Transient Creep Characteristics Near the Transformation Temperatures of Al-5wt%Zn and Al-15wt%Zn Alloys

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Al-Zn alloys are stronger than most aluminum based alloys. They provide materials which combine the high wear resistance, heat resistance and strength with the castability needed for many industrial applications. Constant-stress creep tests were conducted for Al-5wt%Zn and Al-15wt%Zn alloys under various stresses ranging from 114.6 to 129.8 MPa for Al-5wt%Zn alloy and from 129.8 to 150 MPa for the second alloy. The transient creep parameters n and β were determined for each alloy in the temperature range around their transformation temperatures. The results for both alloys revealed two different transient deformation regions around their transition points which existed at 393 and 473 K for the two alloys, respectively. The temperature dependence for each of the transient creep parameters n and β attained peak values at the transition points for all the applied stresses. The transient creep was activated with (31.5 ± 0.5) and (29.9 ± 0.4) kJ/mol in the low deformation regions for the two alloys of 5wt%Zn and 15wt%Zn, respectively. These values characterize a dislocation mechanism involving grain sliding or grain migration. The best fitting equation, obtained by the least squares method of the relation between the steady state creep strain rate $\dot{\varepsilon}_{st}$ *and the transient creep parameter β, was used to correlate the transient and steady state creep stages for each alloy.*

1. Introduction:

The ideal creep curve consists of three distinct stages [1], which are the transient, the steady state and the fracture stages, respectively. The transient creep stage is characterized by the gradual reduction of deformation rate. The effect of dissolution of β- phase on the transient creep characteristics of Al-14wt%Zn alloy has been studied [2]. The energy activating the transient creep characterized a dislocation mechanism. The transient creep parameters of a pre-deformed Al-Zn alloy were determined in the temperature range from 503 to 623 K under different applied stresses [3]. Morris and Martin [4,5] studied the creep behaviour in an Al-Zn alloy. They found the evolution of structure occurs during the creep test. Work- hardening parameters of some Al- based alloys were examined [6]. The value of the activation energy was used in determining the fracture mechanism.

Al-Zn alloys combine the high wear resistance, heat resistance and strength with the castability demanded for many industrial applications. Many publications appeared in literature containing the industrial importance of these alloys. The mechanical properties such as Vickers hardness, fracture elongation and the ultimate tensile strength of some Al-Zn alloys were investigated by Saves and Altintas [7]. They found that the alloy which provided the highest mechanical properties is the most suitable one for the squeeze- casting technique. Some experimental studies on Al-Zn alloy coatings have been carried out [8]. These studies demonstrated the suitability of some Al-Zn alloys for anticorrosion applications. The coatings were characterized with bond strength and deposition efficiency tests. Some properties of pure aluminum and Al-5wt%Zn based alloys were investigated [9]. This investigation indicated that one of the examined alloys can be used as a mould for a sacrificial anode for the cathodic protection of steel structure in seawater. The microstructure properties of some Al-Zn alloys were examined [10]. Some experimental conditions have been used to improve the wear and corrosion resistance of these alloys for applications in bearings.

The broad field of industrial application for Al-Zn alloys attracted our attention to add some information to the steady state creep and creep recovery of Al-5wt%Zn and Al-15wt%Zn alloys in the previous investigation [11]. This work is also dedicated to add more information by studying the transient creep characteristics of the same two alloys, each in a temperature region around its transition point. A least squares method computer program is used to get the best fitting equations for the experimental results and to correlate between some parameters.

2. Experimental Techniques:

Pure Al and Zn (99.99%) were used in producing samples of Al-5wt%Zn and Al-15wt%Zn alloys by vacuum melting. The ingots were rolled into wire samples with 0.7 mm diameter and 50 mm in length. After annealing for 2 h at 523 K for Al-5wt%Zn alloy and at 623 K for Al-15wt%Zn alloy they were quenched in water at room temperature (300 K). After these quenching processes, the samples of both alloys were considered to be in the solid solution phase (i.e. supersaturated) [11]. Tensile creep tests were then made at temperatures ranging from 363 to 423 K for Al-5wt%Zn alloy, and from 443 to503 K for Al-15wt%Zn alloy.

The strain of the transient creep, ε_{tr}, can be represented by the relation [12, 13]

$$\varepsilon_{tr} = \beta t^{n} \quad (1)$$

where, t is the transient creep time and β and n are constants depending on the test conditions.

In the previous work on Al-Zn alloys [14, 15] a marked dependence of β on the steady state strain rate, $\varepsilon^{\bullet}_{st}$, was observed. This dependence was expressed as,

$$\beta = \beta_o(\varepsilon^{\bullet}_{st})^{\gamma} \quad (2)$$

where γ is the steady state strain rate exponent and β_o is a constant.
The exponent γ is therfore expressed as

$$\gamma = \partial \ln \beta / \partial \ln \varepsilon^{\bullet}_{st} \quad (3)$$

3. Results:

In the present investigation, the transient creep of Al-5wt%Zn and Al-15wt%Zn alloys is measured under constant stress values of 114.6, 122.2 and 129.8 MPa for the first alloy and 129.8, 140 and 150 MPa for the second alloy. Isothermal measurements are carried out in steps of 10 K at temperatures ranging from 363 to 423 K and from 443 to 503 K for the two alloys, respectively.

A gradual shift is observed in the relation between $\ln\varepsilon_{tr}$ and lnt shown in Figs.1, 2 with irregularity in the temperature ranges (383-403 K) for the first alloy and (463-483 K) for the second alloy. The relation between $\ln\varepsilon_{tr}$ and lnt is fitted using a least squares method computer program and shows a linear form for each testing temperature with a strong positive correlation coefficient (>0.99) (Fig.1, 2). The transient creep parameters n and β are calculated from the slopes and the intercepts at lnt=0 for these straight lines, respectively.

The transient creep time exponent n has values ranging from 0.68 to 0.83 for the alloy of 5wt%Zn and from 0.57 to 0.73 for the second alloy. The dependence of n on the testing temperature for the two alloys is illustrated in Fig. (3).

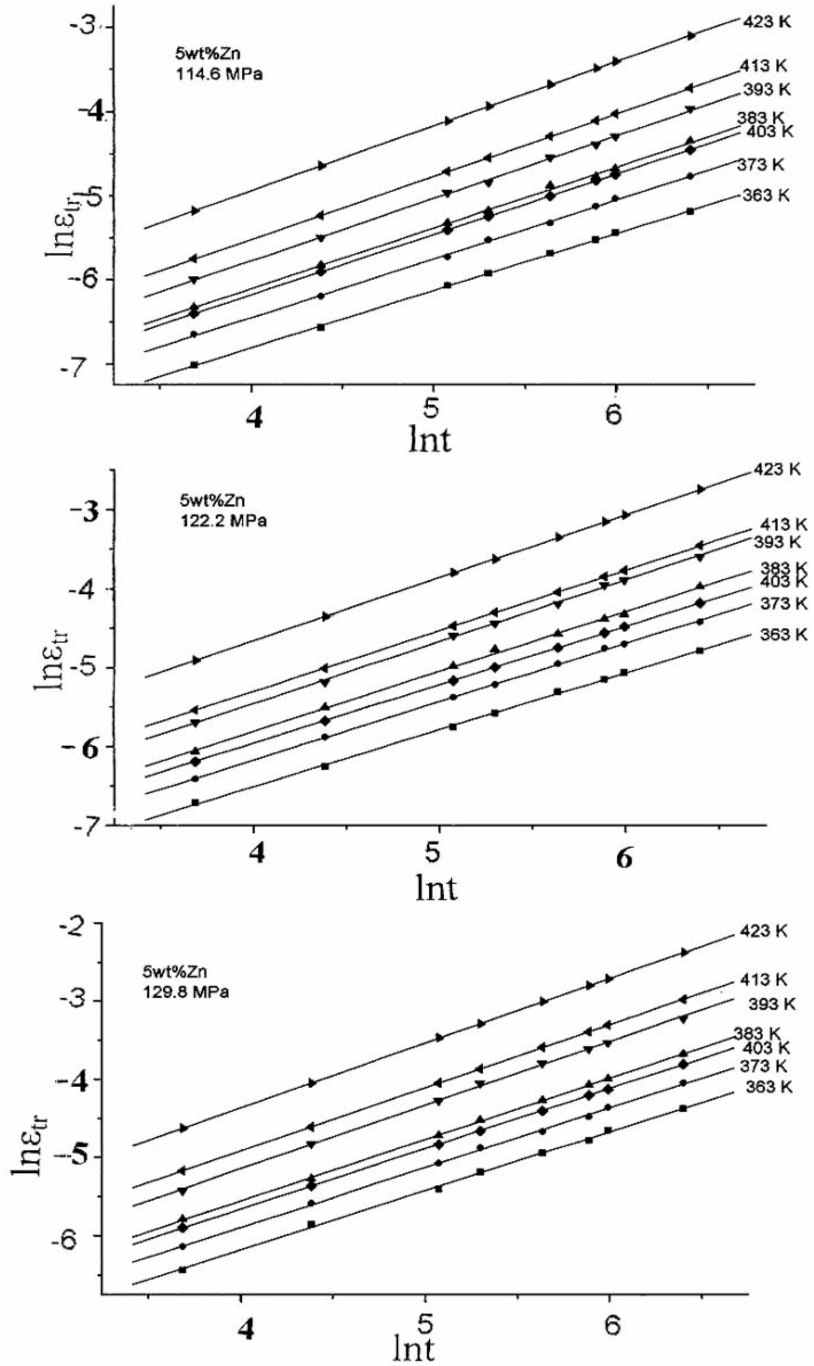

Fig. (1): The best straight lines obtained from the least squares fitting of the relation between $\ln\varepsilon_{tr}$ and lnt for Al-5wt%Zn alloy

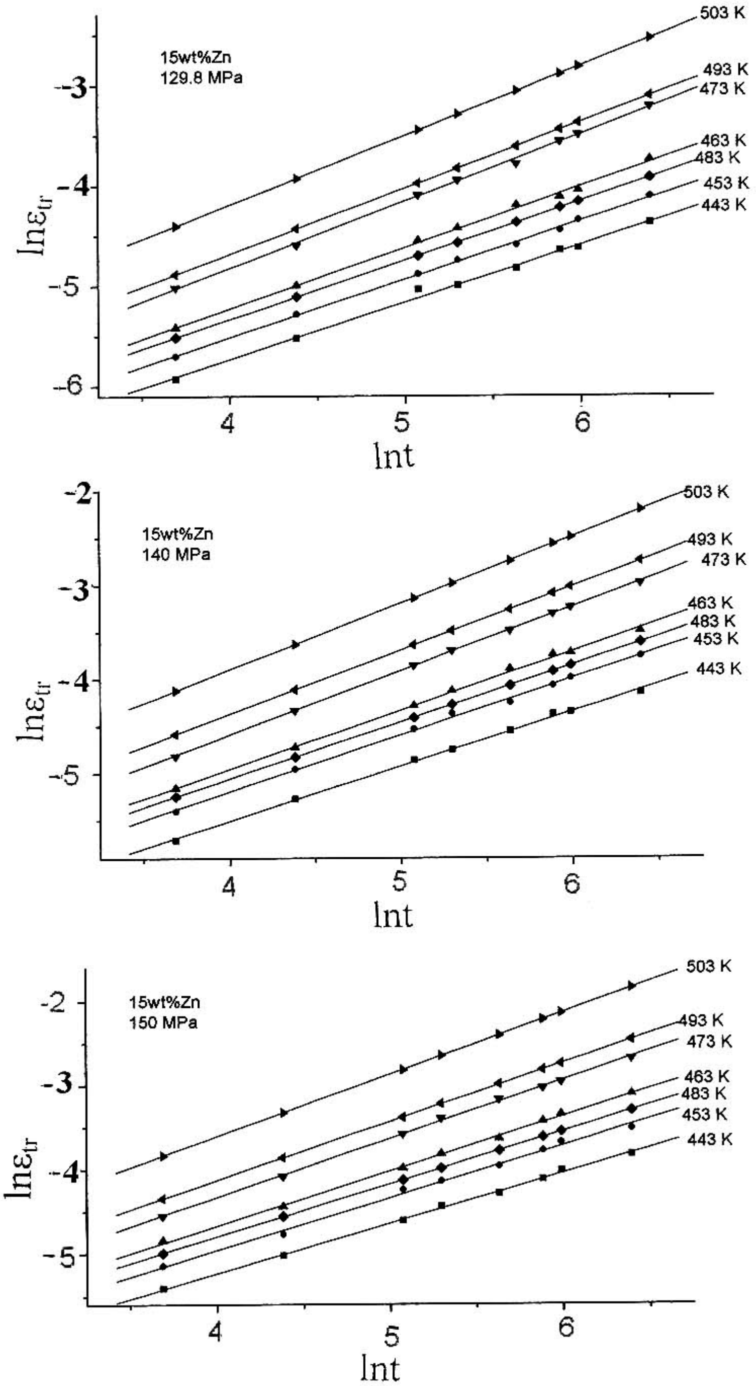

Fig.(2): The best straight lines obtained from the least squares fitting of the relation between $\ln\varepsilon_{tr}$ and lnt for Al-15wt%Zn alloy.

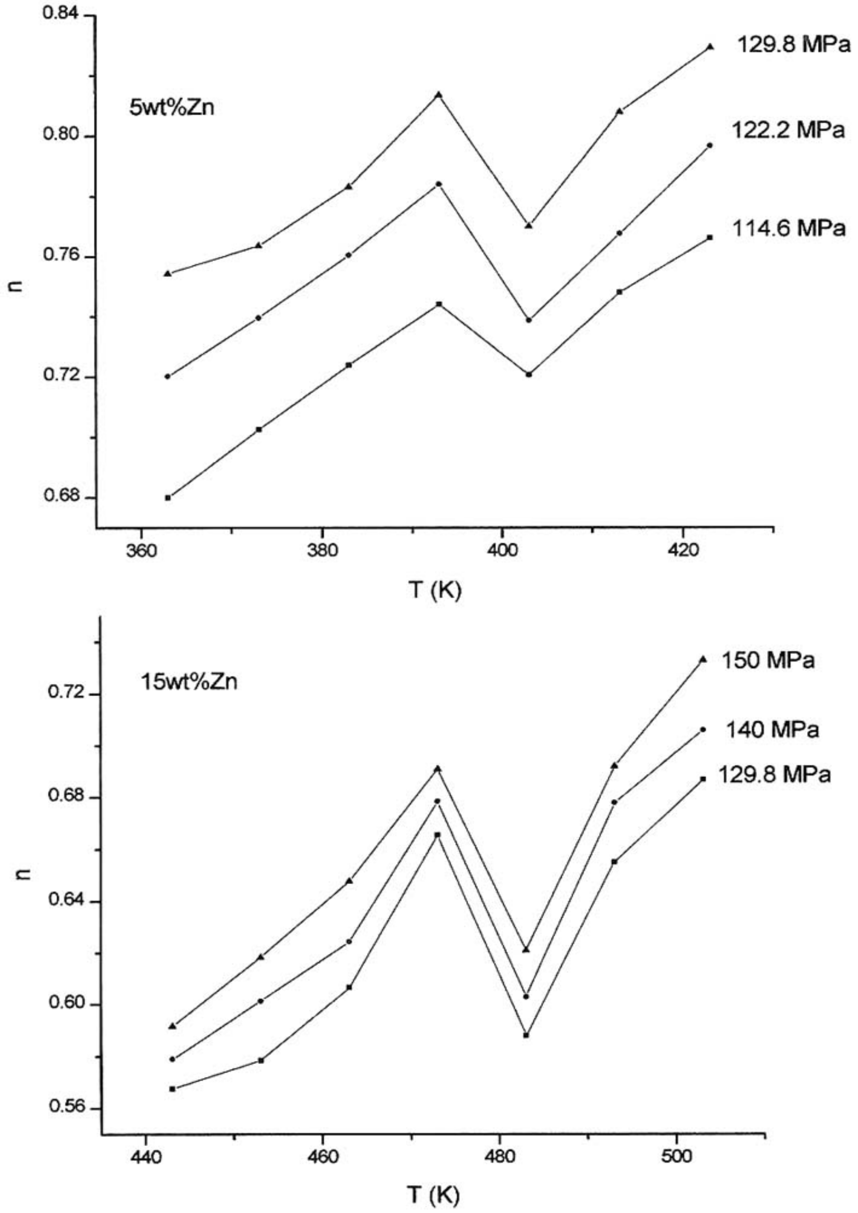

Fig.(3): The dependence of the time exponent n on the test temperature at different constant applied stresses for the two alloys.

The value of the parameter β ranges from 7.2 X 10^{-5} to 4.6 X 10^{-4} and from 3.4 X 10^{-4} to 1.4 X 10^{-3} for the first and second alloy, respectively. Figure (4) depicts the change of β with the test temperature.

Figures (3 and 4) show that both n and β increase with the test temperature and the applied stress and exhibit maxima for all the applied stresses at 393 and 473K for the two alloys, respectively. Also the parameters n and β show two transient creep temperature regions for each alloy. They are the low temperature regions (363-393 K) and (443-473 K) respectively for the two alloys. The high temperature regions are of temperatures higher than 393 and 473 K.

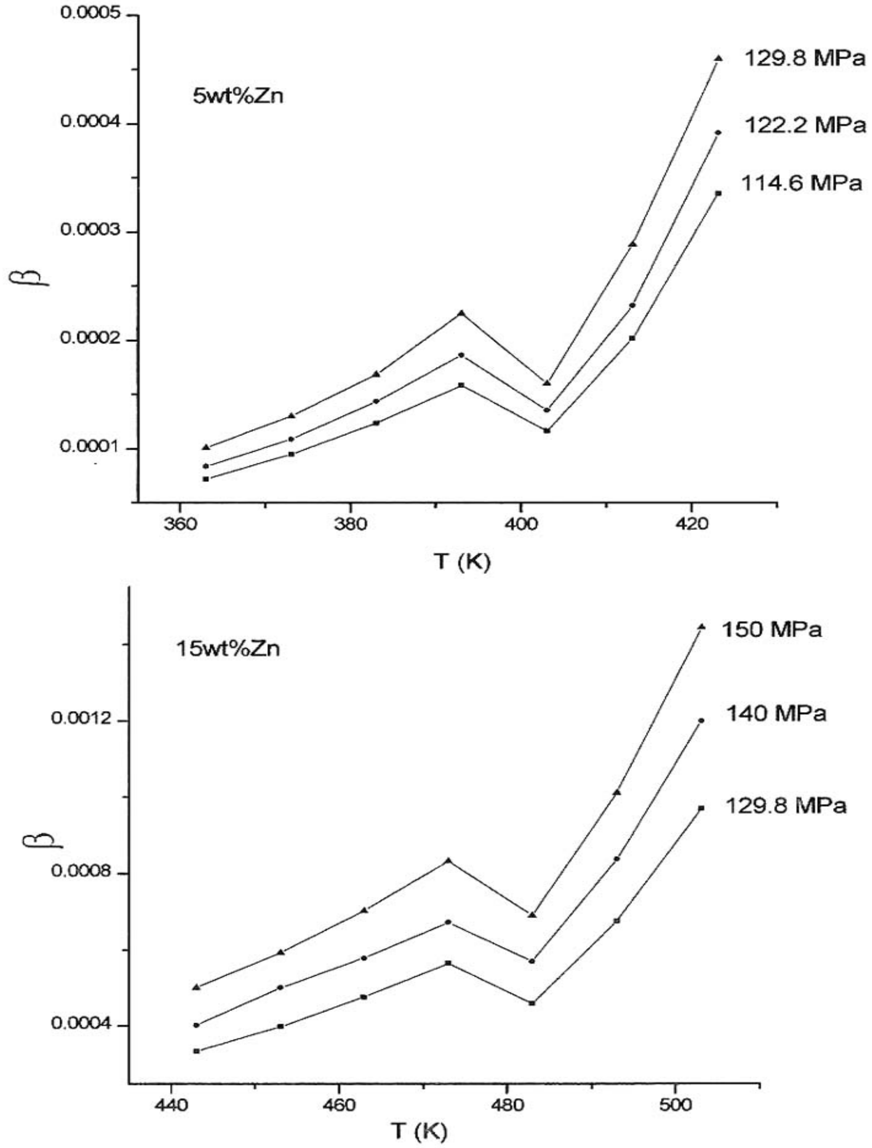

Fig.(4): The change of the transient creep parameter β with the test temperature for the two alloys.

The least squares method fitting of the relation between ln $(\varepsilon_{tr})_{t=1}$ and 1/T, illustrated in Figs.(5) and (6), gives two groups of parallel straight lines of different slopes for each applied stress. This confirms the presence of the two deformation regions around the transition point of each alloy. All the fitting equations for these lines have strong negative correlation coefficients (<-0.99). These straight lines obtained from the relation between lnβ and 1/T indicate that the activation energy of the transient creep, Q, for the two alloys can be calculated using an Arrhenius type equation:

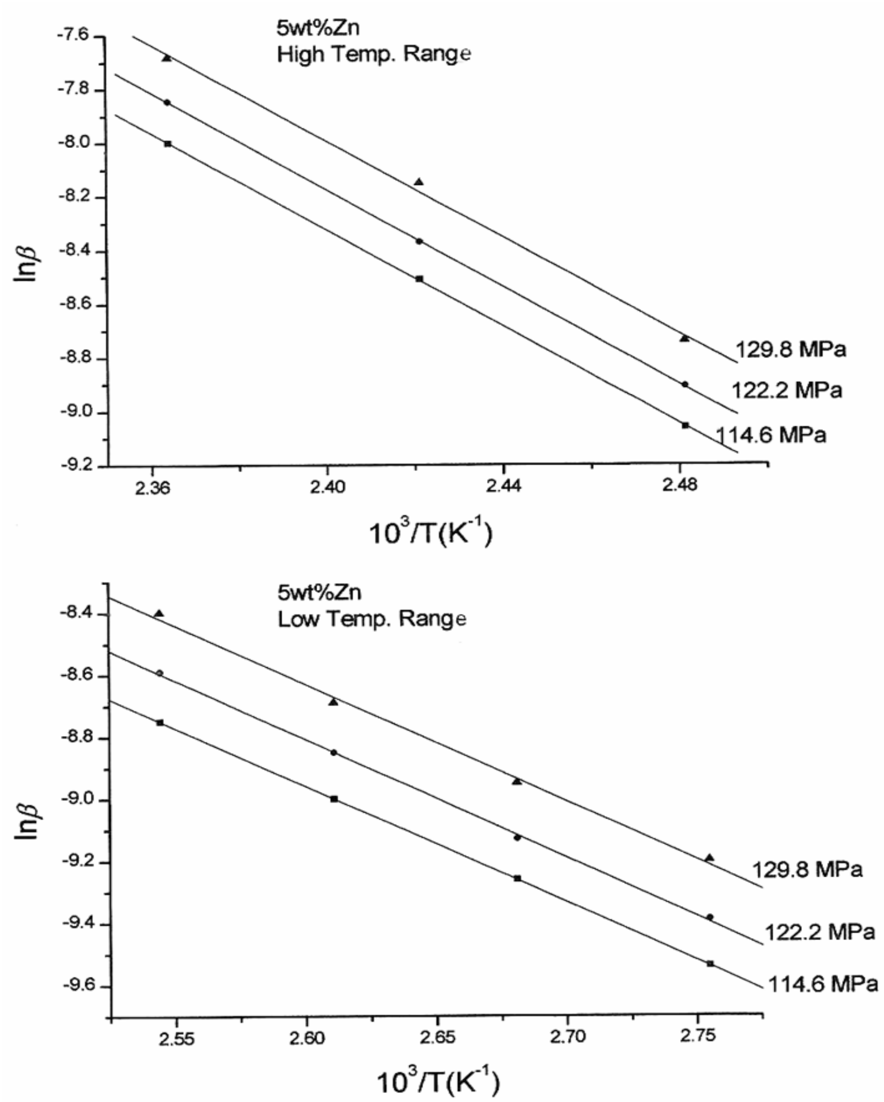

Fig.(5): The best straight lines of the relation between ln β and 10^3/T for the alloy of 5wt%Zn.

$$\beta = \beta_o \exp^{(-Q/RT)} \quad (4)$$

where β_o is a constant depending on the test conditions, T is the absolute temperature and R is the gas constant (J/mol). Therefore, the slopes of these straight lines are used in calculating the activation energy, Q, of the transient creep. The activation energies of the transient creep, Q, of the alloys Al-5wt%Zn and Al-15wt%Zn are found to be slightly affected by the applied stress in both the deformation temperature regions. Q has the average values of (31.5±0.5) and (75.5±0.4) kJ/mol for the first alloy and values of (29.9±0.4) and (75.5±0.5) kJ/mol for the second alloy for the three applied stresses in the two temperature regions, respectively.

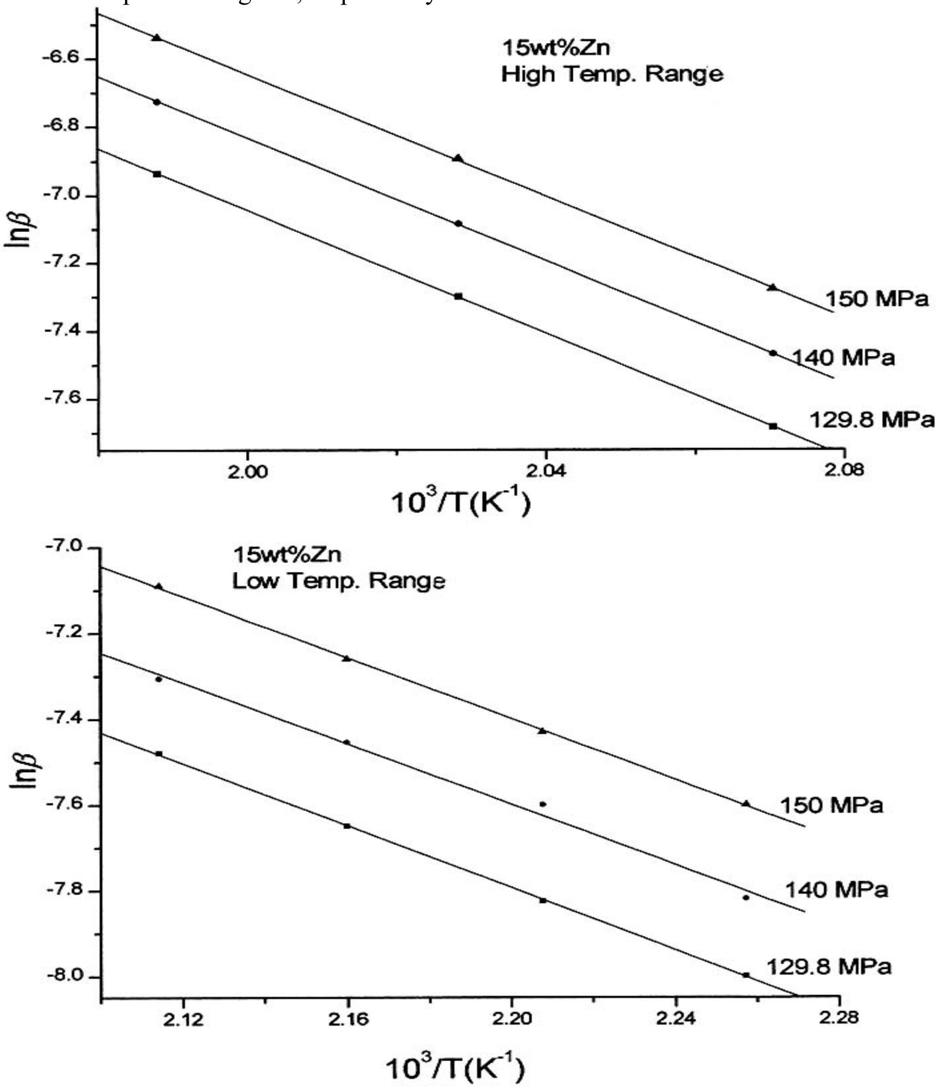

Fig.(6): The best straight lines of the relation between ln β and $10^3/T$ for the alloy of 15wt%Zn.

To correlate between the steady state and the transient creep of the used alloys, the values of the steady state creep rate $\varepsilon^{\bullet}_{st}$ are obtained from a previous investigation [11]. The least squares method program is used to fit the relation between ln $\varepsilon^{\bullet}_{st}$ and ln β as shown in Figs. (7) and (8). This relation is found to be of linear form with strong positive correlation coefficients (>0.99) for all the applied stresses in both the temperature regions for both the test alloys. The slopes of these straight lines give the values of the steady state strain rate exponent γ (see eq. 3). This exponent is slightly affected by the applied stress in all the deformation regions for both alloys. γ has the average values of (0.49±0.04) and (0.63±0.01) for the alloy of 5wt%Zn and (0.44±0.04) and (0.61±0.02) for the second alloy, in the low and high deformation regions, respectively.

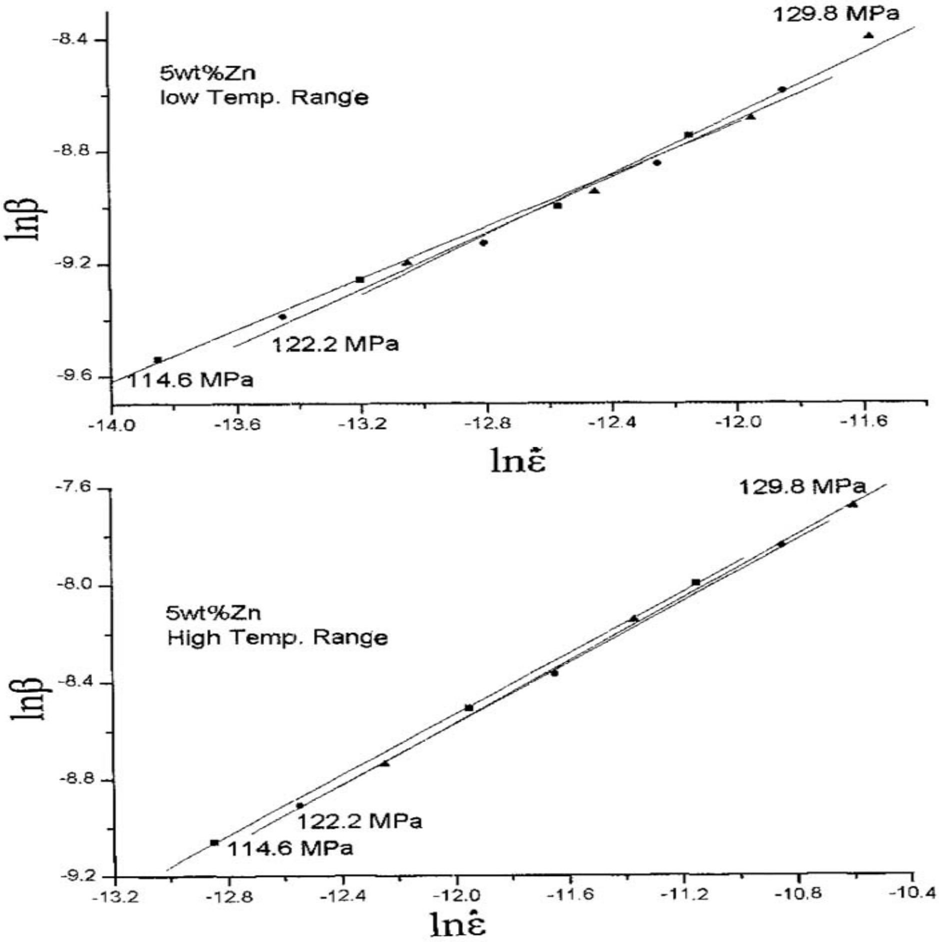

Fig.(7): The straight lines obtained from the best fitting equations relating lnβ and ln$\varepsilon^{\bullet}$ for Al-5wt%Zn.

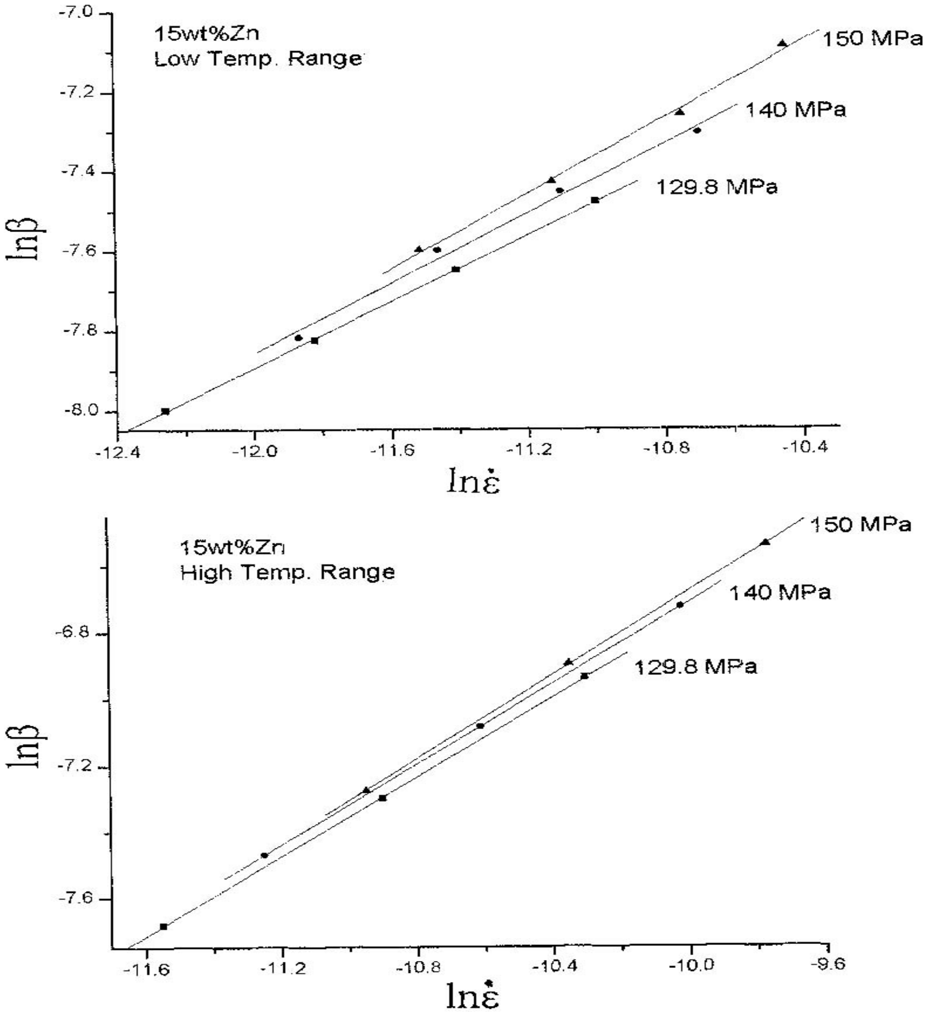

Fig.(8): The straight lines obtained from the best fitting equations relating lnβ and $\ln\dot{\varepsilon}$ for Al-15wt%Zn.

4. Discussion:

The phase diagram of the binary Al-Zn system [16] shows that at room temperature both Al-5wt%Zn and Al-15wt%Zn alloys are consisted of Al-rich phase and the Zn rich phase. By heating these alloys, the solid solubility of Zn in Al increases with increasing temperature until the transition temperatures (393 and 473 K for the two alloys, respectively) after which the dissolution process of the Zn-rich phase in the Al-rich phase occurs.

It is well known that the quenching technique produces samples of the same phases present at the temperature of heating before quenching. Therefore, the quenching processes from 523 and 623 K to room temperature (300 K), yield samples only composed of the supersaturated solid solution phase (Al-rich phase) [11, 16] for the two alloys.

Figures 1 and 2 show an anomalous behaviour in the transient creep in the temperature ranges (383-403 K) for the first alloy and (463-483 K) for the second alloy where irregularity in the temperature sequence is observed for all the applied stresses. This behaviour may be due to the change in the structural states of the investigated materials independent of the applied stresses, indicating a phase transformation process for each alloy.

The enhancement of the transient strain by increasing the applied stress for the two alloys may be attributed to the superposition of the applied stress on the internal stresses set up during transformation caused by the difference in the specific volume ($\Delta v/v$) of product and parent phase [15].

It can be seen from (Figs. 3, 4) that the transient creep parameters n and β increase extensively for temperatures higher than 403 K for Al-5wt%Zn alloy and 483 K for Al-15wt%Zn alloy. This observation can be considered as a superplastic process resulting from the transformation process. This behavior can be explained on the basis of processes associated with the release of stored deformation energy. These processes cause a redistribution of dislocations in the network at transformation and formation of Frank-Read sources [17].

The dependence of the steady strain rate ($\dot{\varepsilon}_{st}$) on the transient creep parameter β (Figs. 7, 8) seems to be induced by the transformation which enhanced the transient and steady state stages. Hence, the processes occurring in the vicinity of transformation are controlled and affected by the redistribution of Zn atoms.

The activation energy of the transient creep has the average values of (31.5 ± 0.5) and (29.9 ± 0.4) kJ/mol in the low deformation regions of the two alloys, respectively. These values characterize a dislocation mechanism involving grain sliding or grain migration [3]. It has an average value of (75 ± 0.5) kJ/mol in the high deformation regions for both alloys. This Q high value indicates that the dominant operating mechanism is a dislocation climb [3, 18] in the solid solution region for both alloys.

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