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Experimental Analysis of Aluminium Alloys AA6082 Employing Friction Stir Extrusion Process

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Abstract: *The aim of this work is to carried out the hardness and scanning electron microscope of wire produced from the recycled machined chips/scrap of aluminum alloy AA6082 aided by Friction Stir Extrusion Process (FSEP). This solid-state recycling technique is advanced principles of friction-based heating, plastic deformation to convert metal scraps directly into usable product. This process utilizes a rotating tool that generates localized heat through the friction, pressure and gets softening the material, enabling it to extruded through a plunger with the absence of melting, by eliminates the issues such as oxidation and gas porosity, resulting in high-quality extrudates with refined grained structures and enhanced mechanical properties by optimizing process parameters such as rotation speed and extrusion pressure force to improve material flow, product uniformity using heavy duty vertical milling machine. This process significantly reduced energy consumption and environmental impact, making it an attractive solution for sustainable manufacturing especially in aluminium recycling. The obtained wire would be tested for hardness and scanning electron microscopy and was compared with parent metal.*
Key Words: *Aluminum Alloys, Friction Stir Extrusion Process, Hardness, SEM.*

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I. INTRODUCTION

Lightweight materials and their alloys are employed in applications calling for weight reduction to save energy and for ease of manoeuvrability. Generally, there are two methods to convert the metal scrap into useful product i.e. Conventional method and Direct conversion method. In conventional method the energy consumed for extruded products is 52% only and the remaining energy is for melting, casting and dross losses in order to recycle into ingot form this results in reduction in purity of material, oxidation losses, casting defects, coarse grain size and poor mechanical properties. In addition, it requires more energy input coal and oil for melting the metal scrap results in environmental pollution and more labour cost. In the direct conversion method, it is a novel solid state energy efficient recycling material technology simplified by waste management, reduces processing time, less energy consumption and achieves good product quality. The Machined chips of Aluminium, Magnesium and Copper alloys can be extruded through direct conversion method consisting of powder consolidation, sintering and extrusion process could be saving energy up to 30-35% with no reduction in purity, no oxidation losses by eliminating melting and casting process it could be minimizing energy consumption with zero greenhouse emissions and reduction in labour cost due to simplified waste management. The extruded wires are free from defects and exhibited good mechanical properties due to refined grain structure. A novel and energy efficient Friction Stir Extrusion Process (FSEP) technology was introduced and developed in Oak Ridge National Laboratory (ORNL) at south wire company by W. Thomas in 1993 Welding Institute of Technology England is extrudes wires from machined chips directly into finished product employing Friction Stir Extrusion Process (FSEP) by replacing powder compaction and sintering process. The extruded product quality depends on methods of materials to be extruded, process parameter such as rotational speed, axial force and chip size etc. The aim of this technique is to produce electrical cable wire with good mechanical and electrical properties and deliver for next generation using light weight, nano materials and improve recycling efficiency up to 95%.

II. LITERATURE REVIEW

In view of this, the observations from previous studies on Direct Extrusion and Friction Stir Extrusion Process (FSEP) are summarised. The Magnesium Alloy, Aluminium Alloy and Copper-Zinc alloy chips were used at a speed of 90, 150,160, 180, 200, 250,355, 400, 600,700,900,1500 and 1600 rpm with an axial pressure force of 14, 18, 22kN and feed rates were 10,14, 20 and 30 mm/min. 5, 7 and 9 mm in diameter of wire extruded with good quality product. The quality of wire depends on plunger rotational speed, axial pressure force, traverse feed rate, chip quality, chips size, die design, temperatures and extrusion ratios [1-5]. The common imperfections encountered in wire was twist, tearing, cracks and swirl defects. High rotational speed, temperature and high strain can result in swirl defects, hot cracking, creation of voids, a sound rod and complex 3D helical material flow is generated on cross section of the extruded profile with recrystallized grains in the centre and heavily stretched grain in the periphery, while low speed and temperature resulted in cold tearing. A smooth wire, free from cracks, finest equiaxed grain structure could be obtained at optimum or intermediate speed [5-10]. The grain size decreases from centre of wire surface whereas micro-hardness increases. The fine homogeneous microstructure showed better strength, ductility, corrosion resistance, uniform composition, free from segregation with lower friction co-efficient as compared with parent metals at optimized process parameters [11-16]. In this process an extrusion ratio was used 5, 3.57, 0.2, 0.28, 0.36, it is speculated that large extrusion ratio results in lower pressure inside the extrusion chamber, as extrusion ratio decreases quality of rod increases because of better compaction and a helical material flow found through experimental observation. In this review mechanical properties, microstructure characterization of fine and coarse grain structure was revealed [17-22]. In conventional process resistive heating would be consuming more than 7000 kJ, whereas in indirect extrusion process the energy consumed is mere ~207 kJ. This technique is for high productivity with Low energy consumption, large metal savings and zero greenhouse gas emission [23-27]. The aim of FSE process is to investigate the various methods like simulation, numerical, theoretical, analytical, experimental mechanics using process parameters such as axial force, feed rate and tool rotational speed is highly influenced on the surface quality of extrudes.

III. EXPERIMENTAL WORK

3.1 Friction Stir Extrusion Process (FSEP)

It is the direct recycling process for extruding wire or rod from machined chips of softer materials like aluminium, magnesium, copper, lead etc. In this work a cylindrical cartridge and plunger with central hole was designed. The Machined chips are loaded into the cartridge a rotating plunger with axial pressure force is applied from top to down ward direction, due to this friction is generated between scrap and bottom of plunger surface it causes to generate heat in the material due to thermo-mechanical effect and gets plasticized, consolidated and extruded through the central hole of the plunger in the form of wire or rod shown in fig.1.

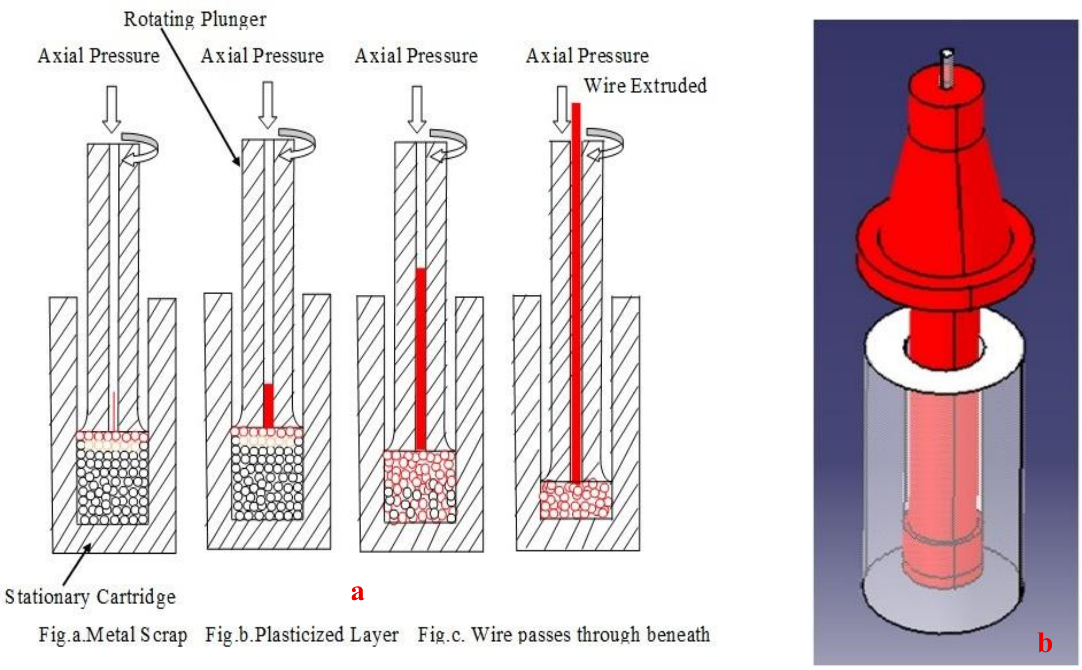


Fig.1. a.b. Friction Stir Extrusion process

3.2 Materials and Methods

The experimental work has been carried out with the aluminum alloy AA6082 machined chips of size 0.5x1.5x2-5mm in length, loaded in stationary cartridge, an axial pressure force is applied on rotating plunger to create friction between container and bottom of plunger thus metal scrap get plasticized and extruded through a center hole of plunger in the form of wire 5mm in diameter carried out on heavy duty vertical milling machine with varying speed, axial pressure force and feed rate. Many attempts were made to extrude the wire and was studied technical and practical problems encountered while conducting this experiment.

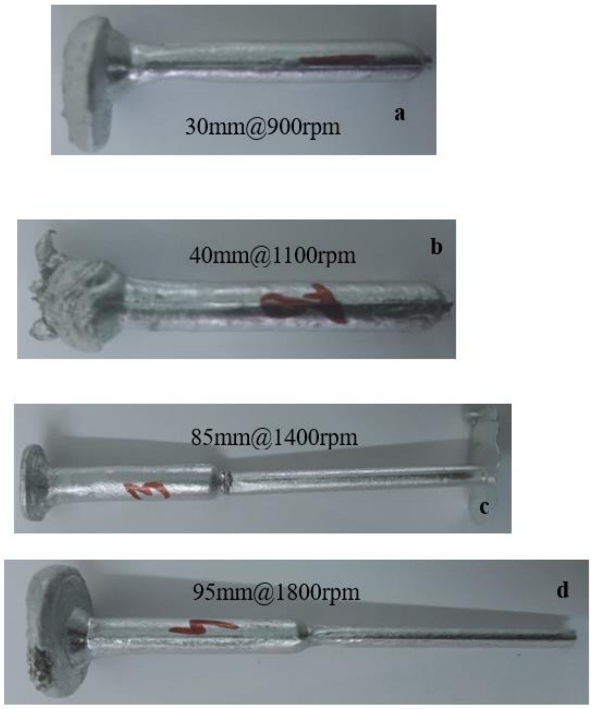


Fig.2. FSE process setup on milling machine Fig. 3. a.b.c.d. Wire Extruded

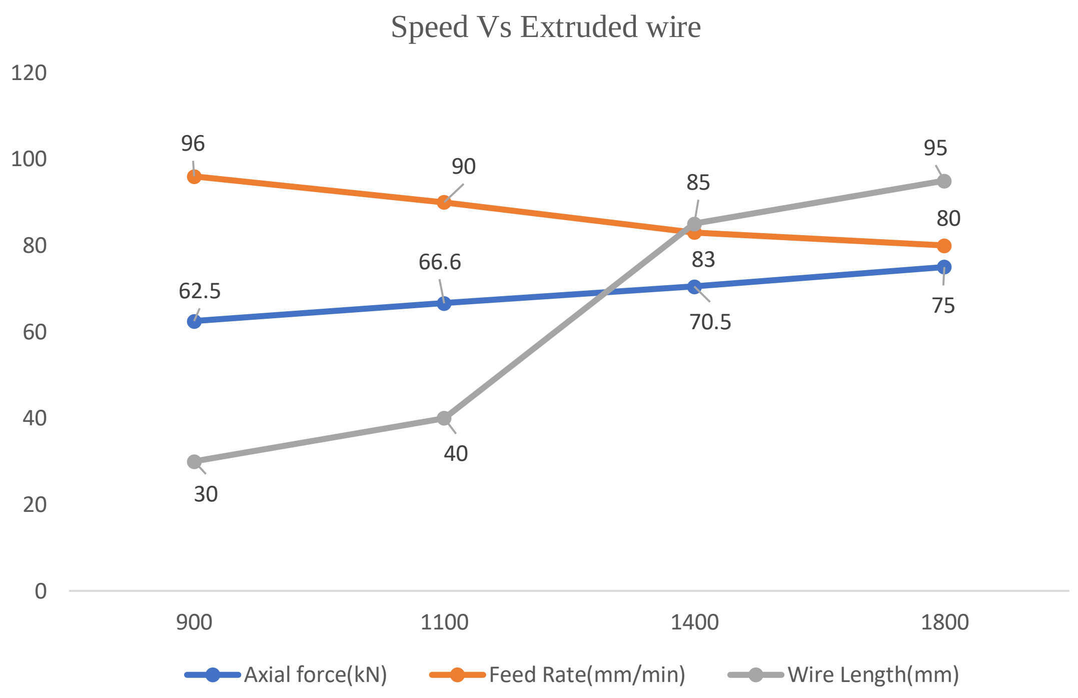
The heavy-duty vertical milling machine has been used to extrude the wire of 5mm in diameter with different process parameters. Wire extruded up to 30mm at speed of 900rpm, 40mm length of wire at 1100rpm, 85mm length of wire extruded at 1400rpm and 95mm of wire at a speed of 1800rpm shown in figure.3.

IV. RESULTS AND DISCUSSIONS

Speed (Rpm)	**Axial Force (KN)**	**Plunge Rate (mm/min)**	Wire extruded in Length (mm)
900	62.5	96	30
1100	66.6	90	40
1400	70.5	83	85
1800	75	80	95

Table.1. Wire Extruded with different lengths

The wire was extruded with deferent lengths of 30,40,85 and 95mm with good surface finish, without defect and free from cracks at different speeds of 900, 1100, 1400 and 1800rpm. An axial pressure force of 62.5, 66.6, 70.5, 70 kN and traverse feed rate of 96, 90, 83 and 80 mm/min respectively shown in table.1. The wire was tested with Scanning Electronic Microscopy and hardness was compared with base metal**.**



Grapgh.1. Speed Vs Extruded wire

From the Graph.1. it was observed that the speed of extrusion process increasing then the length of extruded wire and axial force increases whereas feed rate decreases

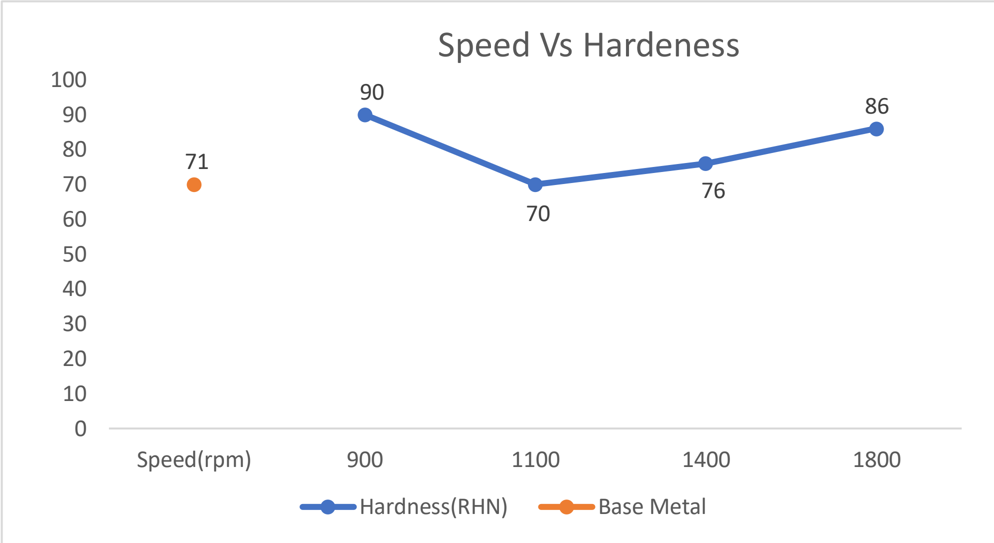
4.1 Hardness

The hardness on the surface of extruded wire has been carried out using Vickers hardness testing machine

Speed (rpm)	**Vicker's Hardness Number**				**Base Metal**
	At Centre	Away from Centre	At outer surface	Avg. VHN	
900	56.0	57.9	58.2	57.36	65.9
1100	56.4	58.7	60.4	58.50	
1400	56.7	57.1	57.5	57.10	
1800	58.3	59.4	59.6	59.10	

Table.2. Vicker's Hardness test

From table.2. It was observed that the hardness value is minimum at 1400rpm and Maximum at a speed of 1800rpm and medium at 1100rpm. It also observed that the obtained average hardness value is near to the parent metal.



Grapgh.2. Speed Vs Hardness

From the Graph.2. The Vickers hardness number of wire extruded is higher at 1800rpm and is lower at1400rpm. It was observed that the value of hardness of extruded wire is near to base metal.

4.2 Scanning Electron Microscopy Test

Scanning Electron Microscopy (SEM) is a powerful tool is used to obtain high-resolution images of material surfaces, Microstructural change, Grain size changes, Grain refinement, Zone characterization, Alloy element distribution and Surface topography such as Voids, tear, cracks, pits formation, grain boundaries, Inclusions, inter-granular, trans-granular and the distribution of alloying elements within the extruded material. FSE is a rotating tool to stir and deform the material, resulting in changes the microstructure of extruded wire have been studied.

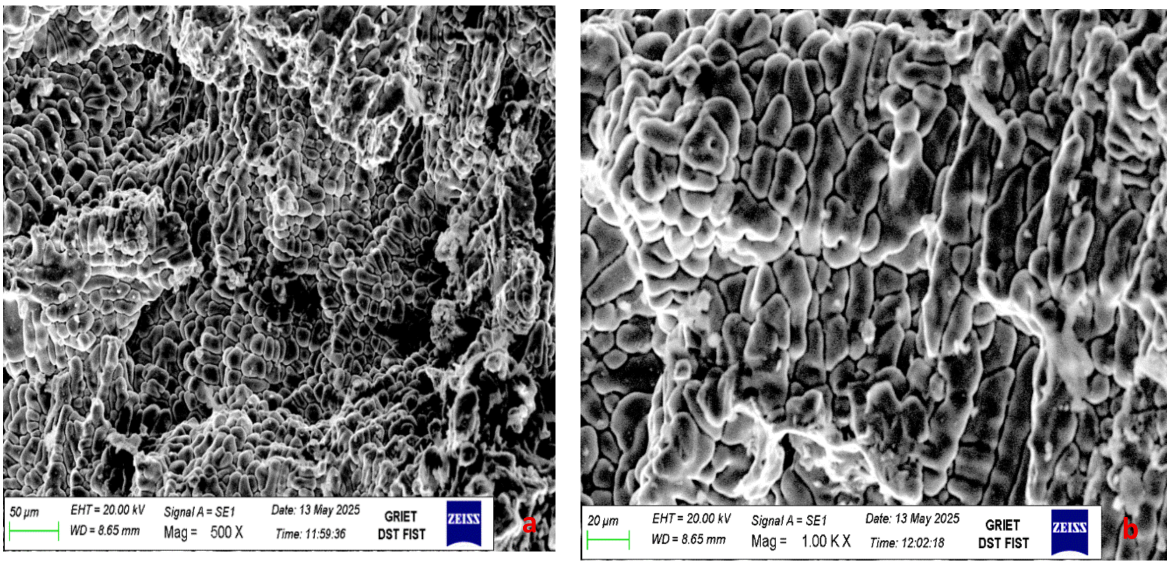


Fig.4. a.b. Scanning Electronic Microscopy of Base Metal

The images of base metal reveal to study the microstructure of materials during FSE process with various process parameters. It shows a uniform microstructure, equi-axed grain size, excellent grain refinement with homogenous distribution of grain structure and grain boundaries with better surface topography without any voids, tear, cracks etc.

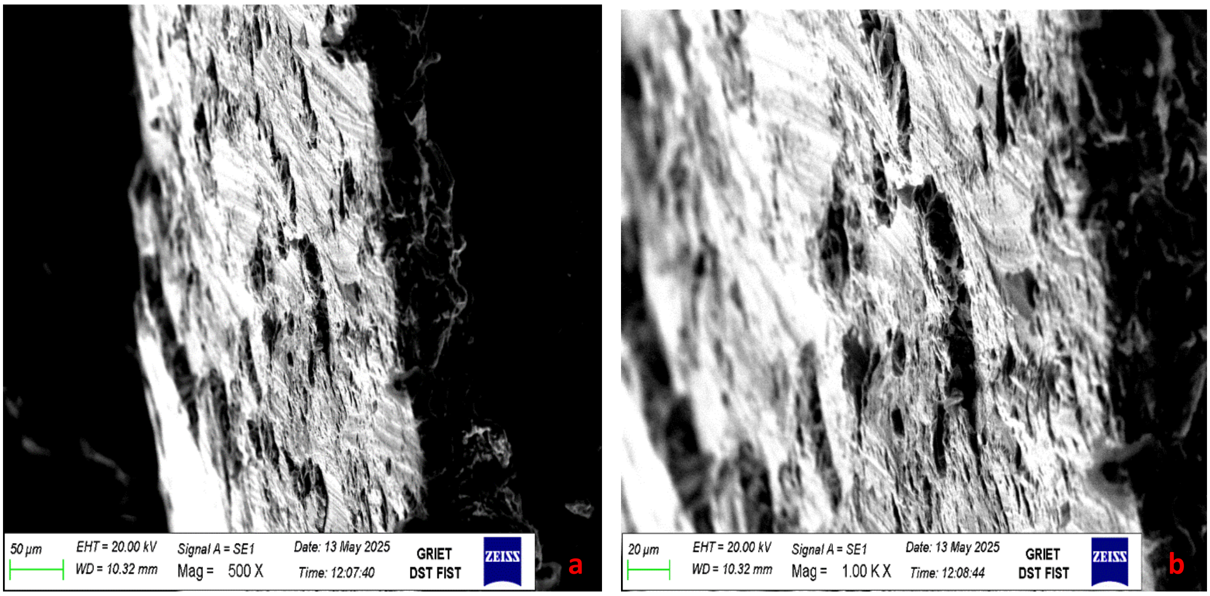


Fig.5. a.b. Scanning Electronic Microscopy of 900rpm

The image reveals a rough, textured surface with visible striations and pores layered structures, indicative of the material's microstructure effects on the grain structure of the extruded material, which can be important for understanding the frictional heat and pressure involved during FSE process.

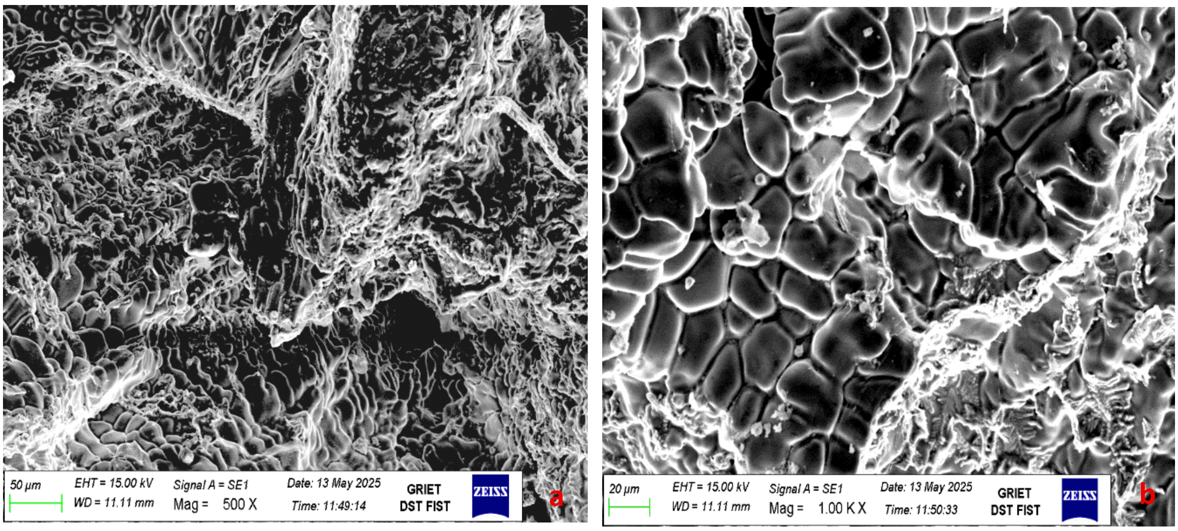


Fig.6. a.b. Scanning Electronic Microscopy of 1100rpm

The images reveal a smooth, fine-equiaxed grain textured surface topography without crack's visible, significantly refine homogeneous distribution of grain size on the structures. Indicative of the material's microstructure effects on the grain structure led to improved strength and ductility, also identified the stir zone (SZ) within the extruded material, which can be important for understanding the frictional heat and pressure involved during FSE process.

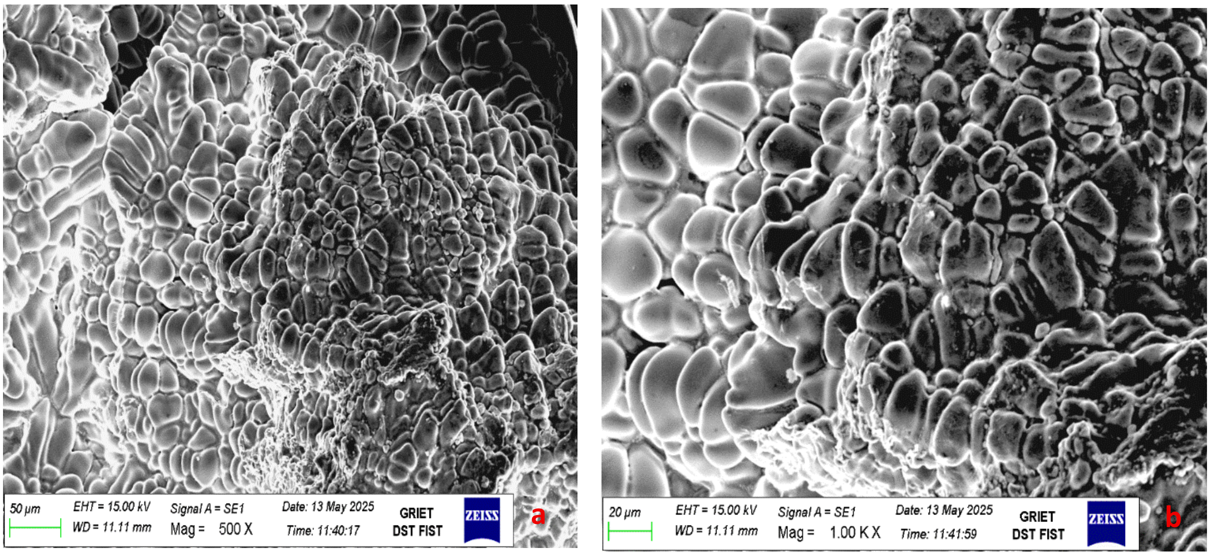


Fig.7.a.b. Scanning Electronic Microscopy of 1800rpm

The images reveal a fine bulge develops, equiaxed grains formed and identified stir zone with smooth textured surface topography, no cracks, voids found and significantly refine homogeneous distribution of grain size on the structures. It led to improved good mechanical properties within the extruded material, which can be important for understanding the frictional heat and pressure involved during FSE process

V. CONCLUSIONS

The heavy-duty vertical milling machine has been used to extrude the wire of 5mm in diameter with different process parameters such as speed, feed and travers rate. A 95mm in length of wire extruded at 1800rpm shown in figure.3.d. with a good microstructure and mechanical properties. The images reveal a rough textured surface with visible striations and pores layered structures at the speed of 900rpm shown in figure.5. The fine-equiaxed grain textured surface topography without crack's visible, significantly refine homogeneous distribution of grain structure and identified the stir zone (SZ) within the extruded material at 1100rpm shown in figure.6. A fine bulge developed uniform equiaxed grains formed, free from tear, cracks and voids. A smooth textured surface topography was observed it led to improved good microstructure and mechanical properties within the extruded material at a speed of 1800rpm shown in figure.7. it could be important for understanding the frictional heat and pressure involved during friction stir extrusion process and it was compared with parent metal.

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