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Investigation on the Creep Behaviour of Friction Stir Processed Al-Ni Composite Material

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ABSTRACT

Indentation creep experiments were carried out on friction stirred Aluminum-Nickel composite. The samples were cut from Al-Ni plate which was undergone by friction stir processing. The specimen was polished by different polishing methods to reveal the macro and micro structure of the material. The macro structure contains two zones (base metal zone and friction stirred zone).

Creep tests were carried out on both friction stirred and base metal region of test specimen at different temperatures with different loads. It was found that there was a significant difference between the creep rates of friction stirred region and that of base metal region when tested under various conditions. The Activation energy determined was found to in the range of 45KJ/Mole to 55KJ/Mole at lower temperatures. Based on these results it can be concluded that the operative mechanism is the dislocation creep. But at higher temperature the Activation energy was found to be in the range of 140KJ/Mole to 170KJ/Mole so the operative mechanism for creep is diffusion creep. Samples were metallographic ally prepared and the microstructures were studied under optical and scanning electron microscope. Results of the experiments were discussed.

KEYWORD: *Composite, Friction Stir Processing, Impression Creep*

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INTRODUCTION

Aluminum and its alloys are an important class of materials because of their versatile properties which render them suitable for use in a variety of applications. There has been a constant effort to improve the mechanical properties of Al alloys by various means. Metal matrix composite technology is one such method which has become very popular in the past three decades. Aluminum intermetallic compounds are expected to serve as practical materials for their resistance for ware, high hardness and stability at an elevated temperature. However, Aluminum intermetallic compounds such as Al3Ni are so brittle that it alone cannot serve as a structural material. Friction stir processing (FSP) is a relatively novel multifunctional metal working method, developed based on the basic principles of friction stir welding (FSW). The severe plastic deformation and material flow in stirred zone can be utilized to achieve bulk alloy medication via mixing of other elements or second phases into the stirred alloys. As a result, the stirred material becomes a metal matrix composite or an intermetallic alloy with much higher hardness and wear resistance. The experiments were designed to research the feasibility of producing Al–Ni intermetallic composites by FSP.

The duplex micro structure consisting of parent region and processed region phases has been observed (Figure 1). This investigation is aimed at understanding the creep behavior of the Al-Ni friction stirred alloy.

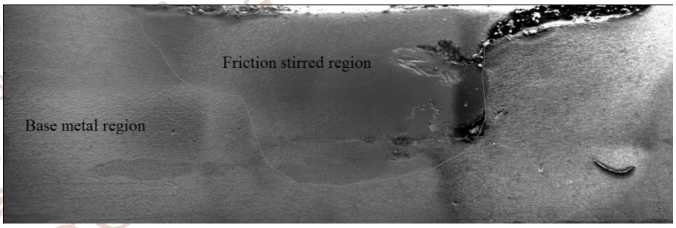

Figure 1: SEM photo macrograph shows clearly the base metal region and processed region of Al-Ni friction stirred alloy.

Impression creep technique is a modified indentation creep test wherein the conical or ball indenter is replaced by a cylindrical, flat bottomed punch. This test has many benefits several over the conventional creep testing. It is the most suitable method to study the creep behavior of parent and processed zones. It takes the shorter duration for test, and small quantity of the testing material. The test can be carried out with a constant stress at constant load.

Utilizing the indentation creep test, the creep behavior of individual zones in Al-Ni friction stirred alloy has been examined. Samples were selected from the plates which had been processed by friction stir processing. Indentation creep behavior of Al-Ni friction stirred composite was studied using tungsten carbide indenter at various stress levels and various temperatures. From the creep profiles steady state creep rates (εs) were calculated. Further activation energy values were determined. Creep rates for processed region and parent metal were compared.

EXPERIMENTS:

Friction stirred Al-Ni composite and its regions were tested for the creep behavior using impression creep apparatus. The specimen was prepared by slicing the friction stirred sample into a single specimen containing two zones (parent zone and stir zone). The samples were polished by using 1/0, 2/0, 3/0, 4/0 grade emery papers and further the samples were polished on a disc polishing machine by using diamond paste as abrasive medium until a flat and scratch-free mirror-like finish was obtained. To reveal the macrostructure, the sections were etched.

Impression creep experiments were carried out both at FSZ and BMZ using a tungsten carbide indenter. A sketch of the tungsten carbide indenter used is shown in Figure 2. During experimentation, the indenter was pierced into the sample (either at FSZ or BMZ). The depth of the indentation of the indenter was noted continuously by using transducer. Generally, the time of Impression creep experiments is 200 minutes, and this time is enough to attain steady state creep conditions. The creep experiments were carried out at30°C, 100°C, 150°C, 180°C, and 210°C.

The indenter displacement in the indentation creep set-up could be measured with an accuracy of 1 micron in LVDT. The data acquisition unit of the computer stores the displacement values occurred over the time in a given test that can be retrieved. The displacement values are to be divided by the indenter diameter to get the strain values. The slope of the strain-time curve at any point gives the creep rate prevailing at that instant. The slope of the curve at the secondary creep stage gives the steady state creep rate (SSCR) value as shown in Figure 3.

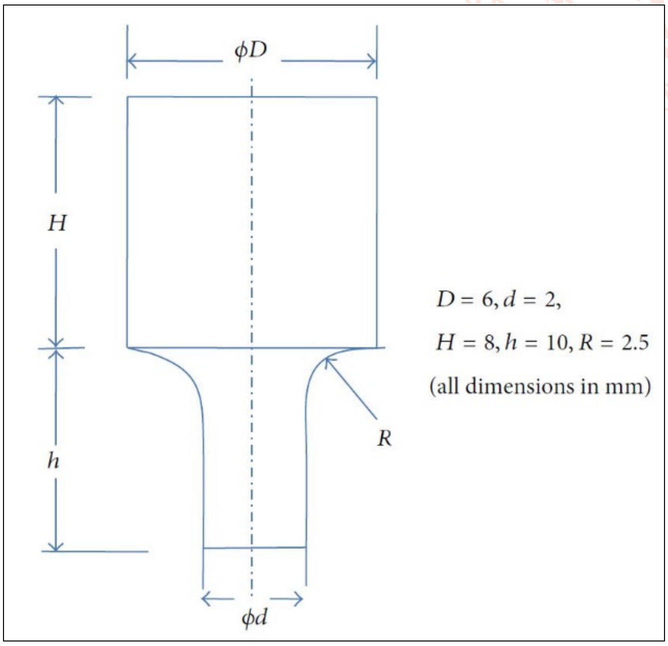

Figure 2: Dimensions of the indenter used for impression creep experiments.

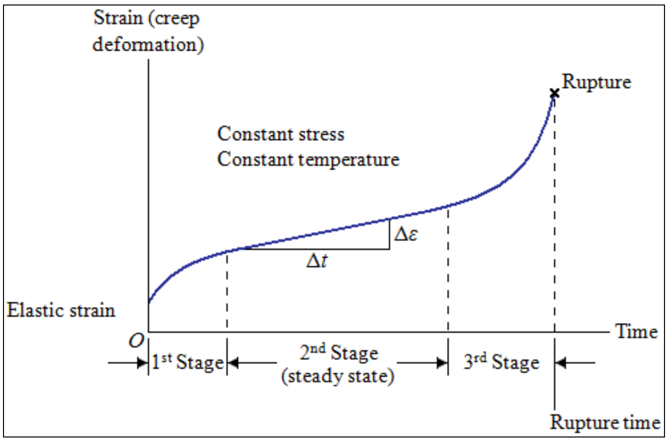

Figure 3: Calculation of steady state creep rate (SSCR) from indentation creep curve.

A temperature differential creep test is often used to measure the activation energy for creep. If the temperature interval is small so that creep mechanism would not be expected to change, it can be written that,

$$A = \dot{\varepsilon}_1 \exp(\frac{Q}{RT_1}) = \dot{\varepsilon}_2 \exp(\frac{Q}{RT_2})$$

$$Q = \frac{R \ln(\frac{\dot{\varepsilon}_1}{\dot{\varepsilon}_2})}{\frac{1}{T_2} - \frac{1}{T_1}}$$

Where, έ1 and έ2 are the strain rates at temperatures T1 and T2 (absolute scale), A, is constant that depends on the structure of the material, Q, is activation energy for creep, R, is the Universal Gas Constant.

RESULTS AND DISCUSSION

Friction stir processing is expected to modify the surface and surface sub portion of the materials and improve their mechanical properties. Intense friction generated during the stirring process under dynamic load leads to alloying by normal as well as ballistic diffusion process. It is associated with heavy plastic deformation of the processed zone. The heavy plastic deformation in the presence of higher temperature leads to dynamic recovery and dynamic recrystallization in the processed zone. These metallurgical events have created clearly two visible regions which can be identified in the optical photomicrographs as presented in the Figure 1.

Impression creep is the best method finding creep properties at each and every spot-on test specimen and constant stress can be maintained throughout the test. Impression creep test has been carried out on test specimen of Al-Ni alloy at various temperatures and steady state creep rates and activation energy values are determined for both friction stirred region and base metal region. When specimen is undergoing creep, there are so many metallurgical events like elastic deformation, plastic deformation, work hardening, dynamic strain ageing, homogenization, dynamic recrystallization and diffusion take place.

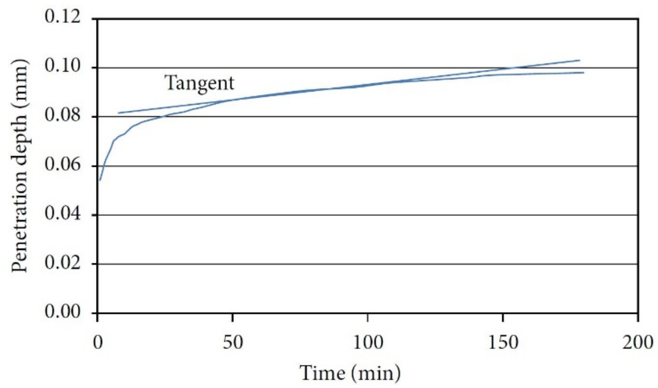

Figure 4: Penetration depth of the indenter as a function of time.FSZ, room temperature, and 5 kg load.

The steady state creep rates for the base metal and friction stirred regions at different temperatures are provided in Table 1. We see that the steady state creep rate value increases as temperature increases, and this is shown in Figure 5.

Table 1: Steady state creep rates in friction stirred zone and basemetal (load: 5 kg).

Temperature (°C)	Steady state creep rate (min^{-1})	
	Base metal region	Friction stirred region
30	2.8×10^{-5}	8×10^{-5}
100	29×10^{-5}	8.5×10^{-5}
150	198×10^{-5}	88×10^{-5}
180	232×10^{-5}	176×10^{-5}
210	4125×10-5	1833×10-5

Table 2: Activation Energy (Q) values of friction stirred Al-Ni alloy for both regions at a load of 5 Kg.

Temperature range(°C)	Activation energy(Q) values in KJ/Mol	
	Base metal region	Friction stirred region
100-150	50	60
180-210	170	140

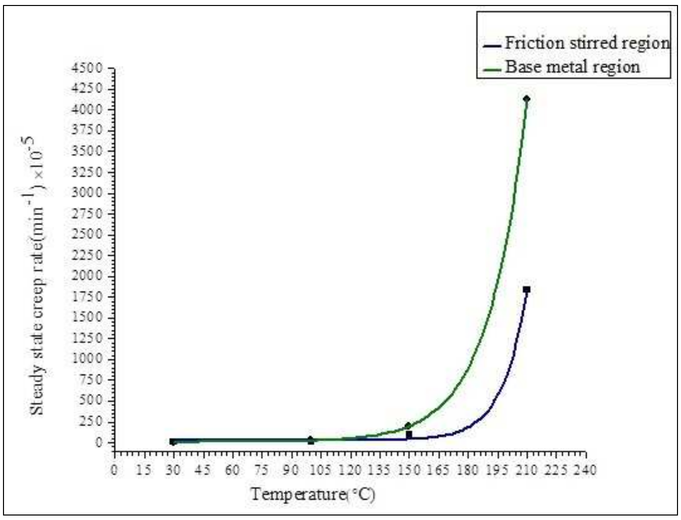

Figure 5: Variations of steady state creep rate ($\times10^{-5}$) as a function of temperature.

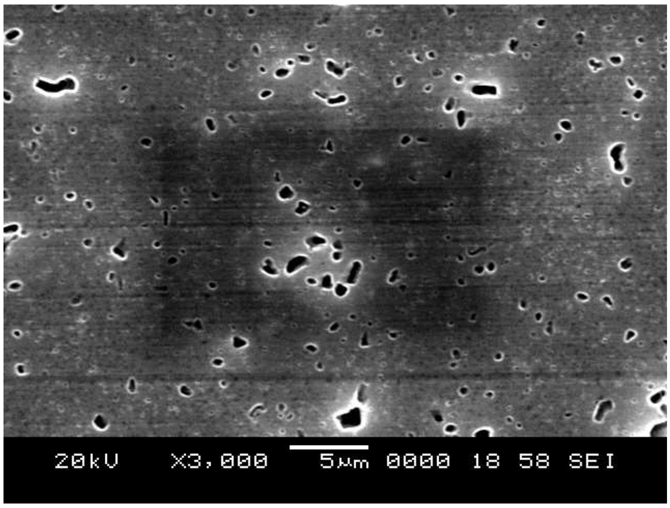

Figure6: SEM photo micrograph shows the Etch pits (black dots) in stirred region of friction stirred Al-Ni alloy

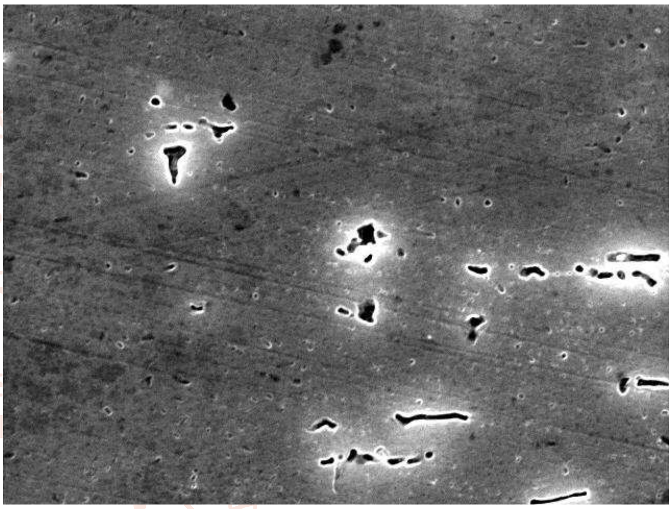

Figure 7: SEM photo micrograph (at 3000X) shows pure Aluminum in base metal region of friction stirred Al-Ni alloy.

The activation energy determined was found to be in the range of 45 KJ/Moleto 55 KJ/Mole in the temperature range 30-150°c, comparing it with the activation energy for the movement of dislocation in Al alloys it could be inferred that the underlying creep mechanism is dislocation creep in the both the regions. In the temperature range of 30-150°C, it is well known fact that, at low temperatures, the thermal activation affects the lattice resistance to the glide of the dislocation. The temperature variation of the creep rate is related to thermally assisted force required to overcome obstacles lying in the plane of dislocation glide. Thus, it is arguably inferred that dislocation creep dominates the mechanism of creep in Al base metal and friction stirred zone, in the temperature range of 30-150°C.

The activation energy determined was found to be in the range of 140KJ/Moleto 170KJ/Mole in the temperature range 150-210°c, is very close to the activation energy for self-diffusion (150KJ/Mole) in aluminum. For this reason, the rate controlling creep mechanism, at higher temperatures in both the friction stirred region and base metal region of Al, has been ascribed to diffusion creep. Higher creep resistant in friction stirred region, due to three reasons:

1. Diffusion of Ni atoms into Al matrix by mechanical alloying.
2. Precipitation of second phase particles.
3. Dislocations created by friction stir processing.

Higher level of creep resistance was exhibited by processed zone compared to parent metal even at high temperature (table1). It suggests that second phase particles play an important role in the creep mechanism. However, the presence and nature of the second phase particles need to be studied under transmission electron microscope. SEM photomicrographs (fig.6, fig.7) reveal that the etch pit density is high in processed zone compared to base metal region. Etch pits are the dislocations cutting through the surface. The etch pits are representing the dislocations indirectly. This is an indirect indication to that the dislocation density is high in processed zone to compared to that of base metal region. Movement of dislocations becomes difficult in the presence of high dislocation density so that processed zone has high creep strength compared to that of base metal region.

CONCLUSIONS

Based on the present investigation following conclusions have been arrived at:

1. Friction stirred zone of Al with Ni particles exhibits higher creep resistant by an order compared to unprocessed Al base metal at all temperatures.
2. The values of experimental determined activation energy, being in the range of 45KJ/Mole to 55KJ/Mole (in the temperature range 30-150°C), suggests that creep mechanism is dislocation creep.
3. At higher temperatures (150-210°C), the values of experimental determined activation energy are in the range of 140KJ/Mole to 170KJ/Mole. It suggests that creep mechanism is diffusion creep.

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