International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Effect of Materials and Designs of Brake Rotor Discs on Factor of Safety and Displacement Assessed using Auto Desk Fusion360

Angamuthu.K, Anandu K B, Abhishek S, Lins Williams, Rouble Pius

Abstract: Brake rotor is one of the top safety elements in many rotating machines and automobile. The temperature distribution in the rotor, the displacement of the rotor and factor of safety during braking are important parameters which will decide about the safety of vehicle and life of the brake rotor. It is very important to study the influence of materials and design on the factor of safety and displacement for better selection of materials and design of brake rotor discs. In this investigation, three designs of rotor namely a solid disc, a ventilated rotor disc with radial slots and a newly designed rotor consisting aero foil grooves and fins are used which are made of cast iron, titanium alloy and C/C-SiC dual matrices composite material. These discs are modeled in Autodesk Fusion 360. The mechanical behavior such as variation of factor of safety and displacement of the rotor discs are analyzed using Autodesk Fusion360. It is found that titanium alloy seems to provide better distribution of factor of safety in all the three designs of rotor discs. It also gives minimum displacement whereas cast iron rotor gives maximum displacement under the gradually applied static load.

Keywords*: *Brake rotor disc, materials for rotor discs, design of rotor discs, factor of safety and displacement.

I. INTRODUCTION

All the rotating parts in many machineries and automobiles must have brake to stop the machines or automobiles. This is done by incorporating a brake rotor disc and pads. Frictional resistance during braking creates uneven temperature distribution in the rotor disc, thermal cracks and wearing of brake pads. In general the brake rotor disc is made of grey cast iron or any other advanced material including composite material [1]-[3]. The rotor discs have many designs such as solid discs, ventilated discs and discs with vanes [4]-[5]. This research work deals with the influence of rotor discs materials and its design on the factor of safety and the displacement of the rotors based on the analysis carried out using Autodesk Fusion 360.

Manuscript published on 30 September 2019

* Correspondence Author

Dr.K.Angamuthu*, Department of Mechanical Engineering, Providence College of Engineering, Chengannur, Kerala, India, Email: angamuthu@yahoo.com

Anandu K B., Department of Mechanical Engineering, Providence College of Engineering, Chengannur, Kerala, India, Email: anandukb74@gmail.com

Abhishek S. Department of Mechanical Engineering, Providence College of Engineering, Chengannur, Kerala, India, Email: abhishakanisreekumar@gmail.com

Lins Williams, Department of Mechanical Engineering, Providence College of Engineering, Chengannur, Kerala, India, Email: linswilliams968@gmail.com

Rouble Pius, Apprenticeship Trainee, Stanadyne, Chennai, India, Email: royrouble96@gmail.com

II. Brake Rotor Disc Materials

The materials with high heat transfer capacity can be selected as brake rotor disc material. The automobile industries use cast iron as the brake rotor disc material due to its high heat transfer capacity. The aluminum metal matrix composite is also considered to be a good material compared to AL7075 alloy for brake rotor discs [6]. Glass fiber composite having higher strength is reported to be a promising material for making rotor disc [7]. The carbon-carbon composite is found to be the suitable material for brake rotor in the aircraft industries [3], [8]. Titanium alloys are good rotor material with surface topography modification, coating and diffusion treatment for improving surface hardness and wear resistance [9].

III. Rotor Design and its Heat Transfer Capacity

Various rotor designs and its influence on the thermal behavior was studied and reported. Masahiro Kubota et al [4] suggested a design of light weight ventilated disc rotor having combination of different shapes of fins such as straight fins and gourd-shaped fins in the rotor and reported improved heat transfer and cooling. The rotor designed with holes and air foil pattern vents showed reduced maximum temperature due to excess surface area in the disc exposed to atmospheric air compared to rotor with flange. Uniform stress distribution is found in the circumferential direction with increasing number of fins which results in reduction in the maximum stress in the rotor. Another investigator used cross drilled rotor disc fixed with caliper for better heat transfer [6]. Drilled rotor designed with vanes and thin cylindrical extrusions provided at the inner side of the rotor have better heat flow and air passage [3]. The study on fluid motion through the radial passage of a rotor revealed that vented rotors can be used for moderate speed. The internal convective heat transfer found to be increased with speed in the rotor [2]. The ventilated rotors have lower thermal capacity compared to the solid disc and repeated braking may damage the ventilated rotors due to fast rise in temperature [10].

The increased thermal capacity of rotor due to higher thermal conductivity of rotor materials can decrease the maximum surface temperature. It will also reduce the maximum applied stress due to its lower Young's modulus [6]. Angamuthu et al [11] reported that in a new design of rotor made of C/C-SiC, the heat transfer is more uniform compared to solid and ventilated design. Transient thermal analysis showed maximum surface temperature of the rotor around 108^{o}C [12]. Daanvir Karan Dhir [5] reported that the maximum temperature in the solid disc of gray cast iron is about 225^{o}C and it decreases in the discs having drilled holes and airfoil vents due to increase in the contact area of the disc with the surrounding atmosphere. Many investigations showed temperature variation of 350^{o}C to 400^{o}C in the rotor discs of solid and vented design [13]-[14]. The decrease in the maximum temperature in the rotor disc and selection of material having high temperature strength will increase the resistant to thermal cracking in the rotor disc [1].

IV. ROTOR DESIGN AND MECHANICAL RIGIDITY

The rigidity of rotor disc is found to decrease in the air foil pattern slots due to material removal [5]. The total deformation is found to be lower in the rotor disc having aero foil grooves, holes and fins made of C/C-SiC composite material [11]. The factor of safety is found to be varied with thickness of the rotor and increase in temperature [12].

V. OBJECTIVE OF THE RESEARCH

The research works reported in the literatures are discussing about the thermal behavior and temperature distribution of different designs of rotor discs. The total deformation of brake rotor discs needs to be further analyzed to ensure better safety of the brake element without causing any failure. The main objective of this work is to study how the different brake rotor materials and its designs influence the mechanical design parameter such as factor of safety and the displacement of the brake rotor for maximum safety.
Considering the above factors, in the present research work, three rotor designs and three materials are selected. A new design of rotor disc reported elsewhere by the authors [11] is used in addition to a solid and ventilated rotor disc in this study. Autodesk Fusion360 is used to analyze the factor of safety and displacement. The distribution of factor of safety and the displacement of rotor discs are analyzed.

VI. METHODOLOGY

A. 3D Modeling

The methodology uses Autodesk Fusion360 for designing the rotors. The materials and design used in this study are tabled in Table I. The properties of materials, the design calculations for the new design to select the number of fins, area of grooves and fins and the design features can be found out elsewhere [11]. The various dimensions of all the three designs are shown in Fig.1(a) to Fig.1(c). The 3D modeling of the new design is shown in Fig.2.

Table- I: Materials and Design of Brake Rotor Discs for Analysis of Factor of Safety and Displacement Using AutoDesk Fusion360

Type of Design	All Three Materials		
Solid design	Cast iron	Titanium alloy	C/C-SiC
Ventilated design	Cast iron	Titanium alloy	C/C-SiC
New design having Aero foil grooves with fins and radial holes	Cast iron	Titanium alloy	C/C-SiC

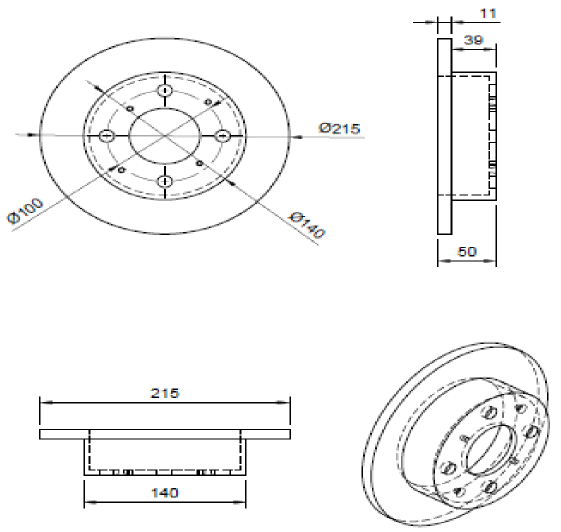

Fig.1(a). Dimensions of solid disc in mm

B. Analysis

The factor of safety and displacement are analyzed using Autodesk Fusion 360 for all the three designs and all the three materials and the results are compared based on the individual analysis. In this analysis a static force of 16 kN was applied over a period of 8 seconds in steps as given in the Table II.

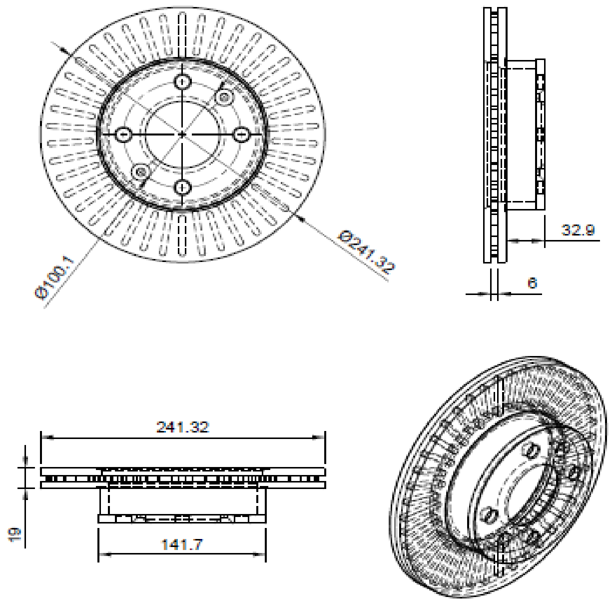

Fig.1(b). Dimensions of ventilated disc in mm

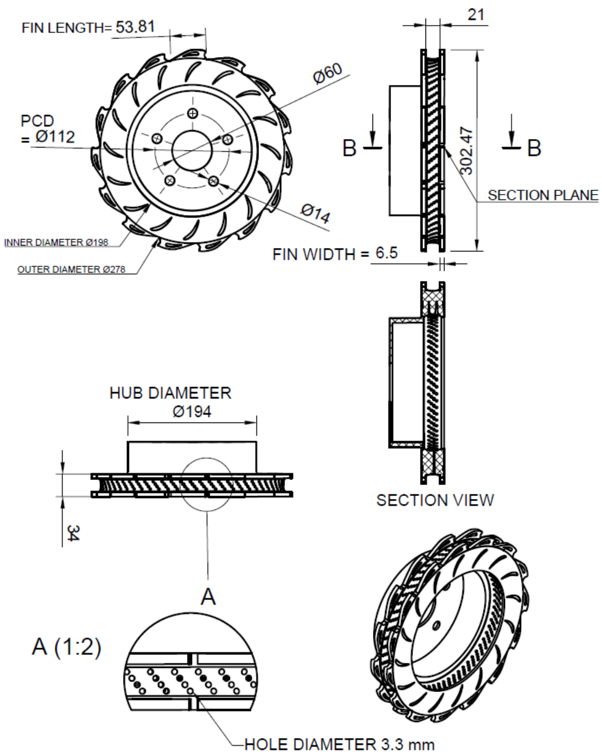

Fig.1(c). Dimensions of new design in mm

Fig.2. 3D model of new design

Table- II. Static Loading of Rotor Discs

Steps	Time (S)	Force (KN)
1	0	0
2	1	2
3	2	4
4	3	6
5	4	8
6	5	10
7	6	12
8	7	14
9	8	16

VII. RESULTS AND DISCUSSION

A. Analysis of Factor of Safety for Different Design of Rotor Discs Made of Different Materials

1. Factor of Safety for the Solid Rotor Disc Design

In general, the factor of safety should not be less than one and the higher the factor of safety, the design will be robust and the dimensions of the component will be large leading to more cost and manufacturing difficulties. The design of a particular engineering component uses a single factor of safety. But in actual practice, due to variation in load distribution in different area of the same component, some area may be loaded beyond yielding and accordingly, the stress distribution and distribution of factor of safety may change in the entire component. The factor of safety of the brake rotor may vary with its temperature history and related thermal stresses. The areas showing higher value of factor of safety indicates that they are safe on the application of static load whereas the areas showing lower values are the areas of concern and weak and there is every possibility that the failure may occur in these areas if the factor of safety is reduced further. In the cast iron disc, the factor of safety ranges from 0.006 to 6.5, showing majority area from the hub to half of the body of the disc (red color) is under lower range of factor of safety as shown in Fig.3. The factor of safety distinctly varied between two regions in the solid discs made of titanium alloy and C/C-SiC composite material as seen in Fig.4 and Fig.5 respectively. The upper range of 6-8 is seen in the surface of the disc which can go up to 15 and the lowest range is found in the regions of hub and bolt hole and it is approximately 0.1 as shown in Fig 4 and Fig 5. For solid design, titanium alloy and C/C-SiC composite material seem to give better distribution of factor of safety.

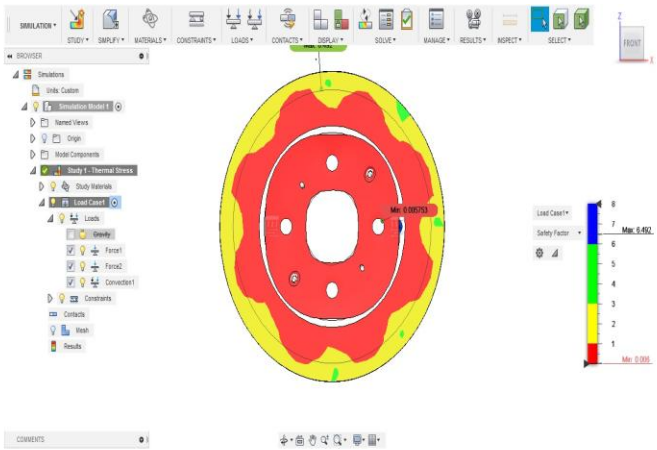

Fig.3. Range of factor of safety in cast iron solid disc

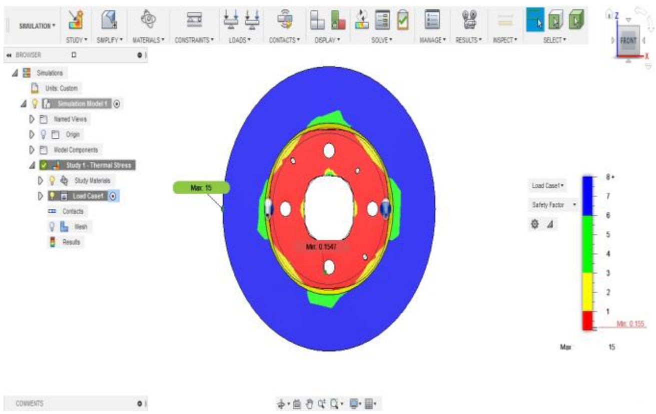

Fig.4. Range of factor of safety in titanium alloy solid disc

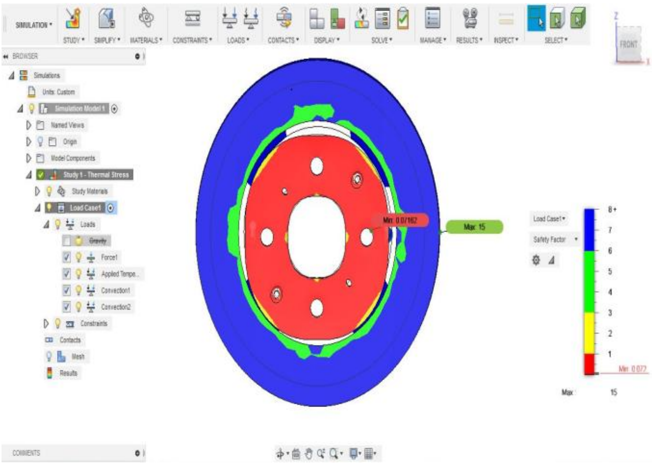

Fig.5. Range of factor of safety in C/C-SiC composite solid disc

2. Factor of Safety for the Ventilated Design

The ventilated disc of cast iron and C/C-SiC composites seems to provide almost similar range of factor of safety as shown in Figs 6 and 8 respectively. The area of minimum range of factor of safety is seen in the bolt hole of titanium alloy disc as shown in Fig. 7 and better safety is possible if the ventilated disc is made of titanium alloy due to higher factor of safety distributed in the surface of the body of the rotor disc.

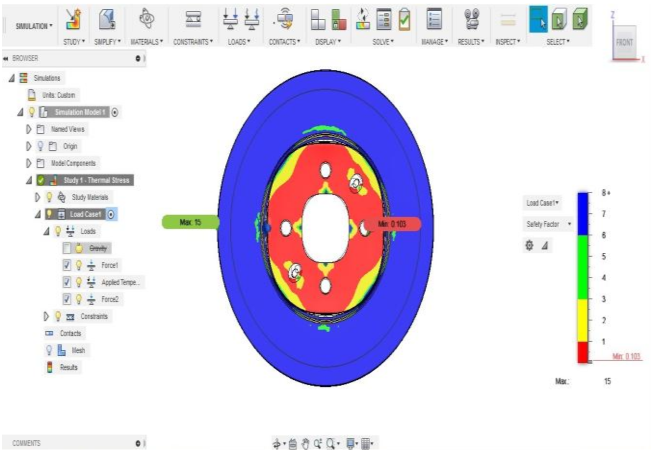

Fig.6. Range of factor of safety in cast iron ventilated disc

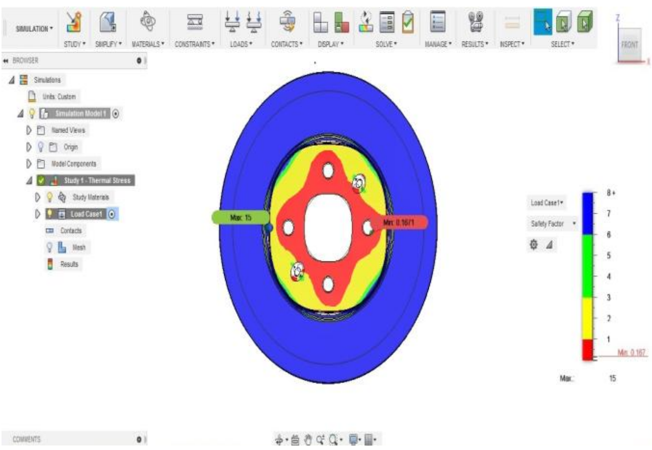

Fig.7. Range of factor of safety in titanium alloy ventilated disc

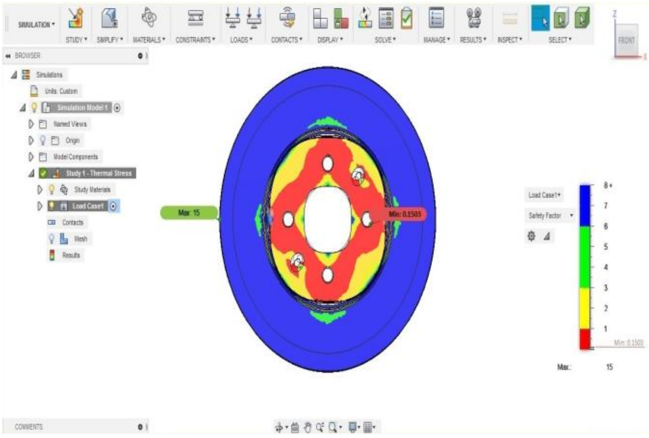

Fig .8. Range of factor of safety in C/C-SiC composite ventilated disc

3. Factor of Safety for the New Design

The range of factor of safety estimated for the applied static load of 16 kN in the three rotor discs of new design are shown in Figs 9-11. In the cast iron disc, the minimum range is found to be in the hub and bolt hole regions. This is shown in Fig 9. In the titanium alloy (Fig.10), the disc rotor experiences high range of factor of safety in the surface of the disc and negligible area experienced minimum range of factor of safety. For C/C-SiC composite material as seen in Fig. 11 the factor of safety is spread across the entire body varying from 2 to 8. This indicates that the titanium alloy disc may be a better choice in this new design because of better distribution of factor of safety compared to other two materials. The general observation in these analysis is that the area or near area of the bolt has minimum factor of safety which is very similar to the observations made in [14] reporting that the highest equivalent Von Mises stress occurred at the bolt holes due to torsion and shear mode. This is the area where possibly failure will occur.

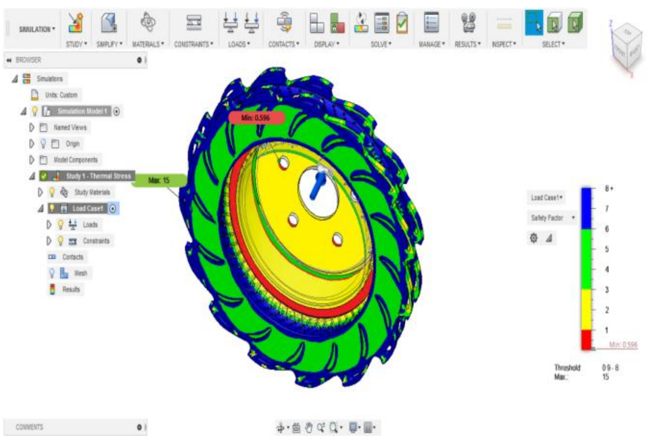

Fig.9. Range of factor of safety in cast iron rotor of new design

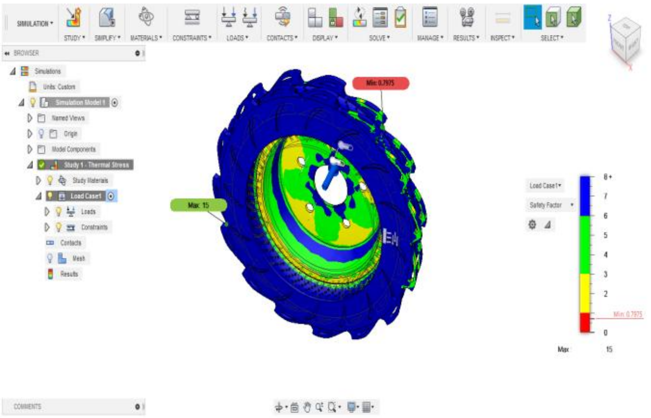

Fig.10. Range of factor of safety in titanium alloy rotor of new design

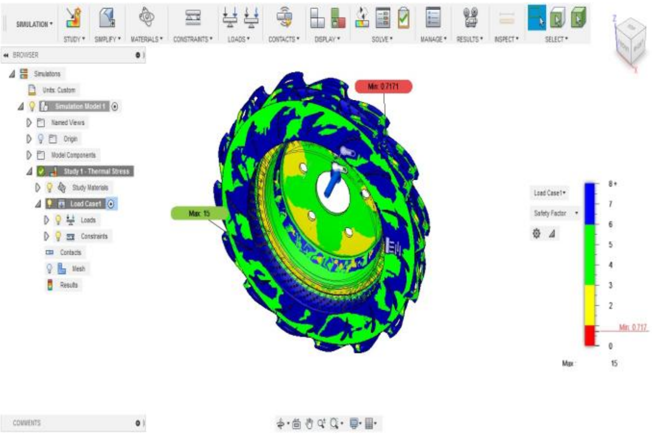

Fig.11. Range of factor of safety in C/C-SiC composite material rotor of new design

B. Analysis of Displacement for Different Design of Rotor Discs Made of Different Materials

1. Displacement of Solid Rotor Discs

The displacement of solid rotor discs made of different materials is shown in Figs 12-14.

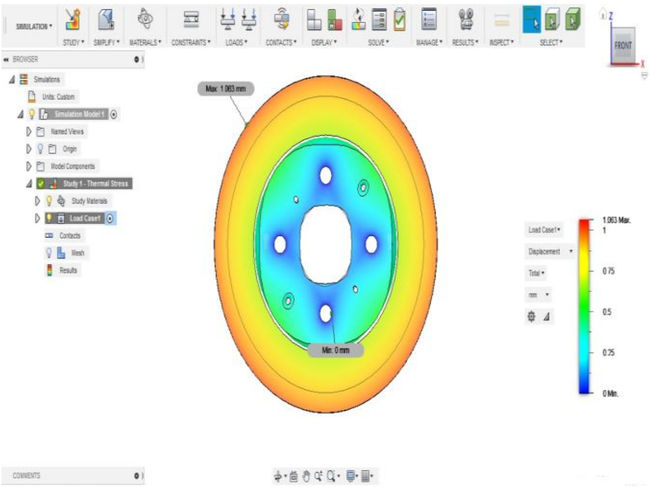

Fig.12. Displacement of cast iron solid disc

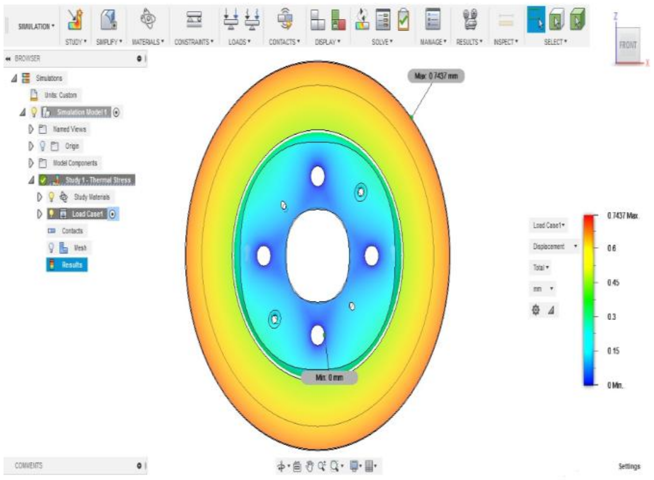

Fig.13. Displacement of titanium alloy solid disc

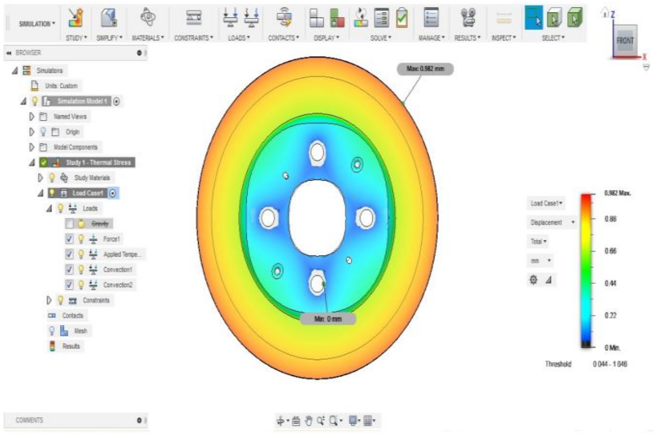

Fig.14. Displacement of C/C-SiC composite solid disc

2. Displacement of Ventilated Rotor Discs

The displacements of ventilated discs made of different materials are shown in Figs 15-17.

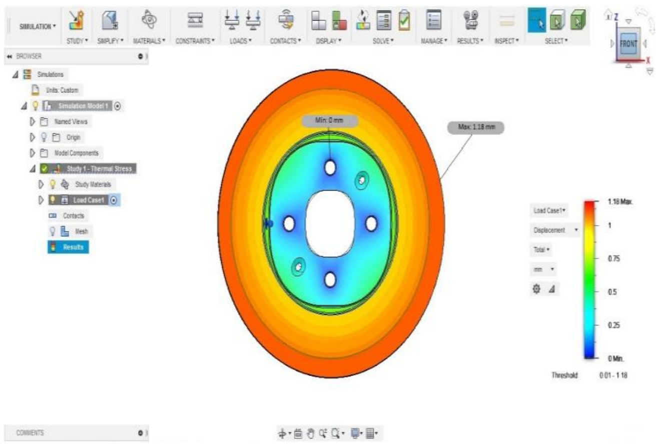

Fig.15. Displacement of cast iron ventilated disc

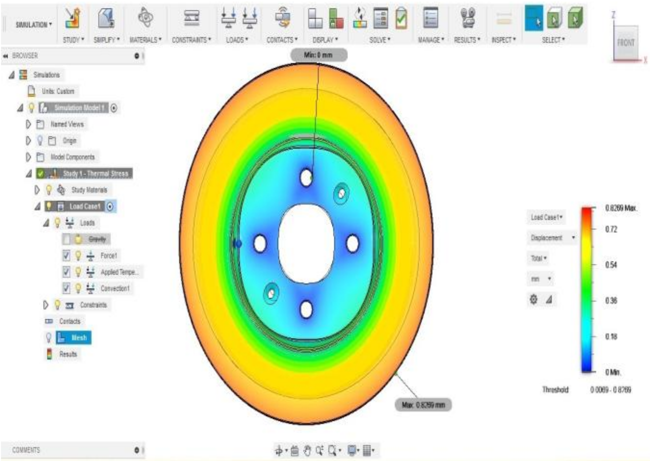

Fig.16. Displacement of titanium alloy ventilated disc

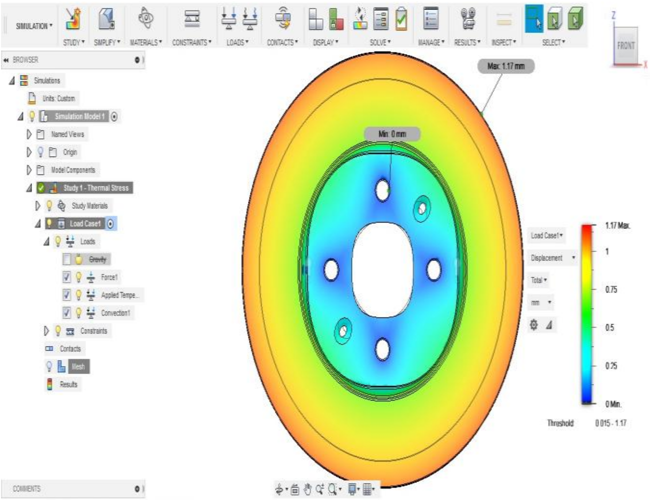

Fig.17. Displacement of C/C-SiC composite ventilated disc

3. Displacement of Rotor Discs of New Design

The displacements of rotor of new design made of different materials are shown in Figs 18-20.

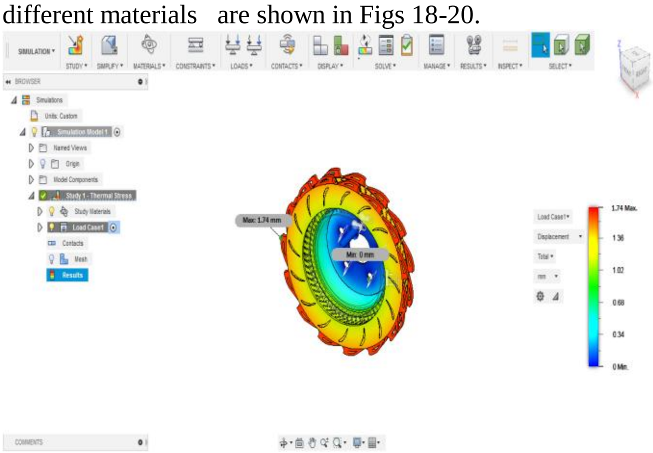

Fig.18. Displacement of disc of new design made of cast iron

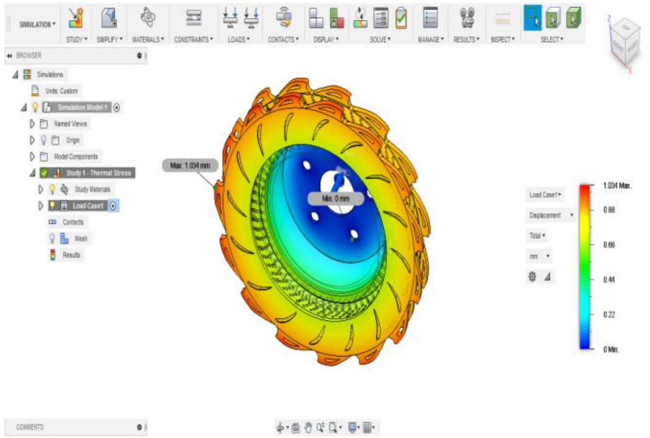

Fig.19. Displacement of disc of new design made of titanium alloy

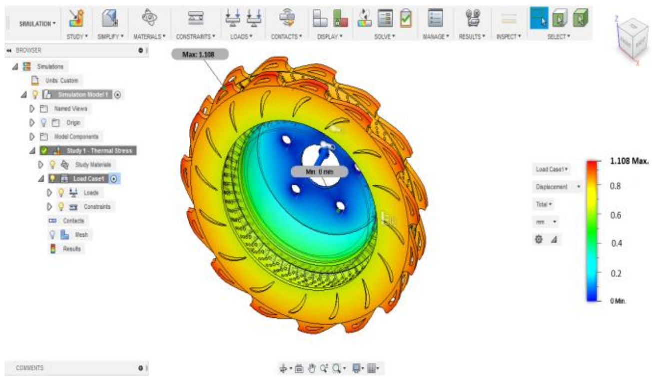

Fig.20. Displacement of disc of new design made of C/C-SiC composite.

Based on the above analysis, the maximum deformation or displacement of different designs made of different materials is shown in Fig. 21. It is seen that the maximum deformation is found to be in cast iron disc and minimum in titanium alloy disc and intermediate deformation is seen in C/C-SiC composite discs. It is reported [4] that increasing the number of fins in the rotor reduces the maximum stress level. In the present study the new design has 30 fins and titanium alloy being high strength material, the displacement is found to be minimum compared to cast iron rotor.

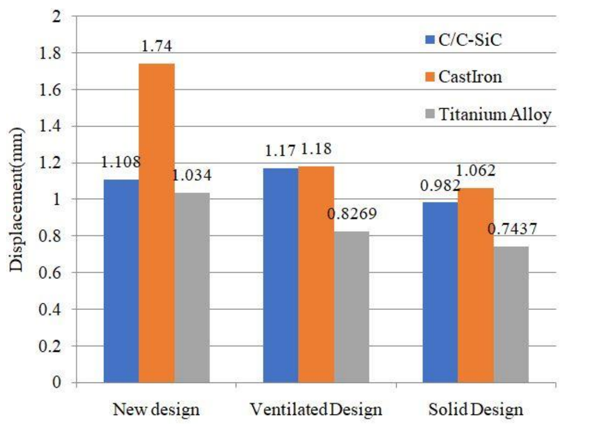

Fig.21. Maximum displacement of different discs made of different material

VIII. CONCLUSIONS

The finite element analysis of brake rotor disc made of cast iron, titanium alloy and C/C-SiC dual matrices composite material are conducted using Autodesk Fusion 360. Three designs of brake rotor discs are used in this study. The distribution of factor of safety and displacement of rotor discs are analyzed for all the designs made of these three materials. The conclusions are

1. The factor safety varied with different design as well as different materials and seen that the titanium alloy rotor disc with new design showed better distribution of factor of safety.

2. The hub and bolt holes of rotor discs are the areas showing low range of factor of safety.

3. The displacement analysis is found to show minimum displacement in titanium alloy rotor and maximum in cast iron disc in all the three designs of rotor discs.

REFERENCES

1. Thomas J. Mackin, et al (2002) Thermal cracking in disc brakes Engineering Failure Analysis 9 63-76.
2. McPhee.A.D and Johnson.D.A (2008) Experimental heat transfer and flow analysis of a vented brake rotor International Journal of Thermal Sciences 47 458–467.
3. Santosh Kumar Kallepalli, Harish Musti and Sudhakar Reddy.K (2017) Enhancement in design and thermal analysis of disc brake rotor ISSN: 2277-9655 6(2): February 2017.
4. Masahiro Kubota, Tsutomu Hamabe, Yasunori Nakazono, Masayuki Fukuda and Kazuhiro Doi (2000) Development of a lightweight brake disc rotor: a design approach for achieving an optimum thermal, vibration and weight balance JSAE Review 21 349-355.
5. Daanvir Karan Dhir (2018) Thermo-mechanical performance of automotive disc brakes Materials Today: Proceedings 5 1864–1871.
6. Baskara Sethupathi P., Muthuvel A., Prakash. N and Stanly Wilson Louis (2015) Numerical analysis of a rotor disc for optimization of the disc materials Journal of Mechanical Engineering and Automation, 5(3B):5-14 DOI: 10.5923/c.jmea.201502.02.
7. Shiva Shanker.P (2018) A review on properties of conventional and metal matrix composite materials in manufacturing of disc brake Materials Today: Proceedings 5 5864–5869.
8. Zhuan LI, Xiao Peng, Xiong Xiang and Huang Bo-yun (2010) Manufacture and properties of carbon Fiber-reinforced C/SiC dual matrix composites New Carbon Materials Volume 25 Issue 3 Jun 2010 25(3):225–231.
9. Jun Qu, Peter J. Blau, Brian C. Jolly (2009) Oxygen-diffused titanium as a candidate brake rotor material Wear 267 818–822.
10. Jung, S. P., Park, T. W., Kim, Y. G. (2012) A study on thermal characteristic analysis and shape optimization of a ventilated disc International Journal of Precision Engineering and Manufacturing 13 (1) (2012) 57–63.
11. Angamuthu.K, Anandu.K.B., Abhishek.S., Lins Williams and Rouble Pius (2019) Comparative study of thermo-mechanical behaviour of different designs of brake rotor discs made of different materials using ANSYS, International Journal of Engineering Research & Technology (IJERT), Vol.8, Issue 8, August 2019, pp 35-43.
12. Harshal Nikam, Prem Mishra & Sayali Bharambe (2014) Design and analysis of brake rotor with parameter optimization International Journal of Automobile Engineering Research and Development (IJAuERD) Vol. 4 Issue 4 Aug 2014 , pp21-30.
13. Viraj Parab, Kunal Naik and A. D. Dhale (2014) Structural and Thermal Analysis of Brake Disc , 2(2), IJEDR 2014, pp1398-1403.
14. Ali Belhocine and Mostefa Bouchetara (2012) Thermal analysis of a solid brake disc Applied Thermal Engineering 32 (2012) 59-67.

AUTHORS PROFILE

Dr.K. Angamuthu is a mechanical engineering graduate, received his Ph.D degree from IIT, Madras in the year 2000. He has about 33 years of experience in teaching and research, worked in different capacities as Professor, Director and Dean in different universities and engineering institutes in India and abroad. His areas of interest are materials engineering and cryogenic engineering. He has published twenty papers in international and national conferences and journals. Currently he is working as professor and head of department of mechanical engineering, Providence College of Engineering, Chengannur, Kerala, India.

Mr.Anandu.K.B is a trainee engineer in the department of mechanical engineering, Providence College of Engineering, Chengannur, Kerala.

Mr.Abhishek S is a trainee engineer in the department of mechanical engineering, Providence College of Engineering, Chengannur, Kerala.

Mr.Lins **Williams** is a trainee engineer in the department of mechanical engineering, Providence College of Engineering, Chengannur, Kerala,

Mr. Rouble Pius is a mechanical engineering graduate undergoing apprenticeship training at Stanadyne, Chennai.