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EXPERIMENTAL INVESTIGATION AND ANALYSIS OF MICROSTRUCTURE AND MECHANICAL PROPERTIES ON TWIST EXTRUSION FORMING PROCESS OF AA7075-T6 ALUMINIUM ALLOY

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ABSTRACT
The objective of this study is to investigate the twist extrusion forming behaviour of AA 7075-T6 Aluminium alloy. Samples of 28x18x70 mm cross sections were subjected to twist extrusion forming with the aim to decrease the grain size and improve the mechanical properties. Four different temperatures and three passes were employed to conduct the experiments. The mechanical and microstructure properties of the as received and twist extruded samples at different temperatures and passes were examined. The results reveal that Twist Extrusion (TE) can refine the grain structure, with increasing number of passes, the hardness increase with structure homogeneity improvement but with decrease in the tensile strength at high temperatures. SEM micrographs show that the twist extrusion passes reduces the sizes of the second phase particles which enhance the improvement in mechanical properties.

Keywords: Twist Extrusion, Severe Plastic Deformation, Grain refinement.

1. INTRODUCTION

Aluminium alloys are used in most of engineering applications, due to its excellent properties such as high strength to weight ratio, corrosion resistance, dimensional stability, good ductility, machinability, formability etc. These characteristics of aluminium allow one to use it as a structural material (Karthikeyan et al., 2009, 2010; Prabhu et al., 2011; Anilkumar et al., 2011). In particular AA7075-T6 aluminium alloy has high mechanical strength, lightweight, good vibration-damping characteristics and stiffness, which makes it suitable for aircraft and aerospace applications (e.g.) sensor and guidance components for flight and satellite systems, aircraft and structural components for helicopters and weight critical structural applications like structural materials in pressure cells, although there is some scatter regarding its ductility (Puchi-Cabrera et al., 2011, Azimzadegan et al., 2010). Various techniques have been adopted to improve the mechanical properties of these alloys. Severe Plastic Deformation is one of the most prominent techniques which are used to improve the properties of these materials (Mousavi et al., 2008, Beygelzimer et al., 2009). A number of severe plastic deformation (SPD) techniques like high pressure torsion (HPT), Equal channel Angular Extrusion (ECAE), Cyclic Extrusion Compression (CEC), Accumulative Roll bonding (ARB) for producing bulk ultrafine grain metals have been developed since 1990's (Valiev et al., 2005). Most suitable technique for producing large size stock is the Twist Extrusion forming process. TE is a severe plastic deformation process which uses extensive hydrostatic pressure to impose high strain on bulk solids to produce excellent grain refinement without any change in the dimensions of the sample. The principle of TE is to extrude a billet through a twist die which is twisted to some angle in one direction and then re-twisted to the same angle in the opposite direction (Beygelzimer et al., 2006, 2009). As the specimen is processed, it undergoes severe deformation while maintaining its original cross section as shown in Figure 1.

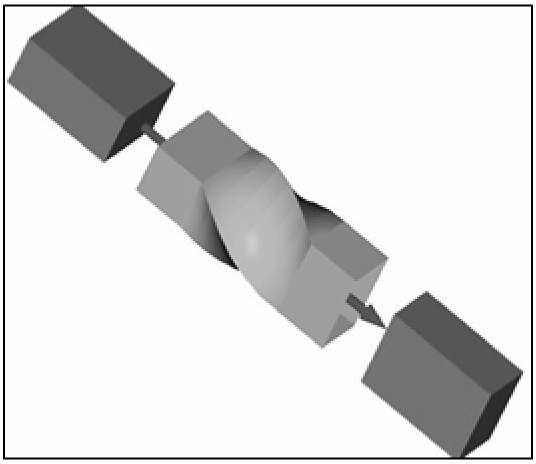

Figure 1 Schematic diagram of twist extrusion of billet

The type of deformation in this process is simple shear in the plane perpendicular to the extrusion axis rather than 45-60 degrees as in Equal Channel Angular Pressing which allows different structures to be achieved (Stolyarov et al., 2005). In addition twist extrusion has many distinguishing features compared to other SPD techniques as it can be easily performed in any standard extrusion equipment by replacing the existing die with a twist die (Beygelzimer et al., 2008, 2009, Orlov and Beygelzimer, 2009). Bahadori et al. (2011) evaluated the effects of loading path during twist extrusion processing. The samples of aluminium 8112 were processed by different routes of twist extrusion. Two consecutive clockwise dies (route I) and alternative clockwise–counter clockwise dies (route II) were used and found that the grain sizes created by route II were significantly finer than those created by route I. Also they found that the mechanical properties, including the strength and hardness, not only enhanced but also distributed more homogeneously across the transverse cross-section of the samples. Akbari Mousavi et al. (2008) carried out Twist Extrusion process for Ti 6Al 4V rectangular specimens and reported that the material is hard to deform, hence a temperature of 700˚C is applied for plastic deformation. Beygelzimer et al. (2008) analysed twist extrusion results for commercial, 99.9 wt. % purity copper. The comparison of mechanical properties inhomogeneity in Cu after Twist Extrusion and Equal Channel Angular Extrusion (ECAE) suggests that alternate processing by ECAE and TE should give the most uniform properties. Marco Berta et al. (2007) used a high resolution electron back scattered diffraction to quantify the deformation structures produced by twist extrusion of Al-0.13% Mg alloy and found that there was large scale inhomogeneity in the processed billets even after eight twist extrusion cycles. Orlov et al. (2008) has used high purity Al (99.99%) which is subjected to severe plastic deformation (SPD) at room temperature using a process of Twist Extrusion. The microstructure evolution and the related change in micro hardness are examined with respect to imposed strain and reported that sub grains develop after the first TE pass with a size of 1.6 mm and this size remains essentially the same for further application of TE passes. Beygelzimer et al. (2006, 2008, and 2009) presented an experimental study of the kinematics of Twist Extrusion and shows that TE has the following properties. As in Equal Channel Angular Processing (ECAP), the mode of deformation in twist extrusion is simple shear. Unlike in ECAP, there are two shear planes; one of them is perpendicular and the other is parallel to the specimen axis. The following processes are present during twist extrusion: vortex-like flow with large strain gradient, stretching and mixing of metal particles. Twist extrusion opens new technological possibilities, e.g., decreased metal waste compared to ECAP, obtaining profile hollow specimens. MohammedIqbal and Senthilkumar (2010) investigated both mechanical and micro structural properties of AA6063 alloy processed by cold twist extrusion process and observed that more twist extrusion passes leads to the grain refinement from 1.25μm to 960nm, enhances the strength and mechanical properties. Jin-feng et al. (2008) investigated the mechanical properties, corrosion behaviours and microstructures of 7075 aluminium alloy with various aging treatments. It was reported that the 7075 Al alloy with the T6, RRA and T6I6 treatments possesses high strength. The T73 and HTPP aging treatments lower its strength. Meanwhile, it is also found that the 7075-T73 alloy possesses the lowest strength. Fine MgZn2 precipitate with high density was obtained in the alloy with the T6 and RRA treatments. Compared with T6 treatment, the RRA, T73, T6I6 and HTPP aging treatments cause the discontinuous distribution of the MgZn2 precipitates at the grain boundary, which decreases the intergranular corrosion and exfoliation corrosion susceptibility of the alloy. Meanwhile, the T6I6 and RRA treatments can keep the high strength of the 7075 Al alloy, but the studied HTPP aging and T73 treatments lower its strength. It is therefore interesting to further examine the possibility of using twist extrusion forming to modify the microstructure and properties of various alloys to enhance the strength of the extruded alloy. The material chosen for the present investigation is Aluminium AA7075-T6 alloy since no work has been reported earlier related to this alloy processed by Twist Extrusion forming process. The aim of this work is to analyse the microstructure of the twist extruded specimen and to study the variation in mechanical properties such as tensile strength, yield strength and hardness of AA7075-T6 aluminium alloy before and after twist extrusion by varying the temperature and number of passes.

2. EXPERIMENTAL WORK

AA7075-T6 Aluminium alloy samples were cut into rectangular pieces of dimensions 28x18x70 mm. The die for performing the twist extrusion forming is designed and fabricated into two split pieces. One die part has an entry dimension of 28x9 mm and an exit dimension of 18x14 mm. Another die part has the same dimension to match with the first. Twist angle of 90˚ is maintained while the slope angle is between 54˚ and 13˚. A container is fabricated to hold the die parts rigidly.

Table 1 Chemical compositions of AA7075-T6 alloy (Weight Percentage)

Al	Zn	Mg	Cu	Cr	Si	Ti	Mn	Fe
90.07	5.6	2.5	1.6	0.23	0.4	0.2	0.3	0.4

EN 31 is selected as material for die fabrication due its high strength and corrosion resistance property. Table 1 shows the chemical composition of the AA7075-T6 alloy. Table 2 shows the major chemical composition of the die material. A punch of dimensions 28x18x70 mm with negative tolerances is fabricated and core hardened. A shank is fabricated so as to clamp the punch with press ram. The entire die set up is assembled with accessories like lid, strap plate and fasteners.

Table 2 Chemical composition of die material EN31 (Weight Percentage)

Mn	C	Si	Al	Cu	Ni	Cr	Mo
0.66	0.36	0.27	0.22	0.22	0.2	0.21	0.02

The exploded view of the die is shown in Figure 2. Hydraulic power press of 100 Ton capacity has been used for performing the twist extrusion forming process. An electric furnace is placed near the die assembly. The billet is heated in the furnace to required temperatures. Then the billet is taken carefully in an asbestos box and transferred into the die assembly immediately to avoid oxidation. The hydraulic press is switched on at a required pressure. Before the billet comes out of the twist portion a plate is inserted in the exit to create a back pressure at the centre of the specimen thus the specimen is subjected to compressive stress on the edges and tensile stress at the centre. A dummy block made of copper is inserted to remove the specimen from the die. The specimen is removed and cooled in an asbestos box. This process is repeated for different temperature levels and for different passes. The specimens before extrusion and after various twist extrusion passes at different temperature are shown in Figure. 3 (a-c). The various mechanical properties such as Hardness, Tensile strength are determined in order to find the variation in properties. Wilson Woltert Vicker's Hardness testing machine is used to calculate the hardness of specimen before and after extrusion at 0.5 kg load for 20 seconds. In order to eliminate the possibilities of error a minimum of five hardness readings were taken from each sample. Specimens for conducting the sub size tensile test were cut as per ASTM (American Society for Testing of Materials) B557 M, with a gauge length of 28 mm, gauge thickness of 6 mm and fillet radius of 6.5 mm. Tensile tests were carried out on a 50 KN, electro-mechanically controlled table top tensometer. The tensile specimens are shown in Figure 4.

Figure 2 Exploded view of the die setup

(a) 200˚C (b) 250˚C (c) 300˚C

Figure 3 Specimens before and after various twist extrusion passes at the indicated temperatures

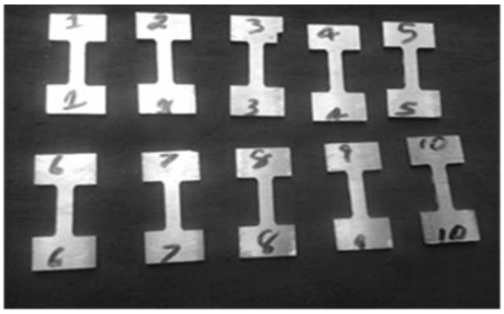

Figure 4 Tensile test specimens

The specimens for microstructural examination are prepared after polishing and etching. Keller's solution is used as an etchant. Hitachi S-3400N Scanning Electron Microscope machine was used for studying the microstructure.

3. RESULTS AND DISCUSSION

Specimens processed by one, two and three twist extrusion passes were analysed for their changes in mechanical properties and microstructures and the results are presented in Table 3.

3.1. Tensile Properties

Table 3 lists the results of the mechanical properties of the as received and the twist extruded AA7075-T6 samples at various conditions of temperature and extrusion passes. Figure 5 shows the variation of tensile strength of the alloy processed with increasing temperature and increasing numbers of passes. It can be noted that the tensile strength increases with more number of passes and at increasing temperature from 200˚C to 300˚C. With increasing twist extrusion passes the homogeneity of the deformed billet was expected to improve because of the generally higher level of deformation and through the transfer of shear to the adjacent material via work hardening (Berta et al., 2007). However it was noticed that there was a decreasing trend in tensile strength of the alloy processed at 350˚C with increasing TE passes. Defects like porosity and blow holes in the twist extruded samples are observed in Figure 12(b) vii. This leads to reduction in the strength. It is also noticed that the grains start to coarsen at 350˚C with high angle grain boundaries which increase the hardness leading to decrease the tensile strength. The inhomogeneous microstructure which is observed is also the reason for this behaviour.

3.2. Hardness

Figure 6 shows the variation of hardness of the alloy processed with increasing temperature and increasing numbers of passes. It was observed that that the hardness increases with increasing temperature and at increasing number of passes. This is due to the fact that the imposed strain is less at the centre of the specimen which increases the hardness of the alloy even after three TE passes than after one TE pass (Orlov and Beygelzimer, 2009). The same trend is noticed with the reports of TE conducted for 99.99% Al. (Orlov et al., 2008) but different results are reported when the hardness was tested at the edge of the sample where large strain is created. It was reported that the hardness is lower for 4 passes than one pass when it is tested at the edge of the sample. Figure 7, Figure 8 and Figure 9 depicts the influence of specimen temperature on hardness and tensile strength for one TE pass, two TE passes and three TE passes. It is observed that there is a non-linearity in the tensile strength of the specimen processed at 200˚C and one extrusion pass. As the temperature and number of passes increases this non linearity disappears (Figure 8, 9) and there is a consequent increase in hardness and tensile strength of the TE samples. This is due to refinement of the grains which is observed at 250˚C to 300˚C [Figure 12(b) iv- vii]. At higher temperatures i.e., at 350˚C and at higher passes the grains begin to coarsen which shows the decrease in tensile strength and increase in hardness.

Table 3. Mechanical Properties of AA7075-T6 alloy at different temperatures and extrusion passes

Condition of Specimens		Hardness	Yield Strength (MPa)	Tensile Strength (MPa)
As received		101.6H.V 0.5	270.52	312.77
At 200°C	PASS I	102.8H.V 0.5	213.46	245.55
	PASS II	103.6H.V 0.5	220.53	250.5
	PASS III	104.9H.V 0.5	199.46	233.64
At 250°C	PASS I	103.2H.V 0.5	195.61	214.61
	PASS II	104.5H.V 0.5	197.23	219.32
	PASS III	105.1H.V 0.5	210.34	241.56
At 300°C	PASS I	103.6H.V 0.5	204.54	236.17
	PASS II	105.8H.V 0.5	234.21	266.76
	PASS III	107.9H.V 0.5	242.12	283.32
At 350°C	PASS I	104.5H.V 0.5	203.02	235.10
	PASS II	105.6H.V 0.5	196.63	214.15
	PASS III	108.6H.V 0.5	195.21	213.81

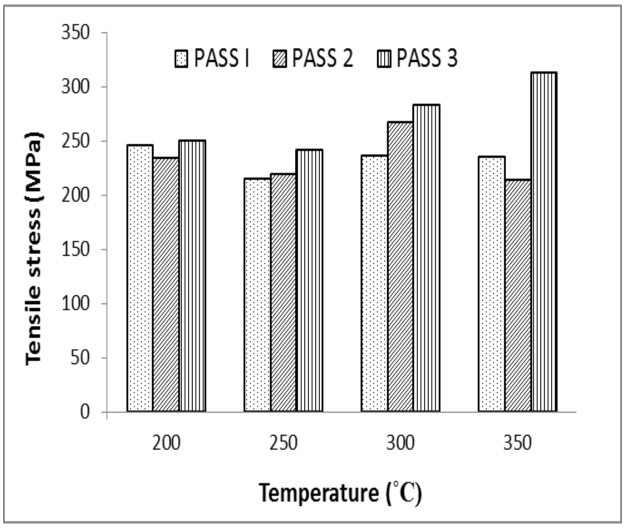

Figure 5 Variation of tensile strength with temperature and number of passes

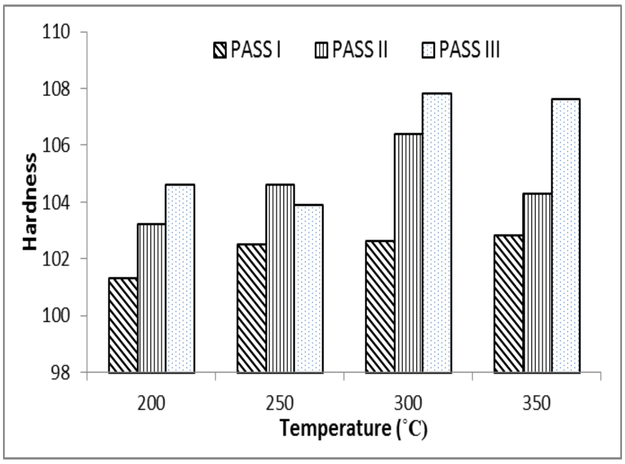

Figure 6 Variation of hardness with temperature and number of passes

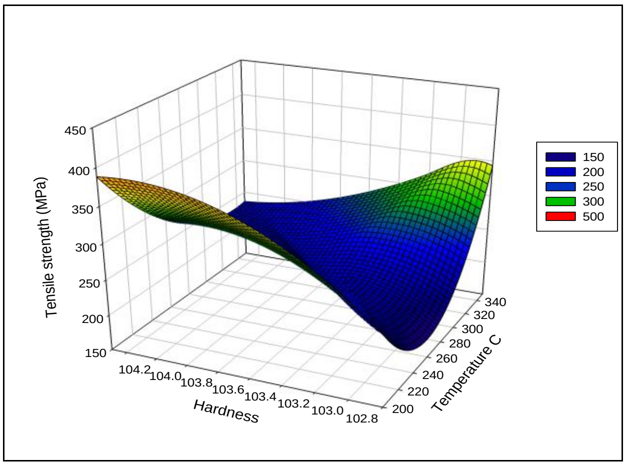

Figure 7 Influence of Temperature on Hardness and Tensile strength after one extrusion pass

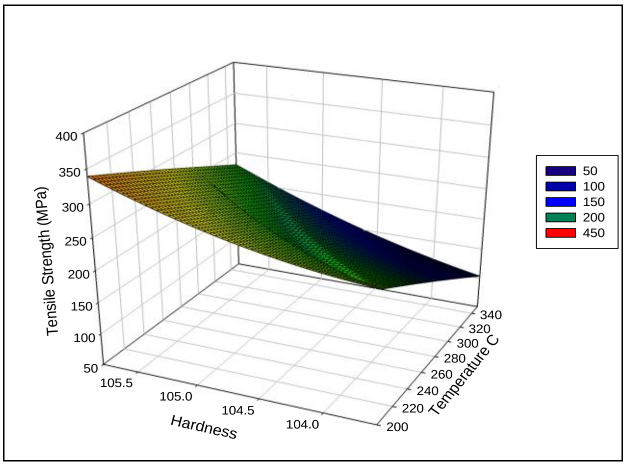

Figure 8 Influence of Temperature on Hardness and Tensile strength after two extrusion passes

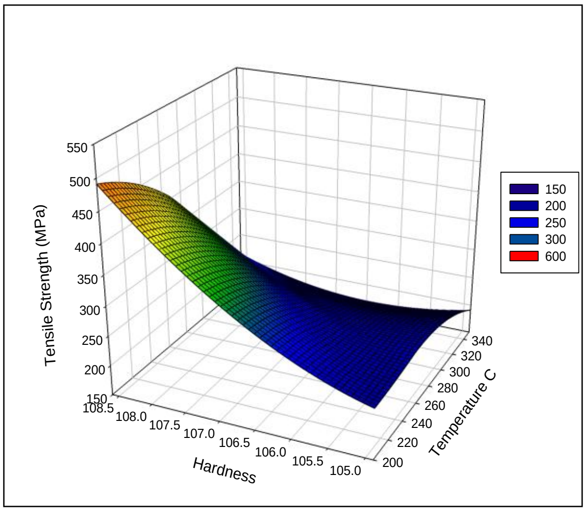

Figure 9 Influence of Temperature on Hardness and Tensile strength after three twist extrusion passes

3.3. Microstructure

SEM micrographs shown in Figure 12 (a) and (b) depict the microstructure of AA7075-T6 before TE and microstructure after one, two, and three TE passes. It appears that grains have a similar size irrespective of the TE passes. But when comparison is made between the samples of one TE pass and three TE passes there are fewer dislocations of grains. The grain boundaries are well defined with more number of passes. It was observed that the dislocation density in the grains is low and the grains contain deformation twins after one pass extrusion. These twins are found to be disappeared at higher temperatures and more extrusion passes. Moreover it was observed that the grains starts to elongate in the direction of twist and high angle grain boundaries are observed. Some pin hole defects tend to originate. The increase in temperature and number of passes decreases the average grain size from 38 µm to 20µm.

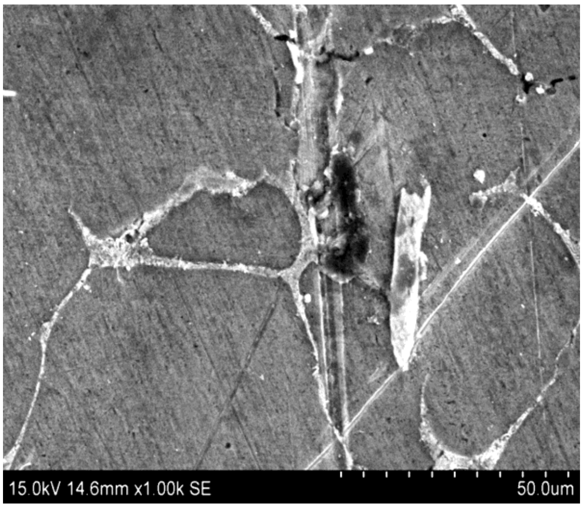

Figure 12(a) Microstructure of AA7075-T6

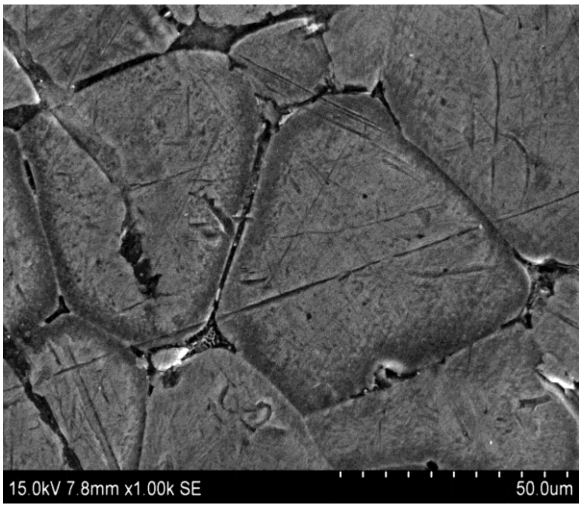

Figure 12 (b) i Microstructure of AA7075-T6 after one TE pass at 200˚C

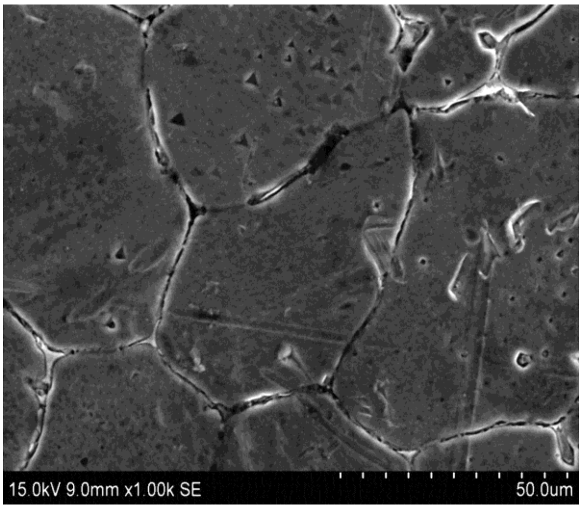

Figure 12 (b) ii Microstructure of AA7075-T6 after two TE passes at 200˚C

Figure 12 (b) iii Microstructure of AA7075-T6 after three TE passes at 200˚C

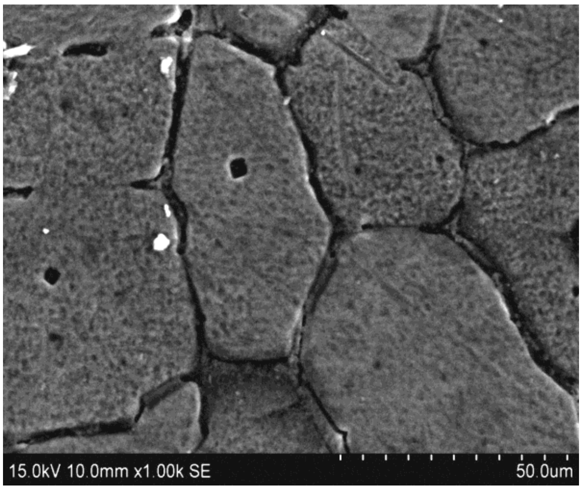

Figure 12 (b) iv Microstructure of AA7075-T6 after one TE pass at 300˚C

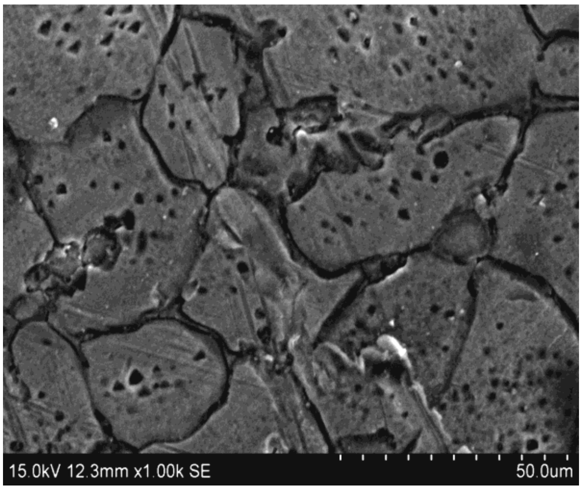

Figure 12 (b) vii Microstructure of AA7075-T6 after one TE pass at 350˚C

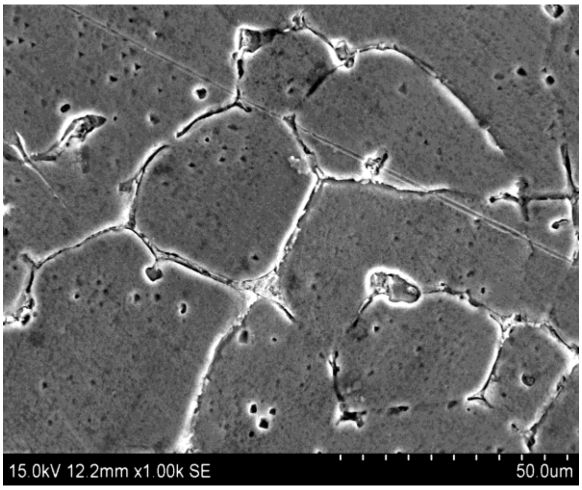

Figure 12 (b) v Microstructure of AA7075-T6 after two TE passes at 300˚C

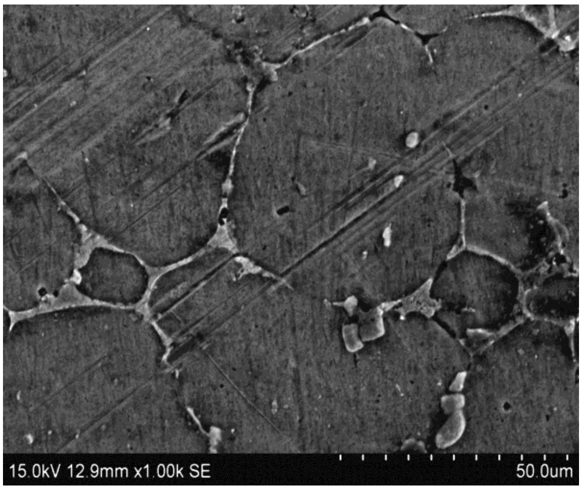

Figure 12 (b) viii Microstructure of AA7075-T6 after two TE passes at 350˚C

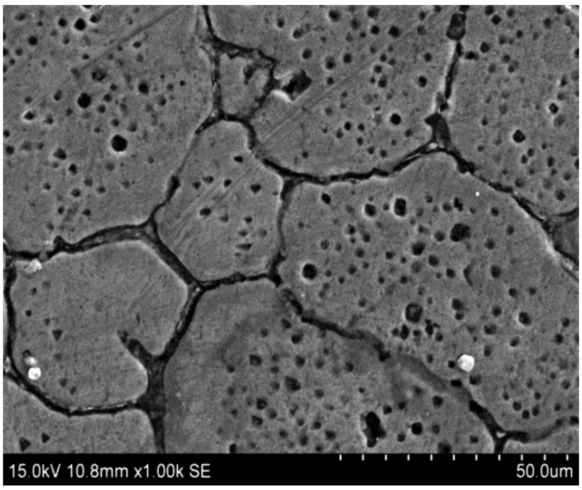

Figure 12 (b) vi Microstructure of AA7075-T6 after three TE passes at 300˚C

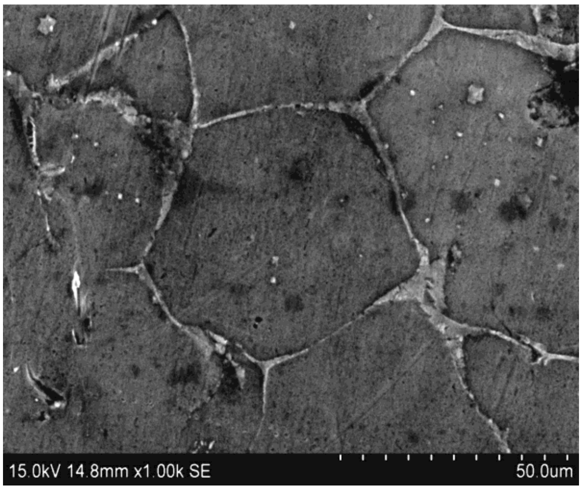

Figure 12 (b) ix Microstructure of AA7075-T6 after three TE passes at 350˚C

4. CONCLUSIONS

The effect of extrusion parameters such as temperature, number of passes on the microstructural and mechanical characteristics of hot twist extruded Aluminium alloy AA7075-T6 samples were experimentally investigated. According to the experiments the tensile strength of the specimen decreases and hardness increases with more extrusion passes at a temperature of 350˚C. However the tensile strength and hardness of the specimen increases with increase in number of twist extrusion passes and increase in temperature above 200˚C and upto a temperature of 300˚C.The results reveal that the optimum temperature range for obtaining better mechanical properties for this alloy is 250˚C-350˚C. From the microstructural analysis it appears that there are fewer dislocations of grains for the specimens processed by three twist extrusion passes than that of the specimen processed by one extrusion pass and the grain boundaries are well defined after three twist extrusion passes. Finally it has been revealed that the grain refinement for this alloy takes place at optimum temperature and more number of passes.

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