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Effect of Loading Conditions on the Scratch Resistance of Coated Aluminium Metal Matrix Composites

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ABSTRACT

This paper considers the potential of use Al-SiC metal matrix composite (MMC) used in automobile, construction and aerospace industry. The properties of composites attracts many researchers due to its high strength to weight ratio, further the work explores aluminium matrix and its importance in the industry. MMC's were recommended as a possible replacement for aluminium and it is seen that the exact set of properties depend on certain factors. Aluminium alloy with silicon carbide particle reinforcement with constant weight fraction is considered for the experimentation. The effect of ramp loading and constant loading conditions is investigated for the scratch resistance of coated specimen. It is observed that for constant loading, initially the traction force is increased and remains constant for the rest of the indentor travel. And for ramp loading, the value increase as the travel length is increased on the specimen. Coating affects both loading type by offering greater resistance for the formation of scratch on the specimen. This indicates the good interaction of the coating material with the substrate material.

Keywords: Scratch test, constant and ramp loading, coating

1. Introduction

In most instances, the choice of materials for different applications is tough, lightweight materials are mostly having less strength while brittle materials having less toughness and fatigue resistance. The search for new and improved materials remains constant, along with modern technological demands for devices and machinery more energy-efficient, more durable, lightweight, cost efficient etc. The most commonly used reinforcements are Silicon Carbide (SiC). SiC reinforcement in- creases the tensile strength, hardness, density and wear resistance of Al and its alloys [1]. The particle distribution plays a very vital role in the properties of the Al MMC and is improved by intensive shearing. Al2O3 reinforcement has good compressive strength and wear resistance. Boron Carbide is one of hard- est known elements. It has high elastic modulus and fracture toughness. The addition of Boron Car- bide (B4C) in Al matrix increases the hardness, but does not improve the wear resistance significantly [2]. Fibers are the important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired. Zircon is used as ally with hybrid reinforcement. It increases the wear resistance significantly [3]. In the last de- cade, the use of fly ash reinforcements has been increased due to their low cost and availability as waste by-product in thermal power plants. It in- creases the electromagnetic shielding effect of the Al MMC

The functions of multilayer coatings [4] include diffusion barrier, residual thermal stress releaser and wetting agent. The specimen's fatigue life has been increased due to surface coating. The coated material's wear resistance and surface hardness have both improved. Tests at LCF show that the hard coating on the coated specimens generated little yielding at the notch tip surface, making it easy to start cracking [5]. Due to its decreased cost and isotropic properties, coated reinforcement in the aluminum matrix is gaining importance in the aerospace and automotive industries. Reinforcement surfaces may be covered with metallic substances to increase adhesion and prevent any adverse chemical interactions between the matrix and reinforcement at increased temperatures. Other coating technologies include Physical Vapour Deposition (PVD), Electroless Nickel Plating (EN), and Chemical Vapour Deposition (CVD). Moreover, PVD is a method in which a thin film of a condensed phase material is deposited in a material phase of vapor [6].

Coating the reinforcement provides various advantages, including protection against reactivity with the matrix acting as a diffusion barrier, enhanced adhesion, wetting between the matrix and reinforcement, and enhanced MMC properties. Coating reinforcements with cobalt, magnesium, copper, borax, nickel and other metals is widespread. The current review examines the impact of uncoated and coated reinforcements on the properties and AMMCs application by merging the findings of numerous researchers. A small number of samples were nickel-coated to enhance wetting between the reinforcement and the molten aluminum alloy. Besides, nickel coatings enhance the preforms' wetting, making them to be infiltrated at lower temperatures. The proposed composites created with nickel-coated carbon fibers are harder than composites made with uncoated carbon fiber [7].

1.1 Scratch tests

Duirs et al. [8] evaluated the fracture toughness of constituent phases by means of a scratch test with an increasing force. The phase was scrapped due to the escalating level of pressure. This approach distinguished the shift from ductile to brittle abrasion based on the onset of lateral cracking. Chipping was a consequence of lateral cracking. It was believed that the ratio of fracture hardness to toughness determined whether the material was ductile or brittle. In numerous scratch investigations, abrasive materials (quartz and alumina) were utilized instead of the usual diamond indentor to simulate abrasive wear in dual-phase alloys [9]. The diamond indentors and Al2O3 p in scratch experiments on Co-based alloys to investigate the mechanisms for removing the material have been studied. Scratch tests were given in increments in multi pass for scratch to be appeared on the surface. There were significant differences in surface features and wear debris between alumina and diamond tools because of their different geometries, but the diamond tool had a deeper penetration depth than the alumina tool, and this tool provided a user simulation of the sub-surface deformation that occurs in actual low-stress conditions. Various laboratory test methodologies can be used to determine the cohesion or adhesion bond strength of thin and thick coatings [10]. However, each one has its own set of pros and disadvantages. Furthermore, comparing the results is challenging. Although the scratch test isn't as precise as other methods, it's simple to use and requires no additional specimen preparation. Scratch testing can also be incredibly useful for fine-tuning plasma spraying parameters. It has long been used to determine the adherence of a coating to its substrate [11]. Scratching the surface of the coating up to 20 microns previously have been used to investigate the adhesive and failure mechanisms of thin layers.

2. Materials and Methods

The versatility of aluminium to take on various forms, its light weight, low melting point, good mechanical qualities, availability, and ease of handling make it the most suitable material for the majority of uses. In the commercial world, stir casting is recognized as a low-cost method for creating aluminium metal matrix composites (AMMCs). Its benefits include being simple to use, adaptable, and suitable for mass production. This technique allows for the production of incredibly huge components and is the most economical of all AMMC manufacturing techniques. The stir casting processes setups are shown in figure 1 below. There is no chemical affinity between the matrix alloy and the reinforcement.

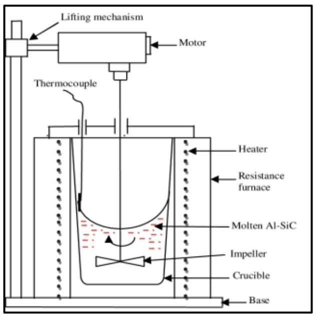

Figure 1: Stir casting setup

The quality of bonding between constituents is defined by good wettability, which has a significant impact on the properties of composite materials. The reinforcements' good wettability and reduced porosity were increased by preheating, which allowed moisture to escape and resulted in the sound casting. The preheating of the mould, according to the researchers, has a good effect on the final casting. The ultimate mechanical and microstructure properties of the composites are influenced by a number of factors. In order to create a casting that is structurally sound, the stirrer speed, stirring period, and pouring temperature are all crucial factors. The following figure 2 shows the digitally controlled scratch tester's diamond indentor is used to perform tests under constant normal load and ramp load. To create scratches on the composite's surface, a DUCOM Scratch tester TR-101 model is used, The specimens are fixed on the table with attachments, after fixing the specimen, types of loads and intensity, stroke length, off set distance can be selected. After parameters are set, the indentor will move above the specimen. Scratch will be initiated and the traction force v/s stroke length graph will be shown on the display provided.

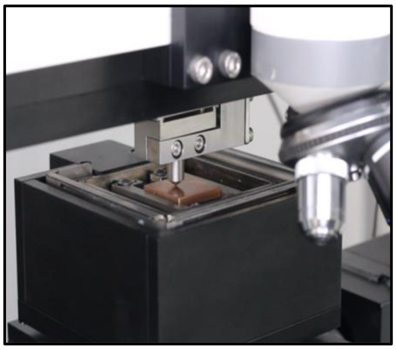

Figure 2: Scratch testing machine

The specimens are fixed on the table with attachments, after fixing the specimen, types of loads and intensity, stroke length, off set distance can be selected. After parameters are set, the indentor will move above the specimen. Scratch will be initiated and the traction force v/s stroke length graph will be shown on the display provided.

3. Results and discussions

The experiments are conducted for two different types of loading namely constant load and ramp load. The studies are made to understand the effect of type of loading on the scratch resistance of 8% SiC particle aluminium matrix composite. The coating thickness is varied for 100 and 200 micron thickness and the results are discussed.

3.1 Effect of ramp load on scratch resistance for coated 8% SiC composite

Tests were conducted for nickel chromium (Ni-Cr) coating with 100 and 200 microns thickness. Initially ramp loading is applied with an initial load of 20N and with an increase of 5N\sec for the 10mm scratch length, and the results were plotted as shown in figure 3. The traction force for without coating and with coating for varying thickness are plotted. It is observed that, coating is well adhered to the substrate and it has not pealed out. The traction force required for 100 micron thickness is much lower than the uncoated specimen as the depth of penetration is not enough to scratch thorough the surface. This avoids the penetration in to the substrate. Further for 200 micron coating thickness, force required is further reduced as the hard particles increase the resistance for the penetration of the indentor in the substrate. It is also observed that the two coating layers have adhered to the surface very well and it is not peeled off during the second layer of coating thickness. For coated and uncoated specimens the trend of increasing force is observed and it is evidenced from the below graph.

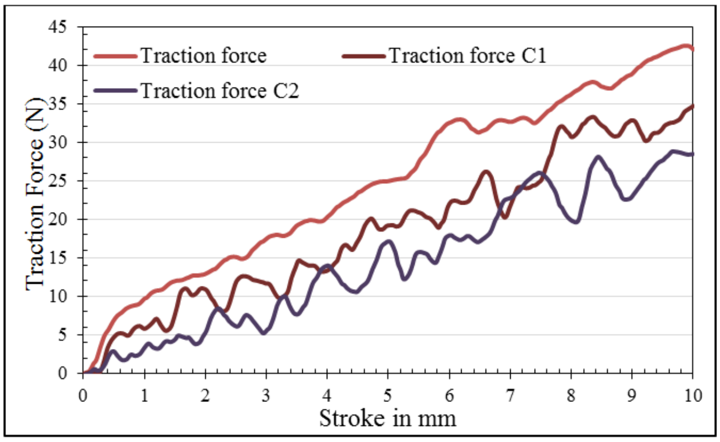

Figure 3: Effect of Ramp load on 100, 200 μ coating thickness on scratch resistance

The hard particle coating offered less resistance as compared to uncoated specimen. It is noticed that the scratch on the surface of the 100 micron coating, the indenter has plastically deformed the coating particle and the surface cracks on the scratch path. The indenter path is smoothened to indicate the less force required to travel across the length of the coated specimen. The width of the scratch measured is around 170 microns and the indenter moves with less resistance on the coating material. For 200 microns coating it is observed that the deformations of the coated particles are reduced further as the hardness is increased. This requires less traction load to be applied on the surface of the coating for producing the scratch. Further observation revealed that indenter has made less penetration in the coating surface and thust less force is applied on the 200-micron coating in comparison with 100 microns coated specimens. The scratch direction and the plastic deformation of the particles have shown the resistance offered by the particles for the scratch

3.2 Effect of constant load on scratch resistance for coated 8% SiC composite

Tests were further conducted for nickel chromium coating for 100, 200 microns thickness. Constant loading parameters were used, and the results were shown in figure 4 The traction force for without coating and with coating for varying thickness are plotted. It is observed that, coating is well adhered to the substrate, and it has not pealed out. The traction force required for 100-micron thickness is much lower than the uncoated specimen as the depth of penetration is not enough to scratch thorough the surface and in to the substrate. The increases in the coating thickness had shown that the material offers less resistance for the scratch. As the hard particles of coating have been uniformly distributed and adhered to the substrate. This can be evidenced from the fluctuating graph of C1 and C2 which are 100 and 200 micron coating thickness respectively.

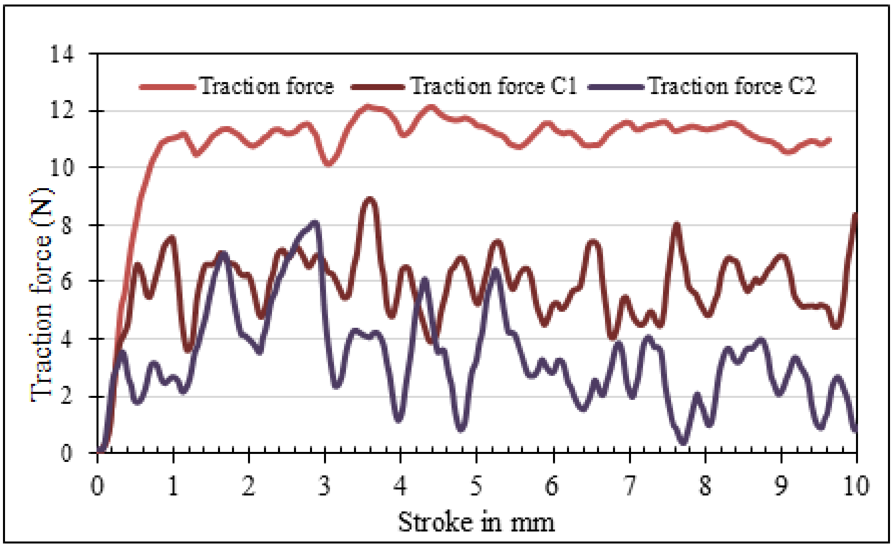

Figure 4: Effect of constant load on 100, 200 μ coating thickness on scratch resistance

Traction force is around 12N and is maintaining its average value but the C1 and C2 values of traction force are well below at 6-7N and 2-5N respectively. This shows that more coating on the surface of the specimen helps in increasing the force required to produce a scratch on the specimen.

4. Conclusions

The results for type of loading for 100 and 200 micron Ni-Cr coating thickness can be concluded as

1. Composites are prepared by stir casting technique
2. For ramp loading, as the loading rate increases the traction force is also getting increased since the amount of material to be removed also increases. The coating has shown the resistance for the traction force. Hard coated particles have resisted for the scratch and allowed minimum resistance for the indenter to be moved over the surface.
3. For constant loading, the initial resistance is increased and reached the constant value for about 10N with some fluctuations showing the presence of the particles of the coating material. For increased coating thickness, the resistance also increased for the scratch and allowed less deformation of the coating material
4. In both cases it is observed that the coating has better wettability for the substrate.

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