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Experimental Analysis of Polo Polymers through Friction Stir Extrusion Process

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ABSTRACT
The aim of this work is to investigate the hardness and microstructure of wire produced from the recycled machined scraps of polymers through a Friction Stir Extrusion Process (FSEP). This an advanced solid-state technique plastic deformation to convert metal chips directly into wire. In this process a rotating tool called plunger is utilised to generates localized heat due to friction and a pressure applied to softening the material, enabling it to extruded through centre of a plunger hole 5mm in diameter without melting, to avoid the issues such as oxidation and gas porosity, results in good quality product extrudates by optimizing process parameters such as rotation speed and extrusion pressure force to improve material flow, product uniformity with refined grained structures and enhanced mechanical properties using heavy duty vertical milling machine. This process significantly reduced energy consumption and environmental impact, making it an attractive solution for sustainable manufacturing. The extruded wire would be tested for hardness and scanning electron microscopy and was compared with parent metal.
Key Words: Polo Polymers, 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 [1]. Machined chips of Aluminium, Magnesium and Copper alloys can be extruded through direct conversion method consisting of powder consolidation, sintering followed by extrusion with 30-35% savings in energy, no reduction in purity, no oxidation losses due to elimination of melting and casting process and less energy consumption with zero greenhouse emissions and reduction in labour cost due to simplified waste management [2,3]. The direct conversion method has more advantages than the conventional method, in this process the extruded wires are free from defects and exhibited good mechanical properties due to refined grain structure [4-6]. 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 [7-9]. The extruded product quality depends on methods of materials to be extruded into wire, process parameter such as rotational speed, axial force and chip size etc. [10-12]. 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 [13-16]. 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 [17-20]. 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 [21-25].

II. LITERATURE REVIEW

In view of this, the observations from previous studies on Direct Extrusion and Friction Stir Extrusion Process (FSEP) are summarised. The materials Magnesium, Aluminium, Copper-Zinc alloys material chips were used in the range of speed from 90-1600 rpm with an axial pressure force of 14 to 22kN and feed rates were 10 to 30 mm/min. The wire 5 to 9 mm in diameter extruded with good quality product [1,2]. 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 [3]. 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 [4-6]. 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 [7-9]. In this process different extrusion ratio was from 0.2, to 5. 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 [10-12]. Friction stir back extrusion (FSBE) process extrudes tubular profile with structurally sound and free from the signs of voids or internal defects from Aluminium, Magnesium and Copper alloy machined chips [13,14]. The inhomogeneous microstructure is attributed to poor deformation characteristics of Magnesium alloy which has HCP crystal structure, similar problems are not observed in aluminium alloy as it is of FCC crystal structure that has favourable number of slip systems [15]. Extrusion marks/scratch lines were observed at the outer periphery and coarse grains were noticed along the tube wall due to trapped heat at a rotational speed of 1500 rpm, axial force 10kN and Extrusion ratio 4.1 [16]. A significant amount of grain refinement in the microstructure, material deformation in the form of outward radial flow in the stirring zone and mechanical properties has been reported [17,18]. 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 [19-21]. As a new attempt to recycle minute metal scrap the possibility of production and design materials by semisolid process by cold pressing and hot extrusion of Aluminium, Magnesium alloy at a pressure of 240, 310 MPa, extrusion ratio is 12, 25:1 with feed rate of 40 mm/min, speed of 1600 rpm. The results indicate that better mechanical properties and fine-grained microstructure due to dynamic recrystallization above 400°C-500°C, at 350-400°C formation of new grains and grain refinement due to cross slip and basal slip and twinning, necklace structures are formed at 300-350°C, the dynamic recrystallization mechanisms are controlled by dislocation climb, and recrystallized grains are homogeneous, no macro cracks or unfilled parts are visible on the surface, Moreover, there was no void defect, and an excellent inner surface was formed [22-25].

III. EXPERIMENTAL WORK

A. Friction Stir Extrusion Process (FSEP)

It is the direct recycling process for extruding wire or rod from polo polymers 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 friction heat 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 figure.1 Another variation of the process is the cartridge is made to rotate keeping the plunger stationary as shown in figure.2.

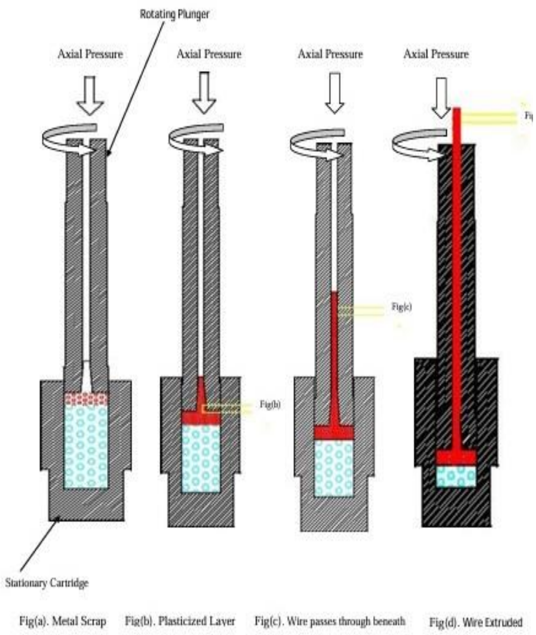


Fig.1. FSE process with Rotating Plunger

B. Materials and Methods

The experimental work has been carried out with the polo polymers scrap 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 extrude the wire and was studied technical and practical problems encountered while conducting this experiment.

Fig.3. FSE process setup on milling machine

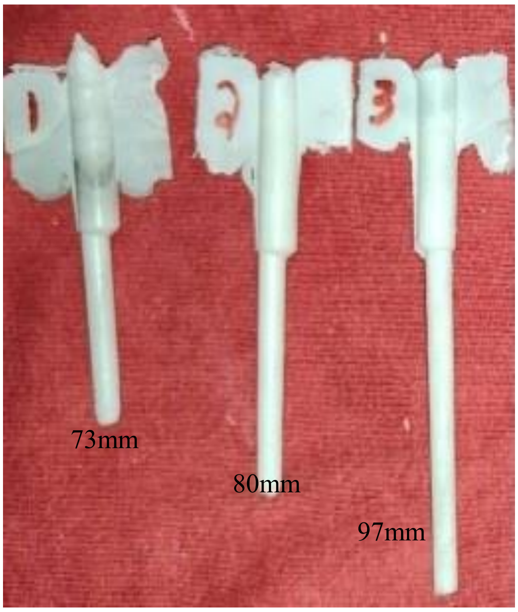


Fig.4. Different Lengths of wire extruded

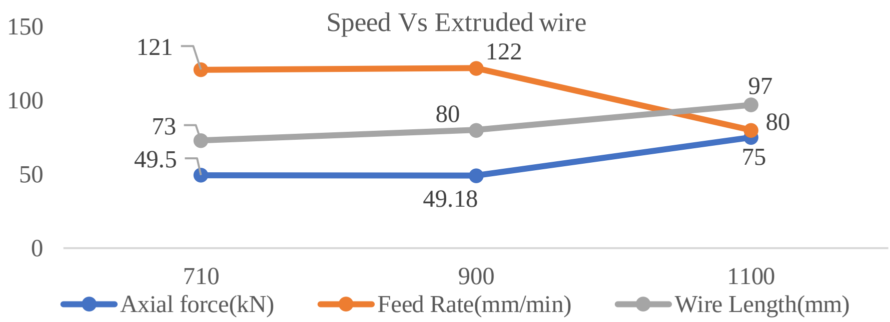
The heavy-duty vertical milling machine has been used to extrude the wire of 5mm in diameter with different process parameters. Wire extruded up to 73mm at speed of 710rpm, 80mm length of wire at 900rpm and 97mm length of wire extruded at 1100rpm shown in figure.4.

IV. RESULTS AND DISCUSSIONS

Speed (Rpm)	Axial Force (KN)	Plunge Rate (mm/min)	Wire extruded in Length (mm)
710	49.5	121	73
900	49.18	122	80
1100	75	80	97

Table.1. Wire Extruded with different lengths

The wire was extruded with deferent lengths of 73, 80 and 97 with smooth surface finish, without defect free and free from cracks at different speeds of 710, 900 and 1100 with an axial pressure force of 49.5, 49.18 and 75kN and traverse feed rate of 121, 122 and 80mm/min respectively shown in table.1. This wire was tested with Scanning Electronic Microscopy and Mechanical properties and was compared with base metal.



Grapgh.1. Speed Vs Extruded wire

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

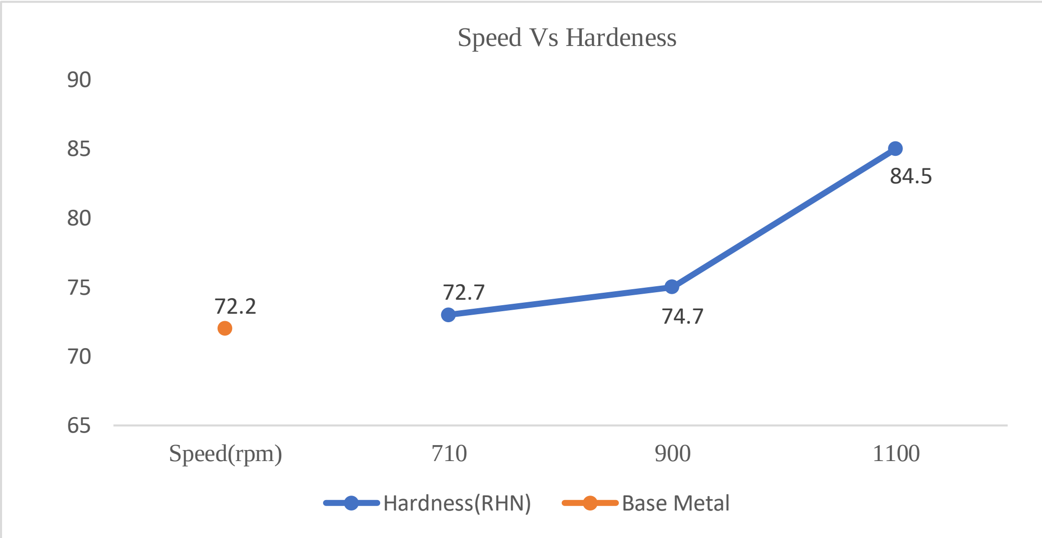
A. Hardness

The hardness on the surface of extruded wire has been carried out using Vicker's hardness testing machine.

Speed (rpm)	**Vicker's Hardness Number**				**Base Metal**
	At Centre	Away from Centre	At outer surface	Avg. VHN	
710	72.4	73	72.8	72.73	72.2
900	74.7	75	74.6	74.76	
1100	84.3	85	84.4	84.56	

Table.2 Vicker's Hardness Test

From the table.2. It was observed that the hardness value is minimum at 710rpm and Maximum at a speed of 1100rpm and medium at 900rpm. It was observed that the of hardness value near to the parent metal.



Grapgh.2. Speed Vs Hardness

From the graph.2. The Vicker's hardness number of wire extruded is higher at 1100rpm and is lower at 900rpm. It was observed that the value of hardness of extruded wire is near to base metal.

B. Scanning Electron Microscopy Test

Scanning Electron Microscopy (SEM) is a powerful tool and a valuable tool for characterizing the structure and morphology of polymers with high magnification and resolution images obtain for studying the dispersion and orientation of fillers in polymer composites and allowing for detailed visualization of morphology of polymers, pore structures, polo shirts, fibers, pores, cracks and other defects of polymer material has been revealed.

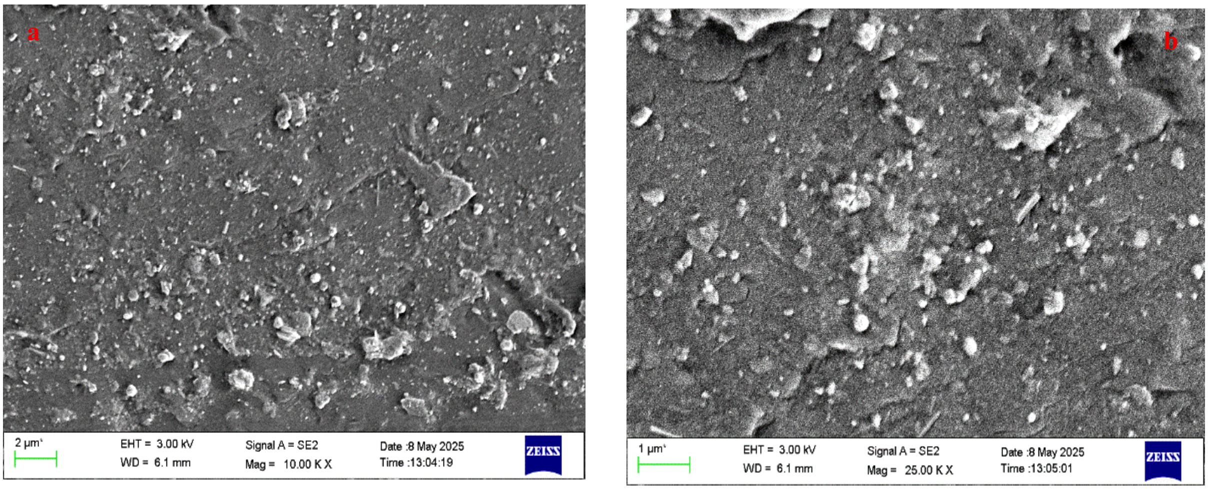


Fig.5.a.b SEM at a speed of 710rpm

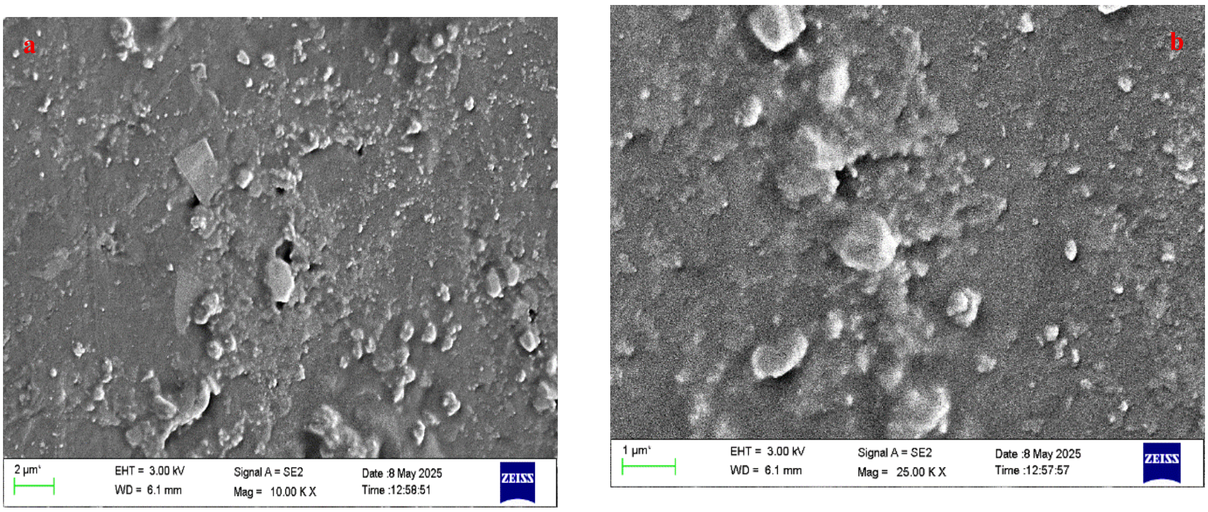


Fig.6.a.b SEM at a speed of 900rpm

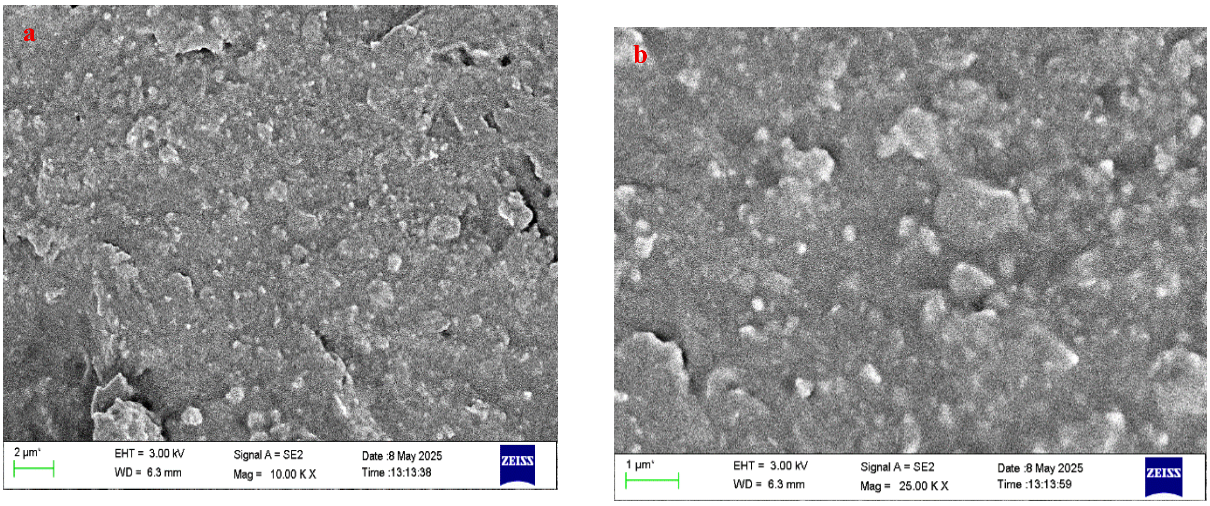
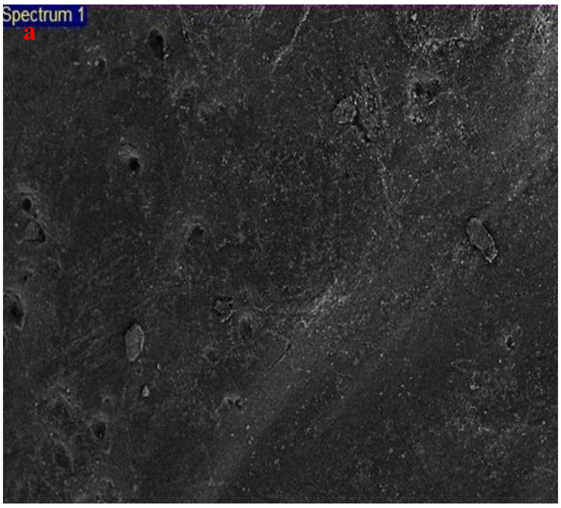


Fig.7.a.b SEM at a speed of 1100rpm



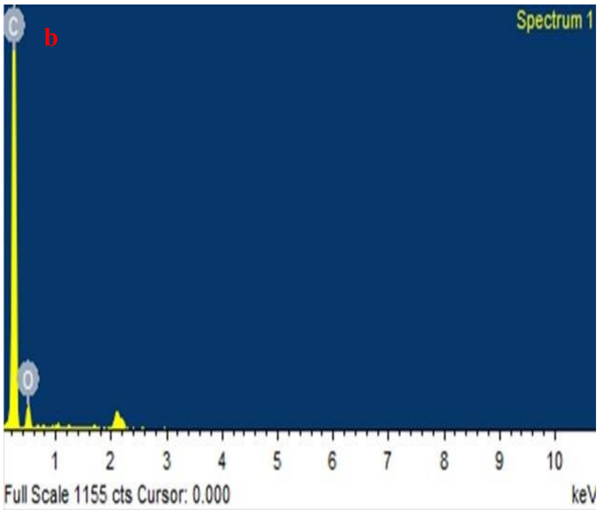
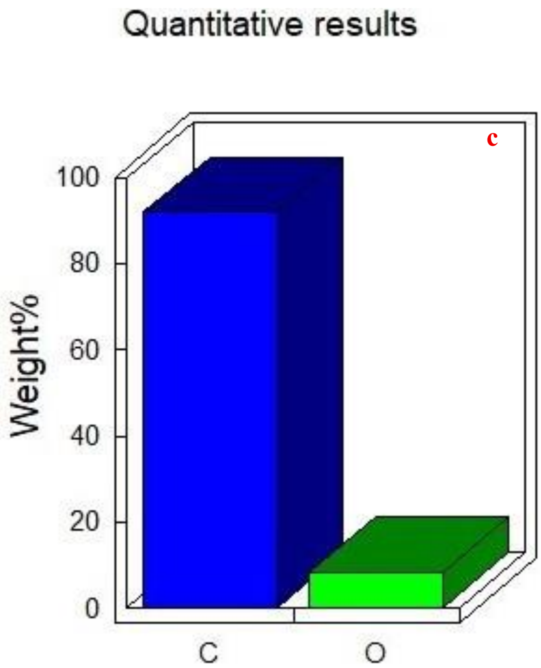


Fig.8.a.b.c. SEM&EDX at a speed of 1100rpm



The SEM and EDX for Chemical composition of polymer has 91.83% weight and 93.74% atomic bases has been reported in FSE Process. The scanning electronic microscopy images of extruded wire at various speeds has been carried out and are shown in figure.5,6,7. The speed at 710rpm of extruded wire images were reveal that an irregular shape granular with pores structure are formed due to low thermo-mechanical effect as shown in figure. 5.a.b. The speed at 900rpm images reveals that the filters, pores structure with round granular shape of polymer material has been observed as show in figure.6.a.b. The speed at 1100rpm images reveals a smooth surface topography, voids or separations within the material with round shape granular has been observed as shown in figure 7.a.b. significantly refine homogeneous distribution grain structure and grain boundaries with better surface topography led to improved strength of extruded material which can be important for understanding the frictional heat and pressure involved during FSE process and was compared with parent metal.

II. CONCLUSIONS

The scanning electronic microscopy images of extruded wire at various speeds has been carried out and are shown in figure.5,6,7. The speed at 710rpm of extruded wire images were reveals that an irregular round shape of granular, pore's structure are formed due to low thermo-mechanical effect as shown in figure. 5.a.b. The speed at 900rpm images reveals that the filters, pores structure with round granular shape of polymer material has been observed as show in figure.6.a.b. The speed at 1100rpm images reveals a smooth surface topography, voids or separations within the material with round shape granular has been observed as shown in figure 7.a.b. It was observed that the hardness value is minimum at 710rpm and Maximum at a speed of 1100rpm and medium at 900rpm and the hardness value is near to the parent metal. The SEM and EDX for Chemical composition of polymer has 91.83% weight and 93.74% atomic bases has been reported in FSE Process shown in figure. 8.a.b.c. The homogeneous distribution of refine grain structure and grain boundaries with better surface topography led to improved strength of extruded material which can be important for understanding the frictional heat and pressure involved during FSE process and was compared with parent metal.

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