Structural and thermal analysis for an optimal design of an automobile brake disc: A review

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Abstract : There has been a considerable amount of research done on brake disc to determine its structural and thermal strength and to choose the right brake disc material which not only provides stiffness but also has high thermal conductivity as brake discs are required to dissipate heat rapidly, especially in the case of racing cars. The article below tries to identify the most significant and proper research done in this field and to highlight the most important aspect of designing and analyzing the brake disc by finite element method. This article will also try to concisely define the various research methodology adopted and their final outcomes in a concrete and precise manner.

***IndexTerms* – Brake disc, Finite element method, Research Methodology.**

I. Introduction

Consider an automobile a well-organized system where different components work together for a common goal, that is to provide the best driving experience which is safe and secure at the same time. In this aspect of safety and security braking system plays a very important, significant and phenomenal part. Braking in automobile essentially revolves around converting the kinetic energy of the vehicle into heat energy. This converted heat energy is dissipated into air through the brake disc rotor. There are other types of brakes such as drum brakes but the focus here would be around disc brakes as these are most commonly used in present day scenario.

The reason being disc brakes have better response to braking; the heat dissipation in disc brakes is quiet efficiently done as they are exposed to air. Also it should be noted in drum brakes are more prone to dust and water collection which could further reduce the effectiveness of the braking system.

Disc brakes basically consist of a disc which could be solid, drilled, grooved, drilled and grooved or ventilated disc or could be designed and manufactured depending upon requirement of the vehicle. This brake disc is bolted to the wheel hub. It also consists of a brake caliper which is stationary housing. The brake calliper consists of brake pad mounted on it. These brake pads are forced on both side of the disc hydraulically, mechanically, pneumatically or electromagnetically on both sides of the disc.The friction thus generated between the brake pad and brake disc rotor causes the vehicle to stop or slow depending upon the requirement of the driver. The heat thus generated in this process is transferred into air. A diagrammatic representation of the disc brake working is shown in Fig-1.

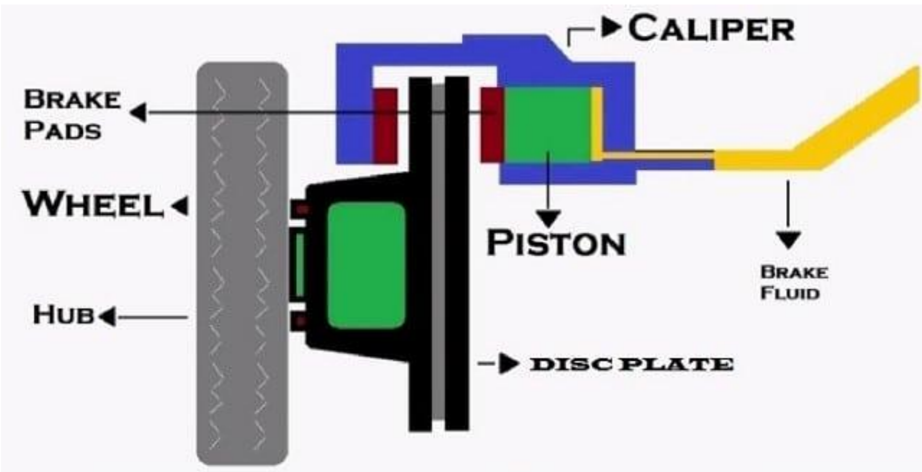


Fig.1: Working principle of a disc Brake

II. BRAKE DISC MATERIAL

To choose the right material for a brake is a quite difficult and uphill task. It usually depends upon the requirement of the automobile. For e.g. the motorcycles and scooters usually employ gray cast iron or cast iron as brake disc material as they are low cost easy to manufacture material. Also they have high melting temperature and they are wear resistant. Henceforth they become a suitable material for motorcycles and scooters.

Whereas, in racing cars where aggressive driving is common or automobiles that require high performance the material used is reinforced carbon as it is able to retain its properties at temperatures more than 2000˚C. This performance could be enhanced by coating the material so as to prevent oxidation.

There are though some basic consideration that could be taken into account while choosing the right material for the brake disc.These are as follows:

1. The material should have a high melting temperature.
2. It should possess a high thermal conductivity and specific heat capacity.
3. It should be resistant to wear and should have good machinability
4. It should have good corrosion resistance.
5. It should be shock resistant.

III. PREVIOUS RESEARCHES DONE IN THIS AREA

Maleque et al. [1] described a process that could be followed while determining right material to employ in the manufacture of disc brake. The process included four steps which were followed as shown in Fig-2. At first the general requirements are considered such as the cost of manufacturing should be less i.e. it should be economical in all respects, it should be light weight, should possess high thermal conductivity and should have high wear resistance. The second step described about few materials such as cast iron, aluminium alloys, titanium alloys and ceramics and composites and there specific properties such as thermal stability and ease of manufacturing of cast iron, the light weight and corrosion resistant titanium alloys and low density and high thermal conductivity aluminium alloys. The third step is about digital logic method, where important properties such as friction coefficient, wear resistance, thermal capacity are high weighting factors while compressive strength and specific gravity have low weighting factor and based on these ranking is allotted to different materials. The forth step involved optimum material selection by comparing the performance index, γ, and the total cost, C_t to that of gray cast iron shown in Fig-3 below.

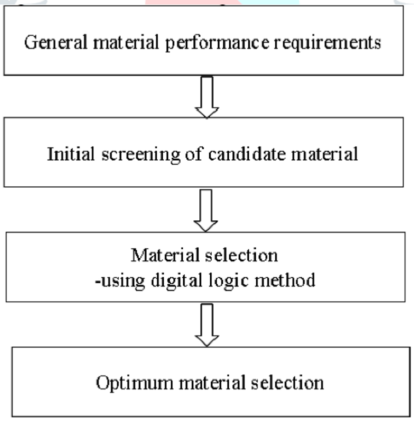
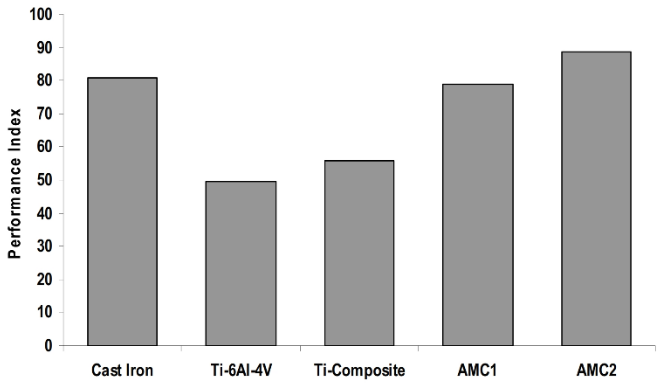


Fig.2: Flow chart of material selection method**[1]**



Material	Relative Cost	Performance Index (γ)	Figure of Merit	Rank
GCI	1	81.0	11.25	2
Ti-6Al-4V	20	49.5	0.56	5
TMC	20.5	56.0	0.58	4
AMC 1	2.7	79.0	10.84	3
AMC 2	2.6	88.6	12.17	1

Fig.3: (a) Plot of performance index (γ) and **(b)** table of comparative results against all candidate materials. **[1]**

Thilak et al. [2] used four different materials Cast Iron, Aluminium Metal Matrix Composites, Glass Fiber and S2 Glass Fiber for assigning the material of brake disc rotor. They stated an important fact that though aluminium based metal matrix composites are being considered for brake disc rotor due to being light weight but they have low melting point, henceforth have less resistance to high temperature. They further carried out transient thermal and structural analysis in ansys software and concluded that S2 Glass Fiber is a suitable substitute which has lowest deformation among the four. The investigation further stated that S2 Glass Fiber are lighter in weight, has a good young's modulus, yield strength and density properties. The material will improve the braking efficiency, being light weight will provide greater stability and also result in low consumption of fuel. The comparative results for the four assigned materials are shown in table of Fig-4.

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
AIMMC	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

Fig.4: Comparison of Results **[2]**

Chengal Reddy et al. [3] performed structural and thermal analysis of solid and ventilated disc using ansys software. The materials employed for brake disc were Carbon-Carbon Composites, Maraging Steels, Cast Iron. Through analysis it was determined that maraging steel gives less deformation and stress as compared to cast iron and carbon-carbon composites also the nodal temperature value is less for maraging steel in both the cases of solid and ventilated disc.The maraging steel is good material that could maintain its properties at high temperatures. The results concluded that maraging steel is a better option and suitable option for brake disc material.

Manjunath T. V. et al. [4] conducted a study to find out whether a solid disc or a ventilated disc is suitable as a brake disc rotor. Stainless steel and cast iron were selected mainly because stainless steel is corrosion resistant due to its high chromium content about 10.5% by mass and less carbon content which is about 1.2% by mass and cast iron due to easy availability and high themal resistance. Finite element analysis(FEA) results were compared with the analytical results and concluded that ventilated disc cast iron disc is a better performer for brake disc rotor of 4 wheeler because there is reduction in temperature, stresses and deformation by approximately 31% and 22%, 8% respectively than the solid disc. The results for both the assigned materials are shown in Fig-5.

Sl No	Material Flange width mm	Analytical Max. Temp °C	FEM Max. Temp °C	Deflection in mm	Analytical misses stress Mpa	FEM Von misses stress Mpa
	Solid Brake					
1	SS 24	464	446	0.0608	270	256
2	CI 24	425	413	0.0590	160	142
	Ventilated Disc Brake					
1	SS	340	321	0.105	186	247
2	CI	**308**	**283**	**0.098**	**99**	**110**

Fig.5: Comparison of results of solid and ventilated disc**[4]**

Shaik et al. [5] carried out comparative analysis of two brake disc viz. brake disc having rotor that has holes on its surface and another brake disc without holes both made of cast iron. The analysis proposed a modular caliper design which asserted that there should be a caliper assembly rather than single block manufacturing also the analysis intended to reduce the weight of the caliper without compromising with its strength and durability. The material used were Aluminium alloy(Al 2219) and titanium. Here titanium parts were kept simple as far as geometry is concerned because titanium is not easy to machine. At first the new caliper design was tested without taking in considerations the thermal expansion effects but when a nodal temperature of 300°F was used the new design showed less thermal displacement approximately around 8% when compared to the conventionally used caliper design.

BELHOCINE et al. [6] asserted in through analysis that ventilation in a brake disc rotor is essential especially in a 4-wheeler simply because the temperature rises very significantly and the ventilation system provides better cooling effect and result in high temperature resistance. The material cast iron was selected because it has the required amount of hardness, stiffness and it is less costly when compared to steel and aluminium. The analysis concluded with the result that total deformation, temperature and von-misses stresses increase as the thermal stresses increases. It is important to note that mechanical stresses generated causes wear of disc and brake pads, thereby cementing the necessary conclusion that ventilation is required in high performance vehicles to ensure the long lasting strength of the brake disc rotor.

Viraj Parab et al. [7] discussed about how different material are suitable for brake disc rotor depending upon different requirements. The analysis was carried out on ansys workbench using cast iron, stainless steel, and carbon-carbon composite material. The results concluded that stainless steel performs better from deformation point of view while cast iron performs better from stress point of view. The minimum and maximum temperature distribution is approximately same in all three materials.
The reason behind stainless steel performing better with regard to deformation is because it a ductile material that could withstand static loads.

Nathi et al. [8] performed analysis considering pure thermal loading, also the kinetic energy of the vehicle is completely lost through the brake disc rotor, thereby asserting that there is no heat loss between the tyres and the road. A thermal conductivity is uniform throughout. The maximum temperature obtained through the analysis at the contact surface was measured approximately 240^{o}C also the maximum von misses stress is observed to be 518 MPa. Here cast iron results are good and could be considered for further testing in the lab so as to find out whether the computer aided design could be used for manufacturing purpose or not.

Rakesh Jaiswal et al. [9] considered the brake disc rotor of PORSCHE CAYMAN with the brake disc material of Aluminium Alloy 6262 T-9. Ansys CFX solver was used to calculate the heat transfer coefficient at the wall of the brake disc.
The ventilated disc brake was meshed using triangular surface mesher. The detailed result is analyzed for the contact zone which exhibits quite high temperature. The temperature reaches approximately around 210^{o}C around the contact area. The result concluded that aluminum alloys result in reduction of weight of the whole braking system and improve structural stability.

Rajagopal et al. [10] performed analysis on different configurations of ventilated rotor disc.A sector of circular pillar vane, modified taper radial vane, diamond pillar vane, was modeled in CATIA software. For meshing hexahedral mesh elements were used. The model is analyzed in ansys CFX. The comparison of final results shows that the mass flow rate is higher in taper radial vane compared to circular pillar rotor vanes also heat dissipation in diamond pillared vane is around 25% higher as compared to the other two designs. Here it was assumed that the surface of the rotor has uniform temperature. Circular pillar vanes have more uniform pressure resulting in uniform temperature drop around the vanes.

Sarkar et al. [11] investigated electromagnetic action in a magnetorheological brake system. Finite element method was used for carrying out the analysis. In this type of brake system torque is changed magnetically by controlling the electric current supplied to the magnet. This kind of brake arrangement has an advantage that it reduces the number of moving links, it also reduces the response time and henceforth increasing the overall stability of the system. Also it provides digital control over frictional power and also reduces wear to quite a considerable extent. It provides a smooth operation. The analysis concluded that low carbon steel material of the shaft increases the MR effect and is better than stainless steel on this regard.

Subramanian P M et al. [12] performed a research by including bolt pretension as a parameter along with stresses induced due to braking torque in the brake disc to study about in detail about the strength of the disc brake. The brake disc and hub were modeled using 3D tetrahedral elements. The disc used was a ventilated brake disc as it provides better cooling effect in the brake disc. The material used was cast iron. The analysis concluded that the the stresses induced for bolt pretension were negligible compared to the braking torque, further outcomes shows that the stresses induced for combined bolt pretension and breaking torque for rear was approximately 73 N/mm^2.

Ishwar Gupta et al. [13] used Maruti 800 car rotor disc and performed structural analysis on it using ansys finite element software. The meshed model of the disc is shown in Fig-6.It aimed at evaluating the rotor performance under severe condition and highlights the best parameters that could be used to determine the wall thickness, flange width, and the composition of the material. The materials used in this study were gray cast iron and aluminium alloys.

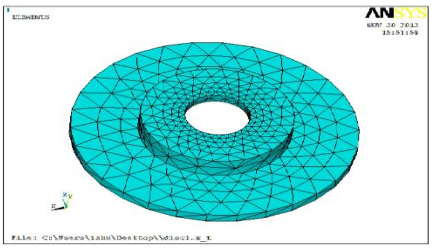


Fig.6: Meshed model of rotor disc in Ansys**[13]**

Ranjith Kumar et al. [14] used solid works for modeling the brake disc and for meshing and hyper mesh for discretization, as this software gives better meshing result. Further ansys was used for steady static thermal analysis of the brake disc. The analysis was carried out on straight vented brake disc and curved vented brake disc. The results showed that the curved vented brake disc has reduced weight and von-misses stresses as compared to the straight vented brake disc also the curved vented brake disc show high thermal flux.The result of the analysis are shown in Fig-

RESULTS	EXISTING MODEL	PROPOSED MODEL
Von misses stresses	273.223	266.06
Displacement vector sum	0.26429	0.13293
Thermal flux vector sum	1094.03	1152.15
Thermal gradient vector sum	20.739	21.1404
Mass	2.7904kg	2.6829kg

Fig.7: Comparison of results**[14]**

IV. CONCLUSION

The present review covers important aspects of the structural and thermal analysis of a brake disc rotor such von misses stresses and total deformation. Few conclusions can definitely be drawn out of the investigation stated above. First of all the grey cast iron is one of the most widely used materials for one particular reason that it more economical that any other alloys of steel, alluminium, titanium, steel etc. Secondly, the material selected should be such that it has high thermal conductivity as heat dissipation is one of the most important aspects when it comes to designing of the brake rotor. Thirdly, the designing criteria used specifically are strength and rigidity. Lastly, aluminium alloys have low density and high thermal conductivity but low melting point therefore they cannot be employed in high performance vehicle.

V. ACKNOWLEDGEMENT

Though every effort has been made to study all the aspects of the research in detail but still there is a chance that minute details are left out. The author wishes to conclude by conveying that any exclusion of references is purely unintentional. .

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