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Review Article

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Particulate Reinforced Aluminium Alloy Matrix Composite Brake Rotor – A Review of the Mechanical and Wear Behaviours

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Abstract Traditionally, automotive brake rotors are made with cast iron. Notwithstanding having economical advantage, Cast Iron rotor exhibits many disadvantages. Due to its weight, it causes reduction in fuel efficacy and increase in green house gas emission. Increase in noise, vibration, excessive wear in the form of dust, corrosion and limited lifetime. Aluminum alloy (Al) metal matrix composites (Al-MMCs) produced with ceramic particulate reinforcement such as Silicon Carbide (SiC) and Alumina (Al_2O_3) have long been considered as significantly lighter weight, potentially longer lasting and more environmentally favorable material for automobile brake rotor. With the development of commercial Particulate Reinforced Aluminum Alloy-Metal Matrix Composites (Al -MMCs), Composite Brake Rotors are now being manufactured. However, the two major ceramic particulate that are widely used for MMCs Brake Rotors are very expensive. This article provides a review on the progress that has been made in the field of particulate reinforced Al-MMCs brake rotor during the past decade, paying particular attention to the Mechanical and Wear performance.

Keywords Aluminium alloy metal matrix composite (Al-MMC), brake rotor, Mechanical Properties, Wear property, Silicon Carbide (SiC), Alumina (Al_2O_3), particulate composite, Tensile strength, Hardness

1. Introduction

1.1 General Background Information

The brake rotor of an automobile is a crucial component from the safety perspective. During braking of an automobile, the entire kinetic energy of the moving vehicle is converted into heat energy due to friction between the brake rotor and brake pad (in the case of a disc brake system) or the brake drum and brake shoe (in the case of a drum brake system). The material used for brake systems should have stable, reliable frictional and wear properties under varying conditions of load, velocity, temperature and environment and high durability [1]. There are several factors to be considered when selecting a material for brake rotors. The most important condition is the ability of the brake rotor material to withstand high temperatures generated in the order of 300 to 800 °C during a braking action [2], its resistance to abrasive wear [3]. The widely used brake rotor material is cast iron [4], which consumes much fuel due to its high specific gravity.

1.2 Metal Matrix Composites (MMCs)

The term “composite” broadly refers to a material system which is composed of a discrete constituent distributed in continuous phase, and which derives its distinguishing characteristics from the properties of constituents, from the geometry and architecture of constituents and from properties of the boundaries between constituents. Composite materials are usually classified on the basis of the physical or chemical nature of the matrix phase e.g. polymer matrix, metal matrix and ceramic composites [5]. In addition, there are some reports to indicate the emergence of Intermetallic-Matrix and Carbon-Matrix Composites [6].

Metal Matrix Composites are being increasingly used in aerospace and automobile industries owing to their enhanced properties such as elastic modulus, hardness, tensile strength at room and elevated temperatures, wear resistance combined with significant weight savings over unreinforced alloys [6-8]. The commonly used metallic matrices include Al, Mg, Ti, Cu and their alloys. These alloys are preferred matrix materials for the production of MMCs. The reinforcements being used are fibers, whiskers and particulates [9]. The advantages of particulate-reinforced composites over others are their formability with cost advantage [10]. Further, they are inherent with heat and wear resistant properties [11, 12].
For MMCs SiC and Al_2O_3 are widely used particulate reinforcements. The reinforcement of hard ceramic particles like silicon carbide and alumina in aluminium alloys has been found to improve the wear resistance as well as high temperature strength properties [13, 14]. The ceramic particulate reinforced composites exhibit improved abrasion resistance [15]. They find applications as cylinder blocks, pistons, piston insert rings, brake discs and calipers [16]. The strength of these composites is proportional to the percentage volume and fineness of the reinforced particles [17]. These ceramic particulate reinforced Al-alloy composites led to a new generation tailorable engineering materials with improved specific properties [18], structure and the properties of these composites are controlled by the type and size of the reinforcement and also the nature of bonding [19,20].
MMCs are generally referred to the materials consisting of a metallic matrix and ceramic reinforcement, such as oxides, borides and carbides The metallic matrix provides ductility, toughness, formability, thermal and electric conductivities while the ceramic reinforcement offers high hardness, strength, modulus, high-temperature durability, and low thermal expansion [21]. From the contributions of several researchers, some of the techniques for the development of these composites are stir casting, powder metallurgy, spray atomization and co deposition, plasma spraying and squeeze-casting [22-26]. The principal advantage of MMCs over other materials lies in the improved in strength, hardness and reduction of weight. It is found that the analysis is still in approach favored by the automobile sector [27].

1.3 Aluminium Metal Matrix Composites (Al- MMCs)

In Al- MMCs one of the constituents is Aluminium/ Aluminium alloy which forms percolating network and is termed as matrix phase. The other constituents are embedded in this Aluminium/ Aluminium alloy matrix and serve as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and $\mathrm{Al_2O_3}$ [5]. Particulate reinforced aluminum MMCs are promising candidate for automotive applications since they offer high specific stiffness and strength, good wear resistance and suitable thermal properties; furthermore, they are readily available at reasonable prices and can be processed using conventional technologies [28].
The addition of reinforced-particles in Al-MMCs produces improvement in mechanical properties like tensile strength, yield strength, wear resistance, specific heat capacity and lower density in comparison with other conventional materials [9]. Generally aluminium based composites produced by casting techniques are considered as economically viable owing to the properties such as low viscosity of liquid metals, net shape manufacturing capability and flexibility in designing the structure by controlled solidification [29, 30].
Many of these composites are based upon age-hardenable aluminium alloys reinforced with ceramic particulates such as SiC and Al_2O_3 [31, 32]. It is well known that these particles can accelerate the aging kinetics of the matrix alloy due to the higher matrix dislocation densities observed in these composites. Matrix dislocations act as nucleation sites for precipitates, and higher dislocation densities facilitates enhanced precipitation. In addition, the dislocations act as preferential paths for solute diffusion further accelerating the aging kinetics [32]. SiC and Al_2O_3 are found to be promising candidates due to their excellent properties such as high hardness, high refractoriness and good thermal properties [5, 33]. They improve the mechanical properties of the AMMC, increase the strength, hardness, improve the thermal conductivity and thermal shock resistance of the composite [5].

1.4 Mechanical behaviour of Aluminium Metal Matrix Composites (Al- MMCs)

Melby and Jagannath, (2014), carried out aging behaviour of 6061 Al-15 vol% SiC composite using Rockwell B hardness measurement. It was discovered that the peak hardness in T4 treatment is 90 HRB which was obtained at 720 hours of aging at room temperature. In T6 treatments, the temperature for under-aging, peak-aging and over-aging was determined using aging curves as well. The composite was under- aged at 140°C and 160°C, Peak-aged at 180°C and over-aged at 200°C. Maximum Peak hardness value of 98 HRB was obtained when the composite was aged at 180°C for 3hours. The peak-aging time was decreased to 3 hours when the aging temperature was increased [34].

Kareem et al., (2017), studied the effects of precipitation hardening on multistage stirred cast alumina reinforced AA 6063 composite by four stage stir casting method. The results trend showed that as the volume fraction of alumina and aging time increase, the strength and hardness values also increase with corresponding decrease in impact value. Composite with 15% Alumina aged at 4 hours showed highest strength and hardness values of 262.77 MPa and 64.12 BHN, respectively with impact value of 9.86 J. The study showed that multistage stir casting method and precipitation hardening heat treatment are capable of improving the mechanical properties of AA 6063 - Al_2O_3 composites [35].

Zulfia et. al., (2017), studied the characteristics of Al-Si-Mg reinforced SiC composite produced by Stir casting route. The effect of SiC addition on the mechanical properties and microstructure of the composites was investigated. The result showed that the optimum tensile strength was reached at 8 V_f% SiC with the value of 175 MPa, while the elongation was 9.1%. The maximum hardness and wear rate were achieved at 10 V_f% SiC with the values of 57 HRB and 0.0022 mm3/m, respectively. It was concluded that the addition of the reinforced SiC particles improves the mechanical properties of the composites such as strength, elongation, hardness, and wear resistance of up to 8 V_f% such increase was related to the microstructures dominated by the presence of Chinese script, primary and eutectic Mg_2Si which were contributed to the mechanical properties of the composites [36].

Rajasekaran et. al., (2012), performed aging treatment of Al 6061- SiC composite and highlighted under aging between 140 and 160 °C, over aging above 200 °C, and peak aging at 180 °C [37].

Meena et al., developed and analyzed the properties of Al-MMC prepared by stir casting techniques. In the experiment aluminium with 10%, 15%, and 20% of SiC were analyzed and concluded that aluminium with 20% of SiC shows superior property than other compositions [38].

Kumar et al., (2010), studied Al 7075-Al_2O_3 Metal Matrix Composites and it was concluded that the tensile strength properties of composites are found higher than that of base matrix Al 7075 alloy and also hardness of the composites increased with increased filler content [39].

AKM and Norul, (2017**),** studied the effect of reinforcement volume fraction on the mechanical properties of the Al-SiC nanocomposite materials, the results showed that a high volume fraction reinforced nanocomposite exhibited better microstructural feature and high hardness as compared to the low volume fraction reinforced nanocomposite. Therefore, concluded that the high volume fraction reinforced nanocomposite can be a potential material to be used in the brake disc of the automobile [40].

Cerit et al., (2008), also observed that the hardness value of the composite increased as the volume of the reinforcement increased. This research used large micro-sized SiC particles to increase the volume fraction of the reinforcements as well as to increase the strength of the composite [41].

Fatchurrohman et. al., carried out the Sustainable analysis in the product development of Al-Metal Matrix Composites (Al-MMCs) automotive component due to the increasing demand for fuel efficiency. It was concluded that Al-MMCs have some prospects for several applications in automobile parts. The objective was accomplished and thus identified the potential of Al-MMCs brake disc for replacement of the conventional cast iron brake disc [42].

Akhilesh and Mahesh, (2014), investigated the property analysis of SiC particles reinforced functionally graded Aluminium matrix composite cylinders and non-reinforced Aluminium cylinders by centrifugal casting to obtain the microstructure and mechanical properties for evaluation. The results obtained showed that the functionally graded composite cylinder shows higher and improved mechanical properties due to the presence of high volume fraction of silicon carbide particles than that of the pure alloy [43].

Pan et. al., (2017), investigated the effect of Al_2O_3 nanoparticles as reinforcement on the Tensile behavior of Al-12Si Composites, Al_2O_3 nanoparticle-reinforced Al-12Si matrix composites were successfully fabricated by hot pressing and subsequent hot extrusion. The influence of weight fraction of Al_2O_3 particles on the microstructure, mechanical properties, and the corresponding strengthening mechanisms were investigated in detail. It was reported that Al_2O_3 particles are uniformly distributed in the matrix when 2 and 5 wt. % of Al_2O_3 particles were added to the Al-12Si matrix. Significant agglomeration was found in composites with 10 wt. % addition of Al_2O_3 nanoparticles. It was finally concluded that the maximum hardness, the yield strength and tensile strength were obtained for the composite with 5 wt. % Al_2O_3 addition, which showed an increase of about ~11%, 23%, and 26%, respectively, compared with the Al-12Si matrix [44].

El-Sayed et. al., (2011), A356/Al_2O_3 was fabricated using a combination of the rheo-casting and squeeze-casting techniques. The A356 matrix alloy was reinforced with Al_2O_3 nano-particulates having average sizes of 60 and 200 nm with different volume fractions up to 5% vol. The results revealed that the A356/Al_2O_3 nano-composites exhibited better mechanical properties than the A356 monolithic alloy. Such improvement in the mechanical properties was observed at both room and elevated temperatures up to 300°C. Increasing the volume fraction and/or reducing the size of Al_2O_3 nano-particulates increased both the tensile and yield strengths of nano-composites [45].

El-Sayed et al., (2011), investigated the electrical and thermal conductivities of cast A356/Al_2O_3 Metal Matrix Nano-composites (MMNCs). The results revealed that the A356 monolithic alloy exhibited better electrical and thermal conductivities than the MMNCs. the Increasing nano-particles size and/or the volume fraction reduced both the thermal and electrical conductivities of the MMNCs [45].

Kaynak and Boyulu, (2006**),** have investigated the friction behavior of Al matrix- SiC particulate reinforced composite specimens in comparison to the matrix Al alloy containing 12 weight percentage Si. They have found that hardness, bending and fatigue tests indicated that reinforcing the Al-alloy matrix with SiC particulates improved hardness, flexural strength and fatigue resistance with increasing content of SiC particulates [46].

Mišković et. al., (2006), investigated composites-castings with A356 alloy base and additions of 1, 2, and 3 % (wt.) of Al_2O_3 reinforcement of 12μm size. The mechanical properties of the composite are improved in relation to the base alloy [47].

Pavitra et al., (2018), carried out a research on the effect of SiC reinforcement (average particle size 30-45μm) on the microstructure and mechanical properties of Aluminum Metal Matrix Composite. Results revealed that, the addition of SiC reinforcement in the Aluminum matrix increases the Hardness and Ultimate Tensile strength gradually from 23 HV to 47 HV and 84 MPa to 130 MPa respectively [48].

Li et al., (2014), made a study on fatigue crack growth in spray-formed Al-Si matrix reinforced with SiC particles and reported that small SiC particles exhibited superior resistance to fatigue compared with larger SiC particles and unreinforced alloy [49].

1.5 Wear behavior of Aluminium Metal Matrix Composites (Al- MMCs)

The property of wear behavior in the application of brakes is most vital. A number of investigators have studied the friction and sliding wear behaviour of AI-Si alloy composites It is well known that improvement in the wear resistance of Aluminum alloys can be achieved by adding ceramic particles such as SiC and Al_2O_3 to the matrix alloy [50]. Particle-reinforced metal matrix composites (MMCs) have been used in brake and piston components in automobile and aircraft's over the last decade owing to their attractive friction and wear properties [51]. It has been found that the wear resistance of Aluminum matrix composites is influenced by numerous factors such as the morphology, size and volume fraction of reinforced particles as well as the strength of the interface [52].

Sahin and Acılar, (2003); Mahdavi and Akhlaghi, (2011), in their studies on properties of SiC particulates reinforced Aluminium alloy composites reported that, wear properties of the Al alloy improved significantly by the addition of SiC particles into the matrix alloy [53,54].

Nagaral et al., (2013), investigated and fabricated 6061Al composites with different weight percentage of Al_2O_3 particles up to 0-9% by liquid metallurgy route. It was revealed that the 6061Al - Al_2O_3 composites have a higher tensile strength than 6061 aluminium alloy with reduced ductility. It was also found that an increase in the Al_2O_3 content in 6061Al alloy contributed in enhancing the hardness of the composites. The wear test was conducted using computerized pin on disc wear tester with counter surface as EN31 steel disc (HRC60) and the composite pin as specimens, demonstrated the superior wear resistance property of the composites [55].

Walker et al., (2005), have found the predominant wear mechanism during lubricated sliding of 2124 and 5056 aluminum alloys is mild wear by abrasion. The introduction of a harder reinforcing second phase to the matrix resulted in an improvement of wear resistance for both alloys [56].
Surendran et al., (2017), carried out wear properties enhancement of Aluminium Alloy with addition of nano alumina. Reinforcement of nano-sized particles with aluminium matrix yields superior mechanical and physical properties and changes morphology of nano-composites. It was finalized that the wear reduction experienced was due to strong bond formation between Al and Al- Al_2O_3 nano composites. The results show that the addition of nanopowder in varying proportions influences the increased wear performance of the aluminium alloy and the maximum wear reduction was obtained with the addition of 2.5% nano Al_2O_3, when compared with the results of pure LM 25and other Al- Al_2O_3 composites [57].
Straffelini et al., (2004), investigated effect of load and external heating on friction and wear behaviour of two Al based metal matrix composite (SiC 10 and SiC 20 containing 10 % and 20 % volume of reinforcement of silicon carbide particle) dry sliding against brake lining material. In actual brake systems, the nominal contact pressure typically varies between 0.3 and 2MPa and the sliding velocity between 1 m/s and above 10 m/s. External heating causes decrease in wear of both composite (negative wear) and decrease in friction coefficient and increase in wear of counter face friction material. It was concluded that as far as wear resistance of metal matrix composite disc is concerned external heating is advantageous since it allows formation of transfer layer [58].
Das et al., (2008), have noted that wear rate of composite (Al - Si alloy with SiC reinforcement) is less than that of Al - Si alloy. Hardness and Strength of composite are higher than that of alloy and they increase with increase in SiC content. The wear rate of Al alloy and Al composite is invariant to the sliding distance and increase with increase in applied load and abrasive size. Addition of SiC particles and heat treatment provide comparable improvement in wear resistance [59].
Uyyurua et al., (2006), reported tribological behaviour of stir cast Al- SiC composite sliding against brake lining material on pin on disc apparatus. The coefficient of friction was about 0.3 and it decreases with increase in load. The coefficient of friction decreases with increase in sliding speed. With increase in sliding speed wear rate decreases for all composites. It was concluded that the presence of depressions in tribo-layer was due to breaking of layer in trashes which may lead to abrasive wear [60].
Yu et. al., (2008), studied the frictional wear resistance and thermal fatigue resistance of brake drums and two kinds of biomimetic coupling materials. The results indicate that frictional wear resistance and thermal fatigue resistance of biomimetic coupling sample is better than that of untreated sample and among the biomimetic samples, laser coating treated sample has superior resistance to wear and thermal fatigue comparing with laser melting treated sample [61].

1.6 Particulate Reinforced Aluminium Alloy Matrix composites Brake Rotor

Grey cast iron is used to manufacture brake disc rotor, The SAE maintains a specification for its manufacture for various applications. For normal car and light truck applications the SAE specification is J431 G3000 (superseded to G10). This specification dictates the correct range of hardness, chemical composition, tensile strength and other properties necessary for the intended use. Some racing cars and airplanes use brakes with carbon fiber discs and carbon fiber pads to reduce weight. Wear rates tend to be high and braking may be poor until the brake is hot. It is investigated that the temperature distribution, the thermal deformation and the thermal stress of automotive discs have quiet close relations with car safety; therefore, much research in this field has been performed [5]. However, Al- MMC is selected considering crucial advantages over cast iron material. Al-MMC has a lower density and higher thermal conductivity as compared to Gray Cast Iron and it results in weight reduction of up to 50–60% in brake systems [1].
Adebisi et. al., (2014), studied the performance assessment of Aluminium composite material for automotive brake rotor. The rotor achieved 50% weight reduction and the braking result reveals that composite rotor exhibited uniform thermal trend with 25% heat dissipation rate for braking pressure within the range of 1.5–2.0 MPa over cast iron. The contour trend of cast iron rotor exhibited high temperature zone which gives rise to formation of intermittent hot spot which is detrimental to braking conditions. Simulation modelling analysis

showed good agreement with actual operating test measurements. It was finally concluded that composites are commercially viable and feasible to replace the existing Cast iron material [62].

Rehman et al., (2012), reported the analysis of Aluminium alloy–Silicon Carbide Metal Matrix Composite (Al–SiC MMC) in the automobile brake drum applications in comparison with cast iron (CI) brake drum. It was stated that Al–SiC MMC can be effectively used in brakes in automobiles due to its comparative coefficient of friction. It was concluded that brake drum and brake shoe interface temperatures with all composite material brake drum are lower than that observed with CI brake drums, that Interface temperature has an important effect on the coefficient of friction of the braking surfaces which affects braking efficiency of the brake drums and Coefficient of friction with composite material is higher due to the existence of SiC particles in the aluminium alloy [63].

Natarajan et al., (2006), investigated the wear behavior of Aluminium metal matrix composites (Al-MMCs) with 25% SiC particulates by sliding against automobile friction material and it compared to the Gray Cast-Iron. It was observed that the Metal Matrix Composites had considerable higher wear resistance than the Gray Cast-Iron and the friction coefficient of Al- MMC was 25% more than the Cast-Iron [64].

Nosa et al., (2014), carried out a computational study on the use of an Aluminium metal matrix composite and Aramid as alternative brake disc and brake pad, the results showed that aluminum metal matrix composite is a suitable alternative. It was concluded that though the conventionally used grey cast irons are no danger to the health and are affordable. Al - MMC has a lower density and higher thermal conductivity as compared to Gray Cast Iron and it results in weight reduction of up to 50–60% in brake systems. Thus it can be applied in cases where less weight is specifically required for good performance, such as Formula-1 racing cars [65].

Gultekin et al., (2010), studied the frictional and wear characteristics of sintered copper matrix composite brake pads against cast Al–Si/SiC particulates composite brake disc and the effects of applied load on the coefficient of friction. The aluminum metal matrix composite material was used as a disc, whereas the graphite reinforced copper matrix composite was used as a brake pad. It was discovered that the amount of wear of both brake disc and pad cannot be measured since trace amount of material was transferred and concluded that the phenomena proved that the brake disc and the pad have high wear resistance [66].

Maleque et al., (2010), carried out the development of material selection method and selected the optimum material for the application of brake disc system emphasizing on the substitution of Cast Iron by any other lightweight material. The analysis led to aluminium metal matrix composite as the most appropriate material for brake disc system [1].

Mohammad A., (2012), carried out the tribo-evaluation of Aluminium based metal matrix composites used for automobile brake pad applications**,** It was observed that the Al- based brake pads posses lower wear rate, same order of Coefficient of friction as in resin bonded brake pads, while the temperature rise is one third as compared with resin bonded brake pads. It was concluded that the development of Al-based metal matrix friction composites has a great potential in making automobile brake pads and may replace the existing resin bonded brake pads in varieties of applications. This can be extended to brake rotor application for a better replacement for cast iron [67].

Dhiyaneswaran et al., carried out the comparative study of disc brake materials through Computer Aided Engineering, the modeling and analysis were done using finite element analysis software. It was finally concluded that Aluminium silicon carbide composite can be used in automotive to replace the conventional material for improved vehicle performance [68].

Telang et al., (2010), investigated an alternate materials in automobile brake disc applications with emphasis on Al - composites, it was reported that, the friction coefficient of aluminium metal matrix composite (Al-MMC) is 25-30% times more than that of cast iron. Thermal conductivity of Al-MMC is about two or three times higher than cast iron. It was finally stated that Al- MMC disc could be 60% lighter than an equivalent cast iron disc [69].

Sourav et al., (2013), studied the braking performance of Al-Si alloys (ADC12 and LM30) brake drums using a brake drum dynamometer test rig. The comparison of the performance of ADC12 and LM30 alloys on the basis of experimental parameters such as coefficient of friction, rise in temperature, braking torque and rotational speed were studied. Stopping distance after applying the brake was also calculated and it was observed that stopping distance reduces as a function of brake force and concluded that LM30 alloy performs better than ADC 12 [70].

Govindan and Viji, (2017), carried out the design and analysis of automobile brake disc using Al/SiC Metal Matrix Composite (MMC), the behaviour of the brake disc with aluminium metal matrix composite material and conventional grey cast iron material in finite element software ANSYS 15.0 was analyzed. Modeling of the disc brake rotor was also done using SOLIDWORKS 2010. The Comparison of stress distribution, displacement and temperature distribution for conventional and proposed material indicates that Al/SiC MMC with 10% SiC satisfies the requirement for disc brake application. It was concluded that Al/SiC MMC with 10% SiC can be used in automotive to replace the conventional material for improved vehicle performance [71].

Erva et al., (2016), carried out the development of aluminium metal matrix composite brake rotors with a selective ceramic function reinforcement gradient (FRG) for automotive applications. Dynamometer testing was performed concentrating on brake friction and temperature to evaluate the macro and micro interfaces in the rotors. The rotors' testing results indicate that a functional reinforced aluminium metal matrix composite rotor is viable option for front and rear brake applications in the automotive and commercial trucking market [72].

Swapnil et al., (2017), carried out the evalution of mechanical properties of Aluminium/ Silicon Carbide /Fly Ash Brake Rotor. Composites containing hard oxides (like SiC) are preferred for high wear resistance along with increased hardness and high temperature oxidation resistance. The result reveals that wear rates of the composite materials is lower than that of the matrix alloy and friction coefficient was minimum. Also, it improves the micro hardness and tensile strength [73].

Laden et al., (2000), investigated the frictional characteristics of Al-SiC composite brake discs. They tested four Al-MMC discs in railway braking devices differing in matrix composition in continuous braking against an organic pad and they concluded that Al-MMC discs show lower friction coefficients and better wear resistance compare to classical steel discs [74].

Straffelini et al., (2004), investigated the influence of load and temperature on the dry sliding wear of Al based composites against friction material. They found that the wear resistance of Al MMC brake rotors are superior to those of cast iron rotor if the structure and composition of lining material are correctly modified [75].

Withers and Tilakratna, (2005), reported that Al-MMC automotive brake drums have high heat dissipation characteristics, better liner wear characteristics and weight less than four tenths of the weight of similar size of Cast Iron brake drum [76].

Mustafa and Adem, (2007), give in the first stage, bronze-based brake linings were produced and friction-wear properties of them were investigated. In the second stage, 0.5%, 1%, 2% and 4% alumina (Al_2O_3) powders were added to the bronze-based powders and Al_2O_3 reinforced bronze-based brake linings were produced. The highest friction coefficient was obtained in the samples containing Al_2O_3 in the range of 4% due to an increase in the temperature during friction. The addition of 2% Al_2O_3 to the samples showed stable friction coefficient [77].

Louies et al., (2016), carried out the Analysis of Disc Brake in Aluminium Alloy 6061 Metal Matrix Composites. The experimental results concluded that the aluminum composite material is a better replacement for conventional cast iron discs and its implementation in vehicles can improve the overall braking efficiency [78].

Fatchurrohman et al (2016), carried out the investigation of product performance of Al-Metal Matrix Composites (Al-MMCs) brake disc using Finite Element**.** The results suggested that the Al-MMCs have the potential to replace the conventional cast iron brake disc. This is supported by better thermal and mechanical performance by the MMCs brake disc during simulated braking operation [79].

Rahul and Swami, (2016), carried out the analysis and computational investigation of brake disc for composite materials, it was discovered that Aluminium alloy based metal matrix composites (MMCs) with ceramic particulate reinforcement showed a great promise for brake rotor applications. It was reported that the composite materials have lower density and higher thermal conductivity as compared to the conventionally used gray cast irons which resulted in weight reduction of up to 50-60% in brake systems. After increasing hard particles content the result showed that the repeated braking operations did not lower the friction coefficient [80].

Sadagopan et al., (2018**),** studied the use of abrasive particle (SiC)-reinforced aluminum metal matrix composite material for brake rotors. The result obtained showed a less generation of heat during braking (due to friction) and also reduction of the unsprung mass of the vehicle resulting in better handling. It is therefore concluded that Al-MMCs brake disc was a better substitute for the conventional cast iron brake disc [81].

2. Summary and Conclusion

A detailed investigation has been carried out to understand the existing literature on development of Aluminium alloy based Metal Matrix Composites (Al-MMCs) for automotive applications and an effort has been put to understand the needs of the growing composite industries. This review also revealed the investigation carried out on various aspects like characterization, fabrication, testing, correlation between mechanical and wear properties of Al-MMCs. The effects of heat treatment on the mechanical properties were also carried out. From the information gathered from the above review, it can be concluded that Al alloy composites were selected as a matrix material for the research works due to their wide range of application, heat treatment capability and processing flexibility. The review also revealed that many researchers focused on the use of reinforcing materials like SiC and Al_2O_3 either as a particulate form or fiber form. These reinforcing materials are generally costly which limits their application. Hence, there is need to explore the use of a lignocellulosic material with value added hard compounds such as Locust Bean Pod ash that has chemical compositions such Al_2O_3, SiO_2, Fe_2O_3, MgO , Pb_2O_5, CaO, K_2O and Na_2O or Rice husk ash that contains chemical compositions such as Al_2O_3, SiO_2 , Fe_2O_3 , MgO , PO_4, Na_2O , ZnO, K_2O, MnO_4 and CaO with low cost option as they are readily available, affordable and accessible which can be used as a substitute for the expensive reinforcing materials. Therefore, there is need to carry out the determination of mechanical and wear properties of heat treated aluminium alloy composite comprising of Aluminium Alloy as Matrix material and Locust Bean Pod Ash or Rice Husk Ash as reinforcement for vehicle brake rotor application.

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