CREEP BEHAVIOR PREDICTION OF ALUMINUM-TITANIUM DIBORIDE (Al-TiB$_2$) METAL MATRIX COMPOSITE USING FINITE ELEMENT SIMULATION

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Abstract: Metal matrix composites are widely preferred for engineering applications, especially aluminum is used as a matrix because of its unique mechanical properties in naval and aerospace industries. In the present paper, the creep behavior of an aluminum based metal matrix composite reinforced with TiB$_2$ particles was studied for various over temperature range and stress levels. Aluminum 6061 was selected to be the metal matrix which has high strength to weight ratio and it is reinforced with TiB$_2$ which has extremely thermal stability. TiB$_2$ powder is added into the aluminum by varying the percentage of the powder by volume in order of 3,6 and 9 percent, respectively. The finite element analysis software package ANSYS® is used to obtain the creep behavior of the composite material. The influence of the over temperature rates, stress levels and volume of the TiB$_2$ powders on the creep behavior were studied by using simple finite element model. Using such a simple composite model, remarkable savings in time and identifying the correct combination of the TiB$_2$ powder can be obtained for creep conditions.

Keywords: Finite Element Simulation, Creep Prediction, Metal Matrix Composite, Al-TiB$_2$ Reinforcement

Introduction

Metal matrix composites (MMCs) are widely used because of their superior properties as compared to those of most conventional materials. They have high specific strength, wear resistant and stiffness. Nowadays, main focus is given to aluminum alloy because of using for commercial applications in the construction, engineering industries and transportation. Especially, aerospace industries raise the demand for the new materials which perform efficiently in very tough environment. Although a variety of matrix materials used for making metal matrix composites (MMCs), the biggest emphasis is on the development of lighter metal matrix composites using aluminum and titanium alloys. Because they have the significant potential in the weight ratio and at the same time the material posses low density, high thermal conductivity, low thermal expansion and high modulus for the aerospace and space engines. The aluminum-based metal matrix composites serve these purposes and also new light aluminum alloys have received considerable attention in the literature (Ioannidis et al., 1989, McShane et al., 1990). Despite of the superior properties of the MMCs, they have lower ductility and fracture toughness than unreinforced alloys (Lloyd, 1994, Srivatsa et al., 1991).

The employ of intermetallic particles (such as titanium aluminides) as suitable reinforcement for aluminum and titanium alloys were proposed as least two decades (Yamada and Unakoshi, 1983, Larrouy et al., 2001). Ceramic particles contribute a pure structural build up for the metal matrix composites. The addition of ceramic particle such as SiC, Al$_2$O$_3$, TiB$_2$ to an aluminum matrix doesn't considerably change the density of the material but instead it leads to a major rise in specific strength and modulus of composite and this plays a good role use in structural applications (Yue et al., 1999). The physical properties such as friction resistance, friction co-efficient and thermal conductivity also changes. This due to fact that TiB$_2$ have outstanding features such as high elastic modulus (530 x 10^3 GPa) , high melting point (2790°C), high hardness (86 HRA or 960 HV) and good thermal stability (Tjong et al., 2005, Mandal et al., 2007, Kumar et al., 2010, Lakshmi et al., 1998). TiB$_2$ particles don't react with molten aluminum, thereby avoiding formation of brittle reaction products at the reinforcement-matrix interfaces. So the Al-TiB$_2$ composites have certain useful and unique characteristics. For example; the wear resistance of the aluminum matrix reinforced with titanium diboride (TiB$_2$) increases as the volume fraction of the TiB$_2$ increased, when compared to the pure aluminum (Popoola et al., 2010). The tensile and ultimate strength of the Al increases with increase in the amount of TiB$_2$ (Suresh et al., 2014). The addition of TiB$_2$ particles increases the hardness value when the formed TiB$_2$ particles have a mix up of cubic, spherical and hexagonal shaped particles (Rajan et al., 2013).

Relationship between microstructure and mechanical property for TiB$_2$ reinforced aluminum have been studied by various authors, however in literature it has lack of study about at the behavior of the Aluminium-Titaninum Dibordine (Al-TiB$_2$) metal matrix composites the high temperatures. For example, creep is an inelastic response of materials loaded at high temperatures. It has important effect on deformation because defect of microstructure rearrangement process is accelerated at high temperatures. So this process tends to soften material they counteract the hardening produced by plastic deformation. Creep can be resembled viscoelasticity behavior because the resulting strain at constant applied stress is a function of time, but in contrast with viscoelastic behavior permanent deformation remains following creep. Additionally, elasticity and plasticity are mechanical responses to loading which is independent of the time. When the load is applied, the corresponding level of strain set in. But, during creep behavior the mechanical response is time dependent.

The aim of the present study is to investigate the creep behavior of Aluminum-Titanium Dibordine (Al-TiB_2) metal matrix composite over a temperature range at various stress levels. Aluminum 6061 and TiB_2 were selected to be the metal matrix and reinforcement materials respectively. The TiB_2 powder was added to the aluminum matrix a 3%, 6% and 9% vol. The influence of these volume rations, over temperatures rates and stress levels on the creep behavior were investigated. The principal aim of the contribution is to define and describe a simple model of metal matrix composite for the numerical simulation and prediction of creep behaviors. For this purpose, finite element models were developed using ANSYS® software and using this model, saving time and identifying the correct combination of TiB_2 can be obtained.

Description of the Aluminum-Titanium Diboride (Al-TiB_2) Metal Matrix Composite

In this work, Aluminum 6061 was selected to be the metal matrix. Different metal matrix composites are obtained by mixing TiB_2 powder with different percentages of reinforcing particles. The mixtures obtained are aluminum with 3, 6 and 9% in volume of TiB_2. The properties of the metal matrix composites not only depend on the matrix and the volume fractions, but also on distribution of reinforcing particle on the matrix. In practically, there is no doubt that achieving homogeneous distribution is difficult. But in the present MMCs, a certain number of fibers are considered to be unidirectional oriented in the z direction, as shown in Figure 1.

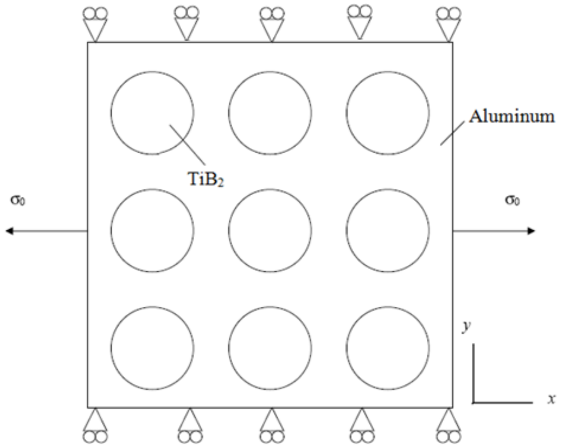

Figure 1. Loading and boundary conditions of Aluminum-Titanium Diboride (Al-TiB_2) metal matrix composite.

The material properties of the matrix Aluminum 6061 and reinforcing particle TiB_2 powder are shown in Table 1.

Table 1: Mechanical properties of Aluminum 6061 and TiB_2 powder (Suresh et al., 2012) [15].

Matrix (Aluminum 6061)	Fiber (TiB_2)
E = 56000 MPa	E= 530000000 MPa
υ = 0.33	υ = 0.33

The standard tension test can be applied to investigate the mechanical response of composite materials deforming at high temperatures. In the present paper the two different high temperatures values were used, they were 232°C and 288°C. The easiest to perform is tension test at constant load and temperature. Using constant loads and temperatures values in this study can be seen in Table 2.

Table 2: Constant temperatures and load value parameters.

Parameters	Temperature (°C)	Load (MPa)
1	T = 232 °C	σ = 27.6 MPa
2	T = 288 °C	σ = 13.8 MPa
3	T = 288 °C	σ = 20.7 MPa
4	T = 288 °C	σ = 27.6 MPa

The resulting strain is measured as a function of time. In this study, time was selected as 2.5 hours (150 minutes). In the creep test, the resulting strain-time curves are called creep curve. The curve in Figure 2 shows the idealized shape of a creep curve. The slope of this curve (de/dt) is referred to as the creep rate. The curve B (dashed line) shows the shape of a constant-stress creep curve. In engineering it is generally the load not the stress that is maintained constant, so a constant-load creep test is more important, but fundamental studies of the mechanism of creep should be carried out under constant-stress conditions.

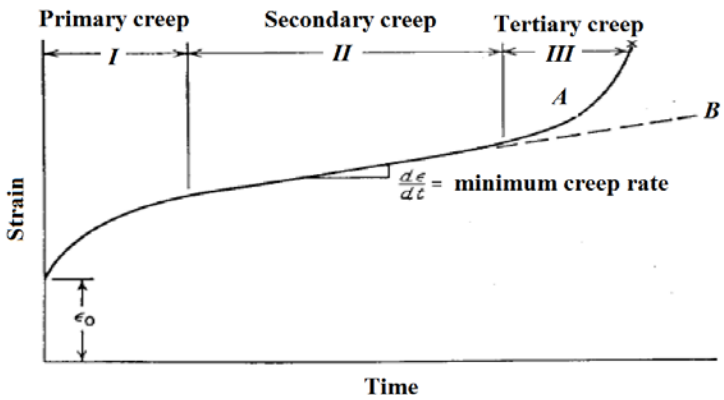

Figure 2. Creep curve.

Strain-time curves obtained from the creep tests at constant load and long periods of time often exhibit three different characteristic stages. These can be defined as below:

* **Primary Creep, I, (Transient Creep);** Following the setting in of the instantaneous elastic strain (ε_0), the material deforms rapidly but at a decreasing rate. The duration of the stage is typically relatively short in relation to the total creep curve.
* **Secondary Creep, II, (Steady-State Creep);** The creep strain rate reaches a minimum value and remains approximately constant over a relatively long period of time.
* **Tertiary Creep, III;** In this stage, the creep strain rate accelerates rapidly.
* **Rupture;** The material in unable to withstand the load anymore and breaks.

In this paper, the matrix (Aluminum 6061) which is a function of tension makes primary (transient) creep and secondary creep (steady-state creep) movement. When an external load is applied, present metal matrix composite materials samples undergoes elastic deformation and then these internal stresses cause creep behavior for the matrix. In calculations, it is assumed that usually only the matrix has been creep and the elastic shape of the fibers has changed but has not been creep behavior. This situation creates creep resistance in the fiber direction. Creep behavior, like other thermo mechanical properties in unidirectional composites, is anisotropy. This is too small in longitudinal direction and can be negligible, but it is worth taking in to account for transverse direction.

Creep Analysis of the Aluminum-Titanium Diboride (Al-TiB_2) Metal Matrix Composite Structure

Finite element models can be simply thought based on to be cylinders placed in the middle of a cube. So the metal matrix composite is modeled as circles arranged symmetrically in a square. An edge length of the square is taken as 1000 units. Finite element analyses were performed using ANSYS® commercial programme. Finite element model of the metal matrix composite structure can be seen in Figure 3(a) and the geometry were meshed by using Plane 182 can be seen in Figure 3(b). Plane 182 element type is used for two dimensional modeling of solid structures. This element is defined by four nodes having two degrees of freedom at each node: translation in the nodal x and y directions. This element is very suitable for studying creep behavior because it can be used in plastic, hyper elastic stress, large deformation and large unit elongation analyses. The ANSYS® package program has 12 different creep relationships that model creep behavior, in this paper it has accepted that matrix material makes both primary and secondary creep movements. The correlation to be used in this model should be appropriate for this type of behavior. So the creep behavior given in 11th place in the ANSYS package program was chosen suitably.

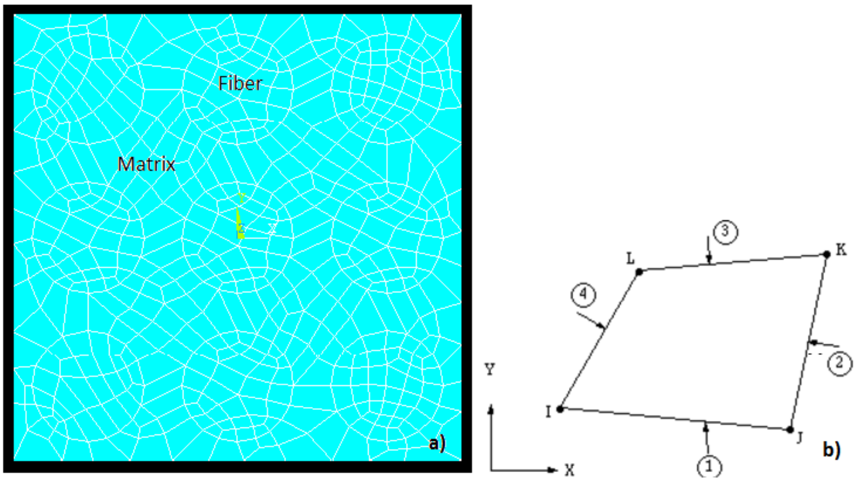

Figure 3.a) Finite element model of the metal matrix composite b) Plane 182 element type.

Analysis Results and Discussion

In this paper, the creep behavior of the aluminum-titanium diboride (Al-TiB_2) metal matrix composite in 150 minutes was investigated. Figure 4 and Figure 5 show the result of the creep analysis performed with the ANSYS at various stress and temperature conditions. Stress is one of the major factors that affect the creep strain. Figure 4 shows that effect of the stress on the creep behavior for the 6% volume of TiB_2. As seen in Figure 4, the creep strain value is 0.027 for T= 288°C, σ = 13.8 MPa conditions. At the same temperatures, when the stress increases 13.8 MPa to 20.7 MPa, the creep strain value increases approximate 2.61 times. Similarly, the creep stain increases nearly 5.38 times when the stress increases 13.8 MPa to 27.6 MPa at the 288°C.

Also, creep behavior for the aluminum-titanium diboride (Al-TiB_2) metal matrix was affected by temperature. At constants 27.6 MPa stress, when 232°C was applied for 6% volume of TiB_2 the creep strain is 0.0017. When the temperature increases from 232°C to 288°C, the creep strain value increases nearly 81.8 times. As seen in Figure 4, the creep strain is 0.1455 for T= 288°C, σ = 27.6 MPa conditions. These result presented that the creep strain of the aluminum-titanium diboride (Al-TiB_2) metal matrix affected for both stress values and temperatures values. Finally, the creep behavior can be significantly controlled by selecting the stress and temperatures as a parameter.

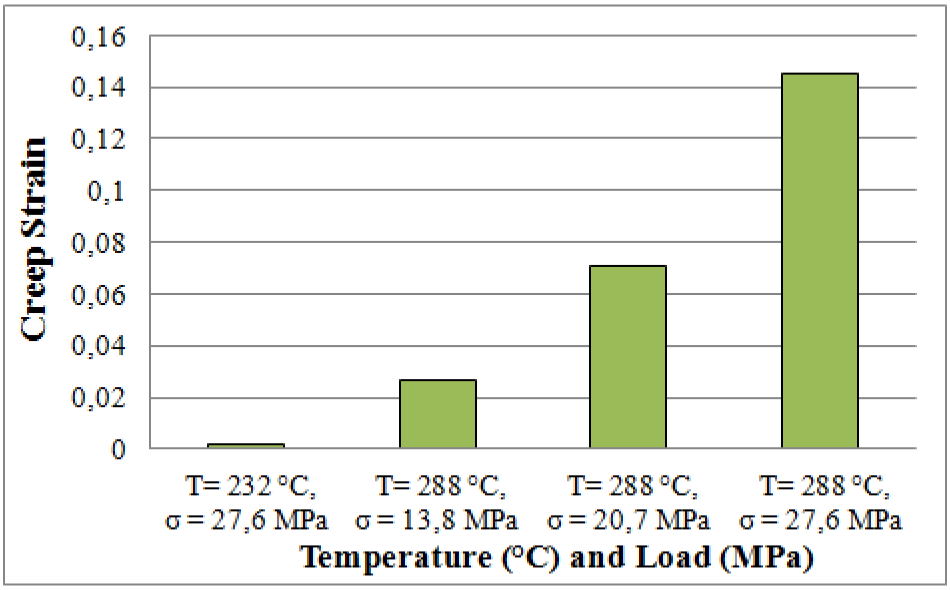

Figure 4. Effect of the temperatures and stress on the creep strain for 6% volume of TiB_2.

From the numerical results, the creep strain of the aluminum-titanium diboride (Al-TiB_2) metal matrix were measured for different design composition of % volume of TiB_2. The plot in Figure 5 clearly shows the benefit provided by the change of the % volume TiB_2. The creep strain values compared for the percentages of TiB_2 volume ratio in Aluminum 6061 in the T= 232°C, σ = 27.6 MPa conditions in Figure 5(a). In Figure 5(b) shows that the creep strain decreases as 30.29% when the percentages of volume ratio of TiB_2 is raised from 3% to 6% for T= 288°C, σ = 13.8 MPa conditions. The maximum change reflecting the differences of the TiB_2 ratio is seen in case of vol. 3% to vol. 9%. For example, in Figure 5(c) for the T= 288°C, σ = 20.7 MPa condition shows that the creep strain decreases nearly 106%. Similarly, when the percentages of volume ratio of TiB_2 is raised from 3% to 9%, the creep strain decreases as 117%, it can be seen in Figure 5(d). These results revealed that composition of the volume %TiB_2 plays a major role in the creep behavior on aluminum-titanium diboride (Al-TiB_2) metal matrix composites. As the % volume ratio of TiB_2 increases, the creep strain values decreases. In other words, the creep resistance can also be said to increase.

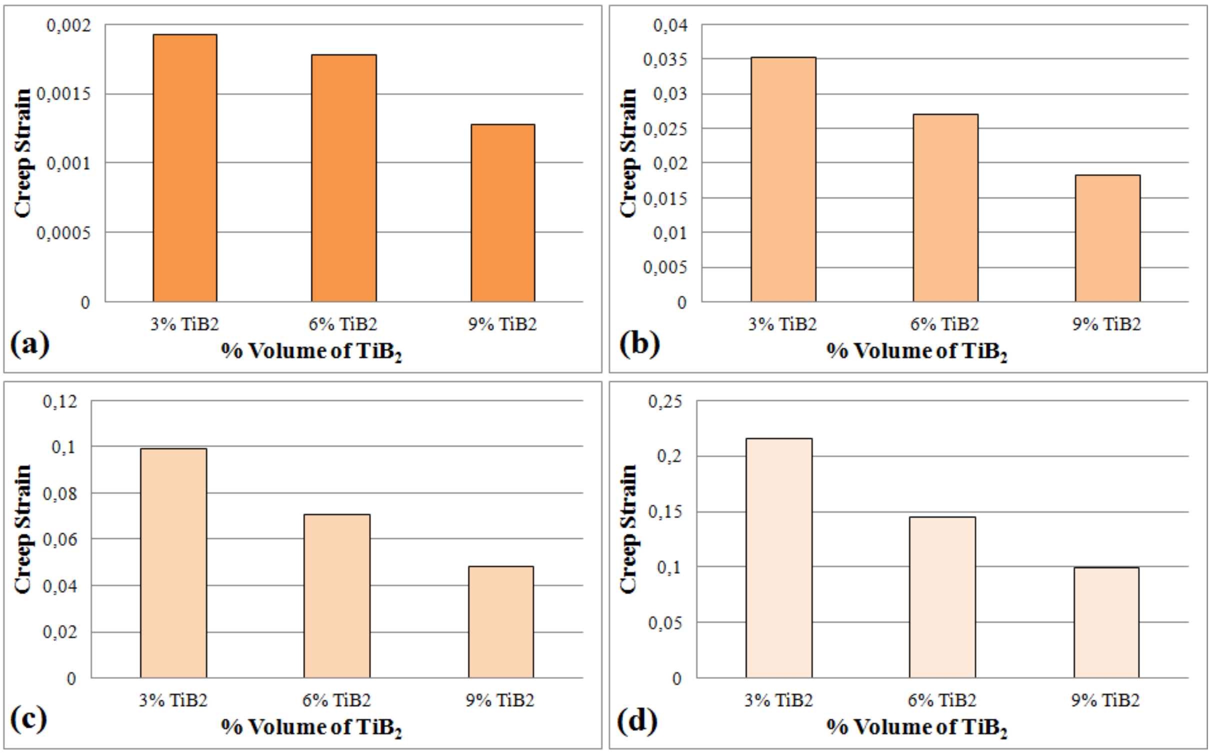

Figure 5. Effect of the volume ratio TiB_2 on the creep strain, a) T= 232°C, σ = 27.6 MPa, b) T= 288°C, σ = 13.8 MPa, c) T= 288°C, σ = 20.7 MPa, d) T= 288°C, σ = 27.6 MPa.

Conclusion

In this study, finite element model was used to estimate the creep behavior of the aluminum-titanium diboride (Al-TiB_2) metal matrix composite for investigating the creep strain values. Firstly, different percentages of reinforcing particles (TiB_2) were chosen as 3, 6 and 9% in volume for obtained different metal matrix composites mixtures and also two different high temperature constant value (232°C and 288°C) were used. Three various stress value (13.8 MPa, 20.7 MPa and 27.6 MPa) were also used for measuring the creep strain which is a function of time. Time was selected as 2.5 hours in this paper. Comparing the obtain results from the numerical investigation, it is seen that the creep strain increases when the temperatures and stress values increase. Also finite element model were investigated for three different percentages of reinforcing particles TiB_2 for obtain the creep behavior. As the % volume ratio of TiB_2 increases, the creep strain values decrease and also it is mean that as the % volume ratio of TiB_2 increases, the creep resistance of metal matrix composite increases. The results indicate that a useful aluminum-titanium diboride (Al-TiB_2) metal matrix composite can be achieved by selecting proper design parameter as a reinforcing particle TiB_2 for high temperatures.

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