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MICROSTRUCTURAL AND TRIBOLOGICAL PROPERTIES OF ULTRA FINE GRAINED HYBRID COMPOSITE PRODUCED BY FRICTION STIR PROCESSING

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Abstract. Ultra fine grained (UFG) Al5083 based hybrid composite reinforced by SiC and MoS_2 particles was prepared by Friction Stir Processing (FSP). A constant tool travel speed of 50 mm/min and different rotation speeds from 630 up to 1600 rpm were used. The microstructure of the Al based composite were investigated and compared to base metal and FSPed samples. It was found that although FSP resulted in decreasing the mean grain size of the base metal to about 2 μm, the addition of reinforcing particles in microstructure led to the more decrease in grain size of the alloy. An ultra fine grained hybrid composite with 500 nm grain size was obtained through rotation speed of 1250 rpm. Moreover, this hybrid composite showed the highest wear resistance and hardness in comparison to all samples due to the modification of microstructure and the addition of particles.

1. Introduction

The plastic deformation behaviors of Ultra Fine Grained (UFG) materials have drawn tremendous interest due to the scientific and technological importance of the problem. The mechanical properties of commercial metals can be dramatically enhanced by extensive grain refinement, thus offering new opportunities to exploit some attractive physical properties in metals having a reasonably high strength for structural applications. Fundamental research works on grain refinement by intense plasticity published in recent years focussed on the mechanisms that effectively reduce grain size down to sub-micrometer in metals. In order to convert a coarse grained solid into a material with ultra fine grains, it is necessary to impose an exceptionally high strain in order to introduce a high density of dislocations which, in turn, re-arrange to form an array of grain boundaries with increase in strain [1, 2].

In contrast to conventional production methods, the severe plastic deformation (SPD) techniques such as Friction Stir Processing (FSP) are processes, where extremely high strains are imposed at relatively low temperatures and can lead to equiaxed microstructure and high angle grain boundary misorientation. Materials processed by FSP have shown superior mechanical properties such as high strength, excellent fatigue life, high toughness and low temperature superplasticity [3, 4].

FSP, which was developed based on the principle of friction stir welding (FSW), is remarkably simple. A rotating tool with a pin and shoulder is inserted into a single piece of material and results in significant microstructural changes in the processed zone, due to intense plastic deformation. FSP has been proved to be an effective way to refine the microstructure of aluminum alloys, and thereby improve the mechanical properties [5, 6]. Previous investigations [7, 8] have indicated that a fine grain structure affects the tribological properties of surface layer. Prasada et al. [9, 10] reported that the grain refinement leads to the improvement of wear resistance and load bearing capacity of Al-7Si alloy. Chandrashekharaiah and Kori [11] also reported similar results for different Al-based alloys. One of the major problems associated with Al5083 like other aluminum alloys, is their relatively poor wear resistance which limits their tribological performance [12].

The present work has been undertaken to develop ultra fine grained Al alloy by FSP to examine its microstructure and mechanical properties. An important objective of this work is to identify and quantify interrelationships between the rotation speed of FSP tool and mechanical behavior of FSPed Al alloy and UFG aluminum based composite processed by FSP.

2. Experimental procedure

Commercially Al5083 rolled plates of 3 mm thickness with a nominal composition of 4.3Mg–0.68Mn–0.15Si–bal. Al (in wt pct) was the base material. Powders of SiC and MoS_2 were mixed at weight ratio of 2 to 1 and used as the reinforcements. MoS_2 particles with 99.9 % purity and 5 μm average size used in this study as lubricating material due to its lamellar morphology. SiC particles with 99.9 % purity and 5 μm average particle size, was also used as hard reinforcing material.

A tool made of steel H-13 with a shoulder of 20 mm diameter and a pin of 6 mm diagonal length and 2.8 mm height with a tilt angle of 3º was used to apply FSP. The mixture of reinforcing particles was packed in a groove of 2 mm depth and 0.65 mm width machined out on the Al plate.

Samples divided in two groups, namely, FSPed samples without reinforcing powder and composite samples with the mixture of reinforcements. Both groups were subjected to one FSP pass along the same direction with travel speed of 50 mm/min and different rotation speeds from 630 to 1600 rpm in room temperature. In order to measure the temperature of the center of the processed line of samples, a thermocouple with the accuracy of $\pm 5\,^{o}C$ were put into a hole under the plates and the variations of temperature were recorded.

Microstructural observations were performed on specimens by transmission electron microscopy (TEM). The micro-hardness of the surface composite layers was measured using 200 gr force. The wear behavior of the specimens was evaluated by using a pin-on-disk tester after 4000 m sliding in air at room temperature. Pin specimens with 5 mm diameter were cut from the center of surface of as-processed samples and ground on emery paper up to 320 grade. Discs made of AISI D3 steel with hardness of 58 HRc used as counterpart. The wear tests were carried out at normal loads of 5 KN and the rotation speed of 60 rpm. The wear weight loss was measured with an accuracy of ±0.01 mg.

3. Results and Discussions

Figure 1 illustrates the variations of temperature of the center of processed line for the samples FSPed at 630 to 1600 rpm. As can be observed in this figure, increasing the rotation speed results in increasing the heat input and hence the material's temperature from 370 ^{o}C for 630 rpm to 575 and 595 ^{o}C for 1250 and 1600 rpm respectively. Therefore, the rotating tool may provide the activation energy for the occurrence of restoration mechanisms in the Al alloy and can result in changing its microstructural and mechanical characteristics. For this reason, the microstructure, hardness and wear properties of the alloy should be investigated.

Figure 2(a) shows the variations of grain size of base metal and samples processed at 630 to 1600 rpm rotation speed. The results indicated that FSP has led to the grain refinement comparing to base metal. Moreover, increasing the rotation speed has resulted in decreasing the grain size of processed zone. It can be mentioned that with increasing the rotation speed from 1000 rpm, the mean size of grains suddenly dropped to its minimum at 1250 rpm. It may be attributed to the occurrence of different restoration mechanism with the increase of heat input. Previous investigations [13, 14] have indicated that in FSP/W, a continuous dynamic recrystallization phenomenon can occur due to the mechanical action of the tool pin and the frictional heat produced. This phenomenon can lead to intensive microstructural refinement. However, with increasing the rotation speed, the mean grain size increases again. Increasing the rotation speed from 1250 up to 1600 rpm has probably led to occurrence of more dynamic recrystallization and grain growth due to higher heat input.

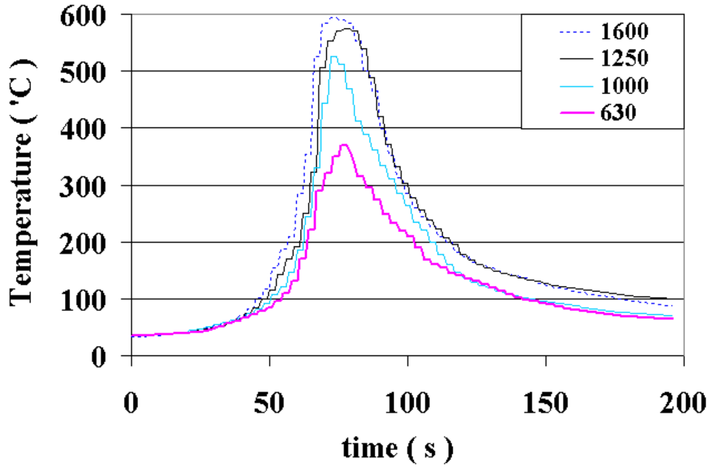

Fig. 1. Variations of temperature of the center of processed line of samples produced by different rotation speeds.

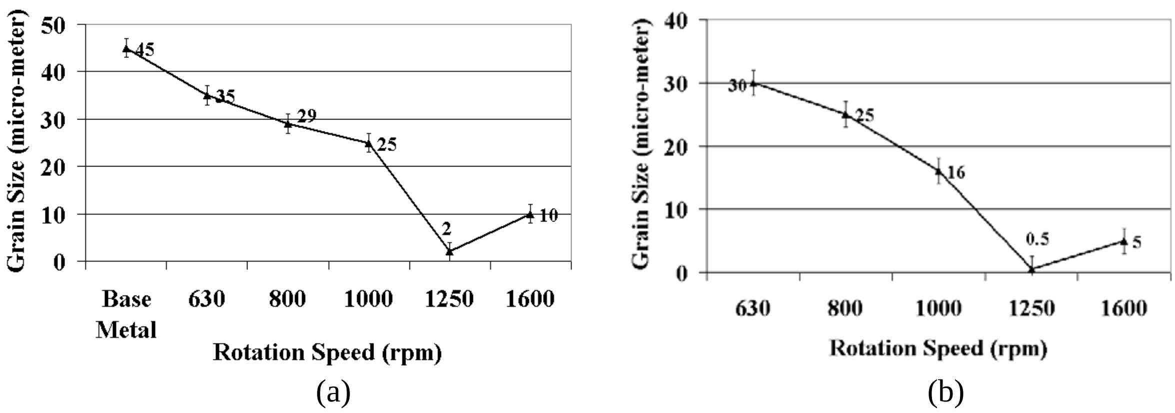

Fig. 2. Variations of mean grain size of (a) base metal and FSP samples processed at the rotation speed of 630 to 1600 rpm; (b) Composite samples produced at the rotation speed of 630 to 1600 rpm.

Figure 2(b) shows the variations of grain size of composite samples produced at 630 to 1600 rpm rotation speed. As can be seen in this figure, FSP has led to the more grain refinement of composite samples in comparison to FSPed specimens. This implies that the existence of reinforcing particles can lead to the more grain refinement. However, the trend of the variations of grain size is as same as for FSPed samples and confirms the change in the restoration mechanism with increasing the heat input due to the increasing rotation speed. Nevertheless, the existence of reinforcing particles has resulted in decreasing the mean grain size of composite samples in comparison to FSP specimens. The results also indicated that increasing the rotation speed up to 1250 rpm, resulted in the formation of ultra fine grains in the microstructure of produced composite material due to the occurrence of restoration mechanisms along with the existence of reinforcing particles.

Figure 3 shows the variations of the mean hardness of base metal and samples processed at 630 to 1600 rpm rotation speed. As can be seen in this figure, FSP has led to the increase in the hardness of samples in comparison to as-received material. Furthermore, increasing the rotation speed has resulted in more increase in hardness of samples. These results are in good agreement with microstructural observations and may be attributed to the increase in yield strength of material owing to microstructural refinement in accordance with Hall-Petch relation [5, 6]. As the rotation speed increases from 1250 to 1600 rpm, the hardness drops due to the increase in the grain size and heat input.

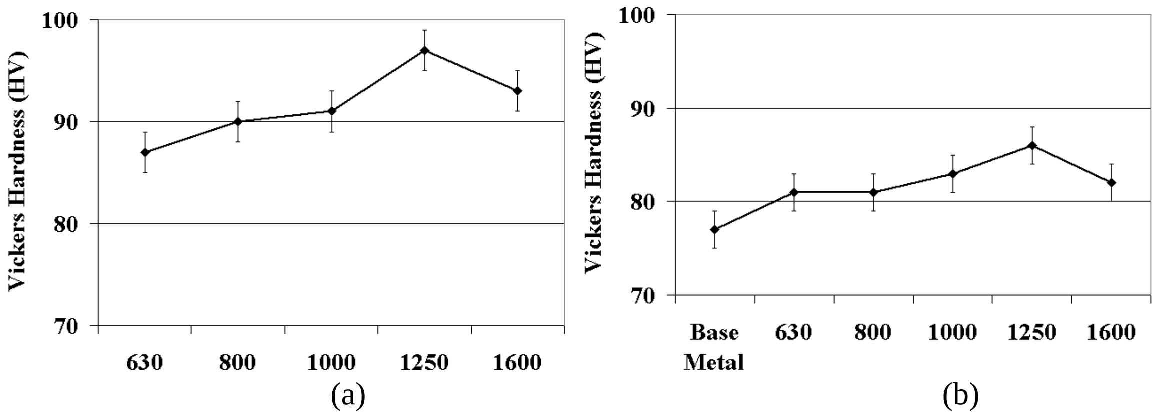

Fig. 3. Variations of mean Vickers Hardness (HV) of processed zone of (a) base metal and FSP samples processed at the rotation speed of 630 to 1600 rpm; (b) Composite samples produced at the rotation speed of 630 to 1600 rpm.

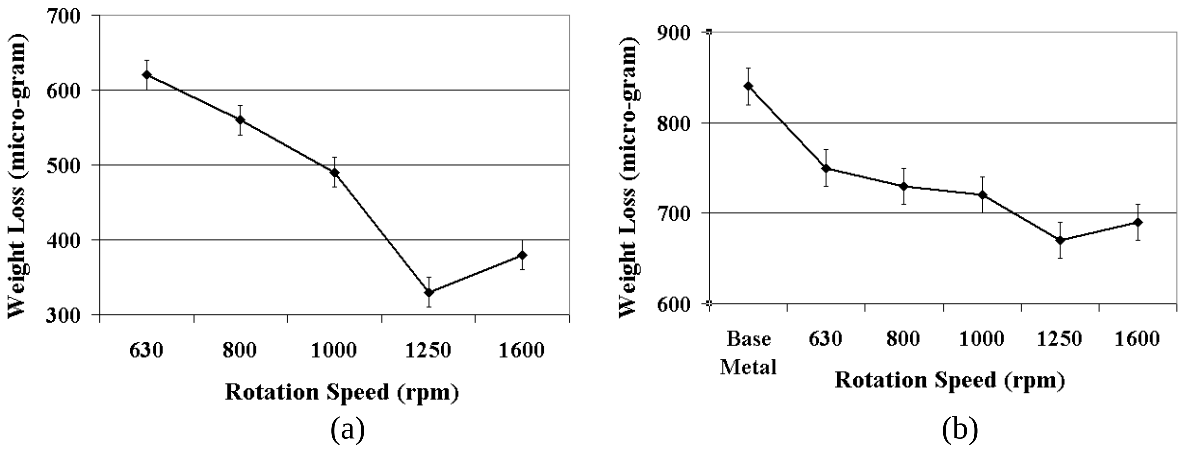

Fig. 4. Variations of weight loss of (a) base metal and FSP samples processed at the rotation speed of 630 to 1600 rpm; (b) Composite samples produced at the rotation speed of 630 to 1600 rpm.

Figure 4(a) shows wear weight loss of base metal and samples FSPed at different rotation speeds. The results indicate that FSP has led to the decrease in wear weight loss compared with as-received metal and hence improving wear resistance. This can be attributed to the increase in hardness due to the microstructural refinement. Besides, as can be seen in this figure, wear weight loss of samples decreases with the increase in the rotation speed of FSP tool. This observation is in good agreement with the trend observed for the hardness of the samples (Fig. 3). Increasing the hardness of metal can lead to the occurrence of less plastic deformation during sliding [9, 10]. The results indicate that FSP can lead to the improvement of wear resistance as well as hardness especially for higher rotation speeds up to 1250 rpm due to the improvement of microstructural characteristics.

Figure 4(b) illustrates wear weight loss of composite samples produced by different rotation speeds. The observed trends for these samples were similar to those for FSP specimens. As can be seen in both Figs. 4(a) and (b), there is a sharp decrease in the amount of weight loss of samples processed at 1250 rpm. This observation is in accordance with the results obtained from the hardness and mean grain size shown in Figs. 2 and 3 and confirms the occurrence of different restoration mechanism occurred in the rotation speed of 1250 rpm.

4. Conclusions

In the present investigation, an attempt has been made to study the microstructural and mechanical properties of Al based composites and compare it to base metal and FSPed samples. The obtained results can be summarized as follows:

1- FSP resulted in grain refinement of the alloy in comparison to base metal. Moreover, increasing the rotation speed led to the more decrease in the size of grains and this factor dropped sharply to 2 μm in 1250 rpm owing to the restoration phenomenon. The same trends were observed for produced composite samples and the rotation speed of 1250 rpm obtained ultra fine grained microstructure with 0.5 μm mean grain size.

2- FSP has led to the increase in the hardness of the alloy. Increasing the rotation speed also led to the improvement of hardness and maximum value were obtained in 1250 rpm. These can be attributed to the microstructural refinement.

3- FSP resulted in the improvement of wear resistance of the alloy. Moreover, increasing the rotation speed led to the improvement of wear resistance. Similar trend were also observed for composite samples and confirmed the improving effect of higher rotation speed on the wear resistance of the alloy. This can be due to the increase in hardness and microstructural refinement. Ultra fine grained microstructure which was obtained by 1250 rpm, showed the highest wear resistance amongst all samples due to the highest hardness and lowest grain refinement.

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