Design and Transient Thermo-Structural Analysis of Wind Turbine Disc Brake

T. Babu, R.V. Aswin, P. Aravind, V. Prasanna

Abstract*: Disk brake is a major component in wind turbine to reach rest position. While applying braking effect disc brake receives Kinetic or static force due to powerful pressure applied on it. While driving the wind turbine, the driving shaft receives increase in sliding velocity and specific pressure. Due to that it receives high wear and increase in temperature. In order to solve this problem, computational methods are used to simulate to identify the problems and do necessary improvements during braking. The numerical simulation is carried out to predict the thermo-structural behavior of the brake disc. This analysis is carried for the two different materials such as steel and aluminum alloy. This analysis is simulated using finite element code called ANSYS. This study shows how the heat generated by the brake disc influence the structural properties of disc and to predict the fatigue life of the brake disc. Comparison of existing material with aluminum alloy brake disc has been discussed.

Keywords: Disk Bake, Wind Turning, Thermo-Structural.

I. INTRODUCTION

Nowadays, the condition of increased usage of electricity has created a demand for more production. Researchers are trying to find various alternate ways to produce electricity with the help of natural resources available. These resources are termed as renewable resources as we can use them as long as they deplete. Wind energy or Wind power generation is considered as a well-known renewable energy because of its economic and environmental friendly production. Wind energy is nothing but the use of wind(air) flow to pass through the wind turbine blades to provide us with necessary mechanical power in order to generate electricity with the help of electric generators. Wind energy is widely popular and considered due to its clean electricity production and moreover it doesn't cause harm to the environment by producing harmful and greenhouse gas. A number of wind turbines together is called as a wind farm where they are linked to a common electric power transmission network. One can construct a wind farm either onshore or offshore.

Generally onshore wind farm are considered as they are inexpensive, but due to the space constraints offshore wind farms are considered as they do not the local people. But the major disadvantage of offshore wind farm is that they require more maintenance and the cost of construction is comparatively high compared to onshore construction. Wind energy production is unpredictable. It purely depends upon the strength of the wind current and the variations of seasons and climatic changes. As a portion of wind power in a region increases, they need to be an up gradation of the grid. In order to increase the quality and effectiveness of the wind energy various research and wind turbine emulators are being developed to study the behaviour of the aerodynamics flow of wind blades and wind turbine energy production.

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II. LITERATURE SURVEY

ANURAG PATEL [1], explained in his study that, model is created using CREO parametric 2.0 then, for analysis ANSYS is used. In ANSYS two materials used namely cast iron and stainless steel and thermo-structural analysis was made. In this analysis temperature distribution, amount of heat generated or lost & thermal fluxes were analysed. The result shows the temperature generated using cast iron disc brake is 30% less than stainless steel. But, comparing the deformation cast iron deforms 27% more than stainless steel. **APOORVS [2]**, in general cast iron is used as a material for disc brakes, instead of that Aluminium Metal Matrix Composite is used to analyse and evaluate the performance of brake disc rotor under severe braking condition. Thermal and static structural analysis was carried out and final result shows it is safe to use composite disc brake instead of cast iron disc brake. **Y.V.N Chandana [3],** A metal matrix composite $AlSiC_p$ is used to analyse the transient thermal analysis. Cast iron is replaced by $AlSiC_p$ and both the disc brakes are analysed and results were compared. In the conclusion composite disc brake gives good performance comparing cast iron disc brake. Also, the heat dissipation is more comparing solid disc brakes. **D. Augustin Rajasekar [4],** Whenever a wind turbine brakes it undergoes extreme stresses. To overcome these stresses, we need to use special alloys in manufacturing the brakes which are capable of withstanding high temperatures of 700^{o}c. The brake system is activated after the wind turbine blades furl. Normally e brakes are applied to stop the shaft from rotating. The mechanical brakes are applied in case of emergency alone. Using FDD(Fault Detection and Diagnosis) various failure modes has been studied. Studying the various braking systems and other components used in wind turbine we can improve the 'sweating' of the wind turbine. **B. Amulnag [5],** The brakes in wind turbine are applied when the blades over speed and at such cases emergency brakes are pressed against the shaft. Due to this we should carefully select the material used in brake pad as the heat is not dissipated in the atmosphere quickly. Thermal conductivity of the material plays an important role in governing the heat generation of the disc brake. While braking Thermo Elastic Instability (TEI) acts at the friction of the ring surface creating erratic hot bands formation around the rubbing path, resulting in the development of so-called hotspots. FEA comparison has been used to compare between two materials. The disc brake can be either solid or ventilated. The discs which we use in wind turbine are comparatively bigger than the disc brakes which we use in automobile and bikes.

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Ventilated disc brakes are used in automobile as the dissipate the heat, but these types of disc cannot be used in wind turbines as they might lead to crack. Considering safety wind turbines use solid brakes instead of ventilated disc brakes.

III. MODELING

Modelling of the wind turbine brake disc is done using Pro/ENGINEER which is a commercial CAD/CAM package that is widely used in industry for CAD/CAM applications. The method of constructing a model of an object is very similar to that followed in the production of a physical component.

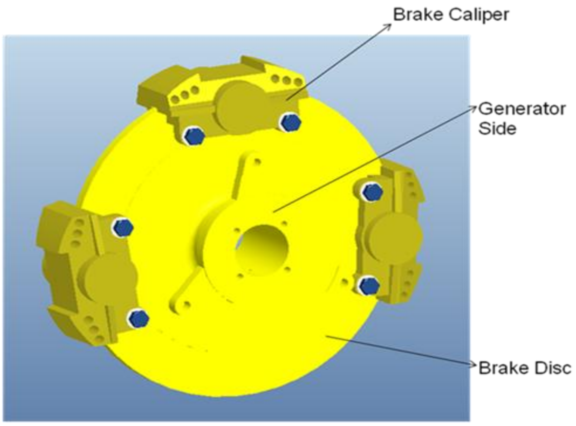

Fig 1.1 Model of wind turbine disc brake with three callipers

A. Basic Requirements of a Brake Disc

- The brakes must be strong enough.
- The brakes must have well anti fade characteristics i.e. their effectiveness should not decrease with constant prolonged application.
- The brakes should have good anti wear properties.

B. Common Problems

In the course of brake operation, frictional heat is dissipated mostly into pads and disc, and an occasional uneven temperature distribution on the components could induce severe thermo elastic distortion of the disc. The thermal distortion transforms the normal flat surface into a highly deformed state, through the thermo elastic transition. This may invoke,

- Transient thermoelastic distortion of the disc due to uneven temperature distribution
- Localized bulging due to frictional heating
- Contact pressure increases due to localized bulging
- Local hot spots due to frictional heating
- Thermal crack on the disc
- Due to the above deterioration in braking performance

The brakes comprising of brake disc and calipers are designed or modelled in such a way that the above-mentioned problems are reduced or minimized to a certain extent. By doing this, the life span, efficiency and performance can be improved further

C. Working of the disc brake

Wind turbines are equipped with various safety devices to ensure safe operation during their lifetime. One of the most important safety devices is the braking system.
The braking system of a wind turbine ensures that it automatically stops when it detects that one of its critical components does not work properly

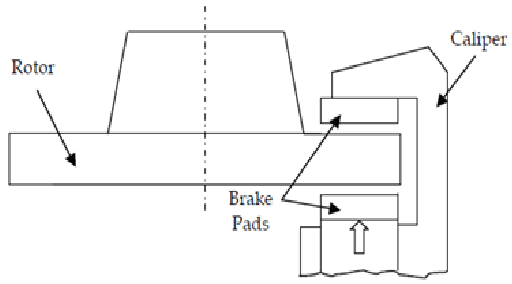

Fig 1.2 Schematic diagram of Wind turbine brake

IV. MATERIAL SELECTION

Steel and Aluminum alloy were selected for the modelling and analysis of the wind turbine brake disc. The material properties of both the alloys are tabulated below

Table 1.1 Properties of Steel

Material Properties (GG-35)	*Disc*
Elastic modulus, *E* (MPa)	210000
Thermal conductivity, K (w/m K)	50
Thermal expansion, α (10^{-6} / *k*)	11
Coefficient of friction, µ	0.4
Density, ρ(kg/m^3)	7400
Specific heat, C (J/Kg K)	540
Poisson's ratio, ν	0.3
Operation Conditions	
Angular velocity, ω (rad/s)	150
Hydraulic pressure, *P* (MPa)	1

Table 1.2 Properties of Aluminum

Material properties (CGI (GJV 450))	*Disc*
Elastic modulus, *E* (Gpa)	145
Thermal conductivity, K (w/m K)	36
Thermal expansion, α (10^{-6} / *k)*	12
Coefficient of friction, µ	0.4
Density, ρ(kg/m^3)	6800
Specific heat, C (J/Kg K)	530
Poisson's ratio, ν	0.3
Operation Conditions	
Angular velocity, ω (rad/s)	150
Hydraulic pressure, *P* (MPa)	1

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V. ANALYSIS

After designing the brake calliper, it must be analysed. So, we used an analysis software called ANSYS to predict the disc brake's behaviour in real-world environments considering the above specified materials.

Ansys is a finite element analysis software used to simulate engineering problems for getting approximate solutions. The software creates simulated computer models of structures, electronics, or machine components to simulate strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow & other attributes. Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests. Because of its range and flexibility as an analysis tool, it is preferred widely in plethora of industries.

Here, Thermal analysis is performed over the brake disc to calculate the thermal distribution and other related parameters. Typical thermal quantities are,

1. The temperature distribution
2. The amount of heat lost or gained
3. Thermal fluxes

A. Thermo elastic behavior in the repeated brake application

To investigate the transient thermo elastic analysis behavior of Disc brake, the ANSYS simulation is obtained in repeated brake applications. In, variation of the rotating speed during braking must be determined through vehicle dynamics. However, in this study, the rotating speed of Disc was a known value. The time history of hydraulic pressure *P* and angular speed ω assumed for brake cycle is shown in Fig –9.1 One cycle is composed of braking (4.5 sec), acceleration (10.5), and constant speed driving (5 sec). In each process, the hydraulic pressure *P* was assumed to linearly increase to 1 *MPa* by 1.5 sec and then kept constant until 4.5 sec. Also, the angular velocity ù was assumed to linearly decay and at last zero at 4.5 sec. The time step Δt =1 sec was used in the computations. The heat convection coefficient is considered as $h = 100\ w / m^2$ K.

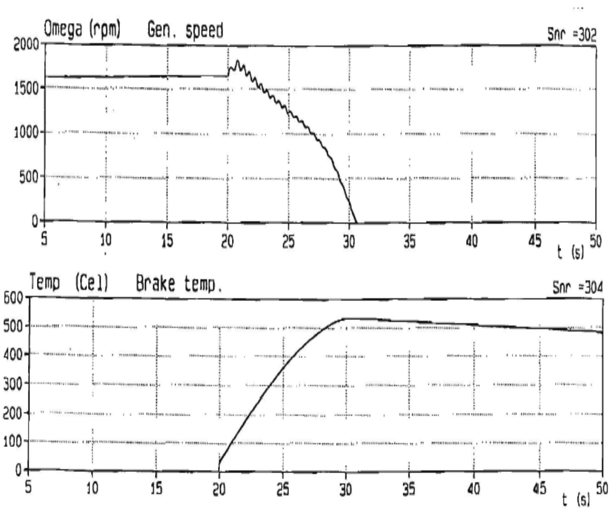

Fig 1.3 Time history of brake history

The temperature distributions show high gradients near the region of friction surfaces and are almost symmetric about the Disc's mid plane at the early steps of brake application. Analysis is carried out with two different materials considering their related properties. By comparing the two materials the result shows the Aluminum Alloy shows the less temperature development across the friction surfaces.

As the braking step progresses, due to the non-uniform growth of normal pressure on the friction surfaces, the distribution of temperature of disc brakes becomes non-symmetric and unstable. The heat flux distribution along braking surface of the present disc brakes at various braking steps is illustrated in Fig 1.4 and 1.5. In this repeated heat flux is applied with respect to various braking and the figures shows the hot spots in the Disc which leads to thermo elastic behavior. This is the phenomenon of thermo elastic instability. By comparing the two materials the result shows the Aluminum Alloy shows the less heat flux accumulation and reduced intensity of hot spots.

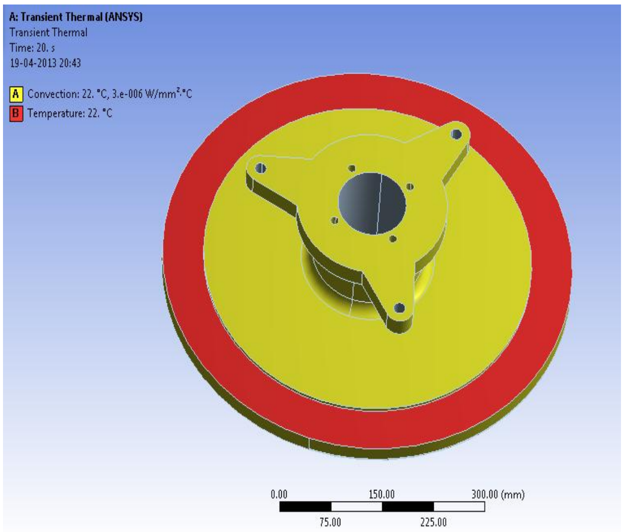

Fig 1.4 Thermal boundary condition of Wind turbine disc brake

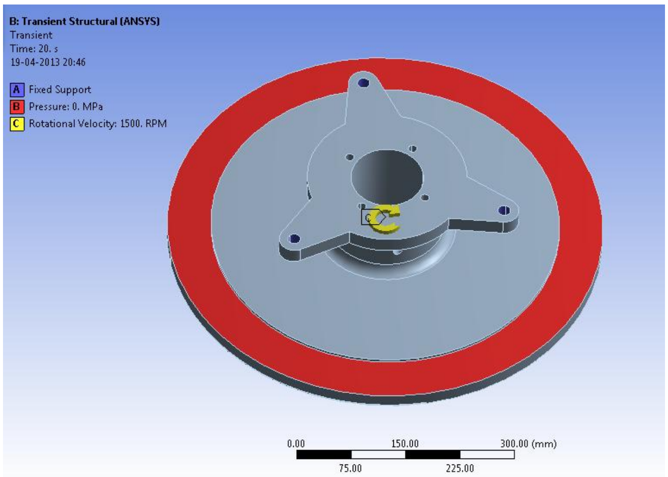

Fig 1.5 Structural Boundary condition of Wind turbine Disc Brake

Now temperature distribution, stress, strain, fatigue life and deformation for both the materials are calculated. The fig 1.6-1.15 shows a clear view about the stress developed during braking process due to the uniform pressure applied on the Disc and due to the frictional heating by comparing the two materials the result shows the Steel shows the less stress development.

The deformed shape of the Disc is clearly shown in the fig 1.7 & 1.12 in that Steel shows a less deformation.

B. Results

For Steel

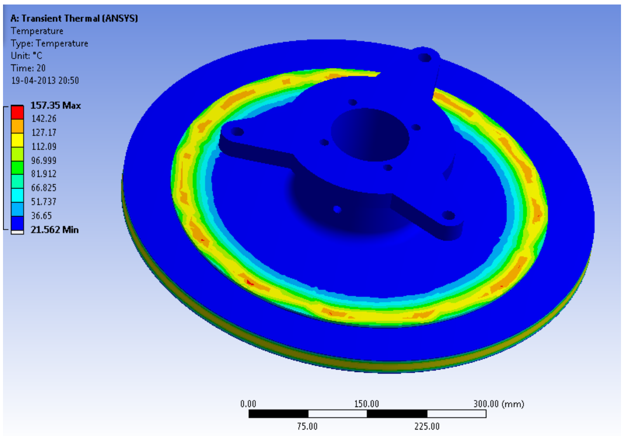

Fig 1.6 Temperature distribution

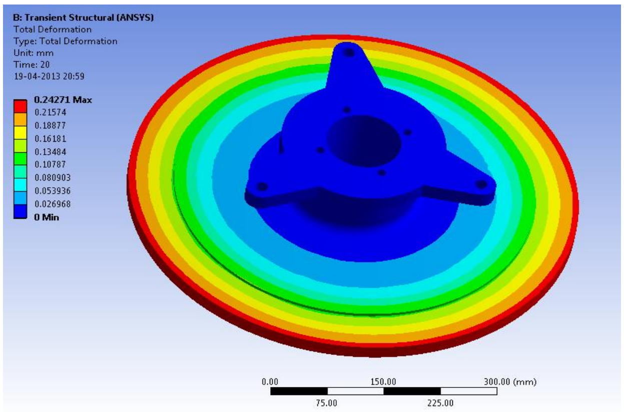

Fig 1.7 Deformation

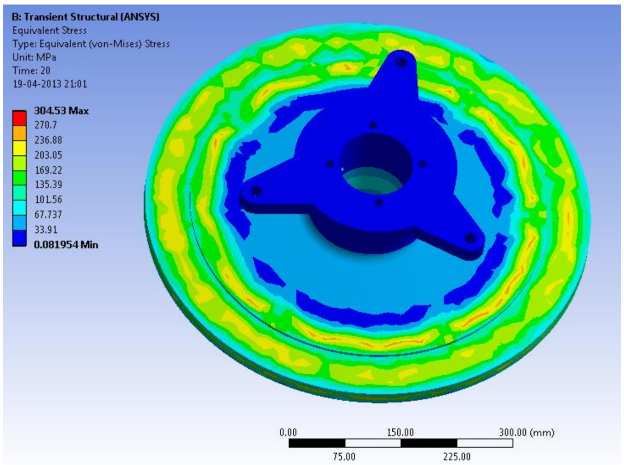

Fig 1.8 Von-mises Stress

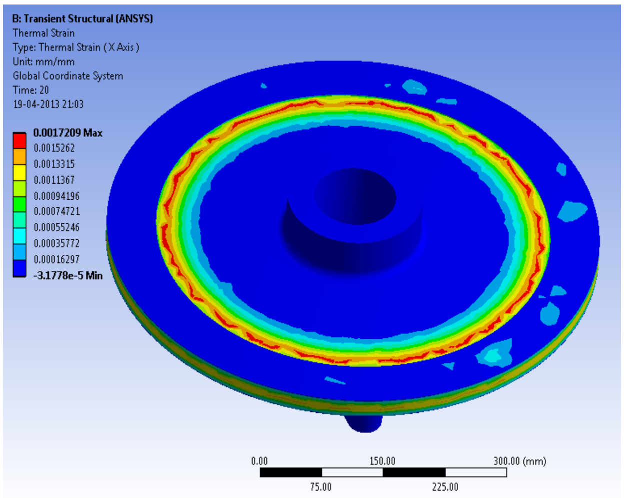

Fig 1.9 Thermal Strain

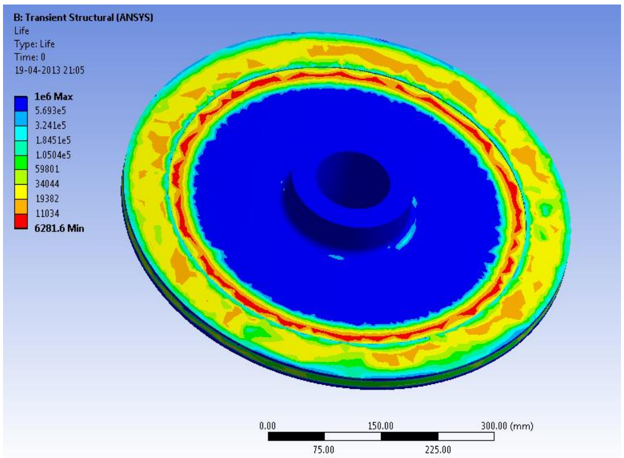

Fig 1.10 Fatigue Life

For Aluminium

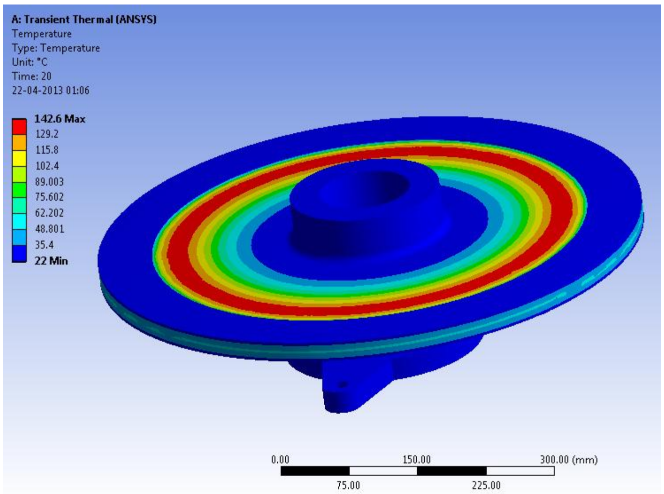

Fig 1.11 Temperature distribution

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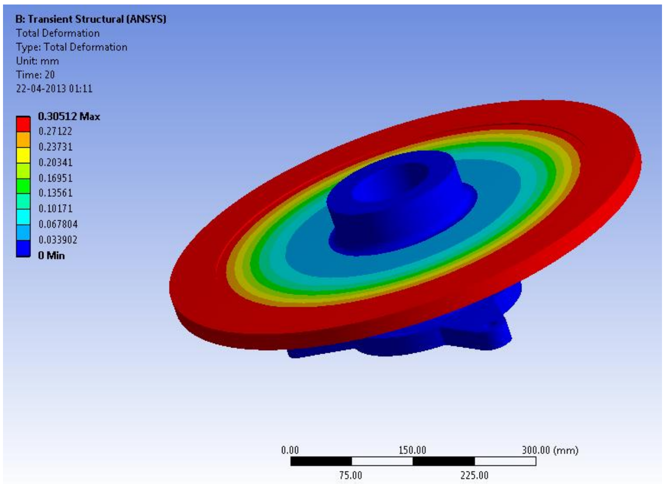

Fig 1.12 Deformation

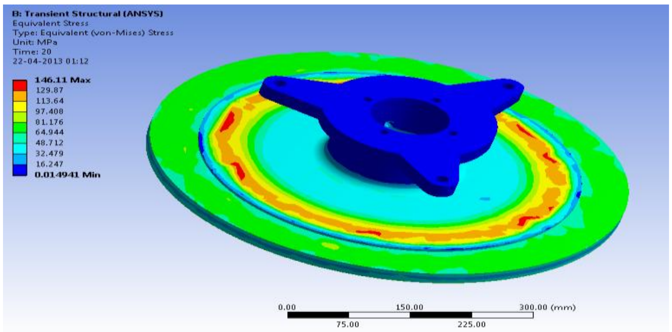

Fig 1.13 Von-mises Stress

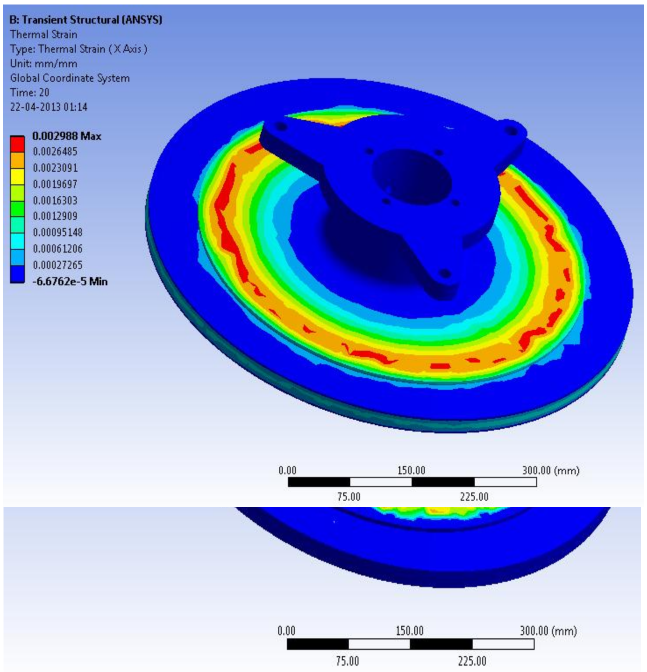

Fig 1.15 Fatigue life

VI. CONCLUSION

The transient thermo elastic analysis of Disc brakes in repeated brake applications has been performed.

ANSYS code is applied to the thermo elastic contact downside with resistance heat generation.

To obtain the simulation of thermo elastic behaviour appearing in Disc brakes, the coupled heat conduction and elastic equations are solved with contact problems. Also, the fully implicit scheme is used to improve the accuracy of computations in the transient analysis. Through the axis symmetric Disc brake model, the TEI phenomenon on each of the friction surfaces between the contacting bodies has been investigated. The present study can provide a useful design tool and improve the brake performance of Disc brake system. Table 1.3 shows the values obtained from the analysis are less than their allowable values. Hence the brake Disc style is safe supported the strength and rigidity criteria. Comparing the different results obtained from analysis in table 1.3, it is concluded that Disc brake with Aluminium Alloy is the appropriate combination for the present application.

Table 1.3 Results and discussions

Sl.no.	Description	Steel	Aluminum Alloy
1.	Nodal temperature (k)	158	142
2.	Von Mises stress (Mpa)	304	146
3.	Deformation (mm)	0.2276	0.3345

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