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TRANSIENT ANALYSIS OF ROTOR DISC OF DISC BRAKE USING ANSYS

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Abstract

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. An investigation into usage of new materials is required which improve braking efficiency and provide greater stability to vehicle. This investigation can be done using ANSYS software. ANSYS is a dedicated finite element package used for determining the temperature distribution, variation of the stresses and deformation across the disc brake profile. 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. Aluminum base metal matrix composite and High Strength Glass Fiber composites have a promising friction and wear behavior 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 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.

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1. Introduction

A disc brake consists of a cast iron disc bolted to the wheel hub and a stationary housing called caliper. The caliper is connected to stationary part of the vehicle like the axle casing or the stub axle as is cast in two parts each part containing a piston. In between each piston and the disc there is a friction pad held in position by retaining pins, spring plates etc. passages are drilled in the caliper for the fluid to enter or leave each housing.Each cylinder contains rubber-sealing ring between the cylinder and piston.The principle used is the applied force acts on the brake pads, which comes in to contact with the moving disc. At this point of time due to friction the relative motion is constrained.

Sok Won Kim [15] investigated the temperature distribution, the thermal deformation, and the thermal stress of automotive brake disks have quite close relations with car safety; therefore, much research in this field has been performed.Xiangie Meng [5] based on the review of researches on the vibration and noise related to automobile brake, the four degrees of freedom nonlinear dynamics model of brake disk and pads is established, the stability of vibration system at the equilibrium points is analyzed.The main idea is to express the thermal energy that the disc stores when abraking action is performed. Inorder to express this energy, the global system that influences the slowing down of the vehicle has to be considered.

This system is composed by the following technical braking components: brake discs, transmission retarders, controlled engine brakes and exhaust brakes.Jadon [15]carries out a transient analysis for the thermo elastic contact problem of the disk brakes with heat generation is performed using the finite element analysis. To analyze the thermo elastic phenomenon occurring in the disk brakes, the occupied heat 12 conduction and elastic equations are solved with contact problems.

2. Finite Element Analysis

The finite element method has become a powerful tool for the numerical solutions of a wide range of engineering problems. The present study is based on the coupled theory in which temperatures and displacements are mutually influenced. If the solution is known at time t, the solution for next time step t+ Δt needs the information of $R_{t+\Delta t}$ on the right hand side. However, the distributions of pressure *P* on the friction surfaces at this time step, which appear in the thermal boundary conditions, are unknown. When solving the frictional contact problems in time domain, Zagrodzki [19] assumed the contact pressure P to be the change in time of the

Total force represented by the applied hydraulic pressure P of the known time function as follows:

$$P(t+\beta\Delta t, r) \approx P(t,r)\frac{P_h(t+\beta\Delta t)}{P_h(t)} \qquad (3.17)$$

However, the solution using the assumption of Eq.(3.17) are generally reasonable in case of the variation in time of contact area or specially, the drag braking condition(constant hydraulic pressure P_h).Consequently, for the frictional contact problems where the time evolution of contact pressure is important, the fully implicit scheme should be used. The numerical simulation for the coupled transient thermo elastic contact problem is carried out in the following way: At time t, it is assumed that the temperature distribution is T is given. Using this temperature, the thermal load vector $P_{\Delta T}$ can be obtained. To solve the contact problem, elastic is iteratively calculated to satisfy the no overlap condition and the equilibrium state on the contact surface. As a result of this calculation, new pressure distribution and new contact conditions on the contact surfaces can be obtained. Then, using new heat flux vector *R* constructed from relation and new contact conditions, the heat and elastic can be solved at time $t+\Delta t$. The fully implicit transient iteration is repeated to calculate the equilibrium state of the coupled thermo elastic equations at every time step. In this way, the solution of thermo elastic state at any time could be obtained.

3. Materials used for Rotor Disc:

3.1 Cast Iron:

Cast iron usually refers to grey cast iron, but identifies a large group of ferrous alloys, which solidify with a eutectic. Iron accounts for more than 95%, while the main alloying elements are carbon and silicon. The amount of carbon in cast iron is the range 2.1-4%, as ferrous alloys with less are denoted carbon steel by definition. Cast irons contain appreciable amounts of silicon, normally 1-3%, and consequently these alloys should be considered ternary Fe-C-Si alloys. Here graphite is present in the form of flakes. Disc brake discs are commonly manufactured out of a material called grey cast iron.

3.2 Aluminum based Metal MatrixComposites:

Metal composite materials have found application in many areas of daily life for quite some time. Materials like cast iron with graphite or steel with high carbide content, as well as tungsten carbides, consisting of carbides and metallic binders, also belong to this group of composite materials. Substantial progress in the development of light metal matrix composites has been achieved in recent decades, so that they could be introduced into the most important applications.

3.3 E-Glass Fiber:

The use of E-Glass as the reinforcement material in polymer matrix composites is extremely common. Optimal strength properties are gained when straight, continuous fibers are aligned parallel in a single direction. To promote strength in other directions, laminate structures can be constructed, with continuous fibers aligned in other directions. E-Glass is a low alkali glass with a typical nominal composition of SiO_2 54wt%, Al_2O_3 14wt%, CaO+MgO 22wt%, B_2O_3 10wt% and Na_2O+K_2O less than 2wt%.These involve melting the glass composition into a platinum crown which has small holes for the molten glass to flow. Continuous fibers can be drawn out through the holes and wound onto spindles, while short fibers may be produced by spinning the crown, which forces molten glass out through the holes centrifugally. Fibers are cut to length using mechanical means or air jets.

3.4 S2 Glass Fiber:

High-strength glass fibers are used in applications requiring greater strength and lower weight. High-strength glass is generally known as S-type glass in the United States, R-glass in Europe and T-glass in Japan. S-glass was originally developed for military applications in the 1960s, and a lower cost version, S-2 glass, was later developed for commercial applications. The most traditional composites that fall within the fiber reinforced plastic composites almost inherently are produced using E-glass fiber. And we tend to think that most advanced composites are manufactured for high strength performance using S-2 glass fiber materials. Silicon dioxide

(SiO_2) is the one of the primary ingredients in both sand and glass fiber, there are a wide number of other ingredients mixed into the system during processing .

PROPERTIES	Cast Iron	AlMMC	S2 glass	E glass
DENSITY, ρ	7100 Kg/m^3	2765.2 Kg/m^3	2460	2580
YOUNGS MODULUS,E	125 GPa	98.5 GPa	86.9 Gpa	72.3
THERMAL CONDUCTIVITY, k	54 W/m.K	181.65 W/m.K	1.45 W/m.K	1.3 W/m.K
SPECIFIC HEAT. C_p	586 J/Kg.K	836.8 J/Kg.K	737 J/Kg.K	810 J/Kg.K
POSSION'S RATIO, υ	0.25	0.33	0.28	0.22
COEFFICIENT OF EXPANSION, α	$8.1*10^{-6}/^0K$	$17.5*10^{-6}/^0K$	$0.9*10^{-6}/^0K$	5.4*10-6/0K

Table 3.4.1 Properties of the candidate materials

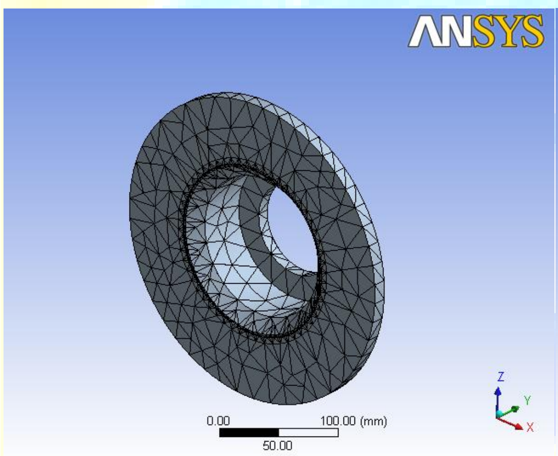
3.5 Model Evaluation

It is very difficult to exactly model the brake Disc, in which there are still researches are going on to find out transient thermo elastic behavior of Disc brake during braking applications. There is always a need of some assumptions to model any complex geometry. These assumptions are made, keeping in mind the difficulties involved in the theoretical calculation and the importance of the parameters that are taken and those which are ignored. In modeling we always ignore the things that are of less importance and have little impact on the analysis.

Due to the application of brakes on the car Disc brake rotor, heat generation takes place due to friction and this thermal flux has to be conducted and dispersed across the Disc

Rotor cross section. The condition of braking is very much severe and thus the thermal analysis has to be carried out. The thermal loading as well as structure is axis-symmetric.Hence axis-symmetric analysis can be performed, but in this study we performed 3-D analysis, which is an exact representation for this thermal analysis. Thermal analysis is carried out and with the above load structural analysis is also performed for analyzing the stability of the structure.

A model presents a three dimensional solid Disc squeezed by two finite-width friction material called pads. The entire surface, S, of the Disc has three different regions including S1 and S2. On S1 heat flux is specified due to the frictional heating between the pads and Disc, and S2 is defined for the convection boundary. The rest of the region, except S1 U S2, is either temperature specified or assumed to be insulated: the inner and outer rim area of Disc.Since the axis-symmetric model is considered all the nodes on the hub radius are fixed. So the nodal displacements in the hub become zero i.e. in radial, axial and angular directions.



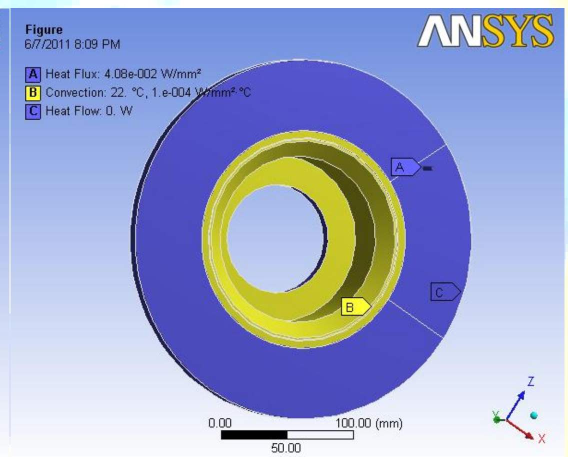


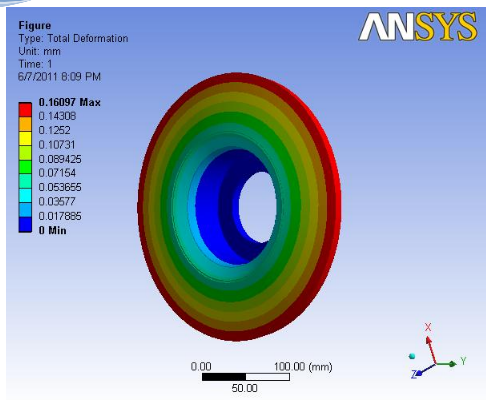
Figure 3.5.1 3-D Meshed Model Figure 3.5.2 Thermal Loading of Brake Disc

In order to validate the present method, a comparison of transient results with the steady state solution of thermo elastic behaviors was performed for the operation condition of the constant hydraulic pressure P =10 MPa, μ=0.2 and angular velocity ù = 50 rad/s (drag brake application) during 4.5 seconds. If the transient solution for this operation condition converges to the steady solution as time elapse, it can be regarded as validation of the applied transient scheme. The thermal boundary conditions used are adiabatic on the boundary of the inner and outer radius and the prescribed temperature condition T = 20°C on the both boundaries along the radius of the lower and upper pad by assumption of the cooling state.

3.6 Results and Discussion

The material properties and operation conditions used for the validation of the transient thermo elastic scheme are given in Table No 4.2.The time step Δt =0005 sec. was used. The heat flux distribution on the friction surfaces for the steady and transient (at t=5 sec) solution. Actually, after time t=3 sec, a change of heat flux distribution does scarcely occur, and then the steady state is reached. Also, this result indicates that the heat flux distribution on each friction surface occur dissimilarly as time elapse. The major cause of these phenomena is that the contact condition on the friction surfaces is changed to satisfy the new equilibrium state due to the rise in temperature.In actually, variation of the rotating speed during braking must be determined through vehicle dynamics. However, in this study, the rotating speed of Disc was considered to be a known value.

The time history of hydraulic pressure *h P* and angular speed ù assumed for brake cycle is shown. One cycle is composed of braking (4.5 sec), acceleration (10.5), and constant speed driving (5 sec). In each process, the hydraulic pressure *h P* was assumed to linearly increase to 1 MPaby 1.5 sec and then kept constant until 4.5 sec. Also, the angular velocity ù was assumed to linearly decay and finally became zero at 4.5 sec. The time step Δt =0.001 sec was used in the computations. The material properties adopted in the computations are shown in Table. The temperature distributions show high gradients near the region of friction surfaces and are almost symmetric about the Disc's mid plane at the early steps of brake application as shown. The distribution of temperatures of the Disc brake is almost symmetrical about the Disc's mid plane and the Thermo Elastic Instability phenomenon does not occur during the braking process.



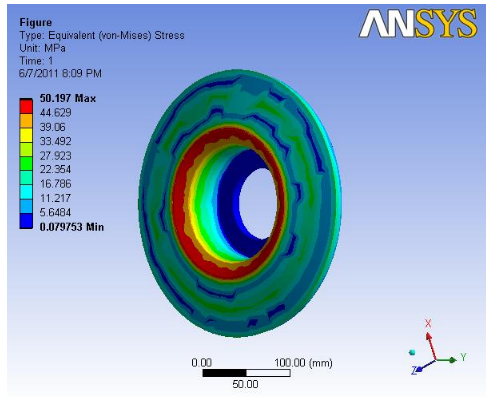
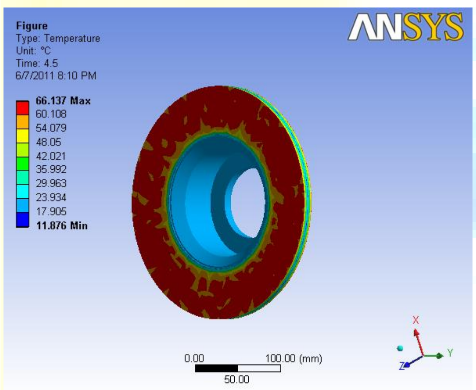


Fig 3.6.1 Total Deformation of S2 Glass Disc Fig 3.6.2 Temperature Distribution in S2 Glass disc



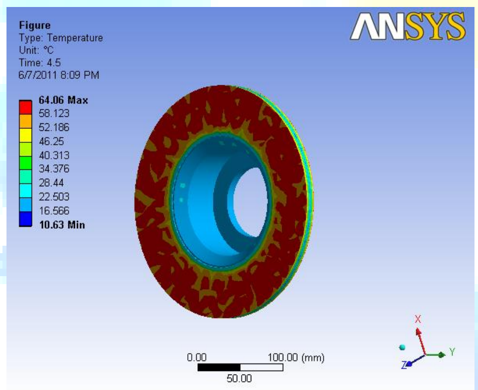


Fig 3.6.3Temperature Distribution in S2 Glass Disc Fig 3.6.4Temperature Distribution in EGlass Disc

The thermal expansion coefficient and the elastic modulus of pad materials have alarger effect on the thermo elastic behaviors of Disc brakes. Therefore, the softer padimproves the contact pressure distribution and results in a more even temperaturedistribution.In this section, the transient thermo elastic analysis of the E-Glass and S2 glass fiber disc is performed for the drag brake application (Ph = 1MPa, ù = 100 rad/s) for 4.5 s, andthen the results in the E-Glass and S2 glass fiber Discs (orthotropic case) are compared withthose using the material properties of CI (isotropic case). Figures 6.9, 6.10 and 6.11 showsthe deformation, equivalent stress and temperature distributions on the friction surfaces attime t = 1 and 4.5 s for the isotropic and orthotropic material respectively. Compared with theisotropic case, the heat flux of the orthotropic one are very uniformly distributed along thefriction surfaces and results in a more even temperature distribution, namely, a thermo elasticstable state. These results show that the

Disc brakes made of isotropic material can providebetter braking performance than the orthotropic metal ones.

Material	Deformation	Von-misses Stresses (MPa)		Temperature (°C)	
	mm	max	min	max	min
Cast Iron	0.35191	50.334	0.92342	486.76	290.2
AlMMC	0.35229	211.98	2.7269	29.232	21.9
E-Glass	1.036	274.14	0.44893	1219.8	22.019
S2 Glass	0.16097	50.197	0.079753	66.137	11.867

Table 3.6.1 Comparison of the obtained results

Comparing the different results obtained from analysis in table 6.1. We found that themaximum temperature rise in Cast Iron Disc is 486.76 ^{o} *C*, as shown in Figure, which ishigher than the maximum temperature rise in S2 Glass fiber (66.137^{o} *C)*.The equivalentstresses induced at 66.137 ^{o} *C* in Cast Iron Disc is 50.3197 MPa as shown in Figure,which is within safe limit and less than the equivalent stresses induced in all the other Discs.It is concluded that the S2 glass fiber brake Disc the best possible combination for the presentBraking application.

3.7 E-Glass Brake Disc Model:

The Finite Element Analysis of the Brake discs of different materials shows that S2glass fiber is suitable for braking application. Since S2 glass fibers are not readily available inthe market and highly priced. Since the density of S2 Glass fibers and E-Glass fibers haveless difference, a model of E-Glass fiber has been developed using the Hand layup process.Hand lay-up is the simplest and oldest open molding method of the compositefabrication processes. It is a low volume, labor intensive method suited especially for largecomponents, such as boat hulls. Glass fabric is positioned manually in the open mold, andresin is poured, brushed, or sprayed over and into the glass plies. Entrapped air is removedmanually with squeegees or rollers to complete the laminates structure. Room temperaturecuring polyesters and epoxies are the most commonly used matrix resins. Curing is initiatedby a catalyst in the resin system, which hardens the fiber reinforced resin composite withoutexternal heat. For a high quality part surface, a pigmented gel coat is first applied to the moldsurface. The final E-glass brake disc model. The weight of this brake disc model is800g, whereas the cast iron brakediscsweight 4.5 kgs. Thus brake disc models of low weight and high strength have been developed using Hand Layup method.

Material	Weight in kg
Cast Iron	3.450
E-Glass	1.020

Table 3.7.1 Weight Comparison

Fig 3.7.1 Final model of E-Glass fiber Brake disc Fig 3.7.2 Cast Iron Brake Disc

3.8 Conclusion:

In order to improve the braking efficiency and provide greater stability to vehicle aninvestigation was carried out and the suitable hybrid composite material which is lighter thancast iron and has good Young's modulus, Yield strength and density properties. The lowweight, the hardness, the stable characteristics also in case of high pressure and temperatureand resistance to thermal shock.

The transient thermo elastic analysis of Disc brakes in repeated brake applications hasbeen performed. ANSYS software is applied to the thermo elastic contact problem withfrictional heat generation. To obtain the simulation of thermo elastic behavior appearing inDisc brakes, the coupled heat conduction and elastic equations are solved with contactproblems. The effects of the friction material properties on the contact ratio of frictionsurfaces are examined and the larger influential properties are found to be the thermalexpansion coefficient and the elastic modulus. It is observed that the orthotropic Disc brakescan provide better brake performance than the isotropic ones because of uniform and mildpressure distributions. The present study can provide a useful design tool and improve thebrake performance of Disc brake system. From Tablewe can say that S2 glass fiber is thesuitable material for the braking operation and all the values obtained from the analysis areless than their allowable values. Hence the brake Disc design is safe based on the strengthand rigidity criteria.

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