A Composite Material an alternative for manufacturing of Automotive Disc Brake: A Review

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Abstract. The brake disc is an indispensable component of an automobile especially in this trending era of electric mobility, where gasoline engines are superseded by electric vehicles in which prominent criteria is to lower down the weight to enhance the performance of the vehicle. Aluminum Metal matrix composites (MMC) play an important role because of researchers as these are not only used in automotive industries but aircraft and locomotives also. In most vehicles, these brakes are made up of Cast Iron which has well anti-wear properties and cheap too. But in certain other cases such as high-performance vehicles, these brake discs are not up to their standards of high performance because the cast iron brake discs are heavy and so reduces the vehicle's performance to a particular extent. This paper reviews on fundamental function of Disc brake and the crucial challenges found in this review are, the problem of evolution of hazardous wear particles in an atmosphere, thermoelectric friction problem during braking, friction-induced vibration which causes squeal, the behavior of abrasive particles, and dynamic stability analysis, etc. an alternative to cease these problems possibly is to adopt novel material.

1. Introduction

Disc brakes: Shoes or pads contract on the outer surface of a spinning disc, having compressive frictional force. The brake disc is a rounded metal disc on which the pads are mounted. It typically consists of material made from cast iron. Depending on the application, amount of exposure, thermal properties of the material and the amount of heat dissipation desired when brakes are applied, and the total mass to be stopped, the configuration of disc brakes varies. Based on its workings functions of brakes can be summered as:

1.1 Function of brakes: The basic functions of the brake system must be described predictably. Circumstances, at fair cost and lifetime of brake wear, thus providing directional stability and reasonable use of tire-road friction. All relevant safety requirements must comply with the braking system. During Safety requirements are considered minimum performance in most situations and Specifications. Brakes must operate safely in all fairly imaginable operating conditions, including slick, wet, and dry roads; with a vehicle that is light or fully loaded, straight or turning brakes, new or worn brakes, beginner or professional drivers, on smooth or rough roads. Mainly brake functions can be divided as follows:

1.1.1 Slowing and/or Stopping: Large values of thermal conductivity, specific heat, and density for brake rotors yield lower swept

1.1.2 Maintaining Speed on a Downgrade: The potential energy is transformed into thermal energy by the brakes during constant-speed downgrade operation, resulting in increased brake temperature. As long as the operating conditions are such that the steady-state brake temperature reached is less than the brake-specific critical temperature vehicle will be able to safely descend the downgrade.

1.1.3 Holding Stationary on a Downgrade: Keeping a vehicle stationary primarily depends on the transmission of force between the application lever and brake tires, or
mechanical advantage. Security in Safety In general, requirements requires a defined capacity for hill-holding. However, a parking brake can be used when the service brake has failed in an emergency.

In the present era, metals are extensively used, and there are many ways of producing a product using only pure molten metal or some other phase of the metal. When it comes to production processes, the following are the most common ones used in large industries. Previously, these brake discs were made by melting the molten metals, according to the application and feasibility. the main drawback of this method was brittleness and high density. To get rid of this challenge, researchers observed that by adding smart contents into the molten metals these difficulties may be eliminated. Hence following materials are proposed for the manufacturing of the brake discs.

- Metal Matrix Composites (MMC)
- Carbon-Carbon Composites
- Aluminum Fly ash (ALFA) composites
- Titanium Alloys.

After the brake disc shape is achieved by heating and cooling the mixture of the parent materials, the addition of other contents into the matrix is carried out to harden the brake disc, resulting in a new material known as composite Material. While manufacturing of brake disc various properties that are required to be considered are as follows:

1.2 Properties for brake disc rotor:

The temperatures induced by friction heating are directly related to the properties of the material. Apart from sliding speed, brake disc material properties need to be addressed. In addition to these, materials should possess the following specifications

a. Corrosion-resistant
b. Ability to withstand high temperature
c. Lightweight,
d. Long life,
e. Low noise,
f. Stable-friction
g. Low wear
h. Fair cost.
i. Imperviousness for atmospheric conditions.

A comprehensive account of the literature review is given in the report. To classify the previous research activities and directions relevant to our focal field. The review-related topic is discussed in chronological order so that the underlying pattern of the development of thoughts and ideas in that area is also suggested. Care was taken to preserve the original terminology used by the authors, to the Freepost address, to retain the originality of the opinions. The crucial challenges found in this review
were the problem of evolution of hazardous wear particles in an atmosphere, thermoelectric friction problem during braking, friction-induced vibration which causes squeal, the behavior of abrasive particles and dynamic stability analysis, etc. The analysis is summarized below.

2. Researcher’s Experimental approaches

Mikael Eriksson et al., [2001] observed that the contact region between a brake pad specimen and a glass disc generated great insights into the dynamics and mechanics of the contact situation. The softer and more porous areas around the contact plateaus are worn out by three-body abrasion. A significant number of small particles (wear debris) are transported through the narrow labyrinth between the surfaces while the disc is slipping against the plateaus, milling down the weaker constituents.

K. Shin et al., [2002] the purpose of the present research were to use the basic model to analyze the effect of damping on a disc-brake system's stick-slip vibration. When the natural frequencies of a pad and disc are nearby, a brake is more likely to be noisy. The amount and distribution of damping in the system is a key factor. To know the mechanisms of brake noise two Degree of freedom model was taken into consideration. It was observed that the damping of the disc is as significant as that of the pad. To illustrate different limit cycles in step space, non-linear analysis is often performed. Further, the machine can become more unstable and therefore noisy by adding damping to either the disc or the pad alone.

N. M. Kinkaid et al., [2003] in the automotive field, disc brake squeal remains an elusive issue. Many researchers have investigated the issue with experimental, computational, and computer techniques since the early 20th century, but there is still no way to effectively suppress disc brake squeal. It is well recognized that a non-linear model is expected to address the cause of instability by the in-depth study.

Ji-Hoon Choi, In Lee, [2004] the study aims for thermoelastic characteristics of carbon-carbon composite disk brakes. It was noted that, due to uniform and mild pressure distributions, the orthotropic disk brakes can provide better brake output than the isotropic ones. This outcome can be used as a design tool for improving braking performance.

M. Kermca, et al., [2005] In this study new Material has been introduced into a braking system in which performance of temperature and coefficient of friction were analyzed It was observed that The temperatures produced by ceramic-carbon composite C/C SiC and metal-matrix composite (MMC) contacts are very high; they reached more than 800 °C under the test conditions, which is more than two times higher than traditional contacts with grey cast iron. Compared to grey cast iron, the coefficient of friction in contacts with ceramic-carbon composite C/C SiC was two times higher and more uniform wear.

P. Liu, et al. [2007] demonstrated the new functionality of ABAQUS/Standard, which allows for a nonlinear analysis to identify the stability of brake systems. The study suggests that to investigate the effects on the disc squeal of device various parameters, such as the hydraulic strain, the rotational velocity of the disc, the coefficient of friction of the contact interactions between the pads and the disc, the stiffness of the disc, and the stiffness of the pads backplates are responsible. The simulation results suggest that the disc brake squeal could be responsible for major pad bending vibration. By decreasing the coefficient of friction, improving the stiffness of the disc, using damping material on the backplates of the pads, and changing the shape of the brake pads, the squeal can be decreased.

Zmago Stadler, et al.[2007] In this paper, Sintered metallic brake wear and friction linings were studied on a composite brake disc C/C-SiC. The addition of SiC increases by more than 50 %.
hardness of the base metallic lining, while its effect on the mean COF is less important. Despite the higher hardness, the wear rate of this lining material is 30% greater than the base metallic lining. In comparison, the addition of graphite significantly decreases the hardness of the padding (by 40%). Since graphite is a lubricant, the COF of the lining increases by 10%, possibly because of the lower hardness. Also, it shows a lower wear rate.

M. Nouby, And K. Srinivasan [2009] FEM is commonly used for simulation and prediction of disc brake squeal using complex Eigenvalue analysis where positive part indicates corresponding Eigenmode which was found to be unstable. So to reduce squeal various modifications have been made such as changing the young's modulus of the backplate, applying chamfers to the pad. It has been discovered that squeal can be reduced by, decreasing the stiffness of the backplate of the pad and by providing different chamfers at the pad side.

Anders Soderberg and Soren Andersson [2009] this paper explore how wear can be predicted using general-purpose finite element analysis tools for the pad-to-rotor interface. To measure the pressure distribution in the pad-to-rotor touch, a three-dimensional finite element model of the brake pad and the rotor is developed. A wear simulation method is used to simulate the wear of the brake pad under steady-state drag conditions based on a simplified form of Archard's wear law and explicit Euler integration. Wear at the pad side is been calculated. It has resulted that deepest wear occurs with high pressure in the field, although almost there is wear. No, wear around the edge at all. After approximately 1600 revolutions, the method a steady state seems to have reached where all points on the wear rate of surfaces are the same without any change in the distribution of pressure or the surface profile. The distribution of steady-state pressure indicates a small negative gradient. In the radial direction, correction for sliding variance spacing over the interface.

Jens Wahlströma, et al.[2010] conducted research to identify airborne particle effects due to wear in the atmosphere. As a piece of test equipment, a pin-on-disc tribometer fitted with particle counting instruments was used. The findings suggested that the low metallic pads cause more wear than the NAO (Non-Asbestos Organics) pads to the rotor material, resulting in higher airborne wear particle concentrations. Similar size distributions have been obtained, although there are variations in the measured particle concentrations. Independent of pad content.

M.A. Maleque, et al. [2010] in this study the material assessment tools for the design and application of automotive brake disc were developed. For the initial screening of the candidate materials using Ashby's selection chart of materials, the functional properties of the brake discs or rotors were considered. The digital logic method showed the highest performance index for AMC 2 material and was listed as the optimum material among the candidate brake disc materials. From a technological and economic point of view, higher friction coefficient and lower density are advantageous.

Ali Belhocine Mostefa Bouchetara [2012] The study was carried out for computational simulation of the thermal behavior of a full and ventilated disc in the transient state employing the computer code ANSYS three variants of materials were taken into consideration i.e. cast iron (AL FG 25, FG 20, FG 15) and obtained thermal behavior for a determined braking mode. It was derived that several parameters are responsible for the quality of outcomes such as several elements, Braking mode, and materials.

Faiz Ahmad et al., [2013] it has been demonstrated that aluminum alloy reinforced with alumina particles (AMC) were tested for various conditions of wear at a different speed. Weight loss was found to be 52% less in the case of AMC compared to Cast Iron due to reinforcement of hard alumina particles which increases stiffness, strength, and fatigue resistance of AMCs.
Dattatray Galhe and Vishnu Wakchaure [2013] in this study it was concluded that the brake squeal is caused by various parameters. Such as friction-induced vibrations, braking pressure, temperature, and roughness, which are directly proportional to the vibrations produced during braking. Checked here are grey iron grade 250, high carbon grey iron, and lightweight graphite iron used in the brake disc rotor. The braking operation requires low braking pressure from these lightweight graphite iron discs. This material is also proposed for the brake disc rotor.

Zhiqiang Li, et al. [2014] there are various fatigue cracks on the surface of the brake disc, including crackles, radial cracks, and circumferential cracks. Conduct initiation and dissemination under various braking conditions. Radial cracks arise and spread on the friction surface of 300 km/h brake discs. Only crackles occur at 200 km/h after repeated emergency braking and no crack propagation during normal braking has been observed. Breaking fatigue crack tests showed that oxides were covering the broken surface of fatigue cracks. The form of the surfaces of the fractures was elliptic.

A.A. Yevtushenko [2014] the research was carried out to compare the transient temperature fields of the pad and the disc, the braking time, and the braking distance at a constant and temperature-dependent friction coefficient. It was concluded that it did not take into account the temperature dependence of the friction coefficient for the studied materials, the component dimensions of the brake, and the operating parameters. Braking distance and wear, although the maximum temperature remains almost unchanged. Due to its low thermal conductivity value for the FC-16L pad material, the high temperature is observed in the vicinity of the friction surface. Cast Iron material was used for the Disc surface.

Ali Belhocine et al. [2015] concluded that the best for the current application is the ventilated style disc brake. Based on the parameters of strength and rigidity, the brake disc design is therefore stable. Compared to the trailing side, interaction pressure is expected to be greater on the leading side and its value increases significantly. Compared to the trailing side, interaction pressure is estimated to be better on the leading side and its value increases significantly with an increase in the speeds of disc rotation. In terms of the variance of the coefficient of friction, there is no important improvement in disc-pad deformation. When the device is in the thermomechanical coupling, the total stresses, and deformations in the disc increase in a notable way.

R.K.Pohane and S.C.Kongare [2016] in this study, the material selection methods for the design and application of automotive brake disc were developed. Based on the highest material performance index listed among the Alternative Brake Disc, Ti-64 Material was found to be an optimal material. Furthermore, the PROMETHEE Rainbow showed that Ti-64 is superior in good compressive strength, higher friction coefficient, density, lightweight, good thermal ability, economically viable, and lacking optimum hardness, the Performance Aggregated Score for Ti-64 was found to be highest.

Lijesh K.P. et al. [2017] observed that a desirable alternative to replacing the traditional disc brake is the Magneto-Rheological (MR) brake. The performance of the experiment was assessed by calculating the weight loss of the blocks before and after the tests. Different hardness discs were suggested to obtain a reliable braking performance of the MR brake, as the brake-disc hardness affects the MR brake performance. MR fluid particles deform the softer disc surface and deteriorate the output of the brakes. To reduce the wear of the disc, an increase in disc-hardness is required. The disc of 63 HRC has lesser impingement of iron particle, wear, and surface cracks compared to the 15HRC disc. Higher hardness of disc leads to enhance of the braking effect.
The goal of this research was to establish the FE model of each part of the disc brake system to understand the impact of material properties on the squeal of the disc brake and to validate it with experimental modal analysis. The purpose of the current analysis was to predict the squeal using a more practical model at the previous stage of invention. For four distinct materials such as Gray C.I-1, Gray C.I-2, carbon-ceramic, and steel, modal brake rotor analysis has been performed as it is one of the critical components of the brake system that contributes more to the Noise Generation. For the rotor, the first ten modes were extracted to predict the natural frequencies. The FEM and EMA results suggested that the various material properties of the components of the disc brake components play a sustainable role in the development of the brake squeal. It was found that, concerning the number of modes and disc stiffness, the ratio between Young’s module and density increases the normal vibration frequencies of the disc.

Satish Pujari and S. Srikiran [2019] To make the brake pads, the use of asbestos content is avoided as it is dangerous and poisonous. It also contributes to numerous health conditions, such as asbestosis, mesothelioma, and lung cancers. Natural fibers such as Palm Kernel are proposed to replace these brake pads. Natural fibers such as Palm Kernel (0-50%), Nile Roses (0-15%), and Wheat (0-10%) can be substituted with additives such as aluminum oxide (5-20%) and graphite powder (10-35%) and 35% phenolic resin is used as a binder. By using these contents composite material have been formulated and tested for its various properties like physical, mechanical tribological. It has been observed that to increase the friction coefficient, particulate Nile roses are used and wheat powder is used to decrease the wear rate. In nature, aluminum oxide and graphite are abrasive. This helps to generate high friction coefficient brake pads with low noise emissions and a lower wear rate.

M.Vijaya and K. Srinivas [2019] Stated that the Liquid Metallurgy route with distinct weight percent of reinforcements effectively-prepared AA 6351/SiC/Gr hybrid composite and AA6351/SiC metal matrix material. The density of reinforced Al/SiC & Al/SiC/Gr hybrid composites with different weight fractions has been measured and the density increases with SiC and decreases with SiC/Gr hybrid particles so that this Al/SiC/Gr hybrid composite can be regarded as a suitable lightweight material for all applications. Also, it has been concluded from the results of various specimens that, 6 wt.% SiC and Graphite reinforced AA6351 to be the best of the tested materials for an experiment.

Vikas Verma, et al. [2019] study involves the processing through the stir casting route of Al MMC reinforced with fly ash and Al₂O₃ particles in various proportions. Their wear activity was further investigated at varying loads (15-25 N), time (3-5 minutes), and velocity (700-900 rpm). Electron micrograph (SEM) scanning of treated composites showed uniform dispersion of coarser particles and agglomeration. It was found that an increase in the hardness of 48%, the strength of 63%, and bending strength of 58%, and substantial reduction in weight loss calculated after wearing 5% fly ash and 12% Al₂O₃ processed Al composite. SEM pure Al alloy micrograph worn surface showed crack and fracture presence at high load, longer time, and at high speed. In composite, the presence of the adhered oxide layer is observed with 5% fly ash and 12% fly ash Al₂O₃, which limited the composite to more wear.

A.A.Agbeleye et al., [2020] research aim to see how different weight fractions of aluminosilicate clay affect the mechanical, friction, and wear properties of Al-clay composites used in brake disc rotors. The UTS of the composite samples increases as the addition of clay increases to a peak value of 133.98 MPa at 15 wt.% addition of clay particles over the conventional AA6063 of 104 MPa. The addition of clay particles was increased to 30 wt.% clay, resulting in a decrease in the UTS to 122.29 MPa. The Al-clay composite’s Vickers hardness values were calculated. An increment in the percentage of clay particles added was accompanied by an increase in hardness values. At 15 wt.%, it
reached a high of 76.7 HV, after which the hardness value dropped to 67.3 at 30 wt. % Strain values typically decrease as clay particle addition improves, with a minimum value of 5.7 percent at 20 wt. percent.

Matheus Henrique Pires Miranda et al., (2020) during the interaction of braking, the temperature plays an important role because it influences the coefficient of friction between the disc and the pads on direct proportionality. Both velocity and pressure are inversely proportional to the coefficient of friction, so a decrease in either one causes an increase in the coefficient of friction, rendering the device vulnerable to squealing.

3. Conclusion

It can be noted here that the quality of the mechanical product, such as the disc brake, depends greatly on the attribute of the material it is made of. While several studies have been undertaken to enhance disc brake efficiency, the deprivation of standardized material presents countless challenges for the automotive industry. There is a good chance that the disc brakes currently used will be replaced by composite material, which has many advantages over them. Such as good thermal capability, good compressive strength, stiffness, and lightweight, etc. Therefore, it is evident from the literature review that a comprehensive analysis to assess the reliability of disc brakes made up of various types of composite material must be undertaken. It can be summarized that Aluminium Material Matrix composite with the addition of fly ash gives better strength, heat stress stability. Apart from these merits addition of fly ash and SiC contents reduces greenhouse gases which are evolved during the manufacturing of Aluminium alloy.

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