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The effect of ECAR on the superplastic behavior of AZ31B magnesium alloy

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ABSTRACT

A fine grain structure of AZ31B magnesium alloy was obtained without surface defects and internal cracks. The ECAR die was modified so that no intermediate annealing is used for restoring the ductility of AZ31B Mg alloy by increasing the die temperature to 200°C using four thermal heaters. The grain size was reduced from 10µm to 4.3µm after six passes also the yield stress was increased from 14MPa to 25MPa while ductility decreases at 350°C.

Keyword: Superplasticity, Magnesium alloy, AZ31B, Severe plastic deformation.

INTRODUCTION

Recently, severe plastic deformation (SPD) techniques have been developed to produced fine-grained microstructure in metals and alloys [1], such as Equal Channel Angular Pressing ECAP, accumulative roll bounding (ARB) and high pressure (HPT) torsion , these techniques is used to impose large strain into the material, However, they are not practical for strip material and sheet, Equal Channel Angular Rolling (ECAR) is a severe plastic deformation process developed by lee et al [2], on the base of ECAP the major difference is the use of feeding rolls instead of plunger to provide the feeding power required, The impotent mater during ECAR is that there are no thickness reduction, which allows multiple passes, also the feeding rolls provide continues operation that is not possible during ECAP, the process is used to produce ultra fine grained (UFG) by imposing large strain into the material [3,4,5]. Microstructure refinement and formation of UFG material result in considerable enhancement in mechanical properties such as yield strength and room temperature ductility, but like other continuous severe plastic deformation techniques are still in an experimental stage [6]. Many researchers have been made to improve the mechanical properties of AZ31B magnesium alloy by using ECAR [7, 8]. However, the effect of ECAR on the mechanical properties at elevated temperature is yet still unknown.

The present study mainly focused on the effect of ECAR on the mechanical properties microstructure evolution of AZ31B magnesium alloy. Tensile test were carried out in order to validate the effect of ECAR on the strength and ductility at elevated temperature.

EXPERIMENTAL WORK

The material used in this study is AZ31B magnesium alloy sheet of 30×20× 2mm dimension with initial grain size of ≈ 10µm, provided from plant of Mg plate product (MgF Magnesium Flachpodukte) Germany. The chemical composition of the alloy is illustrated in table 1 equivalent to AMS 4377 with a H24 temper, which is partially annealed after strain hardening.

Table 1: The chemical composition% of AZ31B magnesium alloy

Element	Al	Zn	Mn	Fe	Cu	Si	Ni	Ca
%	2.67	0.679	0.369	0.00292	<0.001	0.0233	<0.001	<0.001

Equal channel angular Rolling die was made from a block of AISI 5130 alloy tool steel. The die consists of 43 ×2 mm channel clearance intersected at an oblique angle of Φ 115° and Ψ=0°, the die was fitted into a mini roll of 55mm diameter roll as shown in Fig. 1. The die with such geometry can impose strain of 0.74 per each pass[9].

The die was pre-heated to 200° using four heating elements. The temperature of the die were controlled using a K-type thermocouple, a sheet of AZ31B with thickness of 2 mm were cut from the as received plate to a dimension of 30 × 150 mm^2 and pre-heated to 350 C° for five minutes using a resistance furnace (these temperatures were determined after many tests). The gap between the twin rolls were adjusted to 1.9 mm, then the sheet was fed into the gap between the twin roll at speed of 5 cm/sec and entered the channel clearance and the forming zone under friction force, the die channel was lubricated by grease to perform the operation. Sheets with 1pass, 2passes, 3passes, 4 passes, 5passes 6passes were competed.

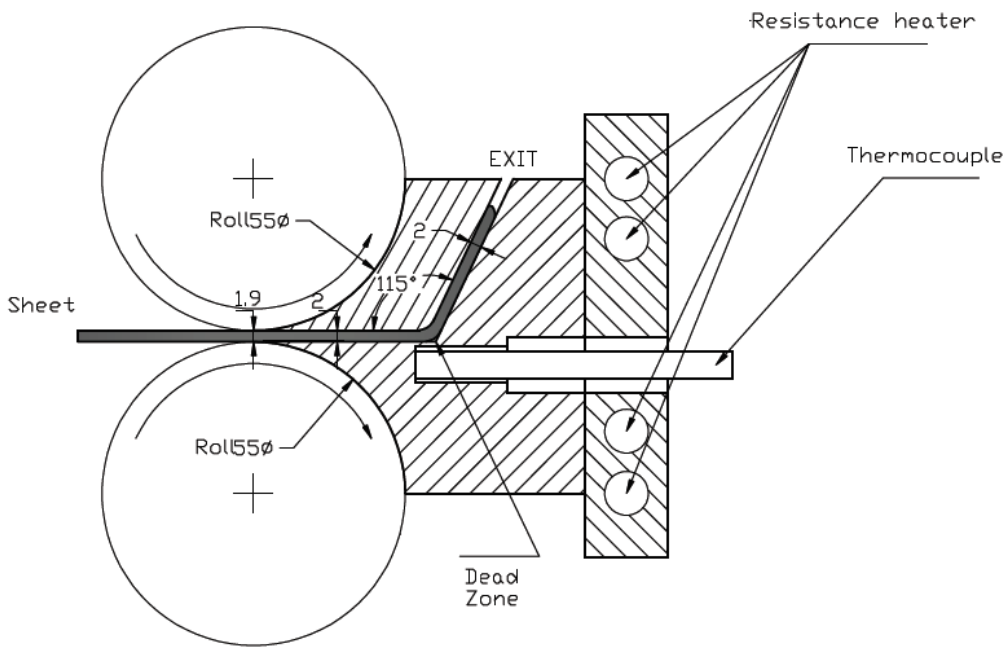


Fig. 1 Schematic illustrates the ECAR die cross section.

Tensile specimens were made from the ECARed samples in the direction parallel to the rolling direction with gauge length of 12mm and gauge section of 6 × 2mm as shown in Fig. 2. Tensile test were conducted at 623K° and strain rate of 7.8 $\times 10^{-4}$ s^{-1}.

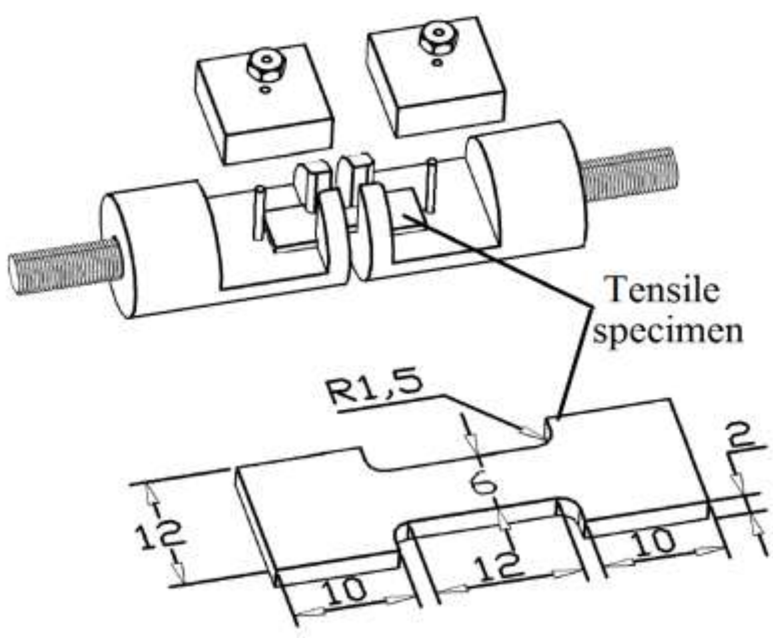


Fig. 2 Tensile specimens used in the superplastic evaluation (dimension mm).

Microstructure examination was carried out using optical microscopy after cutting the samples from the ECARed sheet for different passes in parallel section of Y-plane (ND)-(RD) plane as shown in Fig.3, the samples were mounted using epoxy resin mixed with epoxy hardener. Six steps included five grinding steps: 120, 230, 500, 1000 and 2000 grid SiC paper, then polishing, 3 µm MD-Chem cloth with Al_2O_3 powder based solution, were utilized to obtain scratch-free surfaces with high reflectivity. Samples were etched in 4.2 g picric acid + 10 ml acetic acid + 10 ml H_2O + 70 ml ethanol (95%) solution. The average grain size was measured using linear intercept method [10].

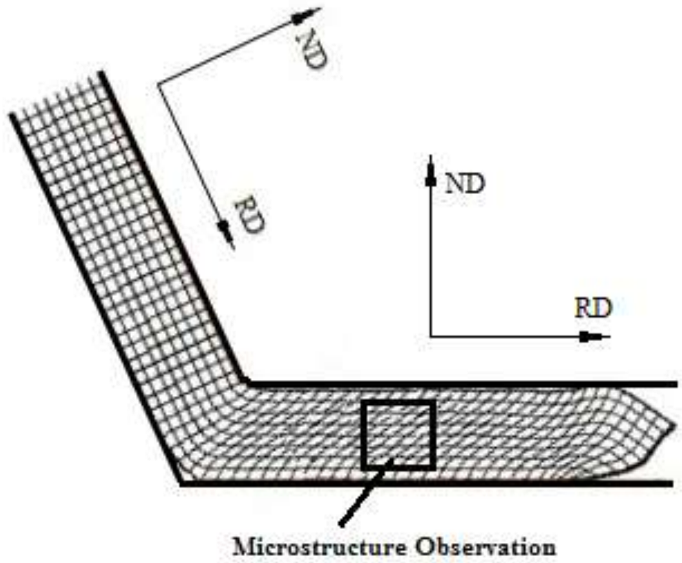


Fig. 3 alignment of the microstructure samples with the rolling direction and the normal direction

Scanning electron microscope images were taken by VEGA\\TESCAN Electron Microscope equipped with One - Touch ED X analysis toolbox One - Touch ED X analysis toolbox that is fully integrated in the EasySEM™ touch screen interface images were taken from the fracture surface of the tensile specimens made from the as received material, For the tensile fracture surface observation. X-ray diffraction analyses were examined for the as received and ECARed samples to analyze the crystal structure orientation and residual stresses the analyses are made by Shimadzu 6000, 2θ ranges from 30° to 40° with a scanning speed of 12 degrees per minute and using Cu target.

RESULTS AND DISCUSSION

MICROSTRUCTURE OBSERVATION

Microstructure observation for the as received and ECARed material is presented in Fig.3. the initial condition of the AZ31B magnesium alloy sheet consists of heterogeneous grains with grain size varies from 3-30µm and the measured average grain size for this condition is 9.7µm. ECAR process at 623 °K shows slight effect to the grain size between subsequent passes and the microstructure continue to decreases with heterogeneous grains as shown in the figure. After six passes of ECAR at the same temperature more equiaxed shape of grains were achieved and the measured average grain size was 4.3µm. the average grain size of the as received and ECARed material is summarized in table 2.

Table 2 Summary of the grain size after and before ECAR at 623°K

Number of ECAR passes	0	1	2	3	4	5	6
Grain size µm	≈10	8.88	7.2	6	5.5	5	4.3

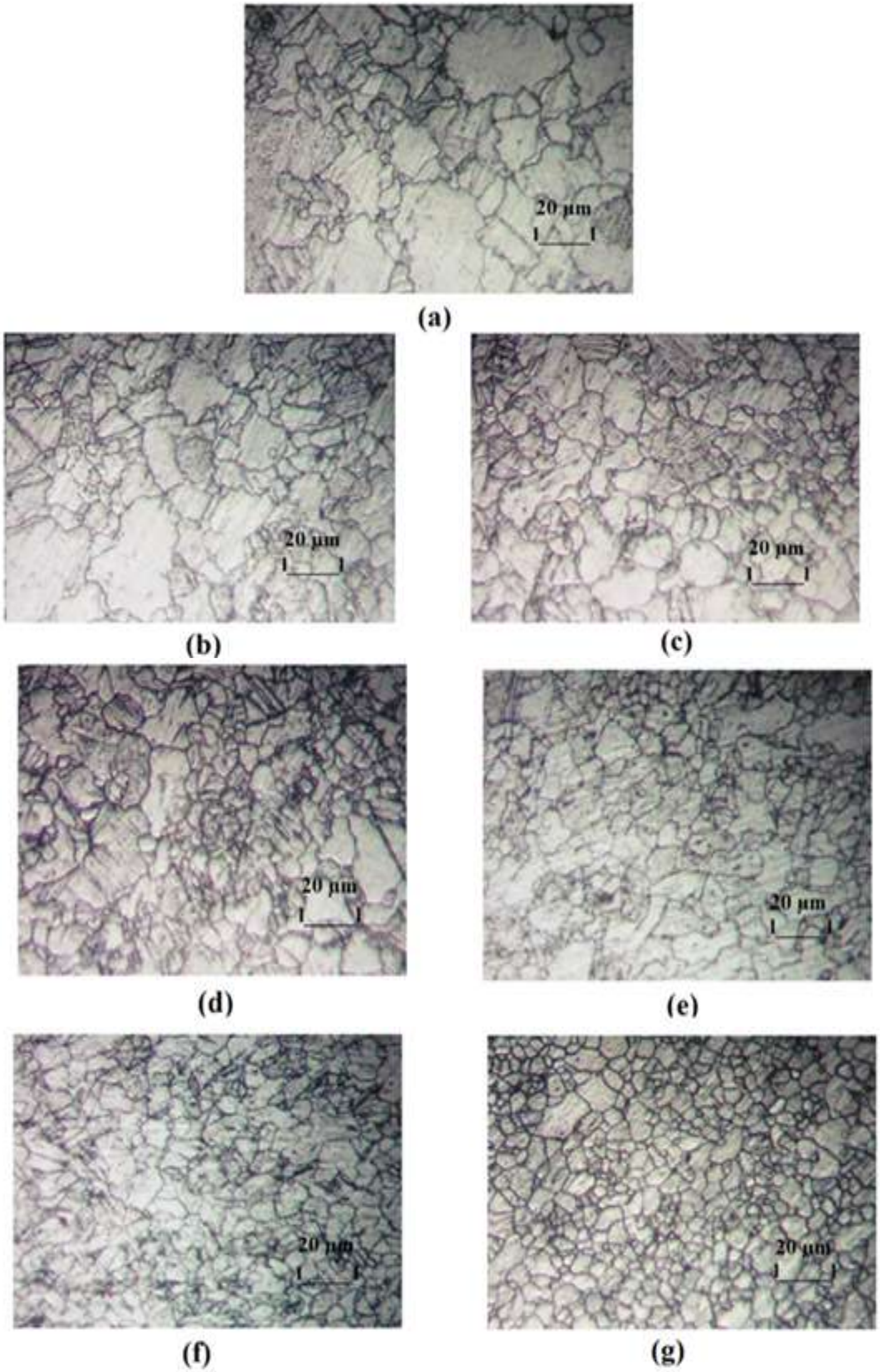


Fig. 3 micro structure observation after ECAR (a) as received (b) 1 pass ECAR, (c) 2 passes ECAR, (d) 3 passes ECAR, (e) 4 passes ECAR, (f) 5 passes ECAR, (g) 6 passes ECAR.

Tensile testing of the ECARed material

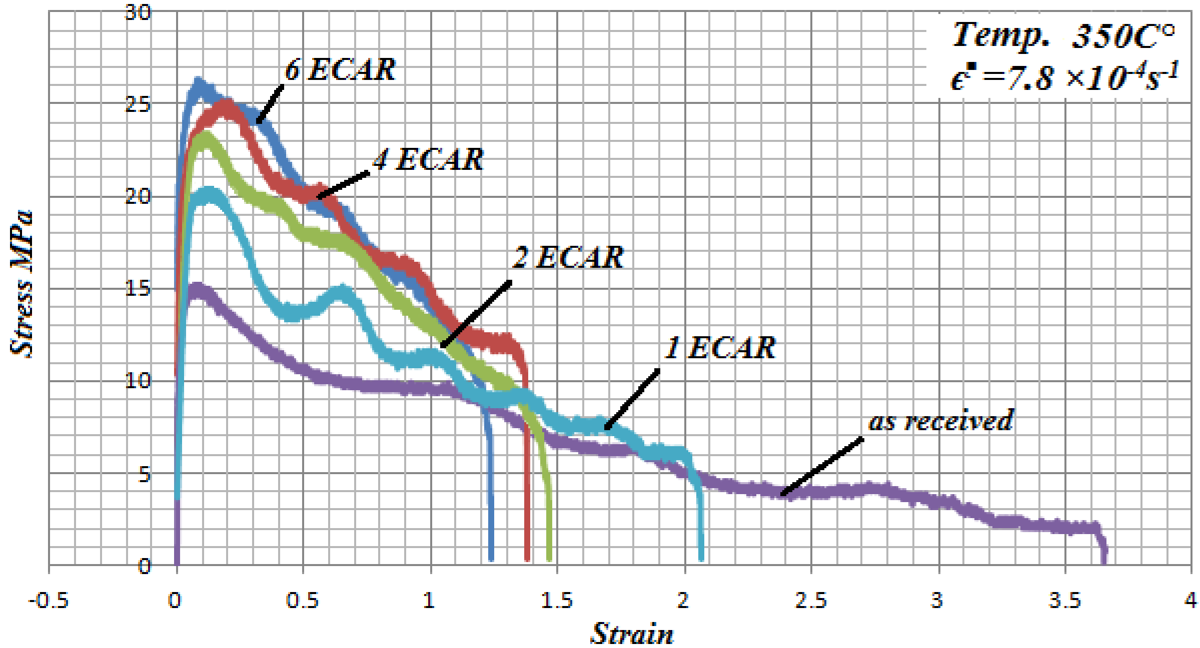


Fig.4 stress strain curves for the as received material and ECARed material.

Stress and strain relationship of the as-received and ECARed samples were obtained by tensile testing at 350C°. Stress-strain diagrams of as received sample and ECARed samples are given in Fig.4. It can be roughly seen that the as-received sample shows a more ductile behavior when compared with ECAR processed samples and the strength of the samples were observed to be increased with ECAR process.

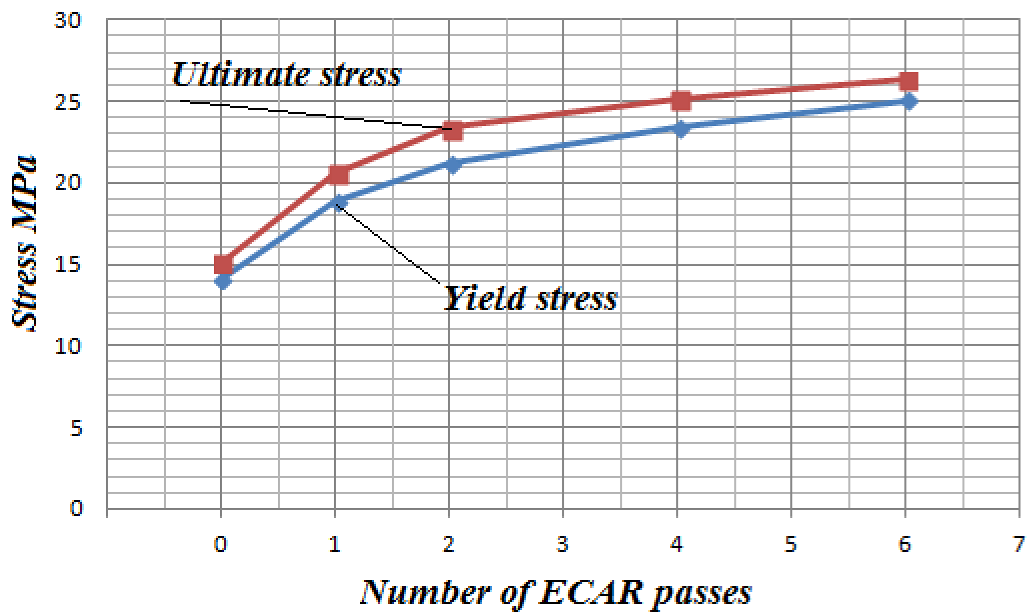


Fig.5 Yield and ultimate tensile stress as a function of number of ECAR passes at 350C°.

Yield strength was increased from 14.1 MPa to 18.86 MPa for the as-received and 1 pass ECAR respectively, yield strength increased to 21.23 MPa after the second ECAR as for the Fourth and Sixth passes the yield stress is 23.36 MPa and 25.04 Mpa respectively, ultimate tensile stress shows similar behavior to the yield stress as shown in Fig.5 that shows the relationship between Number of ECAR passes for yield and ultimate strength, the reason for this behavior is caused by the grain refinement due to ECAR process and increase in the dislocation density due to the shear imposes to the material. The experiments shows that ductility decreased with increasing the plastic deformation by ECAR as it can be seen in Fig.4 and the resultant ductility are plotted in Fig.6 as function of the number of ECAR passes. The values of the tensile yield stress (YS), the ultimate tensile stress (UTS), elongation to failure and grain size are summarized in Table 3.

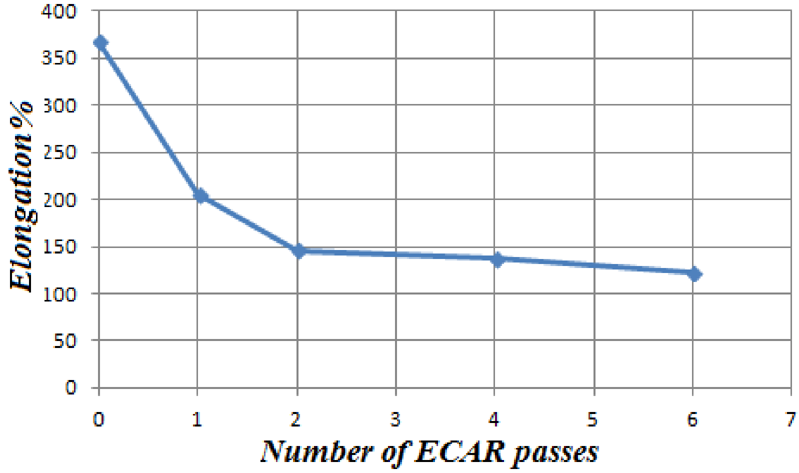


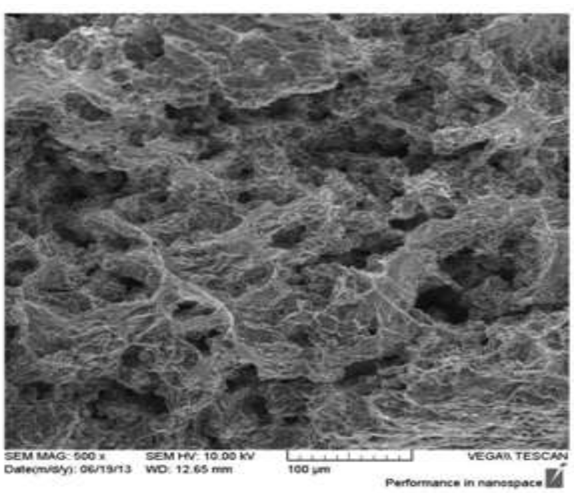
Fig.6 Elongation as a function of number of ECAR passes at 350C°.

Table 3: Grain size and tensile properties at 350C° of the as received and ECARed samples.

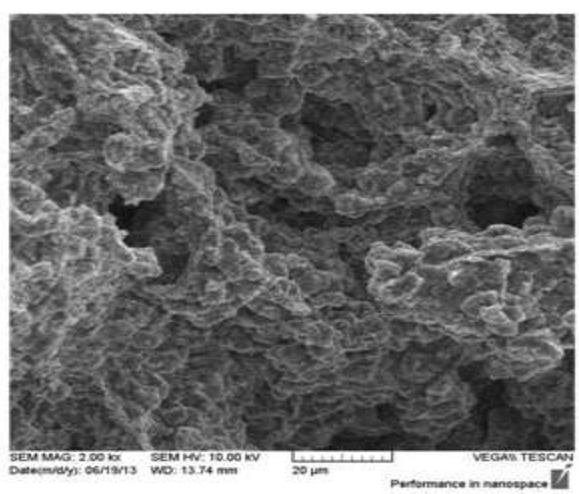
ECAR passes	Yield Stress MPa	Ultimate Stress MPa	Elongation %	Grain size µm
As received	14.1	15.13	367	≈10
1 ECAR	18.86	20.58	206	8.88
2 ECAR	21.23	23.38	146	7.2
4 ECAR	23.36	25.18	138	5.5
6 ECAR	25.04	26.33	123	4.3

Fracture surface observation for ECAR samples

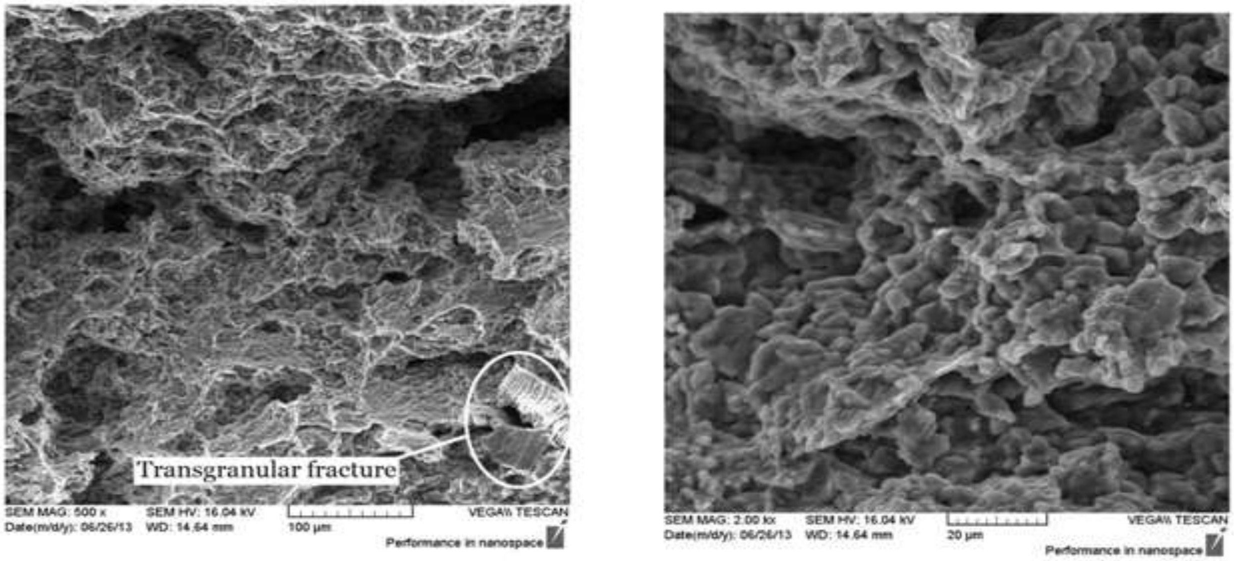
Fracture surface of the tensile specimen made from 6 ECAR passes are presented in Fig.7 the first row represent fracture surface of tensile specimens exhibit superplastic properties , the second row represent the fracture surface of tensile specimen after 6 ECAR passes it is clearly seen from the images that several changes have been attributed to ECAR process , the volume fracture of tearing edges have been increased, size and number microcavities have been decreased, also transgranular fracture is quite clear compared to images in Fig.7 a and b. Generally after six passes of ECAR the grain size has significantly decreases from 10µm to 4.3µm. meanwhile the fracture elongation has dropped from 367% to 123% due to changes in the texture produces by ECAR, considering that the microcavities formation has deactivated which interns decreases the grain sliding during the tensile test.



(a)



(b)



(c) (d)

Fig.7 SEM fracture surface images of tensile specimen after pulled to fracture at 350C° (a), (b) specimens exhibit superplastic behavior (c) ,(d) specimen of 6 ECAR passes.

CONCLUSIONS

1. Experiments were conducted using a commercial wrought AZ31B magnesium alloy the as received magnesium alloys were ECARed up to 6 passes at 350C°. The microstructure shows slight effect in grain refinment between subsequent passes and the grains were refined from 9.7µm to 4.3µm after 6 passes.

2. The mechanical properties of ECAPed specimen were examined using hot tensile test at 350C°the experiments shows that with increasing the number of passes the yield and ultimate strength increased while the elongation decreases from 367% to 123% proportional with increasing the number of ECAR passes.

3. ECAR successfully enhance AZ31B magnesium alloy yield strength so better strength can be achieved at 350C°. The yield strength was increased from 14.1MPa for the as received material to 25MPa after six passes ECAR also the ductility was decreased by changing the deformation mechanism.

4. SEM images of the tensile fracture surface shows that microcavities formation has deactivated after 6 passes ECAR which interns decrease the grain sliding during the tensile test.

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