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Selection of material through 'Thermal-Stress' analysis on Fusion 360 for a brake rotor.

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ABSTRACT

The braking systems are used for reducing speed or halting the vehicle. The brake rotors experience high frictional forces causing their wear and tear; kinetic energy is converted into heat energy which increases the temperature of the rotor. If an appropriate amount of heat is not dissipated it can deteriorate the quality of the rotor. This paper aims to determine better material from the traditionally used Grey Cast Iron. Heat dissipation, deformation and safety factor are determined by the physical and thermal properties of the material. To select the best material, 'Thermal-Stress' analysis is performed on Fusion 360 as a brake rotor experiences not only high torque but also the high temperature at the same time. The results are conferred based on the various criteria discussed in the paper such as material properties, the temperature generated and FEA. The tests lead to Ti-6Al-4V (Ti Grade 5) as the best material.

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1. INTRODUCTION

A brake is a device used to stop the motion of the vehicle. It is one of the many crucial components of any vehicle [1]. Over the years, the braking system has seen tremendous growth with a common goal of increasing braking efficiency and safety factor. It converts the kinetic energy to thermal energy hence stopping or reducing the speed of the vehicle. Prolonged braking causes heat generation, which leads to less braking efficiency and, in extreme cases, causes brake failure. To avoid this, proper heat dissipation is necessary, and the brake design should be able to sustain the braking force on it. The material chosen for manufacturing the rotor plays a vital role here. Therefore, the materials used for manufacturing the brake disc should be reliable and should sustain all loads applied to it. The material properties should be adequate, should have a longer life span, and serve the purpose in all types of environment.

2. RESEARCH METHOD

The brake rotor reaches high temperature as frictional heat is generated on the interface of the disc and pads [2]. If the heat dissipation properties of the disc are not on par with the heat generated it could lead to several problems like brake fading, squealing, warping and cracking, rusting, poor stopping, noise, vibration, etc. Some of the primary defects are stated below.

2.1. Brake Fade

Brake fade is caused by overheating of the brake system and results in a temporary reduction or complete loss of brake power, and it is to be avoided [3]. As the heat doesn't have time to dissipate, this heat buildup at the brake pads and rotor's contact surfaces prevents the rotor from working correctly; the pads get heated up. The brake pad consists of resin; this resin gets heated up and forms gas, and with no way to escape, it creates a layer between the pad and disc, causing loss of frictional force and hence less braking power.

2.2. Warping

When the rotor's surface becomes uneven, it is termed as warping; heat is the leading cause of warping [4]. Generally, the rotor is harder than the pads, but the metal becomes soft enough for the pad to wear down the rotor surface with excessive heat. Therefore, the slightly less dense spot wears down faster and make the harder areas stick out, causing warping

2.3 Cracking

When the distribution of temperature on the disc in non-uniform, the disc expands non-uniformly, which creates stress along these regions, leading to crack formation and propagation, hence damaging the disc, it can be avoided by maximizing heat dissipation and making the temperature uniform.

3. SELECTION OF MATERIALS

The effectiveness of any component depends on the material chosen; the material selected should sustain the frictional forces and the wear and tear under various conditions like pressure, high temperature, and should have high durability [5]. This paper focuses on the following materials.

3.1 Grey Cast Iron (ASTM A48 Grade 30)

It has high compressive strength and high tensile strength, which can be increased by increasing the percentage of vanadium [6]. It offers resistance to deformation and has a low melting point of about 1140℃ - 1200℃.

Composition [7]:

1. Carbon: 3.10 to 3.40wt%
2. Silicon: 2.50 to 2.80wt%
3. Manganese: 0.50 to 0.70wt%
4. Iron: remainder

3.2 Ti-6Al-4V (Grade 5)

It has high strength, low weight ratio and outstanding corrosion resistance. It features good machinability and excellent mechanical properties [8].

Composition [9]:

1. Aluminium: 5.50 to 6.80wt%
2. Vanadium: 3.50 to 4.50wt%
3. Iron: 0.00 to 0.40wt%
4. Titanium: remainder

3.3 SS 440C

It is martensitic stainless steel with high strength, moderate corrosion resistance, and good hardness. It is heat resistant and also cost-effective [10].

Composition [11]:

1. Carbon: 1.00 to 1.20wt%
2. Silicon: 0.00 to 1.00wt%

3. Chromium: 16.00 to 18.00wt%

4. Iron: remainder

3.4 Some Common Mistakes

It is a medium to high strength heat-treatable alloy and it offers good corrosion resistance and machinability [12].

Composition [13]:

1. Silicon: 0.40 to 0.80wt%
2. Magnesium: 0.80 to 1.20wt%
3. Iron: 0 to 0.70wt%
4. Aluminium: remainder

Table 1. Material properties

Material Properties		Grey Cast Iron	Ti-6Al-4V	SS 440C	Al 6061
Mechanical Properties	Yield strength (Mpa)	213.7	882.5	689	275
	Ultimate Tensile strength (Mpa)	275.8	1034	861.3	310
	Poisson's ratio	0.253	0.35	0.27	0.33
	Young's modulus (Gpa)	101.5	113.8	206.7	68.9
	Density (kg/m^3)	7395	4430	7750	2700
Thermal Properties	Thermal Conductivity (W/mk)	48.04	6.7	24.23	167
	Specific Heat Capacity (J/kg-k)	450	526.3	460	897

4. MATERIAL SELECTION

The material selection method is very important for choosing the best material from several candidate materials.

4.1 Mechanical and Thermal Properties

Strength of a material is directly related to its mechanical properties. Ultimate strength and yield strength are two of the most important factors while considering the mechanical property of material along with density, Poisson's ratio and Young's modulus. The stress that a material can withstand can be described by its ultimate strength, whereas the yield strength describes the maximum amount of stress needed to deform the part elastically [18]. The higher the value, the better.

Thermal conductivity and specific heat capacity play an important role here as their values significantly affect the temperature and heat flux generated on the rotor. The lower the value of thermal conductivity (k), the lower value of heat generated, and hence the possibility of any problems reduces significantly

4.2 Temperature generated on the contact patch

The kinetic energy of the vehicle is converted into heat energy, different materials generate different temperature. If the temperature generated on the contact patch is low, the rotor will have a longer life span. The calculation and values are given in table 3.

4.3 FEA

The cad model was developed in Fusion 360 and also the analysis was performed in fusion 360. The calculations of the rotor are done considering a single hydraulic braking system. Mesh size of the model is 3mm.

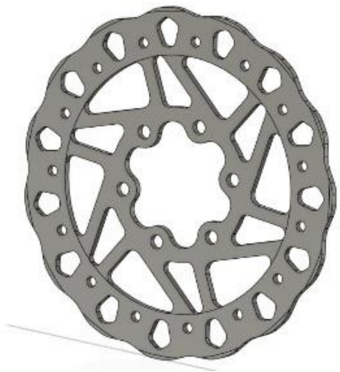

Figure 1. CAD Model of Brake Rotor

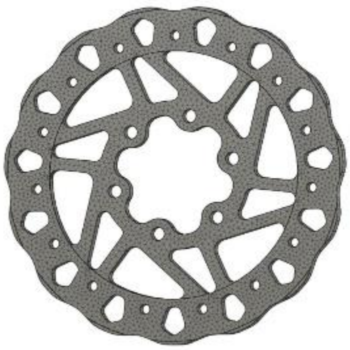

Figure 2. Meshing of Brake Rotor

- Input Data:

Table 2. Input data

Terms	Values
Outer disc diameter	197 mm
Inner disc diameter	147 mm
Effective disc diameter {(Outer disc dia + Inner disc dia)/4}	86 mm
Thickness of rotor	4 mm
Piston diameter	25.4 mm
Type of caliper	2 piston, floating type caliper
Mass of vehicle with driver	180 Kg
Area of contact patch	27 m^2
Torque	404.96 Nm
Velocity	40kmph (11.11m/s)

- Calculations for Heat transfer:

Kinetic Energy (KE) =1/2 mv^2

Now ‘q = KE’ and ‘q = $m*C_p*(T_f-T_i)$

Where, m= mass of the contact patch of the rotor.

T_i = Ambient temperature = 25 °C

T_f = Final temperature generated on the contact patch.

The kinetic energy generated is same for all the materials, KE = 11109 J

T_f will vary with the mass of the contact patch for each material, the values are:

Table 3. Temperature on contact surface

Temperature on contact surface	**Grey Cast Iron**	**Ti-6Al-4V**	**SS 440C**	**Al-6061**
Mass of contact patch (g)	305.169	182.805	319.806	111.416
T_f (°C)	61	85	59.56	99.211

5. MODELLING IN FUSION 360

The analysis that will be done in this paper is-

- Thermal- Stress Analysis: It determines the effect of heat and loads applied to the brake rotor at a constant temperature and a fixed load. The analysis is done considering real-life scenarios as multiple physics acts at the same time. The results help us determine if the rotor can sustain the load applied to it at a temperature higher than ambient [19].
- Torque applied - At the contact patch
- Maximum temperature generated – At the contact patch
- Fixed Point – At the bolting point.
- Mesh size – 3mm

5.1 Grey Cast Iron

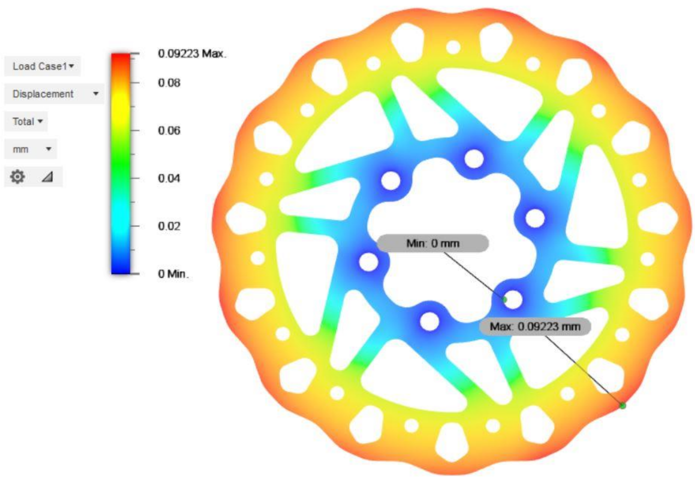

Figure 3. Deformation of Grey Cast Iron

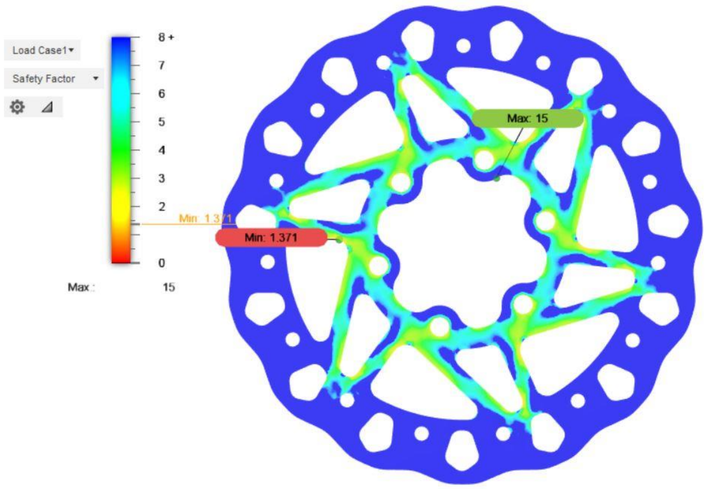

Figure 4. Factor of Safety of Grey Cast Iron

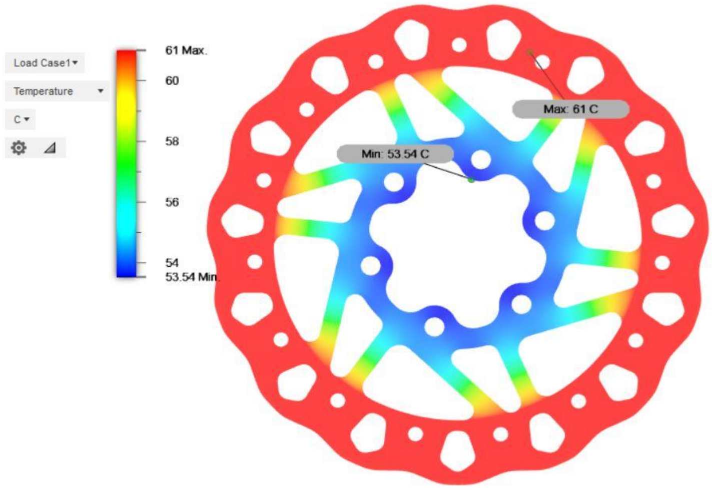

Figure 5. Temperature of Grey Cast Iron

5.2 Ti-6Al-4V

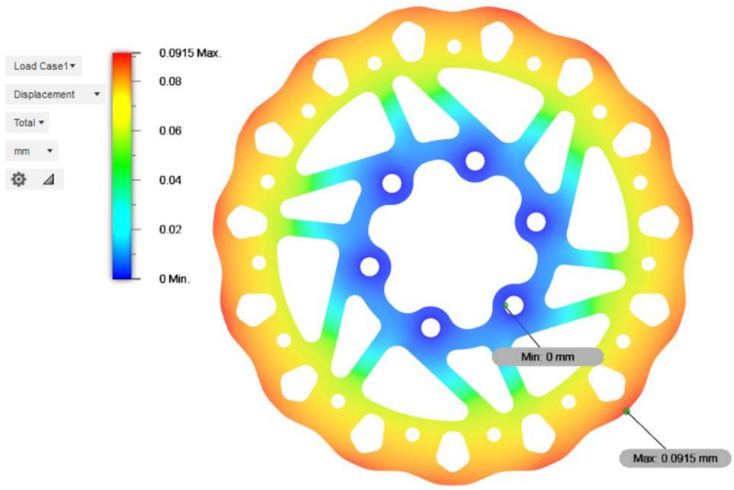

Figure 6. Deformation of Ti-6Al-4V

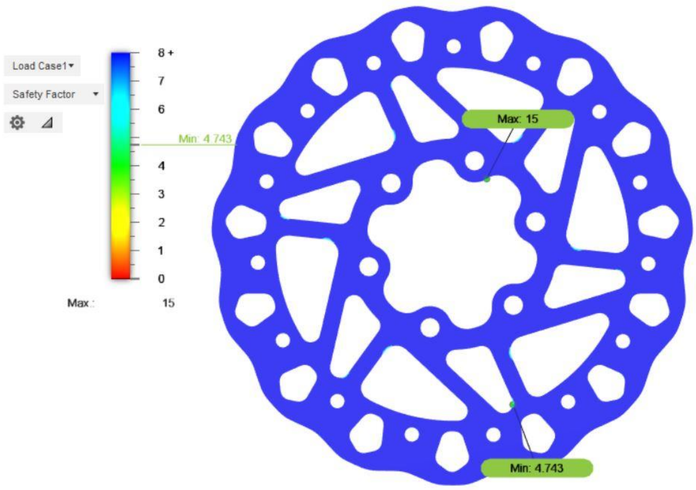

Figure 7. Factor of Safety of Ti-6Al-4V

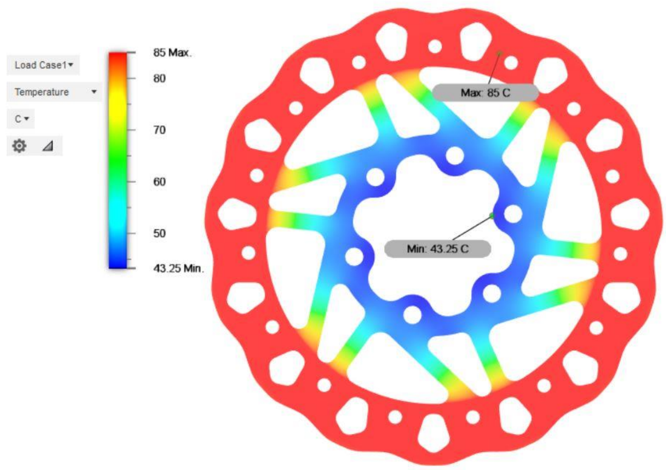

Figure 8. Temperature of Ti-6Al-4V

5.3 SS 440C

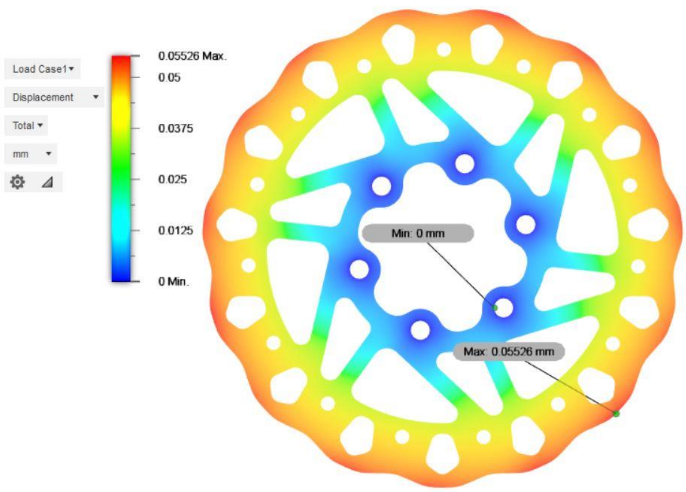

Figure 9. Deformation of SS 440C

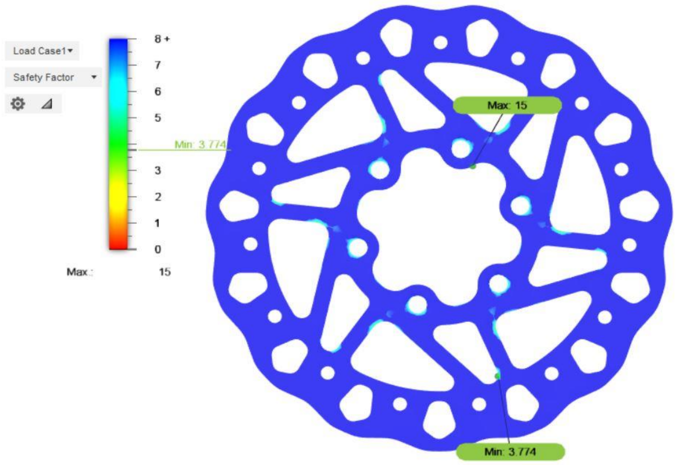

Figure 10. Factor of Safety of SS 440C

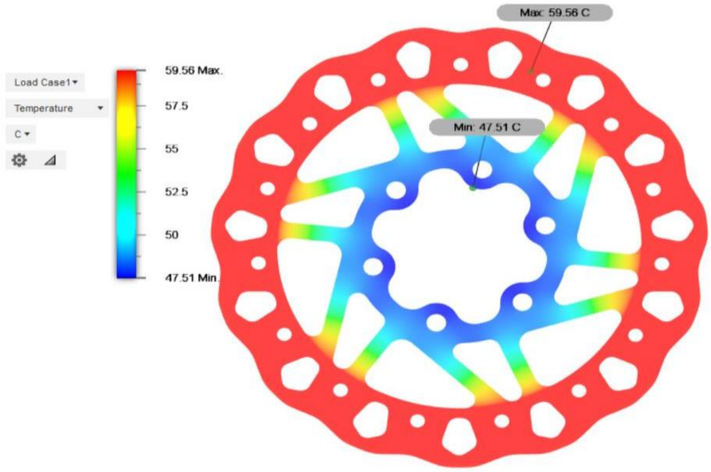

Figure 11. Temperature of SS 440C

5.4 Al 6061

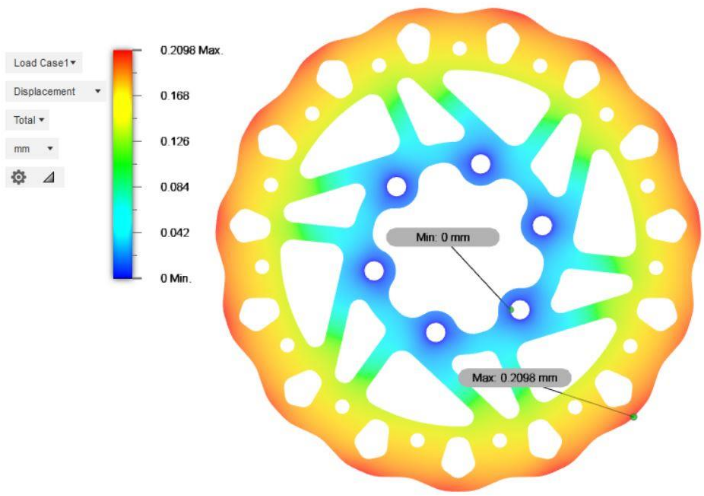

Figure 12. Deformation of Al 6061

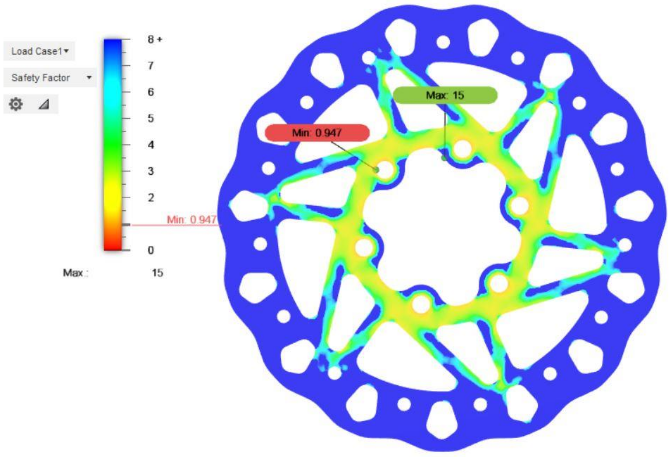

Figure 13. Factor of Safety of Al 6061

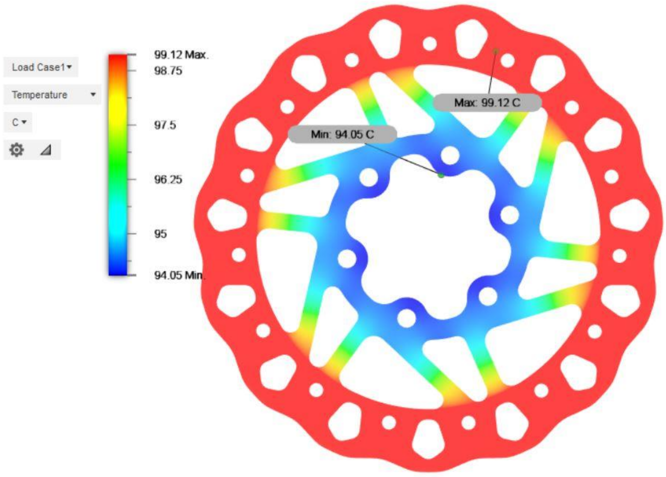

Figure 14. Temperature of Al 6061

Summary of FEA:

Table 4. Summary of FEA

Summary of FEA	Deformation (mm)	Factor of Safety
Grey Cast Iron	0.09233	1.310
Ti-6Al-4V	0.09150	4.743
SS 440C	0.05526	3.774
Al 6061	0.29080	0.947

6. MODELLING IN FUSION 360

- From ‘Table 1’: After comparing the ‘Yield Strength’ and ‘Tensile Strength’ of the sample materials we adjudge that the Ti-6Al-4V has the advantageous numbers i.e highest yield and tensile strength.
- From ‘Table 1’: After comparing the ‘Thermal Conductivity’ of the sample materials we adjudge that Ti-6Al-4V has the best thermal conductivity, i.e low thermal conductivity.
- From ‘Table 1’: After comparing the ‘Density’ of the sample materials we adjudge that Ti-6Al-4V has the best density i.e lowest density i.e lowest mass.

- From ‘Table 2’: After comparing the ‘Temperature on the contact patch’ we adjudge that SS440C has the best temperature i.e lowest temperature. Here we note that Ti-6Al-4V has the 3rd highest temperature out of the four samples.
- From ‘Table 4’: After comparing the ‘Deformation and Factor of Safety’ we adjudge that Ti-6Al-4V has the advantageous numbers i.e it has lowest deformation and highest factor of safety.

The above discussion is summarized in the table below. The materials are rated from 1 to 4 on the basis of different comparison made; 1 being the best while 4 being the worst.

Table 5. Results

Results	Mechanical properties	Thermal properties	Temperature generated	FEA
Grey Cast Iron	4	3	2	3
Ti-6Al-4V	1	1	3	1
SS 440C	2	2	1	2
Al 6061	3	4	4	4

7. CONCLUSION

- From ‘Table 5’ we decipher said that Ti-6Al-4V has best results in 3 out of 4 test. However, Ti-6Al-4V can sustain the temperature generated at its surface and low thermal conductivity allows faster cooling. Therefore, the best material for rotor manufacturing is Ti-6Al-4V.
- This paper has selected the best material for the brake rotor by analyzing the material properties. We have also done FEA for better results. The material selection is a crucial stage before the manufacturing of any components, and we were successful in choosing a material that suits the braking mechanism in all conditions.

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