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Research Article

Material Selection for Manufacturing Disc Brake Rotor for a Racing Go Kart Having Single Hydraulic Disc Brake System

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Abstract

In a racing go kart with single hydraulic disk brake system, disc or rotor is a device for slowing or stopping the motion of a wheel while it runs at a certain speed which converts kinetic energy into heat energy. The widely used brake rotor material is Grey Cast Iron (CGI) which consumes much fuel due to its high specific gravity. Also, it is heavy due to high density which in return affects the performance of the race go kart. The aim of this paper is to develop the material selection method and select the optimum material for the application of brake disc system emphasizing on the substitution of this cast iron by any other lightweight material. Material performance requirements were analysed and alternative solutions were evaluated among cast iron, aluminium 7075 T6, titanium grade 5 alloy, and stainless steel 420. Mechanical properties, thermal properties, FEA (finite element analysis), were used as the key parameters in the material selection stages. The analysis led to Titanium Grade 5 material as the most appropriate material for brake disc system for a 150-cc racing go kart having single hydraulic disc brake system with the top speed of 110 Kmph.

Keywords: Racing Go-Kart; Disc brake rotor; Grey cast iron; Aluminium; Titanium; Stainless steel; Material Selection; Mechanical; Thermal; FEA

Introduction

In motorsports industries, to attain better performance the reduction in vehicle weight is very important no matter what size the component is, the automobile industry has rapidly increased the use of aluminium, carbon fibre and titanium in light vehicles in recent years. These materials have less weight and higher thermal conductivity as compared to the grey cast irons which are expected to result in weight reduction of up to 50-60% in brake systems. Moreover, these super materials have the potential to perform better under severe service conditions like higher speed and load etc.

Since brake disc or rotor is a one of the most important and stressed component from safety point of view, materials used for brake systems should have reliable wear and frictional properties under severally changing conditions like environment, velocity, load, and temperature. There are several factors to be considered when selecting material for a disc brake rotor. The most important factor is the capability of the brake rotor material to withstand high braking forces with less abrasive wear due to high friction. Another requirement is to withstand the high temperature that is generated due to friction. Weight, manufacturing process ability and cost are also important factors those are need to be considered during the design phase. The brake rotor 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 document for comparing a large number of materials at the design phase. The main purpose of the present work is to select the best candidate material for manufacturing brake rotor for a racing go kart and rank the materials according to different selection processes. The schematic diagram showing the location of disc brake rotor is shown in fig.1.

Figure 1: Racing Go-Kart with a single hydraulic disc brake system in rear.

Material selection methodology

In this work, we have developed certain methods which will help in selecting the best material for disc brake rotor application with optimum combination of the desired properties. The stages of material selection method followed in this work are shown using a flow chart in Fig. 2.

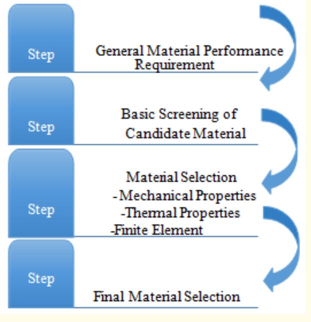

Figure 2: Stages in material selection.

General Material Performance Requirement

A schematic view of the brake rotor system is shown in Fig. 3. In this system, a braking force is generated by clamping the brake pads against a rotor contact patch which is mounted on the axle of go kart via hub. Due to high mechanical advantage, a smaller lever input force at foot brake pedal with pedal ratio 5:1 is converted to a large brake force at the wheel. This force in turn pushes the rotor against brake pad and hence generates a brake force due to large friction. The more brake power can be achieved with material with high coefficient of friction. The amount of frictional force generated is given by the relation Frotor = 2.Cf.pad Fpad. Where, Cf.pad is coefficient of friction for the pad material and Fpad is the force pushing the brake pad.

The candidate material used for disc brake rotor components should have high coefficient of friction, high compressive strength, high wear resistance, light weight, better thermal properties and should be economically viable [1, 2].

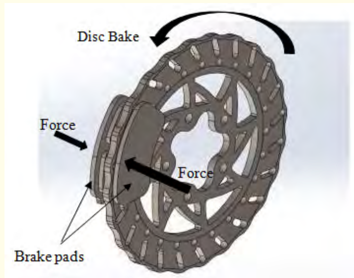

Figure 3: Schematic Representation of disc brake rotor.

Initial Screening of the candidate material

In the initial screening process we have chosen following four materials based on their properties, cost and manufacturability and availability.

- Grey cast Iron
- Titanium Grade 5 (Ti-6Al-4V, 3.7165, R56400)
- Martensitic type AISI Stainless Steel 420 (S42000)
- Aluminum 7075 T6

Grey Cast Iron

It contains 2% carbon dissolved in Fe matrix. It is most widely used material for disc brake rotor application due to its low cast, easy manufacturing and high temperature stability [3].

Titanium Grade 5

These are light weight Ti alloys used for disc brake rotor. Commercially it is known by Ti-6Al-4V alloy. In comparison with traditional cast iron material, it offers about 37% weight reduction for the disc brake rotor with same dimensions. Along with this material also offers better corrosion and high temperature strength.

Stainless Steel 420

This is Martensitic stainless steel material used for disc brake rotor which shows moderate ductility and electrical conductivity among other candidate materials.

Aluminum 7075 T6

It is a 7000-series aluminum alloy with Zn as a main alloying addition and it is solution heat treated and artificially aged to get T6 temper [3, 10, 11].

Material Selection by Mechanical and thermal Properties

Hardness, Brittleness, ductility, toughness, yield strength and ultimate tensile strength are the important mechanical properties which affect the performance of disc brake rotor. These properties were evaluated for the said materials and then materials are ranked from 1-4, 1 being best candidate material and 4 being worst candidate material. Similarly, The ratio of the strength (usually the tensile or compressive strength) of an object to its weight, or that of a substance to its density was also measured it was observed that Higher the strength to weight ratio points, better is the material for the application of brakes and ranking is done accordingly [3, 10, 11].

Materials	***Tensile strength: Ultimate (Mpa)***	***Tensile strength: Yield (Mpa)***	***Density (Kg/m^3)***	***Ranking***
Grey cast iron	260	180	7500	4
Titanium grade 5	1000	910	4400	1
Stainless steel 420	640	380	7700	3
Aluminum 7075T6	560	480	3000	2

Materials	***Strength to weight: bending***	***Strength to weight: axial***	***Ranking***
Grey cast iron	12 points	13 points	4
Titanium grade 5	50 points	62 points	1
Stainless steel 420	22 points	25 points	3
Aluminum 7075T6	50 points	51 points	2

Table 1: Mechanical Properties [4-7].

Thermal properties such as heat capacity and thermal conductivity are also greatly affects the performance of disc brake rotor since during brake application large amount of heat is generated which is need to be dissipated properly. In brakes application, rotor with less thermal conductivity will be better in performance as the material will conduct less heat which will help the rotor to keep its temperature as low as possible. Based on the measured thermal properties, the candidate materials are ranked 1 to 4, 1 being best and 4 being the worst candidate [4-7].

Materials	***Specific heat capacity (J/KgK)***	***Thermal conductivity(W/mK)***	***Ranking***
Grey cast iron	490	46	3
Titanium grade 5	560	6.8	1
Stainless steel 420	480	27	2
Aluminum 7075T6	870	130	4

Table 2: Thermal Properties [4-7].

Material Selection by Finite Element Analysis (Static Structural Analysis)

In this work, initially we have developed the CAD model according to the required geometry for all the candidate materials using Solid Works 2017 software (Fig.4.) and then 3mm Tetrahedron Mesh is done on the generated model (Fig.5). Here, meshing is the process of dividing the whole component into a number of elements so that whenever the load is applied on the component it distributes the load uniformly. Without meshing the load distribution is not uniform and you may get the irregular or faulty results.

Static Structural analysis is basically FEA solver which is used to check the stress generated, factor of safety, total deformation, creep, etc in many engineering components that are to be analyzed. In this work, we have conducted Static Structural Analysis for all potential candidate materials to check Factor of Safety and deformation by inputting the parameters as calculated below. All these analysis works is conducted by using ANSYS workbench 18.1 and all the results are reported below.

Braking calculations, values and consideration [7]

Considerations :	Now,
Max driver force on pedal = 24 kg	$F_{caliper} = P_{mc} \times A_{caliper}$
= 24 X 9.81	$= 9.293 \times 10^{6} \times 506.707 \times 10^{-6}$
= 235.44 N	$F_{caliper}$ = 4.7088 KN
Pedal ratio = 5:1	*Since it is a two-piston caliper is used*
Mass of the kart with driver =180 kg μ_{rotor}& pad=0.5	Fcaliper = 4.7088 x 2 **Fcaliper**
	= 9.4177 KN
Calculation :	Total frictional force = $F_{caliper} \times \mu_{rotor}$
For master cylinder (piston Φ=12.7 mm):	$= 9.4177 \times 10^{3} \times 0.5$
F_{mc}= 235.44 x 5 = 1177.2 N	= 4.7088 KN
Area of Master Cylinder piston = $0.785 * 12.7^{2}$	Disc effective radius =
$A_{mc} = 126.677\ m^{2}$	(D= 200mm, d=138mm)
Pressure in master cylinder	Disc effective radius = R_e= 84.5mm
P_{mc} = 9.293 Mpa	Torque on Rotor = $F_{frictional} \times R_e$
	$= 4.7088 \times 10^{3} \times 84.5 \times 10^{3}$
For caliper (piston Φ=25.4 mm): -	**Torque on Rotor = 397.89 Nm**
$P_{caliper} = P_{mc}$ [Pascal's law]	Tyre Diameter (Rear) = 11 inches = 0.2794m
$A_{caliper}=0.785 *(25.4*10^{-5})^{2}$	Rear Tyre radius = 0.1397m
Acaliper=506.707 x 10-$_{6}$ m2	Force on rear tyre = 2848.175 N **Deceleration(a)= 15.82 m/s^{2}**

	Stopping distance(Sd)	
V = 40 Kmph = $11.11 ms^{-1}$ $\therefore Sd = \frac{11.11 X 11.11}{2 X 15.82}$ $V^2-u^2 = 2aS_d$, where, V= 0 Kmph Sd = 3.9 m	V = 60 Kmph = $16.67\ ms^{-1}$ $\therefore Sd = \frac{16.67 X 16.67}{2 X 15.82}$ Sd = 8.73 m	V = 80 Kmph = $22.22\ ms^{-1}$ $\therefore Sd = \frac{22.227 X 22.22}{2 X 15.82}$ Sd = 15.6m

	Stopping time (t)	
U = 11.11 ms^{-1} a = -15.82 ms^{-2} ∴ v = u + a Xt	U = 16.67 ms^{-1} a = -15.82 ms^{-2} ∴ v = u + a X t	U = 22.22 ms^{-1} a = -15.82 ms^{-2} ∴ v = u + a X t
$t = \frac{-u}{a} = \frac{-11.11}{-15.82}$ t = 0.7 sec	$t = \frac{-u}{a} = \frac{-16.67}{-15.82}$ t = 1.054 sec	$t = \frac{-u}{a} = \frac{-22.22}{-15.82}$ t = 1.405 sec

Result of Static Structural Analysis

Grey cast Iron

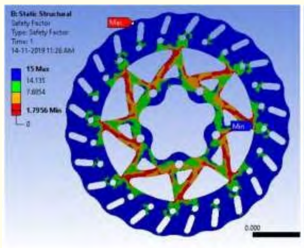

Figure 6: Factor of safety.

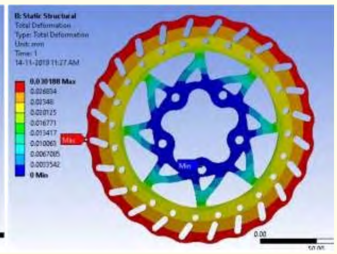

Figure 7: Total deformation.

Grade 5 (Ti-6Al-4V, 3.7165, R56400) Titanium

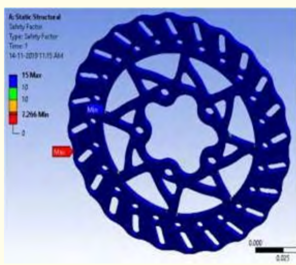

Figure 8: Factor of safety.

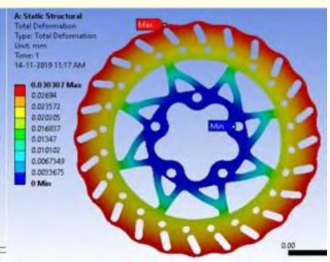

Figure 9: Total deformation.

AISI Stainless Steel 420 (S42000)

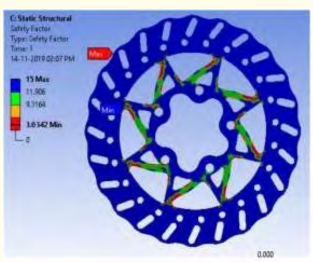

Figure 10: Factor of safety.

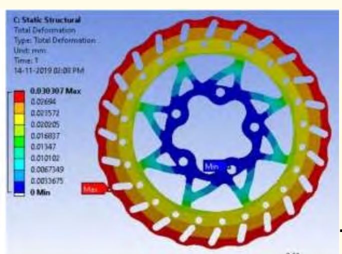

Figure 11: Total deformation.

Aluminum 7075 T6

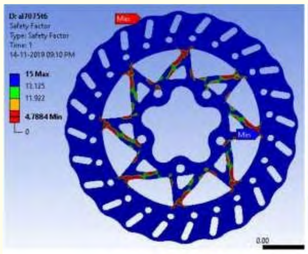

Figure 12: Factor of safety.

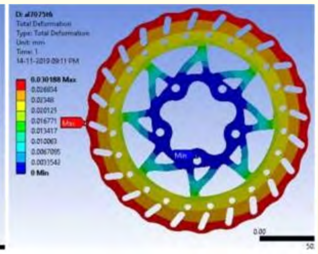

Figure 13: Total deformation.

Result table of FEA [8]

Ranking is done considering the value of factor of safety.

Materials	*Factor of safety*	*Deformation (mm)*	*Ranking*
Grey cast iron	1.7956	0.03016	4
Titanium grade 5	7.266	0.03031	1
Stainless steel 420	3.0342	0.03012	3
Aluminum 7075T6	4.788	0.03037	2

Table 4: Result of finite element analysis.

Conclusion

The comprehensive result of mechanical properties, thermal properties and finite elements analysis for various materials used for disc brake rotor is given in Table 5. The purpose of this paper is to select the optimum material for the application of brake disc system emphasizing on the replacing cast iron by any other lightweight and better material.

Performance requirements of the selected materials were analyzed and alternative solutions were evaluated among cast iron, aluminums 7075 T6, titanium grade 5 alloy, and stainless steel 420. Mechanical properties, thermal properties, FEA (finite element analysis), were used as the key parameters in the material selection stages. The analysis led to Titanium Grade 5 material as the most appropriate material to replace Grey Cast Iron for brake disc system for a 150cc racing go kart having single hydraulic disc brake system with the top speed of 110.

Material	*Mass of Rotor*	*Mechanical*	*Thermal*	*Strength to weight*	*F.E. A*	*Final Selected*
Grey Cast Iron	558.42 grams (3)	4	3	4	4	
Titanium Grade 5	343.49 grams (2)	1	1	1	1	
Stainless Steel 420	597.20 grams (4)	3	2	3	3	
Aluminum 7075 T6	217.94 grams (1)	2	4	2	2	

Table 5: Conclusion.

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Volume 1 Issue 3 December 2021