# Material Selection Procedure for Disc Brake Rotor

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*Abstract*— An automotive brake disc rotor is a device is use to slowing or stopping the motion of a wheel while it runs at a certain speed. The widely used brake rotor material is cast iron which consumes much fuel due to its high specific gravity. The main purpose of this paper is to develop the material selection technique and choice the finest material for the application of brake disc system emphasizing on the substitution of this cast iron by any other lightweight material. Two methods are introduced for the selection of materials, such as cost per unit property and digital logic methods. Material performance wants were analyzed and different solutions were evaluated among cast iron, aluminum alloy, titanium alloy, ceramics and composites. Mechanical properties including compressive strength, friction coefficient, wear resistance, thermal conductivity and specific gravity as well as cost, were used as the key parameters in the material selection stages. The analysis led to aluminum metal matrix composite as the most suitable material for brake disc system.

***Key words:*** Brake Disc, Material Selection, Cost per Unit Strength Method, Digital Logic Method

## I. Introduction

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 excessive promise for such applications These materials having a lower density and higher thermal conductivity as compared to the conventionally used grey 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 necessity is to withstand the high temperature that developed 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 helpful but the evolution of CO2 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.

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 specific material properties and be used to find out a kind of materials suitable for a particular application. In general, the material selection process is performed based on performance indices in chart. As an dissimilar approach, digital logic methods have been occasionally used in material selection for certain engineering application. In order to select an appropriate material for a particular application the designer can use Materials handbook or international standard sources. However, information-made system for selecting and ranking the materials for a particular application are also available in some literature. The information on the development and application of the materials selection method for the design of automotive brake disc is scare in literature. The main purpose this present work is to improve a proper material selection method and apply that for the selection of best candidate material for brake disc application using Ashby's chart and finally rank the materials according to the performance indices using digital logic method.

## II. Objective

The present investigation is aim to study:-

– Material selection of disc brake rotor using digital logic method and improve the strength, rigidity of disc brake by selecting better material
– Design front brake disc rotor (Bajaj pulser150cc bike) using CATIA V5 having its standard specification
– Structural-thermal analysis carried by disc brake rotor (after selecting disc brake material)
– Using structural-thermal analysis calculate stress, deformation, temperature of both disc (grey cast iron and selected material disc) compare the result

## III. Methodology

– Study of Disc Brake, Material, Components
– elect material using Digital logic method
– Design of Disc brake for various materials.
– As per calculation model in CATIA V5
– Analyze same model by using ANSYS.
– Structural-thermal Analysis using ANSYS.
– Calculate stress, Deformation ,temperature of selected disc by applying boundary condition
– Compare result
– Conclusion

## IV. Literature review

M.A.Maleque [1] has developed weighted property method for selection of optimum material for application of brake disc system, to use light weight material instead of cast iron.

 

Two methods were used for the selection of materials, such as cost per unit property and digital logic methods. Cast iron, aluminum alloy, titanium alloy, ceramics and composites Material performance requirements were analysed and alternative solutions were evaluated. Mechanical properties including compressive strength, friction coefficient, wear resistance, thermal conductivity and specific gravity as well as cost, were considered as the key parameters in the material selection stages. The analysis result shows that aluminium metal matrix composite as the most suitable material for brake disc. Vaibhav A.Ajmire [2]evaluating the performance of disc brake rotor of a bike under severe braking conditions through Transient Thermal and Structural Analysis of the Rotor of Disc and there by assist in disc rotor design and analysis. “Structure Optimisation of the disc brake”, the action force, friction force and brake torque on rotor disc are calculated by the simple methods of disc brake. Comparison has been done between the rotor disc of a standard motorcycle “Bajaj Pulsar” and a non-standard rotor disc to find out the relationship value between brake torque, rotor disc dimension etc. Manjunath T V [3] studied analysis the thermomechanical behaviour of the dry contact of the brake disc during the braking phase. The coupled thermal-structural analysis is used to determine the deformation and the Von Mises stress established in the disc for the both solid and ventilated disc with two different materials to enhance performance of the rotor disc. A comparison between analytical and results attained from FEM is complete and all the values obtained from the analysis are less than their allowable values. Hence best suitable design, material and rotor disc is suggested based on the performance, strength and rigidity. N.Balasubramanyam [4] had investigated the numerical simulation for the thermos-elastic behaviour of disk brake is obtained in the repeated brake condition. The computational results are presented for the distribution of heat flux and temperature on each friction surface between the contacting bodies. Also, thermos-elastic instability (TIE) phenomenon (the unstable growth of contact pressure and temperature) is investigated in the study, and the influence of the material properties on the thermos-elastic behaviours (the maximum temperature on the friction surfaces) is investigated to facilitate the conceptual design of the disk brake system. Finally they discuss the thermos-elastic behaviours of the carbon-carbon composites with excellent mechanical properties Based on numerical results. Viraj Parab [5] Design the model a disc. Structural and Thermal analysis is to be done on the disc brakes using three materials Stainless Steel and Cast iron & carbon carbon composite. Structural analysis is complete on the disc brake to certify the strength of the disc brake and thermal analysis is done to analyse the thermal properties. Comparison can be done for deformation, stresses, temperature etc. form the three materials to check which material is best. Lemi Abebe [6] made an analyse the brake disc using analytical as well as finite element analysis for its temperature as well as thermal stress distribution. Four different materials were selected for this purpose namely cast iron, merging steel, Aluminium metal matrix composites and E-Glass. By using vehicle specifications the parameters like brake torque, heat flux and single stop temperature were calculated. Maximum temperatures were calculated for all the materials using analytical method as well as finite element analysis. Maximum principal stresses were also calculated using both analytical as well as finite element analysis. The results obtained were compared and found that ALMMC has less temperature and less stress. Mahmood H.Dakhil [7] Optimized design of performance of disc brake using finite element analysis for evaluating the performance under severe braking conditions. Cast iron and stainless steel stay used equally disc brake materials. They investigate the effect of the temperature distribution with the deformed shape and stress distribution of disc brake rotor design by using different braking conditions. From the results of the above data, the service life and long term stability is ensured. A steady static structure analysis has been carried out to investigate the temperature variation across the disc using the axis symmetric finite elements. Advance structural analysis is also approved out by Joined Field Analysis. possible. Venkatramanan R [8] investigate and analyse the temperature distribution of rotor disc during operation using Ansys. The standard disc brake two wheelers model using in Ansys and done the Thermal analysis and also calculate the Heat flux, Temperature of disc brake model and also design of a disc brake which is proposed with copper liner on its brake disc, the heat transfer of existing and hybrid disc will be calculated for finding the effectiveness of heat transfer. Mr. Milind H.Pendkar [9] Calculate thermal stress creating on disc of 150 cc pulsar. After evaluating result they found that, after apply brake on disc the heat flux goes on decreases and become zero after certain time and maximum stress on disc near the bolt where it mounted on wheel and maximum temperature in disc where disc directly contact to the brake shoe. Telang A.K [10] Redesigning of the braking system by substitution of lighter material like aluminium and carbon composite brakes. Composite materials provide such unique combination of properties. They suggest the alternate materials for automobile brake applications which are aluminium composites. Rakesh Jaiswal [11] When brake is applied to the disc brake it is subjected to high stress, thus it may suffer structural and wear issues. Hence for the better performance, structural, stress and the thermal analysis is preferred to choose low stress material. They prepare the model and analyse stress concentration, structural deformation and thermal gradient of disc brake. Here the disc brake is designed by using Solid works and analysis is done by ANSYS workbench R14.5.

## V. PROBLEM STATEMENT

Discs are made up mainly grey cast iron, so discs are damaged in one of three ways: scarring, cracking, warping or excessive rusting. When brakes are applied then there is friction between brake pad and rotor surface due to this temperature of the brake disc increases and is subjected to thermal stresses. Due to this disc causes cracking scarring warping so a careful design and material selection is necessary to avoid the premature failure of the disc brake.

### A. *Material Requirement for Disc Brake*

Based on the function and the possible disc damage modes above, certain material requirement for disc brake is needed to be taking into consideration. The material necessities for disc brake are as below:

– High strength even at elevated temperatures
– High stiffness (modulus of elasticity)

- Low density
- High thermal conductivity
- Excellent abrasion resistance
- Good creep resistance

## VI. MATERIAL SELECTION PROCEDURE

For material selection there are small numbers of methods that have evolved to a position of prominence. Material selection process is an open-ended and normally lead to several possible solutions to the same problem. This can be explained by the fact that similar component performing similar function, but produced by different manufacturers, are often made from different materials and even by different manufacturing processes However, selecting the optimum combination of material and process is not a simple task rather gradually evolved processes during the different stages of material selection. In this study, the stages of material selection method are shown in using a flow chart

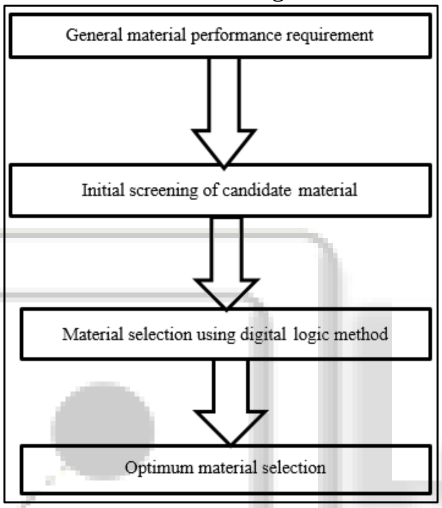


Fig. 1: Flow chart of material selection technique

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### B. *Initial screening of candidate material*

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 define the probable candidate materials those can be recycled 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 colour .Considering its cost, relative ease of manufacture and thermal stability, this cast iron (particularly, grey cast iron),is actually a more specialized material for brake applications particularly the material of choice for almost all automotive brake discs. To work properly, the parts must be created at the foundry with firmly checked 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 compounds have the potential to decrease weight of the brake rotor disc component which is around 37% less than a predictable cast iron with the same dimensions and offering good high temperature strength and better resistance to corrosion

*3) AMC*

Aluminium alloy built metallic matrix composites (MMCs) with ceramic particulate reinforcement must show excessive potential for brake rotor applications. These materials having a lower density and higher thermal conductivity as compared to the conventionally used grey cast irons are expected to result in weight reduction of up to 50-60% in brake systems. The constant braking of the AMC brake rotor dropped the friction coefficient μ and affected major wear of the brake pad. The friction properties of the AMC brake disc are thus remarkable poorer than those of conventional brake disc. After growing hard particles content the effect showed that the repetitive braking processes did not lesser the friction coefficient. Wilson et. al. studied the abrasive wear resistance of the AA6061 with 20 vol % SiCp reinforced composite in short sliding distance testing (about 20m). Adding 20 vol. % SiC particulate impressively greater the wear resistance, higher room-temperature strength and stiffness, and improved high-temperature strength. Three major problems exist with this aluminum-composite rotor. First, because of the density difference between aluminum and SiC, segregation or inhomogeneous distribution of SiC particles during solidification cannot be avoided. Also, adding SiC elements in an aluminum matrix intensely decreases the ductility of the material, resulting in low product liability. The third problem is a lack of a solid lubricant, such as graphite. The lack of graphite in the system results in low braking efficiency, adhesive wear, and galling. In a cast iron rotor, graphite is always extant in the iron. As the break wears, the graphite is freed from the iron matrix to be used as a solid lubricant on the wear surface.

Established on the properties, potential candidate materials for mechanical brake disc were nominated as:

- Cast iron
- Ti-alloy (Ti-6Al-4V)
- 7.5 % TiC reinforced Ti-composite (TMC
- 20% SiC reinforced Al-composite (AMC 1)
- 20% SiC reinforced Al-Cu alloy (AMC 2)

### C. *Material selection using Digital Logic Method*

The digital logic method can be employed for the optimum material selection using with ranking. As a first step, the property necessities for a brake rotor were determined built on earlier conversation. The properties and the total number of choices,

I.e. N (N− 1)/2 = 10 are given in Table 1

| Decision Number | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Compressive strength | 0 | 0 | 0 | 1 | | | | | | |
| Friction coefficient | 1 | | | | 1 | 0 | 1 | | | |
| Wear resistance | | 1 | | | 0 | | | 1 | 1 | |
| Thermal capacity | | | 1 | | | 1 | | 0 | | 0 |
| Specific gravity | | | | 0 | | | 0 | | 0 | 1 |

Table 1: Application of digital logic method to material selection for disc brake

The weighting factor for each property, which is indicative of the importance of one property as compared to others, was obtained by dividing the numbers of positive decisions given to each property by the total number of decisions. The total positive decisions for each property and corresponding weighting factor were calculated and are presented in Table 2

| Property | Positive decision | Weighting Factor (α) |
|---|---|---|
| Compressive strength | 1 | 0.1 |
| Friction coefficient | 3 | 0.3 |
| Wear resistance | 3 | 0.3 |
| Thermal capacity | 2 | 0.2 |
| Specific gravity | 1 | 0.1 |
| total | 10 | 1.0 |

Table 2: Weighting factor

| | Properties | | | | | |
|---|---|---|---|---|---|---|
| Material | | 1 | 2 | 3 | 4 | 5 |
| | | Compressive strength (Mpa) | Friction coefficient (μ) | Wear rate $\times 10^6$ $mm^3$ N/m | Specific heat (KJ/Kg.K) | Specific gravity ($Mg/m^3$) |
| | GCI | 1293 | 0.41 | 2.36 | 0.46 | 4.2 |
| | Ti-6AL- | 1070 | 0.34 | 2.46 | 0.58 | 4.42 |
| | TMC | 1300 | 0.31 | 8.19 | 0.51 | 4.68 |
| | AMC1 | 406 | 0.35 | 3.25 | 0.98 | 2.7 |
| | AMC2 | 761 | 0.44 | 2.91 | 0.91 | 2.8 |

Table 3: Properties of candidates material

Table 3 showed the properties of the candidate materials those are used for ranking purposes. In request to complete the Digital logic method, the following step is to measure the assets of the materials based on their respective weighting factor and the scale value is shown in Table 3. For the present application, materials with higher compressive strength, friction coefficient and thermal capacity are more desirable and highest value is rated as 100. Their scaled values are calculated using the following equation (1)

$$\text{Scaled properties} = \frac{\textit{Numerical value of properties}}{\textit{Maximum value in list}} 100 \quad (1)$$

Since lower wear rate and specific gravity are desirable for the automotive brake disc, therefore, their lowest value is considered as 100 and scaled values are calculated using equation (2)

$$\text{Scaled properties} = \frac{\textit{Minimum value in the list}}{\textit{Numerical value of properties}} 100 \quad (2)$$

Other values in Table IV are rated in fraction. The scaled values and performance index (γ) are given in Table 5 which was calculated using equations (3)

$$\text{Material performance index } (\gamma) = \sum_{i=1}^{n} \beta i \alpha i \quad (3)$$

Where,

B= is the scaled property

α= is the weighting factor and

i= is summed over all the n relevant properties.

Table 4 Scaled value of properties of respectively material and equivalent show index.

The performance index showed that the technical capability of the material without regard to the cost. However, if there are a large number of properties to be considered, the importance of cost may be emphasized by considering it separately as a modifier to the material performance index (γ). It is also significant to contemplate the cost of material previously creating any final design or ranking. Therefore, in this study, the figure of merit (FOM) M is calculated before ranking using the equation (4)

$$M = \frac{\gamma}{C\rho} \ldots\ldots\ldots(4)$$

Where,

C=Total cost of the material per unit weight

ρ = Density of the material

| Material | Relative cost/kg in rupees | Performance index (γ) | Figures of merit. | Rank |
|---|---|---|---|---|
| GCI | 71 | 81.0 | 11.25 | 2 |
| Ti-6AI-4V | 1420 | 49.0 | 0.56 | 5 |
| TMC | 1455 | 56.0 | 0.58 | 4 |
| AMC 1 | 192 | 79.0 | 10.84 | 3 |
| AMC 2 | 185 | 88.6 | 12.17 | 1 |

Table 4: Cost and figure of Merit of candidate materials

The values of the relative cost, performance index, and figure of merits of the different materials are shown in Table 5. The plot of performance indices against all the candidate materials is shown in Fig.2

| Scaled properties | | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | Performance index ($\gamma$) |
| GCI | 99 | 93 | 100 | 61 | 38 | 81.0 |
| Ti-6AI-4V | 82 | 77 | 0.96 | 59 | 61 | 49.5 |
| TMC | 100 | 70 | 29 | 52 | 58 | 56.6 |
| AMC 1 | 31 | 80 | 73 | 100 | 100 | 79.0 |
| AMC 2 | 59 | 100 | 81 | 94 | 96 | 88.6 |

Table 5: Scaled properties

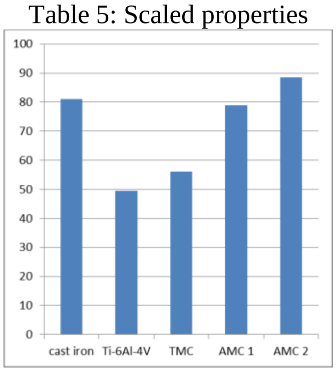


Fig. 2: Plot of performance index vs. candidates material

From Figure 6 it can be seen that AMC 2 (Al-Cu alloy reinforced with 20% SiC) showed higher performance index (γ) followed by gray cast iron (GCI) material.

### *D. Optimum Material Selection*

To study material selection methods for the design and application of automotive brake disc are and also study properties of the brake discs material or were measured for the initial screening of the candidate materials using Ashby's materials choice chart. The digital logic method showed the highest performance index for AMC 2 i.e. Aluminium metal Matrix composite (AL-cu reinforced with 20% SiC) [1]

## VII. Conclusion

The material selection methods for the design and application of automotive brake disc are developed. Functions properties of the brake discs or rotors were considered for the initial screening of the candidate materials using Ashby's materials selection chart. The digital logic method showed the highest performance index for AMC 2 material and identified as an optimum material among the candidate materials for brake disc. In the digital logic method, the friction coefficient and density were considered twice for determining the performance index and the cost of unit property. This procedure could have overemphasized their effects on the final selection. This could be justifiable in this case as higher friction coefficient and lesser density are useful from the nominal and cheap point of opinion for this type of application.

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