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Research Article

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Tribological and Mechanical Properties of Al7075 Metal Matrix Composite Reinforced with CoMoMnNiV High Entropy Alloy Particles

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Abstract

Al7075 metal matrix composite (MMC) reinforced with High Entropy Alloy particles (HEAp) fabricated by stir casting technique. Mechanical and tribological behaviour of alloy and composite with varying content of CoMoMnNiV HEAp (5%, 7.5%, and 10%) were studied. Rockwell hardness of composite is tested with increasing content of HEAp. A hardness value of 112 HRB was obtained with 10 wt.% of HEAp which is 38% higher than base aluminum composite. The impact strength of composite with 10 wt.% of reinforcement has the highest value among other compositions. The tribological properties of the composite were tested under dry conditions using pin-on-disc apparatus with different sliding distances and applied normal load. The wear rate decreases with an increase in reinforcement content and reached to least at 10 wt.% of HEAp. Wear mass loss increases with an increase in applied normal load and sliding distance. The tribological behavior of the composite was significantly improved due to the presence of hard HEAp. The worn surface morphology of the wear sample was examined by images obtained from scanning electron microscopy (SEM). The shallow grooves present on worn surfaces indicate abrasive wear takes place, while deep grooves occur due to an increase in normal load. Composite with 10 wt.% of HEAp has better wear resistance in all loading conditions and substantial sliding distance.

Keywords

Metal matrix composite, High entropy alloy, Stir casting, Hardness, Wear resistance

Introduction

Due to their superior strength to weight ratio and other mechanical properties, aluminum alloys are essential in many technical disciplines, including the aerospace and automotive industries [1, 2]. The disadvantage of aluminum alloys is that they have a poor resistance to abrasive wear in low-lubrication environments and have a poor ability to retain lubricant coating over the sliding surface, making them useless for tribological applications [3]. Ceramic particles (Al_2O_3, TiB_2, SiC, B_4C, etc.) [4], which having improved stiffness [5], impact strength, and high hardness as well as strong wear resistance, are typically utilised as the reinforcing phases in aluminum matrix composites (AMCs) in order to increase their tribological characteristics [6]. However, due to the ceramic particles limited wettability with the matrix, a usually weak bonding contact forms, which leads to the initiation of the fracture under stress [7]. According to reports, using metallic reinforcements rather than ceramic particles can greatly increase the interface bonding [8]. AMC materials reinforced with metallic granular materials, for example, offer high yield strengths due to the high tensile strength of metallic materials and better interface bonding between the Al matrix and reinforcements

[9, 10]. Recently, multi component high entropy alloys (HEA) have attracted our attention. Multi component high entropy alloys typically include five or more primary components, each having a concentration of between 5 and 35 wt.% [11]. HEAp are a promising choice as reinforcement for MMCs due to their extraordinary properties, including better strength [12], improved hardness, superior thermal stability[13], and strong tribological properties [14]. It was discovered empirically that hardness and wear resistance have a positive association that follows the Archard equation [15]. However, subsequent studies have discovered that there is some complexity in the link between wear behavior and AMCs hardness. Grain boundary relaxation and expansion caused the early behavior to vary from the Archard equation, which made the wear track worse. Additionally, an important factor in defining a composite's wear performance is the structure of the interfaces between the HEAp and the aluminum matrix [16].

The goal of this research is to examine the tribological characteristics of HEAp/AMCs and the major influencing elements. In order to do this, we have created AMCs using an ultrasonic casting approach with varying HEAp concentrations. To study the tribological behaviour of HEAp/AMCs, pin-on-disk dry sliding wear tests with various normal loads and sliding speed have been carried out. Further elucidating the fundamental processes governing microstructure growth and the interaction between both the HEAp and aluminum matrix received special consideration.

Materials and Methods

Material

Matrix material

In this study, Al7075 is used as a matrix material. Al7075 is widely used for aerospace and automotive applications. Table 1 shows the chemical composition of Al7075 alloy, which was purchased in the form of cylindrical rods.

Reinforcement material

Raw powder of Co, Mo, Mn, Ni, and V with purity more than 99.9 wt.% and particle sizes ranging from 20 to 60 μm were employed as initial material for the preparation of equiatomic CoMoMnNiV HEA powders. Mechanical alloying for 40 hours in a high-energy planetary ball mill with tungsten carbide balls and stainless-steel vials produced the HEA powders. Toluene was utilised as a process control agent, with a ball-to-powder ratio of 10:1 by weight. After milling for 40 hours, the powders were dried in a sealed chamber and the crystalline size was decreased.

Fabrication of composite

In this experiment stir casting method was used to prepare Al7075 MMCs reinforced with HEAp at various weight percentages. To increase the wettability of the alloy composites, 2% magnesium is added. The base material (Al7075) is melted in a graphite crucible at 750 °C in an electric resistance furnace, and this unit is assembled with a stirrer with a blade to create a vortex and an ultrasonic probe, which generates high-intensity ultrasonic sound waves of 18 kHz in the melt for about 15 minutes to create a cavitation effect. Now, the molten material with reinforcement is placed into a hot cast iron die and allowed to solidify. After casting, the produced composite is brought to room temperature, and the composite specimens are prepared for composite wear behaviour. The casted composite is pure alloy with reinforcement levels of 5, 7.5, and 10% by weight.

Testing

Rockwell hardness tests were performed on the base alloys and composites using a diamond indenter of diameter 1/16 inch with a load of 100 kg and indentation time of 10 second. An average of eight measurements were taken for each hardness value of composite.

Tribological test (wear test) was done at room temperature using a pin-on-disc apparatus (model no: Ducom-TR-20LE-M109) for varying load and sliding distances. The cylindrical specimen was prepared by CNC lathe having a diameter of 10 mm and a length of 35 mm and tested for wear in dry condition. The tests were performed at a sliding velocity of 2.0 m/s and applied load of 40, 60, 80, 100, and 120 N over a sliding distance of 2000 m. The sliding surface disc is made of EN-31 steel (roughness value Ra-1.6) and had an 80 mm track diameter. Another test was performed with increasing sliding distances of 1200, 1600, 1800, and 2400 m under a uniform load of 70 N and velocity of sliding is 2.5 m/s. Prior to each sample wear test, disc was washed and dried with cloth and acetone.

Results and Discussion

Hardness testing

Figure 1 shows that the hardness value of pure aluminum

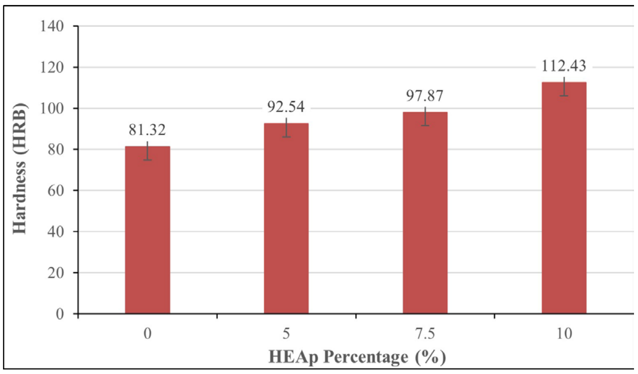


Figure 1: Hardness of Al7075/HEAp composite.

Table 1: Al7075 element composition (%).

Zn	Mg	Cu	Fe	Si	Mn	Ti	Cr	Al
5.1 - 6.1	2.1 - 2.9	1.2 - 2.0	0.5	0.4	0.3	0.15	0.18	Remaining

and reinforced with HEAp. Hardness value increases as the content of HEAp increases. Increased particle content in the Al7075 MMC from 5 to 10 wt.% resulted in a considerable rise in hardness rating. All composite has a hardness value higher than base alloy. Improvement in hardness is due to presence of hard HEAp at interfaces of aluminum matrix. The increase in hardness value may be attributed to the reinforcing effect, the matrix's finer grain size, and the stronger constraint to the localised matrix deformation during indentation as a result of reinforcement and particle solubility in the matrix.

Wear test

Figure 2 depicts the change in wear rate under different loading circumstances, namely an applied load of 40, 60, 80, 100, and 120 N with a sliding distance of 2000 m and a sliding velocity of 2.0 m/s (Figure 3). Under these conditions, adding 5, 7.5, and 10 wt.% HEAp reinforcement to the base alloy Al7075 resulted in a reduced wear rate than the base alloy. When compared to other compositions, the composite with 10% HEAs had a reduced wear rate. Several grooves smaller in size than those seen in the unreinforced alloy can be detected on the worn surface of Al7075/10 wt.% HEAs (Figure 4a and 4b) (Figure 5a and 5b). As the load increases, the temperature of the pin rises, causing wear loss. If the applied load increases while the other input parameter remains constant, the sliding surface asperities of pin deform, resulting in a flat surface layer with a heavy flash temperature. This temperature, as seen in figure 2, induces the formation of a tribo layer, which is responsible for the low wear rate. It was discovered that the wear rate for 10% wt.% HEAp is the lowest.

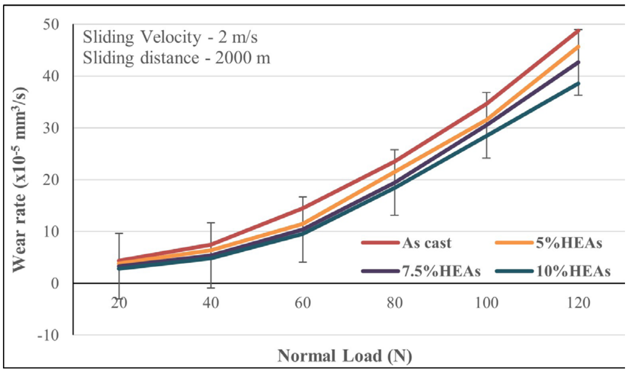


Figure 2: Wear rate of composite with varying normal load and HEAp.

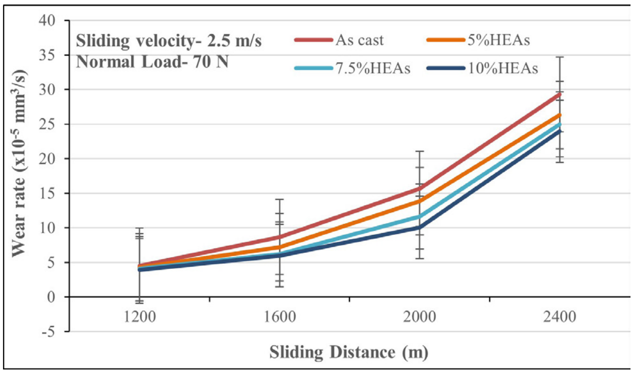


Figure 3: Wear rate of composite with varying sliding distance and HEAp.

The variation of progressive wear rate of base materials and composites as a function of sliding distance at 70 N load and 2.5 m/s sliding velocity is shown in figure 3. Wear rates increase as sliding distance increases for all base alloys and composites. However, wear rate decreases as HEAp increases intensity because of the material's enhanced hardness.

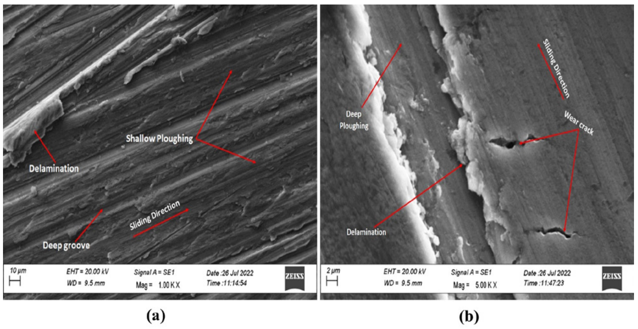
Worn surface morphology

The abrasive wear trails on the composite worn surfaces are visible in these SEM micrographs. On the worn surface of the matrix alloy, further abrasive wear may be seen. In comparison to the reinforced matrix alloy, the parallel ridges and deeper grooves that developed on the worn surfaces of the cast composite samples were significantly deeper and coarser. An increased proportion of HEAs reinforcing the composite was the cause of the improved wear resistance. The enhanced wear resistance and strong interfacial bonding between the particle-matrix are a result of the uniformity of reinforcement dispersion and increased hardness of the composite with HEAs reinforcement particles. Abrasive wear led to the ploughed grooves on the tarnished surface of the composite samples.

Figure 4a and 4b show SEM images of the worn surface morphologies of the as cast aluminum under load of 80 N and 120 N, respectively. There may be noticeable differences in wear surface morphologies as the test load varies. The many deep, and wide ploughing channels, parallel to the sliding direction, are plainly discernible. There is also a noticeable plastic deformation along the grooves. These two abrasive wear characteristics are typical.

As illustrated in figure 5a and 5b, the surface morphology of aluminum composite with 10 wt.% of HEAp. As shown in the figure there are shallow grooves and low plastic deformation on surfaces due to increase in density of HEAp. Abrasive wear appears to be caused by sliding. The grooves are lighter and wider than the cast aluminum surface morphology, and the plastic deformation is more prominent. Furthermore, when compared to the debris at 80 N load, the alloy debris grows and has a disk-like shape. It suggested composite softening and a shift in the wear mechanism from abrasive to delamination wear. The oxygen content of the worn surface and debris is somewhat greater than under low stress circumstances.

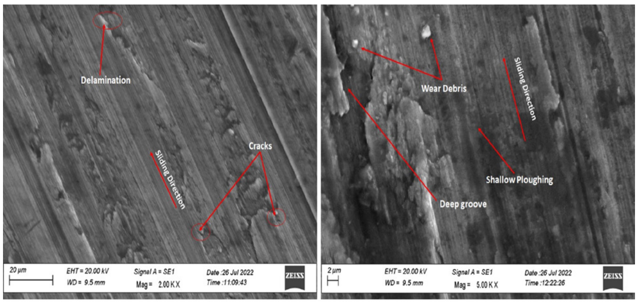
SEM micrographs of the worn surface for Al7075 alloy and composite with 10% HEAp are shown in figure 6a and



(a) (b)

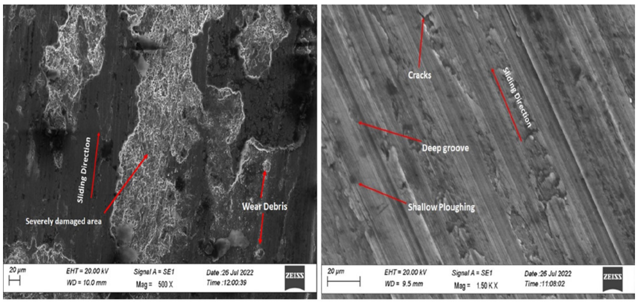
Figure 4: Worn surface morphology of as cast composite after **(a)** 80 N load, 2 m/s sliding velocity and 2000 m sliding distance and **(b)** 120 N load, 2 m/s sliding velocity and 2000 m sliding distance.

6b at 70 N normal load and 2.5 m/s sliding velocity. Deep grooves, a large number of cracks, delamination, and highly damaged regions can be seen on worn matrix alloy surfaces (Figure 6a), which may be caused by the development of intense frictional heating between the surfaces. The composite's worn surface (Figure 6b) has a damaged region, shallow grooves, and less delamination. The firm HEAp particles prevent the worn debris from adhering to the surface, leaving it free. The worn surfaces demonstrate that the wear rate reduces with increasing HEAp content.



(a) (b)

Figure 5: Worn surface morphology of 10 wt.% composite after **(a)** 80 N load, 2 m/s sliding velocity and 2000 m sliding distance and **(b)** 120 N load, 2 m/s sliding velocity and 2000 m sliding distance.



(a) (b)

Figure 6: **(a)** Worn surface morphology of as cast composite at 70 N load, 2.5 m/s sliding velocity and 2400 m sliding distance, **(b)** Worn surface morphology of 10 wt.% HEAp composite at 70 N load, 2.5 m/s sliding velocity and 2400 m sliding distance.

Conclusions

Finding of this study are:

- The hardness increases with increasing HEAp content and this significantly higher at 10 wt.% HEAp. An increase in 38% of hardness value compared to as casted composite were found.
- The wear rate falls as the HEAp content increases, and it was lowest at 10 wt.% HEAp, which has superior wear qualities than other compositions. The wear rate rises with increasing applied stress owing to reinforcement pull out from matrix material.
- On increasing sliding distance an increase in wear rate occurs, this is due to increase in temperature of pin surface rubbing on disc causes surface to get deformed more and loss of material take place.
- The wear resistance of composite was found better as compared to pure aluminum composite for all the reinforced composites.
- SEM images shows that shallow ploughing grooves on worn surfaces associate to abrasive wear. Deep groove on worn out surfaces occur due to higher load and delamination takes place.

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Conflict of Interest

No conflict of interest is to declare.

Credit Author Statement

Pradip Kumar Verma: Experimentation, Data analysis, Writing - original draft preparation; Alok Singh: Writing - review and editing, Supervision; Akshay Kumar: Writing - review and editing. All the authors read and approved the manuscript.

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