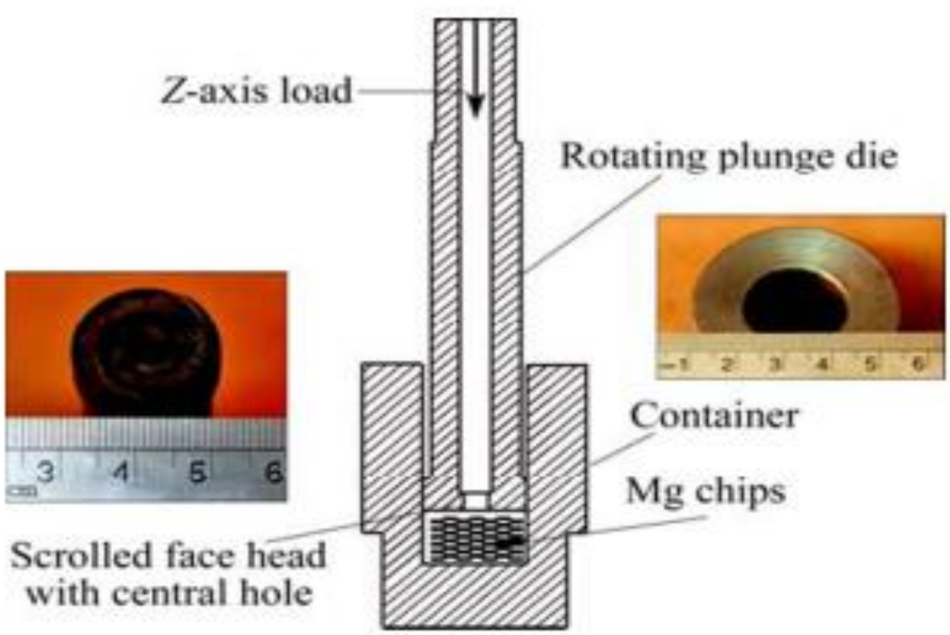


Figure.2. 7 Components used in FSE process (Sharifzadeh et al (2015))

Hangai *et al* (2018), Fabricated the AA1050 tubes filled with ADC12 foam by frictional stir back extrusion and foam able precursor was coated on the surface of the inner wall of the fabricated tube. They can realize metal bonding between the foam and tube and also examine tool rotating rate. First they fabricate Al tube from bulk Al and Next, ADC12 foam able precursor was coated on the surface of the inner wall of the fabricated A1050 tube. they was confirmed that an appropriate tool rotating rate was 1000–3000 rpm for fabricating the A1050 tube and coating the ADC12 precursor, which can be conducted at a lower torque than the maximum torque of the machine used. The compression properties of the tube, it was found that the foam-filled tube exhibited superior compression properties to empty tubes and foams. Only test compression properties not includes other mechanical test.

In frictional extrusion, the qualities of extrudes by depend on the process parameters of fabrication. Hosseini *et al*. (2012), was investigated the effects of traverse speed rate and die rotational speed on physical and micro structural properties of wires produced by a novel friction stir extrusion. Hot crack and cold crack defects were existed on wires produced by using too high and too low die rotational speed, respectively. Defects such as voids in the wires increased with the increase of die transverse speed. By microscopic evaluations proved that the optimum condition for processing is 400 rpm rotational speed and 10 mm/min traverse speed for rotating die. The studies was only examined physical properties of sample, but not investigated microstructural and mechanical properties.

Chiba and Yoshimura (2015)**,** was proved the solid-state recycling of aluminum alloy machining scarp into c-channels by using hot extrusion. The billet material was cast Al-Si alloy ingot, the extrusion temperature of 600k, under extrusion ratio 10 and 18. The extrusion was performed by forward frictional extrusion. At extrusion ratio of 18 shows straight without warping of C-channel and increase ductility because of fine dispersion of Si particle with sufficient void reduction and E.R 10 coarse residual void and cracks existed. They studied the surface appearance, density, microstructure and mechanical properties of different specimens obtained under different recycling conditions. Both the mechanical strength and uniform elongation of the specimen recycled from the turning swarf are inferior to that from the milling swarf. This is the synergetic effect of residual chip boundaries. But not tried by other circular and hexagonal bar.

Barmouz *et al*. (2011), Produced copper reinforced metal matrix composite (MMC) layers by using micron sized SiC particles via friction stir processing (FSP) and Investigated microstructure, micro-hardness, wear and tensile behavior. Higher traverse speeds resulted in poor dispersion of SiC particles and consequently reduced the micro-hardness values of MMC layers. The addition of SiC particles, were improved wear properties. they decided, the MMC layer produced by FSP shows lower strength and elongation than pure copper while a remarkable elongation was observed for friction stir processed specimen without Sic particles. Pure copper reinforced by Sic particles shows a higher wear resistance in comparison with pure copper. The research was only includes composite but not try other ferrous or non-ferrous metals.

Baffari *et al* (2017), Was fabricated defect free, sounded metal matrix composite rod from aluminum alloy AA2024 chips adding Sic powder by friction stir extrusion. During the process, a rotating tool is plunged into a hollows matrix to compact, stir and finally, back extrudes the chips to recycle in a full dens rod as shown Fig 2.8. Experimental campaigns have been carried out in order to investigate the effects on process mechanics of the introduction of silicon carbide micro powders. The report indicated as excessive amount of reinforce (p>1%) causes the formation of big inter granular conglomerate that affects deeply extrudes quality, causing crack opening and non-uniform mechanical properties.

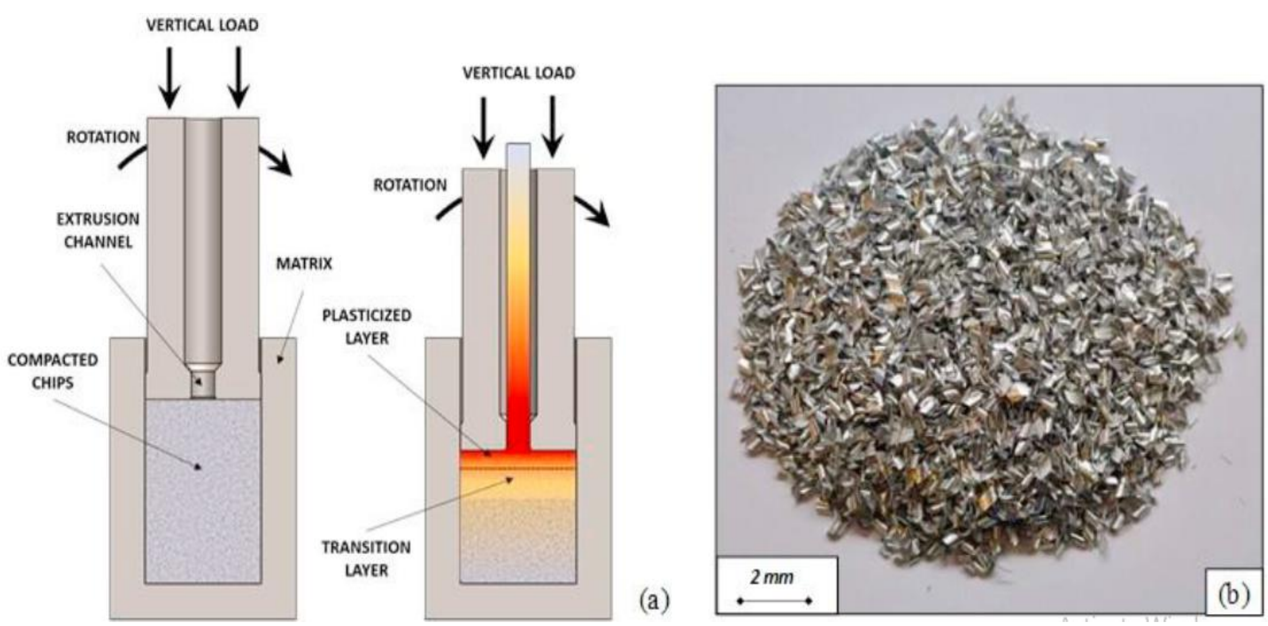


Figure.2. 8 Sketch of the Friction Stir Extrusion process and AA2024 metal chips used during the experimental campaign (Baffari *et al*, (2017)).

Babu *et al*. (2018), Was by experimentally, cared-out the hardness properties of friction stir processed AZ31 magnesium alloy wire at different processing conditions. The parameters was studied at the three different travelling speeds: 20, 30 and 40mm/min with two different rotation speeds 600 and 800 rpm. Experiments were conducted with High speed steel tool with tool depth of 1 mm, Tool shoulder diameter of 18 mm and Tool pin diameter of 6 mm on a vertical milling machine as shown in fig 2.9. The smallest precipitate size is obtained at spindle speed and feed rate combination of 800 rpm and 40mm/min. The corresponding Vickers hardness value is 63 by 1kgf which is around 50% higher than that of the base metal. They observed that single pass FSP of AZ31 alloy results in generation of in-situ precipitates with smallest particle size of the order of 0.8 µm which can get further refined during double pass FSP and also in subsequent passes. The high rotation speed produces smaller precipitates than the low rotation speed and due high rotational speed causing higher temperatures result in more heat input. But not tried to make other shape product.

Figure.2. 9 Experimental setup of friction stir welding of magnesium plate (Babu et al. (2018))

Ma *et al*. (2010), was investigated on how the die conditions (die angle and bearing length) can influence the sticking/slipping lengths in the bearing channel during unlubricated aluminum extrusion processes and the possibility of quantitatively predicting them. The lengths of sticking and slipping regions can be predicted by comparing the shear stress due to friction to material's shear strength. The results show that a high friction coefficient in the bearing will increase the sticking length and shorten the slipping length. Sticking only occurs when the bearing length is long enough to establish a large pressure near the bearing entrance which is large enough for the material to stick to the bearing surface. The surface roughness increases the friction and thus decreases the slipping length in the bearing channel. Not touched any mechanical and microstructural properties

2.2 The Process Parameters of Friction Extrusion

The main process parameters of frictional stir back extrusion are rotational speed, plunge rate, extrusion diameter, transverse force or pressure and transverse speed of die. Ansari *et al*. (2015), was optimized this parameters by using Taguchi L8 orthogonal design of experiments to produce fully-consolidated wires from pure Mg chips. The optimum process parameters are determined with reference to the average grain size of the wire. The parameters are rotational speed (RS), plunge rate (PR), and extrusion hole size. The RS played an important role and contributed 71.6 % to the overall extrusion parameters. The extrusion HS was found to be the least contributing extrusion parameter. The optimum extrusion parameters for the finest GS were the RS of 250 rpm, the PR of 14 mm/min the HS of 5 mm.

By the nature, aluminum alloys are grouped into two, initial tempered or non-tempered (T0). Tempered alloys are T1, T2, T3, T5, T52, T6, T8 etc. Baffari *et al* (2017), was experimentally investigated the effect of process parameters and initial temper of the base metal on the wire quality by frictional stir extrusion. They considered rotational speed and vertical applied force. Extrusions were carried out with varying rotational speed (100 rpm, 200 rpm, and 300 rpm) and extrusion force (26.7 kN, 35.6 kN, 44.5 kN, and 53.4 kN). Die and tool machined from H13 tool steel and billet AA2050 chip and best sounded wire fabricated by 35.9 kN and 100rpm are optimum.

Sato et al. (2002) discovered relationship between control parameters and grain growth in friction stir welded samples. His study shown that higher heat input which brings about high temperature causes grain growth and consequent hardness drop. This is helpful to understand similar microstructure evolution during friction extrusion process. High pressure torsion (HPT) is another metal forming process having aspects in common with friction consolidation and extrusion. It refers to the processing of metals whereby samples are subjected to a compressive force and concurrent torsion in the quasistatic state. The strain in HPT process can be easily calculated and may be helpful to estimate the strain in friction consolidation and extrusion process.

Hosseini *et al*. (2012), was considered traverse speed rate and die rotational speed to produce defect free wire on friction extrusion. Depends on physical and micro structural properties of wire to arrange parameters and decides the optimum traverse speed for rotating die is 10 mm/min or lower and rotational speed from 200 to 400 rpm.

Jayaraman *et al.* (2009), Used by MINITAB software; ANOVA and signal to noise ratio of robust design, effect on tensile strength of FSW process parameters (tool rotational speed, welding speed and axial force) was evaluated and optimum welding condition for maximize tensile strength determined. He used full factorial experimental design (3^3) with taguchi's robust design concept in order to optimum tensile strength (TS) of frictional stir welded joint of A329 alloy. He conclude that tool rotation speed has been dominant parameter for TS followed by welding speed and Axial force minimum effect on TS compared to other parameters. Maximum TS (147Mpa) exhibited by FSW joint with optimal process parameters (tool rotation speed, 1200 rpm; welding speed, 40mm/min and axial force, 4kN) shows a reasonable agreement with experimental value.

Patel *et al*. (2016), Studied the effects of process parameters on cavitation during friction stir process of 7075Al. Cavitation is a prominent defect in the FSP due to inappropriate selection of the process parameters such as tool rotation speed, traverse speed and tool tilt. Low heat input samples generated little cavitation because of the low thermal cycle as well as lesser grain growth. Tool pin geometry plays a major role in the generation of cavitation during FSP. The studies was not be covered microstructure of sample and hardness test.

Wang *et al*. (2014), was examined the effect of friction stir friction stir welding on microstructure of aluminum alloy 7022 and wear properties. The rotating tool was non-consumable, harder than the base metal and made from tool steel with a threaded, tapered pin profile. That plunged into the abutting edge of the plates joined under sufficient axial force. The microstructure was observed by using optical microscopy and the wear test was checked by using a steel ball-on-disc wear apparatus at room temperature without adding lubricant. Normal force of 1.47N and rotational speed at 5min. Micro structure observed four zone: negated, heat affected zone, base metal and thermomechanical. The grain size changed from coarse to fine from top-to-bottom of the nugget.

Tahmasbi *et al*. (2018), Investigated the effect of frictional stir extrusion processing parameters on the microstructure and mechanical properties of AA7022 aluminum alloy. Hardness and compression test results indicated that with increasing rotational speed, mechanical properties such as hardness and yield strength is reduced. Increasing the extrusion force to a certain extent caused increase in yield stress of material. The increase of extrusion force results in the adhesion and compression of the materials to be better. Too low temperature results in cold tearing and porosity defect. The best sample was produced at the rotational speed of 500 rpm and extrusion force of 38.4 KN shown as Fig 2.10. It shows variation of physical shape of wire at different rpm.

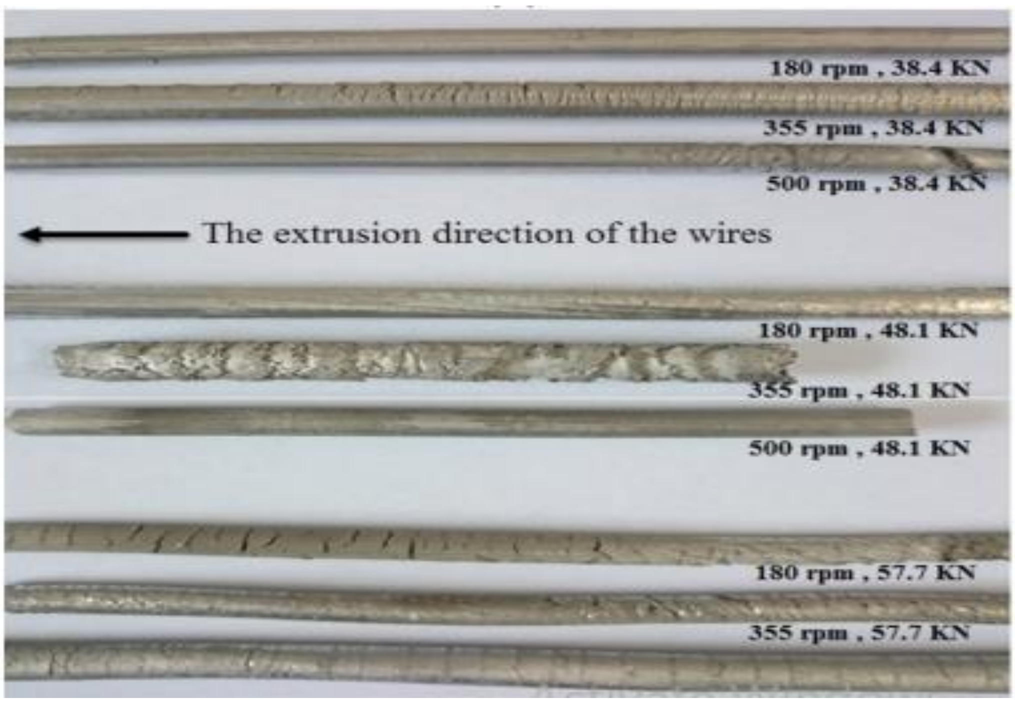


Figure.2. 10 Samples extruded at different process parameter condition (Tahmasbi *et al* 2018)

2.3 Material Required to Friction Extrusion that Proposed By Previous Work

2.3.1 Dies

Die and chamber was the most basic materials used to fabricate any product that are applicable shape to frictional extrusion. Die must be stronger and high strength than billet because of deformation occur within tool and chamber cavities, therefore during design of die failure limit must be considered**.** Arif *et al*. (2003), was analyzed and identifies different mechanisms that lead to extrusion die failure and studied the relationship between die profile and mode of failure. The three most commonly reported modes of dies failure are fatigue-based fracture, wear and plastic deformation /deflection. The analysis reflects three different perspectives: (a) overall and class-wise break-up of failure modes, (b) failure analysis for dies of different complexities, and (c) shape-wise break down of each failure mode. Total 616 die failure involving 17 different die profiles and were made from H-13 steel, while the billet material was Al-6063.Total number of failure belonging to the solid category was 271, that hollow type was 241, and the remaining 104 were of semi-hollow shape. At each failure mode, fracture was found to be mostly in solid dies (74%), followed by a (14%) shared in hollow dies and (12%) in semi-hollow ones. Of the break down related to wear, (56%) were in hollow dies, (25%) in solid one and (19%) in semi-hollow dies. Out of dies scrapped due to plastic deformation, (68%) were hollow (26%) were semi-hollow and (6%) were solid. Mixed- mode failure were mostly in hollow dies (69%), miscellaneous one in solid (58%) and mandrel breakdowns predominantly in hollow dies (82%).

2.3.2 Types of Scrap Applicable to Friction Extrusion

The most common recommended material for friction stir extrusion was non-ferrous metal to use as billet and H-13 tool steel for die and chamber. Some authors published their research on friction stir extrusion by using non-ferrous metal as billet. Farha (2012) Used aluminum alloy 6063-T52 billet, Azarsa *et al*. (2012) Aluminum alloy AA2025 machining chips, Dinaharan *et al*. (2014) Used pure copper billet, Ansari *et al*. (2015) Used magnesium billet and Schikorra *et al*. (2007) used aluminum alloy 6060 billet and etc. the selected extrude material to this research was aluminum alloy 6063 as a billet because of the best extrusion properties and surface smoothness.

2.4 Rotational Directions of Dies

Dies and scroll faced punch is basic component in frictional stir back extrusion to fabricate any desired product. The scrap compacted inside cavity of chamber and the face of die rotates the axis of dies to plasticize the billet and after some minute extrude product with in the hollow of die. There are three rotational options of chamber and die. First one was chamber fixed and dies rotate as shown fig 2.11, secondly dies fixed and chamber rotates and then both chamber and dies rotates opposite direction. Hangai *et al* (2017), was fixed dies and rotates the punch within range of 1000rpm-3000rpm to fabricate defect free sounded tube from aluminum alloy 1050.

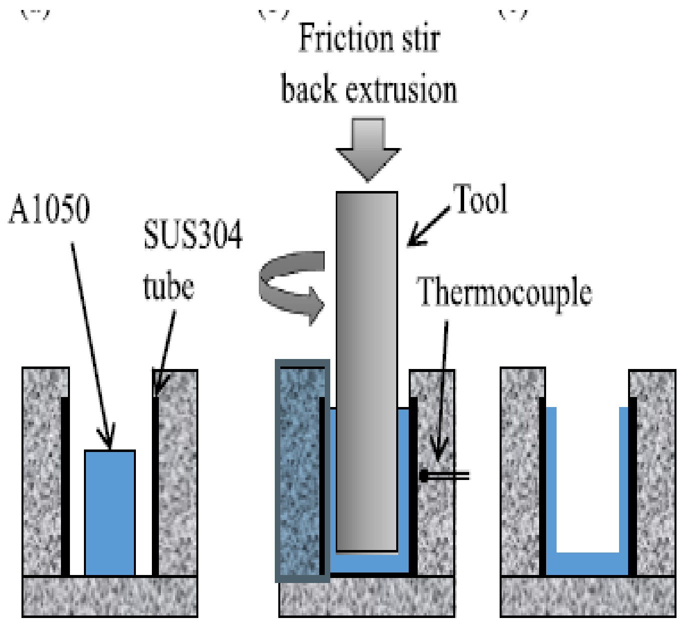


Figure.2. 11 frictional stir back extrusion setup and tool rotational direction (Hangai 2017)

2.5 Summary of Literature Review

Friction stir extrusion is a friction based extrusion method for producing high quality wire, rod and other form of shapes from low cost precursors (scrap and chips) by one step fabrication without melting. Most of time the material used for FE was, non-ferrous metal used as a billet and H-13 tool steel as a die. The working principle of friction stir extrusion is, the die moves down or the ram goes up to compress the precursor in the chamber. Then the die rotates in order to generate frictional heat at the die/precursor interface. Under high pressure and continued frictional heating, the precursor (such as machining chips and metal scrap) in the chamber will be extruded out through the extrusion hole after experiencing softening but not melting. The extruded sample was fully consolidated, defect free and sounded fine grain compared with base material. The main process parameter of FSBE are die rotational speed, plunge rate, transverse speed of die and transverse force. The die rotational speed plays an important role in FSBE and contributes about 71% of the overall extrusion parameter.

2.6 Research Gap

The literatures reviewed are describing about how friction stir processing is preferable than conventional recycling method and how the effect of process parameters namely rotational speed of die, transverse speed of chamber, plunge rate etc. are playing critical role in solid phase metal recycling. After the deep review of previous work the following three points are clarified:

1. Many researchers have done on frictional stir welding, frictional stir extrusion and channeling, some researchers experimental proved frictional stir back extrusion by rotating the die and fixed chamber to produce tube, wire, rod, and c-channel. But no one applied frictional stir back extrusion to produce hexagonal shaped bar which was proposed in this work.

2. No work has been reported in the area of studying mechanical properties like hardness and compression strength of aluminum alloy AA6063 friction extruded bar, which was carried out in the present work.

3. Some of the above researchers fabricated wire, rod and tube produced by using frictional stir back extrusion to fix the chamber on machine table and rotates die. This study has proved the possibility of manufacturing defect free hexagonal bar by change the die and chamber rotational direction.

CHAPTER THREE
METHODOLOGY

3.1 Introduction

The general procedures and method of pre-extrusion, extrusion and post-extrusion process of experimental works includes sample test are shown by the flow chart Fig 3.1.

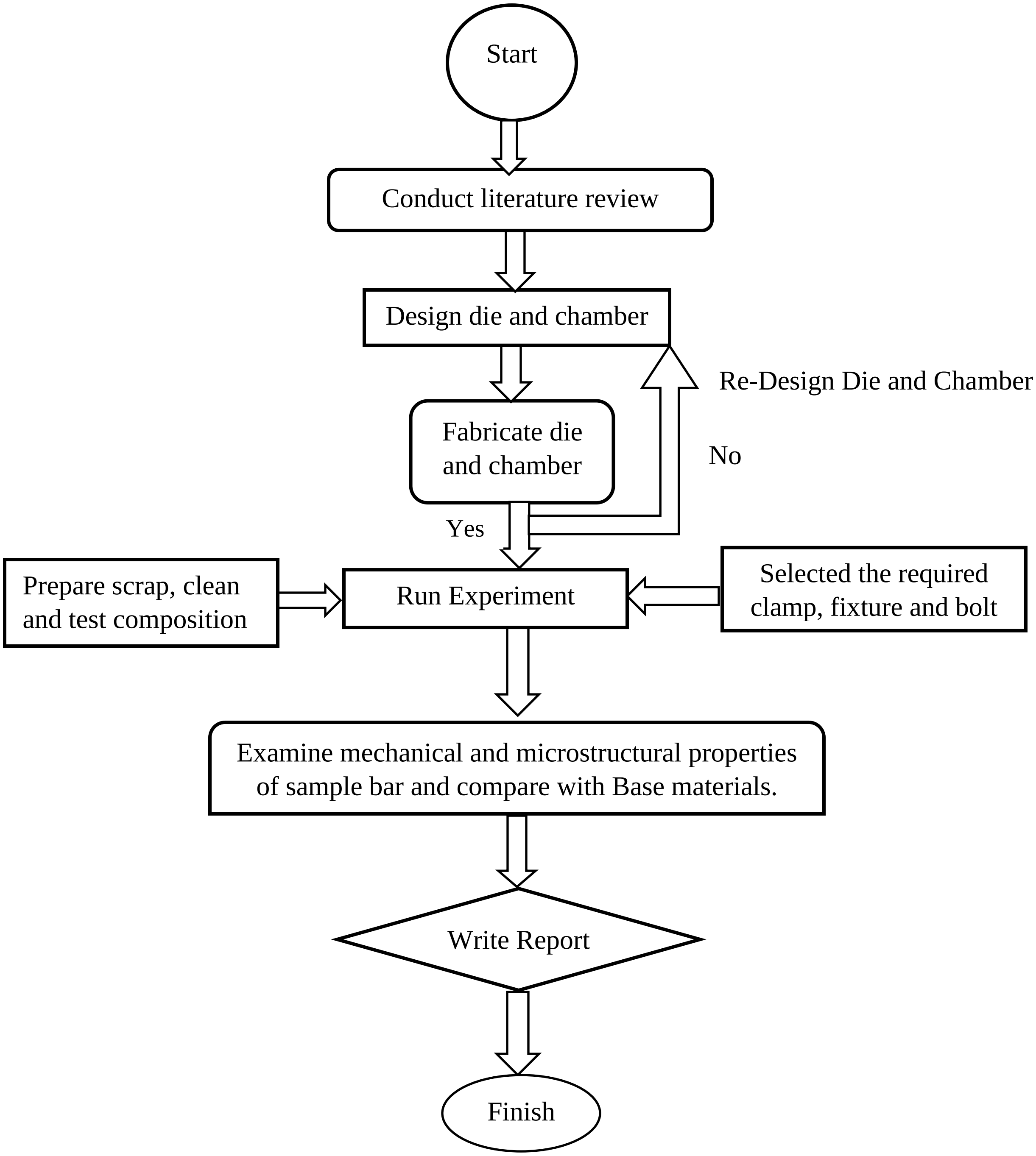


Figure 3.1 The flow chart of overall methods of experimental work and testing step

3.2 Materials and Equipment

The material used to perform this project are as follows

- H-13 tool steel die and chamber
- Aluminum alloy billet
- 210mm length M16x2 bolts
- Three jaw chuck
- Rotary table
- T-headed bolt

The equipment to facilitate this friction stir back extrusion to produce hexagonal bar are adjustable wrench, chuck jaw Allen key, file and silicon carbide paper, small hammer and box wrench. Table 3.1 shows equipment's and its specification.

Table 3.1 Equipment's and machineries used for experimentation and sample test

No.	Equipment	Tasks.	Machine specification.
1.	Universal milling machine	To fabricate hexagonal bar and produce key way in chamber	Excel vertical milling machine, FU-281.
2.	CNC milling machine	Produce spiral in face of die	Fanuc series Oi Mate-MB
3.	Lathe machine	Turn, taper turn, face, threaded out and bored of chamber and die	Excel XL-420
4.	Forging machine	Make hexagonal shaped hole at center of die	Forge machine new 2010 version
5.	Drilling machine	To make hole in die	Universal drill TSAR-25
6.	Heat treatment machine	Heat treat both die and chamber up to HRC-55	Fours nagat 44550-montoir de Bretagne-france
7.	Universal test machine (UTM)	Compression strength of sample	GUNT WP 310 Hydraulic
8.	Optical microscopy	Microstructural test	Magnification X50, X100, X200, X500 and X1000
9.	Vickers hardness tester	Hardness test	Serial no 0009

3.2.1 Universal Milling Machine

The main application of milling machine was used to cut the excess part of material from metal or alloy work piece by either vertically or horizontal rotational motion of spindle. Cut spur gear, helical gear and different types of rake and pin gear are also a duties of universal milling machine. On top of the above mentioned application, milling machine is selected in this study for friction stir back extrusion with in the boundary range of maximum power, rotational speed and torque of milling machine. In the below table, the maximum and minimum torque of milling machine was the calculated value and the others are constant machine parameter. The specification of the milling machine was as follows indicated in the table 3.2.

Table 3.2 Specification of universal milling machine code F-281(Excel machine manual)

No	Spindle description	Units.	Maximum range.
1.	Main driven range normally	RPM	40-2000
2.	Motor power	kW	5.5
3.	Maximum torque	Nm	1313.7
4.	Minimum torque	Nm	26.27
5.	Feed motor power	kW	1.5
6.	Feed motor rotational speed	RPM	920
	Feed range as follows.		
7.	Vertical, horizontal and transvers.	mm/min	6.25-315
		“	“
		“	5.2-262
8.	Gear transmission ratio	-	1:1

3.2.2 Properties of H-13 Tool Steel

The properties of AISI H13 tool steel differs from the other materials by addition of about 1 per cent vanadium, which contributes to increased hot hardness, abrasion resistance and reduced sensitivity to heat checking. These properties are needed in die casting, particularly of aluminum, where the tools are subjected to drastic heating and cooling at high operating temperatures. Besides die-casting dies, H13 is also widely used for extrusion dies, trimmer dies, stamping dies, hot gripper and header dies, and hot shear blades (Erik, *et al.* (2008)). Many researchers were carried out their experiment by using H-13 tool steel as a die in frictional stir extrusion successfully to completed (Li (2016), Farha (2012) and Sharifzadeh (2015)).

3.3 Design and Fabrication of Die and Chamber

3.3.1 Geometrical Design of Die and Chamber

To produce a sounded extrudes by FSBE, the geometric design of die and chamber plays a great role. The detail dimensions of die and chamber must be decided based on an experiment provided by pervious researchers by which mention to improve efficiency and minimize excess friction and power consumption. The rotating die has external diameter of 38.1mm, center of extrusion die hole diameter of 4mm, the extrusion land height before wide 1mm. the friction land of scrolled faced die before extrude bar; the pitch of die shoulder presents a twin clockwise scroll of 8.9mm and a second through hole 8mm far from the extrusion channel (Baffar *et al* (2017)). He was successfully achieved his research with in this dimension of die and chamber. According to the above explanation of researcher to design die and chamber must be dependent on the literature review and standards of hexagonal bar in order to avoid the extra friction between center hole of die-billet interface and twisting of bar. The sample size thickness was 6mm because of the standard of hexagonal bar. The dimension of clearance between outer diameter of die and inner diameter of chamber cavities was 0.5mm. The depth of hole to form hexagonal shape is 2mm in order to minimize the excess friction with in extrusion land. After 2mm depth the hole increased into 14mm diameter up to though out.

The geometric modeling of die and chamber done by mechanical software which is called solidwork. So this modeling was done by milling machine (FU-281) arbore dimention and chamber cavities diameter and depth by depend on litereture review paper. the below Fig 3.2(a) and (b) shows that the surface of chamber and scroll faced die with hexagonal shaped center hole. The isometric view of die and chamber get after consecutive modeling stape of solid work. First draw line by accurate dimention and rovolved after draw center line. Finally made scroll shape on die face and key way at chamber.

3-D Geometric Modeling of Chamber and Die by Sollid Work

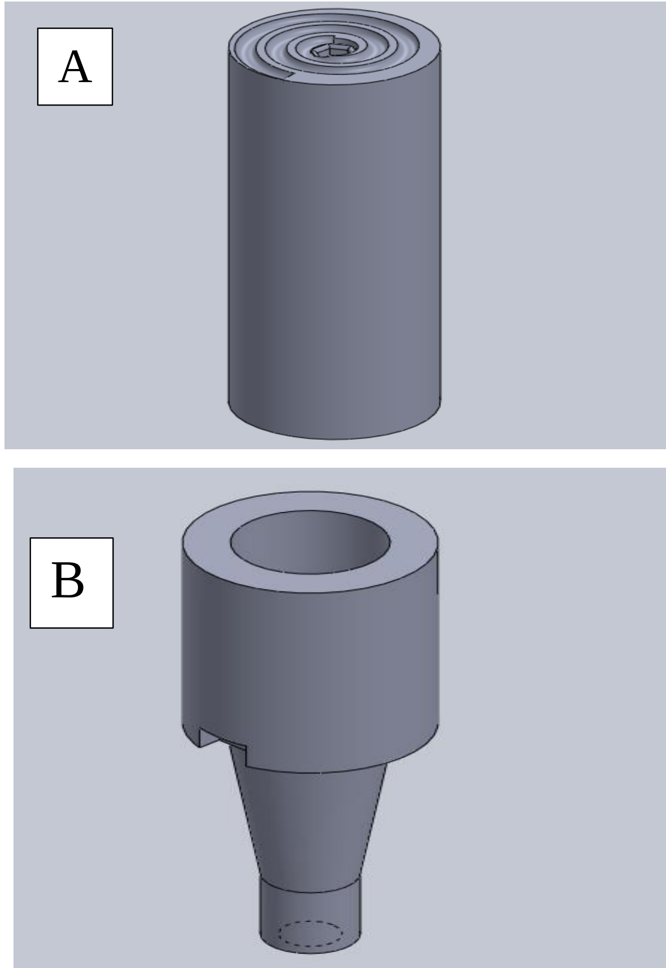


Figure 3.2 Geometrical design of die (A) and chamber (B) by solid work

3.3.2 Fabrication Methods of Die and Chamber

Scroll faced die and one side cavity chamber was the mandatory equipment to manufacture hexagonal bar by friction stir back extrusion. Due to this, the fabrication processes demands serious attention to improve the efficiency of die and decreases the defect. Before chamber fabricate detail dimension is required to obtain minimum tolerance as indicated in Fig 3.3. The procedure followed to manufacture chamber was as follows.

1. Chosen the small diameter H-13 tool steel circular rod that approaches to the outer diameter of chamber in-order to minimize material, machine and power cost.
2. Cut a short billet by 176mm length from 65mm diameter rod using a grinder.

3. Rough turn and face a all surface of chamber to remove dust particles and corrosion. The machining processed on lathe machine with feed rate of 0.5mm/rev by using high carbon steel cutter.
4. Continued turning and facing by the same cutter and machine to get 64mm dimeter and 174mm length.
5. Then bored one face of chamber to make a cavities by using high carbon steel boring cutter up to 70mm depth and 40mm diameter from center by lathe machine.
6. Opposite to the bored face, turn chamber from the end to left side 94mm up to get 43mm diameter feed rate of 1mm/rev.
7. Again turns the opposite to bored face up to 25mm diameter get from end face to left 27mm. length and still used the same machine and cutter.
8. Then taper turn operation was done between 43mm and 25mm by taper angle 7:24.
9. Drill 14mm diameter hole having depth of 27mm in the direction of opposite end of bored face to create internal thread M16x2.
10. The last operation was done by drilling machine between 64 and 43mm diameter to made key way hole in two side.
11. Finally heat treatment was performed up to HRC-54 by using heat treatment machine. Heat treatment process is deferent from the other manufacturing process by performed at high temperature oppression. First the furnace was heated up to 940°C and both the die and chamber were inserted in the furnace. Then after 40minute of stay in furnace they are removed off and quenched with water media. Finally both the die and chamber where tempered at 400^0C to minimize brittleness of the material.

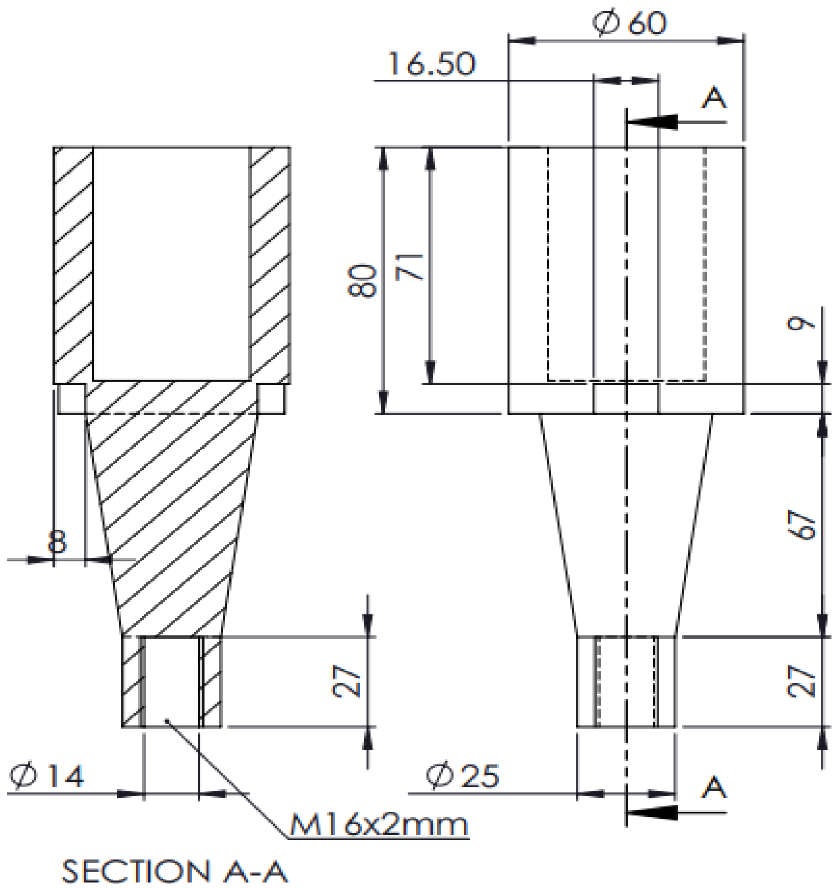


Figure 3.3 the 2-D detail dimension of designed chamber

Die was manufactured using three different machines such as lathe, punch and CNC milling. The fabrication procedure was similar to chamber fabrication except application of CNC milling machine to make the spiral profile on one face of die as indicated in Fig.3.4. The die fabrication step was as follows.

1. Cut 133mm length a short billet from long 40mm diameter H-13 tool steel rod using grinding machine.
2. Similar to chamber fabrication rough turning was done to remove dust particles.
3. After rough turning and facing, again face and turn up to get 130mm length die on lathe machine by using high carbon steel cutter using 0.5mm/rev feed rate.
4. Then continues turning up to 39.5mm diameter by the same machine, cutter and feed rate.
5. After the completion of turning and facing operation, produce drill 14mm diameter hole from left face to right side at center having 114mm length by using high speed steel drill

bit. The operation was performed by lathe machine, to fixed drill bit by tailstock clamp work piece on rotating headstock. The feed rate was 0.4mm/rev.

6. Then 8.5mm diameter hole is again drilled from previous hole located at distance of 10mm length and the remaining portion is drilled throughout with diameter of 6mm.
7. Then produce hexagonal shaped hole by 6mm length and width by using punching machine. The punching was done after heated die up to 600^0C and punch by specified 6mm diameter hexagonal tool high force.
8. The last machining operation was to cut the spiral shaped hole from center to end of die face by using CNC milling machine. Before machining the spiral shaped hole, programming cod was generated using Master-CAM software and these codes are imported to CNC milling machine. The spiral was made 4mm diameter pin-end mill cutter and the depth was 2.5mm. The Fig 3.4 below shows fabrication step of die in CNC machine.

Figure 3.4 producing spiral shaped die using CNC machine

Finally after successfully manufacturing of the die to the required dimension and accuracy, it was to be heat-treated up to obtain hardness HRC-55.

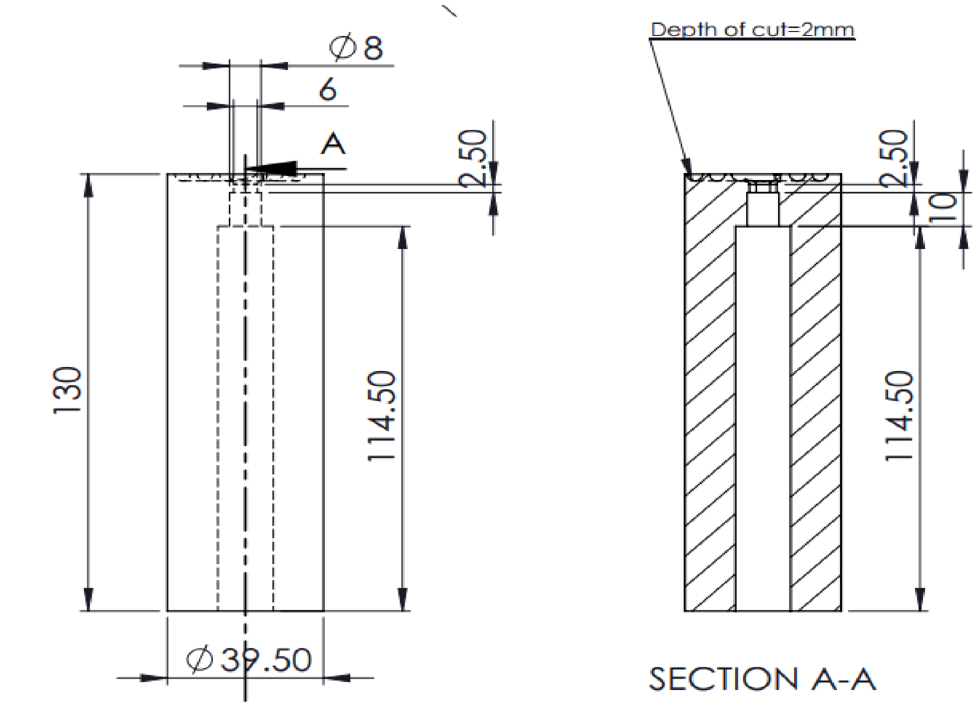


Figure 3.5 the detail dimension of die

3.4 Clamp and Fixture Selection

To fix the die and chamber for the production of hexagonal shaped sample bar, the following fixture and clamps have been used as indicated in table 3.3.

Table 3.3 selected experiment setups international standards

S.No	Item	Quantity
1.	Rotary table.	1pic
2.	Three jaw chuck	1pic
3	Hexagonal headed bolt, M16x2	1pic
4.	Nut and bolt M12x1.75	2pic

Rotary table means a precision work positioning device that used in metal working. It enables the operator to drill or cut work pieces at exact interval around fixed axis. The main function was to machine spanner flats on a bolt, to drill equidistance holes on a circular flange, to cut arcs etc. but in this project it was clamped on milling machine table and used as a chuck holder making use of its hole center, label surface and fixed key ways. A rotary table was already designed by accurate and fixed standard. The geometry of rotary table as shown below in Fig 3.6.

Figure 3.6 Rotary table that fixed with milling machine table (manual of Excel machine tool)

A chuck is a specialized type of clamp that used to hold an object with radial symmetry especially a cylindrical shape. In drilling and milling machine, it holds the rotating tools whereas lathe it holds the rotating work piece. On a lathe machine the chuck is mounted on the spindle which rotates with in the headstock. The selected chuck for this work was three jaw chuck because of high accuracy than four jaw and simple to fix on surface of rotary table. Die was vertically clamped by three jaw chuck. The chuck was also designed to fit an existing standard lathe machine shop to hold the die in milling machine table.

Figure 3.7 Three jaw chuck (From manual of Excel machine tool)

The rotary table was fixed with milling machine table by using T- headed bolt and hexa-headed nut. The M16x1.75 T-head bolt was selected from table American National Standard T-Head Bolts ANSI/ASME B18.5 (Erik, *et al.* (2008)). It was already designed by international standard. Fig 3.8 shows T-headed bolt and nut

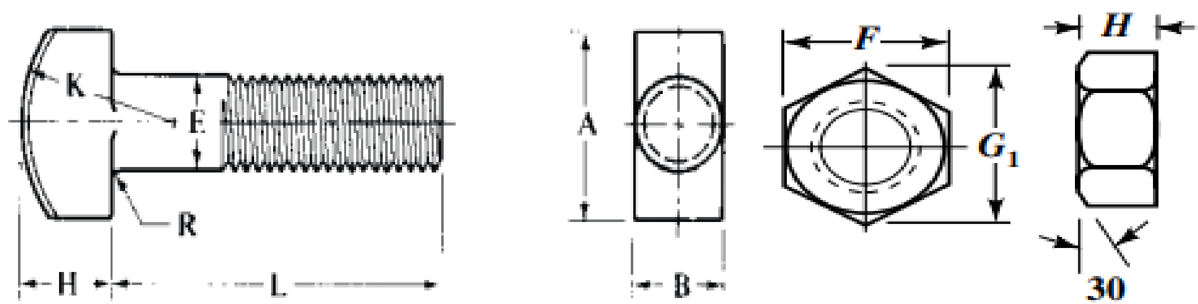


Figure 3.8 T-headed bolt and hexa-nut. (Erik, *et al.* (2008))

After the set-up was installed on milling machine table, extrusion chamber fixed with machine spindle by using 200mm length, M16X2 end threaded hexa-headed bolt and that means the same as arbor clamp with machine head. Then hexagonal shaped bar was simply extruded.

3.5 Sample Size

Sample size depends on the distance betewen chamber and milling machine table, and extrusion ratio. The maximum transverse distance of milling machine table was 420mm and the volume of chamber equals to height times cross sectional area of cylinder.

Volume of ciylinder = area times height

$V = A * H,$ A=area of cylinder face and H= hight of cylinder

Area of cylinder face= $\pi * r2$

The internal diameter of chamber cavites was 40mm and radius equals to half of diameter.

A=3.14*$(20mm)^2$

=1,364mm^2

Volume of chamber cavites equals to area of hole face times depth of hole. The depth chamber 70mm.

Volume of cylinder = area times height of cylinder

$V = A * H$

=1,364mm^2*70mm

=95,480mm^3

The extruded sample was hexagonal shape and the thikness which is equals to six millimeter.

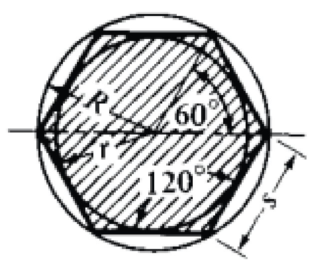


Figure 3.9 cross sectional area of hexagonal shaped bar

A =2.598s*2* = 2.598R*2* = 3.464*r*2

R = s = radius of circumscribed circle = 1.155r

r =radius of inscribed circle = 0.866*s* = 0.866RAccording to (Erik, et al, 2008)

S=R=1.155r, the area of extruded sample cross section equals to 3.464S^2

S=thickness divided by two

=6/2

S=3mm.

Cross sectional area of sample=$2.59s^2$.

$= 3.464r^2$

$= 31.176mm^2$

The maximum length of extruded bar is depend on this extrusion ratio or area of chamber divided into die extrusion hole.

Extrusion ratio, R=area of chamber/hole area of die.

$$R = 1{,}364mm2/31.176mm2$$

$= 43.75$

The maximum length of sample bar is going up to extrusion ratio times depth of chamber which equals to 3062.5mm or 306.25c.m. But the allowable extrusion maximum length of milling machine table was 280mm. Therefore, the maximum length of sample to be not more than 280mm.

3.6 Aluminum Alloy

3.6.1 Chemical Composition of Aluminum Alloy Billet

The chemical composition of aluminum alloy highly affect the mechanical properties, microstructural orientation of extrudes. For the purpose of this study aluminum alloy billet was tested spectrometer instrument found in Hibret Manufacturing and Machine Building Industry, Addis Ababa. The purpose of the test was to check whether aluminum alloy used meets the international standard of AA6063 or not. The composition test procedure was as follows. Connect the socket cable with an electric power and on spectrometer machine. Open the argon cylinder with not blow to pass 95% of argon gas and wait 15 minutes up to hot spectrometer and arrangement of other set up. Then polish aluminum billet surface by silicon carbide paper. Put the nozzle by perpendicular to and which connected with spectrometer by flexible hose. Finally take the average of four test and printed by hard copy.

Figure 3.10 Chemical composition test instrument (spectrometer at HMMBI)

3.6.2 Changing Aluminum Billet into Scrap Form

The size and shape of scraps have significant effect on physical, mechanical and microstructural properties of extrudes. To produce a sounded product; the scrap must be properly cleaned, dry, non-corroded and dimension to extrusion. Some researcher's works on the size and shapes of scrap materials before extrude. Buffa *et al*. (2016), Milled magnesium plate by with-out any lubricant in order to get clean, regular and applicable to frictional extrusion chips. The average size of chips was 5mm length, 2mm width and 0.2mm thickness. Baffar *et al*. (2017), Produced metal matrix composite rod from 2mm length aluminum chips by frictional extrusion. By the same technology (Khodabakhshiaa *et al* (2018)), proved consolidation by shear assisted processing and extrusion from AZ92E magnesium alloy scrap. The optimum scarp size was 10mm length to fabricate a sample with-out any extra pressure. According to the above author's explanations, the optimum average size of scrap is 7mm length, 3mm width and 0.5mm thickness shown in Fig 3.11. In this study, 6063 aluminum alloy billet was collected and carefully changed into the required dimension using milling machine. The procedures of scrap preparation was as follow

1. Machined all surface of circular billet by rough turning and facing with-out use any lubricant in order to remove corrosion and dust particle by lathe machine.

2. Clamped rough turned and faced aluminum billet using work piece holders on the table of milling machine.
3. Cut chips to the average size of 7mm length and 3mm width aluminum with constant feed rate by using end mill cutter.

Figure 3.11 Prepared aluminum alloy chips for study.

3.7 Process Parameters of milling machine to fabricate hexagonal shaped bar

The process parameter (die rotational speed and plunge rate) and constant parameter (die, chamber, plunge diameters and contact land length of die) plays a critical role in frictional stir back extrusion to produce a quality extrudes. The selected rotational speed was 200rpm, 250rpm, 315rpm, 400rpm, 500rpm and 630rpm and with transverse speed 12.5mm/min as shown below table 3.4. The range of rotational speed and plunge rate were considered based on previous research work; because of too high and low rotational speed of milling machine was not recommended in friction extrusion. Hot crack and cold crack defects were existed on wires produced by using too high and too low die rotational speed, respectively (Hosseini, *et al*, (2012)). The process parameters of frictional stir extrusion optimized and decided the plunge rate 14mm/min, hole size 5mm and initial contact land length was 2mm to produced sounded wire (Ansaril, *et al*. (2015)).

Table 3.4 Friction stir back extrusion process parameters

Test number	Die rotational rate (rpm)	Transvers speed milling table (mm/min)
1.	200	6.25
2.	250	6.25
3.	315	6.25
4.	400	6.25
5.	500	6.25
6.	630	6.25

With-in the above given rotational speed and transvers speed the experiment had been done

3.8 Consolidation and Extrusion period of Time

Friction consolidation is the period of time that compaccted the scrap material with in cavities of chamber and maximized density of chips and scrap. The combination of high temprature and plastic deformation to be made the scrap material highlly compacted. Friction extrusion is the whole process that includes consolidation, stiring and extrusion by using scroll or spiral shaped die feed to the center plastisized material. The local temprature of extruded material increased up to 0.6-0.9 Tm (Khodabakshia *et al*. (2018)). In this experment the transverse feed was given by manually up to consolidate aluminum alloy scrap by above 0.6Tm and engaged automatic feed after consolidate of material. This temprature was measured by using infferard termometer reflect the sensior ray perpendculary into the outer surface of chamber. The extrusion period was taken 1.28 minute to each sample using automatic feed. Because of the die moves up 8mm length with in 1.28minute constant speed. In this time the extrusion ratio high large length of sample extruded.

3.9 Fabrication of Hexagonal Sample Bar

3.9.1 Sample Fabrication Procedures

To produce sample bar, the prepared scrap was compacted within cavities of chamber using small size ball pen hammer. This pre-compact process used to increases the length of output hexagonal bar. Then the compacted chips and scrap were taped by a circular disc 40mm diameter and 5mm thickness. The taper disc was made from the same aluminum alloy the chips made of to hold the scrap and increases friction between scrolls faced die up to consolidate. It was turned by lathe machine at high speed steel cutter. Again the machined chips was used as scrap to fabricate hexagonal bar and disc as a taper. Fig 3.12 shows disc and chips compaction procedure.

Figure 3.12 Pre compaction and Disc preparation of aluminum alloy 6063

To produce hexagonal sample bar the compacted chamber with scrap was installed on the spindle of milling machine and also die was fixed milling machine table with proper alignement as indicated in Fig 3.13. the machine started after engaging proper gear ratio to obtain the reqiured rotational speed. Hand wheel is rotated by manually to clockwise direction to move up milling table at constant force until consolidation occurs. The consolidation time dependes on rotationa speed of chamber. Then after chips are plastisezed automatic transverse gear engaged. In this process the machine table moves up 6.25mm distance per one minute. Then after the sample bar extruded, the die is removed by engaging the clach downward to change feed direction. Die removal needs great care and should be operated without tuning off the machine power. The machine power is turned off, both die and chamber may be locked by the plastsized aluminum chips. After the sample bar is removed from the die hole, plastisized aluminum chips were clear from the die spiral ways by using a small 3mm diameter nose end chisel.

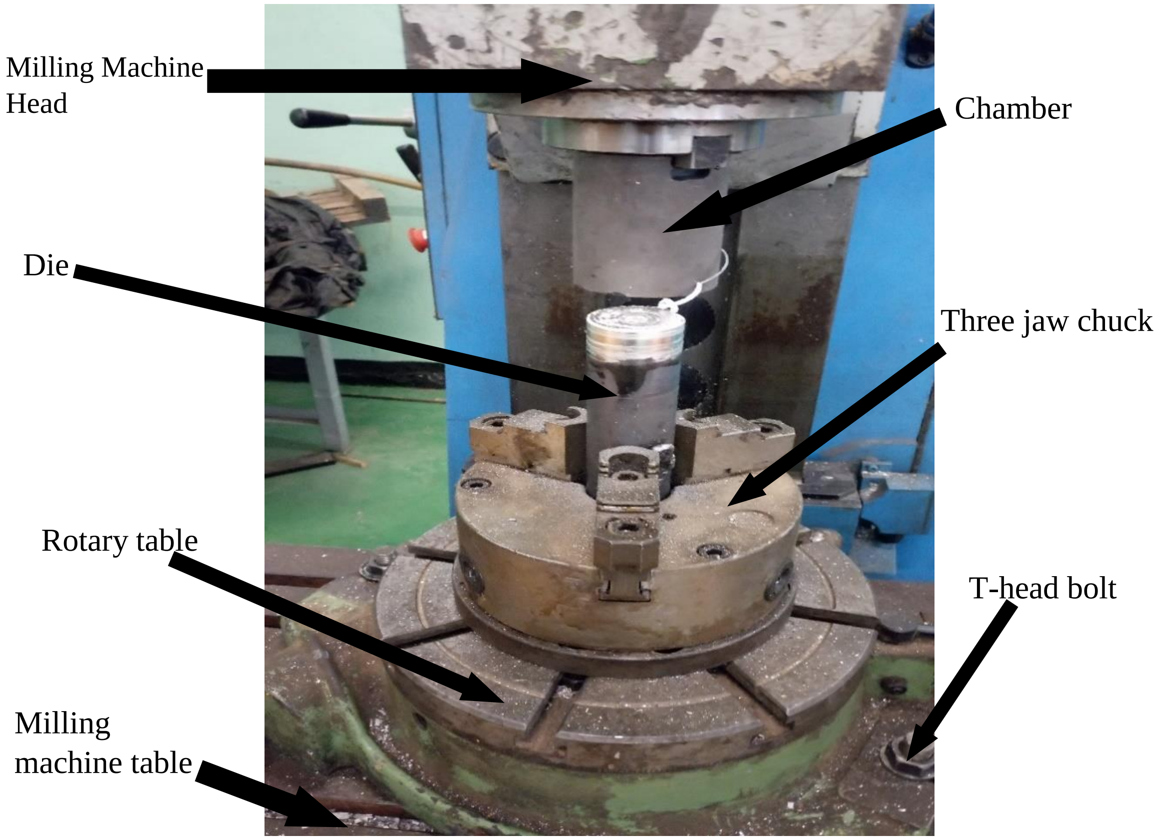


Figure 3.13 Set up confgration of friction stir back extrusion process

3.10 Sample Preparation for Microstructural Observation

Determining grain size, shape and distribution of various phases and inclusions was important as these affects the mechanical properties of the metal. The microstructure would expose the mechanical and thermal treatment of the metal, and it may be possible to predict its behavior under a given sets of conditions. The specimen preparation of sample to examine microstructure were cutting of specimen, grinding, polishing, etching and observing microstructure by optical microscopy. The procedure of specimen preparation metallographic test was as follows.

3.10.1 Cut Specimen from the Sample

The first step of any microstructural test is to, cut the specimen from the sample to the required testing size. By accurately dimension by required size. For this work six sample were selected to examine microstructure for each rotational speed of 200rpm, 250rpm, 315rpm, 400rpm, 500rpm and 630rpm. Then one centimeter length specimen were cut from each sample by using consumable high speed rotating disc abrasive cutter.

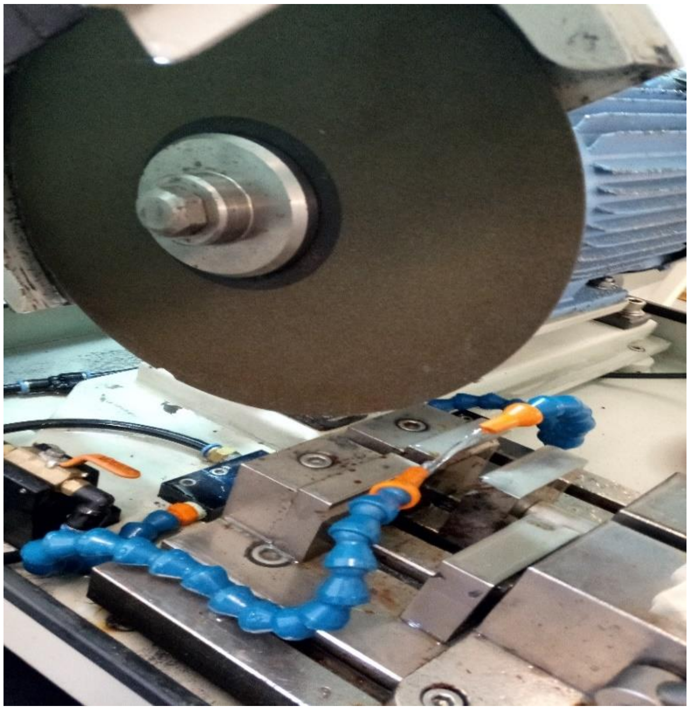


Figure 3.14 Cutting sample specimen for microstructure test by using abrasive cutter.

3.10.2 Mounting Specimen for Microstructural test

The second step of specimen preparation was mounting specimen for microstructural. Specimens cut from each sample were fixed in a holder to be handled easily during polishing, which is necessary to examine microstructure. The mounting operation was done by RB 206 Metpress-A machine using two cup MC-PRC/ phenolic resin conductive powder. The maximum heating temperature was 250^0C and took 30minute for each samples. The machine consists of upper ram, lower ram, heating part and cooled by water controlled by solenoid valve. A small piece of specimen increased in to a 32mm diameter pellet before grinding and polishing.

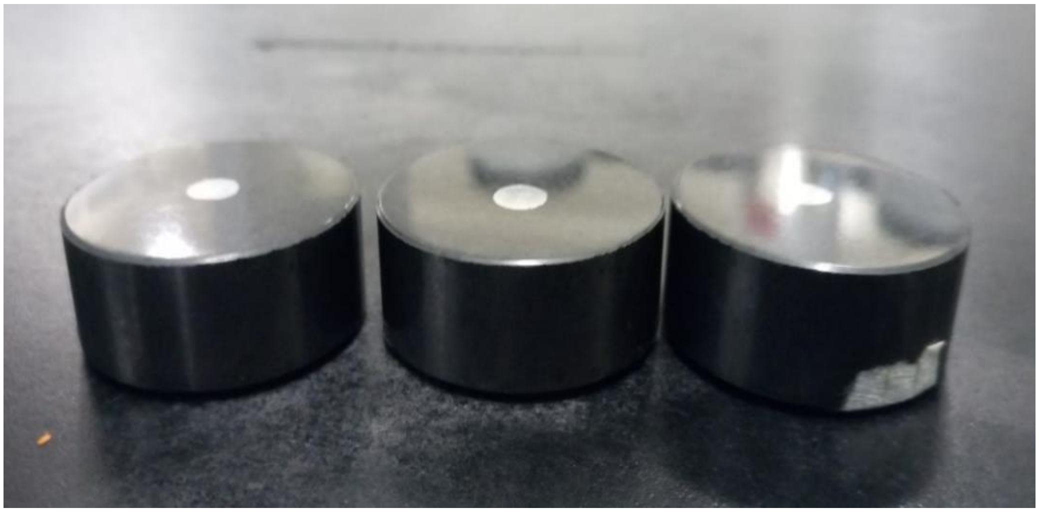


Figure 3.15 Samples of mounted specimen.

3.10.3 Grinding of Specimen

After a mounting operation, two grinding process were applied on each specimen. The first one was a rough grinding by using silicon carbide paper and second one intermediate grinding process by using metpol machine. All the specimen were grinded by the same method and procedure. First by 220 grit size silicon carbide paper ground for about two minute to one direction. Then the grinding is rotated 45 or 90 degrees to previous steps (center to edge) grinded with 400 grit size silicon carbide paper for similar duration. Again grinded by the following carbide papers 600, 800, 1200 and 2000 grit size. After each step of grinding dust particle is removed by compressor. The rough grinding of sample was continued until the surface in flat and free from nicks, burrs, etc.

3.10.4 Polishing of specimen

The success of fine polishing depends largely upon the care that was worked during a previous grinding operation step. The final approximation to a flat scratch-free surface was obtained by using of the wet rotating wheel covered with a special cloth that charged with carefully sized abrasive particles. In this step of specimen preparation, the specialized liquid spray on the surface of polishing cloth was one micro-meter diamond suspension. Six specimen of sample polished four times before the etching. In each of the polishing step, the specimen is washed with water and dried using pressurized compressor. The process continued up to four times until the specimen is free from any scratch and shine surface is obtained.

Figure 3.16 Polishing step of specimen.

3.10.5 Etching

Etching was the final step of specimen preparation to make the sample visible to many structural characteristics of the metal. This was accomplished by using an appropriate reagent which subjects the polished surface to chemical action**.** All sample was etched by 25ml hydrochloric acid, 25ml nitric acid, 25ml methanol and one droplet hydrogen fluoride combination. The duration of time for each sample etching was 10second as Fig below 3.17.

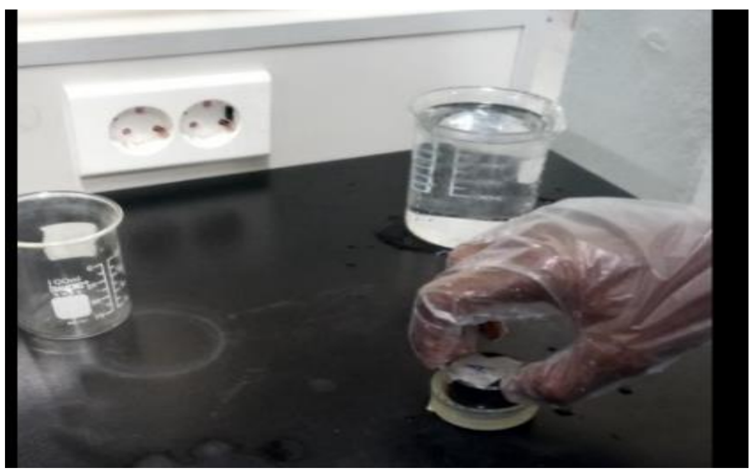


Figure 3.17 Etching of sample by HF, HNO3, HCl, and Methanol.

Then the shine surface of specimen put on the table of optical microscopy and examine its microstructure properties. The optical microscopy was having five magnification ranges which are 50x, 100x, 200x, 500x and 1000x. The scanning area covers 104mmX102mm. Microstructural properties observed by 1000X magnification label.

3.11 Hardness Test

Hardness is the properties of material that allows to resist a plastic deformation, usually measured by penetration. It was not a fundamental property of the material. The value of this property was the result of a defined dimension procedure, thus depending on the hardness method used; the hardness value will be different. All hardness tests contain the use of a specifically shaped indenter, significantly harder than the test sample. This indenter is pressed into the external surface of the sample using a specific force. Either the size or depth of the indent is measured to determinate a hardness value. Hardness measurements were extensively used for the superiority control of materials because they are rapid and considered to be non-destructive tests when the marks or indentations produced by the test are in low stress areas. There are many methods to determine the hardness, among those Brinell, Vickers and Rockwell hardness tests are frequently used. In this experiment Vickers's hardness test was used to measure the sample extrudes qualities. Vickers hardness test was measured to determine the hardness of a material, calculated from the size of an impress produces under load by a pyramid shaped diamond indenter. The diamond was pressed on the surface of material at measuring range up to approximately 50kgf (kilogram force) and the size of the impression was measured with the help of a calibrated microscope. The Vickers hardness number (HV) was calculated using the following formula:

HV = constant * test force/surface area of indentation.

$= 0.102*2F\ (\sin 136^0/2)/d^2$…………(Hardness machine manual)

Square-based pyramid diamond indenter with an angle 136^0 between the opposite faces at the vertex. Where F being the applied load (measured in kilogram force) and D2 the area of the indentation (measured in square millimeters). The Vickers hardness should be reported like 400 HV/10, which means a Vickers hardness of 400, was obtained using a 10kg force. Very accurate readings can be observed in this test, which is one of the main advantages of the Vickers hardness test and just single type of indenter is used for each and every type of metals or surface treatments. From six sample, 10mm length and 6mm diameter hexagonal specimen were cut at the cross section for microstructural study and micro-hardness measurement from each sample. Before micro hardness measurement cross-section of extrude mounted and grinded with 220, 400, 600, 800, 1200 and 2000 grit size and polished by diamond suspension. Micro-hardness was measured with Vickers micro-hardness tester just after microstructural test.

Figure 3.18 Macro hardness test of sample.

3.12 Compression Test

Compression test was a very common testing method, that used to establish the crash resistance of material and ability of material to recover after a specified compressive force was applied. The device that used to perform compression test was GUNT WP 310 Hydraulic Universal Testing Machine. Main Parts of GUNT WP 310 Hydraulic Universal Testing Machine are (1: double-acting hydraulic cylinder, 2: working area, 3: force sensor, 4: height adjustable lower cross-member with lock, 5: frame, 6: displays and controls, and 7: displacement sensor) shown as indicated in Fig 3.19 A. Elements of the display and control unit are (1: main switch, 2: on/off switch, 3: emergency switch, 4: button for moving upper grip downwards, 5: button to make grip movement fast, 6: button to move upper grip upwards, 7: force display, and 8: elongation display) as blow Fig 3.19B. Two samples were examined by this machine after consecutive specimen preparation. Equal diameter and length samples cut from base metal and extruded sample. Prepared sample were put on table of UTM machine and set force and elongation gage zero. Finally two samples were taken and the test reported and analyzed.

Main Parts of the GUNT WP 310 Hydraulic Universal Testing Machine

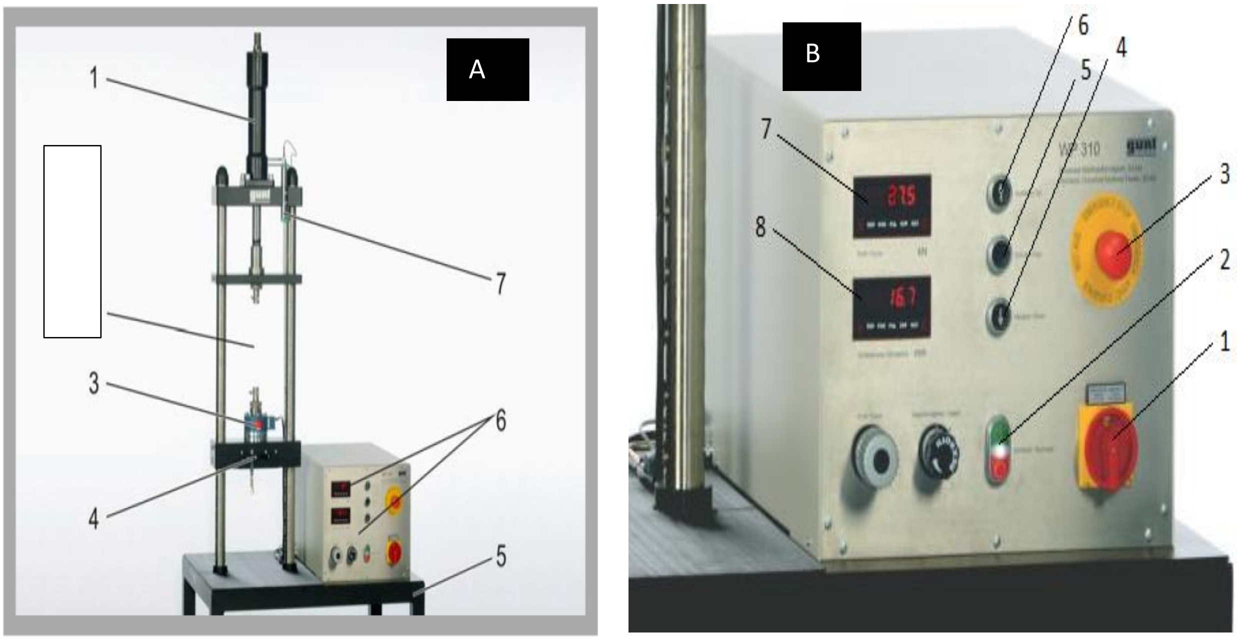


Figure 3.19 Main Parts of GUNT WP 310 Hydraulic Universal Testing Machine (A) and displays and Control units (B)

CHAPTER FOUR - RESULTS AND DISCUSSION

4.1 The Fabricated Die and Chamber

The scroll faced die and one side cavity chamber is the basic equipment in friction stir back extrusion. The function of this die and chamber is to consolidate, stir and extrudes aluminum scrap. To resist wear occurrence in the process of stirring and hexagonal shaped sample bar production it should be heat treated. The color is look like black after heat treatment as Fig 4.1.

Figure 4.1 Surface of die and chamber (A), Spiral face of die (B) and Cavities of chamber(C)

4.2 Chemical Composition Test Result of Aluminum Alloy Scrap.

Aluminum was different from the other metal by its alloying element. An aluminum alloy contains on average more than 20 elements, but the name of alloy serious mainly depends on elements such as copper, magnesium, manganese and silicon. Not all of them decides the alloy serious. But depends the main element such as copper, magnesium, manganese and silicon decide the name alloy of serious. The composition was tested by spectrometer at Addis Ababa, Hebert manufacturing and machine building industry. The percentage of composition is shown below table 4.1.

Table 4.1 Chemical composition of base material

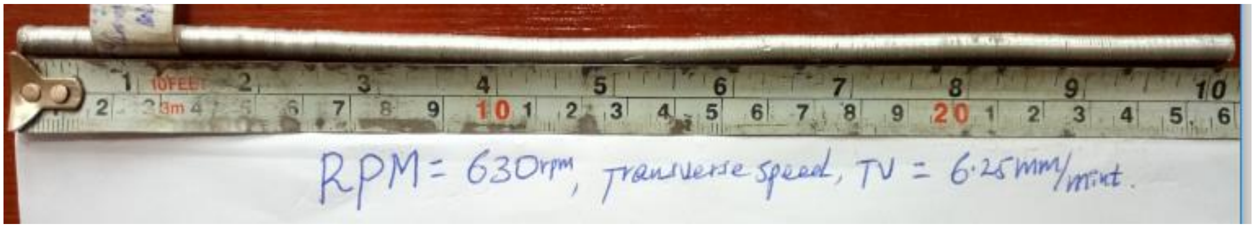
Alloying element	Symbol	Percentage (%)
Silicon	Si	0.58
Iron	Fe	1.35
Copper	Cu	0.017
Manganese	Mn	0.014
Magnesium	Mg	0.7
Zinc	Zn	0.092
Tin	Sn	0.039
Chromium	Cr	0.033
Lead	Pb	0.015
Nickel	Ni	0.019
Aluminum	Al	97

Aluminum alloy A6063 contains the main alloy element (0.45-0.9%) of magnesium, (0.2-0.6%) of silicon and 97.5% of aluminum as per ASM standard. After the composition test the result shows that all elements have accurate and much approximated to ASM standard but only Fe element increased one by percentage. Magnesium, aluminum and silicon percentage was within the range of AA6063 alloy. By default, iron content was increased by one percentage, and that do not much affect the properties of the metal. Because the properties of AA6063 mainly depends on silicon and magnesium content.

4.3 Extruded Samples at Different Speeds and Discussion

FIG. 4.2 below shows that, sample fabricated at different rotational speed and their shapes at each rotational speed. For example, sample one is extruded at 630rpm and 6.25mm/min, sample two 500rpm and 6.25mm/min etc.

Sample one



Sample two

Sample three.

Sample four.

Sample five.

Sample six.

Figure 4.2 Samples extruded by friction stir back extrusion at different rotational speed.

The above Fig.4.2, shows that, the possibilities of friction stir back extrusion to fabricate hexagonal shaped bar and other shapes from aluminum alloy scrap. Most of extrudes twisted and circular shapes. The reason of twist is, in friction stir back extrusion die shape, machine power and extruded material properties affects the shape, length and mechanical properties of extrudes. Sample one is performed at the rotational speed of 630rpm, and transvers speed of 6.25mm/min. In this process parameter the extruded product is resulted with large twisting angle almost like a circular rod shaped. This sample is longer than the other and is about 280mm in length and circular in shape due to higher rotational speed. The rotational speed played an important role and contributed 71.6 % to the overall extrusion parameters (Ansari, *et al* (2015)). If the rotational speed increases the possibility of consolidated aluminum to be changed into liquid form is high. In this time the die land length must be done longer than the other because it takes few second to solidify for melted aluminum. To this work, the die center hole depth (hexagonal shape former) was 2mm. the much-plasticized aluminum extrude out immediately by not formed hexagonal shape. It made circular shape due to high rotational speed and shortage of depth of hexagonal shape formed hole.

Sample two also almost the same shape to sample one, it is some hexagonal form related with sample one. It has been performed by rotational speed of 500rpm and constant transverse speed 6.25mm/min. The consolidate time took 5minute and extrusion time 1.28min and the result is shown in the above Fig 4.2 10.5mm length and 6mm diameter extrudes by friction stir extrusion. As explained above in sample one, rotational speed changed also resulted in shape change of the extruded products. The solution to this problem is design and manufacture die by deepened on each rotational speed of chamber. And also die center shape formed hole depth varied (means above 2mm). Sample three is manufactured at a rotational speed of 400rpm and constant transvers speed 6.25mm/min. The shape of sample was almost hexagonal but twisted. The twist angle is very small related with sample two. This shows that the decrease rotational speed decreases the twist angle. The length of sample is 80mm and twist angle 14^0. The bar is sounded good, defect free and also the smooth in surface. During the fabrication, the consolidated period or plasticized time was seven minutes. Up to seven-minute automatic feed was not engaged, because it over force and may damage machine and die. After the seven minute the feed was 6.25mm/min at constant speed engaged gear. The extrusion period took 1.28minute to fabricate. Sample four is also fabricated by the same method and procedures to other extrudes but the process parameters is different. It is performed at 315rpm and 6.25mm/min transverse speed. The consolidation and extrusion period take 8 and 1.28minute respectively. The shape is completely hexagonal but some twist angle was observed. The twist angle very small compared to sample one, two and three. The surface is also very smooth compared to other extrudes. Sample five is very well shaped hexagonal bar compared with the other extrudes. The fabricated process parameter is 250rpm and constant transvers speed of 6.25mm/min. During the fabrication the sample took 9 min to consolidate and 1.28mint to extrude. This sample was also twisted, but very small compared with the others and some part circular due to small rotational speed and minimum temperature. Up to 14mm length the sample is circular and then has changed into hexagonal shape. These results showed that rotational speed minimize the plasticized temperature. In this case the shape of hexagonal deformed at start then the working time increased the temperature with in chamber, scrap and die interface. In this time defect free hexagonal shaped bar extruded. Sample six shows that decrease in rotational speed results in decrease of shape deformation due to temperature reduction. The temperature decreases in die and scrap interface, some melted chips were welded on the corner of hexagonal angles. These welded chips were removed at high rotational speed of die, which is resulted in melting and cleaning of the corner. The samples are manufactured at rotational speed of 200rpm and transverse speed 6.25mm/min. The consolidation period has been 10 minute and extrusion time 1.28 mint. The surface of sample is not smooth as sample three. The process parameters, consolidation and extrusion time are shown below in Table 4.2.

Table 4.2 Duration of scrap consolidation and extrusion time at each rotational speed.

Sample No.	Rotational speed	Transverse speed(mm/min)	Consolidation time(mint)	Extrusion period
1.	630	6.25	5min	1.28 min
2.	500	6.25	7min	1.28 min
3.	400	6.25	7min	1.28 min
4.	315	6.25	8min	1.28 min
5.	250	6.25	9min	1.28 min
6.	200	6.25	10min	1.28min

Conclude to all the above discussion, the optimum rotational speed was 250rotasional speed and 6.25 mm/min transverse speed. Because less twisting angle (6^0) was got in this range of rotational speed. If the rotational speed increased the twist angle was also increased. In the case of surface smoothness, the optimum rotational speed was 325rpm and the consolidation time also affect the physical properties of sample or hexa-bar. To solve all this problem and twisting angle, the die land (depth) is increased up to some limit (5mm). When to increase the die land length the machine power must be considered. That means the die land length (depth of center hole of die) increased high pressures are required to extrude. Additional to this, the extrusion ratio and die land needs extra investigation to prevent the problem of twisting. In this case the optimum hexagonal bar was obtained at rotational speed 250rev/min. therefore before done friction stir back extrusion decides rpm by depend on die land and machine power.

4.3.1 Twist Angle Analysis

From the above Fig 4.2 it has been seen as the rotational speed of chamber increased, the twisting angle also increases. This means at high rotational speed, the extrusion temperature also become high but the die dimension is constant. Because of high rotational speed, chips will be highly plasticized or approaches to melting temperature to be extruded through hexagonal shaped hole. In this time immediately extruded out shape of hexagonal is not formed.

The twist angle can be calculated by Pythagoras theorem. That means; selecting one side of hexagonal shaped bar and follow its twisting direction attentively up to one complete revolution. Then measuring the height of one full rotation perpendicular to face and the base length as indicated in the Fig 4.3 below.

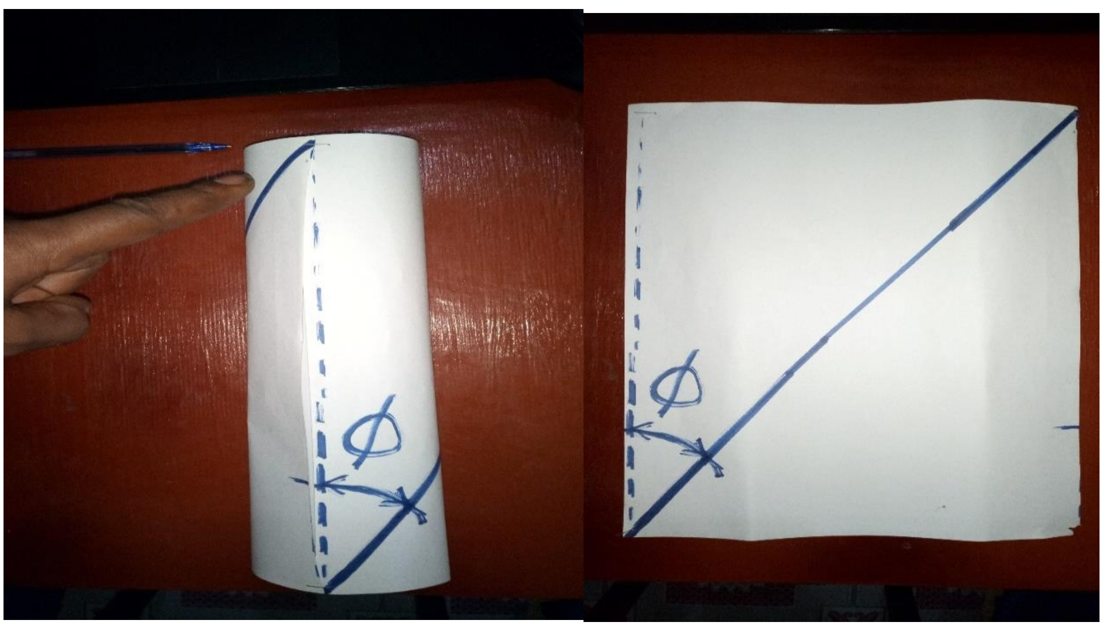


Figure 4.3 Simple draft of hexagonal shaped bar to get twisting angle.

The only cause of hexagonal bar sample twisting was as explained above is the rotational speed and extrusion land. The twisting angle of each bar was calculated by this simple method by depend on the length of twist height. The above paper shows the diagonal length to rotate 360 degree paper, the diagonal line to be twisted one completed revolution. Therefore the twist angle Φ equals to the width of paper divided into height paper.

The twist angle was measured from the Y-axis or perpendicular vertical length of sample. By this method of measurement, sample one was twist angle to be 90^0. Tan Φ which equals to L (=6mm) divided into Height (x). The height of sample one twists by one revolution equal to zero. Therefore the length divide into height of sample approaches into 90^0. Twist angle of sample two value was also the same as sample one. It approaches to infinitive because of one revolution of twist height approximately zero. Sample three made hexagonal shape in perfect cross sectional by twisted and calculated as follows.

Sample 3. Height = 23mm

Length = 6mm

Tan (Φ) = (height/length)

$\Phi = \mathrm{Tan}^{-1}$(height/length)

$= \tan^{-1}(23/6)$

$= \underline{\underline{14^0}}$

Sample 4. Height = 33mm

Length = 6mm

Tan (Φ) = (33/6)

$= \underline{\underline{10^0}}$

Sample 5. Height = 57mm

Constant length of sample=6mm

Then tan inverse which equals to 57mm/6mm.

$\Phi = \tan^{-1}(57/6)$

$= \underline{\underline{6^0}}$

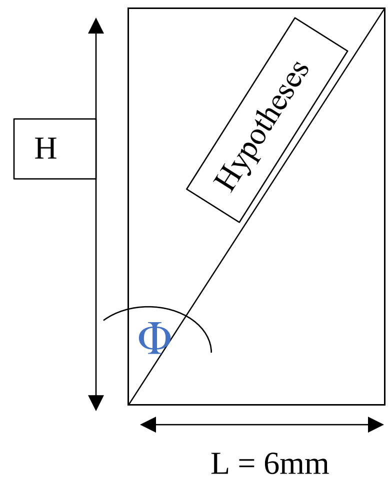


Figure 4.4 Calculation of twist angle measurement a) pytagorous b) measurement

Sample 6. Was the same as sample one and two; the twist angles approaches to positive 90^0. To conclude that the samples of hexagonal shaped bar fabricated by friction stir extrusion increase rotational speed also increased twisting angle. But the minimum and maximum rotational speed of chamber the samples fabricated was completely circular shape in this case angle Φ to infinite. The minimum twist angle got by sample five at rotational speed 250rpm. From twist angle point of view, the optimum spindle rotational speed was 250rpm because of minimum twist angle observed.

As explained above, twisting of bar response of variation of chamber rotational speed. The optimum bar got by 250rpm and transverse speed constant 6.25mm/min. in this time the minimum twist was achieved. The blow graph shows analysis value of Φ-rpm.

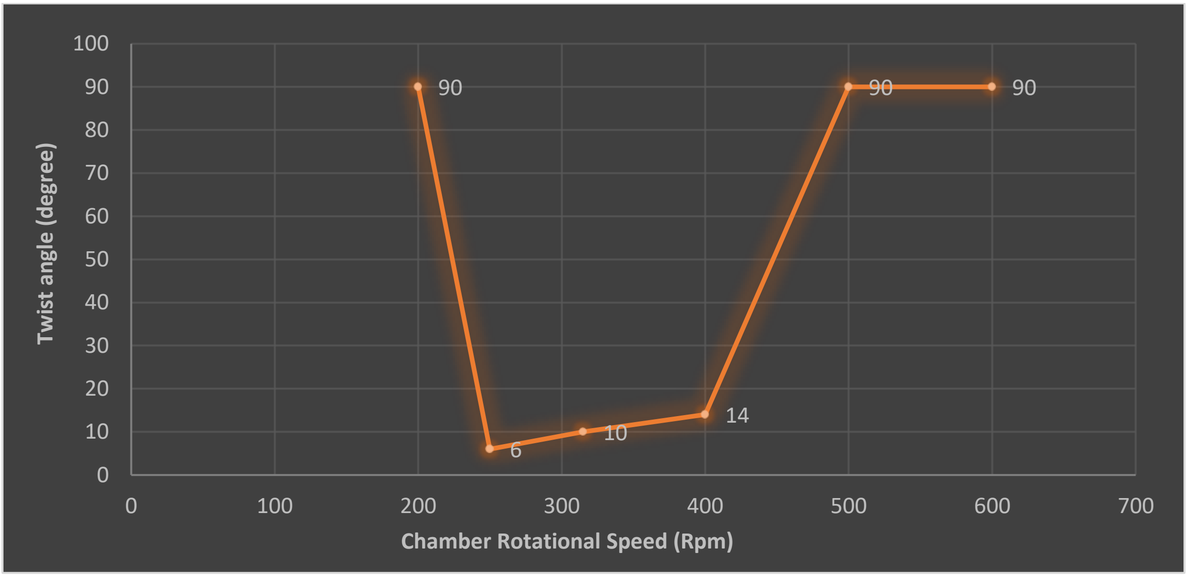


Figure 4.5 Twist Angle vs Rotational Speed Analysis Graph.

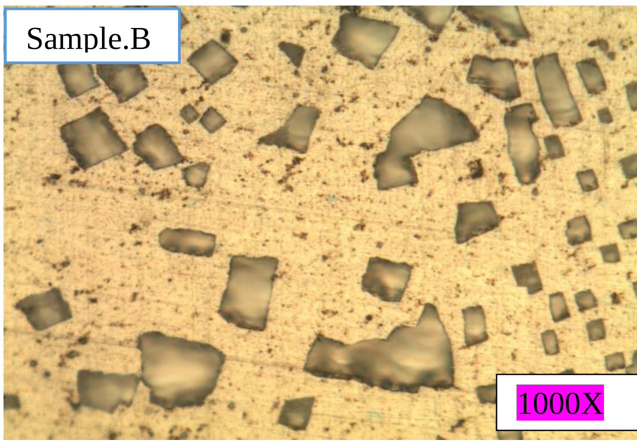
4.3.3 The measured value of consolidate and extrude temperature

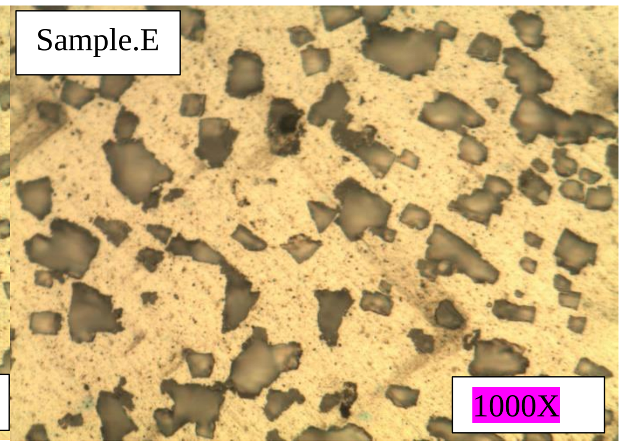
The below fig.4.6 (A) shows the measured value of surface temperature of die at consolidation period of time by using infrared thermometer. It used to change the feed from manually to automatic during fabrication of bar when above the average temperature of die 349^{0}C. The time to consume to obtain this measured temperature is different and depends on the rotational speed of chamber. The RPM increased the consolidation period decreased. Fig 4.6 (B) shows the average temperature of extrusion (545.5^{0}C). It must be less than the melting temperature of Al (620^{0}C)

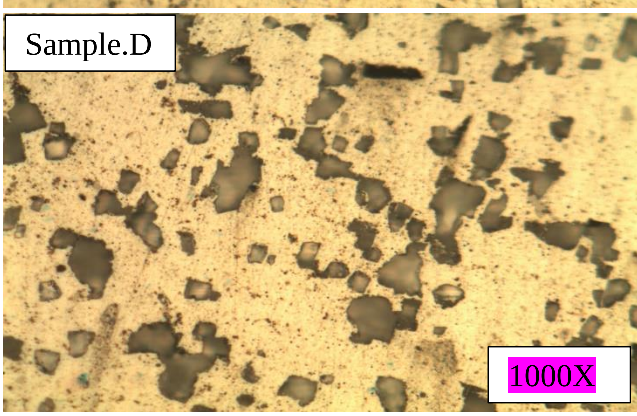
Figure 4.6 the measured value of fully consolidated and extrusion temperature.

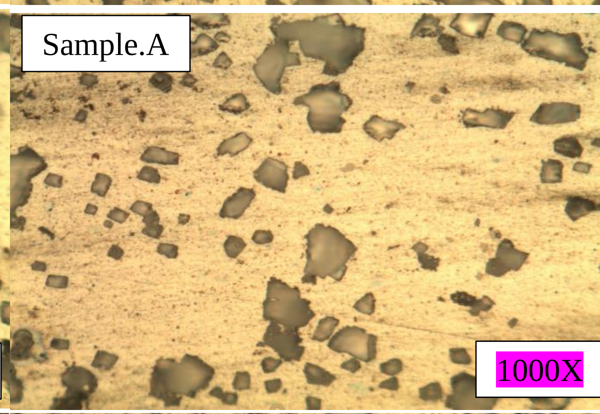
4.4 Microstructural Test Result

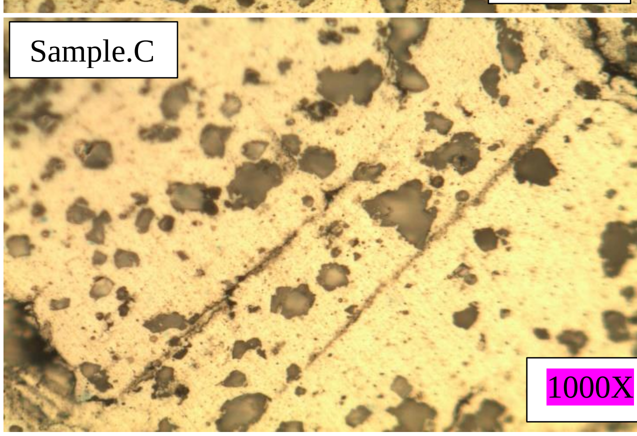
The sample was selected and cut from a specific location of bar that fabricated by friction stir back extrusion. Seven samples includes parent metal were polished by using a diamond paste 1µm before etching. Then after polished by carefully, washed by water and dry by pressurized compressor. The etchant used to test this microstructural was 1droplet HF, 25ml HCl, 25ml HNO3 and 25ml Methanol. Microstructural test was performed by 1000X Magnification to all samples

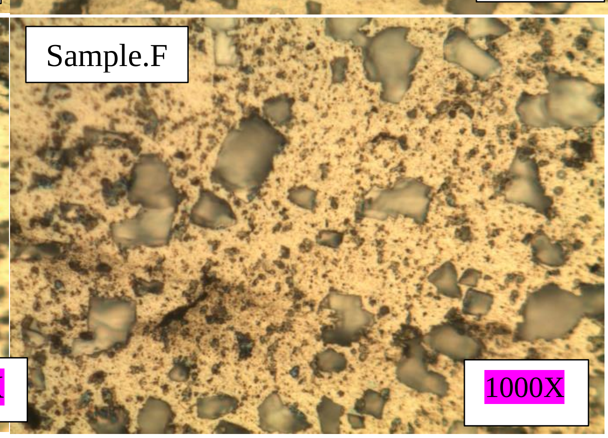












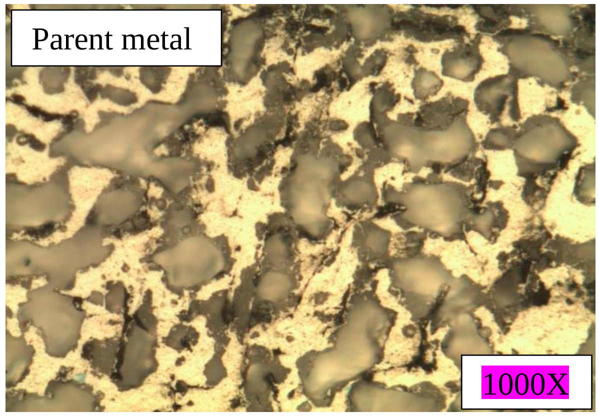


Figure 4.7 The Microstructural

The cross section of aluminum alloy 6063 hexagonal bar sample shown in Fig 4.2. In this Figure sample A was a cross section of extrudes which performed by friction stir extrusion at rotational speed of 630rpm and constant transverse speed 6.25mm/min. the microstructure to be uniform and small dopant elements are there compared with other extrudes. Because of the chemical composition of base metal (AA6063) increased by 1% iron content from international ASME standard. That means the correct value of iron with in AA6063 is 0.3%, but in this base metal 1.3%. Then this iron content changes whole alloy element properties when at rotational speed increased and increased. Due to this, Fig 4.1 shown as the alloying element recrystallized at high temperature and rotational speed. From microscopic result, at high rotational speed the dopant element with in grain boundary decreased compared with base metal and also no more corrosion and additive element in specimen cross section. Sample B is fabricated at rotational speed of 500rpm and constant transverse speed 6.25mm/min. the microstructural test shows dopant element greater than sample one. The rotational speed increased, the grain refinement and recrystallization is occurred. Because of this recrystallization of grain boundary, changes the properties of additional alloying element. In this time corrosion and other dopant formed probabilities minimum. For example sample F is fabricated by less rotational speed; that means less extrusion temperature. In this sample microstructural test shows high dopant and corrosion within grain boundary. Base metal microscopic result shows that a highly corroded and doped than all extrudes. Conclude from all tested result, if the rotational speed increased and increased, the grain boundary to be clear due to recrystallization of alloying element and the corrosion to be decrease. To this conclusion, with in grain and grain boundary, the other additive element to be high in base metal and very low in sample one.

4.5 Hardness Analysis

The hardness test was performed by Vickers hardness tester and the result as shown below Fig4.8. The dwelling period was 15 second and done by square-based pyramid diamond indenter with an angle of 136^{0}. The maximum allowable test range of this machine was 50kgf and 2900HV. All samples are examined within this range of forces. Totally seven samples are tested by force of 5kgf and 10kgf. The hardness test is started from center to end of each sample by three to four trials and took the mean value (Tahmasbi, *et al* (2018)). To this work, six sample and one base material (aluminum alloy scrap) were tested by three trials and analyzed the average value. The Fig 4.8 below shows that analyzed value by 5kgf and dwelling time 15sec of sample one at 630rpm.

Sample one.

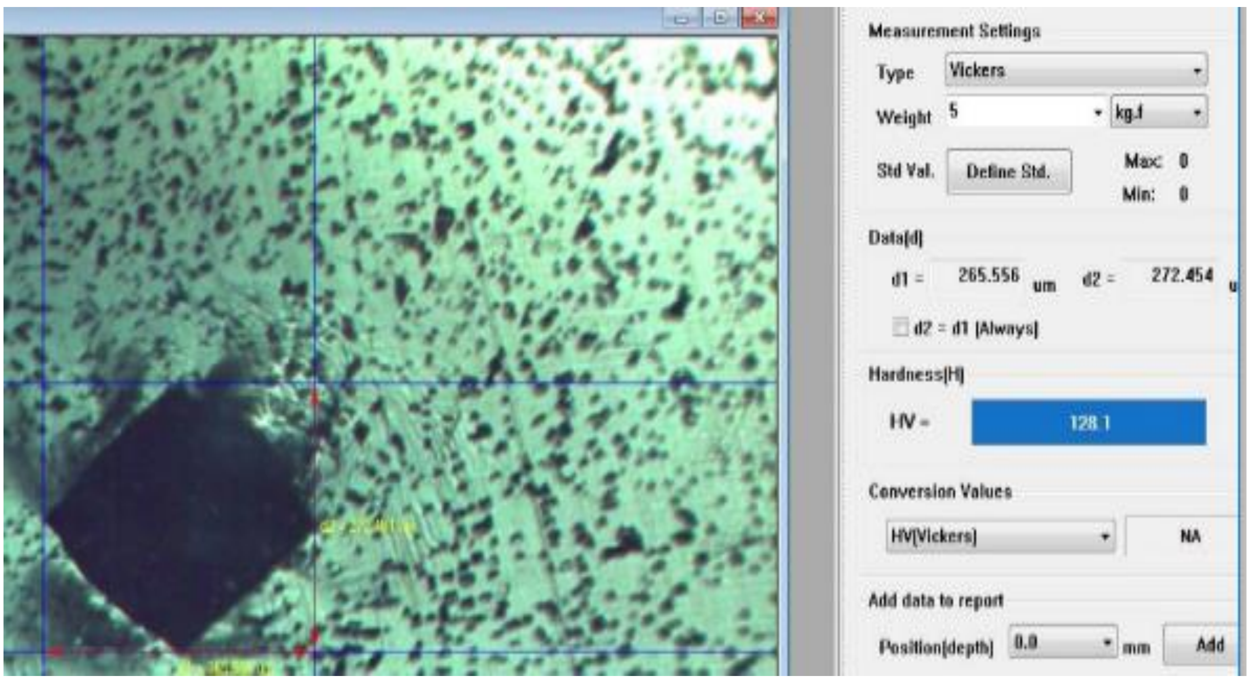
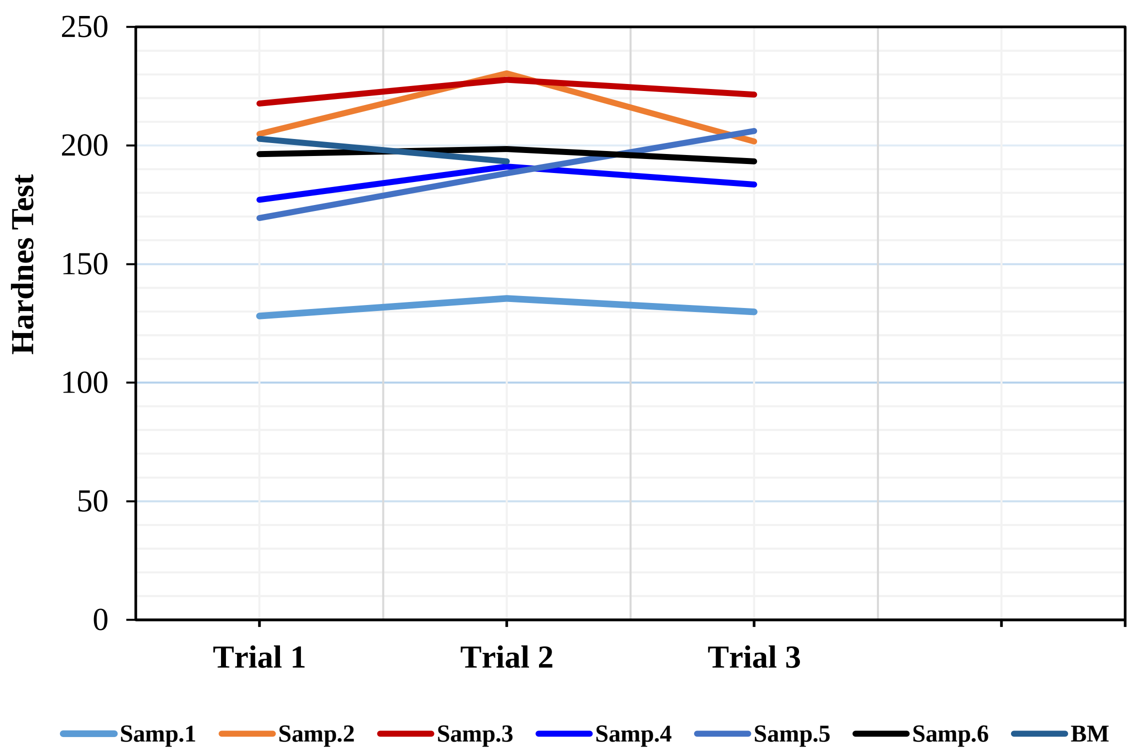


Figure 4.8 The Vickers hardness test result of extruded sample by 5kgf.

Table 4.3 The mean value and each trial value of hardness tested value

S.No	Test. 1 (HV)	Test. 2. (HV)	Test. 3 (HV)	Tested mean value. (HV)
Sample one (630rpm).	128.1	135.5	129.8	131.13
Sample two (500rpm).	204.9	230.4	201.7	212.3
Sample three (400rpm).	217.7	227.7	221.4	222.3
Sample four (315rpm).	177.1	191.3	183.5	184
Sample five (250rpm).	169.4	188.3	206.1	188
Sample six (200rpm).	196.4	198.5	193.3	196
Base material	202.8	193.3	189.3	195



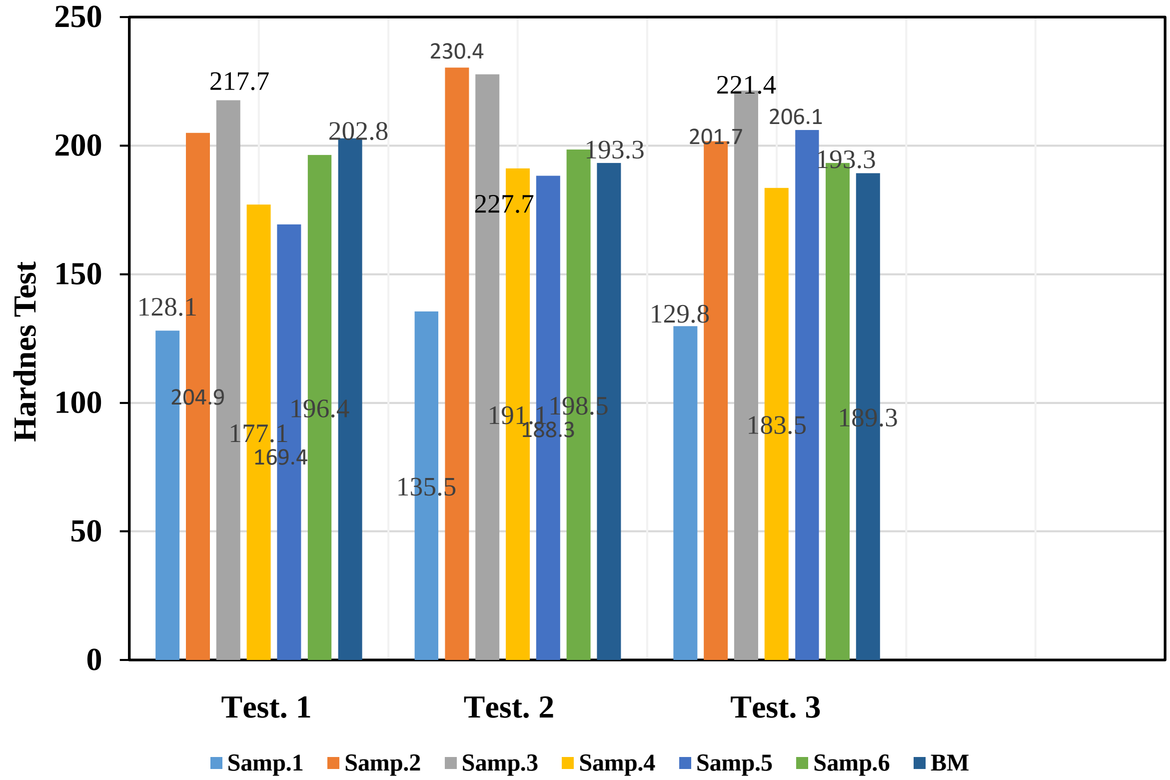


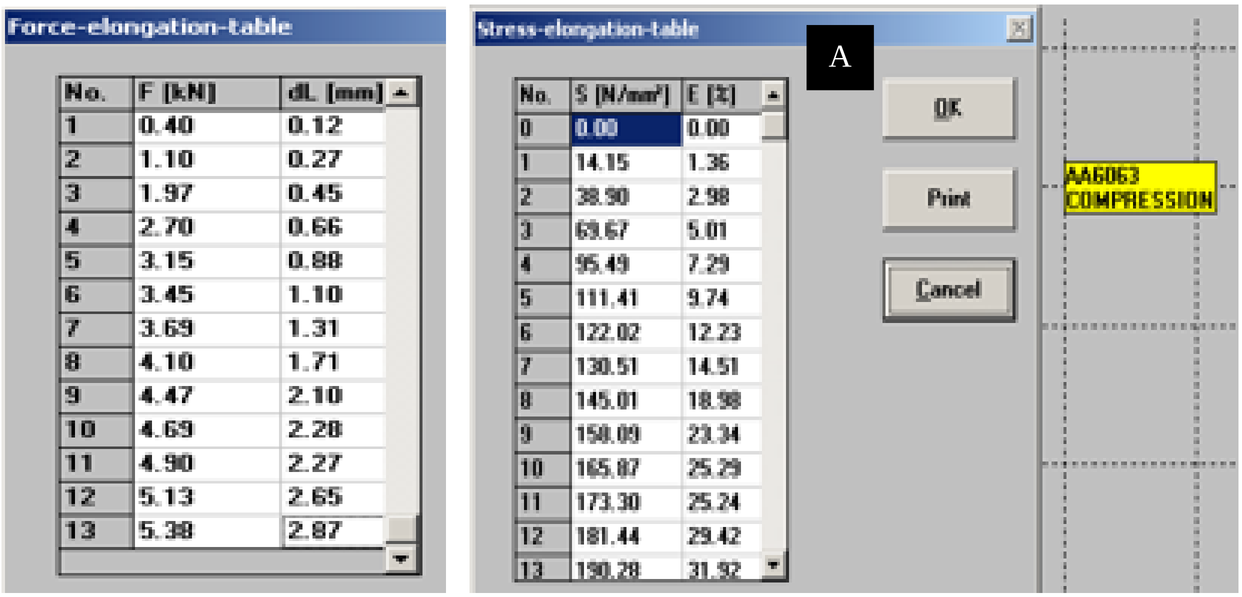
Figure 4.9 hardness test result by three trials in graph form

The test result of hardness value shows that, the rotational speed of chamber increased (from 200 to 315rpm) and the value of hardness decreased by linearly. Then also the hardness value continuously decreased after a certain value of rotational speed. From this result observed as the hardness of base material greater than the experiment run at rotational speed of 250rpm, 315rpm and 650rpm. But the hardness value of base material has less than the sample extruded at 200rpm, 400rpm and 500rpm. To conclude that, the optimum rotational speed of chamber to get the high hardness value of sample is extrude at 400rpm and 6.25mm/min transverse speed. The hardness value of some extruded sample bar have increased by a certain label that compared with base material. This is a cause of high consolidation and stirring of aluminum chips and scrap to compact by non-consumable rotating die. The recrystallized aluminum precursor microstructure to be fine and dense. When the grain and grain boundary minimize the hardness to be increased.

4.6 Compression Test Result and Discussion

As much as possible to test compression strength of hexagonal shaped bar which fabricated by friction stir back extrusion, it is well recommended to check how much improve mechanical properties after friction extrude that compared with the base material. The below Fig 4.10 shown that the compression strength of base material AA6063 and extruded sample by Universal Test Machine.

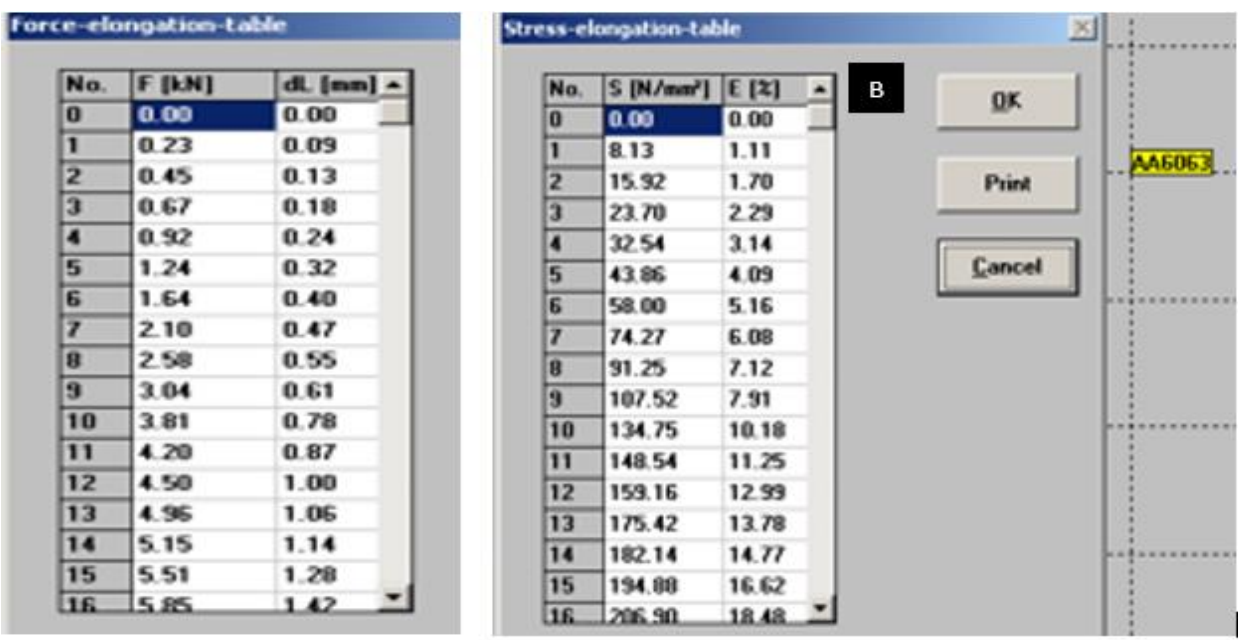
A. Force Vs elongation and stress Vs elongation table of base material (AA6063) test result.



No.	F [kN]	dL [mm]
1	0.40	0.12
2	1.10	0.27
3	1.97	0.45
4	2.70	0.66
5	3.15	0.88
6	3.45	1.10
7	3.69	1.31
8	4.10	1.71
9	4.47	2.10
10	4.69	2.28
11	4.90	2.27
12	5.13	2.65
13	5.38	2.87

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	14.15	1.36
2	38.90	2.98
3	69.67	5.01
4	95.49	7.29
5	111.41	9.74
6	122.02	12.23
7	130.51	14.51
8	145.01	18.98
9	158.09	23.34
10	165.87	25.29
11	173.30	25.24
12	181.44	29.42
13	190.28	31.92

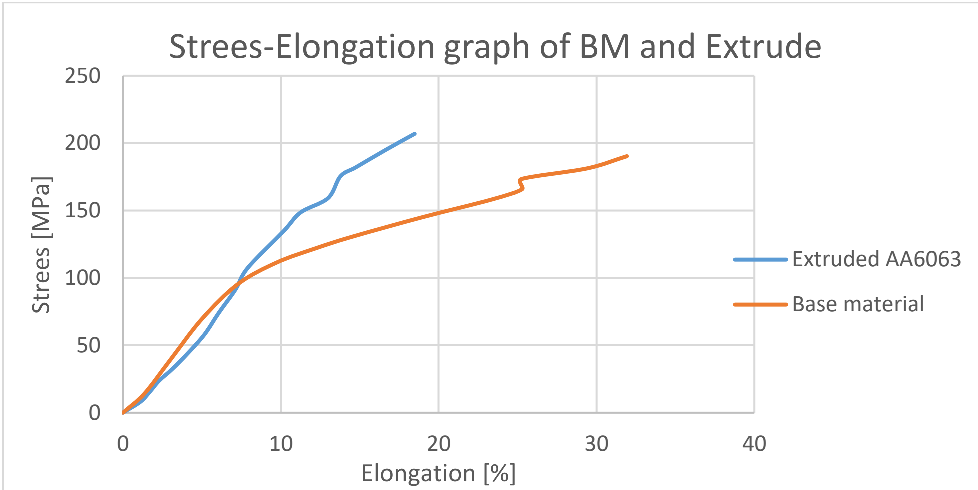
B. Force Vs elongation and stress Vs elongation table of extruded hexa-bar (AA6063) test result



No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.23	0.09
2	0.45	0.13
3	0.67	0.18
4	0.92	0.24
5	1.24	0.32
6	1.64	0.40
7	2.10	0.47
8	2.58	0.55
9	3.04	0.61
10	3.81	0.78
11	4.20	0.87
12	4.50	1.00
13	4.96	1.06
14	5.15	1.14
15	5.51	1.28
16	5.85	1.42

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	8.13	1.11
2	15.92	1.70
3	23.70	2.29
4	32.54	3.14
5	43.86	4.09
6	58.00	5.16
7	74.27	6.08
8	91.25	7.12
9	107.52	7.91
10	134.75	10.18
11	148.54	11.25
12	159.16	12.99
13	175.42	13.78
14	182.14	14.77
15	194.88	16.62
16	206.90	18.48

Figure 4.10 Stress-strain and force elongation result data of extruded and base material from UTM machine board.



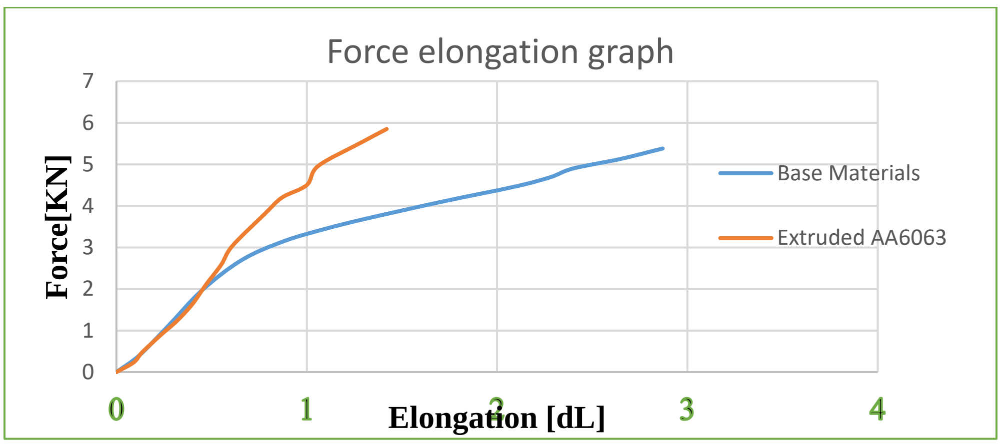


Figure 4.12 stress elongation and force elongation graph of extruded sample and base material.

The above two graphs shown that, the Stress-Strain and Force-Elongation test result of AA6063 bar before extrusion (Base Material) after extrude. Two equal dimension (diameter) samples were tested by using GUNT WP 310 Hydraulic Universal Testing Machine. The compression speed of die to press sample was 1mm/min. Base material changed from original length 9mm into 6mm and extruded bar 7.7mm into 3mm. from the above graph result observed as, under equal compression force different elongation had seen. That means the extruded bar was need higher force to get equal elongation to base material. And also the extruded bar was a higher strength than the base material (AA6063) under equal elongation rate. This test result verified as, the hexagonal shaped bar fabricated by FSBE was higher strength than the original material because of grain refinement.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Defect free sounded hexagonal shaped bar has been fabricated by using FSBE process from aluminum alloy 6063 scrap. The considered process parameters are constant transverse speed 6.25mm/min and variable rotational speed (200rpm, 250rpm, 315rpm, 400rpm, 500rpm and 630rpm) of milling machine FU-281. From this interval of rotational speed, the accurate hexagonal shape bar obtained at 250,315 and 400rpm and all others are completely circle. If the rotational speed increases twist angle also increased. The measured value of twist angle when the experiment run at 250rpm=6^0, 315rpm=10^0 and 400rpm=14^0. Extrusion performed at 200rpm is also circular, because of it takes a long duration of time to consolidate than the others. In this time by default first plasticized scrap is welded at corner of hexagonal hole and all the remained scrap extruded by circular form due to the taped of hexagonal corner. Therefor the optimum rotational speed to extrude hexagonal bar by minimum twist angle is 250rpm and transverse speed 6.25mm/min. The hardness test was performed by using Vickers hardness tester by 5and 10kgf. All samples tested by dwelling time of 15sec includes base material. The hardness value of sample extruded at 200, 400 and 500 rpm are higher than the base materials by the same dwelling period of time (15sec)and the same applied force (5K.gf and 10K.gf). To the compression test the selected one is the minimum twisted bar extruded by FSBE and compared with base material. The test was performed by using GUNT WP 310 Hydraulic Universal Testing Machine. The initial dimension of extrude sample before compression which equals to 7.7 mm length and 6mm subscribe diameter and after deformation it changed into 4mm length and 10mm diameter. The base material deformed from 9mm length and 6mm diameter into 6mm length and 10mm diameter. The compression strength of extruded sample at 250rpm (182MPa by 5.15kN compression force) are higher than base material (173MPa by 5.15kN) by 5%. Microstructural observation has done by optical microscopy and the etchant used to this investigation is 25ml HCl, one droplet HF, 25ml HNO_3 and 25ml methanol. All samples observed by equal magnification lens 1000X. The test value shown as the rotational speed increased recrystallization and refinement occurred between aluminum and alloy element. For example, sample one extruded at 630rpm and microstructure seen by clear and clean from any corrosion but in base material blurred surface observed.

5.2 Recommendation

Having passing through the observation and experience, the researchers would like to recommend the following points for Adama Science and Technology University. So that the student and researchers can be able to extend their research areas on friction stir back extrusion processes.

1) To replace the existing old machine with latest machine. Especially milling and lathe machines.
2) To install digital or computerized milling machine which can read the applied force of the cutter on the work piece.
3) To make functional the existing SEM machine. Because it is difficult to analyze microstructure of different metals with the available optical microscope.

5.3 Future Work.

Due to the cost material increased day to day, frictional stir back extrusion is a well recommended method of metal forming that is the possible shape by simple extrusion. Therefore, it is best to whom worked in this area.

1. Optimize processes parameter such as rotational speed of chamber, transverse speed of table, plunge rate) to get a best output.
2. Detail analysis of thermal properties during consolidation and extrusion period of time.
3. Worked by other shape like L-shape, windows frame shape.
4. Worked by mass production or continuous extrusion. In project the maximum extrusion length of sample limited by the distance of maximum downward movement machine table. By adding other necessary fixture fabricate other shape by horizontally spindle rotation.
5. Remove twisting of extrude by increased center hole land length (depth of hexagonal shaper) and used by high power machine.
6. Using friction stir back extrusion process for composite material fabrication.

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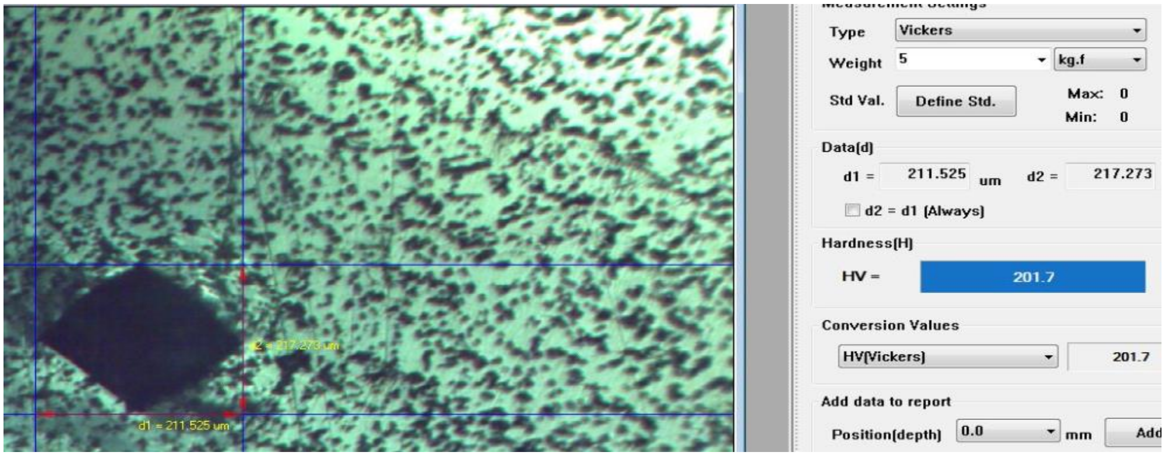
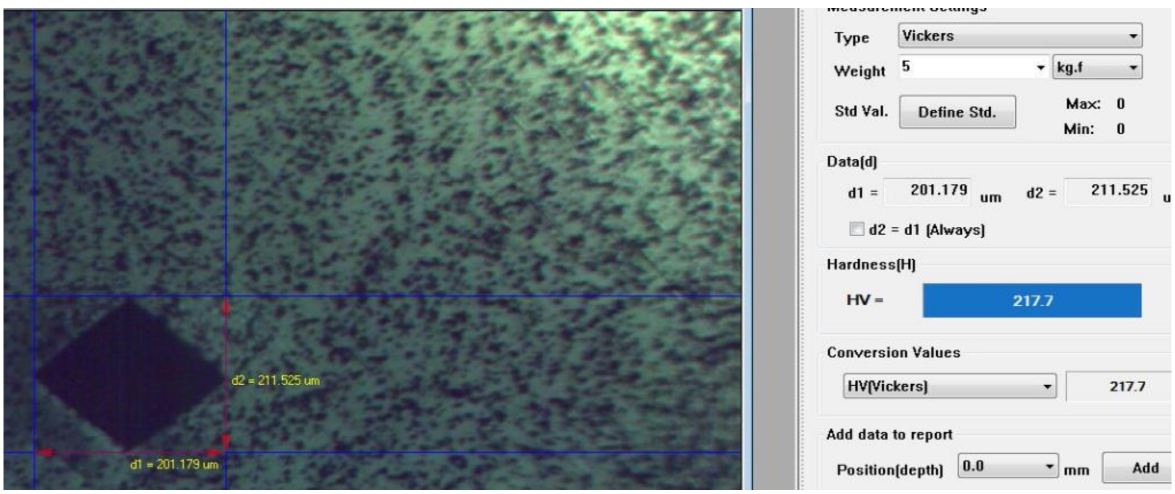
APPENDIX

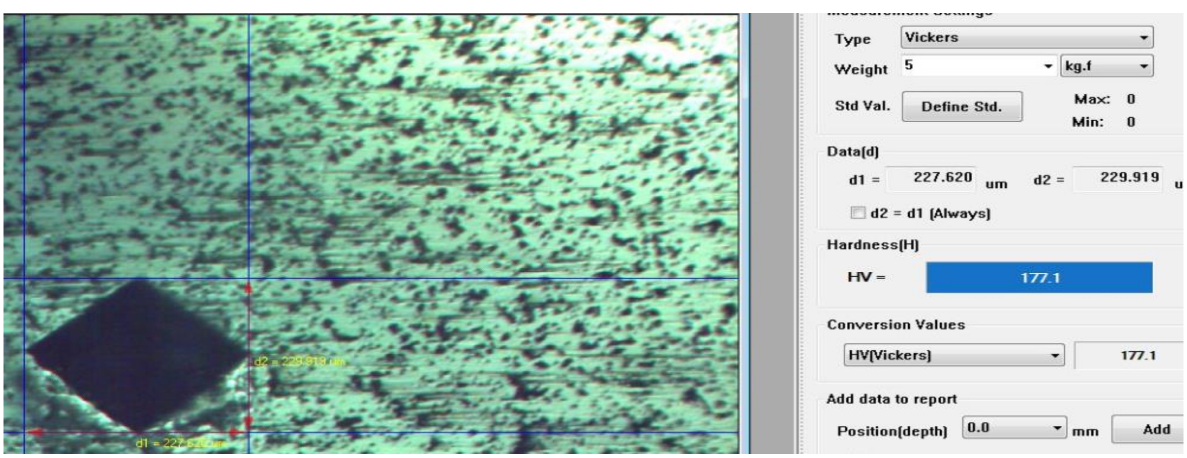
A. The hardness value of sample bar produced at different RPM and Base material



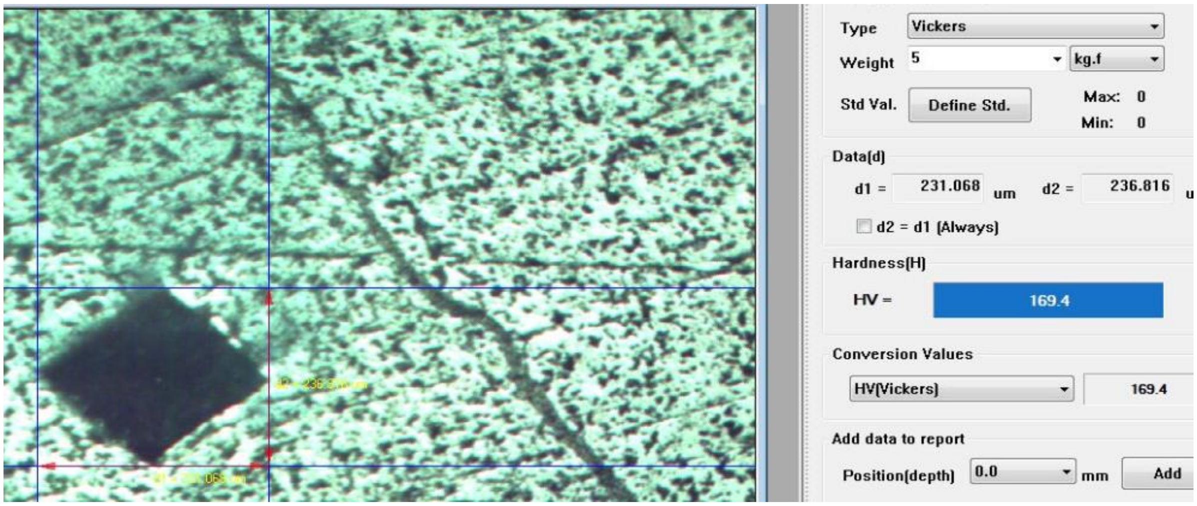
At 500rpm (Sample two)



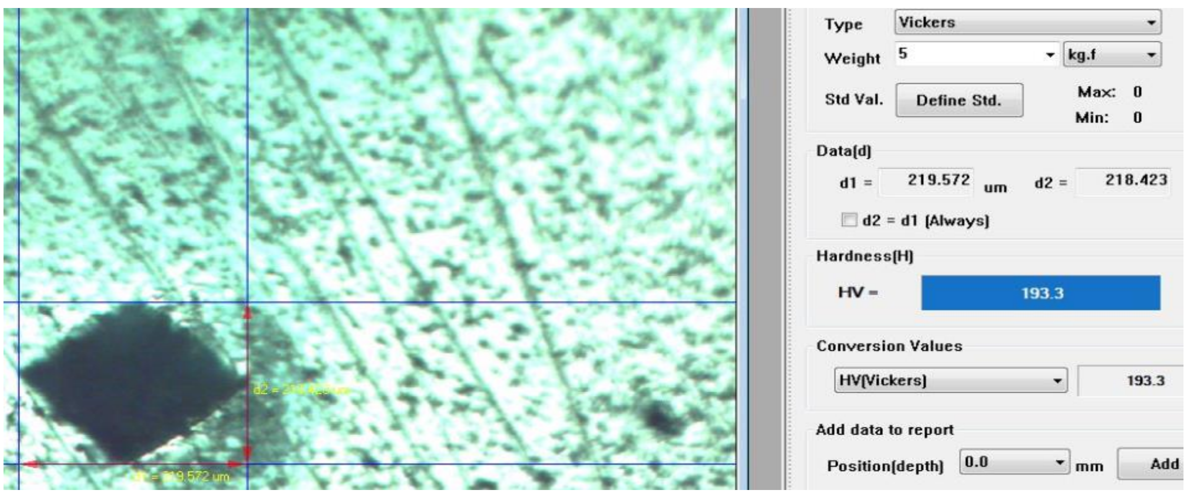
At 400rpm (Sample three)



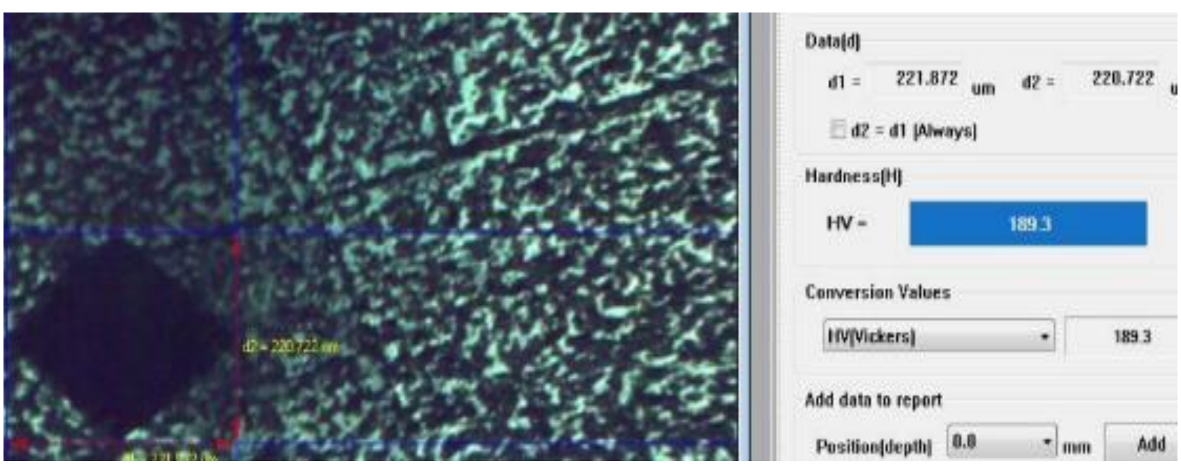
At 315rpm (Sample four)



At 250rpm (Sample five)



At 200rpm (Sample six)



Base material (AA6063 Parent metal)

B. The Composition tested value of aluminum alloy 6063

HIBRET MANUFACTURING AND MACHINE BUILDING INDUSTRY

Chemical composition Laboratory Test Result Form

Page 1 of 1

Date: 22/08/10

Requested by: Ato Gizaw Yohannis

Sample type: ALUMINUM

Purpose: IDENTIFICATION

S.N	Sample Name	Chemical composition												
		Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr	Pb	Sn	Ti	Al	CSN
1	Round bar	0.58	1.38	0.017	[illegible]	0.7	0.097	0.019	0.013	0.015	0.025	0.041	97	Aluminum

Prepared by: Dinko

Sign:

Date: 22/08/10

Checked by: Beruke

Sign:

Date: 22/08/10

Approved by: GEADA

Sign:

Date: 22/08/10

C. Over all process