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Effect of Cryogenic Treatment on Microstrucutre and Tribological Properties of Al6061 Hybrid Metal Matrix Composite

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Abstract **- The cryogenically treated aluminium metal matix composite is subjected for the tribological properties to measure the improved performance of the wear resistance in pin on drum wear testing machine. Cryo means cold born crystal structure in metallurgical aspect. Cryogenic treated nonferrous metals will exhibit longer wear and more durability. During metal making process, when solidification takes place, some molecules get caught in a random pattern. The molecules do move about at subzero and deep cryogenic treatment slowly. In this experimental study the effect of deep cryogenic treatment for Al6061 alloy with SiC and TiO_2 of each 2.5% for equal volume fraction is studied. The execution of cryogenic treatment on both alloy and MMCs changed the distribution of β precipitates. The XRD crystallogram reveals that the cryogenic treatment can change the diffraction peak intensity of some crystal planes in MMCs. The influences of different volume fraction of reinforcement and cryogenic process on microhardness of Al6061 alloy and composite were compared with alloy and composite without cryo treatment and the results showed that the cryogenic treatment improves the wear resistant and hardness of Al6061/SiC-TiO_2 hybrid composites.**

Keywords: MMCs, Cryogenic treatment, Microstructure, Micro hardness

INTRODUCTION

The metal matrix composite for its enhanced properties has wide applications in automobile and aerospace industries due to their weight saving characteristics and providing high beneficiaries over existing materials[1].To further increase the properties of these composites several process like heat treatment for whole material and surface processing is also being carried out, In other hand cryogenic treatment also known as subzero treatment is done which is very old process and widely used for the high precision parts and objects especially for the ferrous and tooling materials earlier [2]. The subjecting of the material to extreme cold hardens, strengthens and molecular alignment in the micro level is fine and smooth the material has longer life [3]. Now the cryogenic treatment which is whole material teatment is widely used in many automotive, aerospace, electronic and mechanical engineering industries to improve mechanical strength and dimensional stability of components [4]. For the past few years the cryogenic treatment for the nonferrous metals such as aluminium and magnesium alloys has been done for the their improvement of properties [5]. The improved mechanical properties and microstructure changes of the metals and alloys in cryogenic processing drew the attention of researchers towards this process. The researchers [6,7] showed the beneficial effects of cryogenic treatment on nonferrous metal aluminium. The effect of cryogenic treatment on the wear performance of copper alloy showed least significant changes [8]. The researcher Adam [9] showed the significant improvement of the mechanical properties strength, hardness, toughness of aluminium alloy when subjecting it to cryogenic treatment. This lead to the idea of analyzing the properties when a MMCs is undergoing cryogenic treatment. This field is rapidly growing and is used by many manufacturers. The present work intends to construct a facility to research the process and results of the cryogenic treatment. This helps to create standards for both processing and testing that are currently unavailable. Hence it gives importance that mechanical properties of the MMCs developed are evaluated at cryogenic temperatures. Thus in this experimental work cryogenic treatment was applied to Al6061/SiC-TiO_2 MMCs to study its effect on microstructure and hardness of Al6061/SiC-TiO_2 MMCs.

1. EXPERIMENTATION

The hybrid Al6061, SiC and TiO2 composite of equal volume is prepared by stir casting method by taking matrix material as Al6061 alloy and the particulate reinforcement as SiC and TiO_2 upto a volume fraction of 7%. The chemical composition of Al6061 alloy is given in the table 1. The reinforcement particles were chosen as commercial SiC anad TiO_2 with 99.5% purity.

Table 1 Chemical composition of Al6061 aluminium alloy

Cu	Si	Mg	Mn	Fe	Ti	Ni	Zn	Sn	Al
0.17	0.8	1.2	0.15	0.15	0.13	0.006	0.06	<0.001	balance

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The SiC and TiO_2 of 30-50 µm size were used as the particle reinforcement in the hybrid composite material. The reinforcement particle used as equal volume fraction by 2.5% SiC and TiO_2 2.5%. The reinforcement particle is preheated to a temperature of 550°C to remove the moisture content before adding into the molten aluminium.

Fig 1

The stir casting method as shown in fig 1 is used to fabricate the composite, in which the preheated SiC and TiO_2 particle is introduced into the molten pool in the vortex created in the melt, by the use of power operated stirrer, its speed is maintained as 550 rpm and the stirrer is coated with alumina to prevent the migration of ferrous ions from the stirrer material to the molten metal. The depth of immersion of stirrer was two thirds the depth of the molten metal. The resulting mixture of Al6061 alloy and SiC and TiO_2 is tilt poured into the preheated permanent mould. Thus the equal volume fraction of reinforced SiC and TiO2 composite material is fabricated[10].

Cryogenic treatment of samples is performed by placing Al6061 alloy and Al6061/SiC-TiO_2 specimen in a cryogenic chamber. The cryogenic treatment is done nitrogen reservoir. The sample temperature is monitored by a K type thermocouple which was used to operate a stepper motor which lowered the sample and maintained a temperature decline at the rate of 1°C/min. The temperature is lowered to -196°C the time taken to reach is nearly 4 hours.

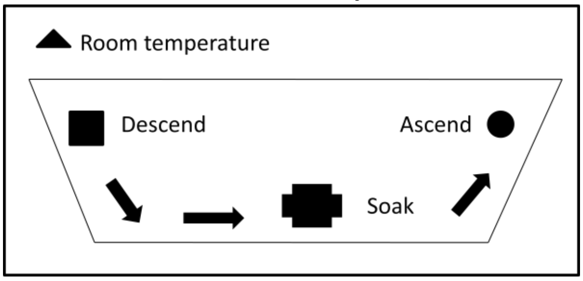
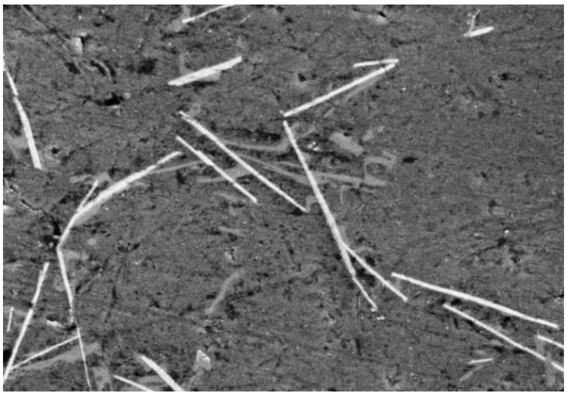


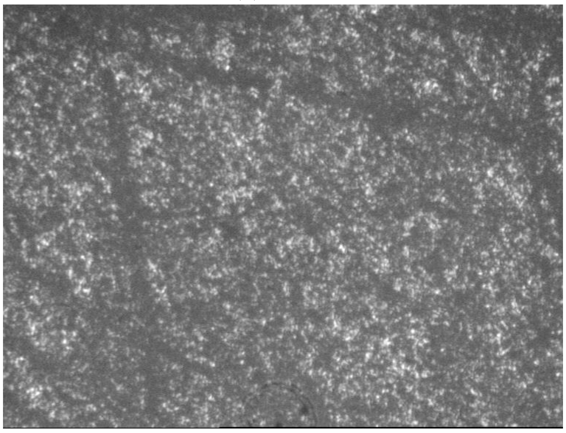
Fig 2 Cryogenic processing

The pain stacking method is very slow microprocessor controlled process which eliminates the probability of thermal shock and micro-cracking. The sequence of process is shown in Fig 2.Specimen were held at -196°C for various time duration such as 20 hours and slowly brought up to approximately +25°C. The cryogenic processing is followed as per Kaveh Meshinchi et al [5]. After the completion of cryogenic processing the specimen is prepared for microstructure analyzes according to ASTM E3 standards. The samples were subjected grinding and polishing followed by etching by nital. The optical microscope was taken using metallurgical microscope and then the specimen is washed with acetone and dried thoroughly for the hardness test.

2. RESULTS AND DISCUSSION

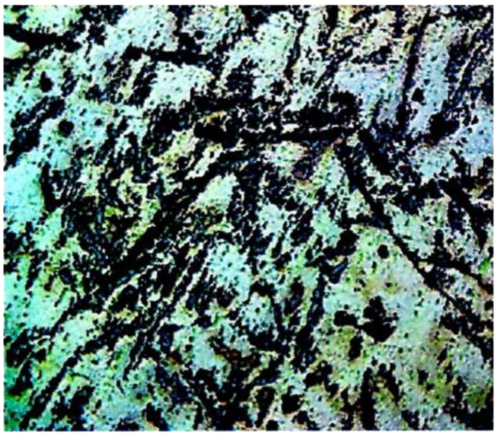


(a)



(b)

Fig 3. Microstructure of (a) Al6061 alloy and (b) Al6061 SiC+TiO_2 MMCs before cryogenic treatment



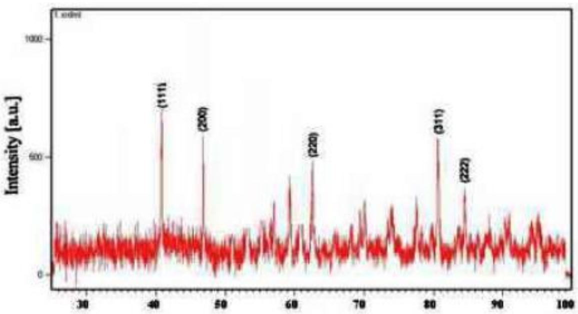
(a)

(b)

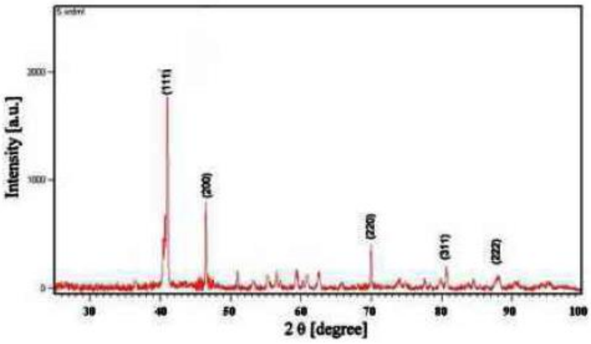
Fig 4. Microstructure of (a) Al6061 alloy and (b) Al6061+SiC-TiO_2 MMCs after cryogenic treatment

Fig 3.and Fig 4. Shows the microstructure image of the Al6061 alloy and its composite before and after cryogenic processing with 5% volume fraction of SiC + TiO_2. The impact of cryogenic processing has significant changes in the microstructure of MMCs and led to the transformation of α-Al to β ($Mg_{17}Al_{12}$) phase. In the Al6061 alloy the β phase exhibited irregular morphologies (eutectic β phase) and tiny laminar shaped morphologies. The β phase has main strengthening effect on Al-Mg based alloys at room temperature proved by Mehta et al. [11]. The lower mechanical properties at elevated temperature is due to the low melting point of these alloy Kaveh meshinchi et al. [5].

The cryogenic treatment of MMCs of Al6061+SIC-TiO_2 lead to the changes in microstructure as shown in Fig 3 (b). The coarse divorced β phase penetrated the matrix alloy. This improved hardness is the strengthening of the matrix against propagation of the existing defect which is due to the important role of β precipitates in the microstructure which are the main strengthening effect at room temperature.



(a)



(b)

Fig 5. (a) and (b) XRD patterns of Al6061+SiC-TiO_2 MMCs before and after cryotreatment

The XRD pattern before and after cryogenic treatment was studied. It reveals that the cryogenic treatment can change the diffraction peak intensity of the crystal planes in these alloys. Fig 4(a) shows the XRD pattern of Al6061+ SIC-TiO_2 MMCs before cryogenic treatment, the range of incident angle is between 30° and 100°. The target is Cu Ka, the tube voltage is 40KV and the electric current is 60 mA. The properties of MMCs are related to its XRD patterns gained from the surface of MMCs.

In fig 4. (b) for virgin surfaces of Al MMCs, it is mainly consistent with the standard pattern for FCC Al. The XRD pattern after cryogenic treatment, all the peaks are consistent but for half width of (111) peak decrease. This indicates that grain in MMCs becomes large after cryogenic treatment. The researcher Govindan potti et al. [12] showed that the crystallization strengthens after the specimen have been cryotreated. Due to this change in microstructure the hardness of the cryogenic treated samples increased compared with the as cast specimen with no treated.

Effect on Hardness of Al6061 hybrid composite

The Brinell hardness procedure consists of imprinting a steel ball of diameter D, with load F, on the piece to be examined and measuring the diameter d of the imprint left on the surface fig 5, after the load has been removed was done the results proved that the cryogenic treated sample showed higher hardness value compared to untreated sample and Al6061 alloy. The hardness increase for the composite material is due to the reinforcement and further the increase in hardness is to the cryo processing which favors for the molecular alignment in the microstructure as shown in the above fig 4.

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Fig 6. Effect on hardness of the Al6061+SiC TiO_2 MMCs

Effect on wear resistance for the cryo treated Al6061+SiC+TiO_2

In this experimental analysis, the hybrid composite material subjected to wear testing in pin on drum wear tester as shown in fig 7 (a) (b) is analyzed and presented in detail.

The sliding experiments are conducted at room temperature in a pin on drum of dia 150mm and 500mm length wear testing machine having coarse abrasive sheet of 60 grade.The pins are loaded against the disc by a dead weight loading system. The pin specimen is flat ended with 8mm diameter and 20mm length. Wear test on composite specimen Al6061, Al6061+SiC +TiO_2 untreated cryo sample and Al6061+SiC +TiO_2 cryogenic treated material. The load applied during test is 1kg.. During the test the relative humidity and temperature of the surrounding The photographic view of the pin on disk wear tester used in this investigation is shown in Fig. 7(a). The sem image of the wear tested sample is shown in Fig. 8. The sliding wear mechanism shows that larger grooves and dimples for the untreated sample fig 8(b) and cryo treated sample shows the smoother grooves and less material is removed while testing. The percentage of material loss before and after wear testing are shown are calculated. The cryogenic treated hybrid composite exhibited longer wear resistance and there is 12% difference in material loss between cryo processed material and untreated composite. The wear resistance increases for Al6061 +SiC +TiO2 hybrid composite material from the aluminium alloy Al6061. The enhanced wear resistance is due the addition of reinforcement material SiC and TiO_2. The SiC is harder material and TiO2 has lubricating property which favours for the wear resistance. In case of cryo treated hybrid composite the wear resistance further increases due to the molecular alignment at the subzero temperature.

Fig 7 (a) Wear testing samples

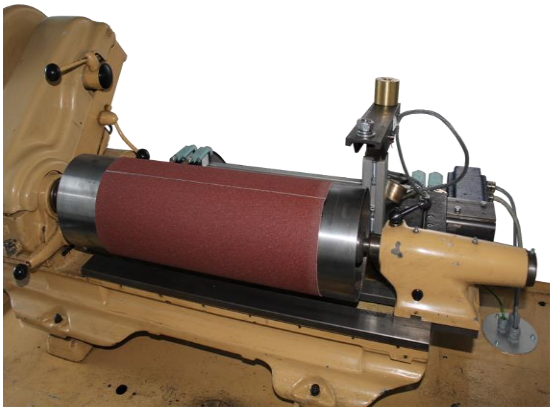

Fig 7(b). Pin on drum wear testing machine

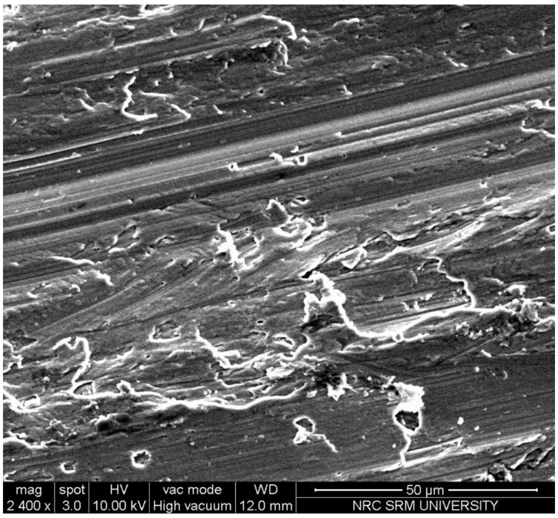

Fig 8 (a) SEM image of untreated cryogenic sample

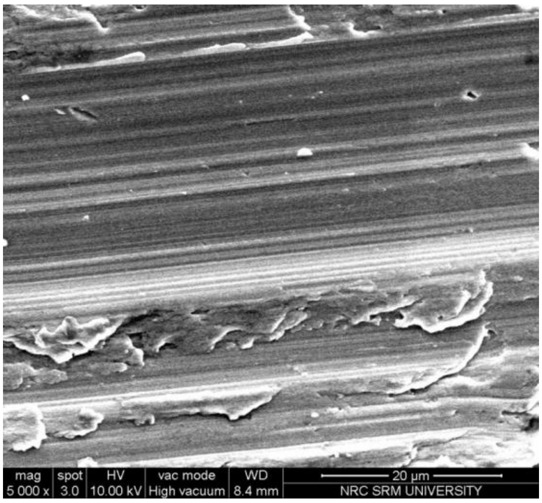

Fig 8 (b)SEM image of cryogenic processed hybrid composite

CONCLUSION

The Dry sliding wear behavior of this hybrid metal matrix composite (Al6061+SiC+TiO2) led to the following conclusion:

- Cryogenic treatment changes the morphology of precipitates in both Al6061 alloy and the Al6061+SiC+TiO_2 composite. The hardness of the cryogenic treated MMCs samples improves due coarse eutectic β phase present in the matrix compared with as cast samples.
- The hardness increase with the increasing volume percentage of reinforcement for the MMCs for the same cryogenic condition. The application of cryo treatment has increased the effects of particulates with the increase in particulate percentage but pure Al decreased the effect of Cryo treatment
- Microstructural change occur during initial cryogenic treatment which is felt in the changes in the diffraction pattern in XRD.
- As usual result, particulate reinforcement composite has high strength, hardness and wear resistance when compared with matrix material the wear resistance increases in the hybrid composite material when the SiC and TiO2 is added as reinforcement Unreinforced aluminium alloy exhibits more wear followed by SiC reinforced binary metal matrix composites and then the hybrid composite (Al6061+SiC+TiO2).
- The wear rate decreases with increasing volume content of the reinforcement, the reason is lubricating property and hardened nature of the TiO_2 particulte favors for the increased wear resistance
- The coefficient of friction decreases with increase in particle reinforcement and load (for the fixed size of SiC and TiO2 particulates) The coefficient of friction and wear rate of the hybrid composite Al6061 -SiC+TiO2 is less when compared with the matrix alloy and the binary composite.

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