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Static and Thermal Analysis of Disc Brake

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Abstract: Disc brakes have been failing for quite a lot of times during extreme conditions of braking which eventually brings down the efficiency and performance of the dis rotor. This can be due to excess temperatures acting at one place of the disc which deforms the disc.The material used in these disc brakes are not very rigid so the vehicles are prone to accidents. Thus the main aim of this paper is to mitigate the failure by using a material which will overcome the negatives of all the current materials used in a disc brake. Static analysis is done on the disc rotor to validate the ductility and a thermal analysis is done to determine the heat flux acting on the disc. The temperature distribution around the disc rotor is also analysed. Three existing materials that is Stainless Steel, Cast Iron and Carbon-Carbon Composite is being compared with Vanadium Steel to check for the maximum deformation, stress and temperature. The disc brake is modelled using Creo Parametric 3.0 and the analysis is done in ANSYS Workbench 15.0. By finishing the analysis, it is proved that VanadiumSteel has better strength and temperature distribution factors than the other three materials.

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I. INTRODUCTION

As the level of technology of human transportation has increased, the mechanical devices used to slow down and stop the vehicles has also become more complex. Before there was horse-less carriage, wagons and other vehicles which relied on the animal's power for accelerating as well as decelerating the vehicle. Eventually there was the development of supplemental braking systems consisting of a hand lever to push a wooden friction pad directly against the metal thread of the wheels. In wet conditions, these crude brakes would lose any effectiveness.

It was in the year 1902 the disc brake was designed in England and incorporated into the Lanchester car produced between 1906 through 1914. These early disc brakes were not as effective at stopping as the contemporary drum brakes of that time. After the World War II, technological progress began to arrive in the 1950s, leading to a critical demonstration of superiority, a 24 hour of Le Mans race, which required braking from high speeds several times per lap. Compared to drum brakes, disc brakes offer better stopping performance because the disc is more readily cooled. As a consequence, discs are less prone to the brake fade caused when brake components overheat. Disc brakes also recover more quickly from immersion.

A disc brake works on the principle of Pascals's Law/Principle of Transmission of fluid pressure. This law states that "the pressure exerted anywhere in a confined incompressible fluid is transmitted equally in all directions throughout the fluid such that the pressure ratio remains same." Thus the working is very simple. When the brake lever or pedal is pressed, the push rod which is connected to the lever or pedal moves and pushes the piston of the cylinder. This movement allows the master cylinder piston to slide and push the return spring inside the bore of

the cylinder, which generates the pressure in the reservoir tank. Here, a primary seal allows the brake fluid of reservoir tank to flow over it into the brake hosepipes. A secondary seal ensures that brake fluid does not go on the other side. Then the fluid enters into the cylinder bore of caliper assembly via brake hosepipes and pushes the caliper pistons. Then the caliper piston pushes the brake pad. This movement causes the brake pads to stick with disc brake which creates friction and stops the disc rotor to rotate. When the brake lever or pedal is released the piston ring pushes the caliper piston back to cylinder bore of caliper till both, caliper piston and piston ring comeinto their original shape. At this time retraction spring pushes the brake pads to their original position. The return spring in master cylinder assembly pushes the master cylinder piston back into its original position and allows the fluid to flow back to reservoir via hosepipe and master cylinder bore.

Knowing the failures faced in the disc brake, a deep study was made on the existing materials and it's staticand thermal analysis during forced braking. [1] In this journal, a comparison was done on three different materials namely Stainless Steel, Cast Iron and Carbon-Carbon Composite to check the strength and it's temperature distribution. This proved that Carbon-Carbon Composite increases the performance of the disc brake. [2] The main aim of this journal is to increase the efficiency of the disc rotor by reducing the vibration, cracking, rusting, etc.., using the existing material. [3] This project covers the important aspects of the brake disc with the emphasis on material selection methods, structural and thermal analysis, FEA and optimisation of the disc in order to relate the values. [4] The thermal behaviour of the ventilated disc brake was analysed using Titanium Alloy (Ti 550) to prove that Titanium is the suitable material for disc brake. [5] An investigation was done on the effect of strength variations on the predicted stress distributions by using Cast Iron, Aluminium Metal Matrix Composite and high strength glass fibre composite materials. The stress was distributed equally when the disc was made of glass fibre composite material. [6] During the braking phase, the frictional generated at the interface of the discand pads can lead to high temperatures. Thus the surface temperature is predicted for the brake rotor. [7] In this journal, Carbon Ceramic Matrix is used as the disc material to calculate the different forces acting on it. Thermal and Modal Analysis was done to calculate the deflection and heat flux. [8] The author has examined the deformation and the Von Mises stress established in the disc for both solid and ventilated disc using two different materials along with thermal analysis to enhance the performance of the rotor disc. [9] Based on the relationship obtained between rotor weight, thickness, undercut effect and offset between hat and friction ring, the criteria for designing the disc rotor has been established in a vehicle. [10] The final temperature and the total heat flux dissipated by using different materials like Aluminium Alloy, Cast Iron and Stainless Steel was compared. [11] The rise in temperature and it's durability during the time of braking was studied and analysis is done. The result obtained was used for calculating the rotor rigidity and maximum temperature rise.

II. INTRODUCTION TO CREO PARAMETRIC 3.0

PTC Creo Parametric offers powerful, reliable, yet easy-to use modelling tools that accelerate the process design process. The software lets helps to design parts and assemblies, create manufacturing drawings, pre-form analysis, create renderings and animations, and optimize productivity across a full range of other mechanical design tasks. PTC Creo Parametric will help design higher quality-products faster and allow communicating more efficiently with manufacturing and your suppliers.

III. INTRODUCTION TO ANSYS WORKBENCH 15.0

The ANSYS Workbench environment is an intuitive up-front finite element analysis tool that is used in conjunction with CAD systems and/or Design Modeler. ANSYS Workbench is a software environment for performing structural, thermal, and electromagnetic analyses. The class focuses on geometry creation and optimization, attaching existing geometry, setting up the finite element model, solving, and reviewing results. The class will describe how to use the code as well as basic finite element simulation concepts and results interpretation.

IV. MATERIAL AND METHODS

The first step after designing the model of a component is to select the material with which the model has to be analysed and manufactured. Getting this selection right the first time by selecting the optimal combination of your design has enormous benefits to any engineering-based business. It leads to lower production costs, faster time-to-market, a reduction in the number of in-service failures, etc., But to realise these benefits, engineers have to deal with an extremely complex problem. There are literally like thousands of materials and no engineer can expect to know more than a small subset of this ever-growing body of information. So a detailed study is necessary before selecting a material.

Factors: When we talk about choosing materials for a component, various factors have to be taken into account. These factors can be broken down into the following areas.

1. Material Properties
2. Material Cost and Availability
3. Manufacturing Process
4. Environment

Selection Process: The material selection process generally involves four basic steps which has to be analysed before concluding the final material. They are

a. **Translation:** In this step, the design requirements are expressed as constraints and objectives. Basically, we must first know the function of the component and the work that component is going to do. In our project, the disc brake is going to withstand tensile load during braking. Next we must understand the main objective of selecting one particular material. Here Vanadium Steel has more strength and ductility due to which the deformation occurred is very small.

b. Screening: Screening is the process of eliminating the materials which cannot the prescribed job. This can be done using material bar charts plotting density in X-axis and Young's Modulus in the Y-axis. These two properties are evaluated and analysed. This way the sub materials are rejected. It is not a problem if there are two or more materials selected from the list.

c. Ranking: In this step, the two or more materials selected are ranked based on it's objective. The material which most meets the objective is selected as the main material and the other materials are kept as a substitute if in-case the material fails during manufacturing, the next material in the ranking is selected.

V. METHODOLOGY USED

Initially we decided the domain in which we are planning to work on based on the interest of the team members. So we finalised on automobiles. When a detailed study was done on the various aspects of automobiles, we realised that brake plays a vital role in this field because a considerable amount of accidents have been due to brake failure. Hence we decided to analyse the disc brakes used in in two-wheelers. A number of reputed and international journals were studied and we came to know that brakes also fail due to improper selection of materials. The brake material should have good ductility in order to withstand forced stresses and avoid major deformation. Using the material selection process, we researched a number of materials and it's properties to decide which material is suitable for the disc rotor. Also the disc material must be able to withstand considerable temperatures during extreme conditions. The specific heat and thermal conductivity of Vanadium Steel is less when compared to the current existing materials.This is how Vanadium Steel was selected because it has less density so the weight of the disc can be reduced considerably and coefficient of friction is less. After which the disc brake model was done using Creo and analysis was done using Ansys. Finally the report was generated where we received a positive result.

Table No 1: Properties of Vanadium Steel

Density (kg/m^3)	Young's Modulus (GPa)	Poissons Ratio	Thermal Conductivity (W/m-K)	Specific Heat (J/kg-K)	Coefficient of Friction
6100	125.5	0.36	31	489	0.25

MODEL OF DISC BRAKE

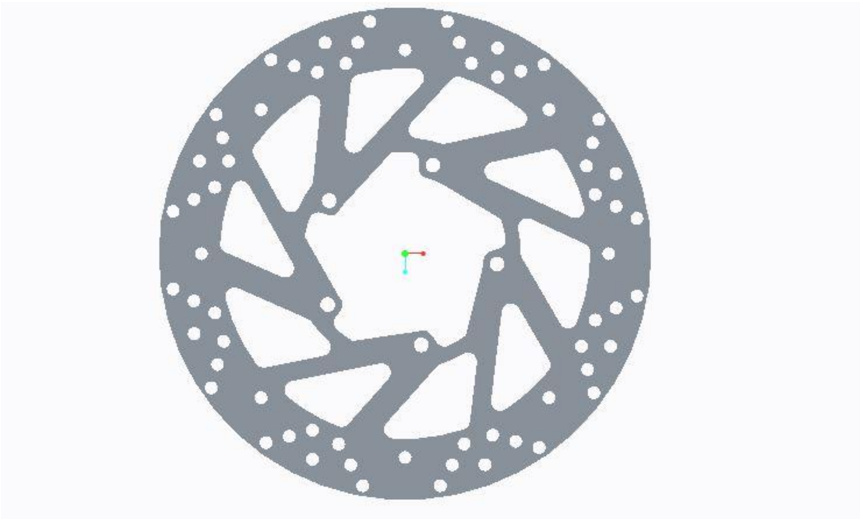


Fig.1 Top View of Disc

The two-dimensional solid with shape and dimensions is created in Creo. The disc diameter is 266mm and the thickness of the disc is 3mm.

PROPERTIES

Table no 2: Properties of Material

Properties	Stainless Steel	Cast Iron	Carbon-Carbon Composite	Vanadium steel
Density (kg/m^3)	7750	7100	1800	6100
Young's Modulus (GPa)	190	125	195	125.5
Poison's Ratio	0.3	0.25	0.31	0.36
Thermal Conductivity (w/m-k)	26	54.5	40	31
Specific Heat (J/kg-k)	500	586	755	489
Coefficient of friction	0.22	0.2	0.3	0.25

VI. RESULTS AND DISCUSSIONS OF DISC

1. STATIC

(a) Stainless Steel

Then the result of Total deformation, Normal Stress, Normal Elastic Strain of Stainless Steel after analysis was observed as,

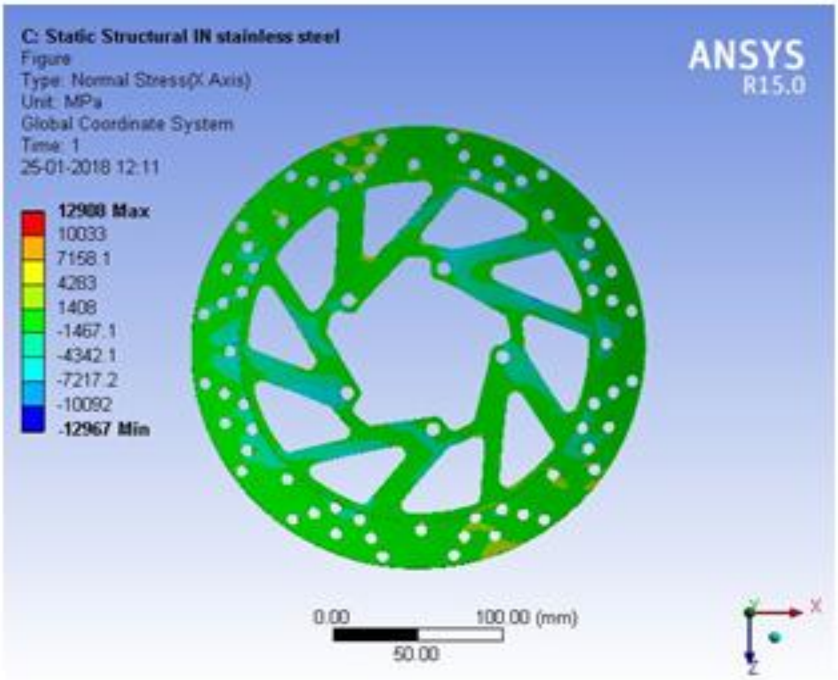
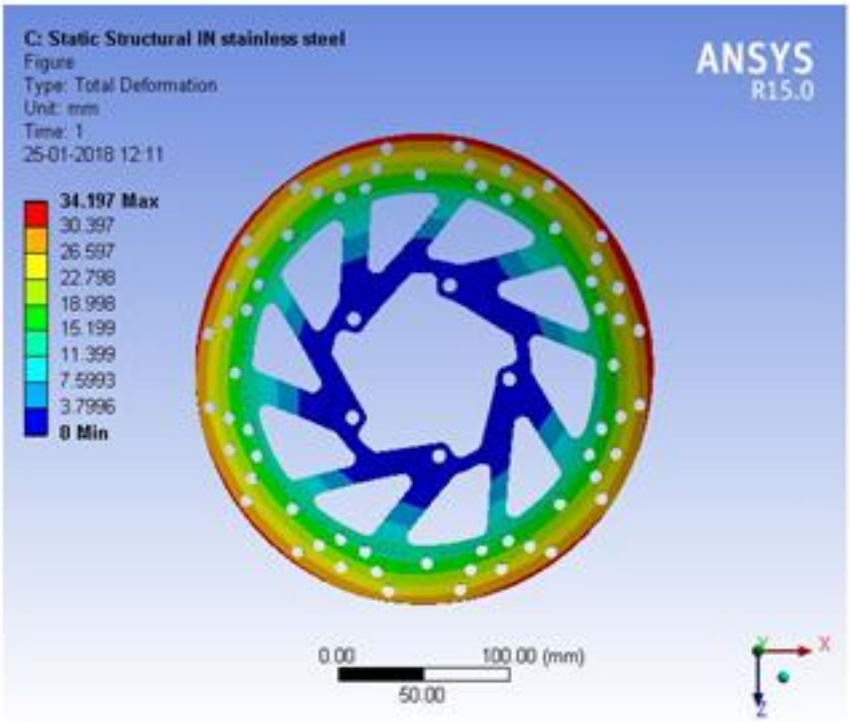


Fig.2 Total Deformation Fig.3 Normal Stress



Deformation Fig.3 Normal Stress

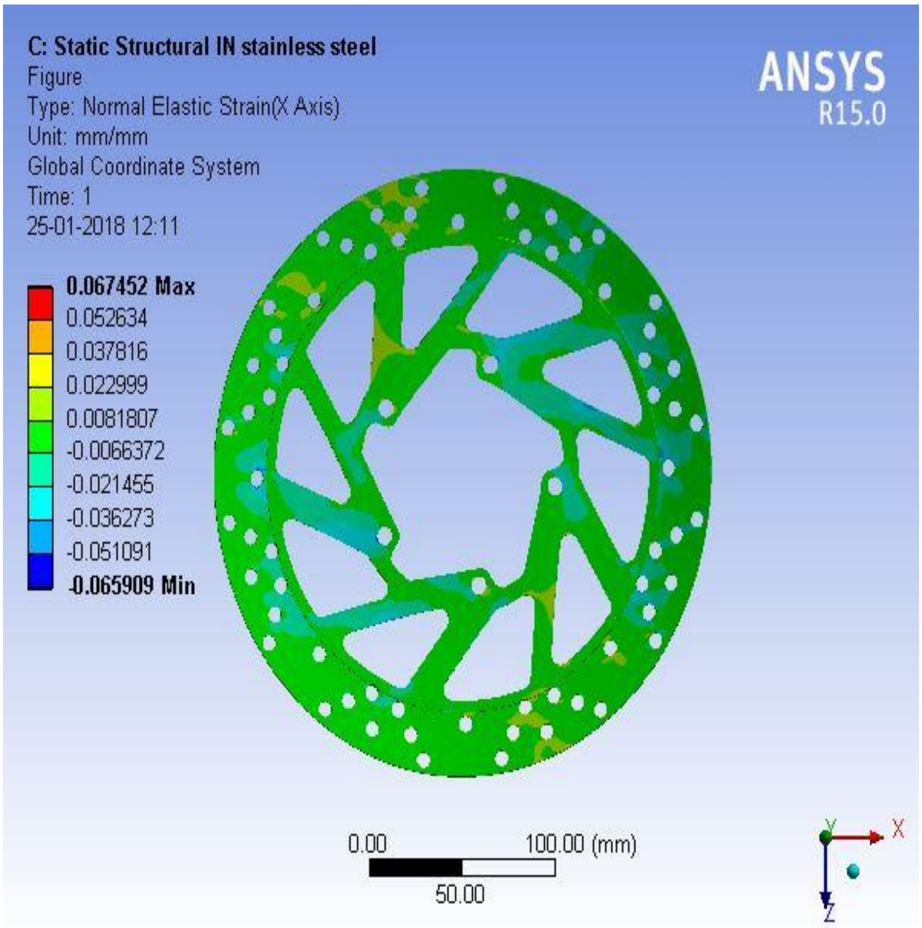


Fig.4 Normal Strain

(b) Cast Iron

Then the result of Total deformation, Normal Stress, Normal Elastic Strain of Cast Iron after analysis was observed as,

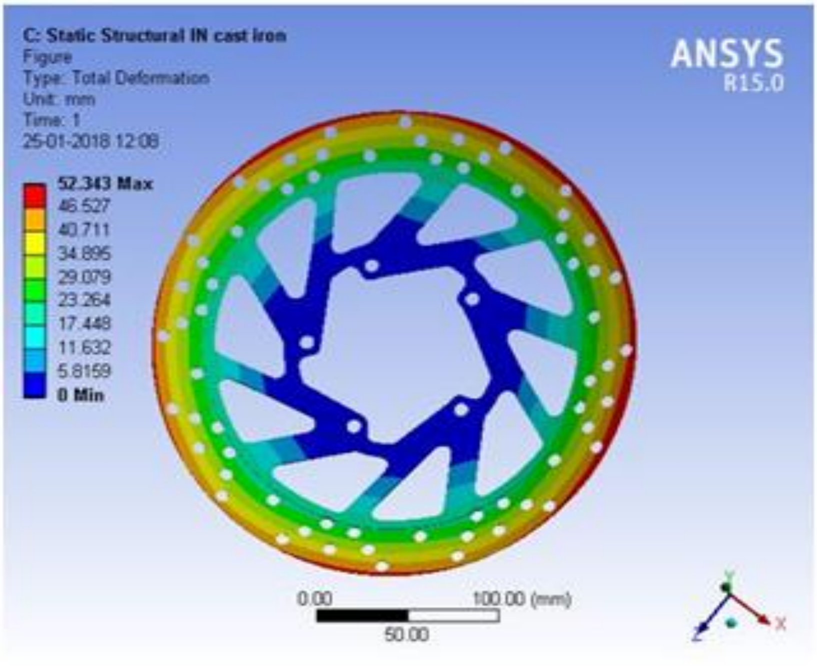


FIGURE 11
Model (B4, C4) > Static Structural (C5) > Solution (C6) > Directional Deformation > Figure

Fig.5 Total Deformation

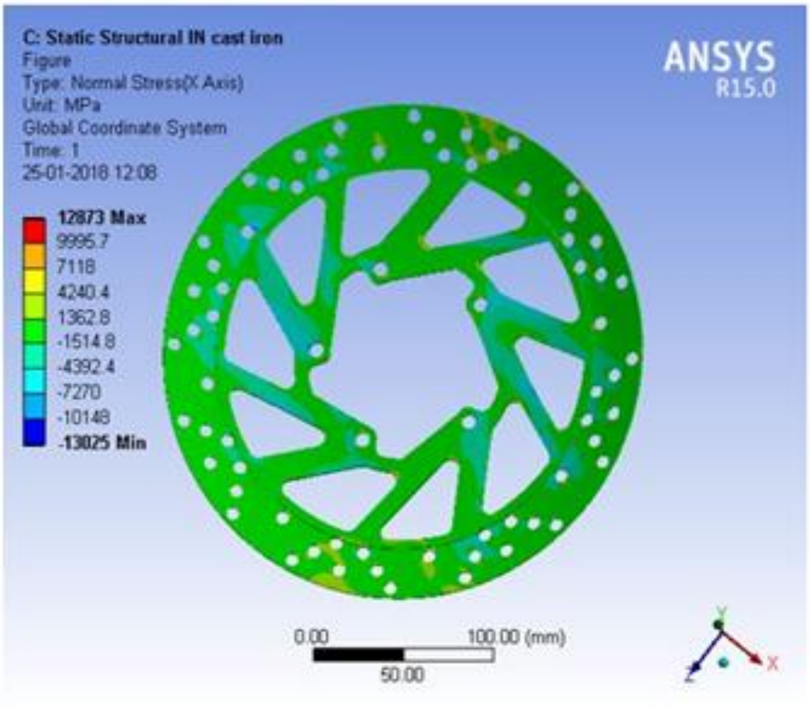


Fig.6 Normal Stress

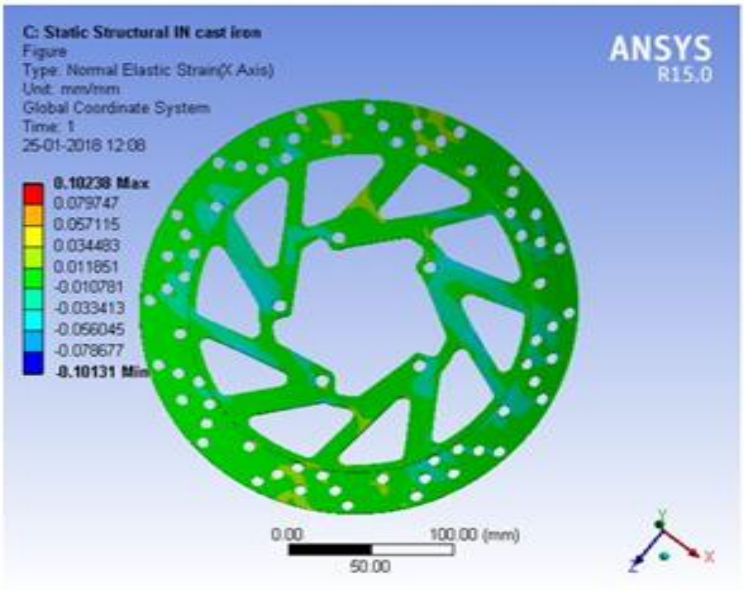


FIGURE 13
Model (B4, C4) > Static Structural (C5) > Solution (C6) > Normal Stress > Figure

Fig.7 Normal Strain

(C) Carbon-Carbon Composite

Then the result of Total deformation, Normal Stress, Normal Elastic Strain of Carbon-Carbon Composite after analysis was observed as,

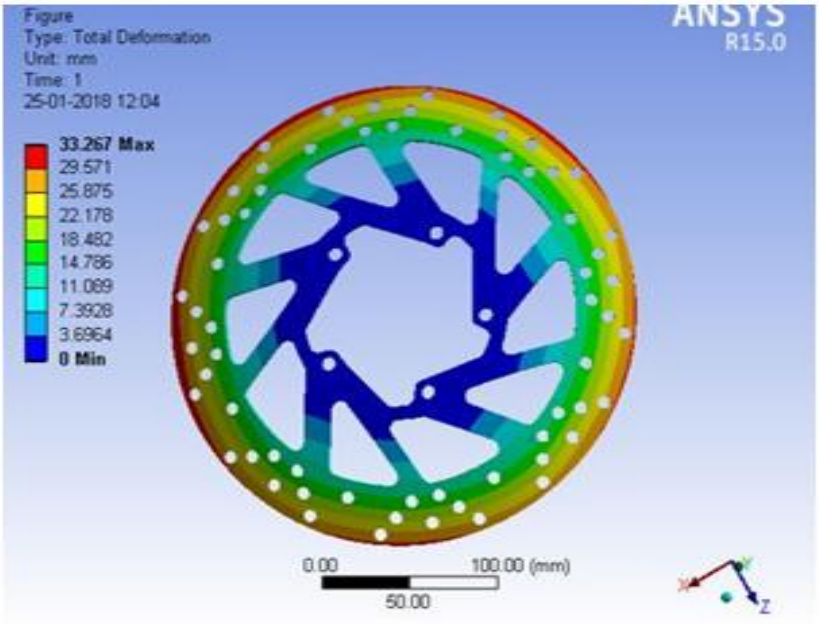


Fig.8 Total Deformation

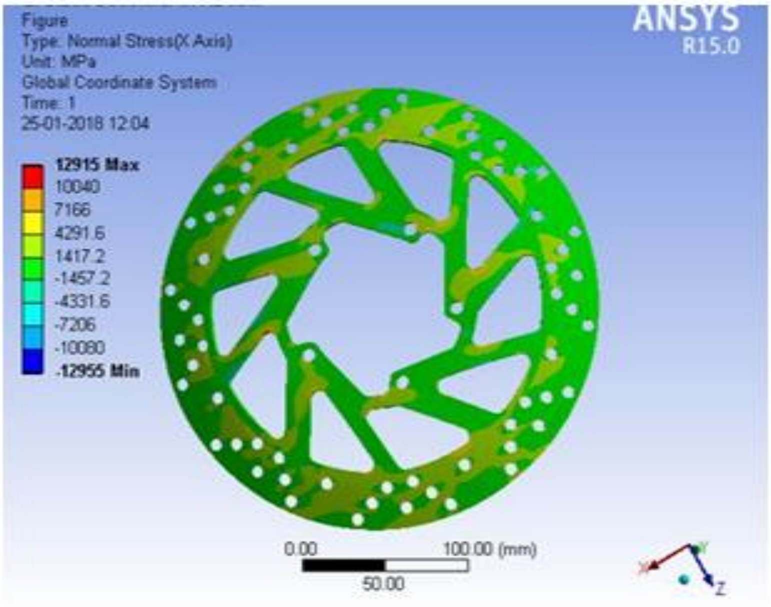


Fig.9 Normal Stress

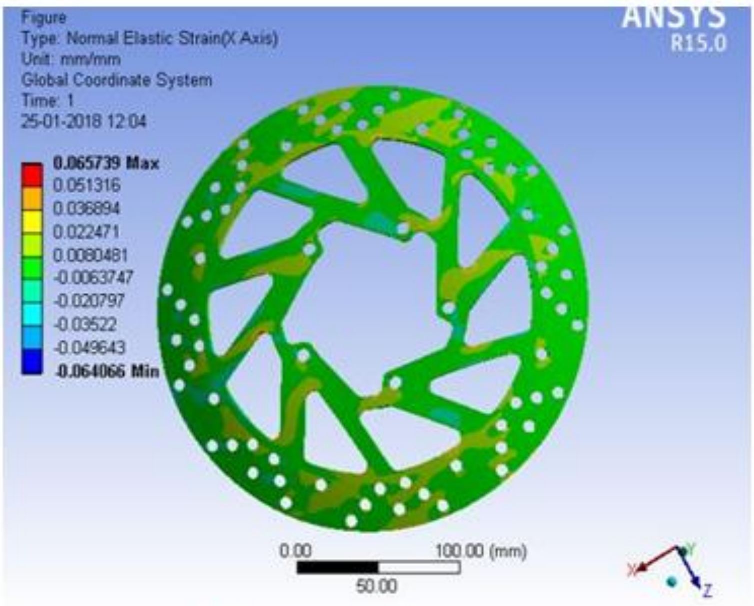
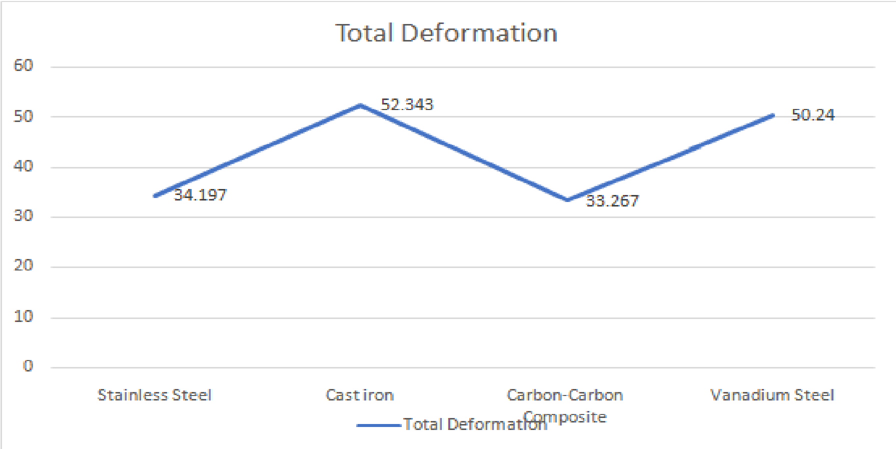


Fig.10 Normal Strain

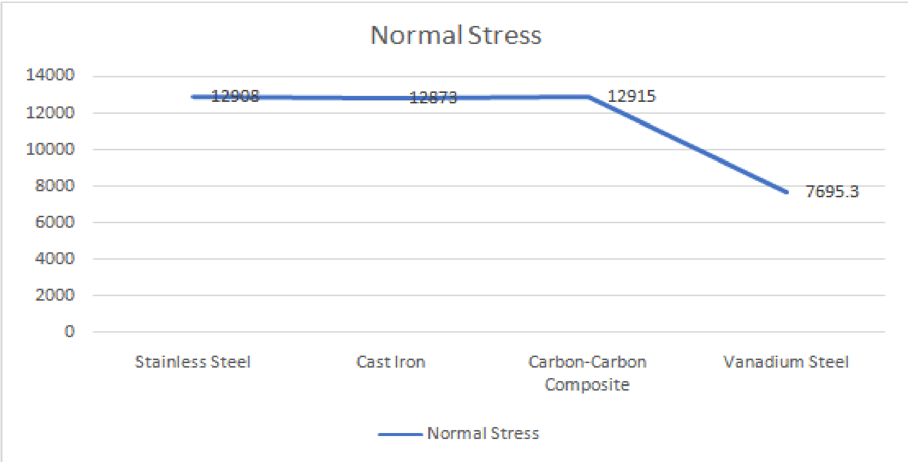
Table no 3: Result of Different Materials

Results	Stainless steel		Cast Iron		Carbon-Carbon Composite		Vanadium Steel	
	Max	Min	Max	Min	Max	Min	Max	Min
Total Deformation	34.197	0	52.343	0	33.267	0	50.24	0
Normal Stress	12908	-12967	12873	-13025	12915	-12955	7695.3	-7934.7
Normal Strain	0.067452	-0.065909	0.10238	-0.10131	0.065739	-0.06406	0.0382	-0.04117

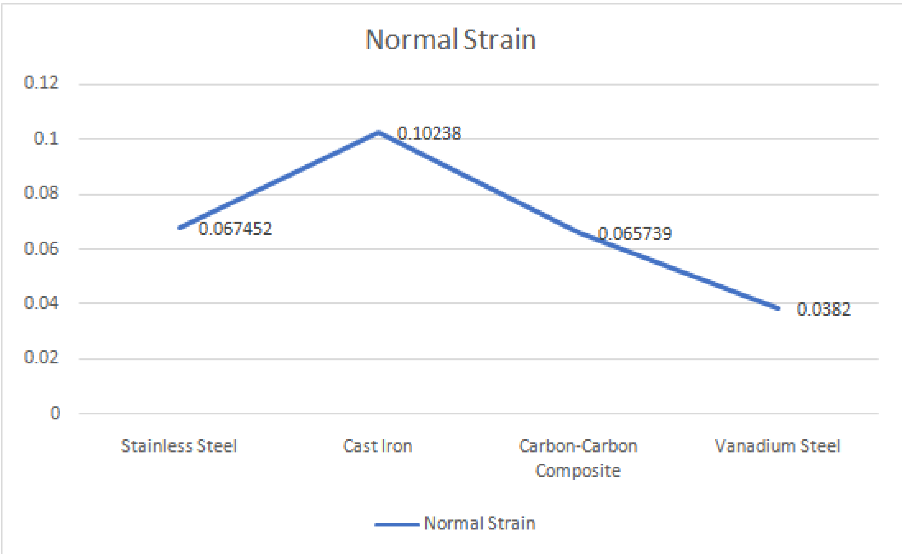
Graph No 1: Deformation of Disc Brake using different materials



Graph No 2: Normal Stress of Disc Brake using different materials



Graph No 3: Normal Strain of Disc Brake using different materials



2. THERMAL

a) Stainless Steel

Then the result of Total Heat Flux of Stainless Steel after analysis was observed as,

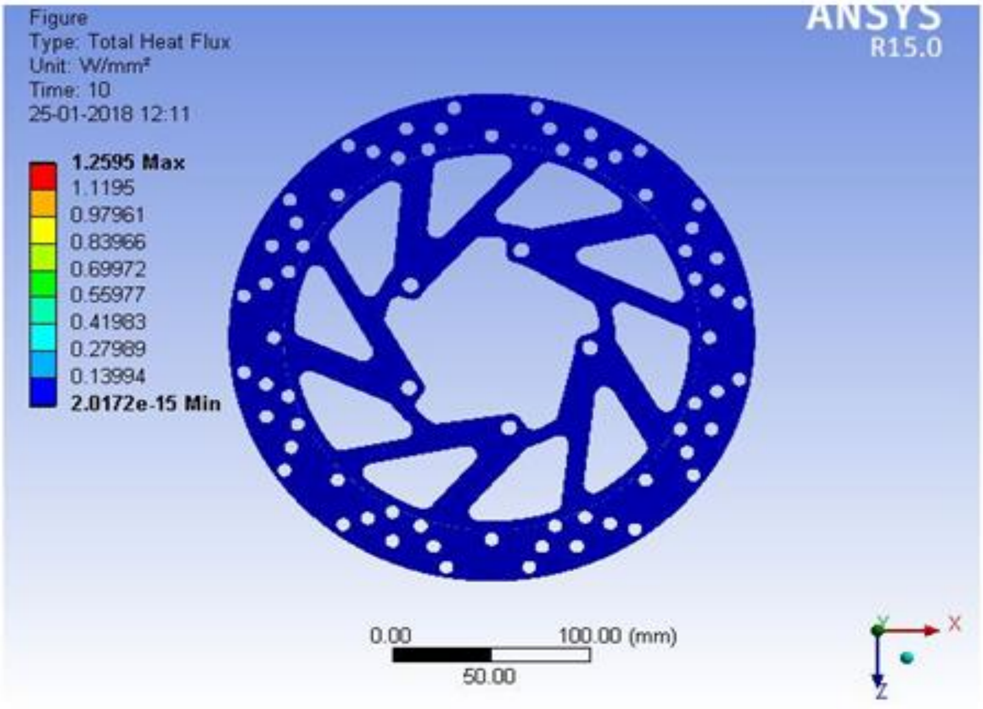


Fig. 14 Total Heat Flux

b) Cast Iron

Then the result of Total Heat Flux of Cast Iron after analysis was observed as,

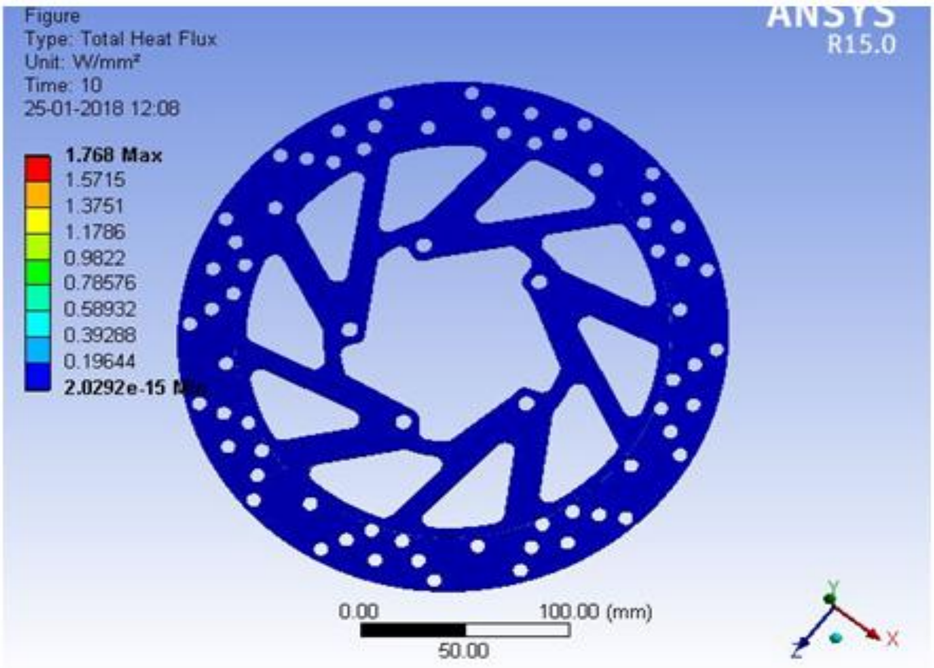


Fig. 15 Total Heat Flux

c) Carbon-Carbon Composite

Then the result of Total Heat Flux of Carbon-Carbon Composite after analysis was observed as,

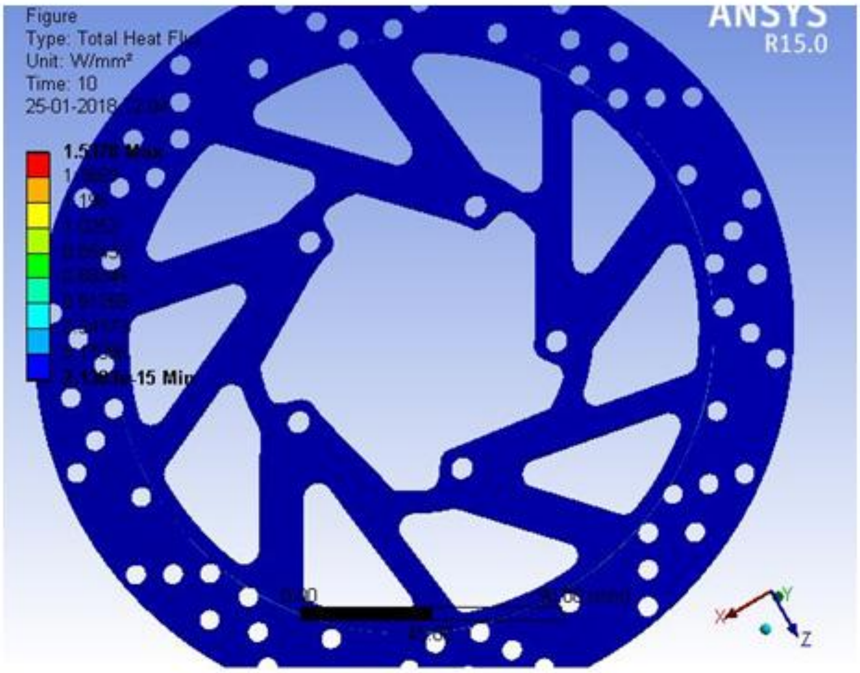


Fig. 16 Total Heat Flux

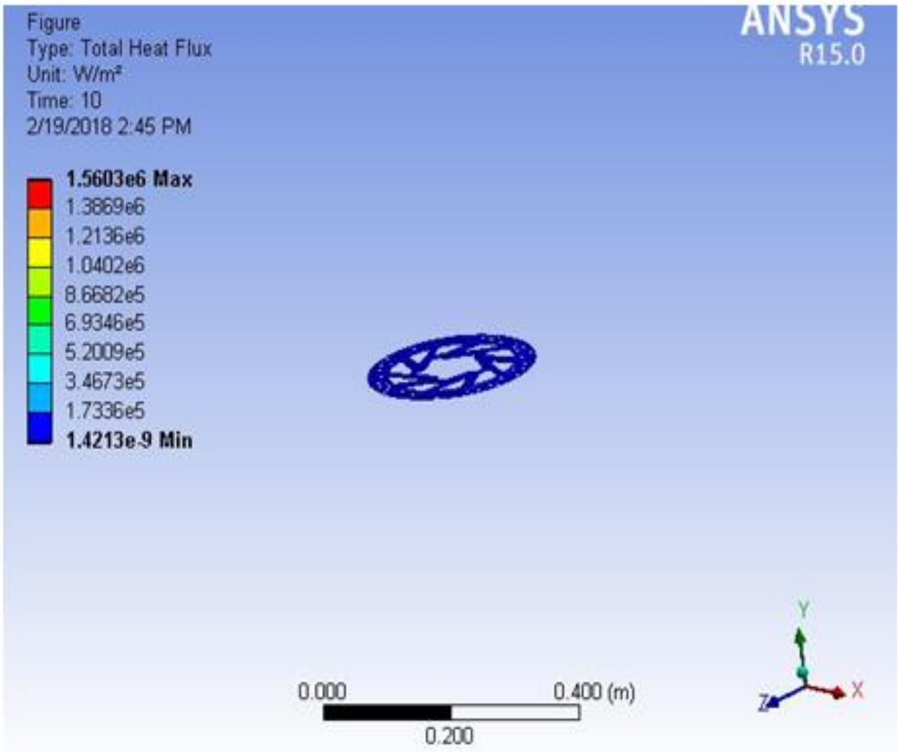


Fig. 17 Total Heat Flux

d) Vanadium Steel

Then the result of Total Heat Flux of Vanadium Steel after analysis was observed as,

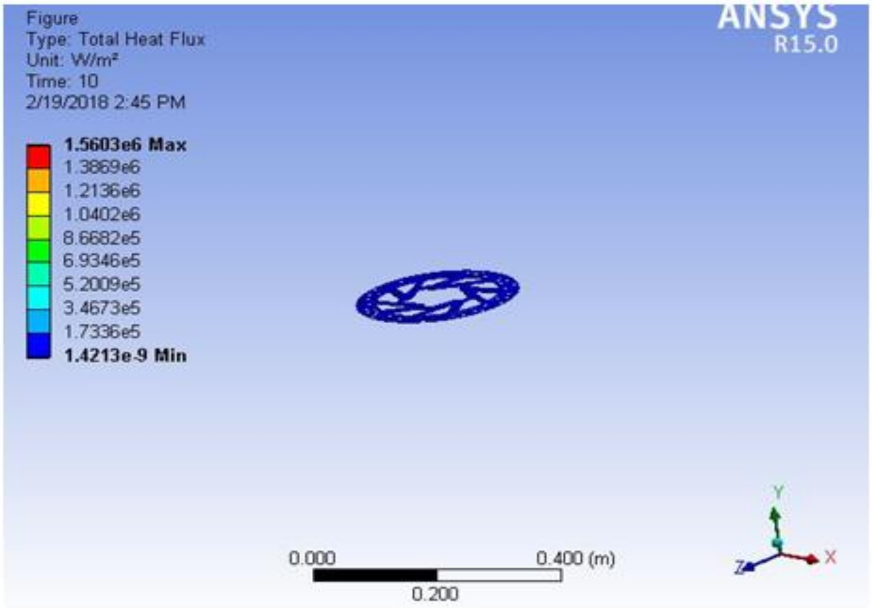
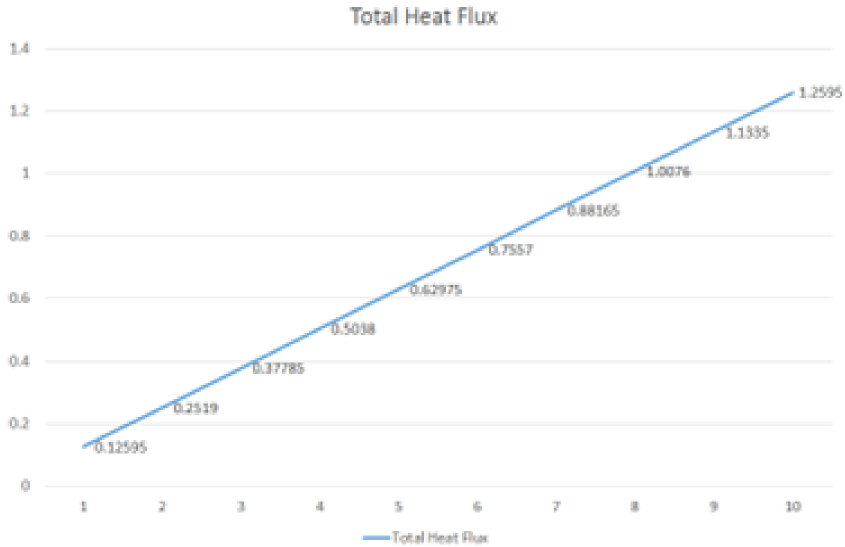


Fig. 17 Total Heat Flux

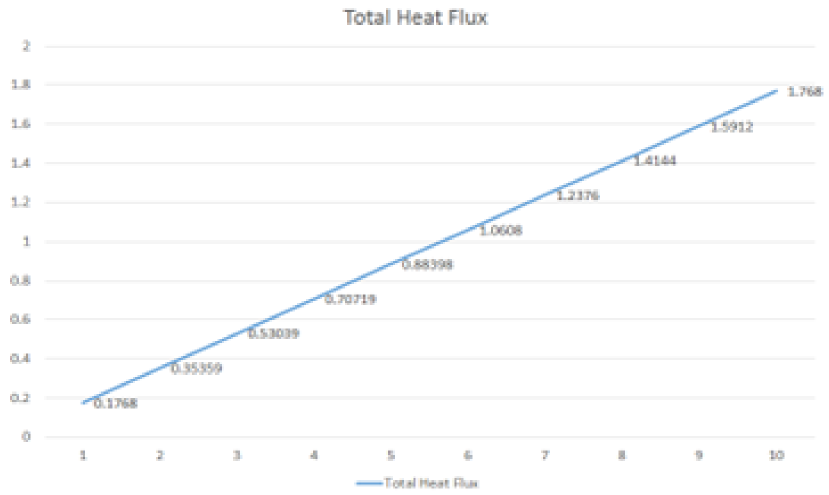
Table no 4: Result of Total Heat Flux

Results	Stainless steel		Cast Iron		Carbon-Carbon Composite		Vanadium Steel	
	Max	Min	Max	Min	Max	Min	Max	Min
Total Heat Flux	1.2595	2.0712e-15	1.768	2.0292e-15	1.5378	2.1383e-5	1.5603	1.4213e-15

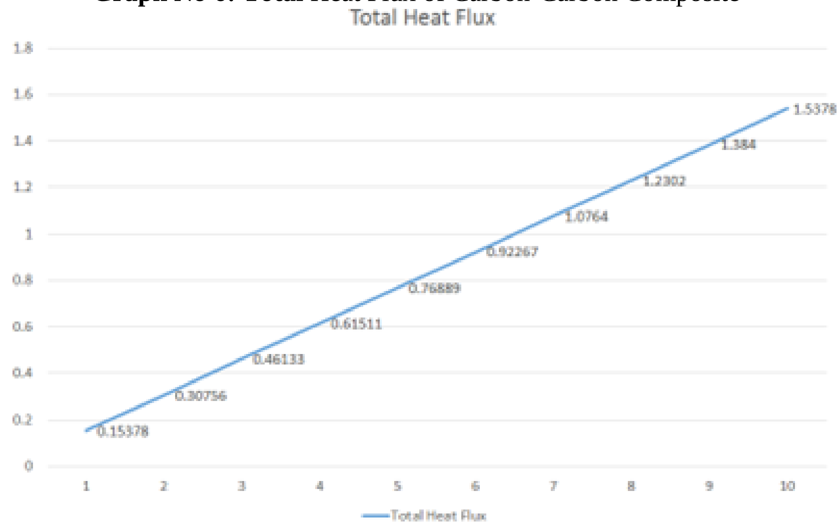
Graph No 4: Total Heat Flux of Stainless Steel



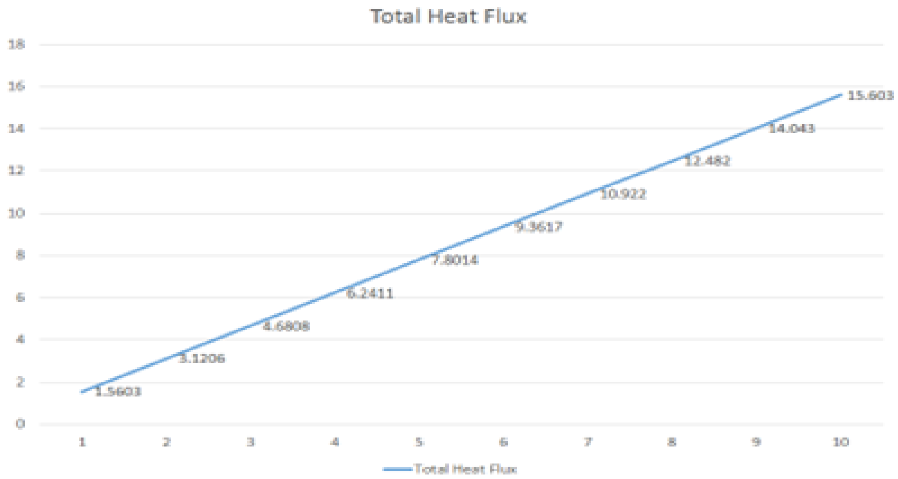
Graph No 5: Total Heat Flux of Cast Iron



Graph No 6: Total Heat Flux of Carbon-Carbon Composite



Graph No 7: Total Heat Flux of Vanadium Steel



IV. CONCLUSION

Thus a detailed analysis was done on the disc brake rotor for both static and thermal conditions. A comparison was done for the materials Stainless Steel, Cast Iron and Carbon-Carbon Composite with Vanadium Steel. The analysis has proved that Vanadium Steel has better strength than other materials as it can withstand forced stresses thereby showing that the deformation occurring on the disc rotor will be minimum. It has also proved that the total heat flux in Vanadium Steel is comparatively less than the other materials. This shows that even during harsh conditions, the temperature rise will be spread and deformation can be avoided. The values obtained from both the analysis are less than the prescribed values. Hence the design of the Disc Brake Rotor is safe.

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