Analysis of Static Structure on Disc Brake with Different Friction Materials Using ANSYS 19.2

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Abstract-- Each and every automobile system, including the braking system, has gone a long way in recent years. A braking system is a mechanical device that is linked to a moving machine element that simulates frictional safety in order to stop the machine from moving. Braking is the process of using mechanical force to reduce the kinetic energy of a wheel. The decrease of kinetic energy is accompanied by the formation of thermal energy on the rotor disc's surface. The most common disc brake material used in two-wheeler braking systems is alloy martensitic stainless steel, however carbon – carbon composite and grey cast iron are also utilized on high-end bikes. The disc is placed between two pads that are triggered by cylinders located on the stud shaft and supported by calipers. However, when brakes are subjected to structural and wear concerns, it is necessary to do analytical calculations in order to get temperature, heat flow, and heat produced, among other things, with the assistance of which the best material for the vehicle system is chosen. This work presents a complete examination of structural and thermal analysis for disc rotors. UG-NX was used for the design, while ANSYS WORKBENCH 19.2 software was used for the analysis. Finally, by comparing the acquired findings in the study, the needed profile and material with reduced thermal stresses and structural deformation is identified.

Key Terms **- Disc Brake, UG-NX, ANSYS WORKBENCH 19.2, Aluminum alloy, Stainless Steel, Gray Cast Iron, Strain, Stress, Total deformation.**

1. INTRODUCTION

Brakes assist in decelerating the vehicle and bringing it to a complete stop in a predetermined amount of time at a predetermined stopping distance or braking distance. The rule of conservation of energy governs the function of brakes. A brake is a mechanical device that slows down or stops motion by absorbing energy from a moving system. It's utilized to slow down or stop a speeding car, wheel, or axle, as well as to stop the most common friction motion. Figure 1.1 depicts a general overview of Brake.

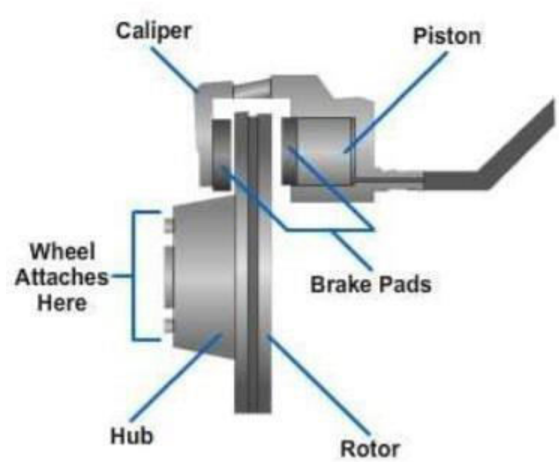

Fig.1.1 Overview of Brake

Because the energy received by brakes is released in the form of heat to the surrounding atmosphere, a braking system should meet the following conditions for proper operation:

- The brakes must also be powerful enough as to drive the vehicle to the complete stop within a short distance.
- The driver must maintain good control of the car when braking in order to avoid interlocking.
- The brakes should provide strong anti-fade qualities, which means that their efficacy should not degrade with time.
- The brake should also have high wear resistance.

1.1 The basic idea of braking mechanism.

- A brake is a device that provides simulated friction resistance to a moving machine part.
- While the braking system is in operation, the kinetic energy impacting the automobile is transformed into thermal energy.

1.2 The following variables influence brake design or capacity.

- The pressure unit that exists between the braking surfaces.
- The coefficient of friction between the tire's surfaces.
- The speed of the braking drum's rim.

1.3 The stopping distance is determined by

- A contact between the tire’s surface and the roadway.
- The status of the treads on the tires.
- Nature of the road surface

1.4 Stopping distance calculation

$$D=kv^2$$

Where D (in kilometers) is the distance between two points.
k = A constant dependent on the street and tire inflation.
v denotes the vehicle's speed per hour.
The value of k for the 4-wheel braking system is 1/25. 1/12 braking system for two wheels.

1.5 The equation evaluates braking effectiveness.

$$\eta=v^2/3D$$

Where v = the vehicle's velocity and D = the stopping distance.
The following elements influence braking effectiveness:

- Perfect 90%
- Outstanding 77%
- Good 70%
- Fairly 60%
- Poor at 50%
- Bad 37%
- Extremely poor 30%

Under Fair, it is very hazardous

1.6 Brake system function

- To stop the vehicle in the least amount of time feasible.
- To help with speed control.
- To assist in turning in a busy area.
- To keep the vehicle motionless in the operator's presence once it has been brought to a stop.

1.7 Classification of Brake

There are several types of brakes utilized in the automotive industry. These include main and secondary brakes, vacuum and air brakes, disc and drum brakes, and so forth. The following are the brake classifications.

1.7.1 In accordance with the purpose:

a) Primary or service brake:
When the vehicle is running, this brake is utilized to either stop or slow it down. This is the primary braking system, which is located in both the vehicle's back and front wheels.

b) Secondary brakes:
Secondary brakes, often known as parking brakes or emergency brakes, are used to keep

the vehicle stopped. Because it is normally operated by hand, it is also known as a hand brake. The primary function of this brake is to keep the vehicle motionless when parked.

1.7.2 In accordance with the construction:

a) Drum brake:

A drum is connected to the axle hub with this sort of brake, and a rear plate is installed on the axle casing. The back plate is composed of pressed stainless steel sheet. It supports the expander, anchor, and brake shoes.

b) Disk brake:

A disc brake is made up of a cast iron disc that is connected to the wheel hub and a stationary housing known as a caliper. The caliper is attached to a stationary portion of the vehicle and is divided into two pieces, each housing a piston. A friction pad is located between each piston and the disc and is maintained in place by holding pins, spring plates, and other mechanisms. The caliper has provisions for the fluid to enter and exit each housing. There are additional connections to other passageways for bleeding. Between the cylinder and the piston, each cylinder has a rubber sealing ring.

1.7.3 Based on source of power

a) Mechanical Brakes:

It is a kind of braking system in which the driver's brake force is transmitted to the ultimate brake drum or disc rotor by different mechanical linkages such as cylindrical rods, fulcrums, springs, and so on. To slow down or come to a complete halt, use the brake pedal.

b) Hydraulic Brakes:

Instead of mechanical linkages, brake fluid is used in hydraulic brakes for the transmission of brake pedal force in order to stop or de accelerates the vehicle.

c) Pneumatic or air brakes:

It is a form of braking system in which atmospheric air is utilized to convey brake pedal energy from the brake pedal to the final drum or disc rotor through compressors and valves.

d) Vacuum Brakes:

It is the traditional form of braking system in which vacuum inside the brake lines forces the brake pads to move, causing the vehicle to stop or decelerate.

1.8 Materials for brake linings

The brake lining material should be distinguished by the following characteristics:

- With minimal fading, it should have a high friction coefficient.
- It should be worn low.
- It should be highly resistant to heat.
- It should have a large ability for heat dissipation.
- It should have a low thermal expansion coefficient.
- It should be mechanically strong enough.
- Moisture and petroleum should not affect it.

1.9 Introduction of ANSYS

ANSYS is a general-purpose program used to model interactions between all fields of physics, electrical, turbulence, fluid mechanics, heat transfer, and electromagnetic engineering.

1.9.1 What's the ANSYS workbench?

ANSYS Workbench provides efficient tools to communicate with ANSYS. The solver family. Its framework offers special CAD functionality. Systems and the method of creation.

ANSYS Workbench consists of different programs.

- Mechanical for conducting structural and thermal analysis using an ANSYS solver. Meshing is also used in the mechanical specification.
- Geometry (Design Modeler) for the development and adjustment of CAD geometry for the planning of CAD geometry. Solid model for use in mechanics.
- Engineering Data on the description of material properties.

- Meshing Software to produce CFD and Explicit Dynamics mesh.
- Design Analysis for Optimization Evaluation.

2. LITERATURE REVIEW

Suraj S. Rana, et. al. (2016) illustrated the study of the coupled dry contact thermomechanical behavior between the brake pad and disc when subjected to braking. Transient thermal structural analysis was done in ABAQUS/CAE 6.12 considering five different materials of the brake disc and corresponding temperatures, shear, and von-misses stresses, and contact pressure values were simulated and the best suitable material was determined. The simulation results obtained were satisfactory when compared with specialized literature.

Coupled Transient Thermo-Mechanical Analysis of a disk brake is studied and analyzed. Following conclusions are elaborated from the present study

- AL MMC exhibited better thermal behavior as compared to other disc materials.
- Grey Cast Iron exhibited better shear properties.
- Von-Misses stresses were least in AMMC.
- GCI and AL MMC exhibited better characteristics than other disc brake materials. However, the thermal conductivity of AL MMC is almost thrice of GCI. Also, density is less than half of GCI, hence AL MMC is lighter than GCI, which can contribute to better braking performance.

G.V.R. Seshagiri Rao, et. al. (2017) dealt with the design and fabrication of the eddy current multi caliper brake exclusively for the two-wheeled vehicles. This Brake was a combination of a Foucault brake and a Conventional disc brake. This has both the advantages of an Eddy current brake and a disc brake. The Brake was modified with optimized materials like Aluminum alloys and Tungsten Alloys. The Tungsten alloys show the required properties of an eddy current brake and satisfy the forces seen in a disc brake. These materials can be implemented for commercial use. Several other factors affecting the braking can also be minimized by using electromagnets than permanent magnets. These can help the actuation of the brake with ease when compared to that of a complicated hydraulic actuated disc brake.

Ayush Gupta, et. al. (2017) gave an idea about the design and thermal analysis by analyzing the ANSYS workbench of a two-wheeler disk tray comparing the initial temperature and dissipated total heat. The design was drawn out of the true globe. Bajaj's dimensions were drawn up and published in solid works for assessment; materials such as aluminum alloy, cast iron, or stainless steel were chosen to compare with distinct models at two distinct car speeds. After all the study, the outcome is discovered to conclude the finest material with a model that also compares the percentage increase in the final temperature and the dissipated total heat flux.

- Disc plate design should be thoroughly chosen with the least weight and more holes of different sizes so that the highest temperature distribution outcomes can be achieved.
- The results we obtained show that aluminum alloy yields better outcomes than gray cast iron compared by stainless steel, which provides greater heat flux and therefore maximum heat dissipation.
- Most of the disk brakes are produced of gray cast iron because it is cheaper and easier to machine and the findings are close to aluminum alloy.
- It indicates an increase of roughly 70% in the complete flux and an increase of

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60% in the lowest temperature at 80 km / h.

Thus, a vehicle's optimum velocity should be about 50 km / h.

Prof Anshul Choudhary et al. (2017) used ANSYS 14.5 to determine the von-misses stress, deformation generated, and Maxi heat dissipation in the brake disc at varied braking circumstances.

- In our present investigation, we took several disc rotor profile shapes and discovered that the 3-star shape on the disc rotor delivers superior comparison results than others.
- It also determines that for the two materials grey cast iron and steel, three star configurations provide the least amount of pressure in the disc rotor.
- Thermal study is performed on distinct profile shapes on the disc rotor and it is discovered that the maximum heat dissipation effect is achieved when all three forms are stacked diagonally (disc 5) then the disc rotor. (The greater the temperature differential, the greater the rate of heat / cooling action.)

3. METHODOLOGY

3.1 Development tools

The dimensions of the disk brake were collected from the Yamaha SZ-R model to continue with this research. The disk brake assembly 3D model has been built in UG-NX.

a) Siemens NX

NX is a professional, high-end CAD / CAM / CAE software, originally known as "UG," that has been run by Siemens PLM Software since 2007. In 2000, Unigraphics purchased SDRC I-DEAS and began an endeavour to merge parts of both software products into a single solution, which became Unigraphics NX. Figure 3.1 depicts the first view of the UG-NX.

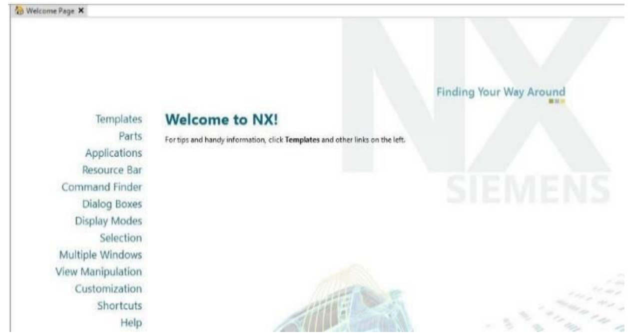

Fig. 3.1 starting view of UG-NX

NX competes directly with CATIA, Creo, Autodesk Inventor, and Solid Works.

b) ANSYS

The ANSYS Workbench environment is a simple finite-element analysis tool that may be used in combination with CAD and/or Design Modeler systems. ANSYS Workbench is a software system for structural, thermal, and electromagnetic performance. Figure 3.2 depicts the ANSYS 19.2 initializing view.

Fig.3.2 Initializing view of ANSYS 19.2

3.2 Design procedure

Brake system is one of the modern auto motive's most important aspects. Its responsibility is to reduce and stop the vehicle's velocity. Disc brake shifts the rotating components (wheels) kinetic energy to heat and dissipates it to air. Specific sizes of the disk

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brake are modeled and simulated and analyzed using Finite Elements software (ANSYS 19.2).

Three disk brake materials, Grey Cast Iron, aluminum alloy and stainless steel were selected.

a) Disk rotor modeling

Exact modelling of the brake disc is extremely difficult, and certain assumptions must still be made to simulate any complicated design. These assumptions are developed by taking into account the theoretical calculation's challenges well as the relevance of the parameters used and those ignored. Depending on the information and precision needed in modeling, the assumptions are always produced. The assumptions produced during the process modeling are provided below:

- The disk's substance is thought to be homogenous and isotropic.
- The domain is thought to be a symmetrical axis.
- During the assessment, the impacts of inertia and body force are negligible.
- The assessment does not determine the disk brake life.

Using UG-NX, disk brake modeling is produced. 3D Model view of Brake Disc show in fig. 3.3. The disk is 122.5 mm in radius and 40 mm in thickness.

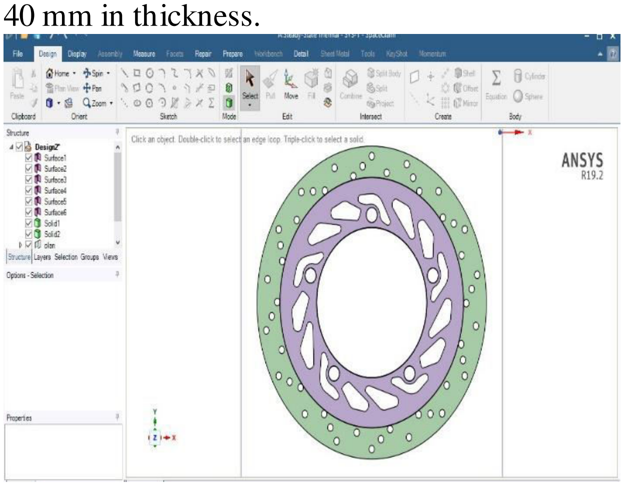

Fig.3.3 3D view of disc

b) Transformation of model

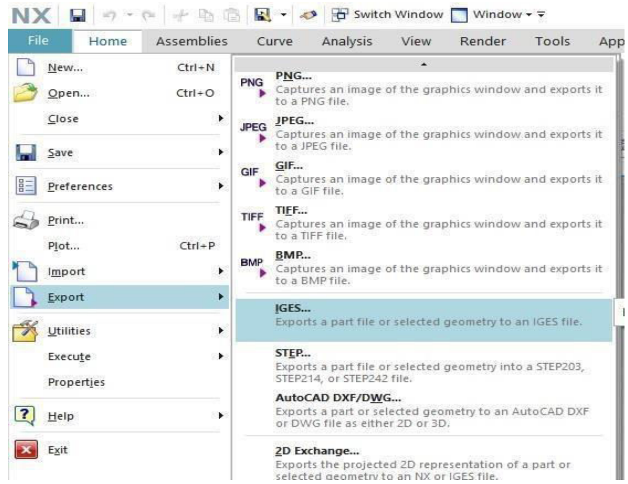

Fig.3.4 Transformation of model

Then the model is transformed to the most appropriate and simple access IGES format for any other software. Using the IGES format the Brake model can be imported from UG-NX to ANSYS.

c) Meshing

Meshing is intended to convert an entire object into a finite number of components known as discretization. ANSYS was used to perform brake disk meshing. Tetrahedral shape as show in fig. 3.5 is the component used for meshing.

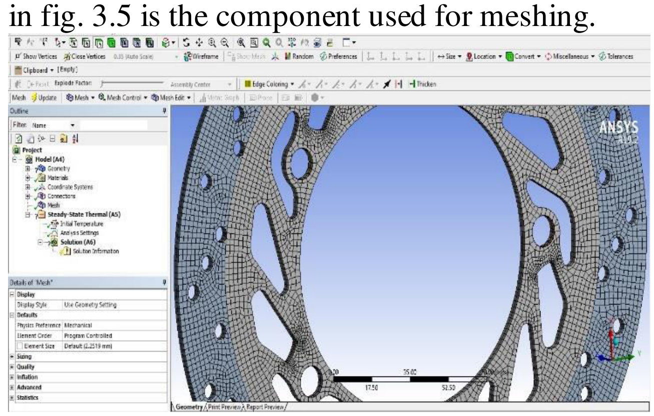

Fig.3.5 Mesh view of disc

3.3 Materials for Disk Brake

Aluminum, gray cast iron, stainless steel have been used as disc brake in this study.

A Schematic view of materials selection in workbench 19.2 is show in fig. 3.6.

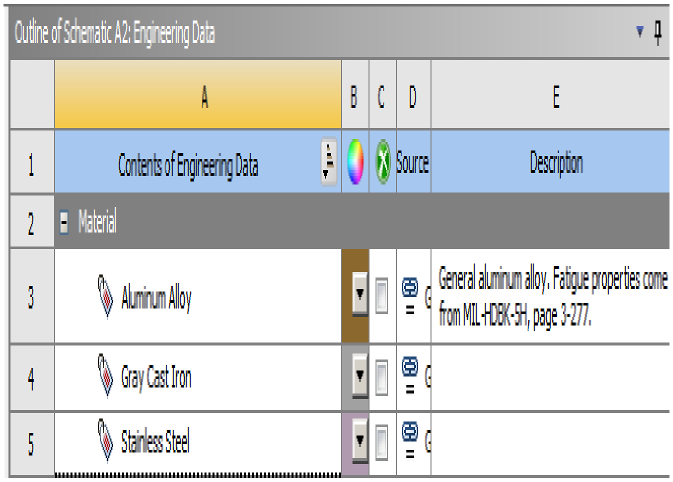

Fig.3.6 Schematic view of materials in workbench 19.2

Mechanical properties of selected materials is shown in table 3.1.

Properties	Stainless steel	Gray cast iron	Aluminum alloy
Density (kg/m^3)	7950	7350	2780
Young's Modulus (GPa)	190	125	70
Poison's Ratio	0.30	0.25	0.33
Thermal Conductivity (w/m-k)	26	54.5	205
Specific Heat (J/kg-k)	460	590	920
Coefficient of friction	0.22	0.2	0.33

Table: 3.1 Properties of material

4. RESULTS AND CONCLUSION

4.1 Specimen parameters

To start with this research, the sizes of the disk brake were accrued from the Yamaha SZ-R model. The 3D model seize meeting were built in UG-NX.

DIMENSION OF THE ROTOR DISC	245 mm
MATERIAL OF ROTOR DISC	Grey Cast Iron
AREA OF PAD BRAKES	0.0047 m^2
MATERIAL FOR PAD BRAKES	Asbestos
FRICTION COEFFICIENT (WET)	0.07-0.13
FRICTION COEFFICIENT (DRY)	0.3-0.5
TEMPERATURE MAXIMUM	100 °C
OPTIMAL PRESSURE	1MPa (10^6 Pa)

Table.4.1 Parameters of disc brake of Yamaha SZ R

4.2 Calculations

a) The tangential forces between the pad and the rotor (inner face)

FTRI denotes the normal force between the pad brake and the rotor (Inner)

μ=Friction coefficient = 0.5

Pad brake area = A

FTRI= μ.FRI

FRI=$p_{max}/2 \times A$

FTRI = 0.5 x 0.25 x 10^6 x 0.0047

=587.5 N

Tangential force between the FTRO pad and rotor due to the same normal force and the same material is equal to FTRI.

b) Brake torque (TB)

Assumption of equal friction coefficients and normal pressures on the faces:

$$TB = FT.R$$

$$TB = (587.5)\ (122.5\times10\text{-}3)$$

$$= 71.96\ \text{Nm}$$

Where, TB = Brake torque

μ is the friction coefficient, FT is the total normal brake force (internal and external) = 587.5 N, and R is the radius of the rotor disc.

c) Brake Distance

We understand the tangential braking force at the brake contact point and

Work done=*FT*

Where FT denotes the total normal forces acting on the disc brake and x is the distance travelled by the vehicle (in metres) before coming to rest. We comprehend the kinetic energy of the vehicle.

K.E. – $mv^2/2$

Where m is the car mass and v is the car speed. To stop the car, the friction function must be equivalent to the vehicle's kinetic energy. Comparing Eq.

v = 60 km/h = 16.66 m/s = 134 kg (Vehicle dry weight)

As a result,

x = (134 (16.66)2 / (587.5) =63.30 m

d) Braking generates heat.

Heat (J/s) generated in the disc rotor

$$Q=m.C_p.$$

Heat Flux (W/m^2)

Where the disc weight is 0.768 kg, the specific heat capacity is 490 J / kg K, the time needed to stop the vehicle is 6 seconds, the temperature differential created (T) is 15 degrees Celsius, and the disc region is 0.04714 m^2.

Q = 0.768 × 490 × 15= 5644.8 J

Heat flux = (5644.8 /6) / 0.04714 = 19857.57 W/m^2

Thermal gradient =19857.57/ 53.3=372.56 K/m

4.3 Results

a) Stainless steel

Then after, evaluation in **ANSYS 19.2**, Value of Total deformation, Equivalent Stress, Equivalent Strain.

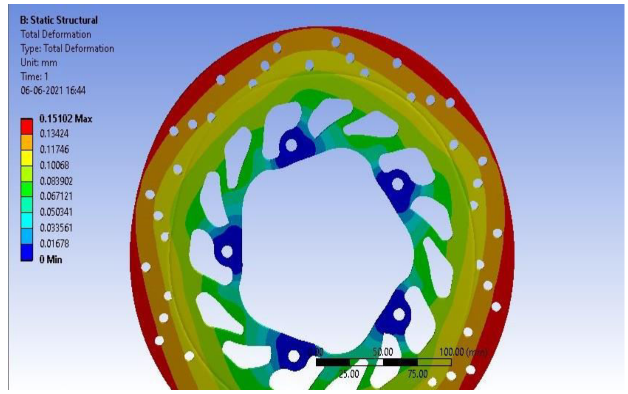

Fig.4.1 Total Deformation

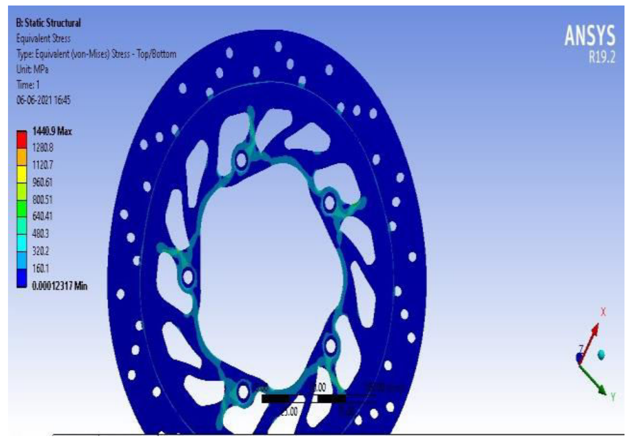

Fig.4.2 Equivalent stress

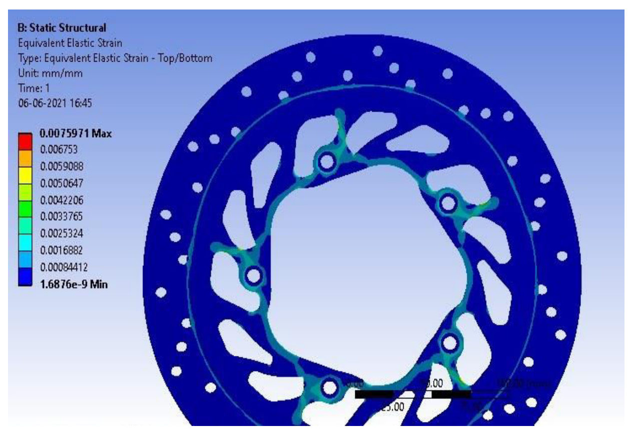

Fig.4.3 Equivalent strain

b) Gray Cast Iron

Then after, evaluation in **ANSYS 19.2**, Value of Total deformation, Equivalent Stress, Equivalent Strain.

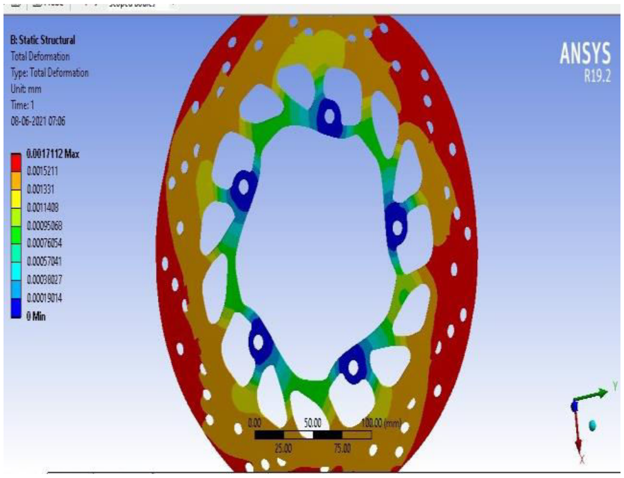

Fig.4.4 Total Deformation

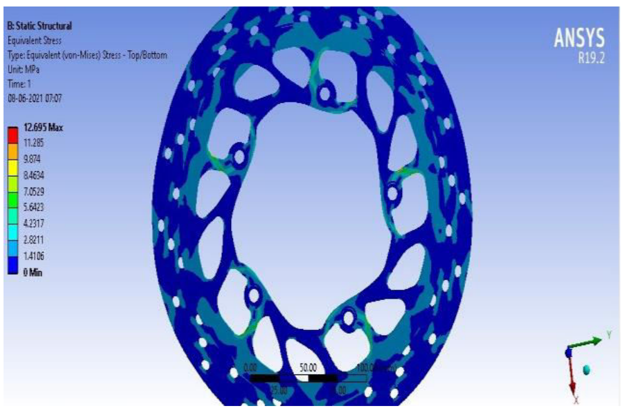

Fig.4.5 Equivalent Stress

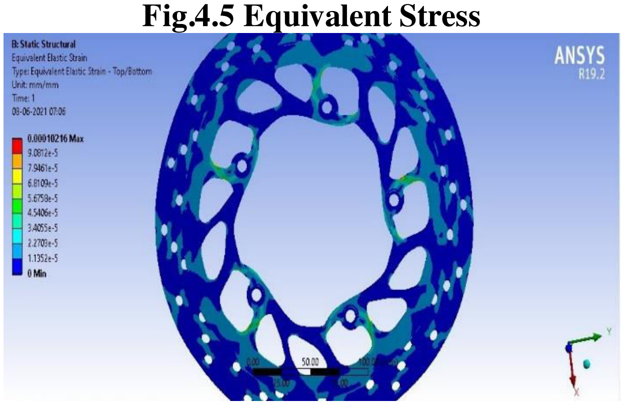

Fig.4.6 Equivalent Strain

c) Aluminum Alloy

Then, following evaluation in ANSYS 19.2, the value of Total deformation, Equivalent Stress, Equivalent Strain.

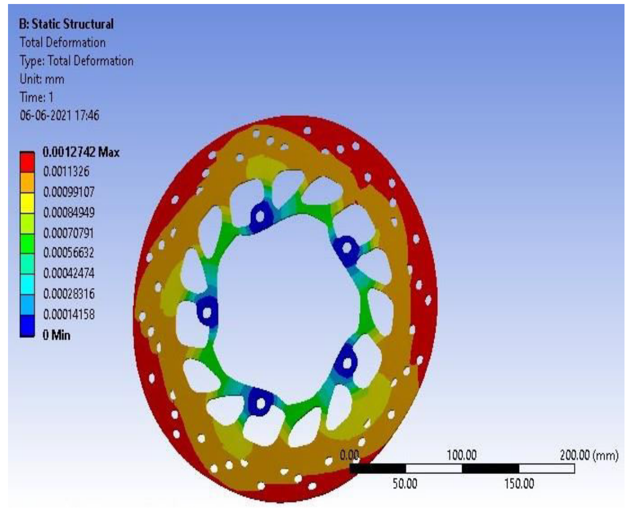

Fig.4.7 Total Deformation

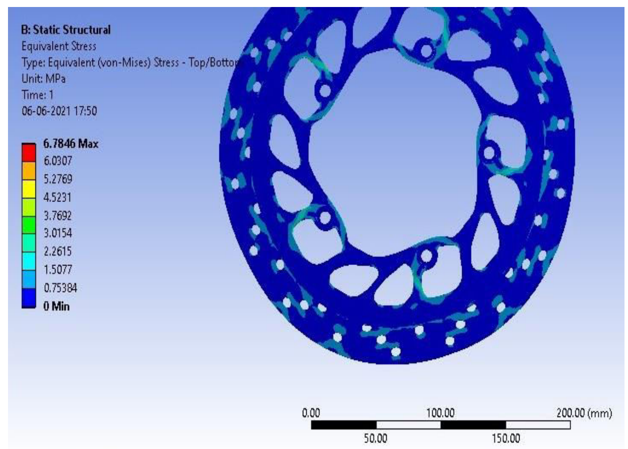

Fig.4.8 Equivalent Stress

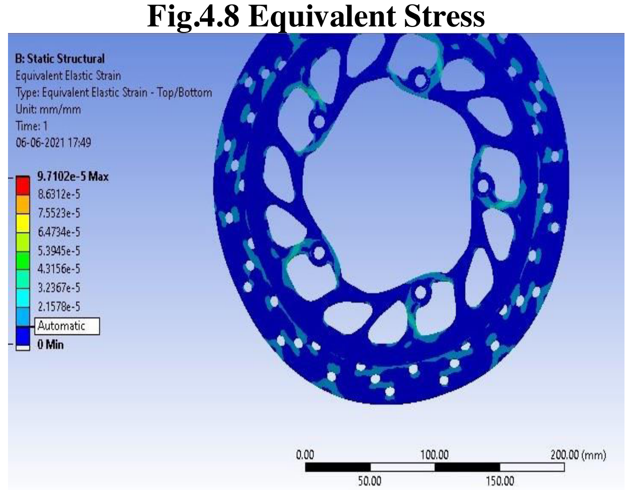

Fig.4.9 Equivalent Strain

4.4 CONCLUSION

Results	Stainless steel		Gray Cast Iron		Aluminum Alloy	
	Max	Min	Max	Min	Max	Min
Total Deformation (mm)	0.15102	0	0.001711 2	0	0.00127 42	0
Equivalent Stress (MPa)	1440.9	0.00012317	12.695	0	6.7846	0
Equivalent Strain	0.0075971	1.6876 e-9	0.00010216	0	9.7102 e-5	0

Using Ansys software, a computer-aided disk brake model can be simulated and will best match the experimentally acquired outcomes. It can be concluded from the outcome table that the material can play a very significant part in the event of a coefficient of heat transfer. More than any other portion of the disk will affect the disk's contact region. The Gray Cast iron disk considered to be able to resist this stress. The advance experiment can therefore be carried out with added stress and analyzed. Modifications on structural design can be produced to enhance the efficiency of the disk brake, material and design. A model with ventilated region is also suggested that can resist structural and thermal differences.

Table.4.2 Estimation of results

This research can provide a helpful design tool and enhance disk brake system brake efficiency. We can conclude from Table 4.2 that all the values acquired from the evaluation are below their permissible values. The brake disk design is therefore secure depending on the requirements of strength and rigidity.

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