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ON COMPRESSION CREEP OF METAL MATRIX COMPOSITE (Al 6061) AT ELEVATED TEMPERATURES .

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Abstract

The potential of metal matrix composite (MMC) materials for significant improvements in performance over conventional alloys has been widely recognized . The effect of the reinforcement material (Al2O3) on the compression creep behaviour of MMC material (Al6061) was investigated . The compression creep tests were carried out at 300,350,400°C on four different materials have (0 , 10 , 15 and 20%) of Al2O3 . The specimens were taken from hot extruded rods . Creep properties were characterized in terms of the stress and temperature dependence of the minimum creep strain rate $\dot{\varepsilon}_{\min}$ *and ductility*

Introduction

In recent years , very few studies have been reported on the compression creep behaviour of the metal matrix composites (MMCs) . Therefore there is a need for a proper studying of the influence of the reinforcement type and volume fraction of such composite materials . There are three basic types of (MMCs) : dispersion strengthened , particle reinforced and fiber (whisker) reinforced . Metal matrix composites , in general consist of at least two components : the first is the matrix metal or alloy and the second component is the reinforcement (in general an intermetallic compound materials such as oxides , carbides or nitrides) [1,2].

In this work aluminium oxide (Al2O3) was used as a reinforcement for aluminium alloy matrix Al6061 because of their high modulus , low cost and can be used in the molten metal processed composites . There are many reasons for selecting aluminium alloy as matrix because it possesses a wide variety of properties such as good corrosion resistance , low density and increased strength to weight ratio . It was found that aluminium oxide and silicon carbide have an excellent compatibility with the aluminium matrix [3] . However , it is established that alumina is unsuitable in aluminium alloys containing magnesium , and a chemical reaction occurs at the interface [4]

Generally there are two methods of fabrication of the metal matrix composites :

(1) Solid - phase fabrication methods such as diffusion bonding , PM technique , rolling , extrusion , drawing , etc .
(2) Liquid - phase fabrication methods such as liquid metal infiltration , squeeze casting , compocasting , pressure casting , spray codeposition , etc .

In the last decade , rather extensive investigations of high temperature creep of aluminium alloys strengthened by Al2O3 , Al4C3 and SiC were carried out [5,6] .The investigations based on tensile creep tests which gave rather different characteristics of creep than the investigations of creep in compression on materials of the same types . This fact and other data giving the ratio of the high temperature yield strength in tension and compression of about 0.5 indicate a pronounced difference in mechanical behaviour of the material in tension and compression [7] . Then , it is important to have more informations about the mechanical behaviour of the aluminium matrix composites in compression creep to compare it with that in tension creep , where the application loading not only tension but also compression .
Most creep rupture tests of metalic materials are conducted in uniaxial tension . Although this method is suitable for ductile metals , compressive testing is more appropriate for brittle, flaw senstive materials .

Materials and Experimental Technique

Materials

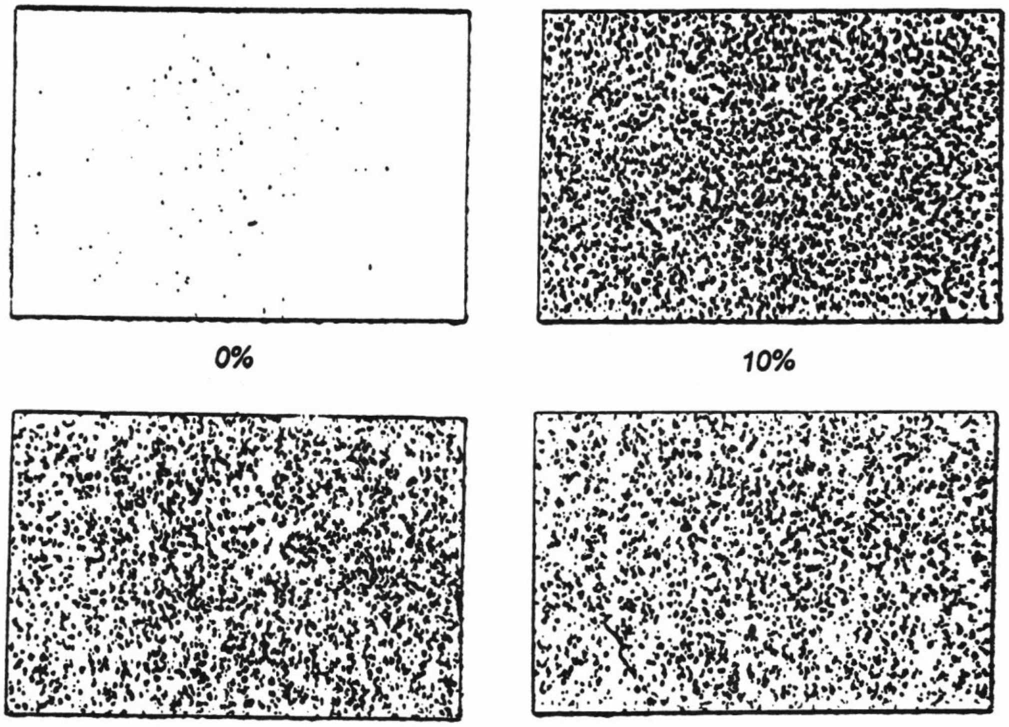
The tested materials are aluminium based alloy Al 6061 , received in the form of extruded rods of 15 mm. in diameter . The materials were firstly produced by casting of the molten matrix with the required volume percentage of Al_2O_3 . The chemical composition of the matrix listed in Table 1 . The aluminium oxide particles were found in 0% , 10% , 15% and 20% by volume fraction . The distribution of Al_2O_3 particles in the aluminium alloy matrix is shown in Fig.1 .

Creep Specimens

In case of uniaxial compression testing , specimen design can be simple , small diameter 5 mm. of right cylinders 7.5 mm. length . These specimen geometries are well suited for creep testing , saving the material if it is expensive , and reducing also the machining operations particularly when the composite material is difficult to be machined .

Table 1 Chemical Composition of Al 6061 (AlMgSi1)

Elements	*Al*	*Mg*	*Si*	*Cu*	*Cr*	*Fe*	*Mn*	*Zn*	*Ti*
%	*base*	*0.8-1.2*	*0.4-0.8*	*0.15-0.4*	*0.04-0.35*	*0.7*	*0.15*	*0.25*	*0.15*



0%

10%

15%

20%

Fig.1 Microstructure of the distribution of Al_2O_3 in the aluminium matrix

Creep Test Procedure

The compression creep tests were carried out on the same tensile creep testing machines . Only two parts were introduced to reverse the direction of loading as shown in Fig. 2 . All tests were conducted under constant load conditions in air . The creep load was applied smoothly at the beginning of the test . The temperature was measured using Cr- Ni thermocouple and it was controlled by automatic control system to keep the creep test temperature ± 0.5°C . Reads of elongation have been recorded to 0.001 mm .

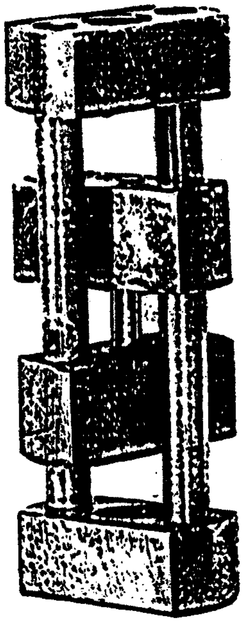


Fig.2 Two parts of chromium steel were used to reverse the direction of loading on the creep test machine

Results and Discussion

Microstructures

Fig.1 shows the distribution of Al_2O_3 particles in the aluminium alloy matrix . Fig.1(a) presents the optical micrographs of Al 6061 without additions of Al_2O_3 . Fig. 1(b,c,d) present the optical micrographs of 10 % , 15 % , 20 % Al_2O_3 in aluminium composite specimens respectively . These specimens were taken from the longitudinal direction of extruded bars . The above figures 1(b - d) reveal that the distributation of alumina particles appears barely homogeneous for the MMCs reinforced with three different percentages of Al_2O_3 . However , in case of Fig.1(a) it is shown the effect of the alloying elements such as Mg , Si and Fe on the microstructure of the aluminium matrix .

Compression Creep Behaviour

All the compression creep tests were performed at temperatures of 300°C under four different engineering stresses . Also , to study the effect of the creep temperature on the behaviour of the material , every material was tested at 350 and 400°C in addition to 300°C at the same stress . A typical compression creep curves are illustrated in Fig. 3 .

All tests were stopped after a specified strain $\approx$ 50 % because there is no failure or fracture of these aluminium composite materials where they are ductile . Then time to rupture is not found here as shown in Fig. 3 .In general it was observed that the onset of the third stage creep and fracture is usually delayed in compression compared with that in tension . This delay can be attributed to two reasons . First , the menimized effect of microstructural flaws and cracks particularely in the ductile materials such as aluminium and its alloys . Second , the inability to form "a neck like " mechanical instability but increase of the.cross sectional area of the specimen in the compression case .

As shown in Fig. 3.a , in which creep strain is plotted against time , the creep curve exhibts the following main features : (a) a decelerating primary creep stage where $d\varepsilon / dt < 0$, (b) a secondary stage (steady - state stage) where $d\varepsilon / dt = 0$, and (c) the tertiary stage in cmpression creep where $d\varepsilon / dt < 0$ as a result of the increase of the cross sctional area of the specimen . This last feature is in opposite with that in tensile creep where in the steady state stage $d\varepsilon / dt > 0$ owing to the formation of neck *or increasing the cavities and cracks. In Fig.3.b when the strain rate was plotted with the creep time in a double logarithmic scale, it was observed that the rate of strain decreases gradually with time in the first stage reaching a constant value of change in the.secondary stage which can be called the minimum creep strain rate $\dot{\varepsilon}_{\min}$ after that there are a sharp decreae in the strain rate . The length of the first stage and the rate of decrease will depend upon the type of the material , the temperature of the creep test and the applied stress .In Fig.3.d , it can be seen that the strain rate decreases gradually with increasing the strain from the beginning of the test i.e. in the first stage of creep after that the strain rate decreases highly with the increase of the strain which can be attributed to the increase of the cross sectional area of the specimen due to the compression effect .*

Effect of Volume Fraction

In Fig.4 it is clear that the addition of Al2O3 has a good effect on the behaviour of compression creep of MMC materials . For example , the total strain at any time will be affected by the percentage of these additions because the hard particles of alumina will restrict the dislocation motion during creep due to impeding the motion of dislocations through the materials does not shear as easily as the matrix . Fig.5 shows the effect Al2O3 as a reinforcement material on the minimum creep strain rate of the composite materials . The decrease of the minimum creep strain rate with the increase of the volume fractions of the hard particles , can be attributed to the velocity of the mobile dislocations . The velocity (v) of dislocation motion is strongly dependent on the stress (σ) according to [8]

$$v = A\,\sigma^{m'} \qquad (1)$$

where A is a material constant and m' is described by

$$m' = \frac{1}{m} - \frac{\partial(\ln \rho)}{\partial(\ln \sigma)} \qquad (2)$$

where m and ρ are the strain rate senstivity and dislocation density respectively . From the above equations , it is obvious that the strain rate senstivity increases with decreasing dislocation velocity . The addition of reinforcement is a barrier to the dislocation motion which will reduce the velocity of mobile dislocations . Hence , it will force the strain rate senstivity to increase .

These results were in good agreement with the modern dislocation theories which assume that dislocation motion is opposed by back stresses which result from interactions between the moving dislocation and substructure and that the creep rate is determined by a net stress , equal to the difference between an applied stress and a back stress . That can be described in composite materials in terms of the threshold stress below which creep rate is negligible and which must be overcome in order for dislocations to pass particles [9] .

Effect of Temperature

In general , creep is thermaly activated process . It has been established that steady state creep rate under the usual creep conditions is best expressed as a function of temperature and stress . Also the temperature has a high effect on the creep behaviour of the composite materials such as strain as shown in Fig.6 , and the minimum creep strain rate $\dot{\varepsilon}_{\min}$ as shown in Fig.7 for all the materials with or without additions of Al2O3 . That is due to the softening of the matrix . From these data , the creep results can be expressed as :

$$\dot{\varepsilon}_{\min} \propto \sigma^{n}\left(\frac{-Q}{RT}\right) \qquad (3)$$

Where n is the stress exponent , Q is the activation energy , R is the gas constant .and T is the absolute temperature .

Effect of Stress

Fig. 8 is an example of the change of strain rate $\dot{\varepsilon}$ with the increase of the strain ε for specimens of the matrix only without additions of Al2O3 tested at 300°C over a range of stresses from 20 to 50 MPa . The data indicates clearly that there are a decrease in the primary stage with the increase of the stress . In the primary region the creep rate *decreases gradually with increasing the strain and that is followed by a steady state region in which the strain rate is approximately constant . The tertiary stage can not be seen here owing to the increase of cross sectional area of the specimens with increasing the strain . That means the material is ductile . But for the brittle materials like ceramics , it was found that the strain rate will increase at the end of the secondary creep stage owing to the increase of the cracks and cavities in specimens [10]*

The experimental results obtained in this work at 300°C are summarized in Fig.9 in double logarithimic scale between the applied stress and the minimm creep strain rate . There are three important points to note from these data . First , the increase of the volume fraction of Al2O3 will increase generally the resistevity to deformation and then decrease the minimum creep strain rate . For example at 40 MPa and 300 °C the minimum creep strain rate was 2.4×10^{-2} *of the matrix without additions of Al2O3 and that will decrease to* 4.6×10^{-3} *of 10 % Al2O3 and was* $1.76\times10^{-3}\mathit{and}5.13\times10^{-2}$ *of 15 % and 20 % Al2O3 respectively . Second , the figures indicate that the creep results may be expressed in the form*

$$\dot{\varepsilon}_{\min} = A\sigma^{n} \qquad (4)$$

where A is constant , n is the stress exponent . Third , it can be seen that the composite material containing 15% Al2O3 shows the best values of the minimum creep strain rate , irrespective of the creep temperature and creep stress . The poor strength of 20 % Al2O3 reinforced composite material can be attributed to the porosity . This phenomenon can be verified by metallographic as shown by Doong [11] . Torerefore if the strengthening effect of the additional aluminium oxide particles is smaller than the deteriorating effect of the porosity , the strength of the composite material will not increase . On contrary , it will decrease as seen in Fig. 5 , 7 and 9 .

Fig.10 represents the relationship between the true stress σ' *and the true strain rate* $\dot{\varphi}$ *. It is shown that the true stress decreases gradually with time due to the increase of the cross sectional area of the specimen . At the beginning of the test when the stress is applied to a material , that causes an instantaneous elastic strain* ε_e *to occur . If the stress is sufficiently high , an initial plastic deformation* ε_p *also occur . This initial strain or sudden extension is known as* ε_o *where*

$$\varepsilon_o = \varepsilon_e + \varepsilon_p \qquad (5)$$

The primary creep stage is characterized by an initial high creep rate $\dot{\varphi}$ *which decreases gradually with time . In the secondary stage there are a gradually decrease in the true strain rate* $\dot{\varphi}$ *where*

$$\dot{\varphi} = \dot{\varepsilon}/\left(1-\varepsilon\right) \qquad (6)$$

where $\dot{\varepsilon}$ *and* ε *are the creep strain rate and the creep strain respectively .*
If the true stress σ' *is expressed as*

$$\sigma' = \sigma\left(1-\varepsilon\right) \qquad (7)$$

where σ *is the applied stress calculated at the beginning of the test . It can be seen in Fig.10 that all the curves of any group of these materials will meet together in the secondary stage when they have the same true strain rate . In this case all the curves at a true stress of 25 MPa , they have the same strain rate . That can be attributed to the increase of the cross sectional area of any specimen to have the same value at more or less time depending on the applied stress .*

Conclusions

(1) The tertiary stage can not be seen in all the curves of the compression creep tests owing to the increase of cross sectional area with the increase of the strain instead of the ability to form a neck like as in tension , also to the menimized effect of the microstructuralflaws in the ductile materials.

(2) The addition of Al2O3 will affect the three main characteristics of the composite material.

First , it will reduce the ductility of MMCs irrespective of the stress and temperature .

Second, it will leads to high temperature strengthening over the whole stress range used in the present investigation.
Third, it will increase the apparant activation energy of MMCs in comparing with the self dffusion energy of aluminium.

(3) The composite materials containing 15% Al2O3 the best values of the compression creep behaviour.

(4) The creep temperature has a high effect on the creep properties of the aluminium metal matrix composite.

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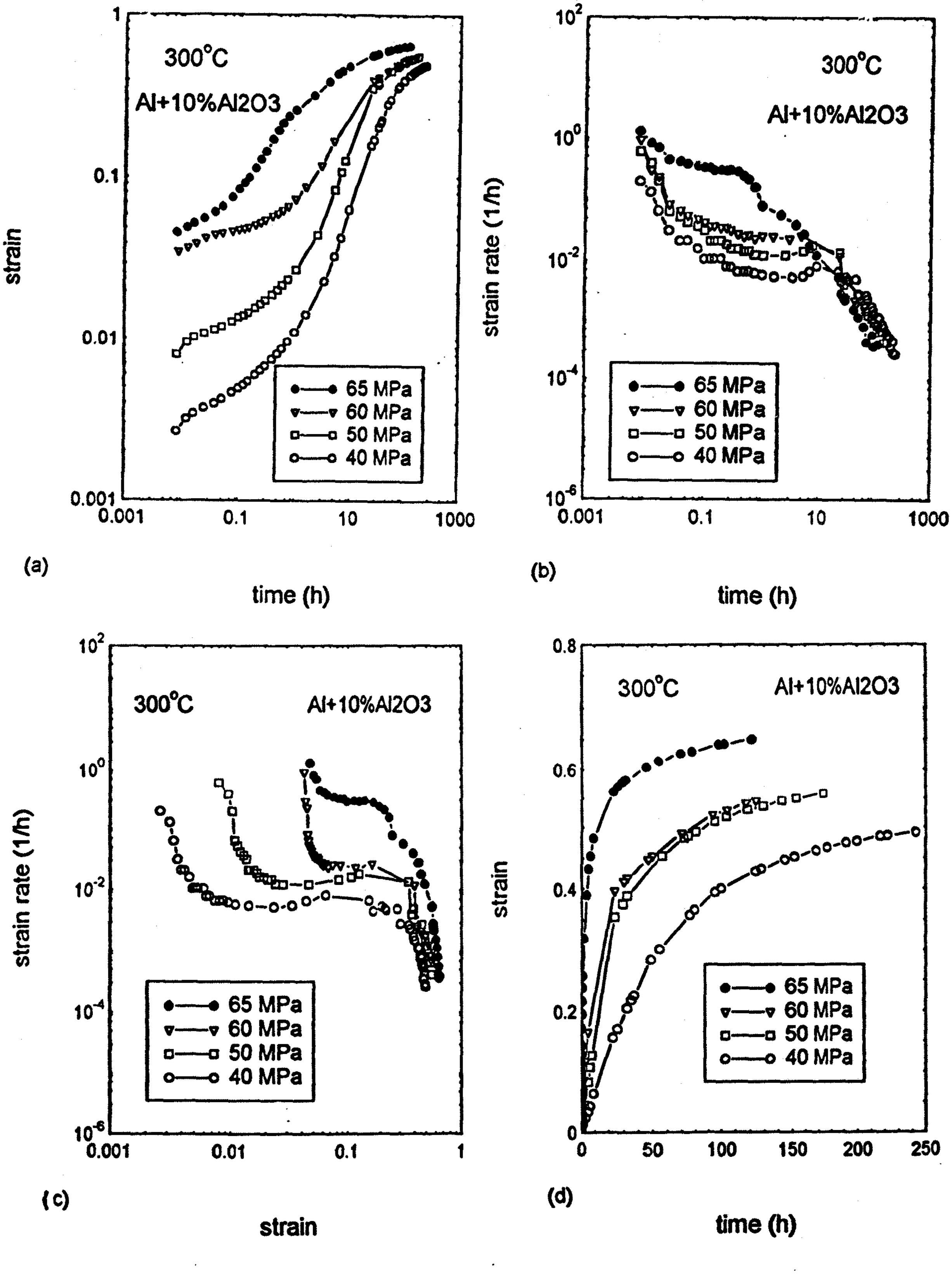

Fig.3 Example of compression creep curves of aluminium composite material (Al6061) with 10% Al2O3 .
(a) Relationship between strain and time at 300°C on a logarithmic scale
(b) Effect of stress on creep strain rate .
(c) Creep strain rate as a function of creep strain .
(d) Effect of stress on the creep strain .

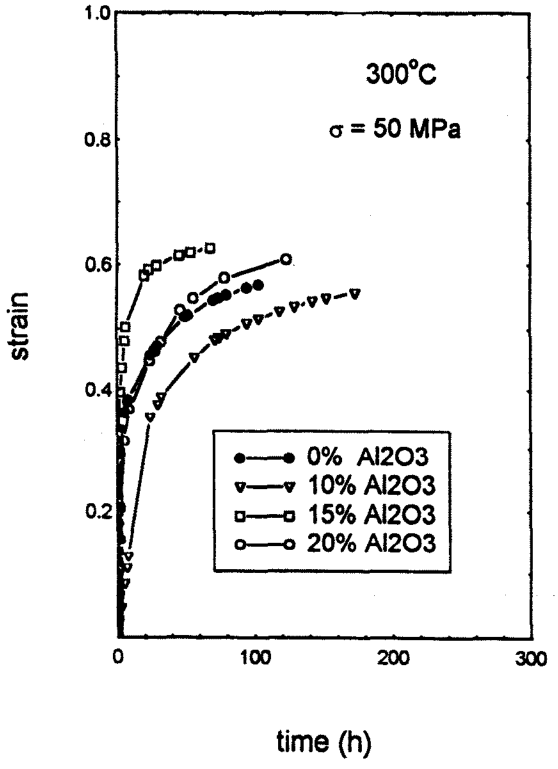

Fig.4 Effect of the additions of Al2O3 on the creep strain at 300°C

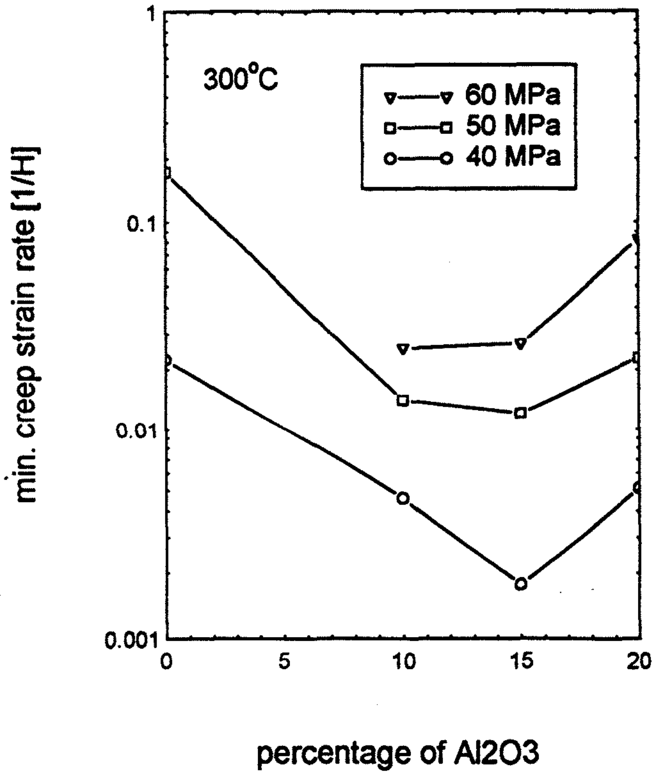

Fig.5 Minimum creep strain rate as a function of the percentage of Al2O3 at different creep stresses .

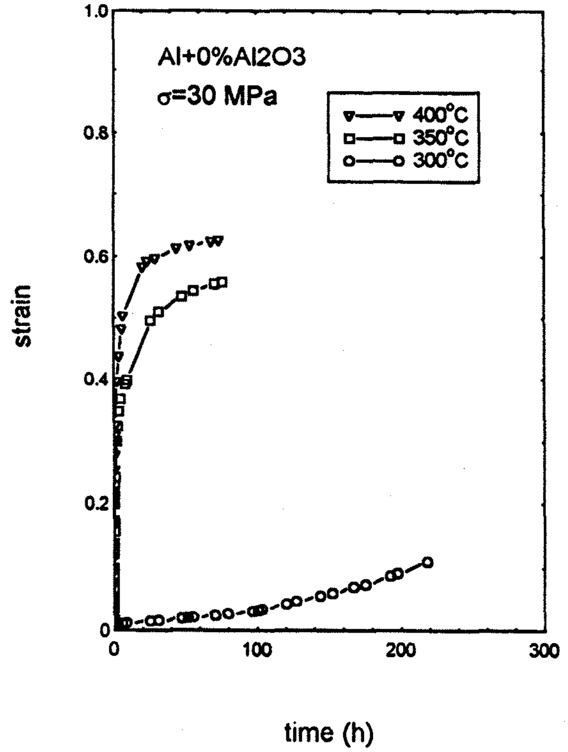

Fig.6 Relationship between creep strain and temperature of aluminium matri at 30 MPa .

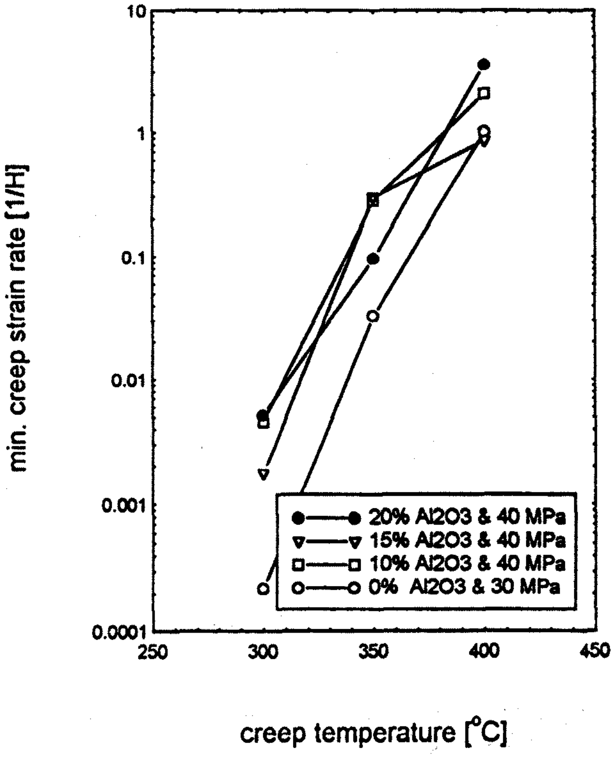

Fig.7 Steady state creep rate as a function of creep temperature for aluminium matrix and three different percentages of of Al2O3

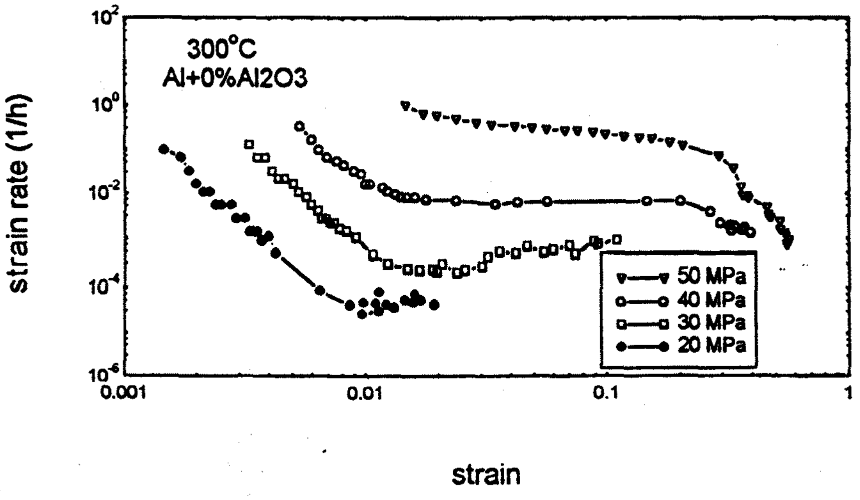

Fig.8 Effect of stress on the minimum creep rate (logarithmic scale) for aluminium matrix .

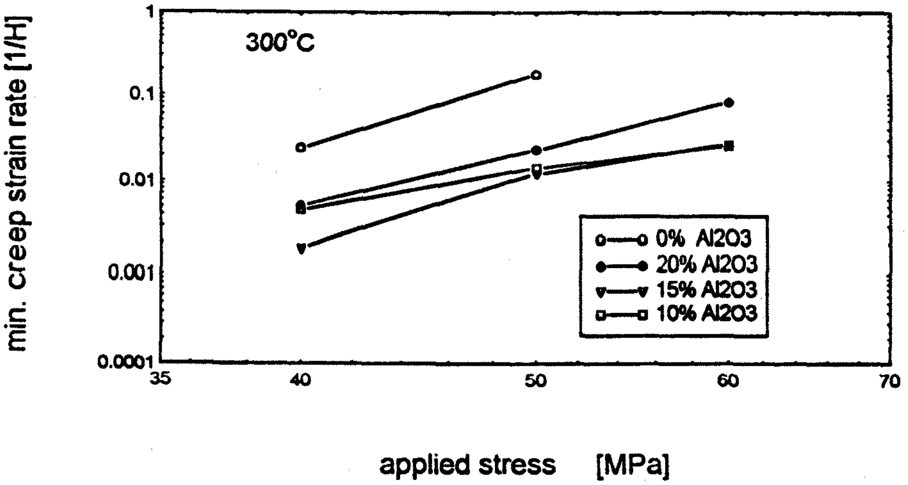

Fig.9 Minimum creep strain rate as a function of various percentages of Al2O3 at 300°C .

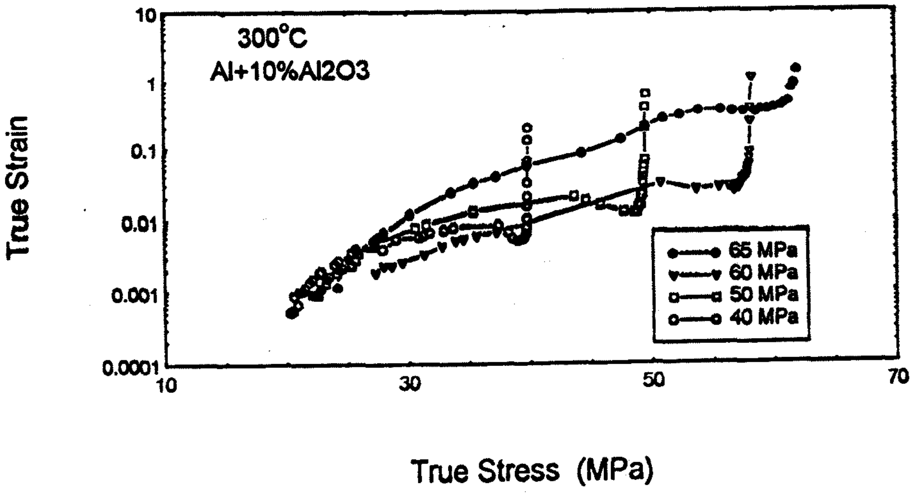

Fig.10 Relationship between true stress and true strain for aluminium matrix + 10% Al2O3 at four different stresses .