Analysis and Computational Investigation of Brake Disc for Composite Materials

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Abstract - The study describes the design and finite element analysis of alternating material for brake rotor. The design and finite element analysis is performed by using computer aided design (CAD) software. The objective is to design and analyse the thermal and structural stress distribution of brake rotor at the real time condition during braking process. Transient thermos-elastic analysis of the Rotor Disc of Disk Brake is aimed at evaluating the performance of disc brake rotor of a bike under severe braking conditions and there by assist in disc rotor, design and analysis. In the present work, an attempt has been made to investigate the suitable hybrid composite material which is lighter than stainless steel 321 and has thermal strain, Yield strength and density properties. The optimization is carried out to reduce the stress concentration and weight of the brake rotor, which keeps the unsprang mass low thereby increasing the stability of the vehicle. With using computer, aided design (CAD), Catia v5 software the structural model of brake rotor is developed. Furthermore, the finite element analysis performed with using the software ANSYS 16. Aluminium base metal matrix composite, High Strength Glass Fiber and carbon fiber composites have a promising friction and wear behaviour as a Disk brake rotor. The transient thermos-elastic analysis of Disc brakes in repeated brake applications has been performed and the results were compared. The prototype of composite brake disc was tested practically on the Honda Unicorn Bike. The suitable material for the braking operation is carbon fiber and all the values obtained from the analysis are less than their allowable values. Hence the brake Disc design is safe based on the strength and rigidity criteria. By identifying the true design features, the extended service life and long term stability is assured.

Keywords - Analysis, Computational Investigation, Disc Brake, Carbon fiber, Composite material.

1. 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 lightweight, technologically superior vehicles. The continuously increasing demand for personal mobility has led automobile manufacturers to strive continuously for cheaper, more efficient and safer vehicles. These requirements are competing with respect to each other. However, the tough competition in today's automotive market forces vehicle manufacturers to strive for improvement in each of these fields.

To improve vehicle safety without the burden of increasing vehicle weight, more and more active safety features are introduced. However, the most critical part with respect to safety is, and has always been: the brake system. Due to its critical role, very high demands are imposed on the brake system with respect to reliability, durability and consistency in its behaviour. These severe demands have forced the brake system development in a rather conservative direction. Introducing drastically new technology is never completely free of risk and in brake system development; there is no room for mistakes. Therefore, the brakes on modern vehicles are an extreme optimization of a very old design.

1.1 Introduction to 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. 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. 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. 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

1.2 Problem Statement

Brakes are often described according to several characteristics including: Peak force - The peak force is the maximum decelerating effect that can be obtained. The peak force is often greater than the traction limit of the tires, in which case the brake can cause a wheel skid.

• Continuous power dissipation - Brakes typically get hot in use, and fail when the temperature gets too high. The greatest amount of power (energy per unit time) that can

be dissipated through the brake without failure is the continuous power dissipation. Continuous power dissipation often depends on e.g., the temperature and speed of ambient cooling air. Fade - As a brake heats, it may become less effective, called brake fade. Some designs are inherently prone to fade, while other designs are relatively immune. Further, use considerations, such as cooling, often have a big effect on fade.

• Smoothness - A brake that is grabby, pulses, has chatter, or otherwise exerts varying brake force may lead to skids. For example, railroad wheels have little traction, and friction brakes without an anti-skid mechanism often lead to skids, which increases maintenance costs and leads to a "thump" feeling for riders inside.

• Power - Brakes are often described as "powerful" when a small human application force leads to a braking force that is higher than typical for other brakes in the same class. This notion of "powerful" does not relate to continuous power dissipation, and may be confusing in that a brake may be "powerful" and brake strongly with a gentle brake application, yet have lower (worse) peak force than a less "powerful" brake.

• Durability - Friction brakes have wear surfaces that must be renewed periodically. Wear surfaces include the brake shoes or pads, and also the brake disc or drum. There may be trade-offs, for example a wear surface that generates high peak force may also wear quickly.

• Weight - Brakes are often "added weight" in that they serve no other function. Further, brakes are often mounted on wheels, and unsprang weight can significantly hurt traction in some circumstances. "Weight" may mean the brake itself, or may include additional support structure.

• Noise - Brakes usually create some minor noise when applied, but often create squeal or grinding noises that are quite loud.

1.3 Objective

In automotive industries, to achieve reduced fuel consumption as well as greenhouse gas emission is a current issue of utmost importance. To reduce automobile weight and improve fuel efficiency, the auto industry has dramatically increased the use of aluminium in light vehicles in recent years. Aluminium alloy based metal matrix composites (MMCs) with ceramic particulate reinforcement have shown great promise for such applications. These materials having a lower density and higher thermal conductivity as compared to the conventionally used gray cast irons are expected to result in weight reduction of up to 50 - 60 % in brake systems. Moreover, these advanced materials have the potential to perform better under severe service conditions like higher speed, higher load etc. which are increasingly being encountered in modern automobiles. Since brake disc or rotor is a crucial component from safety point of view, materials used for brake systems should have stable and reliable frictional and wear properties under varying conditions of load, velocity, temperature and environment, and high durability. There are several factors to be considered when selecting a brake disc material. The most important consideration is the ability of the brake disc material to withstand high friction and less abrasive wear. Another requirement is to withstand the high temperature that evolved due to friction. Weight, manufacturing process ability and cost are also important factors those are need to be considered during the design phase. In material selection stage, the recyclability of cast iron is advantageous but the evolution of CO during re-melting has to be taken in consideration. The brake disc must have enough thermal storage capacity to prevent distortion or cracking from thermal stress until the heat can be dissipated. This is not particularly important in a single stop but it is crucial in the case of repeated stops from high speed.

1.4 Methodology

The materials selection chart is a very useful tool in comparing a large number of materials at the concept design phase which could be reflected the fundamental relationships among particular material properties and be used to find out a range of materials suitable for a particular application. The main purpose of the present work is to selection of best candidate material for brake disc application and in order to analyse the thermal characteristics of disk brakes, thermal deformation analysis and thermal stress analysis due to heat transfer was carried out through the finite element analysis.

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Figure 1: Flow chart of material selection method

1.4.1. General Material Performance Requirements

Disc brake systems generate braking force by clamping brake pads onto a rotor that is mounted to thehub. A schematic view of the brake system is shown in Fig. 2. The high mechanical advantage of hydraulic and mechanical disc brakes allows a small lever input force at thehandlebar to be converted into a large clamp force at thewheel. This large clamp force pinches the rotor with friction material pads and generates brake power. The higher thecoefficient of friction for the pad, the more brake power willbe generated. Coefficient of friction can vary depending on the type of material used for the brake rotor. Typicallyservice brakes are concerned with dynamic coefficient of friction, or the coefficient of friction measured while thevehicle is moving.



Figure 2: Schematic View of Real Size Brake System (Brake Disc And Brake Pad)

All modern disk brakes systems rely on brake pads pressingon both sides of a brake rotor to increase the rollingresistance and slow the car down. The amount of frictional force is found by multiply the force pushing the pad into the rotor by the coefficient of friction of the pad. So, the force

slowing the brake disc or rotor is

 $F_{rotor} = 2.C_{\rm f.pad}.F_{pad}....(1)$

The braking system is a vital safety component of ground-based transportation systems; hence the structural materials used in brakes should have possess some combination of properties such as good compressive strength, higher friction coefficient, wear resistant, light weight, good thermal capacity and economically viable.

1.4.2. Initial Screening of Candidate Material

IJEDR1604141 International Journal of Engineering Development and Research (<u>www.ijedr.org</u>)

Traditional material for automotive brake rotor is the cast iron. The specific gravity or density of cast iron is higher which consumes much fuel due to high inertia. Following section will describe the potential candidate materials those can be used for brake rotor application.

1. Cast Iron

Metallic iron containing more than 2% dissolved carbon within its matrix (as opposed to steel which contains less than 2%) but less than 4.5% is referred to as gray cast iron because of its characteristic color. Considering its cost, relative ease of manufacture and thermal stability, this cast iron (particularly, gray cast iron), is actually a more specialized material for brake applications particularly the material of choice for almost all automotive brake discs. To work correctly, the parts must be produced at the foundry with tightly monitored chemistry and cooling cycles to control the shape, distribution and form of the precipitation of the excess carbon. This is done to minimize distortion in machining, provide good wear characteristics, dampen vibration and resist cracking in subsequent use.

2. Titanium Alloys

Titanium alloys and their composites have the potential to reduce weight of the brake rotor disc component which is about 37% less than a conventional cast iron with the same dimensions and offering good high temperature strength and better resistance to corrosion.

3. Aluminium-Metal Matrix Composite (AMC)

Aluminium alloy based metal matrix composites (MMCs) with ceramic particulate reinforcement have shown great promise for brake rotor applications. These materials having a lower density and higher thermal conductivity as compared to the conventionally used gray cast irons are expected to result in weight reduction of up to 50-60% in brake systems. The repeated braking of the AMC brake rotor lowered the friction coefficient μ and caused significant wear of the brake pad. The friction properties of the AMC brake disc are thus remarkable poorer than those of conventional brake disc. After increasing hard particles content the result showed that the repeated braking operations did not lower the friction coefficient.

4. Carbon Fibre

Strength of a material is the force per unit area at failure, divided by its density. Any material that is strong AND light has a favourable Strength/Weight ratio. Carbon Fibre reinforced plastic is over 4 times stiffer than Glass reinforced plastic, almost 20 times more than pine, 2.5 times greater than aluminium. Although carbon Fibre themselves do not deteriorate measurably, Epoxy is sensitive to sunlight and needs to be protected. Other matrices (whatever the carbon Fibre is embedded in) might also be reactive. Resistance to Fatigue in Carbon Fibre Composites is good. However, when carbon Fibre fails it usually fails catastrophically without significant exterior signs to announce its imminent failure. Carbon Fibre can have a broad range of CTE's, -1 to 8+, depending on the direction measured, the fabric weave, the precursor material, Pan based (high strength, higher CTE) or Pitch based (high modulus/stiffness, lower CTE). In a high enough mast differences in Coefficients of thermal expansion of various materials can slightly modify the rig tensions. Low Coefficient of Thermal expansion makes carbon Fibre suitable for applications where small movements can be critical. Telescope and other optical machinery is one such application.

2. LITERATURE REVIEW

AdriaanNeys [1], The brakes system is critical with respect to vehicle safety. One situation during which the brake system is put to the test is an Alpine descent. Such a descent causes very high brake system temperatures and may even induce brake fluid vaporization. In following report an In-Vehicle Brake System Temperature Model is developed and tested. This model makes use of the information that is available on the vehicle CAN-bus in order to estimate the temperature of the brake system and detect the risk of brake fluid vaporization. Implementing such a model in production vehicles would improve vehicle safety and in the long run allow downsizing of the brake systemwithout giving in on any safety margins.Firstly, possible approaches for estimating the amount of kinetic energy that is converted into heat by the brake system are investigated.

Secondly, the Temperature Estimation Model is developed. This is composed of models

of different parts of the brake system which are combined and matched to the measurements. This thesis is to develop preliminary version of a Brake SystemTemperature Model (BSTM) for vehicle implementation and perform the requiredtesting to tune this model. This system should estimate the temperature of the differentbrake system components in order to detect dangerous situations that can arise due toover-heating of the brake system.

Abd Rahim Abu-Bakar, Huajiang Ouyang [2], This paper studies the contact pressure distribution of a solid disc brake as a result of structural modifications. Before modifications are simulated, four different models of different degrees of complexity for contact analysis are investigated. It is shown that the contact pressure distributions obtained from these four models are quite different. This suggests that one should be careful in modelling disc brakes in order to obtain correct contact pressure distributions. This work could help design engineers to obtain a more uniform pressure distribution and subsequently satisfy customers' needs by making pad life longer.

Abd Rahim Abu-Bakar, Huajiang Ouyang [3], The detailed and refined finite element model of a real disc brake considers the surface roughness of brake pads and allows the investigation into the contact pressure distribution affected by the surface roughness and wear. It also includes transient analysis of heat transfer and its influence on the contact pressure distribution. The

focus is on the numerical analysis using the finite element method. The simulation results are supported with measured data in order to verify predictions. An improved numerical methodology is presented by considering three-validation stages, namely, modal analysis at component and assembly levels and verification of contact analysis. Prior to that, a realistic surface roughness of the brake pad at macroscopic level is considered in the finite element model instead of assuming a smooth and perfect surface that has been largely adopted by most previous researchers. These two aspects have brought about significant improvement to the validation as well as analysis. Wear and thermal effects are other distinct aspects of disc brakes that influence contact pressure distributions and squeal generation in a disc brake assembly and they are also included in the current investigation. Transient analysis of disc brake vibration using a large FE model that includes thermal effects are carried out.

Ali Belhocine, MostefaBouchetara [4], The objective of this study is to analyse the thermal behaviour of the full and ventilated brake discs of the vehicles using computing code ANSYS. The modelling of the temperature distribution in the disc brake is used to identify all the factors, and the entering parameters concerned at the time of the braking operation such as the type of braking, the geometric design of the disc, and the used material. The numerical simulation for the coupled transient thermal field and stress field is carried out by sequentially thermal-structural coupled method based on ANSYS to evaluate the stress fields and of deformations which are established in the disc and the contact pressure on the pads. The results obtained by the simulation are satisfactory compared with those of the specialised literature. In this study, we presented a numerical simulation of the thermal behaviour of a full and ventilated disc in transient state. By means of the computer code ANSYS 11, we were able to study the thermal behaviour of three types of cast iron (AL FG 25, FG 20 and FG 15) for a determined braking mode.

In addition to the influence of the ventilation of the disc, we also studied the influence of the braking mode on the thermal behaviour of the disc's brake. The numerical simulation shows that radial ventilation plays a very significant role in cooling of the disc in the braking phase. The obtained results are very useful for the study of the thermomechanical behaviour of the disc brake (stress, deformations, efficiency and wear).

BanakarPrashanth&Shivananda H.K. [5], The objective of this research was to gain a better understanding of Mechanical properties of epoxy resin composites reinforced with carbon Fibre. The effect of Fibre orientation of laminates has been investigated & experimentation was performed to determine property data for material specifications, the laminates were obtained by hand layup process. The laminates were cut to obtain ASTM standards. This investigation deals with the testing of tensile and flexural strength on a universal testing machine. The graphs that are obtained from the tests are documented. This research indicates that the mechanical properties are mainly dependent on the Fibre orientation of laminated polymer composites.

Chavan Prashant, ApteAmol[6], Gives simplified yet almost equally accurate modeling and analysis method for thermomechanical analysis using brake fade test simulation as an example. This methodology is based on use of ABAQUS Axisymmetric analysis technique modified to represent effect of discrete bolting, bolt preloads, and contacts within various components of the assembly.

Caol Q, Friswell M I, Ouyang H, J E Mottershead1 and S James [7], This paper presents a numerical method for the calculation of the unstable frequencies of a car disc brake and the analysis procedure. The stationary components of the disc brake are modelled using finite elements and the disc as a thin plate. This approach facilitates the modelling of the disc brake squeal as a moving load problem. Some uncertain system parameters of the stationary components and the disc are tuned to fit experimental results. A linear, complex-valued, asymmetric eigenvalue formulation is derived for disc brake squeal. Predicted unstable frequencies are compared with experimentally established squeal frequencies of a realistic car disc brake.

FaramarzTalati& Salman Jalalifar [8], In this paper, the governing heat equations for the disk and the pad are extracted in the form of transient heat equations with heat generation that is dependant to time and space. In the derivation of the heat equations, parameters such as the duration of braking, vehicle velocity, geometries and the dimensions of the brake components, materials of the disk brake rotor and the pad and contact pressure distribution have been taken into account. The problem is solved analytically using Green's function approach. It is concluded that the heat generated due to friction between the disk and the pad should be ideally dissipated to the environment to avoid decreasing the friction coefficient between the disk and the pad and to avoid the temperature rise of various brake components and brake fluid vaporization due to excessive heating.

The results obtained for contact surface temperatures of the pad and the disk show that there is a heat partition between two components in sliding contact, because of thermal resistance constituted by accumulation of wear particles at the contact surface between the pad and the disk and lack of necessary provisions for ventilation of the disk and heat dissipation to the environment through the disk. The brake rotor must serve as an efficient energy dissipation and storage device. In order to achieve this purpose, air must be circulated through the rotor to provide adequate cooling. The passages, formed by the radial fins between the braking surfaces, act as a centrifugal fan, facilitating the required air flow for cooling.

Goutham Kumar Reddy Challa, Abhinoy Krishna Guduru, Siddhartha Patlori and Dr.M.Madhavi [9],The paper describes the design and finite element analysis of carbon Fibre-epoxy resin brake rotor. The design and finite element analysis is performed by using computer aided design (CAD) software. The objective is to design and analyse the thermal and structural stress distribution of brake rotor at the real time condition during braking process. The optimization is carried out to reduce the stress concentration and weight of the brake rotor which keeps the unsprang mass low thereby increasing the stability of the vehicle. A carbon Fibre brake rotor was designed, structural and thermal analysis was performed with different thickness and a 12mm disc has very less deformation. The most important aspect is that it was found to be 50% lighter than a conventional brake disc rotor (mass properties by computational method).

Hao Xing [10], A disc brake system for passenger car is modelled and analysed using both approaches i.e. the transient analysis and complex modal analysis. Complex modal analysis is employed to extract natural frequencies and a transient analysis is carried out to study the thermal effects during braking. The effect of friction in complex modal analysis is investigated.

Jung S. P., Park T. W., Lee, J. H. W. H. Kim, and Chung W. S [11], A simple finite element model of a disc and two pads was created, and TEI phenomenon was implemented by rotating the disc with a constant rotational speed of 1400 rpm. The

intermediate processor using the staggered approach was used to connect results of two other analysis domains: mechanical and thermal analysis. By exchanging calculation results such as temperature distribution, contact power and nodal position at every time step, solutions of fully coupled thermo-mechanical system could be obtained. Contact pressure distribution of the pad surface was varied according to the rotational direction of the disc. DTV and temperature of the disc were calculated and tendency was verified by earlier studies.

Kevin A. Calzada [12], In this research, both experimental and finite element-based modeling approaches are undertaken. Fibres oriented in 0, 45, 90, and 135 degrees with respect to the direction of tool motion are investigated and unique failure theories are developed for each of these orientations. The model based on experimental observations is focused on explaining the micro-scale failure mechanisms occurring in the machining process. The finite element machining model developed in this work uses a unique modeling approach, which is capable of explaining the Fibre failure mechanisms occurring throughout the chip formation process. After development of the two machining models, the machining responses are compared to a set of machining experiments for validation purposes. Fibres oriented in the 45 and 90 degree orientations were found to fail in compressive crushing-dominated failure while Fibres oriented in the 135-degree orientation were found to fail in bending below the surface of the cut. In the 0-degree orientation, the Fibres were proposed to fail in buckling or bending-dominated failure, depending on the depth of cut, and tool geometry of the process. The micro-scale Fibre failure mechanisms were observed to differ significantly from their macro-scale counterparts. The machining responses of the two models were found to gree well with the experimental validation analyses indicating that these models are an accurate representation of the chip formation process.

Khalid Mahmood Ghauri, Liaqat Ali [13], Ceramics contain a distinctive property of completely absence of slip planes and have least probability of deforming by the application of force. Among these ceramics, the silicon carbide occupies a competent place to be used as a reinforcing agent for aluminum or its alloys. It has the density close to aluminum and is best for making composite having good strength and good heat conductivity. Stir casting has been used to synthesize Al/SiC MMCs by reinforcing silicon carbide particles into aluminum matrix. The reason for using stir casting is to develop technology for the development of MMCs at affordable cost. The selection of SiC as reinforcement and Al as matrix is because of their easy availability. The practical data acquired, analyzed and optimized will be interpreted in the light of information available in the literature and be shared with the relevant industries. The present work was mainly carried out to characterize the SiC/Al composite which was produced by reinforcing the various proportions of SiC (5, 10, 15, 25 and 30%) in aluminum matrix using stir casting technique. Mechanical properties of test specimens made from stir-casted Aluminum-Silicon Carbide composites have been studied using metallographic and mechanical testing techniques. It was observed that as the volume fraction of SiC in the composite is gradually increased, the hardness and toughness increase. However, beyond a level of 25-30 percent SiC, the results are not very consistent, and depend largely on the uniformity of distribution of SiC in the aluminum matrix

Kumar Santhosh M, Dr. S. G. Gopala Krishna &Dr.Rajanna. S [14], This project presents the study of tensile, flexural & moisture absorption properties of composites made from Sglass, Carbon and E-glass Fibre. The specimens are prepared using hand lay-up techniques as per ASTM standard for different thickness 2mm and 3mm and Fibre orientation of 30°, 45° and 60°, where an attempt is made to study the properties of composite materials by composing the different materials together to obtain the desired properties by increasing the thickness and Fibre orientation. By the variation of thickness tensile strength of hybrid composite is observed for each thickness and is compared with the finite element analysis results. The test ready specimens were subjected to tensile and flexural loads on UTM. This research indicates that tensile strength is mainly dependent on the Fibre orientation & thickness of laminated polymer composites. The moisture absorption increases with the Fibre, filler content and duration of immersion in water.

Maruthi B. H., H.L. Guruprasad and Yogesh Kumar [15], Transient Thermal and Structural Analysis of the Rotor Disc of Disk Brake is aimed at evaluating the performance of disc brake rotor of a car under severe braking conditions and there by assist in disc rotor design and analysis. In the present work, an attempt has been made to investigate the suitable hybrid composite material which is lighter than cast iron and has good Young's modulus, Yield strength and density properties. Aluminium base metal matrix composite and High Strength Glass Fibre composites have a promising friction and wear behaviour as a Disk brake rotor. The transient thermo elastic analysis of Disc brakes in repeated brake applications has been performed and the results were compared. The suitable material for the braking operation is S2 glass Fibre and all the values obtained from the analysis are less than their allowable values. Hence the brake Disc design is safe based on the strength and rigidity criteria

Mazidi H, Jalalifar S., Chakhoo J. [16], In this study, the heat conduction problems of the disc brake components (Pad and Rotor) are modelled mathematically and is solved numerically using finite difference method. In the discretization of time dependent equations, the implicit method is taken into account. In the derivation of heat equations, parameters such as the duration of braking, vehicle velocity, Geometries and the dimensions of the brake components, Materials of the disc brake rotor and the PAD and contact pressure distribution have been taken into account.

Nouby M., D. Mathivanan, K. Srinivasan [17], Proposes an approach to investigate the influencing factors of the brake pad on the disc brake squeal by integrating finite element simulations with statistical regression techniques. Complex eigenvalue analysis (CEA) has been widely used to predict unstable frequencies in brake systems models. The finite element model is correlated with experimental modal test. The 'input-output' relationship between the brake squeal and the brake pad geometry is constructed for possible prediction of the squeal using various geometrical configurations of the disc brake. Influences of the various factors namely; Young's modulus of back plate, back plate thickness, chamfer, distance between two slots, slot width and angle of slot are investigated using design of experiments (DOE) technique. A mathematical prediction model has been developed based on the most influencing factors and the validation simulation experiments proved its adequacy.

Ouyang Huajiang, Nack Wayne, Yongbin Yuan, Frank Chen [18], Covers two major approaches used in the automotive industry, the complex eigenvalue analysis and the transient analysis. The advantages and limitations of each approach are examined. This review can help analysts to choose right methods and make decisions on new areas of method development. It

points out some outstanding issues in modelling and analysis of disc brake squeal and proposes new research topics. It is found that the complex eigenvalue analysis is still the approach favoured by the automotive industry and the transient analysis is gaining increasing popularity.

P. Liu a, H. Zheng a, C. Cai a, Y.Y. Wang a, C. Lua,K.H.Ang b, G.R. Liu [19], An attempt is made to investigate the effects of system parameters, such as the hydraulic pressure, the rotational velocity of the disc, the friction coefficient of the contact interactions between the pads and the disc, the stiffness of the disc, and the stiffness of the back plates of the pads, on the disc squeal. The simulation results show that significant pad bending vibration may be responsible for the disc brake squeal. The squeal can be reduced by decreasing the friction coefficient, increasing the stiffness of the disc, using damping material on the back plates of the pads, and modifying the shape of the brake pads.

PatilDeogonda&Vijaykumar N Chalwa [20],The development and mechanical characterization of new polymer composites consisting of glass fibre reinforcement, epoxy resin and filler materials such as TiO2 and ZnS. The newly developed composites are characterized for their mechanical properties. Experiments like tensile test, three point bending and impact test were conducted to find the significant influence of filler material on mechanical characteristics of GFRP composites. The tests result have shown that higher the filler material volume percentage greater the strength for both TiO2 and ZnS filled glass epoxy composites, ZnS filled composite show more sustaining values than TiO2.

Piotr GRZEŚ [21], The aim of this paper was to investigate the temperature fields of the solid disc brake during short, emergency braking. In this paper transient thermal analysis of disc brakes in single brake application was performed. To obtain the numerical simulation parabolic heat conduction equation for two-dimensional model was used. The results show that both evolution of rotating speed of disc and contact pressure with specific material properties intensely effect disc brake temperature fields in the domain of time.

PrashanthBanakar& H.K. Shivananda [22], The objective of this research was to gain a better understanding of Mechanical properties of epoxy resin composites reinforced with carbon Fibre. The effect of Fibre orientation of laminates has been investigated & experimentation was performed to determine property data for material specifications, the laminates were obtained by hand layup process. The laminates were cut to obtain ASTM standards. This investigation deals with the testing of tensile and flexural strength on a universal testing machine. The graphs that are obtained from the tests are documented. This research indicates that the mechanical properties are mainly dependent on the Fibre orientation of laminated polymer composites.

PohaneRajendra, R. G. Choudhari [23], FEM model is prepared for contact analysis. A three dimensional finite element model of the brake pad and the disc is developed to calculate static structural analysis, and transient state analysis. The comparison is made between the solid and ventilated disc keeping the same material properties and constraints and using general purpose finite element analysis. This paper discusses how general purpose finite element analysis software can be used to analyze the equivalent (von-mises) stresses& the thermal stresses at disc to pad interface.

3. DESIGNING THE BRAKE DISC

The first step is development of CAD model according to geometric specifications followed by selection of material. Finite element analysis is done using simulation software for different materials. Deformation, Von Mises stress and Maximum temperature generated are investigated by coupled thermomechanical.

3.1. Geometrical Modelling

The model is constructed by using CATIAV5R21, the explode view of the model as shown in Figure 3.



Figure 3: CAD Model of Brake Disc.

3.2. Design Calculations of Brake Rotor

The dimensions of Honda Unicorn brake rotor were considered for the design purpose

- Disc diameter = 240 mm
- Pad rotor contact = 60 mm (radius)

- P =fluid pressure, Pa
- FP = pedal force = 25 Kg = 245 N
- R = pedal lever ratio = 4:1
- H = Pedal efficiency = 0.8
- Standard size of master cylinder is 12.055mm.
 - **Actual Pressure Generated by The System:** i.

 $P = (FP \times R \times \eta) / A$ $P = (245 \text{ x} 4 \text{ x} 0.8 \text{ x} 4) / (\pi \text{ x} 12.0552 \text{ x} 10-6)$

P = 6.87MPa.

ii. **Clamping Force Is Calculated as:**

The clamping load is assumed to act on all friction surfaces equally. For dry disc brakes it doesn't matter whether the brake is of the sliding type or opposed piston. Newton's Third Law state every force has an equal and opposite reaction and a reaction force from a sliding caliper is the same as an opposed piston one.

 $CM = PM \times AT$

Where, CF = Clamping Force (N)

PM = Maximum hydraulic pressure (Pa)

AT = Total effective area of calliper pistons (m²) - for fixed callipers this is the actual area of the pistons,for floating callipers this is equal to 2 x the actual area of the pistons.

 $CF = (6.87 \text{ x } 106 \text{ x } 2\pi \text{ x } 0.025912)/4$

CF = 7240.88 N

iii. **Brake Torque Developed Is Calculated as:**

Having decided which wheels will need braking to generate sufficient braking force the torque requirements of each wheel need to be determined. For some legislation the distribution between front and rear brakes is laid down. This may be achieved by varying the brake size or more likely using a valve to reduce the actuation pressure.

 $T_{Bd} = CF \times \mu_L \times R_e$

Where, T_{Bd}= Brake Torque Developed (N-m)

CF=Clamping Force(N)

 μ =Coefficient of friction between brake pads and rotors (= 0.3)

Re = Effective rotor radius (m) – measured from the centre of the rotor to the centre of the brake pad.

 $T_{Bd} = CF x \mu x Re$

 $T_{Bd} = 7240.88 \ge 0.3 \ge 0.105$

 $T_{Bd} = 228 \text{ Nm}$

During a dynamic application of a brake the energy of the machine will be converted to heat, generated between the pad and the disc. It is the temperature of the disc surface that is normally used to assess the brake performance. Failure to take account of the peak temperature can lead to a reduced braking performance due to the onset of brake fade.

In order to provide a consistent controlled performance of a brake it is also important to check the power dissipated during a stop. This affects the condition of the brake pads. To calculate the power dissipation, it is necessary to calculate the total energy absorbed during the stop, estimated as follows:

iv. **Kinetic Energy:**

Assuming the stop is from the test speed down to zero then the kinetic energy is given by: -

K.E.= $\frac{1}{2} \times M \times v^2$ (joule)

Where, K.E = Kinetic Energy (joule),

M = Total weight of vehicle (kg),

v = Velocity of vehicle (m/s)

K.E.= $\frac{1}{2} \times 220 \times 27.778^2$

K.E. =84876.543Joule

Braking Power: v.

Only when the brake is applied (but rotating) is energy being dissipated in the brake system. Some of the stop energy is dissipated in the tyre as wheel slip. Managing the ideal wheel slip is the ultimate goal of ABS development but here assume 8%. The energy to each brake depend on the number of brakes and the proportion of braking on each axle. In order to calculate the power, we need to know the brake on time:

Time t = $\frac{v}{a \times g}$ (sec) Where, t = Stopping Time of vehicle (sec) $a = Deceleration (m/s^2)$ g = acceleration due to gravity 27.778 $t = \frac{27.778}{0.45 \times 9.81}$ $t = 6.29 \text{ sec} \approx 6 \text{ sec}$ The power is then given by: Power P = $\frac{E}{t}$ (Watt) Where, P = Average power (watt)

E = Total energy (Joule)

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t = Stopping time (sec) $P = \frac{84876.543}{6.5}$ P =13057.93Watt This is the average power, the peak power at the onset of braking is double this. Heat Flux into One Side of the Disc: Heat flux, $q = \frac{4 \times P}{\pi \times (Do^2 - Di^2)}$

Where, q = Heat Flux (Watt/m²) P = Average Power (Watt) Do = Disc useable outside diameter (mm) Di = Disc useable inside diameter (mm) q = $\frac{4 \times 13057.93}{\pi \times (0.240^2 - 0.180^2)} = 659756.859$ watt/m²

3.3. Material Properties

vi.

Properties	Stainless Steel	Aluminium Silicon Carbide MMC	Carbon Fibre	E-glass Fibre
Modulus of Elasticity(GPa)	195	192	70	72.3
Poisson's Ratio	0.25	0.25	0.1	0.22
Density (kg/m ³)	7900	3000	1600	2580
Coefficient of Thermal expansion(1/K)	7.5e-5	7.5e-6	2e-6	5.4e-6
Thermal conductivity(W/mK)	16.1	160	28	1.3
Specific Heat(J/gK)	510	0.74	400	810

3.4. Finite Element (Fe) Model

The first step was to prepare a structure model of the brake disc with pads. This was carried out using finite element software (Fig. 5). Then it was meshed and defined by boundary conditions to put on ANSYS Multiphysics and to initialize the calculation. A commercial FE software, namely ANSYS 16 (3D) is fully utilized to simulate structural deformation, stress, temperature and contact pressure distributions of the disc brake during braking application.

3.4.1. Meshing of The Disc

The elements used for the meshing of the disc are quadahedral three-dimensional elements with 10 nodes (isoperimetric). In this work, a three-dimensional FE model consists of adisc as illustrated in Figure 4. Whilst, Figure 5 shows contact zone between the discand pad, details of the mesh properties are given inTable 1. A frictional contact pair was defined betweendisc-pad interfaces. In this simulation, the meshing was refined in the contact zone (disc-pad). This is important because in this zone, the temperature varies significantly. Indeed, in this strongly deformed zone, the thermomechanical gradients are very high. That is why the correct taking into account of the contact conditions involves the use of a refined mesh. Multiphysics and to initialize the calculation.



Figure 4: Meshing of Brake Disc



Figure 5: Contact Zone of the Disc and Pad

3.4.2. Loading and Boundary Conditions Transient Thermal Analysis

The principle of braking is kinetic energy with which the vehicle is propelling is converted to heat energy when brakes are applied. Therefore, the disc should possess high heat transfer rate to dissipate the heat produced when brake is applied. The mode of heat transfer at brakes is combination of convection and radiation. Heat produced when brake applied is dissipated into surroundings through convection between pad-rotor and air around it. Heat generated on the disc is cooled to ambient temperature through radiation. The thermal loading is characterised by the heat flux entering the disc through the real contact area (two sides of the disc). The initial and boundary conditions are introduced into module ANSYS Workbench. The thermal calculation will be carried out by choosing the transient state and by introducing physical properties of the materials. The selected data for the numerical application is summarised as follows:

- Total time of simulation = 8 (s).
- Increment of initial time = 0.25 (s).
- Increment of minimal initial time = 0.125 (s).
- Increment of maximal initial time = 0.5 (s).
- Initial Temperature of the disc = 60 (°C).
- Materials: Stainless Steel, Aluminium Silicon Carbide MMC, Carbon Fibre and E-glass Fibre.



Figure 6: Boundary Conditions Transient Thermal Analysis

3.4.3. Results and Discussions for Transient Thermos-Elastic Analysis

Thermal and structural analysis is performed in order to know the displacement, rotor stress component, maximum temperature generated, Thermal strain and Thermal stress developed on a rotor disc brake for different materials as shown in figures below. For different materials for Rotor disc brake the same procedure has been followed and the results are tabulated.

A. Results of Coupled thermomechanical analysis of Stainless steel 321 brake disc



Figure 7: Maximum Temperature Generated in Stainless Steel 321 Brake Disc



Figure 8:Thermal Strain in Stainless Steel 321 Brake Disc



Figure 9: Maximum Deformation in Stainless Steel 321 Brake Disc



Figure 10: Maximum Stress Developed in Stainless Steel 321 Brake Disc

B. Results of Coupled thermo mechanical analysis of Aluminium silicon carbide MMC brake disc



Figure 11: Maximum Temperature Generated in Aluminium Silicon Carbide MMC Brake Disc



Figure12: Thermal Strain in Aluminium Silicon Carbide MMC Brake Disc



Figure 13: Maximum Deformation in Aluminium Silicon Carbide MMC Brake Disc



Figure 14: Maximum Stress Developed in Aluminium Silicon Carbide MMC Brake Disc

C. Results of Coupled thermomechanical analysis of Carbon Fibre brake disc



Figure 15: Maximum Temperature Generated in Carbon FibreBrake Disc

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Figure 16:Thermal Strain in Carbon FibreBrake Disc



Figure 17: Maximum Deformation in Carbon FibreBrake Disc



Figure 18: Maximum Stress Developed in Carbon FibreBrake Disc Table NO 2: Transient Thermos-Elastic Analysis Result Table

Sr. No.	r. o. Material Maximum generated (°C) Maximum temperature generated st		Maximum thermal strain	Maximum Deformation (mm)	Maximum Stress (MPa)	Weight (Kg)
1.	Stainless steel 321	81.32	5.72E-02	5.38E-04	11.634	1.3008
2.	AlSiC MMC	394.33	4.30E-04	2.53E-02	166.45	0.49713

3.	Carbon Fibre	74.315	1.54E-05	1.06E-03	3.1443	0.26513	
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Table No 2 shows the result of Transient Thermos-Elastic Analysis. From above analysis result, Maximum temperature is generated in AlSiC which is 74.315 °C and minimum temperature is generated in Carbon Fiber which is 123.67°C but the thermal strain and stress in carbon Fibre is less than that the stainless steel. The weight of carbon Fibre disc is 265.13 grams which is 75% less than that the stainless steel brake disc.

Figure no. 24 represents the Stress, strain and weight of material in graphical form and gives better idea about the different material brake disc. Time vs temperature graph is shown in figure no. 25 which shows the temperature of brake disc of all candidate's materials at various time of braking.



Figure 19: Stress, Strain and Weight Comparison Chart Transient Thermos-Elastic Analysis



Figure 20: Time VS Temperature Chart of Transient Thermos-Elastic Analysis

4. SAMPLE PREPARATION

4.1. Aluminium Silicon Carbide Sample Perpetration

The composition of the commercial purity aluminium used for casting Al-matrix composite is as shown in Table 1. The reduction in particle size of SiC from micron level to the nano level was carried out using a ball mill in a stainless steel chamber using tungsten carbide and zirconia balls. The estimated particle sizes of SiC were found to be ranged from 10 to 15 μ m. Silicon carbide (SiC) has been used as reinforcement. It has a theoretical density of 3.1 g/cm³. The SiC contents in the composites were adjusted to be either 60 to 63 wt%. SiC was originally produced by ball milling.

Table No 3: Chemical composition of commercial purity aluminium (wt%).

Al%	Ti%	Zn%	Ni%	Mg%	Mn%	Mn%	Fe%	Si%	Cu%
99.8377	0.0003	0.0019	0.0018	0.0012	0.0021	0.0021	0.09	0.06	0.005

The experimental set up for a stir casting process is shown in Figure 1. The aluminum was melted into a graphite crucible inside aBituminous Coal Furnace at 750°C. No wetting agent to bind molten metal and reinforcement powder was used. The furnace temperature was kept, above melting point of aluminum, at 750°C, for 10 minutes. Aluminum dross is then removedfrom the surface of the molten metal. Steel Stir impeller was then lowered down into the molten metal and allowed to rotate at 100 rpm for 10 minutes. When the vortex appears, the hot powder of SiC, preheated to 1000°C, was uniformly added to the molten matrix. The angular velocity of stirrer during adding process is then raised to 150rpm. The powder is added at a rate of 6 g/min. The cruciblecontaining the melt mixture was then carefully takenout of furnace and poured into a specially designed permanent mold. The mold was left to cool and castings wereejected.



Figure 21: Casting Furnace.

Figure 27shows the differentspecimens prepared for testing. It consists circular disc with 250 mm diameter.



Figure 22: Sample specimens of AlSiC Composite

4.2. Carbon Fibre Sample Preparation

Material used for sample preparation is as follows:

- Type of resin: Polyester
- No of Laminates: 8
- Type of Fibre: Uni-Directional (UD)
- Hardener: ARADHUR HY 951

Nature of Laminate: Symmetric type (Ex. 0,90,0,90) s Method of manufacturing: Hand Layup technique.

Composite Fibre material consisting of extremely thin Fibres about 0.025 mm in thickness. The Uni-directional Fibres are available in the standard form 395 GSM. Uni-Directional Fibres are cut to the required size & shape. These are stacked layer by layer of about 8 layers to attain the thickness of 4 mm as per the Standard Specimen. Bonding agent (Polyester) is applied to create bonding between 8 layers of sheet. Polyester is a copolymer; that is, it is formed from two different chemicals. These are referred to as the "resin" and the hardener". The resin consists of monomers or short chain polymers. The process of polymerization is called "curing", and can be controlled through temperature and choice of resin and hardener compounds. In this work the composite laminate is prepared using compression molding technique. The laminates were cured in room temperature and constant pressure for two days. Here 8 plies of Carbon Fibre are taken in a symmetric manner i.e. (0,90,0,90) s one over the other and Polyester resin is used as an adhesive. The size of the mould taken as $250 \times 250 \times 4 mm$. The laminated test specimens were prepared by a wire cutting machine and edges were grinded.



Figure 23: Carbon Fibre Sample Preparation



Figure 24: Carbon Fibre Sample Plate

5. TESTING OF SAMPLES

5.1. Carbon Fibre Disc Testing



(b) (c) Figure 25: Testing of carbon Fibre on UTM, (a) Clamping of sample, (b) Deformation after applying load, (c) Deformation at maximum load

The composite laminates were subjected to various loads and computer controlled UTM. The specimens were clamped and tests were performed. The tests were closely monitored and conducted at room temperature. The load at which the complete fracture of the specimen occurred has been accepted as breakage load.

Carbon Fibre sample can have sustained up to 4000N load after which it starts braking which is much higher than that the aluminium sample which can have sustained load up to 2000 N.



Figure27: Actual Assembly of Carbon Fibre Brake Disc on Vehicle

Carbon Fibre brake disc was mounted on Honda Unicorn Bike for testing purpose. Figure No. 31 and Figure No. 32 Shows the actual mounting and assembly of carbon Fibre brake disc on bik

Table4: Testing Results

Sr. No.	Testing Parameters	Stainless steel 321	Al Si C MMC	Carbon Fibre	Testing Instrument
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01	Maximum temperature generated (°C)	79.94	348.42	76.81	Infrared Sensor
02	Maximum thermal strain	6.82E-02	3.560E-04	1.84E-05	Strain Meter
03	Maximum Deformation (mm)	4.38E-04	3.53E-02	1.08E-03	Computerized UTM
04	Maximum Stress (MPa)	18.56	188.85	2.823	Computerized UTM
05	Weight (Kg) before wear	1.310	0.5213	0.2424	Digital Weighting
06	Weight (Kg) after wear (3 Days)	1.308	0.5108	0.2406	Digital Weighting

6. COSTING OF SAMPLING

Local market cost of Honda Unicorn bike brake disc which is made up of stainless steel material is Rs. 1850/-. Table no. 4 shows the material cost as well as manufacturing cost different material. Table no. 4 shows that the total cost of brake disc made up of alternating material is approximately near to the traditional brake disc.

1 dbie	Table 4. Cliff Costing of Different Material Samples					
Aluminium Sili MM	icon Carbide C	Carbon Fibre				
Material Cost		Material	Cast			
Aluminium	Rs.320	Carbon Fibre Sheet	Rs.1750			
Silicon Carbide	Rs.550	Hardener	Rs.40			
		Resin	Rs.250			
Casting and Machining	Rs.1200	Manufacturing and Machining	Rs.250			
Total	Rs.2070	Total	Rs.2290			

Table 4: Unit Costing of Different Material Samples

7. CONCLUSIONS

This project gives a numerical simulation of the thermal behaviour of brake disc for four different materials in transient state. By means of the computer software ANSYS 16.In order to improve the braking efficiency and provide greater stability to vehicle, an investigation was carried out and the suitable hybrid composite material which is lighter than traditional materials used for brake disc and has preferably good Young's modulus, Yield strength and density properties. Though the disc has low weight, it has hardness, greater stable characteristics which can withstand high pressure, temperature and resistance to thermal shock. The results obtained from above study leads to the following conclusions:

- Traditional material has many problems such as scarring, cracking, warping or excessive rusting.
- SiC/Al composites can be made in an open atmosphere by stir casting using fabrication scheme derived from the literature review and mentioned in the experimental.
- AlSiC had good thermal properties as well as lighter in weight than traditional materials but it is difficult to cast it with regular casting technique which make the manufacturing of AlSiC complex and costly than other materials.
- Glass Fibre had good thermal properties showing thermal strain as 0.0018205, but cannot withstand to dynamic load coming on brake disc. Due which it fails in compressive loading.
- Carbon Fibre having lowest thermal strain than any material i.e 0.0010157 as well as it can withstand the dynamic load coming on brake disc.it is approximately 70% lighter than traditional brake disc
- In carbon Fibre brake disc, the temperature change due to application of brake is also less and therefore heat dissipation takes place at faster rate and wear of the disc is also very less.

From above discussion we can conclude that the carbon Fibre is the optimum material for the brake disc as it can withstand to both dynamic load as well as thermal load coming on brake disc also it lighter in weight.

Future Scope of the Project

In our function, the best a mix of both composite material that's brighter compared to toss in terms of iron and possesses good Young's modulus, provide energy along with density properties is usually been recently looked into. A transient thermal research will likely be carried out to analyse the actual heat alternative over the utilizing asymmetric aspects. Additionally, structural research also is carried out by simply coupling thermal research. A transient thermal research will likely be carried out to produce light weight, cost effective and eco-friendly material having combine properties of Fibre and ceramic.

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