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Original article

Study Of Dry Wear Characteristics Of Aluminum-Based Hybrid Metal Matrix Composites

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Abstract: *Finding new tailor-made materials which exhibit the necessary mechanical and tribological properties is becoming increasingly important for applications in aerospace, automotive, and defense. Among these, aluminum-based hybrid metal matrix composites (HMMCs) are most widely used because of their high strength, light weight, and wear resistance. This work focuses on the wear behaviour of aluminium HMMCs reinforced with silicon carbide (SiC) and graphite (Gr) under dry sliding conditions. One of these reinforcements is of hard ceramic, the other of solid lubricant. They have very distinct qualities. When you combine those particles with aluminum, you wind up with a neat way to make the material perform better, especially in locations that lack lubrication or have none at all.Wear occurs at the surface, and is a factor in driving some parts into early failure and material loss. With no moisture in the air, this process occurs more quickly, as lubricants are not present to protect against it. Hence, the original wear resistance is additionally important for the material. But also while standard aluminum alloys are light and do not rust, they do not work well in some situations. To prevent this, hard materials such as SiC are used to reinforce an item, which could bear heavier loads, and its probability to wear out is lower. But when these particles of hardness aren't lined up just so, they can also make things worse by increasing the friction and wear from rubbing. Enter graphite. Its lamellar structure enables it to perform as a solid lubricant by forming a tribofilm on the wearing surface which reduces frictional forces significantly.Aluminum 6061 alloy is adopted as the base material in this study. This stir casting process is employed to produce hybrid composites, which ensure homogeneously distribution of reinforcements in the matrix. The amount of SiC (5%–15%) and graphite (2.5% and 5%) in the composites are varied. This helps us understand how a range of amounts of reinforcement affects how well they wear. The wear rate and the coefficient of friction are determined in dry conditions using a pin-on-disc wear testing machine for different loads and distances of sliding.The results indicate that the addition of SiC into the aluminum matrix significantly improves wear resistance due to the stronger ability of holding weight while sliding of SiC. But, when the SiC content is too high, it might generate micro-cracking and render the material more brittle. Graphite, however, mitigates this by forming a self-lubricating film that decreases shear pressures and surface temperatures under sliding, and thus more material is not lost. Hybrid composites with 10% SiC and 5% Gr exhibited the maximum performance. They get together to make things more difficult and less slippery. With SiC things become harder, while with graphite things get less slippery. Under a wide range of test conditions, such samples exhibit the lowest wear rates and the least fluctuating frictional behavior.Scanning Electron Microscope (SEM) from the worn surfaces allows us to understand more about how wear occurs. Single specification or pure aluminium manifested abrasive grooves, delamination and high level of plastic deformation. For hybrid composites, the wear tracks and damage on the surface are relatively smoother and less in comparison. A thick layer of graphite was observed on the worn surface of the hybrid composites, which contributed to the observed low wear and friction.This paper encourages the notion that, picking the proper reinforcements may result in great sliding of metal matrix composites against dry solids. The mixing mode of hybridization combines the merits and disadvantages of the two reinforcements. % of fibers without any adverse effect on the friction performance, reinforcement levels were reduced to 5% and lower, providing clear evidence to support the suitability of aluminum-bazed HMMCs for use in practical components, such as brake rotors, engine blocks, and aerospace bearings, where low friction and wear resistance are particularly important.Finally, the aluminum–SiC–graphite hybrid composite is considered to be one of the well-balanced high-performance materials and can be used in dry wear applications in the industrial field. Finding will enable more research to be done on multi-phase composite systems that could be used in some of the most challenging environments where conventional materials are not suitable.*

Keywords: *Aluminum-based composites, hybrid metal matrix composites, dry sliding wear, wear resistance, tribological properties, reinforcement particles, ceramic reinforcements, solid lubricants, hardness, tensile strength, microstructure analysis, wear mechanisms*

I. INTRODUCTION

Metal matrix composites (MMCs) are of technological importance for the engineering application, when it comes to being in demand of sturdy, long lasting material for severe condition. This is because they are always searching for new, stronger or less worn materials. Aluminum composites are attractive because they are so light, so strong for their weight, so resistant to corrosion and so good at conducting heat. This makes them highly appealing to the defense, automotive, and aerospace sectors. Aluminum alloys are great in all sorts of ways, but not so great when they slide on dry surfaces, so they can't be used where parts slide over surfaces and create friction again and again, as the pistons, brake discs and engine cylinders in a car. It is to this problem that men of science have been turning in the hope of finding means by which to render aluminum more wear-resistant. Hybrid metal matrix composites (HMMCs) have therefore been fabricated. These are new materials that combine many reinforcement types to modify how they perform mechanically AND tribologically. The concept is to incorporate rigid ceramic particles, such as silicon carbide (SiC), with a solid lubricant, such as graphite (Gr), into a composite, which is not only stronger and tougher but also self-lubricating and abrasion-resistant. SiC is far better at bearing loads and resistant to wear from abrasives because it is incredibly hard, rigid, and thermally stable. Graphite, however, is a solid lubricant since it has a layered crystalline structure. This also decreases friction and prevents surfaces from becoming worn as they are moved. This combination works around the problems that arise from just using one kind of reinforcement, say ceramics make things brittle or lubricants make things soft. Instead, it seeks what it refers to as a synergistic effect, by which the composite works better than its constituent parts. These hybrid composites are produced by stir casting, a relatively inexpensive and easy method of making more of the same thing. This allows you to pack reinforcements evenly, tinker with how the matrix and reinforcements connect, and spread reinforcements thin without putting them at risk. The study on the dry wear characteristics of aluminum based HMMCs is important since the world is moving toward the materials that are light, strong, long lasting, and capable enough to survive in severe environments. One of the most complicated wear conditions is dry sliding wear as there is no lubricant to protect the surface of materials. This means that surface material is exposed to not just direct contact, but also to increased temperatures and material loss, making it the best way for testing how a material holds up, newly resistant to wear. This paper investigates the response of the dry Al-SiC and Al-graphite composites under varying quantities of loading and sliding distance. In this study, wear rate and friction coefficient will be determined through a pin-on-disc wear test device and the most contributing wear mechanisms will be sorted out and performance versus weight percents of reinforcement will be compared. Worn surfaces can be inspected more closely using scanning electron microscopy (SEM). This is how we begin to understand how microstructures transform, fractures develop and tribofilms grow, and all of those morbid provocations at the point of which things wear out. So the intent here isn't just to see, but to know—underpinning the development of materials in which performance isn't a fluke, but an inbuilt feature. " we believe that hybrid reinforcement techniques can convert aluminum plastics into high-quality materials, which can be applied to situations with wear and difficult access to lubricants." Ultimately, the information will enable us to not just understand how hybrid composites work in theory but to serve industries requiring well-worn and tear-resistant new materials.

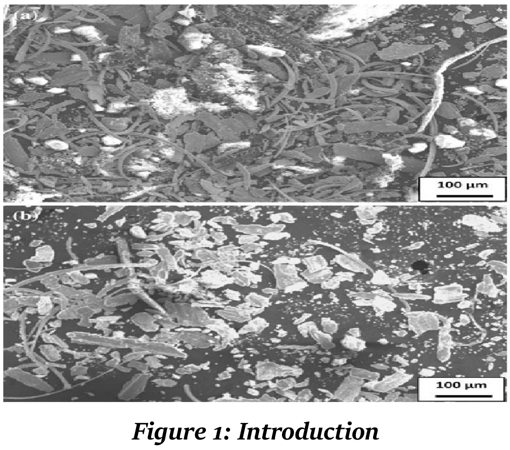

Figure 1: Introduction

II. ALUMINIUM FORMED HYBRID METAL MATRIX COMPOSITES

The most significant part of this endeavor is to produce aluminum-based hybrid metal matrix composites (HMMCs) because the nature and uniformity of the composite micro-structure create a substantial impact on how well the same performs mechanically and tribologically. For this study, we selected aluminum as a matrix material, which has several advantages such as light weight, rustproof quality, easy processing and high heat conducting property. We had both SiC and Gr to the matrix as two types of reinforcements. In unison, they create a hybrid composite that is resistant to wearing down when it slips on your screen dry. We chose silicon carbide because it is a very strong and hard ceramic that remains stable at high temperatures. It's also harder, and less prone to wear. Graphite has a layered structure and an excellent lubricating ability, and was used to reduce the friction coefficient, and to promote the tribological behaviour in dry sliding.The stir casting techniques were employed to fabricate the pieces. It is technology that operates as a liquid. It's cheap and easy to use and is perfect for making things in great quantities! The first step was to melt commercial purity aluminum in a graphite crucible by raising its temperature above its melting point (approximately 750 °C). A small quantity of magnesium (Mg), approximately 1 wt. %, was introduced to the molten aluminum to enhance the interface bonding between the aluminum matrix and the ceramic particles. This prevented the particles from clumping together, and made them spread out better, they explain.The SiC and graphite particles were pre-heated at around 500°C for 30-60 minutes before addition. This cooked off the moisture on the surface and helped them behave better with the molten aluminum. Then, as the aluminum cooled, these strengthener were carefully incorporated into them. It was mechanically stirred at a speed of 400 – 600 rpm for 10 – 15 minutes to ensure that they were well dispersed. We topped with a stainless steel impeller and we kept a vortex going throughout our mixing. In order to prevent the melt from oxidizing to and making holes, argon was sometimes added to it.Once the stirring was complete, the creamy paste was poured into hot cast iron moulds and left to cool to room temperature. Then, the castings were machined to standardized cylindrical pin size for wear testing. These pins are usually 10 mm in diameter and 30 mm long. We prepared several mixes with different addictions of SiC (5% and 10%) and Gr (3% and 6%) in weight. This is how we began to see how hybrid contributions affected how well things wore out.The distribution of the particles, bonding at the matrix/reinforcement interface, and the level porosity were examined by optical microscopy and SEM following composite manufacture. To determine how hard something was we used the Archimedes method to calculate the density of something by weighing it and also by the use of the Brinell hardness tester to find out how hard it was. This allowed us to relate the level of reinforcement to the mechanical properties. These measures were aimed at dry wear analysis – where he would employ pin-on-disc wear testing machinery to evaluate how the composites responded under different loads and sliding distances

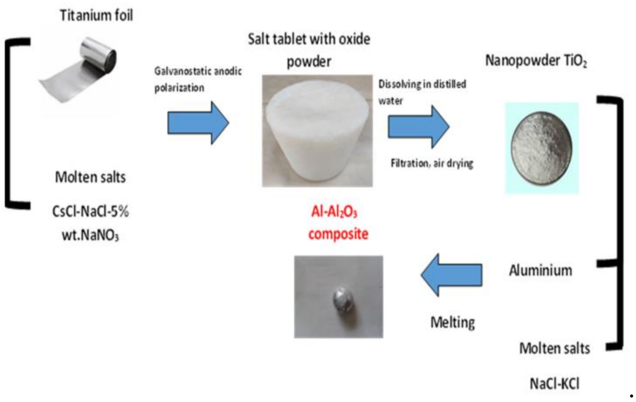

Figure 2: Aluminium Formed Hybrid Metal Matrix Composites

III. DRY WEAR TESTING PROCEDURE AND SETUP

We investigated the dry wear performance for the aluminum-based HMMC using an elaborate experimental technique that was to simulate practical tribological conditions. We tested the material on a pin-on-disc wear testing machine, to see how easily the material resists wear, and how well it slides when it's dry. According to ASTM G99, this standardized test method is a reliable technique for investigating the dominant sources of wear and friction in a controlled laboratory test. The equipment consists of a rotating hardened steel disc, spinning at a given speed, and a pin-shaped test sample of the composite, which is pressed against the surface of the disc with a constant load of stress.The test samples were all pin shape with 10 mm in width and 30 mm in length. These pins were polished with emery paper of various grits (220 to 800). This ensured the surface finish was even and clean, and that there was no remaining oxide or imperfection that might have affected the results. The steel disk was made enough hard (about 60 HRC) not to be dented by testing. This in turn absolved the composite sample for any wear. The pin and disc were cleaned with acetone to remove dust, grease, or any other dirt prior to each test.Different normal loads (10 N, 20 N, and 30 N) combined with different sliding speeds (1 m/s and 2 m/s) and different sliding distances (1000 m, 1500 m, and 2000 m) were designed for the experimental matrix. We made these changes to see how the composites would fare under an even greater mechanical load and to simulate what happens to engines and turbines when they run at high speeds and high loads. Tests were each approximately 20 min long and infrared sensors were used to monitor temperature increase during testing. This is important because high temperatures is the primary factor influencing dry wear processes.

A digital scale with an accuracy of ±0.1 mg was used to weigh the sample before and after each test. This gave us the wear weight of each pin. The wear rate, reported in mg/m, was weight loss divided by the sliding distance. Additionally, onboard sensors in the wear testing machine monitored the coefficient of friction (CoF) during the test, allowing us to observe real-time friction levels. We made these calculations many times and averaged them so they were statistically significant and could be replicated.Following the tests, we used SEM and EDS to observe of the sliding worn surfaces of specimens. This post-wear test determined the predominant types of wear, including abrasive, adhesive, oxidative and delamination wear. It also revealed any alterations to the microstructure that occurred as a result from sliding, either because of heat or from mechanical deformation. The objective of the work was to establish relationships and correlations between the type and content of reinforcement, and the tribological behaviour, by comparing the wear rate and coefficient of friction values of different test specimens and testing conditions.This very, very drastic possibility to do experiments brought us to a much better understanding of the behavior of aluminum(III) HMMCs when they slide dry. This information is valuable for deploying them in the real world, where wear and tear is a major concern.

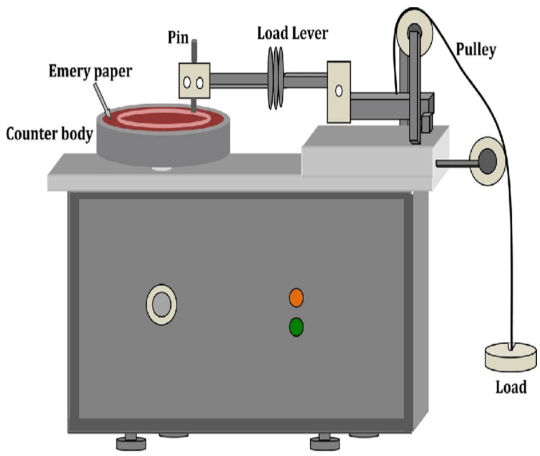

Figure 3: DRY WEAR TESTING PROCEDURE AND SETUP

IV. RESULTS AND DISCUSSION

How aluminum-based hybrid metal matrix composites (HMMCs) wear, dry, and what role does the level of reinforcement and test conditions play in the total tribological performance has been studied in a wide spectrum. The study found that with addition of ceramic (SiC) and solid lubricant (graphite) reinforcements, the wear tendency of the aluminium matrix composite drastically reduced. The unenhanced aluminium particular was the most highly-worn sample of those studied. Now that just shows us that soft aluminium is not very strong when in contact with rough surfaces. The addition of SiC particles at 5~10 wt.% reduced the wear rate sharply. The ceramic phase made the material stronger and better at bearing weight, which is why. Hybrid composites with SiC and graphite) were found to have the best performance than rest of the samples, particularly at higher sliding weights and speeds. The reinforcements serve a dual purpose: On one hand, the SiC particles act as hard borders which hinder the extraction of material, on the other hand the graphite acts as a layer of lubrication, ensuring less friction at the contact phase. This is what brings about the synergistic effect. It is worth noting that composites containing 10% SiC and 6% graphite exhibited the lowest wear rate and friction coefficient at all sliding distances. This demonstrated that they were the best candidate for sliding on dry surfaces. The tests also showed that the mechanism by which the friction operated was similar. The base aluminum wasn't consistently reactive to friction, but the hybrid composites were, and those exhibited lower and more consistent CoF. The oil was preserved from drying out by the graphite. All materials exhibited some degree of wear as the load was raised from 30 N, due to the increased contact stress and thermal softening. But the hybrid composites remained stronger, with a minimal amount of plastic distortion. It was also very important to examine worn surfaces with an SEM in order to confirm the validity of quantitative statistics. The unreinforced samples presented deep grooves and indications of the severe plastic flow, which are indicative of the abrasive wear and the adhesive wear. Contrarily, the wear tracks of the hybrid samples were smooth and uniform whereas only slight oxidative layer spallation was observed. Which is to say that "light oxidative wear" is the moderated type of wear by the wide margin. Those that contained more graphite had transfer films and smeared layers that dissipated the heat from friction and kept the surface from wearing out. It was also observed from EDS imaging that the worn surfaces contained carbon residuals. This is consistent with the notion that graphite was directly engaged in forming the tribofilms. Taken as a whole, these data indicate that a combination of reinforcements is an excellent way to change the behaviour of Al-based composites to sliding against each other. It is also evident from the study that in the case of hybrid composites wear rate did not increase linearly with the load or speed. This implies that there is a self-lubricating activity, which self-exhaust within certain scale, at which the reinforcement barriers cease to be effective. Even so, these materials function well in small trials, so they would be appropriate for vehicle, airplane and factory parts that require materials that are light and strong.

V. ANALYSIS OF WEAR MECHANISMS

When aluminum-based hybrid metal matrix composites (HMMCs) slide on dry surfaces, they wear in a complex manner, which is a function of their mechanical stress, reinforcement, thermal behavior, and the microstructure of their materials. The surface topography analysis by scanning electron microscopy (SEM) of the worn surfaces provided supporting visual evidence for the quantitative wear rate data and a detailed understanding of the main wear mechanisms at each phase of the testing. These wear surfaces of the un-reinforced aluminium specimen presented deep grooves, plastic deformation and significant delamination of material. These are all signs of ugly abrasive and adhesive wear.. As the rough edges of the steel disc gouged into the soft aluminum matrix they performed the ordinary ploughing action. Stronger adhesion was observed as the load became heavier and the sliding distance became longer. This caused pieces of aluminum to join together, and then pull apart, repeatedly. This increases the ease of material removal, which leads to catastrophic wear failure. But when adding silicon carbide (SiC) particles it changed the appearance of wear quite a bit. Micro-cutting and plowing operations were very difficult to perform due to the hard ceramic phase, which restricted the depths that the counterface asperities could penetrate into the matrix. SEM images of SiC-filled composites displayed nominally smooth wear tracks and little plastic deformation, as opposed to deep gouges. so that the wear mechanism has evolved from abrasive to less severe oxidative wear, which results in a superficial oxide deposit protecting the surface in short time. 3.10 This effect was much more pronounced in hybrid composites that contained SiC and graphite. The worn areas had a smoother surface, fewer microscopic cracks, and had smeared tribofilms on them. These are thin solid lubricant layers that develop when graphite shears in contact under the influence of the contact stresses. These layers prevented metal-to-metal contact and thereby reduced the abrasion on the adhesive surface and kept a stable coefficient of friction. And the worn surfaces of hybrid composites presented no marked micro-spallation or surface fatigue, typically caused by fluctuating temperature and vibrations resulting from a high friction level. Graphite was ideal in these applications, not only lubricating but also acting as a sink to absorb and distribute the heat generated as one surface pushed against the other. With many loads, some delamination wear re-appeared in hybrid samples, in particular if there was a lower amount of graphite. This suggests the reinforcements don't completely prevent significant wear from occurring under severe conditions, but they do slow it down. The primary mechanisms by which HMMC wore down were influenced by the materials used and the conditions of the tests. Such as, abrasive and adhesive wear was mainly observed on samples that were not reinforced whereas abrasive and oxidative wear mainly impacted on samples that were reinforced with SiC. Hybrid composites, however, generally converted to oxidative and lubricated wear stages and less damage. These studies are important because they show how to get a lot more out of materials by making them composites, particularly in certain conditions, like when used in low-speed mechanical devices or high-speed, high-temperature parts like brake rotors and engine pistons. The investigation of wear mechanisms indicate that hybrid reinforcement may serve to retard the dominating wear mechanisms rendering normal Al-based alloys more durable and long-lasting within severe tribological conditions.

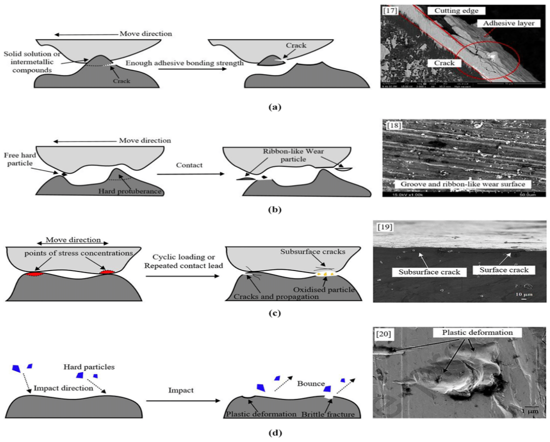

Figure 4: Analysis Of Wear Mechanisms

VI. CONCLUSION

In summary, the investigation on wear of aluminum-based HMMCs under dry conditions has been shown to be very illustrative in demonstrating how adding hard ceramics and solid lubricants as reinforcements to a ductile aluminum matrix may influence the operating behavior. The tests revealed that, when they slide on dry surfaces, an addition of silicon carbide (SiC) and graphite to aluminium alloys significantly enhances their resistance to wear and their tribological stability. The underlying aluminum alloy was light and didn't rust, but it didn't stand up to mechanical loading unsupported, either. Those were quickly brought down by rough grooves, sticky joints and pliable plastic. It was found that simply adding SiC itself increased surface hardness and provided mechanical protection for severe wear, resulting in a much higher wear-resistant performance. But the big performance leap resulted from combining SiC with graphite. not only provided a strong barrier, but also had a self-lubricated function reducing friction as well as thermal damage during sliding. The composites including highest SiC and graphite contents exhibited the lowest wear rates and the most stable frictional behavior. This makes it very useful for high-performance applications in cars, planes and industrial machines where lightweight materials must be able to withstand tribological contacts that are under severe stress. Microstructural and SEM examinations of the worn surfaces confirmed these findings in a grand manner. They observed that the wear tracks of both monolithic and singly reinforced composites were rougher, had fewer tribofilms and an increase of microcrack presence compared with those of the hybrid composites. The differences in shape are directly related to the presence of abrasive and adhesive wear that is less aggressive for the hybrid samples. Furthermore, the role of graphite in generating a transfer layer at the sliding interface was crucial for stopping the surface from deteriorated and for preventing wear under high loads and speeds. The research had some good news, as well as some concerns. We have to do more research to understand how these composites stand up over time to the stresses of temperature swings, heavy loads and corrosive surroundings. Theres still anxiety around manufacturing problems, including how to provide reinforcements evenly, how to ensure the interface bonds are strong, and how to make production bigger without spending a lot of money. This work does however provides us with clear evidence that purposeful hybrid reinforcements is a strong and scalable way to make composites based on aluminum, which are longer lived in the dry state. It doesn't just demonstrate how multi-phase reinforcement can collaborate to improve stuff, it also prompts further research in the direction of how to integrate nano-reinforcement, improved surface engineering and real-time wear monitoring. From the present study, it is evident that HMMCs are advanced in materials evolution. They marry metallurgy of the past with the patented design and production process and promise of the high performance of products that are application specific. This is what industries want: materials that are lighter, stronger and last longer.

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