Synthesis of nano particles reinforced composites using A356 aluminium alloy as matrix for brake shoes using stir casting route

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Abstract: Being limitation of heavy density and corrosion resistance imposed by ferrous materials, nonferrous material come into existence especially aluminium and its alloys. Among aluminium alloys, Aluminium A356 has gained wide attention because of its excellent fluidity. Because of superior mechanical property of composites, number of investigations was carried out using different reinforcements like SiC, B₄C, TiB₂ and Al₂O₃. Nano particles are well mixable with corresponding matrix while processing metal matrix composite using stir casting technique. Most of the work has been carried out using aluminium A356 alloy as matrix with different reinforcements using stir casting processing route with an intention for automobile applications. But scanty of literature is available in the domain of processing hybrid composite. Thus, in the present investigation an attempt has been made to process A356 aluminium alloy as matrix material along with SiC and Al₂O₃ as reinforcement with an end application of brake shoe pads in which wear resistance is one of the main criteria. Among all the three processed (composite and other two hybrid composite), hybrid composite having 2% SiC and 1% Al₂O₃ exhibited maximum hardness and offers maximum wear resistance and it may be attributed to mixed mode of both abrasive and adhesive mechanism. Hence, this hybrid composite is recommended for brake shoe application.

Key words: Matrix, reinforcement, nanoparticles, hybrid composite, abrasive, adhesive.

1. Introduction

Steel is one of the globally accepted materials being economic one with excellent mechanical properties. In the recent days it has been observed that there is a demand for lighter materials in the domain of aircraft and automobile sectors with an intention of fuel economy and easiness in mobility [1-2]. Being non-availability of magnesium and titanium costlier, aluminium and its alloys paves a way to encroach several segments where ferrous alloys have dominated [3-8]. Having processing limitation of alloys, composites are being developed with the same intention of catering superior mechanical properties and especially aluminium alloys are considered as suitable matrix that led to development of aluminium metal matrix composites (AMMC’S) [9]. It has been witnessed that the
integration of different reinforcement with the matrix results properties of one particulate complement the properties deficient in the other one [10]. It has been observed that hybrid composites using rice husk and SiC as reinforcement results in improvement of high wear and corrosion resistance [11]. Siva Prasad et.al. [10] Reported that hybrid metal matrix composites up to 8% of rice husk and SiC particles could be easily fabricated by double stir casting process and its coefficient of thermal expansion of hybrid composites decreases with the increase in weight percent of reinforcement. It has also found that the micro and macro hardness of hybrid composites increased with respect to addition of one reinforcement and the other one maintaining constant [12]. The wear rate of A356 decreases with incorporation of 6% volume fraction of fly ash as reinforcement while as the compressive yield strength of A356 increased linearly with the density of composite [13-14]. The hardness of hybrid composite varies linearly with hybrid ratio, and impact energy was found to be marginally lower than the unreinforced alloy [15]. From aforesaid, it has been interpreted that ample number of investigations are being carried out using A356 aluminium alloy as matrix material along with different reinforcement to process hybrid composite, but scanty of literature is found that SiC and Al2O3 combined together to process hybrid composite. Thus present investigation aims at enhancement of wear resistance of matrix material by incorporating in different proportion of 2% SiC and 1% Al2O3 to increase wear resistance with an end application of brake pad for automobile industries.

2. Materials and method
The base material used in this study is A356 aluminium alloy having 6.8% Silicon, 0.15 copper (Cu), 0.3 magnesium (Mg), 0.25 manganese (Mn) and remaining aluminium on weight percentage basis. Silicon Carbide (SiC) and Alumina (Al2O3) nano-powder (30nm mesh size) of purity 99.92% was received as it in condition. Stir casting route is adopted for processing composite and hybrid composites. Continuous stirring having 750rpm was maintained while processing to ensure uniform mixing of reinforcements. Schematic diagram of set up is depicted as Figure 2.1.

Pin on disc (Ducom- make) was used to conduct dry slide wear test of base, composite (Aluminium along with SiC) and hybrid composites (Aluminium along with different proportion of SiC and Al2O3). The specimens in the form of cylinders having Ø4mm and length 25mm were machined from both the base metal and fabricated composite and hybrid composites to conduct the wear test. The rotating disc of wear testing machine was made of hardened alloy steel having hardness of 65Re. The applied load was 490N and sliding speed was maintained at 640 rpm during wear test. Scanning electron microscopy (SEM) was done on the worn out surfaces of wear-tested samples to predict the
possible wear mechanism. Vicker micro hardness test was done to evaluate surface hardness under 0.3 kgf of load. Metallurgical specimens were prepared from the sections of base metal i.e. A356 aluminium alloy, composite (A356 aluminium alloy along with SiC) and hybrid composites A356 aluminium alloy along with 1% SiC and 2% Al2O3 and 1% SiC and 2% Al2O3) by following standard metallographic practices. Polished surfaces were etched with Kellar reagent (95% H2O, 2.5% HNO3, 1.5% HCl, 1% HF).

3. Results & Discussion

3.1. Microstructure

The major outcomes of metallurgical analysis are depicted in optical micrographs as shown in Figure 3.1(a) shows i.e. the base metal (A356 aluminium alloy) while as Figure 3.1(b) shows the uniform distribution of both silicon carbide and alumina powder in processed hybrid composite.

![Figure 3.1(a) Base metal](image1)

![Figure 3.1(b) Hybrid composite.](image2)

3.2 SEM analysis

From the SEM micrograph of processed cast portion of HMMC as shown in Figure 3.2. It can be interpreted that the stirring action during processing has ensured thorough mixing of reinforced particles i.e. SiC and Al2O3.

![Figure 3.2. SEM micrograph of thorough mixing reinforced particles.](image3)
3.3. Hardness testing

Base metal A356 aluminium alloy, base metal along with SiC reinforced composite i.e. Metal matrix composite (A356Al-SiC), hybrid composite 1 (2% Al₂O₃ along with 1 % SiC) i.e. HMMC1 and hybrid composite 2 (1% Al₂O₃ along with 2 % SiC) i.e. HMMC2 were subjected to Vickers micro hardness test and the values are given in Table 3.1. These values are reported on the basis of average of 5 representative sample readings.

| S. No | Sample Condition    | Vickers hardness (in VHN) |
|-------|---------------------|---------------------------|
| 1     | Base metal          | 34                        |
| 2     | MMC (A356 Al-SiC)   | 97                        |
| 3     | HMMC 1              | 135                       |
| 4     | HMMC 2              | 152                       |

From the above Table 3.1, it can be interpreted that there is a significant improvement in hardness of MMC (A356Al-SiC) compared to base metal while as marginal enhancement in hardness while comparing among hybrid composites. In MMC made by incorporating SiC using stir casting route consisted of fine distribution of SiC that suppress the grain growth and lead to grain refinement. Presence of SiC particles in the MMC favour grain refinement in MMC and it is attribute d to the restricted grain growth as result of grain boundary pinning by the SiC particles. In addition to above, significant morphological modification like microstructural refinement, homogenization and densification achieved during stir processing led to yield higher hardness in MMC. Regardless of reinforced particles, grains break into smaller size and a large number of high angle boundaries are produced during mechanical stirring while processing of composites and hybrid composites. Mechanical rupture of inherent grain boundaries is also attributed to the stirring action of rotating tool that results in the formation of high angle boundaries. These high angle boundaries will impede the free movement of dislocations and enhances strength and hardness. Furthermore, the presence of nano reinforced particles also assists in effective grain refinement due to the restrain of grain boundary and the development of induced strain.

3.4. Wear test

3.4.1. Wear analysis on A356 aluminium alloy, composite and hybrid composites

Wear rate of the base metal and that of both composites and hybrid composites in different conditions is shown in the Figure 3.3. Wear rate is found to be maximum for base i.e. A356 aluminium alloy and all the obtained wear curves have shown the similar type of profile.
Figure 3.3. Variation of wear with time for samples under different conditions.

From the Figure 3.3, wear rate is found to maximum in the initial stage of wear test. It is attributed to the detachment of projecting nano particles from the surface of the MMC and HMMCs specimen. It is also revealed that the wear resistance is significantly improved by incorporating nano particles. It has also illustrated that base material i.e. A356 aluminium alloy exhibits higher wear rate compared to other MMC and other hybrid composites. It may be accounted to the presence of softer phase i.e. base which undergoes heavy plastic deformation on the surface during contact with rotating disc. High wear rate of base metal sample can also be the attributed to change of wear mechanism from the adhesion to abrasion during dry sliding which is further being supported by SEM images later. While as, MMC and hybrid composites exhibit better wear resistance which is attributed to the presence of higher volume fraction of the nano particles in the same matrix area and influence the reduction in mating matrix contact. The hard particles embedded in the other than base metal have high resistance to the micro cutting process of the moving disc due to their cushioning effect. The presence of hard particles may decrease friction between the rotating disc and the specimen as a result, the counter face is no longer able to abrade, hence the mechanism of wear changes from abrasion to adhesion.

3.4.2. Wear mechanism using SEM micrograph

Figure 3.4. shows the SEM micrographs of the worn tracks of A356 alloy and that of other stir processed composite and hybrid composites. Extensive study is done to illustrate the possible wear mechanism for enhancing wear resistance.
The abrasive action can be easily understood from the plough marks of base as shown in Fig. 3.4(a). Figure 3.4(b), 3.4(c) and 3.4(d) shows the worn tracks observed in the surface composites and hybrid composite. Detailed examination of the worn track of HMMCs revealed the existence of both adhesive and abrasive wear mechanisms. It is evident that the extents of adhesive and abrasive wear decreased in HMMCs due to a comparatively lower coefficient of friction and higher hardness respectively. The worn surface appeared comparatively smooth and was comprised of grooves.

4. Conclusions
1. Grain boundary pinning by the nano particles, uniform distribution of these particles and associated distribution of these nano particles during stir casting has attributed to the enhancement of the hardness in both MMC and hybrid composites.
2. There is a drastic reduction in wear rate of HMMCs which can be attributed to the enhanced hardness of the HMMCs i.e. presence of nano particles changes the wear mechanism from abrasive to adhesion and resulting in improved wear resistance over the base A356 aluminium alloy.
3. The improved wear resistance in hybrid composites is due to the presence of nano particles which act as load bearing elements and facilitates adhesive mechanism of wear.
4. Thus present processed hybrid composites can be used for brake shoe application where wear resistance is one of the major requirements.

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