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# Superplastic behavior of AZ31B Magnesium alloy at elevated temperature

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## ABSTRACT

**Superplastic behavior of the AZ31B magnesium alloy was evaluated at temperatures 623K° and strain rate ranging from $7.8\times10^{-4} \sim 1\times10^{-2}s^{-1}$. The test showed that maximum elongation of 367% can be achieved at 623K° and strain rate of $7.8\times10^{-4}s^{-1}$, the strain rate sensitivity (m) was evaluated by two different methods; Uniaxial tensile test on the basis of the true stress true strain curve and by method of strain-rate jump test. The results show small differences between the two methods (m=0.42-0.45), which demonstrate that the Grain Boundary Sliding (GBS) is the dominant deformation mechanism during superplastic test.**

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

## INTRODUCTION

Magnesium alloys are the lightest structural material for aerospace, automotive and electronics applications owing to their low density and high strength-to weight ratio, it offers a great potential for weight reduction by replacing steel and aluminum, However, the HCP structure of magnesium have poor formability and limited ductility at room temperature, the use of magnesium alloy in structural applications will be highly useful if the formability improved. Superplastuc forming of magnesium alloys increases its formability and produce components with complex shapes for automotive application [1, 2]. Superplasticity is the ability of polycrystalline to undergo uniformly extreme elongation in tension without the development of necking in certain fine grained metal alloy systems at a proper temperature and at controlled strain rate [3,4]. For superplastic application the material must have a fine grained microstructure (grain size less than 10μm) of equiaxed structure with the formation of large number of high angle boundaries [5,6]. Equal Channel Angular Pressing (ECAP)[7,8] or hot rolling[9,10] have been used to obtain these properties. The present study aim to focus on the superplasticity of AZ31B magnesium using uniaxial tensile test also determine the strain sensitivity coefficient.

## EXPERIMENTAL WORK AND PROCEDURES

The material used in this study is AZ31B magnesium alloy sheet of 30×20× 2mm dimension with initial grain size of ≈ 10μm, provided from TU Bergakademie Freiberg University. 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 |

Tensile specimens was made from the as received material in the direction parallel to the rolling direction with gauge length of 12mm and gauge section of 6 × 2mm as shown in Fig. 1. Tensile test were conducted at 623K° using WDW-200EIII mechanical testing system with computer control software equipped with environmental chamber. The strain rates used in the experiments varies from $7.8\times10^{-4}\ s^{-1}$ to $1\times10^{-2}\ s^{-1}$ to evaluate the potential of the alloy superplasticity.

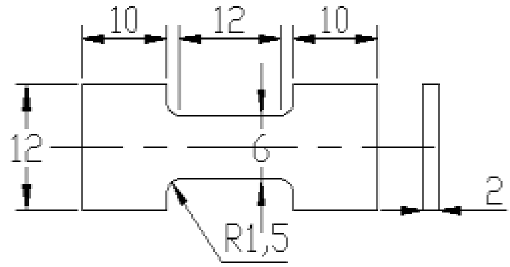



**Fig. 1: tensile specimes used in the superplastic evaluation.**

The fracure surface of tinsile specimens were studied by Scanning Electron Microscope (SEM) using VEGA\\TESCAN Electron Microscope.

## RESULTS AND DISCUSSION

**True stress true strain curve at 623°K**

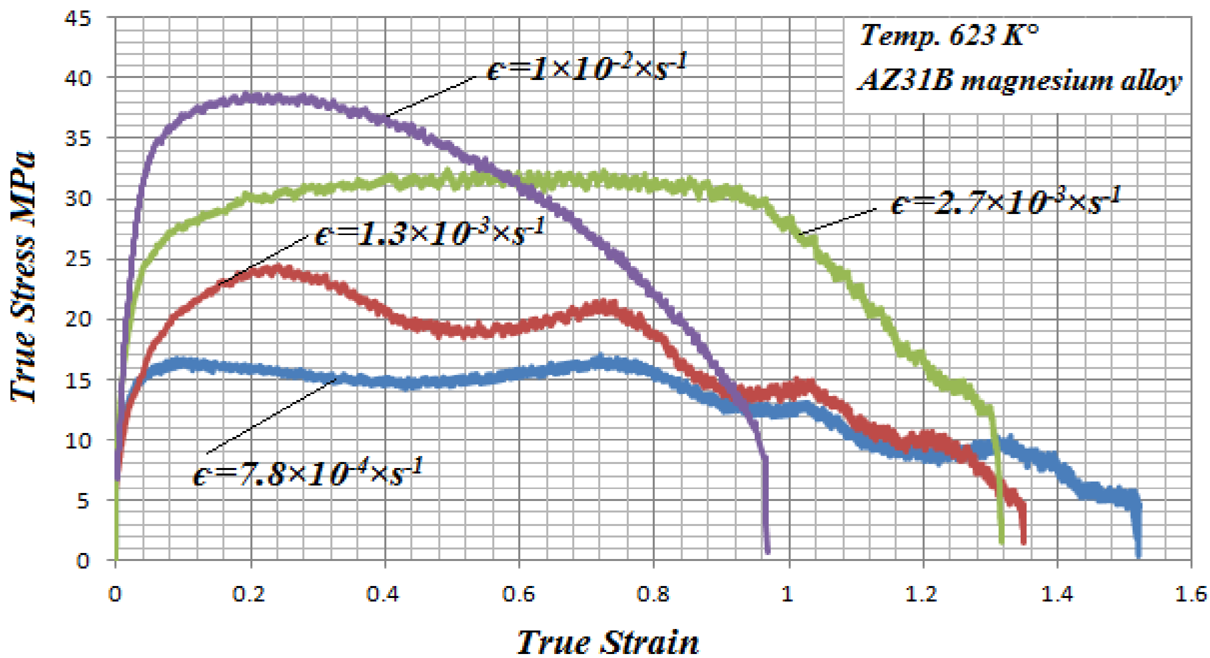



**Fig. 2: True stress versus true strain curves for different strain rates at 623° K for AZ31B Mg alloy.**

The uniaxial tensile curves obtained at strain rate vary from $7.8\times10^{-4}$ $s^{-1}$ to $1\times10^{-2}$ $s^{-1}$ and temperature of 623 K° is shown in Fig.2. It is seen from the figure that the flow stress follows different patterns with different strain rate, for the specimen conducted at strain rate of $1\times10^{-2}$ $s^{-1}$ the flow stress decreases rapidly after reaching a peak value followed by fracture, the specimen conducted at strain rate of $2.7\times10^{-3}$ $s^{-1}$ exhibit stable flow stress after reaching a peak value then decreases rapidly followed by fracture, as for $1.3\times10^{-3}$ $s^{-1}$ and $7.8\times10^{-4}$ $s^{-1}$ the alloy exhibit subsequent softening after strain hardening caused by large amount of strain as the specimen elongated during the test as shown in Fig.2. It is demonstrated that the elongation of the AZ31B magnesium alloy increases progressively with decreasing strain rate.

The elongation increases from 166% to 267% as the strain rate decreases from $1\times10^{-2}$ $s^{-1}$ to $2.7\times10^{-3}$ $s^{-1}$ whereas the flow stress decreases significantly this shows that AZ31B exhibit superplasticity at temperature of 623 K° and maximum elongation of 367% were achieved at strain rate of $7.8\times10^{-4}$ $s^{-1}$. In general the flow stress decreases while the elongation increases significantly with decreasing strain rate during the test. Tensile specimens after pulled to fracture for the experiments in Fig2 is shown in Fig.3 the upper specimen is untested the lowest specimen tested to an elongation (δ) of 367% at strain rate of $7.8\times10^{-4}$ $s^{-1}$, it can seen from the figure specimens exhibit a uniform deformation within the gage length without or with little necking within the gauge lengths that confirms the occurrence of true superplasticity at these lower strain rates [11]. But some necking is visible at the high strain rate of $1\times10^{-2}$ $s^{-1}$.

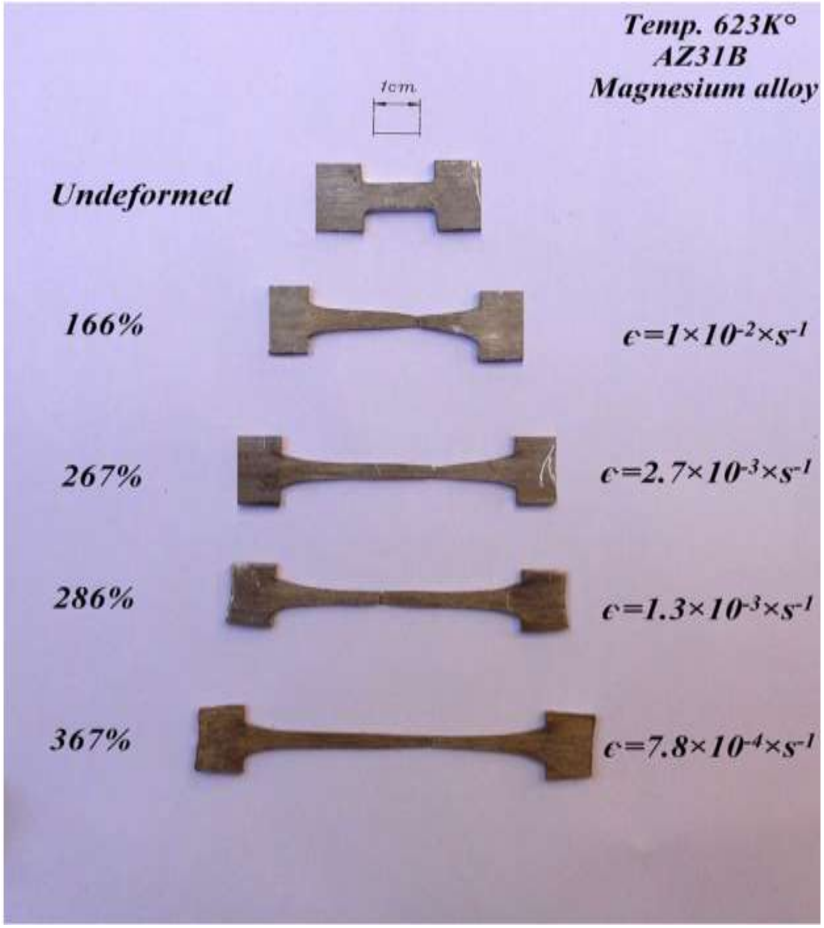



**Fig. 3 fractured specimens after pulled to failure at 623°K with various strain rates.**

A full summary of all of the tensile elongations is given in Fig. 4 where the results are plotted against the testing strain rate. The figure shows variations in elongation above and below the trend curve, it is reported by researches that highly different elongation data has been frequently observed among the same superplastic condition [12] which can explain this behavior.

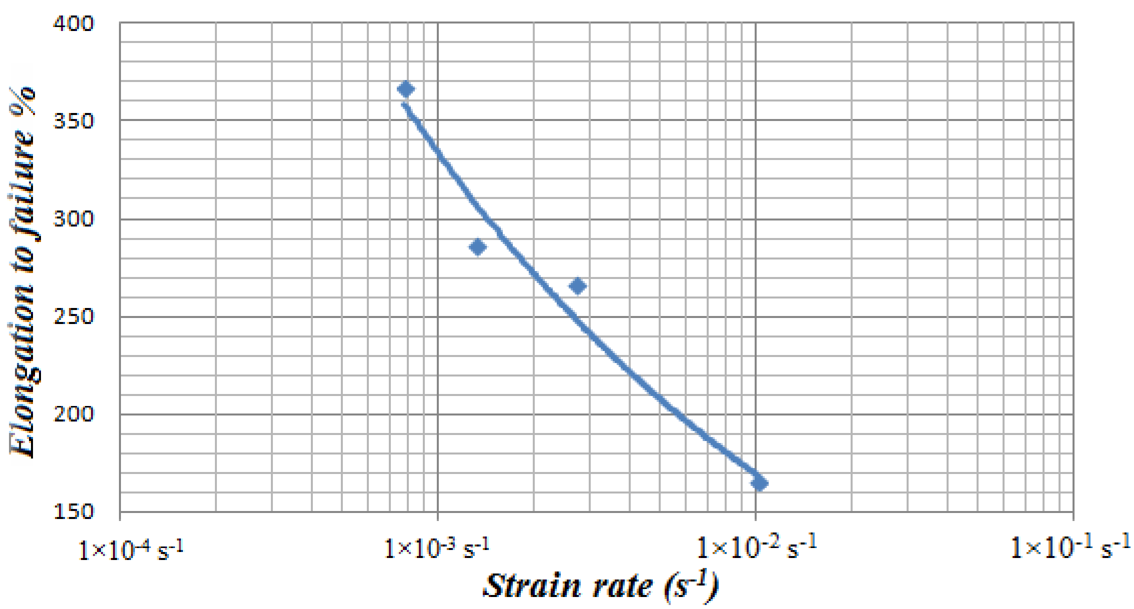



**Fig. 4 A semi log diagram for the trend of tensile elongation as a function of test strain rate for AZ31B magnesium alloy.**

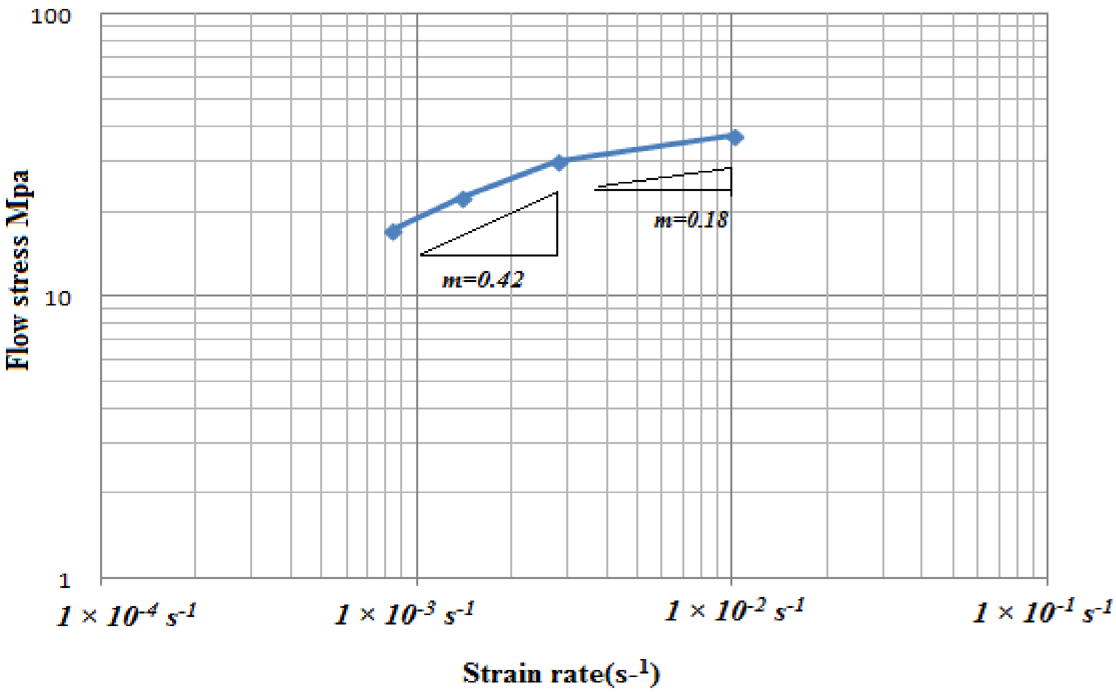



**Fig. 5 Double logarithmic scale of Flow stress-strain rate relationship at 0.1 strain rate and 623°**K.

Fig.5 shows logarithmic relation between flow stress and strain rate at true strain of 0.1 and superplastic temperature of 623°K, the figure shows a sigmoidal relation between flow stress and strain rate, which is the point where the highest slope can be found is called the inflection point of the curve, and the flow stress increases with increasing strain rate, m value is the slope of the flow curves (where m is the strain rate sensitivity $m=\partial Ln\sigma / \partial Ln\dot{\epsilon}$ , σ is the flow stress and $\dot{\epsilon}$ is the strain rate) the maximum strain rate sensitivity exponent m reaches 0.42 at 623°K and strain rate ranges from $7.8\times10^{-4}s^{-1}$ ~ $2.7\times10^{-3}s^{-1}$.

Further investigation to the value of m in the strain rate ranges between $7.8\times10^{-4}\,s^{-1}$ and $2.7\times10^{-3}\,s^{-1}$ was examined by using strain rate jump test method as shown in Fig.6. Strain rate sensitivity value was calculated as 0.45.This value was very close to m value obtained from true stress, true strain basis method, demonstrating the dominant mechanism of superplastic deformation is grain boundary sliding (GBS)[13].

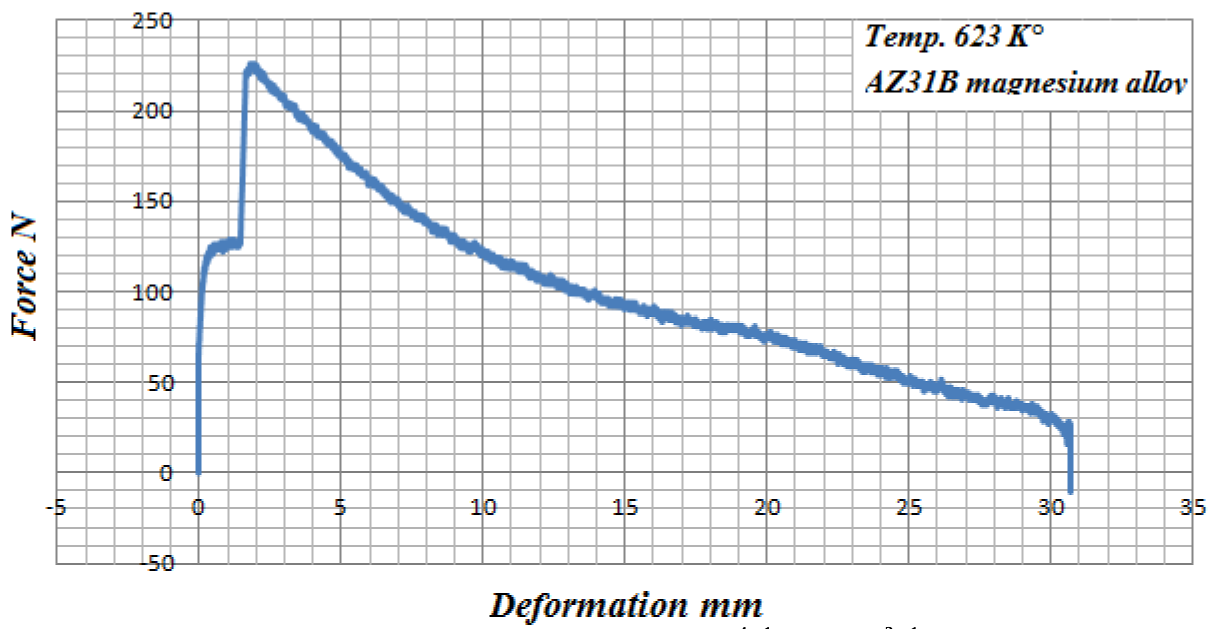
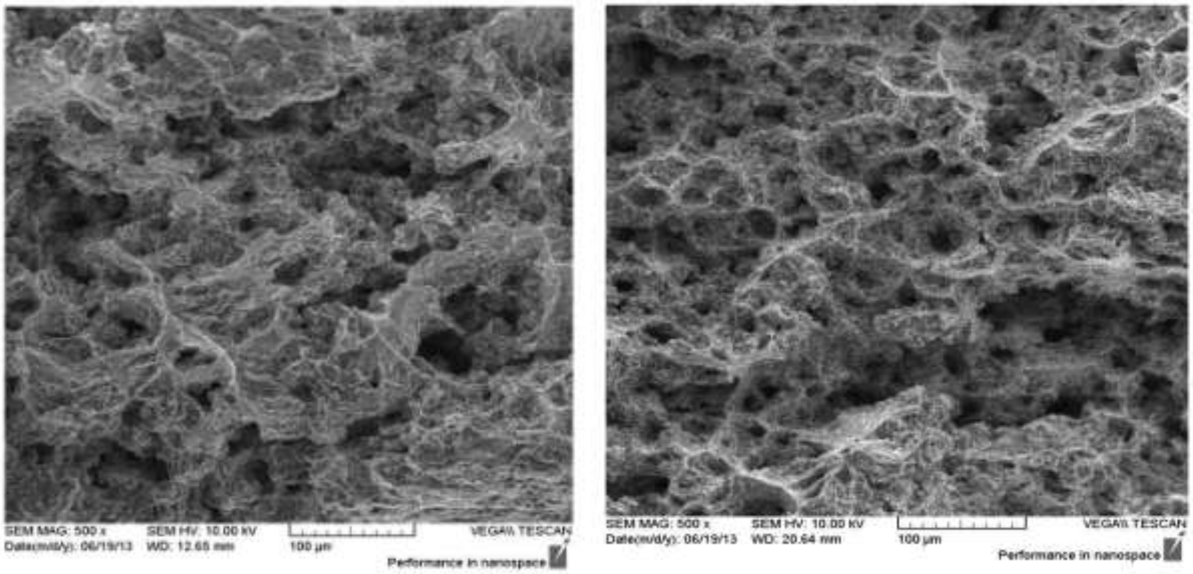



**Fig. 6 Strain rate jumped from $7.8\times10^{-4}s^{-1}$ ~ $2.7\times10^{-3}s^{-1}$**

**Fracture surface observation**

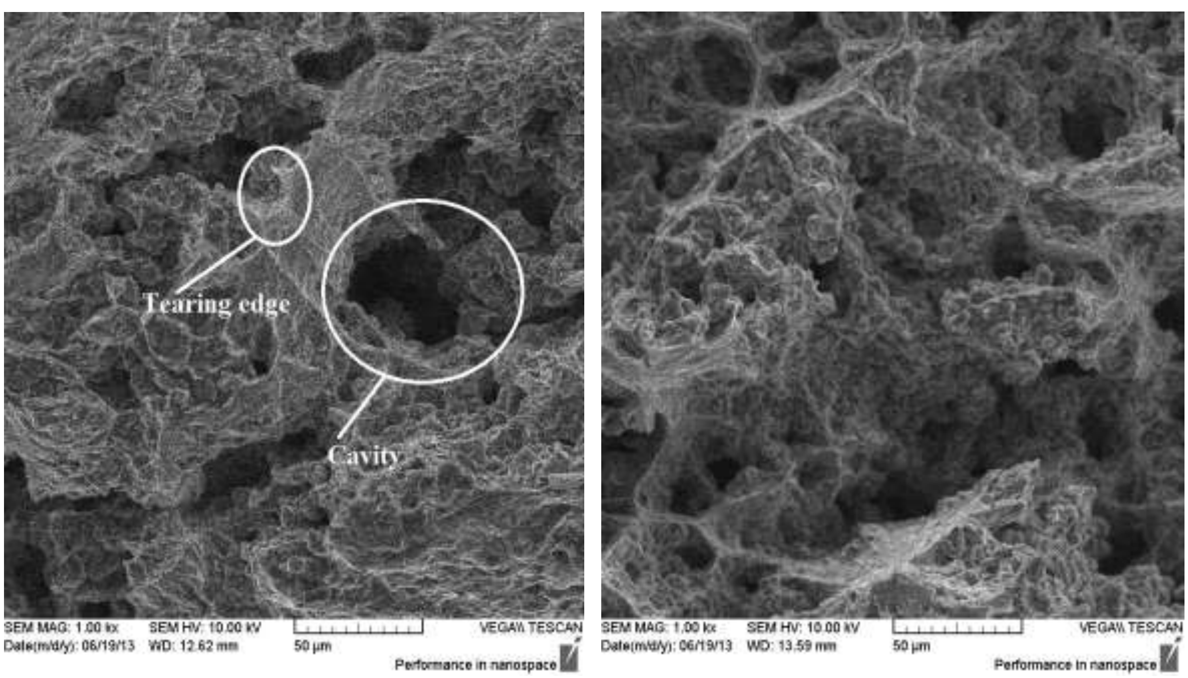
The tensile fracture furnace of AZ31B magnesium alloy sheet at 623 K° is presented in Fig.7. it can be seen clearly that the image contains lots of microcavities distributed in the fracture surface along with recrystallized grains, the microvcavities are surrounded by tearing edges as it interlace with each other and form cavities microstructure as seen in Fig.7(a) and (b).




(a) (b)

**Fig. 7 SEM image of the tensile fracture surface of specimens conducted at 623 K° and strain rate of (a) $\dot{\epsilon} = 1.3\times10^{-3}s^{-1}$ (b) $\dot{\epsilon} = 2.7\times10^{-3}s^{-1}$**

The microstructure of specimens conducted at lower strain rate is contains much bigger and deeper cavities as shown in Fig.8 (a) , where a cavity of about 40µm has been found, this means that the cavities were formed at an early stage of the tensile test and it is increased with decreasing testing strain rate.




(a) (b)

**Fig. 8 SEM images showing the microcavities of the tensile specimens conducted at 623 K° and strain rate of (a) $\dot{\epsilon} = 1.3\times10^{-3}s^{-1}$ (b) $\dot{\epsilon} = 2.7\times10^{-3}s^{-1}$**

The main feature of the fracture mechanism is Intergranular cracking along grain boundaries and without the appearance of Transgranular fracture which explains the high ductility of tensile test, some recrystallized grains is also found as shown in Fig.9. Microcavites formation during tensile test gives direct evidence that the main deformation mechanism is grain boundary sliding (GBS).

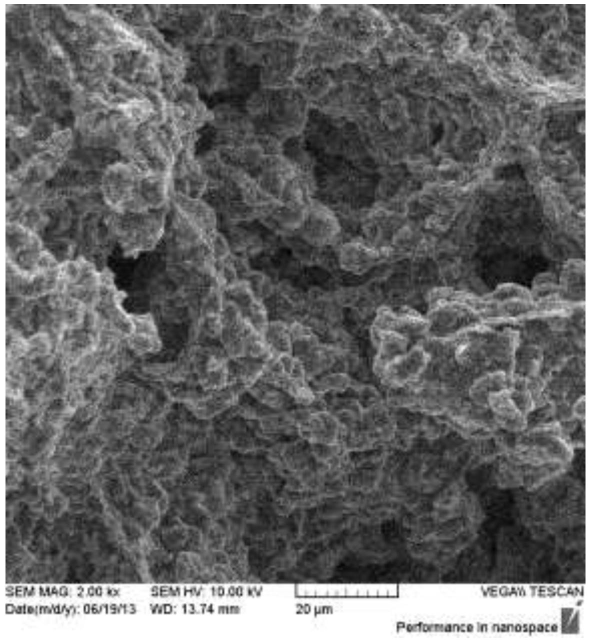



**Fig.9 SEM image of the fracture surface showing the recrystallized grains along with microcavities**

## CONCLUSIONS

1. Maximum elongation (δ) of 367% was achieved at 623K° and strain rate of $7.8\times10^{-4}s^{-1}$.
2. The strain rate sensitivity was evaluated using two different methods, uniaxial tensile test on the basis of the true stress true strain curve and by method of strain-rate jump test, the result shows small different between the two methods m=0.42~0.45 respectively, indicating that the dominant mechanism in superplastic deformation of AZ31B is grain boundary sliding (GBS).
3. Microcavities formation was observed during the superplastic deformation that gives another evidence for (GBS).

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