ALTERNATE MATERIALS IN AUTOMOBILE BRAKE DISC APPLICATIONS WITH EMPHASIS ON AL COMPOSITES- A TECHNICAL REVIEW

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ABSTRACT

Brake technology just like suspension & fuel system technology has come a long way in recent years. Automobile braking systems normally use brake discs of steel or grey cast iron, which are then paired with composite organic brake pads. These types of materials are suitable for use in braking systems with moderate loads, but vehicle manufacturers are tending to design increasing number of vehicles with more braking power. In addition, a history of high operating costs for on - highway vehicles and for aircrafts has encouraged designs for weight reduction with long service of braking systems. Redesigning of the braking system by substitution of lighter material like aluminum and carbon composite brakes primarily have been responsible for this state of the art technology, which is being used in aircrafts and formula one racing cars (1). The requirement is of the materials that have light weight, are strong, abrasion resistant and are not corroded easily. Composite materials provide such unique combination of properties. In this review the alternate materials for automobile brake applications with special attention to aluminum composites has been done.

KEYWORDS Braking systems, organic brake pads, composite materials, aluminum composites.

INTRODUCTION

The need of efficient use of energy & materials is being felt strongly because of diminishing resources in the present times. There has been an important role of materials in the development of civilizations. In the transportation sector when earlier large bulky automobiles are compared with today’s light weight, technologically superior vehicles. Man has been using iron, copper & their alloys for thousands of years, but surprisingly until the last century he was oblivious of the bauxite ore (which has aluminum) is the second most abundant ore in earth crust. It became an economic competitor to steel & cast iron in engineering applications because of its excellent combination of properties like lightweight, high specific strength, stiffness & good corrosion resistance, higher ductility.
etc. However, the poor mechanical and tribological properties of aluminum (yield strength : 30 Mpa, tensile strength : 70 Mpa) limits its wider range of usage. Realizing the potential as well as availability of Aluminum, considerable efforts are being made to explore the possibilities of improving the mechanical strength and wear resistance so as to meet the requirements of various applications. More aluminum is being consumed now a days than all other non ferrous metals/ alloys including Copper. The transformation of the automobiles requiring more fuel, frequent maintenance to the energy efficient automobiles requiring lesser maintenance and which are also environment friendly has resulted from better engineering & materials. With the turn of century material technology in automobiles undertook a shift towards all aluminum cars. In order to improve the mechanical strength & modulus of aluminum, it is alloyed with various alloying elements such as Cu, Zn, Mg, Si, Mn etc.(3) Amongst the various Aluminum alloys Al-Zn-Mg alloys are found to show tremendous improvement in mechanical strength and finds its application in aerospace and automobile structural components. Al-Mg cast alloys show excellent corrosion resistance, good machinability and attractive appearance when anodized. In internal combustion engines, Al-Si alloys are used extensively because of their properties like low coefficient of thermal expansion, bearing properties, good corrosion resistance in association with the strength.

**Composite Materials**

Composite materials signify that two or more constituents are combined on microscopic scales to synthesize a useful material. A variety of materials can be combined on a microscopic scale. The advantage of the composite materials is that their individual constituents retain their characteristic unlike alloys. As a result, various combinations of useful properties, usually not attainable by alloys, can be obtained through composite materials by suitable tailoring the matrix and reinforcement [dispersoid]. The dispersoids/second phase particles may be either harder or softer than the matrix alloy and affect the properties of the composites accordingly. For e.g. softer dispersoids like graphite, talc, mica shell etc. impart solid lubricating properties wherein the total wear resistance of the material improves (4-5). In this case, other properties such as strength, hardness etc. of the
composites is less than that of the matrix alloy. However, they have been found to be within acceptable limits as confirmed through some experiments (6-8). The reinforcement of hard ceramic particles like silicon carbide, alumina, silica, zircon etc. in aluminium alloys has been found to improve the wear resistance as well as high temperature strength properties (9-11).

**Types of Composite Materials**

The nature of the reinforcing phases and the matrix are the important factors on the basis of which composites are classified as:

a) Fibre reinforced composite
b) Whisker reinforced composite
c) Particle reinforced composite
d) Laminated composite

Different types of composites with reference to the nature of the matrix are as follows:

- Ceramic Matrix composites [CMCs]
- Metal Matrix composites [MMCs]
- Polymer Matrix composites [PMCs]

Fibre reinforcements dominate composites. The reinforcing phase may be continuous, that is, extending the full length of the composite [as wire or filament] or discontinuous [as particulates, whiskers or short fibres]. In the fibre reinforced and whisker-reinforced composites, the second phase has an aspect ratio [i.e. ratio of length to diameter] from 50 to 10,000. A number of such composites with reinforcement of alumina fibres, carbon, boron, silicon carbide (12,13) are now commercially available for structural applications requiring exceptionally high specific strength and specific modules. The second category of composites involves the dispersion of soft or hard particles. These composites are of great interest in tribological applications. In the case of particle dispersed composites there can be some reduction in tensile strength [especially at room temperature], ductility and fracture toughness (14). These can be used by tribological purpose where strength is not the-main criterion (15). In the case of laminated composites, alternate layers of different materials are put over each other with the help of some binding agents. In some cases secondary processing is also required in order to improve the strength properties of the composites.

**Aluminum Matrix Composites (AMCs)**

There is a broad family of materials in this category aimed at achieving an enhanced combination of properties and this can be attained by selecting different matrices as well as reinforcing phases. In addition to the matrix microstructure, reinforcing phase
also controls the characteristics attainable by the MMCs (16). Matrices reinforced with high modules short fibres, whiskers or particulates have improved strength and stiffness and are isotropic in nature. This variety of the composites is less expensive to produce. In the case of continuous fibre or whiskers with high aspect ratio [length / diameter], to align fibres in the desired stress direction and to transfer the applied load to the fibres the matrix serves to hold them together. The mechanical properties of the composites are dependent upon the efficiency of the matrix in transferring the load to the reinforcement fibres and are therefore related to the quality of the fibre/matrix interfacial bonding (17). This type of composites exhibits significantly higher strength and stiffness. But they are non-isotropic in nature and are expensive. Aluminium and its alloys form the most widely investigated matrix for use in MMCs. This popularity of Al-alloy as a matrix material can be attributed to its low cost relative to other light structural metals such as Mg, Ti, etc. its current dominance on the aerospace structural application and so on. There are two types of reinforced aluminum alloy composite:

1. Discontinuously [short fibre, whisker and particulate reinforced] and

2. Continuously reinforcement aluminum alloy composites [long continuous fibre reinforced].

The early work on composites, considered that the continuous fibre reinforcement composites are very expensive and hence limit their applications (18). It was apparent that the cost of continuous fibres, complex fabrication routes, and limited fabricability would restrict their use to those applications requiring the ultimate in performance. This led to the development of discontinuously reinforced composites, particularly short staple Al$_2$O$_3$ fibre and SiC whiskers (5) reinforced composites. Discontinuous fibre has found commercial application as selective reinforcement in the ring land area of diesel piston [24] and whisker reinforcement is under development for aerospace applications. Particle reinforced light metals, with their potential as low cost, high modulus and strength, high wear resistance and easily fabricated material, are just reaching the commercial production stage. Understanding the factors that influence the physical and mechanical properties of these materials is yet to be crystallized, because they are sensitive to several factors like the type of reinforcement, the mode of manufacture and
the details of any fabrication processing of the composite after initial manufacture etc.

**Wear of Al matrix composites**

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 Al-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$_2$O$_3$ to the matrix alloy. 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. 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. Hosking et al. observed an increase in wear resistance of 2014 Al-Al$_2$O$_3$ with increasing weight percent and size of ceramic particles. However conflicting reports exist in the literature when metallic interfaces are used as rubbing pairs. For example, Alpas and Embury observed a decrease in the sliding wear resistance with increasing particle volume fraction in a 2014 Al-SiC/steel system. Saka and Karaleskar reported a decrease in sliding wear resistance, with increasing particle concentration in a Cu-Al$_2$O$_3$ composite. Therefore, the selection of the rubbing pairs with metal matrix composites seems important and different wear mechanisms may result in different wear behaviour. Because steel or steel alloy components as wear counter faces are widely used in tribo systems, the study of MMCs/steel wear system has become an important topic in recent years. Lhasa et al. have studied the wear resistance of various eutectic and hyper eutectic Al-Si alloys with various compositions and processing routes on pin on disc machine at two different test speeds. At lower disc speed the influence of the composition and alloy processing is very strong and a severe wear transition is observed for the alloys with low fraction of primary Si particle. At higher disc speed wear of all alloys except the one with high silicon content, is very low. The higher wear is caused by cracking & fracture of large Si particles upon impact with abrasive disc material. Jang H and others have reported the effect of different metallic fibres (Cu, steel and Al) upon friction and wear performance of various brake disc (grey cast iron and aluminum MMC) to investigate the friction
characteristics such as speed sensitivity, pressure sensitivity, temperature fade resistance and wear resistance. When the grey cast iron is used as a counter disc at low temperatures, the friction material containing Cu or steel showed high speed sensitivity, when Al-MMC disc are used the speed sensitivity was small between different friction materials. High temperature fade resistance was improved by using friction materials with copper or steel fibres on the grey cast iron. The greatest amount of wear occurred in the friction material containing steel fibres followed by copper fibre friction and Al fibre friction materials. Recent studies [27] revealed that in addition to the volume fraction, and spatial distribution of second phase particles, wear resistance is largely affected by the strength of particle-matrix interfaces as well as the mechanical properties of matrix materials, consequently under the service conditions where the particles lose their ability to support the applied load [either owing to interfacial, depending, particle fracture or pull out] second phase reinforcement may cause no improvement or even a deterioration in the wear properties [28-31]. A detailed understanding of the micro mechanism of wear is necessary to model the wear behaviour of composites and set design guidelines for manufacturing of materials with optimum tribological properties. The wear behaviour of these alloys has been studied in details [32-37] and it has been shown that eutectic and hypereutectic composites exhibit the highest wear resistance.

**Review of brakes**

Automotive brakes include drum and disk brakes for vehicle applications. Drum brakes predominantly use internally expanding shoes with brake linings that load the majority [typically 50 to 70%] of the drum rubbing surface. Most automotive disk brakes use shoes that load a much smaller portion [from 7 to 25%] of the disk rubbing surface. Disk brakes offer faster cooling, with their larger exposed surface areas and better cooling geometry, but are more vulnerable to either liquid or solid particulate contamination. Rhee and others have related measurements on friction material wear with the brake cast iron temperature. These data indicated an essential constant wear rate for low temperature and a nearly exponential one at elevated temperature (38). Because of cooling, contamination, and other basic design issues, front disk brakes and rear drum brakes are commonly used. The
friction material is called a brake lining, whether it is used on drum. Drum brake linings are known as segments or strips, and heavy truck drum brake linings are called blocks. Particulate reinforced aluminum MMCs are promising candidates for automotive applications since they offer high specific stiffness and strength, good wear resistance and suitable thermal properties; further more, they are readily available at reasonable prices and can be processed using conventional technologies. (39) A review of disc materials used by the automotive industry today, will show that there are two basic material philosophies. The first, used for family sized vehicles, operates on the principal of small diameter, high strength, discs with sufficient inherent strength to resist any tendency towards the formation of thermal cracking, and distortion at high operating temperatures. These discs whilst having good strength properties have relatively low thermal conductivity. The second principle, that of large weaker, low strength discs with high thermal conductivity, has been applied more commonly, to the larger high powered type of vehicle where space constraints are not so critical, and as a consequence, a large diameter thicker discs can be employed. (40). Laden and others (41) have tested four AMC discs in railway braking devices differing in matrix composition in continuous braking against an organic pad. They have reported that AMC discs show lower friction coefficients and higher wear rates than classical steel discs. By increasing the reinforcement rate up to 8 weight percentage angular SiC, the disc exhibited a low wear rate, particularly at high braking power and a relatively high friction coefficient because of high angular SiC content with same SiC content, the spherical SiC reinforced disc exhibited a lower friction coefficient due to spherical SiC reinforced disc exhibited a lower friction coefficient due to spherical morphology resulting in a sliding contact instead of ploughing one. M J Denholm, [42] has reported the use of Al MMC rotor and drum technology and how it might move light vehicle brake systems to new levels of customers' satisfaction. Al MMC technology exhibits a remarkable fit, in addressing all of these areas simultaneously while offering valuable rotating mass reduction. Nobuyuki and others (43) have developed the laboratory tests for studying local physical phenomenon caused by friction in railway braking. Similar contact conditions to those at full scale have been generated. An original braking tribometer is presented whose design is based on
similitude rules between reduced scale and full scale. The drive to reduce vehicle weight, and improve efficiency, has led to the investigation of alternative materials for use as brake disc materials. To date, two alternative materials, carbon carbon composites and aluminium metal matrix composites have found limited use. Blau et al (44) have done the sliding friction and wear tests simulating the geometry of a flat brake pad on a flat rotor, on four different material combinations; commercial pad material on grey cast iron, ceramic composite (C/SiC) sliding self mated, commercial pad material on Al metal matrix composite and commercial pad material on iron alumina alloy. They have reported that average friction coefficients were similar for the sliding couples involving cast iron and the ceramic composite but were lower for the other two, with lowest being for the couple containing the MMC. The surface roughness of the cast iron and ceramic composite disc were reduced after sliding, but that of the MMC remained about the same, and that of intermetallic alloy increased due to abrasive wear. Zhang and Wang (45) have investigated the friction and wear behavior of the same brake materials dry sliding against two different brake drums made of Al –Matrix composite reinforced with different sizes of SiC particles. It is found that the brake material against the drum with large size SiC particles showed better friction performances and wear resistance than those against the former associated with small sized SiC particles. Friction coefficient in both decreased with increase of load and speed. Friction fade took place at high temperature. Natrajan et al (46) have compared the wear behavior of aluminum metal matrix composite sliding against automobile friction material and reported the friction coefficient of Al MMC 25% higher than cast iron. The influence of load and temperature on the dry sliding wear of Al based composites against friction material has been investigated by Straffelini et al (47), they have found that 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. Das and others (48) 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. Kaynak and Boulu (49) 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 the hardness, flexural strength and fatigue resistance with increasing content of SiC particulates. Walker et al(50) have found the predominant wear mechanism during lubricated sliding of 2124 & 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. Mondal & Das (51) have found that wear rate in Al composites increases linearly with applied load irrespective of the material and abrasive size. Withers & Tilakratna (52) 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 CI brake drum. In the study of the wear behavior of Al-Si/SiC composites against automobile brake pads Uyuru et al (53) reported that wear rate and friction coefficient vary with applied load and sliding speed and a tribolayer can act as a protective layer for the matrix material. In the study of wear & friction behavior of SiC particle composites sliding against automobile friction material on pin on disc apparatus, Daud et al (54) found that friction coefficient of composite disc decreased with applied load. Kaynak and Boulu (55) found that by reinforcing the Al-alloy matrix with SiC particulates improved the hardness, flexural strength and fatigue resistance with increasing content of SiC particulates.

CONCLUSIONS

The properties of AMCs have been widely examined and would appear to offer several major advantages, namely:

- The friction coefficient of AMC is 25-30% times that of cast Iron and better wear characteristics.
- The thermal conductivity of AMC can be two or three times higher than cast iron.
- An MMC disc could be 60 % lighter than an equivalent cast iron component.
- The Thermal Diffusivity, which is the rate of heat dissipation compared to that of storage, is four times that of cast iron.
Clearly an impressive material, the performance of which depends on the nature of the composite dispersion.

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