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Optimization Of Wear Control On Disc Breaking System For High-Speed Vehicles

Lakavathu Chinna Balu[1*]
[1*]Research Scholar of Mechanical Engineering Department, University College of Engineering (A), Osmania University, Telangana, India.

R Rajendra[2]
[2]Professor of Mechanical Engineering Department, University College of Engineering (A), Osmania University, Telangana, India.

Abstract

The present work based on the friction and vibroacoustic tests of a heavy vehicle disc brake on a brake stand. The vibration signal generated by the friction linings provides information on their wear and evaluates the braking process, i.e., changes in the average friction coefficient. The study of amplitudes leads to the determination of models in the entire braking speed range from 50 to 200 km/h, despite the lower accuracy compared to the model, based on the spectral analysis. There has also been intensive fundamental research about the evolution of the tribological interface of the disc-pad system. In a disc brake system, a set of pads pressed against a rotating disc, and due to friction, generated the heat at the disc-pad interface. This heat ultimately transfers to the vehicle and environment, cooling down the disc. Transient analysis for the thermo-elastic contact problem of the disk brakes with heat generation is performed using the finite element analysis. The numerical simulation for the thermo elastic behaviour of disk brake is obtained in the repeated brake condition. The computational results are presented for the distribution of heat flux and temperature on each friction surface between the contacting bodies.

Keywords: Friction stair casting, AA3033, Compression, Tensile and Tribological behavior.

1. INTRODUCTION

The braking system of a vehicle is crucial to its safety. They create artificial frictional resistance to help stop the moving vehicle. Brakes in vehicles have two purposes: stopping the vehicle and holding it in place once it has stopped [1]. To inspire trust in drivers, the braking system must meet the requirements of manufacturers, users, and regulators. Car speeds need to be lowered in a managed way that has minimal impact on the surrounding environment. Modern brakes, such as the anti-lock braking system (ABS), traction control system (TCS), brake assist system (BAS), and electronic stability control (ESC), serve a variety of functions in addition to slowing and stopping vehicles. For this reason, a braking system's dependability and uniformity are of the utmost importance. Passenger car accidents cause the deaths and injuries of countless people every year [2]. According to studies, the primary reason cars crash is because drivers are ill-prepared to stop abruptly in an emergency [3]. To lessen the number of mishaps, the brake disc's thermal behaviour could be enhanced. This is because, as speed increases, the brake pads heat up, and greater amounts of kinetic energy necessitate greater amounts of heat dissipation [4]. Brake fade, brought on by the system's exposure to too much heat, compromises stopping power and safety. Strong brakes with good fade resistance are essential. After using the brakes, the kinetic energy is transformed into waste heat that must be quickly dissipated from the contacting surface. The brake's thermal efficiency must be exceptionally high if it's going to fulfil this requirement. The development of brakes over time it’s the engines only that can [5]. According to studies, the primary reason cars crash is because drivers are ill-prepared to stop abruptly in an emergency. To lessen the number of mishaps, the brake disc's thermal behaviour could be enhanced. This is because, as speed increases, the brake pads heat up, and greater amounts of kinetic energy necessitate greater amounts of heat dissipation [6]. Brake fade, brought on by the system's exposure to too much heat, compromises stopping power and safety. Strong brakes with good fade resistance are essential. After using the brakes, the kinetic energy is transformed into waste heat that must be quickly dissipated from the contacting surface. The brake's thermal efficiency must be exceptionally high if it's going to fulfil this requirement. The development of brakes over time it’s the engines only that can [7]. When brakes are used frequently, they generate heat, which is released by convection, conduction, and radiation from the brakes' exposed surfaces. Overheating causes malfunction in the braking system, which poses a threat to the driver's safety. Brake technology has advanced in a fashion analogous to how engines have improved over time [8]. The compared to the heavy grey cast iron used in traditional disc brake rotors, the lighter aluminium MMC has seen increased use in recent years. They also benefit from lower carbon dioxide emissions. When appropriate reinforcing elements are added to an aluminium matrix, the matrix's properties significantly improve. Some examples include enhanced damping capacity and thermal expansion, reduced thermal expansion, increased thermal shock resistance, etc. Particulates, fibres, whiskers, etc. are all forms into which dispersoids can be introduced, and each has its own unique method of introduction [9,10]. Al-Fe composite was created using impeller mixing and chill casting. Particles in the second phase have been shown to have a negative impact on the properties of composite materials. The ideal material for brake discs is one that can withstand high levels of abrasive wear, friction, and temperature. It needs to be heat-absorbent so that it doesn't warp or break under the pressure of the heat being applied [11,12]. An optimal solution is a composite material system, which consists of a blend of multiple materials in an appropriate configuration. There is an irreconcilable boundary between them at the interface. Furthermore, their structure and chemical make-up are dissimilar [13]. Because AMCs' mechanical qualities vary depending on the ratio of reinforcement and the chemical composition of the Al matrix, they have been tried and proven beneficial in a variety of industries [14]. All of the alloys were made with different amounts of Silicon and observations of wear rates on Al and Al-7Si alloys showed that they improved with decreasing grain size and DAS. The struggle to produce ever-faster and more capable automobiles is heating up in the ever-expanding global auto market [15]. Disc brake assembly is undergoing a lot of recommended changes to enhance its performance. Disc brake applications benefit greatly from the metal matrix composite's exceptional properties. Composites are multi-phase materials made from blending different types of materials together intentionally to achieve a desired effect. Composites' main advantages are their lightweight, enhanced mechanical properties, and easy assembly. With their high specific strength, stiffness, and improved tribological properties, lightweight composite materials like Al- or Ti-based alloys are finding more and more use in disc break application today. The combination of silicon carbide (SiC) and boron carbide (B4C) particles reinforced with aluminium alloy results in a material with a high modulus of elasticity, high hardness, low coefficient of thermal expansion, and density, making it an excellent choice for disc brakes [16,17]. Low weight and with a Young's modulus equal to 70 GPa, aluminium alloy has a density of 2700 kg/m^3. It melts at a relatively low 660 degrees Celsius, and its many benefits include low processing temperatures, low cost, and simple availability. Aluminum and its alloys are also easily produced, making them a go-to material choice thanks to their combined qualities with other metals or ceramics; these materials are used in a wide range of industries, from automotive to construction to electronics, among others [18]. When it comes to advanced technology, reinforcing composites is crucial. When added together, these reinforcements improve the composites' mechanical and physical qualities [19]. Composites typically have superior thermal stability, tensile and compressive strength, Young's modulus, process ability, and cost, in comparison to matrix alloys. Thermodynamic stability, thermal expansion rate, density, Young's modulus, compatibility with matrix material size, shape, and cost are all factors to consider when deciding on a ceramic-based reinforcement [20]. Selecting appropriate reinforcements is crucial for enhancing the subsequent properties of matrix materials. More and more industries, including aerospace engineering, automotive, space, submarine, and shipping, are making use of AMC reinforced with Silicon carbide particles. Enhanced mechanical and Tribological qualities are mostly responsible for this. The enhanced qualities of an unreinforced matrix are combined with the fact that they are less expensive to produce [21]. The AlTiCr master alloy composite used in this

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investigation was made using the stirring die casting technique. The developed material featured silicon carbide (SiC) and boron carbide weight % reinforcement (B4C). Mechanical, microstructural, and surface morphological features of Al MMC were studied alongside those of B4C reinforced with varying amounts of SiC [22].

2. MATERIAL AND METHODS

The experimental research that was conducted to check for uniformity in particle distribution and mechanical qualities. The properties of the composite material were investigated by means of experimentation, with the results being compared to those of the starting alloy. The homogeneous distribution of reinforcement particles in the aluminium matrix is an essential criterion for achieving a high strengthening effect. This is because uneven distribution of secondary particles frequently results in failure upon application of stress due to the occurrence of dislocations and the initiation of micro-cracks in areas of the material that are weaker. In stir casting, the dispersal of particles throughout the moldable matrix is a crucial factor. Cast composites can have their reinforcing distribution verified by observing their microstructure and chemical reactivity. The elements that have been considered for composites with a fly-ash content of 5, 10, and 15 percent are listed in Table 1. Chemical reactions between reinforcement and matrix produce trace amounts of other elements, however these are not included.

Table 1: Material Preparation.

S. No	Element	Wt.% of different element in MMC		
		5	10	15
1	Magnesium	0.31	0.50	0.71
2	Nickel	2.22	2.53	2.64
3	Silicon	2.48	3.24	3.79
4	Oxygen	5.32	6.93	7.15
5	Aluminum	83.21	80.12	78.58

3. RESULTS AND DISCUSSION

The compressive properties of materials that are subjected to compressive loads can be determined via a compression test, tensile test and tribological test. The sample is subjected to compressive load and the deformations that occurred due to loading are recorded. Calculations of compressive strain and stress are made, and the results were displayed as a stress-strain diagram.

3.1 Compression Test

In order to ensure that the compression test results were accurate, the specimens were made in accordance with ASTM E9. Figure 1 displays sample sizes. The specifications for the cylinder specimens were achieved by means of precision machining.

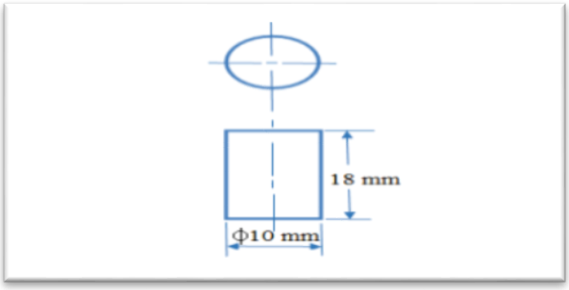

Figure 1. Dimension of specimen for compression test.

The manufactured specimens were subjected to compression testing, and the stress vs strain graphs were plotted. Prior to the compression test, the samples' cross-sectional area and height were recorded. The samples were subjected to a controlled, progressive load using a cross-head that travelled at a rate of 0.05 cm/min. The measurements of load and deformation were recorded on a chart recorder and from these values stress and strain are calculated and ploted as shown in Figure 2. After reaching a certain stress (yield strength), all the specimens distorted without further stress increase. Figure 3 demonstrates how the fly-ash volume percentage affects the compressive strength of AA6063, revealing that the composite has greater compressive strength than the basic alloy. Adding fly-ash to the composite at a volume percentage of up to 10% was found to boost compressive strength.

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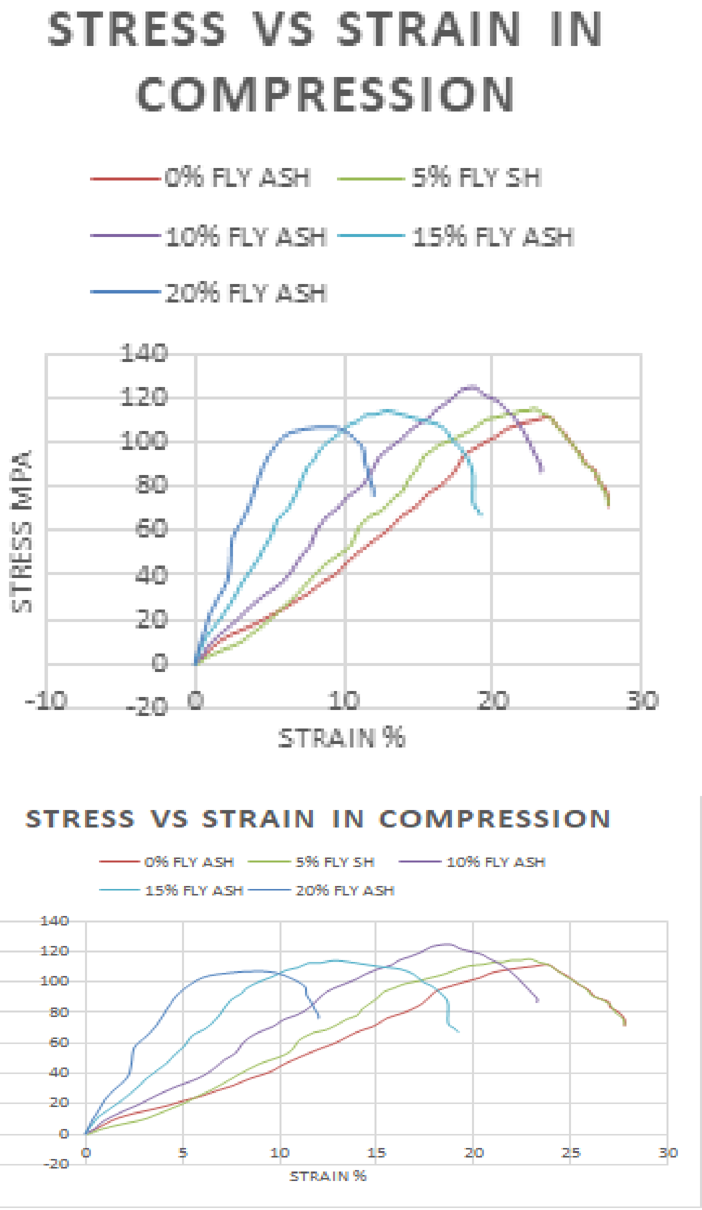

Figure 2. stress vs strain in compression load.

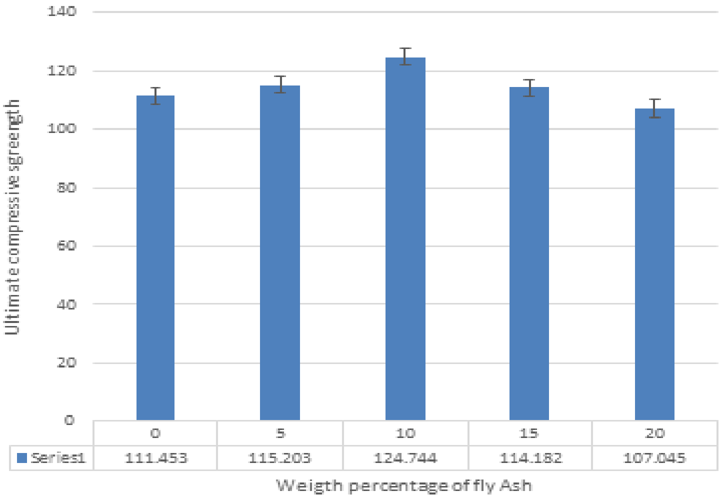

Figure 3. Varying of Ultimate compressive strength of composite with respect to fly ash.

For each specimen, the ultimate compressive strength and compression modulus were calculated. Table 2 displays results of the compression test.

Table 2. Propetries under compression

% of Fly Ash	Modulus in compression	Ultimate compressive strength (MPa)
5	75	115.203
10	86	124.744
15	74	114.182

Compressive strength increased by 4 and 11 percent, respectively, with increases of 5 and 10 percent by volume of cenoshpere. Less compressive strength was discovered in the composites that contained fly-ash in excess of 10% by volume. The pattern that was seen was consistent found for fly-ash composites produced by powder metallurgy. The strength of composites decreased as the potential of clustering rose with an increase in fly-ash content. Compressive strength decreases as fly-ash content increases due to inadequate interfacial bonding between fly-ash particles and matrix material. The aluminium matrix surrounding the fly-ash particles flowed away in a direction perpendicular to the applied load when the composite were under compressive stress, which decreased the matrix's capacity to transfer load.

3.2 Tensile test

The according to ASTM E08-8, a tensile test was performed using a Universal Testing Machine (UTM) to determine the tensile properties including tensile modulus, percentage elongation and breaking strength. The specimen for tensile test as shown in Figure 4 illustrates the specimens that were prepared in accordance with the ASTM E08-8 standard in order to undergo the tensile test. The examination was performed at the ambient temperature.

Figure 4. Tensile test specimens.

Using the stir-casting apparatus, a total of 5 specimens were produced for each volume fraction of fly-ashs that was 5, 10, and 15. These volume fractions were as follows: 5, 10, and 15. In order to achieve the desired dimensions, the cylindrical specimens were subjected to machining. After this the specimens were knurled at both ends so that it would have a better hold in the jaws of UTM machine. To evaluate the strength, a tensile test was performed on the prepared specimens. The UTM with computer interface applied the load hydraulically. Both the yield and the breaking points were recorded. Different tensile properties of the specimens were determined by analysing the results of tensile tests. Figure 5 displays stress-strain graphs for all of the composites. It was found that the specimen needed a higher loading rate at the outset of elongation as the proportion of reinforcement increased. Since fly-ash makes the composite more brittle, it was discovered that strain decreases with increasing load.

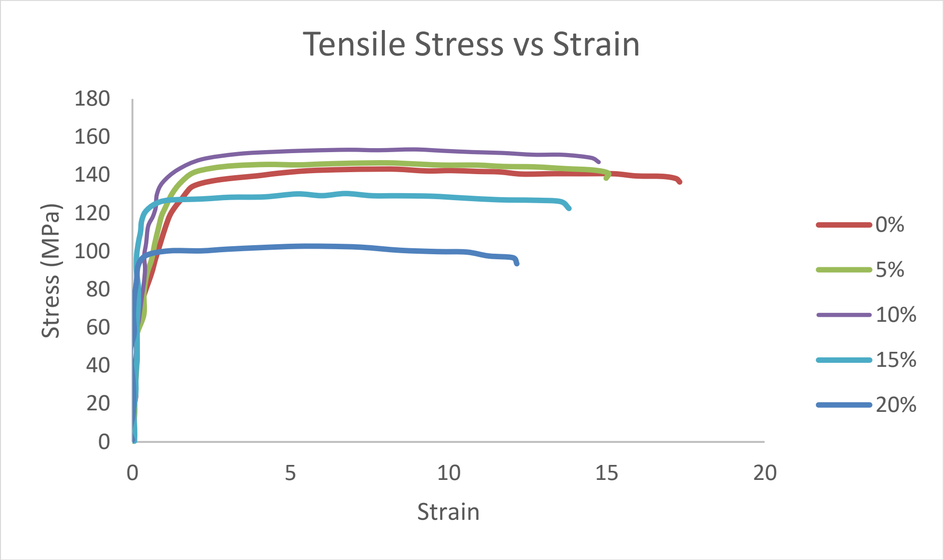

Figure 5. Tensile stress vs strain.

Table 3 compares the unreinforced alloy to the composite in terms of tensile strength. Incorporating fly-ash at concentrations of 5 and 10% by volume was shown to boost tensile strength by a small but noticeable 3.5-7.2%. Tensile strength is typically reduced by 10 and 25 percent when fly-ash is added at concentrations of 15 and 20 percent by volume compared to the unreinforced aluminium alloy. It was found that the composite's yield strength increased with fly-ash content up to 10% by volume, but then began to decrease with the further addition of volume percentage of fly-ash.

Table 3. Properties of material under tensile test

% of Fly Ash	Modulus in tension	Ultimate tensile strength(MPa)
5	83	146.5
10	94.1	153.3
15	95	130

After adding a particular volume fraction of fly-ash, the ultimate tensile strength (UTS) began to fall due to the formation of weak compounds at the interface of the reinforcement and the matrix. Prior to this point, the UTS had shown an increase, indicating that it was getting stronger. When investigating the decreased in strength of samples with high volume percentage of fly-ash-containing composites, it is important to take into account and examine the interfacial reaction. These reactions take place during the process of particle inclusion and have a tendency to change the composition of the matrix, which in turn affects the strength of composites. The results of a number of studies that were conducted in the past have demonstrated that the addition of Al_2O_3 to AA6061 and AA7005 results in an increase in the materials' tensile strength. The observed a decrease in UTS with the addition of Al_2O_3 to 2024 Aluminum alloy came to similar results with aluminum-graphite composite. This drop may be the result of particle pull-out and fracture propagation during testing, both of which began at the matrix contact and occurred simultaneously. Also from Figure 6 indicate a low percentage of eleongation resulting in brittleness of samples. This brittleness in sample with the addition of fly-ashs is due to the fact that the aluminium matrix and fly-ash particles get debond under high load which results in particle pullout and a lower degree of elongation. This sort of behaviour might be the end result of a failure brought on by the accumulation of internal damage within the particles, which might have been brought about by particle fracture or interfacial failure. This damage, in turn, leads to voids, which, as a result, multiply in these composites and impair their ductility.

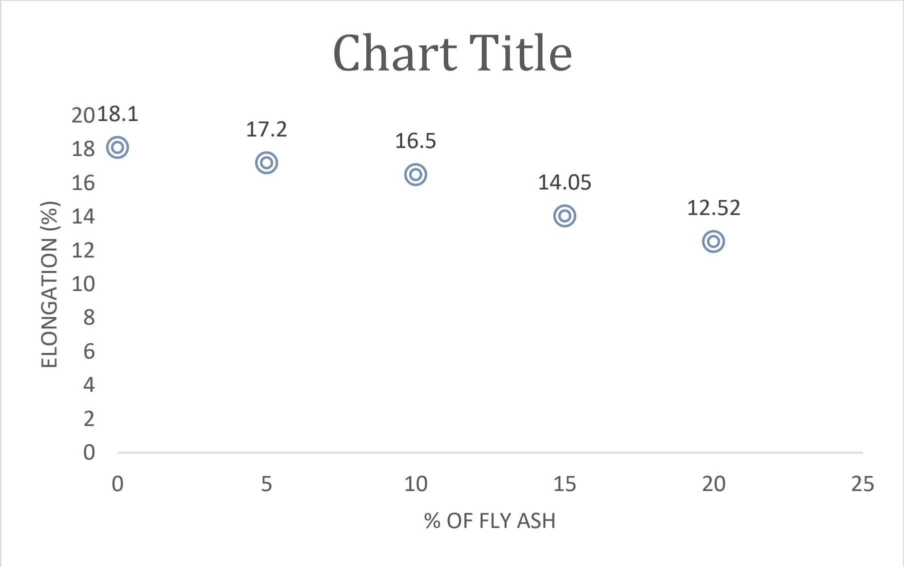

Figure 6. Percentage elongaation of sample

The brittle nature of the particles that make up the fly-ash leads to a reduction in ductility, which in turn leads to a reduction in elongation of the material. By analysing the tensile fracture surfaces, one can gain a better understanding of the inherent micro-structural impacts that are caused by the tensile fracture properties of the composites. The peaks and valleys were visible in a microscopic examination of the fractured surfaces. Moreover the tear ridges indicating the ductile zones encircling the broken reinforcing fly-ash particles are witness. The establishment of a tri-axial stress condition in the matrix of the composite, which was a major contributing component, made it difficult for the hard fly-ash matrix to deform upon loading. This phenomenon limits the flow of stress patterns in the particulated reinforced aluminum matrix and also includes void nucleation and growth. The particles that caused the decrease in tensile elongation and the subsequent failure had brittle fracture, as evidenced by their higher fly-ash content. The separation at the interface and brittle fracture of the particles were the modes of failure of the composites, when analysis fractured surface under high magnification microscopes. In the soft and ductile aluminium alloy metal matrix, the presence of brittle and hard fly-ash particles led to the initiation of small microcracks at low applied stress levels. Tensile fracture surfaces were analysed, and it was found that the fracture damage was concentrated almost entirely within the fly-ash particle, with minimal indication of void formation elsewhere. The hard and brittle particles of the fly-ash were more likely to break when they were clustered together, since the confined plastic deformation and brittleness of the reinforcement made the particles more likely to crack. Due to an increase in particle content and stress concentration, the stress leading to particle failure was reached at a lower level of applied stress. Because of the stress concentration, cracks formed close to the reinforcing particles. As tension increases, initially the larger particles break and then the smaller ones. An examination of the tensile fracture surface revealed that the fracture plane of the fractured particulates was aligned in a direction that was perpendicular to the far field load axis. This finding provided conclusive evidence that the fracture of the particle was caused by tensile stress. The early crackings of fly-ash particle combined with de-cohesion at the interfaces between the matrix and fly-ash were mostly responsible for the inferior tensile ductility of the composites.

3.3 Tribological Characterization of Materials

The following test was performed on the sample for wear analysis pin on disc, wear test, co-efficient of friction. The DUCOM (TR-20-M26) pin-on-disc machine was used in this experiment to investigate the wear behaviour and coefficient of friction (COF) of the aluminium alloy AA6063 and the fly-ash reinforced AA6063 at varied volume percentages of the constituents. It is a multifunctional machine developed to assess the wear and friction properties of various materials exposed to sliding contacts in dry settings. Dry sliding wear tests (ASTM G99-05) were performed at room temperature using circular pins to evaluate the wear rate. A pin-on-disc wear testing machine (see Figure 7) with a rotating hardened steel disc of 40 mm diameter, 0.11 μm surface roughness and hardness of 850 HV was used in this experiment. The wear test pins were mounted perpendicular to the rotating disc in the holder during the experiments. The wear test parameters were used as follows: the load applied was 1 kg, 3 kg and 5 kg, the wear track diameter was 120 mm. The pin on disc test was conducted as per ASTM standard ASTM G99, the range of rotational speed of disc was 10.5 rad/sec to 209.5 rad/sec. the maximum normal load and frictional load that can be applied on pin is 200N. The maximum range of wear that can be measured is up to 4 mm. The size of pin needed is 12 mm diameter, the size of rotating disc is 160 mm diameter and 10 mm thick with wear track diameter of 10-140 mm. the cooling fulied is discharged at 1 lit/min.

Figure 7. Pin on disk experimental setup

In this particular research endeavour, the factors that were taken into consideration to be variables were the proportion of fly-ash content in the composite, the sliding velocity, and the load. Studies were performed on a composite material that had been manufactured with 5, 10, and 15 percent of fly-ash content by volume. Each sliding speed and load level was varied over the course of the experiments. Therefore, there were a total of 45 different experiments. Table 4 is a listing of the various levels of the parameters that were utilised.

Table 4. Various levels of the parameters

Parameter	Level 1	Level 2	Level 3
Fly Ash (%)	5	10	15
Sliding velocity (m/s)	1.26	2.51	3.77
Load (kg)	1	3	5

The dry sliding wear tests are conducted at room temperature. Following metallographic polishing, cylindrical pins with a diameter of 10 millimetres and a length of 30 millimetres are machined from the aluminium metal matrix composite casting. For each combination of AA6063 and reinforcement from 5 volume percentage to 15 volume percentage with step of 5% inctrament and one without any reinforcement, total of 3 (5, 10 & 15%) specimens were prepared. Figure 8 shows the test specimens in their various states.

Figure 8. Pin on disc sample

The results of wear tests were utilised in an investigation of the influence that process factors have on the wear and frictional behaviour of the newly designed composite material. Experimental results are provided in Table 5.

Table 5. Pin on disc results

S.No	Fly ashvolume	Sliding velocity (m/s)	Applied load (N)	Wear rate(10^{-10}) (m^3/min)	Specific wear rate(10^{-10}) (m^3/Nm)	Coefficientof friction
1	5	1.26	9.81	3.58	18.27	0.4174
2	5	2.51	29.42	4.65	7.90	0.4509
3	5	3.77	49.03	4.39	4.48	0.4577
4	10	1.26	29.42	4.44	7.55	0.4768
5	10	2.51	49.03	4.17	4.25	0.5481
6	10	3.77	9.81	1.95	9.95	0.3646
7	15	1.26	49.03	5.32	5.43	0.6816
8	15	2.51	9.81	3.34	17.04	0.4811
9	15	3.77	29.42	3.95	6.71	0.5362

4. Conclusion

Aluminum is the prime matrix component used in MMCs since the early stages. The binders/ reinforcement varied accordingly to the development and requirement. This work is an attempt to develop a new MMC material using Fly ash, which is a byproduct of coal, as reinforcement. The addition of fly ash to the aluminum metal matrix has been shown to result in improvement in mechanical and tribological properties. The composite specimens containing fly ash in the range 5-15% by volume in aluminum alloy AA6063 were fabricated. The stir casting technique which is a cost-effective and simple method of casting the composite was adopted. The composite specimens were tested for their mechanical and tribological properties. Based on these investigations, a suitable combination of flyash and aluminum was chosen and its suitability to be used as a brake disc material was investigated and established.

- The hardness of the composite material was found to be better than the existing monolithic material. It is inferred from the study that significant improvements in tensile and compressive strengths can be achieved using fly ash addition up to 10% by volume.
- The chosen aluminum alloy was reinforced with various volume percent of cenospheres, out of which, 10 percent fly ash addition was found to result in improved wear resistance. Resistance-to-wear increased upto a certain limit of fly ash addition and decreased thereafter. The quantity of fly ash addition can be determined depending on the other characteristic requirements of the composite and specific to the application.
- From the analysis of the impedance spectra of fly ash reinforced AA6063 specimen immersed in seawater solution at ambient temperature, the excellent anti-corrosion characteristics of AA6063 with 10 percent fly ash reinforcement have been demonstrated. AA6063 did not show considerable improvement in corrosion resistance at 5 and 15 percent reinforcements. Hence among all the above mentioned compositions AA6063 with 10 percent of cenosphere is chosen as the best material as it has high wear resistance as well as corrosion resistance property.

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