Microstructure, Mechanical And Wear Properties Of Aluminum 5083 Alloy Processed By Equal Channel Angular Extrusion

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Abstract

In this study, commercially available aluminum magnesium (Al 5083) alloy was subjected to equal channel angular extrusion (ECAE) up to two passes using route-B_c at room temperature. Microstructure, mechanical and wear properties of the alloy before and after ECAE were investigated to examine the effect of ECAE on Al 5083 alloy. Microstructural investigations were carried out along the flow and transverse planes of the extruded alloy using optical microscope and it revealed that the coarse microstructure of the alloy was refined to a considerable amount. The micro hardness and tensile strength of the alloy increased with increase in pass number. The wear properties of the alloy after ECAE were improved considerably along with improvement in hardness and tensile strength. It is clear from the results that the mechanical properties of the alloy were improved to a particular extent due to the highly refined grains imparted by ECAE process and it makes the alloy to be used in various engineering applications requiring high strength.

Keywords: *Equal channel angular extrusion, optical microscope, wear, aluminum 5083 alloy*.

1. Introduction

Aluminum and its alloys are being widely used as a predominant material in various engineering applications. More significantly, ultra fine grained (UFG) high strength aluminum 5083 alloy is in great demand to be used in various applications such as shipbuilding, vehicle bodies, pressure vessels and armor plates due to its exceptional strength, good weldability and corrosion resistance. Due to this great demand for bulk materials with fine grains and combinational properties, researches are being done on various severe plastic deformation (SPD) techniques to produce high strength UFG materials.

Equal Channel Angular Extrusion (ECAE) is the most significant and attractive SPD technique in which the materials are extruded without any change in the cross section by subjecting to very large shear strain. The processing technique of ECAE involves pressing a billet through a die consisting of two channels of equal cross section intersecting at a specified angle (Φ). A very high shear strain is imposed on the material when it passes through the shear zone of the die [1-3]. Since the billet material has nearly the same cross section before and after ECAE, it can be pressed through the die repeatedly for more passes. The deformation route can be varied between consecutive passes by rotating the billets through 0º (route-A), 90º alternate direction (route-B_A), 90º same direction (route-B_c) and 180º (route-C) [4]. The strain developed and the microstructural changes in the material are controlled by choosing the appropriate channel angle (Φ), deformation route (route-A, route-B_A, route-B_c or route-C) and the number of passes [4-6]. Extensive research has been done on ECAE for the past two decades to process materials such as aluminum alloys, magnesium, chromium, copper, silver, steel and titanium [7-17, 25]. Most of the studies revealed that the coarse grain structure of the material has been replaced with highly refined equiaxed grain structure after ECAE [12-13]. For the processed material, mechanical and wear properties were found to be high making ECAE an important technique for processing bulk materials [10-14].

In this study, commercially available aluminum magnesium (Al 5083) alloy is subjected to ECAE through route-B_c at room temperature, to improve the strength. Investigations are done on microstructure, mechanical and wear properties of the alloy before and after ECAE.

2. Experimentation

2.1. Sample Preparation

A commercial grade aluminum magnesium (Al 5083) alloy was purchased which is in H34 condition. The sample for ECAE was prepared by machining the alloy to a diameter of 20mm and length 80mm. The chemical composition of the alloy as shown in table.1 was analyzed by the ARL spark analyzer. It confirmed that the alloy purchased was an Al 5083 by having a maximum of 4.37% of magnesium.

2.2. Die Setup

The ECAE die was made from steel consisted of two equal channels of circular cross section 20.2mm in diameter. Channel intersection angle (Φ) of 105º was selected because it produced strain homogeneity in the billet material and some reduction in the pressing load [18-19]. Outer corner angle (Ψ) of 18º along with a fillet radius of 6mm was used to avoid bending like deformation which is more popular with higher outer corner angles [20-21]. As sharp inner corner produced damage in the specimens [22], fillet of radius 2mm was made in the inner corner of the two intersecting channels to avoid the cracks and damage in the top surface of the samples. A split type die design was used for the easy removal of extruded specimen from the die. A schematic of the ECAE die is shown in fig.1.

The equivalent strain for N passes can be calculated by using equation (1) formulated by Iwahashi et al. [23].

$$\varepsilon = N/\sqrt{3}[2\cot(\Phi/2+\Psi/2)+\Psi\operatorname{cosec}(\Phi/2+\Psi/2)] \quad (1)$$

where ε is the equivalent plastic strain, N is the no of passes, Φ is the channel intersection angle and Ψ is the outer corner angle.

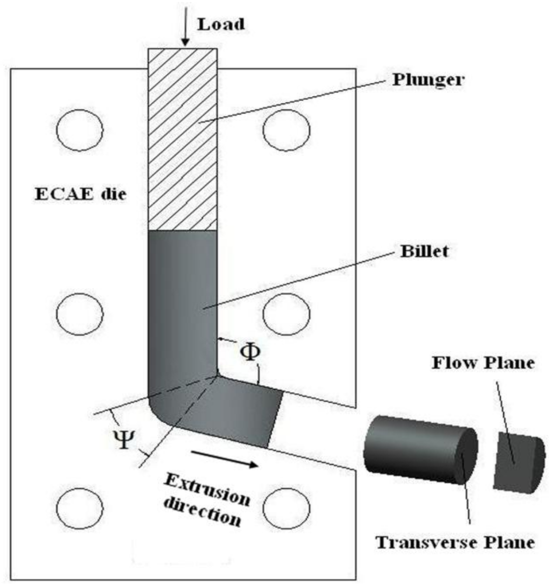

Fig.1 A schematic of ECAE die

2.3. Processing

The samples prepared were pressed through the ECAE die at room temperature using a hydraulic press of 100 tons capacity up to two passes. MoS_2 grease and SAE 68 oil were used as lubricants to reduce the friction between the sample and die surface. The samples were rotated to an angle of 90° (Route-Bc) after each pass. Microstructural investigations of the samples before and after ECAE were conducted using optical microscope. The extruded samples were cut along the flow and transverse plane for microstructural investigations and ground manually using 240, 320, 400, and 600 grit silicon carbide abrasive sheets. The surfaces are then polished with alumina powder with a low speed polishing machine. The polished surfaces of the samples were then etched by immersing it in Keller's reagent (1 volume part of hydrofluoric acid, 1.5 volume part of hydrochloric acid, 2.5 volume parts of nitric acid, 95 volume parts water) for 15-20 secs.

Microhardness of the samples before and after ECAE was measured along the transverse plane using Vickers microhardness tester by applying a load of 100grams for 20secs. Tensile testing of the samples was done at room temperature using extensometer. The samples for tensile testing were machined along the extrusion direction with 6mm gauge diameter and 30mm gauge length.

Dry sliding wear test was conducted to reveal the wear properties of the as-received and extruded samples. The samples for wear test were machined to a

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Table.1 Chemical composition of Al 5083 alloy

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Ni	Pb	Sn
0.18 %	0.23 %	0.015 %	0.60 %	4.37 %	0.04 %	0.042 %	0.07%	0.001 %	0.002 %	0.002 %
Na	**Ca**	**B**	**Zr**	**V**	**Be**	**Sr**	**Co**	**Cd**	**Sb**	**Ga**
0.00003%	0.0001 %	0.0007%	0.004 %	0.0007 %	0.002 %	0.00003%	0.01%	0.0003 %	0.005 %	0.004 %
P	**Li**	**Al**								
0.007 %	Nil	94.33 %								

pin of diameter 10mm and length 30mm. The wear test was conducted at room temperature using pin on disc wear test apparatus with a track diameter of 100mm and load range of 40, 50 and 60N. The samples were made to wear on a hardened EN31 steel disc having a diameter of 165mm and hardness 56HRC at a constant velocity of 4.19m/s. The surface roughness of the disc surface was maintained to 0.3µm. Each test was conducted for three trials and the average of these three runs was taken into consideration. The mass loss of the samples was calculated using a microbalance to find the difference in wear resistance of the as-received and extruded samples for different load conditions. The wear rate was calculated from the corresponding mass loss and wear rates for the various load conditions were plotted. To study the effect of sliding distance on mass loss and wear rate, tests were conducted by varying the sliding distance from 1.3 to 3.3km and the graphs were plotted. Scanning Electron Microscopic (SEM) images were taken to examine the morphologies of the worn surfaces of the samples.

3. Results and discussion

3.1. Microstructure

Optical micrographs of the as-cast aluminum 5083 alloy in the transverse and flow direction are shown in fig.2 (a) & 2 (b). The alloy without ECAE is found to have coarse grain structure. Fig.3 (a) shows the microstructure in the transverse direction of the billet after one pass ECAE. It is seen that the coarse grain structure of the as-cast alloy is broken down when it is pressed through the die due to the imposed high plastic strain by ECAE. The microstructure along the flow direction of the specimen after one pass is shown in fig.3 (b). It clearly shows the deformations produced in the material by ECAE. Most of the coarse grain structure of the unprocessed material is replaced with fine and homogeneous grain structure after two ECAE passes which is shown in fig.3 (c). The micrograph shown in fig.3 (d) is taken along the flow plane of the specimen processed by two pass ECAE. It reveals that more deformations are produced in the material after two passes. Thus processing through ECAE refined the microstructure of as-cast aluminum 5083 alloy.

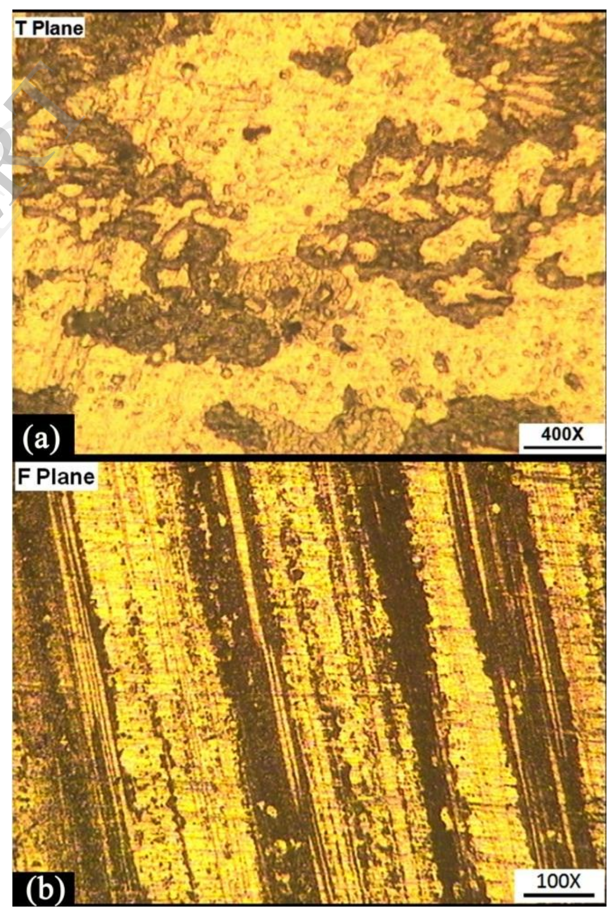

Fig.2 Microstructure of AL 5083 before ECAE

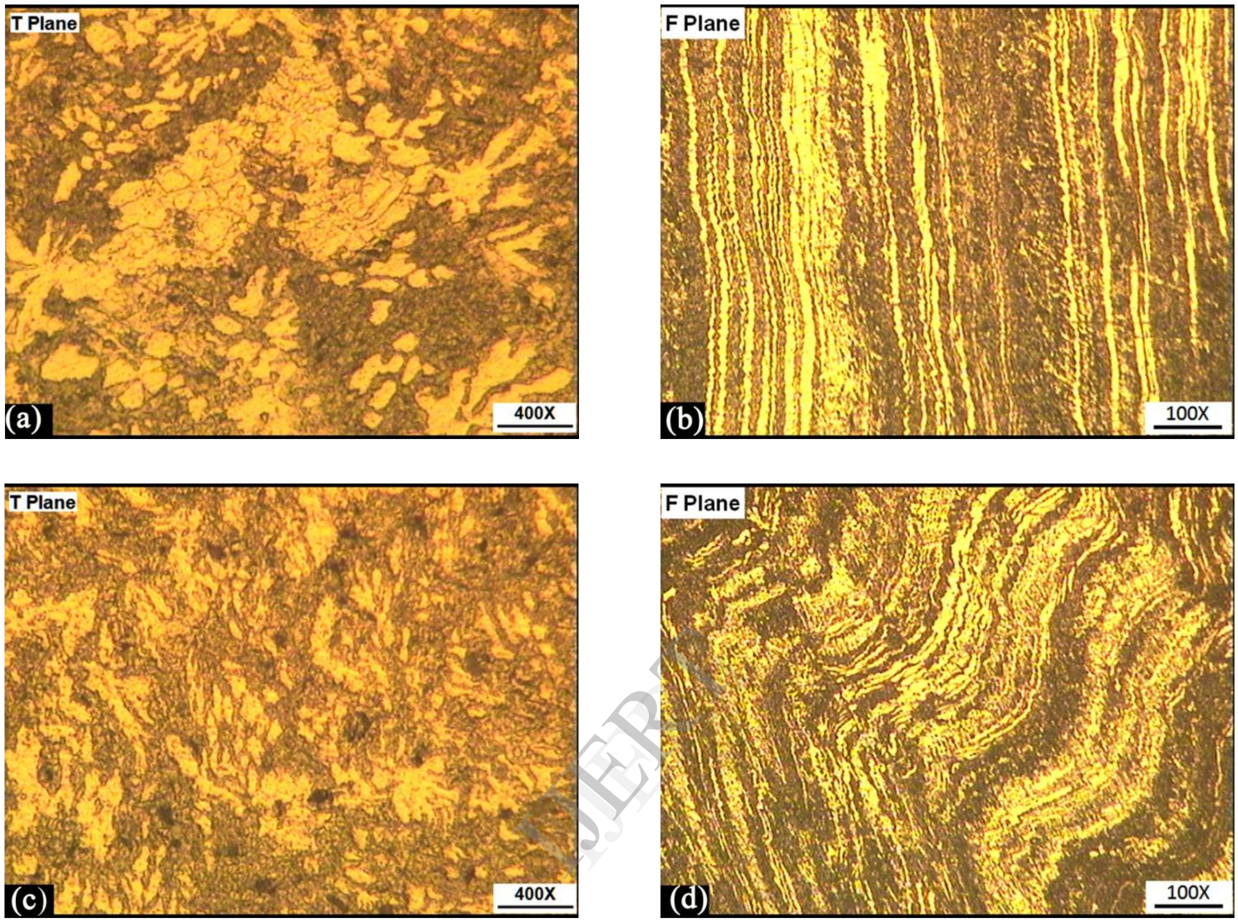

Fig.3 Microstructure of AL 5083 alloy (a) & (b) after one pass ECAE; (c) & (d) after two pass ECAE (T- transverse, F- flow)

3.2 Mechanical Properties

3.2.1. Microhardness

Vickers microhardness measurements before and after ECAE using route B_c at room temperature are shown in fig.4. The microhardness of alloy after ECAE is higher than that of the unprocessed alloy and it increased with increase of pass number. The hardness of the processed alloy increased suddenly from 105HV to 142HV after first pass and it increased to 151HV after second pass. The percentage increase of the hardness after one pass is higher when compared to the increase in hardness of two pass ECAE specimen. It is clear that the increase in hardness of the alloy is due to the homogeneous and highly refined microstructure of the alloy.

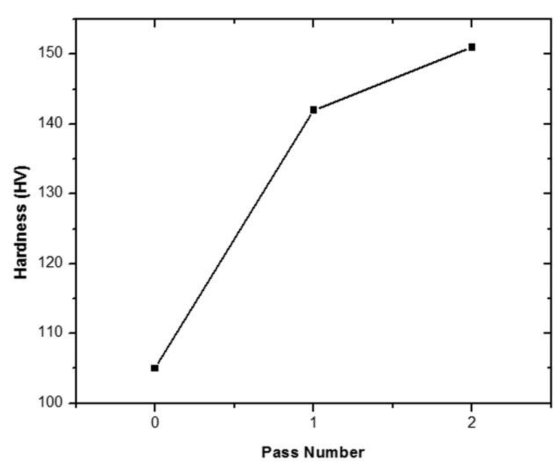

Fig.4 Vickers hardness of Al 5083 before and after ECAE

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3.2.2. Tensile Properties

The tensile properties of aluminum 5083 alloy before and after ECAE are shown in Table.2. The yield strength (YS) and ultimate tensile strength (UTS) of the alloy before processing by ECAE was 309MPa and 342MPa with an elongation of 25%. After ECAE with one pass, the YS of the alloy increased by 29% to 397MPA and UTS by 18% to 404MPa with 16% elongation. With further processing by ECAE to two passes, the YS of the alloy increased by 43% to 441MPa and UTS by 31% to 47MPa with 15% elongation when compared to unprocessed alloy. Though the strength of the alloy increased, the ductility reduced from 25% to 15%. This may be due to the strain hardening of the alloy after ECAE. It is revealed that the increase in strength of the alloy processed by ECAE is mainly due to refinement of grains as according to Hall-Petch relation [24].

The specimens after the tensile test are shown in fig.5. It is observed that necking occurs only in the unprocessed alloy near the fracture surface. This shows that the type of fracture is ductile in unprocessed alloy and brittle in processed alloy. The plot of engineering stress versus engineering strain of the alloy before and after ECAE is shown in fig.6. The curve exactly denotes that the specimens after ECAE has fractured just after reaching the tensile strength while in the as cast alloy considerable reduction in the stress value is achieved which denotes the ductile type of fracture. The brittle fracture of the processed alloy is due to the increase in hardness value and tensile strength of the material.

Table.2 Tensile properties of Al 5083 alloy before and after ECAE

No of passes	YS (MPa)	UTS (MPa)	Elongation to failure (%)
0	*309*	342	25
1	397	404	16
2	441	447	15

Fig.5 Fractured specimens after tensile test

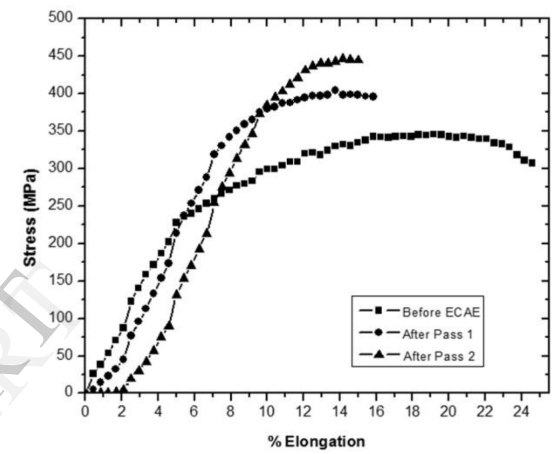


Fig.6 The stress-strain curves of unprocessed and processed Al 5083 alloy

3.3. Wear Properties

Fig.7 (a) shows the effect of load on mass loss of both processed and unprocessed aluminum 5083 alloy. It reveals that the mass loss of alloy before and after ECAE increased with increase of load. The sample without ECAE has higher value of mass loss when compared to extruded samples. There is considerable reduction in the mass loss after two pass ECAE.

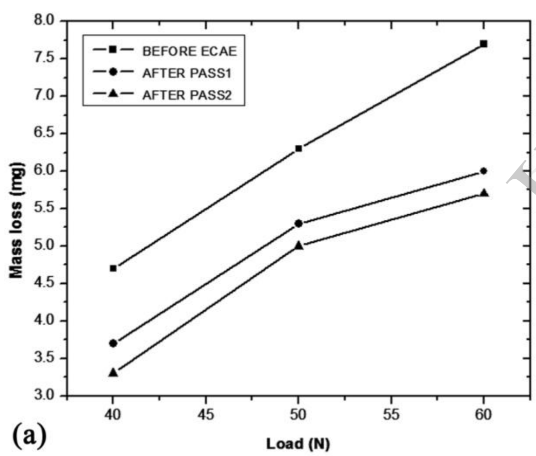
Fig.7 (b) explains the relation between loads and wear rate for the samples before and after extrusion. The wear rate of the sample without ECAE increased with respect to load. The samples processed by ECAE with one and two passes has maximum wear rate at a load of 50N and it gets reduced with further increase in load.

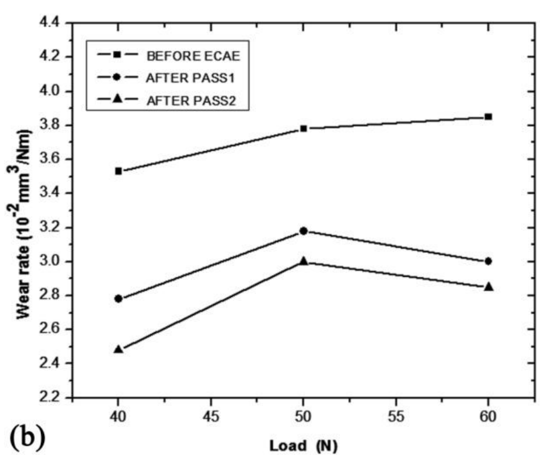
Fig.7 (c) illustrates the effect of load on the friction co-efficient of the unprocessed and extruded samples. The friction co-efficient is high for the sample without ECAE and it increased with increase in load.

Initially the friction co-efficient is low for the samples after ECAE with one and two passes at a load of 40N and it reached its maximum value at a load of 50N with further reduction at a load of 60N. When compared to the unprocessed alloy, the friction between the processed samples and disc surface is very low which made the samples to wear a very less mass of material with considerable reduction in wear rate.

Fig.8 (a) shows the effect of sliding distance on the mass loss of the samples with and without ECAE. It is clear from the figure that the mass loss of both processed and unprocessed samples increased with increase of load. After processing by ECAE with one pass, the mass loss has reduced to certain extent when compared to unprocessed samples. With further processing by ECAE up to two passes, mass loss gets reduced further.

Fig.8 (b) shows the effect of sliding distance on the wear rate of the samples before and after ECAE. The wear rate of the sample before ECAE is high when compared to the samples after ECAE. The high wear rate of the unprocessed samples is due to the presence of large grains and low hardness. The wear rate of the samples after ECAE reduced due to grain refinement.





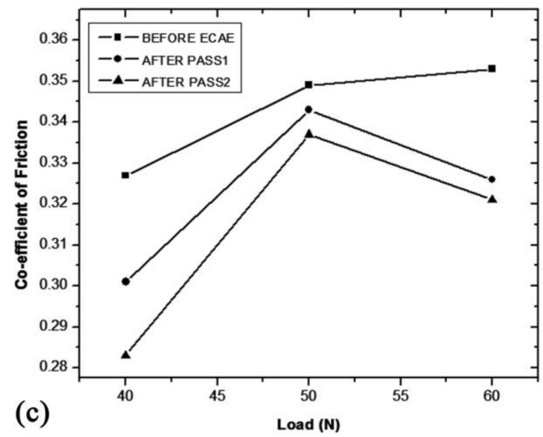
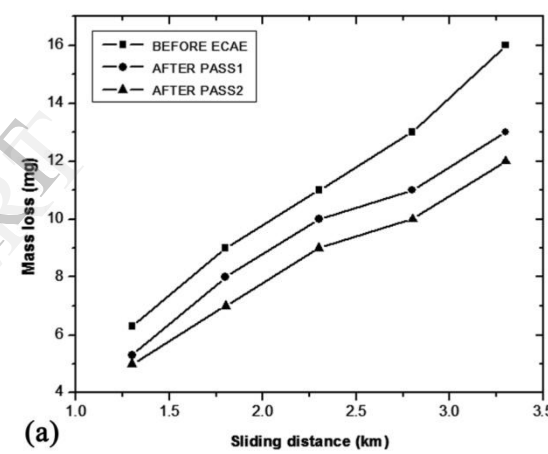


Fig.7 Effect of load on (a) mass loss (b) wear rate (c) friction coefficient of aluminum 5083 alloy under a constant velocity of 4.19m/s and time 5secs



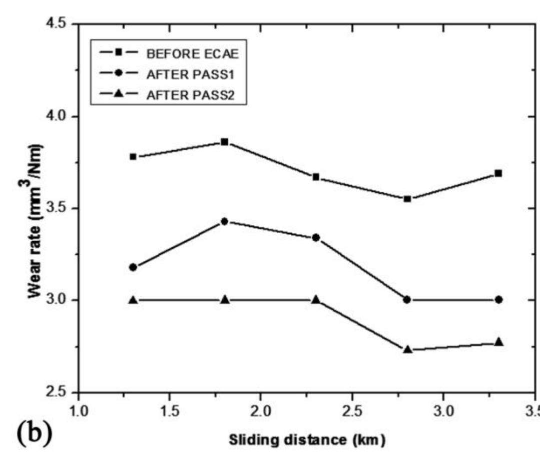


Fig.8 Effect of sliding distance on (a) mass loss (b) wear rate of AL 5083 under a constant velocity of 4.19m/s and load 50N

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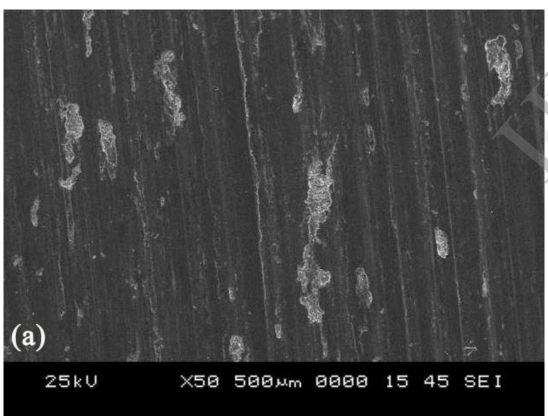
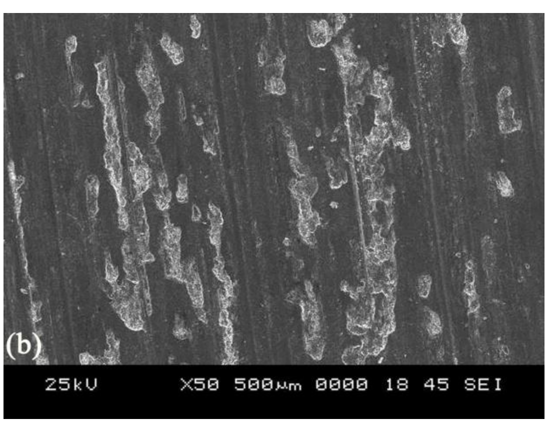
It is obtained from the wear test that the wear resistance of the alloy has improved after processing by ECAE with two passes. This is mainly due to the formation and homogeneous distribution of ultra fine grains. The increase in the hardness after ECAE made the alloy to resist the scratch deformation. The morphologies of the worn surfaces of the samples before and after ECAE are shown in fig.9.

The worn surface of the specimen before ECAE is shown in fig.9 (a). The mechanism of wear for the specimen before ECAE is found to be abrasive with some delamination on the surface. The delamination is mainly due to the cracks formed beneath the surface by high plastic strain on the surface during sliding. Some grooves are formed on the surface due to delamination. From fig.9 (b), it is seen that the abrasive type of wear reduced with the increase in delamination type of wear for the specimen after one ECAE pass. As the growth of cracks is facilitated by imperfections or defects in the material, the high density of dislocations imparted by ECAE increased the delamination wear. With further processing upto two passes, the wear mechanism is mostly of delamination type due to increase in dislocation density as shown in fig.9 (c). The wear particles delaminated is parallel to the sliding direction.





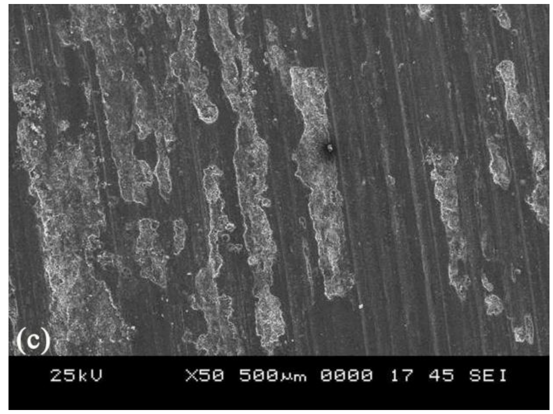


Fig.9 SEM morphologies of worn surfaces of AL 5083 alloy (a) without ECAE (b) after one pass ECAE (c) after two pass ECAE

4. Conclusions

The equal channel angular extrusion was carried out on aluminum 5083 alloy using a suitable die design to improve the strength and wear properties of the alloy. The main findings and conclusion of this study can be summarized as follows.

The coarse grain structure of the as-cast alloy is replaced with highly refined and homogeneous microstructure after processing by ECAE up to two passes using route B_c. The microhardness of the alloy increased with increase in pass number and attains a maximum value of 151HV after two passes due to the formation of fine grains. The tensile strength of the alloy also increased with increase in pass number but there is some reduction in ductility due to the hardening of the alloy. The wear resistance of the alloy increased after ECAE with minimum amount of mass loss and co-efficient of friction. Thus processing by ECAE has made the alloy to resist the scratch deformation.

It can be concluded that processing by ECAE increased the mechanical and wear properties of aluminum5083 alloy. The improvement in the mechanical and wear properties have made it possible to use the alloy in various engineering applications requiring high strength.

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