Selection of Materials for Manufacturing of Disc Brake Rotor for a Racing Go-Kart Having Single Hydraulic Disc Brake System

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Abstract Disc brake or rotor is a common device used in a racing go-kart with single hydraulic brake system for slowing down or stopping the motion of wheel running at a certain speed. In this paper, an extensive study was carried out to develop material selection methods for disc brake rotor. Materials, namely grey cast iron, stainless steel 420, aluminium 7075 T6 and titanium grade 5 alloys, were studied for general performance requirement, thermal and mechanical properties and static structural analysis (FEA). The results obtained were used to identify the promising material among the candidate materials for disc brake rotor.

Keywords Racing go-kart · Disc brake rotor · Grey cast iron · Aluminium · Titanium · Stainless steel · Material selection · Mechanical · Thermal · FEA

1 Introduction

In motorsports industries, to attain better performance, the reduction in vehicle weight is very important irrespective of its component size. In the recent years, the automobile industry has rapidly increased the use of aluminium, carbon fibre and titanium for manufacturing light vehicles. These materials have less weight and higher thermal conductivity as compared to the traditional grey cast irons and 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.

Since disc brake or rotor is one of the most important and stressed components 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, which need to be considered

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while 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 needed 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. In this work, certain methods were developed to select the best candidate material for manufacturing of brake rotor for a racing go-kart. All the materials were studied and analysed according to the developed methods and ranked accordingly.

2 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 involved in the selection of material are shown in Fig. 1.

2.1 General Material Performance Requirement

A schematic view of the brake rotor system is shown in Fig. 2. 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

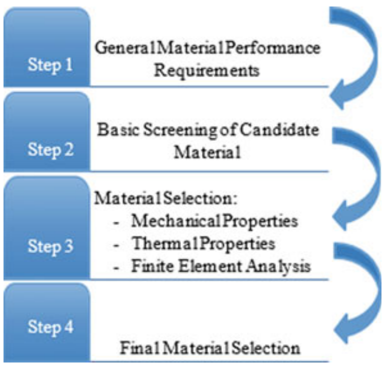

Fig. 1 Stages in material selection

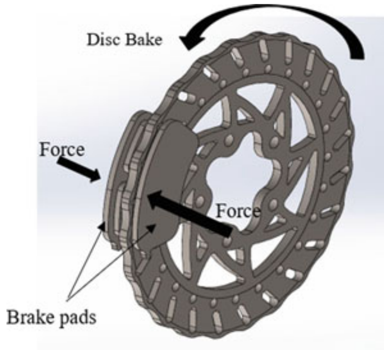

Fig. 2 Schematic representation of disc brake rotor

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 $F_{\text{rotor}} = 2 \cdot Cf_{\text{pad}}\, F_{\text{pad}}$, where Cf_{pad} is coefficient of friction for the pad material and F_{pad} 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, lightweight, better thermal properties, and should be economically viable [1, 2].

2.2 *Initial Screening of the Candidate Material*

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

- Grey cast iron
- Titanium grade 5 (*Ti-6Al-4 V, 3.7165, R56400*)
- Martensitic-type AISI stainless steel 420 (*S42000*)
- Aluminium 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. But it consumes much fuel due to its high specific gravity. Also it is heavy due to high density which in turn affects the performance of the racing go-kart [3].

Titanium Grade 5: These are lightweight Ti alloys used for disc brake rotor. Commercially, it is known by Ti-6Al-4 V 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.

Aluminium 7075 T6: It is a 7000-series aluminium alloy with Zn as a main alloying addition, and it is solution heat treated and artificially aged to get T6 temper [3–5].

2.3 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 were ranked from 1 to 4, 1 being the best candidate material and 4 being the 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 was done accordingly [3–5].

Thermal properties such as heat capacity and thermal conductivity are also greatly affecting the performance of disc brake rotor since during brake application large amount of heat is generated, which is need to be dissipated properly. In brake application, rotor with less thermal conductivity gives better performance as it conducts less heat and also helps the rotor to keep its temperature as low as possible. In this work, the specific heat capacity and thermal conductivity values for all the alternative materials were obtained based on the observed values. The candidate materials were ranked 1 to 4, 1 being the best and 4 being the worst candidate [6–9].

2.4 Material Selection by Finite Element Analysis (Static Structural Analysis)

In this work, first CAD model was developed according to the required geometry for all the candidate materials using SOLIDWORKS 2017 software as shown in Fig. 3, and then, 3 mm tetrahedron mesh was done on the generated model as shown in Fig. 4.

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 analysed. In this work, static structural analysis for all potential candidate materials were conducted to check factor of safety and total deformation by inputting the parameters as calculated below. All this analysis work was conducted by using ANSYS Workbench 18.1.

Braking calculations, values and consideration [10].

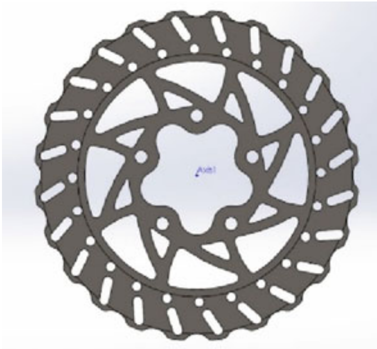

Fig. 3 Geometrical model of disc brake rotor

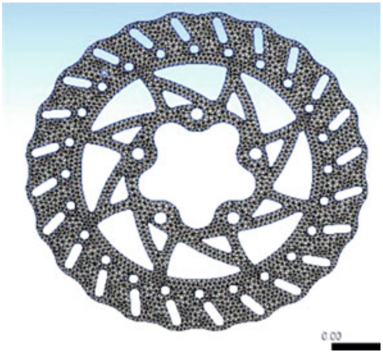

Fig. 4 3mm tetrahedron meshing done on rotor

Considerations	$P_{mc} = 9.293$ Mpa *For caliper (piston $\Phi = 25.4$ mm)* $P_{caliper} = P_{mc}$ [Pascal's law] $A_{caliper} = 0.785 \times (25.4 \times 10^{-5})^2$ $A_{caliper} = 506.707 \times 10^{-6}\ m^2$
Max driver force on pedal $= 24$ kg $= 24 \times 9.81$ $= 235.44$ N Pedal ratio = 5:1 Mass of the kart with driver = 180 kg μ_{rotor} & pad = 0.5	
Calculation *For master cylinder (piston $\Phi = 12.7$ mm)* $F_{mc} = 235.44 \times 5$ $= 1177.2$ N	Now $F_{caliper} = P_{mc} \times A_{caliper}$ $= 9.293 \times 10^6 \times 506.707 \times 10^{-6}$ $F_{caliper} = 4.7088$ KN
Area of master cylinder piston	*Since it is a two-piston caliper used*
$= 0.785 \times 12.7^2$ $A_{mc} = 126.677\ m^2$	$F_{caliper} = 4.7088 \times 2$ $F_{caliper} = 9.4177$ KN
Pressure in master cylinder	

(continued)

(continued)

Total frictional force	Torque on rotor = $F_{\text{frictional}} \times R_e$
$= F_{\text{caliper}} \times \mu_{\text{rotor}}$ $= 9.4177 \times 10^3 \times 0.5$ $= 4.7088$ KN	$=4.7088 \times 10^3 \times 84.5 \times 10^3$
	Torque on rotor = 397.89 Nm
	Tyre diameter (rear) = 11 in = 0.2794 m
Disc effective radius=	Rear tyre radius = 0.1397 m
(D = 200 mm, d = 138 mm)	Force on rear tyre = 2848.175 N
Disc effective radius = R_e = 84.5 mm	Deceleration (a) = 15.82 m/s^2
Now	

Stopping distance (Sd)		
V = 40 Kmph = 11.11 ms^{-1}	V = 60 Kmph = 16.67 ms^{-1}	V = 80 Kmph = 22.22 ms^{-1}
$V^2 – u^2 = 2aS_d$, where, $V = 0$ Kmph $S_d = \frac{11.11 \times 11.11}{2 \times 15.82}$ $S_d = 3.9$ m	$S_d = \frac{16.67 \times 16.67}{2 \times 15.82}$ $S_d = 8.73$ m	$S_d = \frac{22.227 \times 22.227}{2 \times 15.82}$ $S_d = 15.6$ m
Stopping time (t)		
$U = 11.11$ ms^{-1} $a = -15.82$ ms^{-2} $\therefore v = u + a \times t$	$U = 16.67$ ms^{-1} $a = -15.82$ ms^{-2} $\therefore v = u + a \times t$	$U = 22.22$ ms^{-1} $a = -15.82$ ms^{-2} $\therefore v = u + a \times t$
$t = \frac{-u}{a} = \frac{-11.11}{-15.82}$ $t = 0.7$ s	$t = \frac{-u}{a} = \frac{-16.67}{-15.82}$ $t = 1.054$ s	$t = \frac{-u}{a} = \frac{-22.22}{-15.82}$ $t = 1.405$ s

3 Results and Discussion

The results obtained from the analysis of mechanical properties, such as tensile strength and strength-to-weight ratio both in bending and axial conditions for all the candidate materials, are reported in Table 1. Ranking of the materials is also shown in Table 1. Highest values of tensile strength and strength-to-weight ratio were observed for titanium grade 5 material. Hence, it has ranked 1.

Similarly, the results obtained for the specific heat capacity and thermal conductivity values for all the alternative material are reported in Table 2. Again better thermal properties, i.e. low thermal conductivity, were observed for titanium grade 5 material; hence, it has ranked 1.

Table 1 Mechanical properties

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
Aluminium 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
Aluminium 7075T6	50 points	51 points	2

Table 2 Thermal properties

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

The static structural analysis to measure factor of safety and total deformation was conducted for all the candidate materials as shown in Figs. 5, 6, 7, 8, 9, 10, 11 and 12. The measured values for factor of safety and total deformation are also reported in Table 3. The materials were ranked based on factor of safety. The highest factor of safety was recorded for titanium grade 5 material, and hence, it has ranked 1 [11].

The comprehensive result of mechanical properties, thermal properties and finite elements analysis for various materials used for disc brake rotor is given in Table 4. From the analysis of all the material selection stages, the titanium grade 5 material has ranked overall 1 and could be the best material for manufacturing disc brake rotor.

4 Conclusion

The material selection methods for manufacturing disc brake rotor were successfully developed in this study. In order to identify the best material, the mechanical

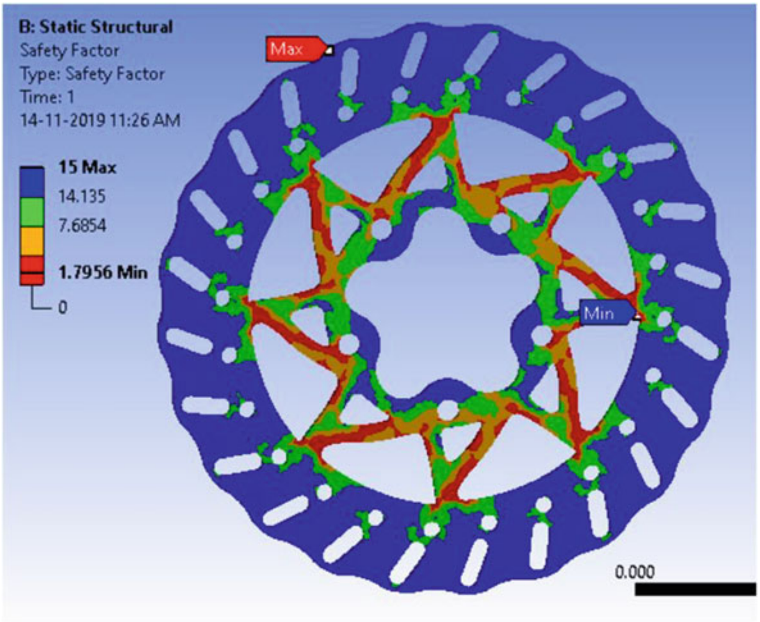

Fig. 5 Factor of safety for grey cast iron

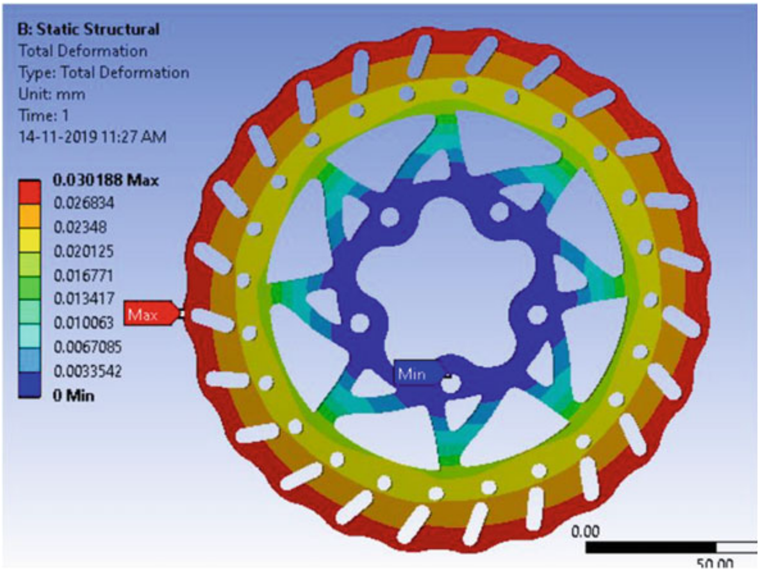

Fig. 6 Total deformation for grey cast iron

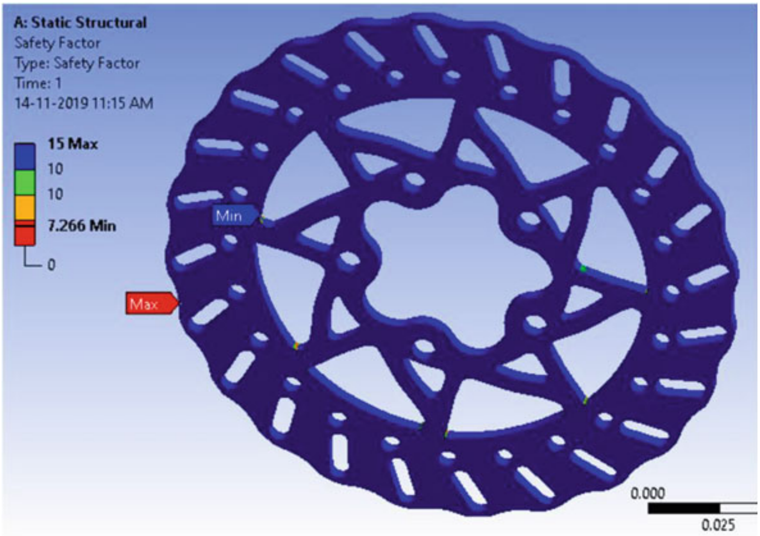

Fig. 7 Factor of safety for titanium grade 5

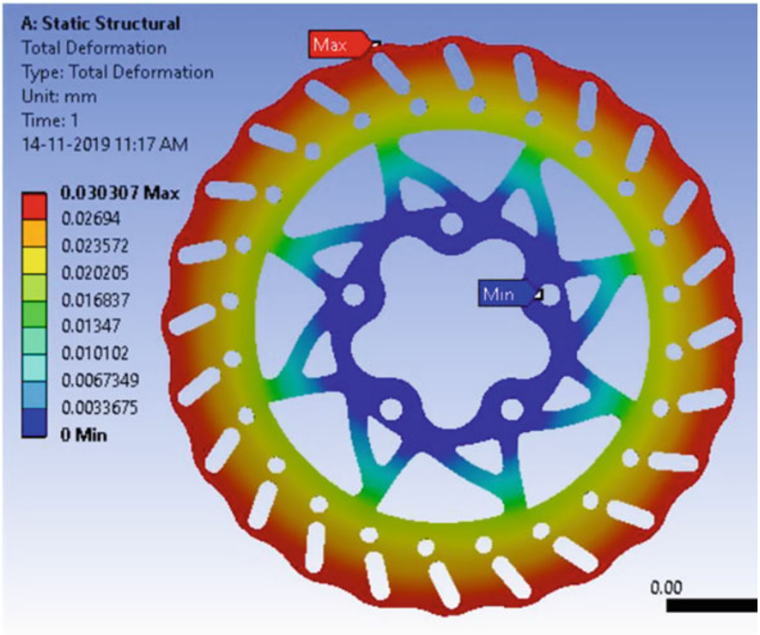

Fig. 8 Total deformation for titanium grade 5

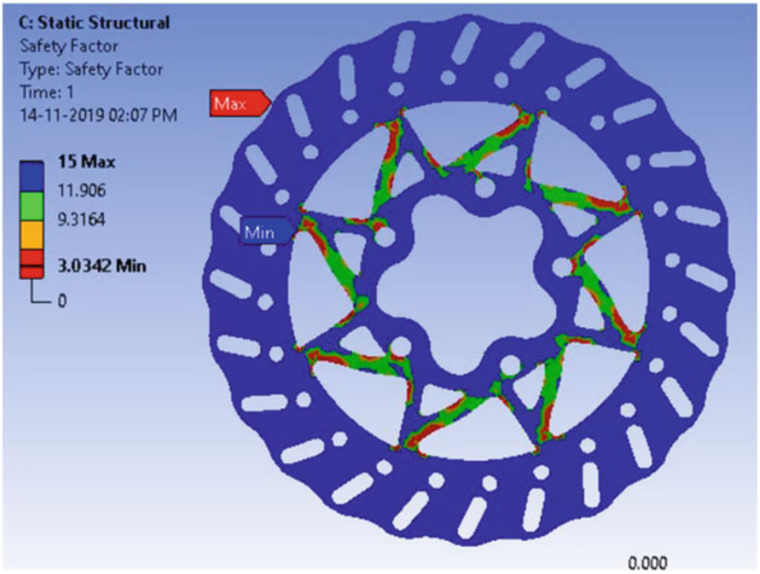

Fig. 9 Factor of safety stainless steel 420

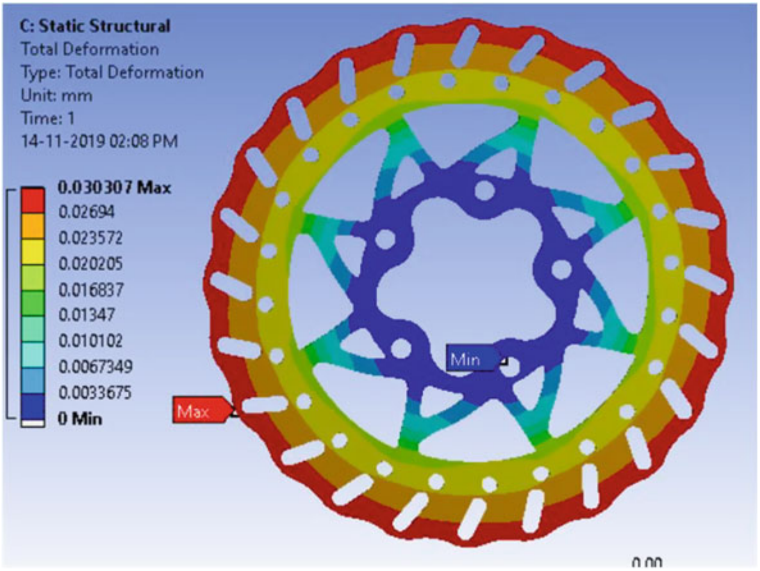

Fig. 10 Total deformation for stainless steel 420

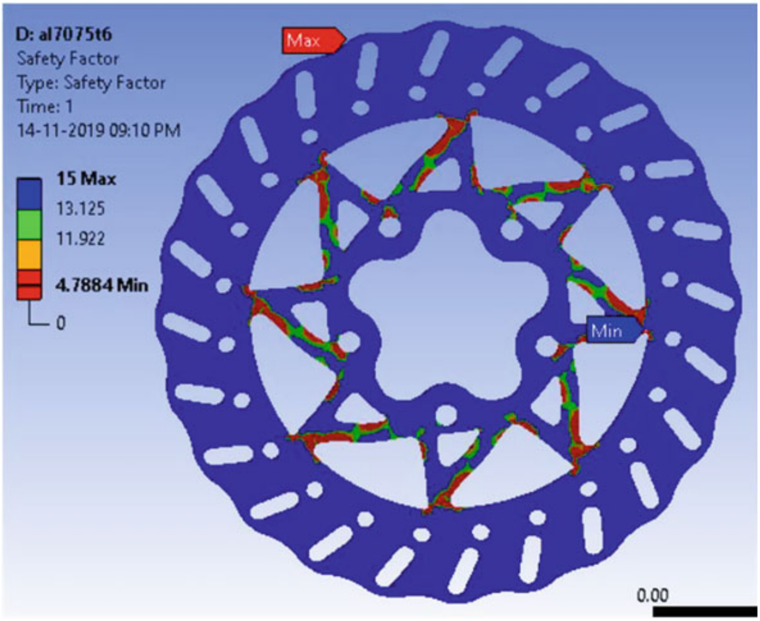

Fig. 11 Factor of safety for aluminium 7075T6

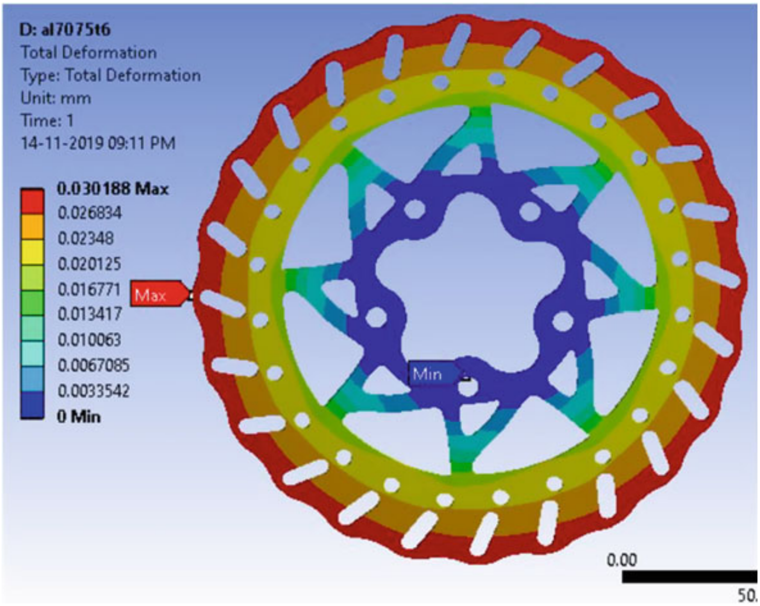

Fig. 12 Total deformation for aluminium 7075T6

Table 3 Result of finite element analysis

Materials	Factor of safety	Deformation (mm)	Ranking
Grey cast iron	1.7956	0.03016	4
Titanium grade 5	7.2660	0.03031	1
Stainless steel 420	3.0342	0.03012	3
Aluminium 7075T6	4.7880	0.03037	2

Table 4 Comprehensive result

Material	Mass of rotor (g)	Mechanical	Thermal	Strength to weight	FEA	Final selected
Grey cast iron	558.42 (3)	4	3	4	4	
Titanium grade 5	**343.49 (2)**	**1**	**1**	**1**	**1**	✓
Stainless steel 420	597.20 (4)	3	2	3	3	
Aluminium 7075 T6	217.94 (1)	2	4	2	2	

Significance of bold in this table is to show final material selected for manufacturing disc brake rotor. Bold helps in recognizing material easily

properties, such as tensile strength, strength-to-weight ratio, thermal properties like specific heat capacity and thermal conductivity values for all the candidate materials, i.e. grey cast iron, titanium grade 5, stainless steel 420 and aluminium 7075 T6, were obtained and compared. Also, the candidate materials were critically analysed by static structural analysis to check the factor of safety and total deformation. The results obtained indicated that among all the candidate materials studied, titanium grade 5 materials had high tensile strength of 910 Mpa, high strength-to-weight ratio, low thermal conductivity of 6.8 W/mK, maximum factor of safety of 7.26 and least total deformation of 0.03031 mm. Hence, it could be the most appropriate material for manufacturing disc brake rotor used for 150 cc racing kart having single hydraulic brake system with top speed of 110 kmph.

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