Design and Thermal Analysis of a Disc Brake in Car by using Finite Element Method

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Abstract— The disc brake is a device for slowing or stopping the rotation of a wheel. A brake disc (or rotor), usually made of cast iron or ceramic composites (including carbon, Kevlar and silica), is connected to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads (mounted on a device called a brake caliper) is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop. Brakes convert friction to heat, but if the brakes get too hot, they will cease to work because they cannot dissipate enough heat. This condition of failure is known as brake fade. Disc brakes are exposed to large thermal stresses during routine braking and extraordinary thermal stresses during hard braking. The aim of the project is to model a disc brake used in Honda Civic. Structural and Thermal is done on the disc brake. The materials used are Stainless Steel, Cast Iron and Aluminum Alloy. "Analysis is also done by changing the design of disc brake. Actual disc brake has no holes; design is changed by giving holes in the disc brake for more heat dissipation." Modeling is done in Pro/Engineer and analysis is done in Ansys.

Key words: Design and Thermal Analysis, Mechanically, Hydraulically

I. INTRODUCTION

A brake is a device which inhibits motion. Its opposite component is a clutch. The rest of this article is dedicated to various types of vehicular brakes.

Most commonly brakes use friction to convert kinetic energy into heat, though other methods of energy conversion may be employed. For example regenerative braking converts much of the energy to electrical energy, which may be stored for later use. Other methods convert kinetic energy into potential energy in such stored forms as pressurized air or pressurized oil. Stillo the braking methods even transform kinetic energy into different forms, for example by transferring the energy to a rotating flywheel.

Brakes are generally applied to rotating axles or wheels, but may also take other forms such as the surface of a moving fluid (flaps deployed into water or air). Some vehicles use a combination of braking mechanisms, such as drag racing cars with both wheel brakes and a parachute, or airplanes with both wheel brakes and drag flaps raised into the air during landing.

Since kinetic energy increases quadratically with velocity (K = mv2 / 2), an object traveling at 10 kilometers per second has 100 times as much energy as one traveling at 1 kilometer per second, and consequently the theoretical braking distance, when braking at the traction limit, is 100 times as long. In practice, fast vehicles usually have significant air drag, and energy lost to air drag rises quickly with speed.

Almost all wheeled vehicles have a brake of some sort. Even baggage carts and shopping carts may have them for use on a moving ramp. Most fixed-wing aircraft are fitted with wheel brakes on the undercarriage. Some aircraft also feature air brakes designed to reduce their speed in flight. Notable examples include gliders and some World War II-era aircraft, primarily some fighter aircraft and many dive bombers of the era. These allow the aircraft to maintain a safe speed in a steep descent. The Saab B 17 dive bomber used the deployed undercarriage as an air brake.

Friction brakes on automobiles store braking heat in the drum brake or disc brake while braking then conduct it to the air gradually. When traveling downhill some vehicles can use their engines to brake.

When the brake pedal is pushed the caliper containing piston pushes the pad towards the brake disc which slows the wheel down. On the brake drum it is similar as the cylinder pushes the brake shoes towards the drum which also slows the wheel down.

A. Types Of Brakes

Brakes may be broadly described as using friction, pumping, or electromagnetic. One brake may use several principles: for example, a pump may pass fluid through an orifice to create friction.

Frictional brakes are most common and can be divided broadly into "shoe" or "pad" brakes, using an explicit wear surface, and hydrodynamic brakes, such as parachutes, which use friction in a working fluid and do not explicitly wear. Typically the term "friction brake" is used to mean pad/shoe brakes and excludes hydrodynamic brakes, even though hydrodynamic brakes use friction.

Pumping brakes are often used where a pump is already part of the machinery. For example, an internal-combustion piston motor can have the fuel supply stopped, and then internal pumping losses of the engine create some braking. Some engines use a valve override called a Jake brake to greatly increase pumping losses. Pumping brakes can dump energy as heat, or can be regenerative brakes that recharge a pressure reservoir called an hydraulic accumulator.

Electromagnetic brakes are likewise often used where an electric motor is already part of the machinery. For example, many hybrid gasoline/electric vehicles use the electric motor as a generator to charge electric batteries and also as a regenerative brake. Some diesel/electric railroad locomotives use the electric motors to generate electricity which is then sent to a resistor bank and dumped as heat. Some vehicles, such as some transit buses, do not already have an electric motor but use a secondary "retarder" brake that is effectively a generator with an internal short-circuit.

Fig. 1: Disc Brake of a car

II. MODELING OF DISC BRAKE IN PRO-E

Pro/ENGINEER Wildfire is the standard in 3D product design, featuring industry-leading productivity tools that promote best practices in design while ensuring compliance with your industry and company standards. Integrated Pro/ENGINEER CAD/CAM/CAE solutions allow you to design faster than ever, while maximizing innovation and quality to ultimately create exceptional products.

Customer requirements may change and time pressures may continue to mount, but your product design needs remain the same - regardless of your project's scope, you need the powerful, easy-to-use, affordable solution that Pro/ENGINEER provides.

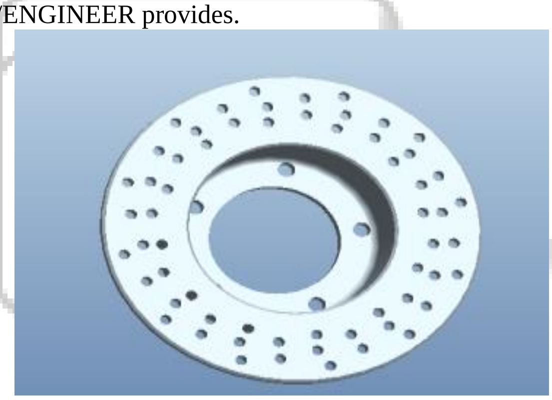

Fig. 2: Disc Brake Model in PRO-E

III. ANALYSIS BY USING ANSYS

ANSYS is the standard FEA teaching tool within the Mechanical Engineering Department at many colleges. ANSYS is also used in Civil and Electrical Engineering, as well as the Physics and Chemistry departments. ANSYS provides a cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping. With virtual prototyping techniques, users can iterate various scenarios to optimize the product long before the manufacturing is started. This enables a reduction in the level of risk, and in the cost of ineffective designs. The multifaceted nature of ANSYS also provides a means to ensure that users are able to see the effect of a design on the whole behavior of the product, be it electromagnetic, thermal, mechanical etc.

A. *Steps Involved In Ansys*

1) *Preliminary Decisions*
   a) Analysis type
   b) Model
   c) Element type
2) *Pre processing*
   a) Material
   b) Import the model
   c) Mesh the model
3) *Solution*
   a) Apply loads
   b) Solve
4) *Post processing*
   a) Review results
   b) check the solution

B. *Structural Analysis Of Disc Brake Without Cross Drilled Holes*

1) *Stainless Steel*

Imported Model from Pro/Engineer

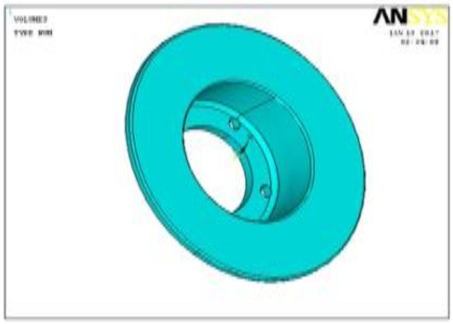

Fig. 3: Imported Model

a) Element Type: solid 20 node 95

b) Material Properties

Young's Modulus (EX) : 200000N/mm^2

Poisson's Ratio (PRXY) : 0.28

Density : 0.000007612 kg/mm^3

2) *Meshed Model*

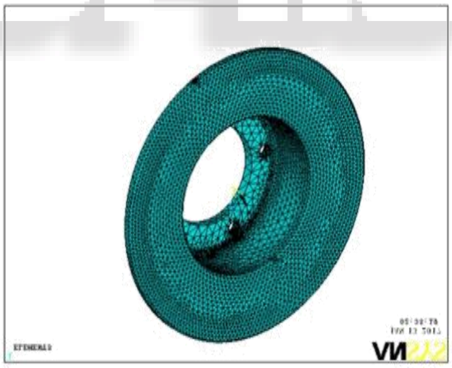

Fig. 4: Meshed Model

Loads

Pressure – 1.2N/mm^2

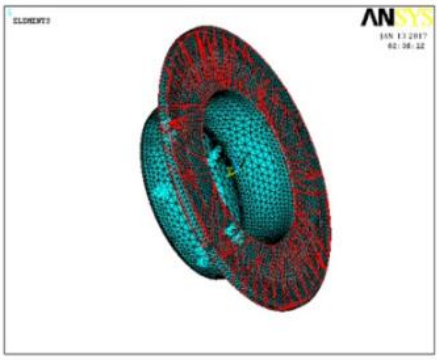

Fig. 5: Apply Load

a) Solution
Solution – Solve – Current LS – ok Post Processor
General Post Processor – Plot Results Contour Plot - Nodal Solution – DOF Solution –Displacement Vector Sum

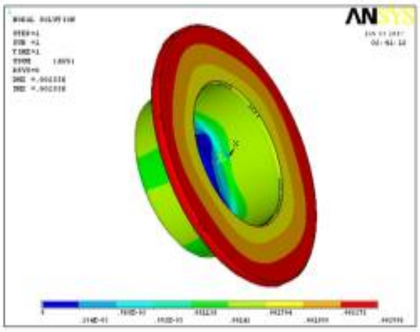

Fig. 6: Displacement

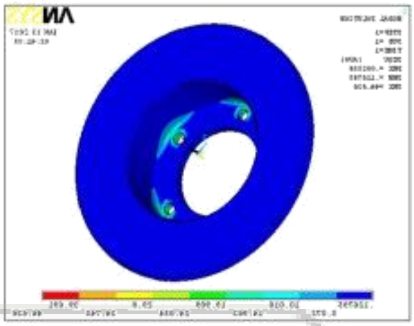

Fig. 7: Von Mises Stress

3) Cast Iron

Element Type : solid 20 nodes 95
Material Properties
Young's Modulus (EX) : 103000N/mm^2 Poisson's Ratio (PRXY) : 0.211
Density : 0.0000071kg/mm^3

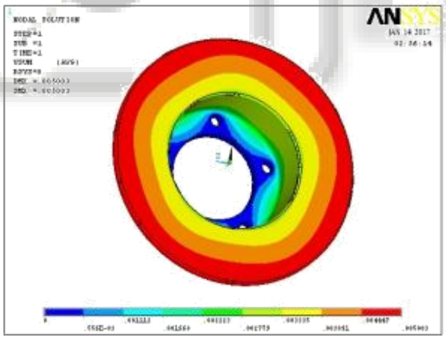

Fig. 8: Displacement

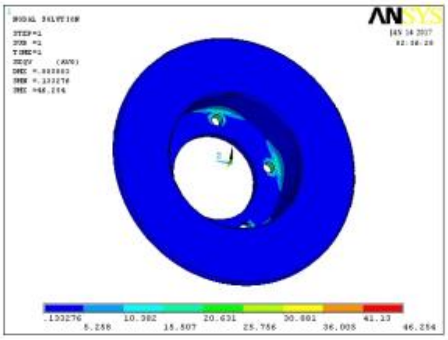

Fig. 9: Von Mises Stress

4) Aluminum Alloy

Element Type : solid 20 nodes 95
a) Material Properties
Young's Modulus (EX) : 70000N/mm^2
Poisson Ratio (PRXY) : 0.33
Density : 0.0000028kg/mm^3

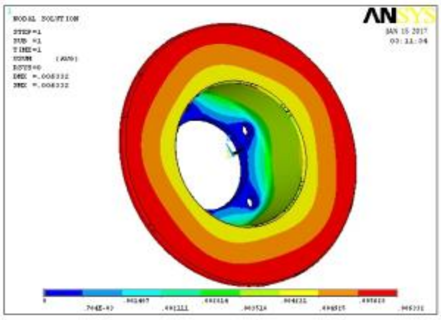

Fig. 10: Displacement

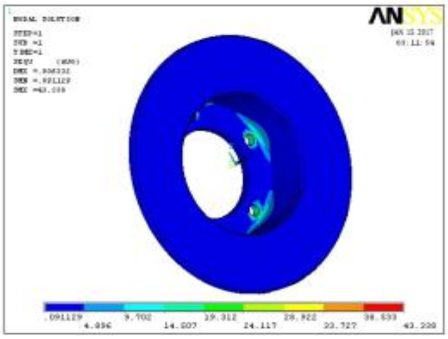

Fig. 11: Von Mises Stress

C. Thermal Analysis Of Disc Brake Without Cross Drilled Holes

1) Stainless Steel

Element Type : solid 20 nodes 90
Material Properties
Thermal Conductivity: 25w/m k
Specific Heat : 460.5 j/kg k
Density : 0.000007612kg/mm^3

2) Apply Loads

Loads – Define Loads – Apply – Thermal – Temperature
Temperature – 353k
Loads – define Loads – Apply – Thermal – Heat flow – On – nodes
Heat flow – 2kj/sec
Loads – define Loads – Apply – Thermal – Convection – on areas
Bulk Temperature – 20k
Film Coefficient – 222W/mmK

3) Solution

Solution – Solve – Current LS – ok

4) Post Processor

General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Nodal Temperature Vector sum

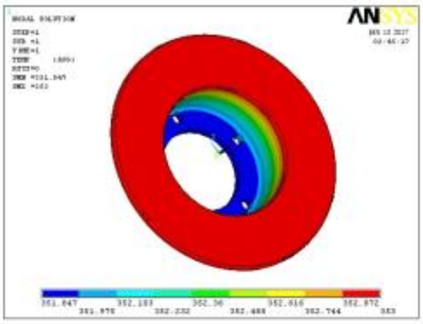

Fig. 12: Nodal temperature

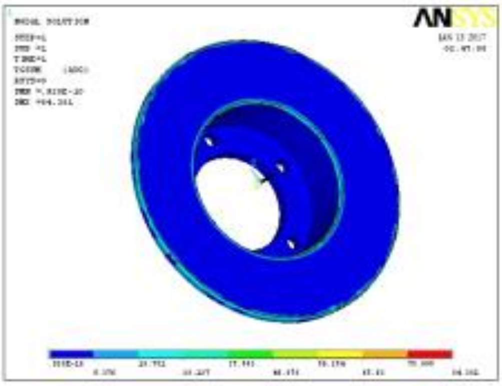

Fig. 13: Thermal gradient

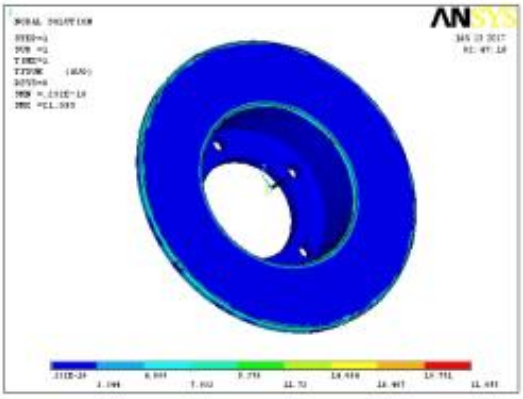

Fig. 14: Thermal flux

5) Cast Iron

Element Type	: solid 20 nodes 90
Material Properties	
Thermal Conductivity	: 50w/mk
Specific Heat	: 540j/kg k
Density	: 0.0000071 kg/mm^3

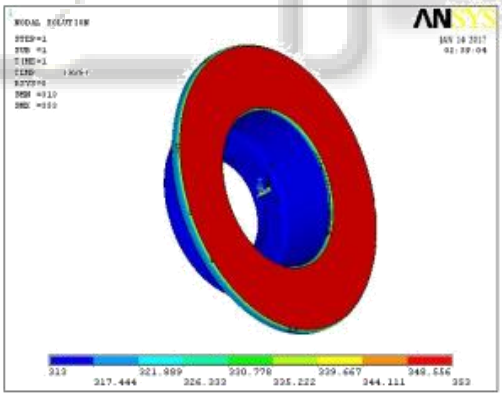

Fig. 15: Nodal temperature

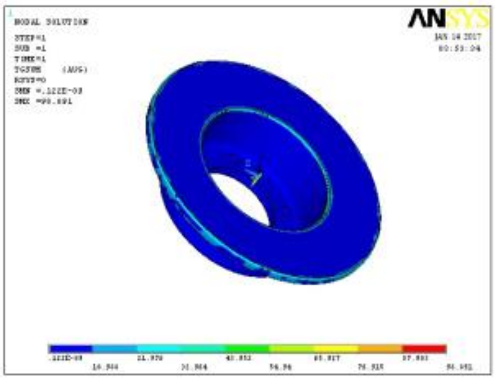

Fig. 16: Thermal gradient

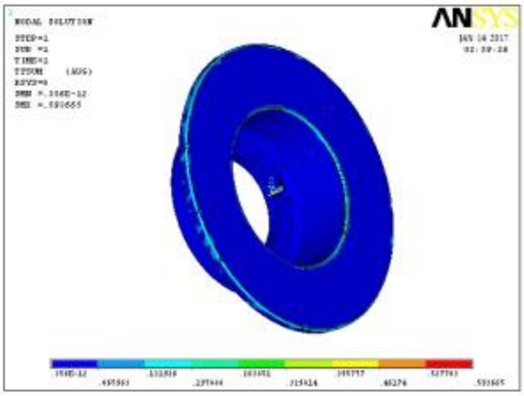

Fig. 17: Thermal flux

6) Aluminum Alloy

Element Type	: solid 20 nodes 90
Material Properties	
Thermal Conductivity	: 113w/mk
Specific Heat	: 963 j/kg k
Density	: 0.0000028 kg/mm^3

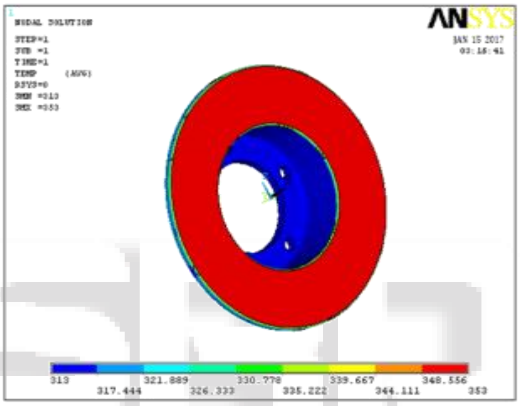

Fig. 18: Nodal temperature

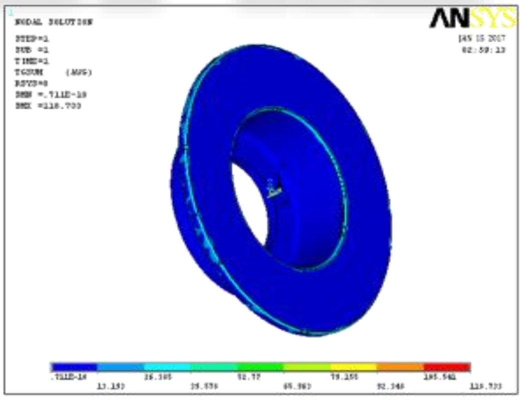

Fig. 19: Thermal gradient

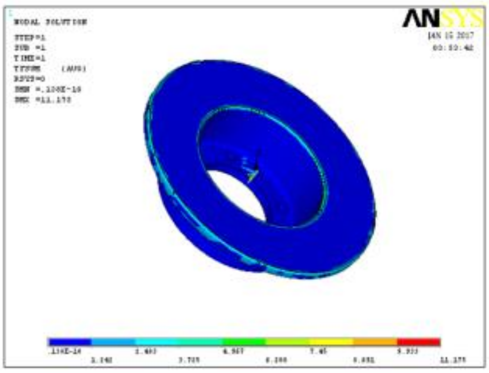

Fig. 20: Thermal flux

D. Structural Analysis Of Disc Brake Drilled Holes

1) Stainless Steel

a) Imported Model from Pro/Engineer

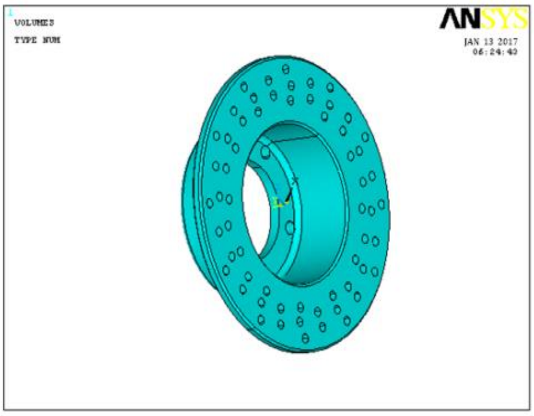

Fig. 21: Imported Model

Element Type : solid 20 nodes 95
Material Properties
Young's Modulus (EX) : 200000N/mm^2
Poisson's Ratio (PRXY) : 0.28
Density : 0.000007612 kg/mm^3

b) Meshed Model

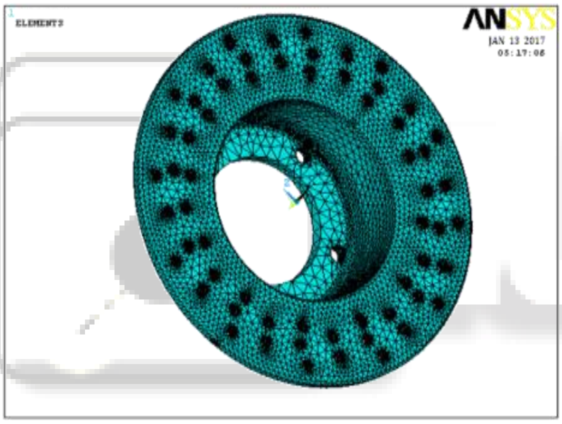

Fig. 22: Meshed Model

Loads
Pressure – 1.2N/mm^2

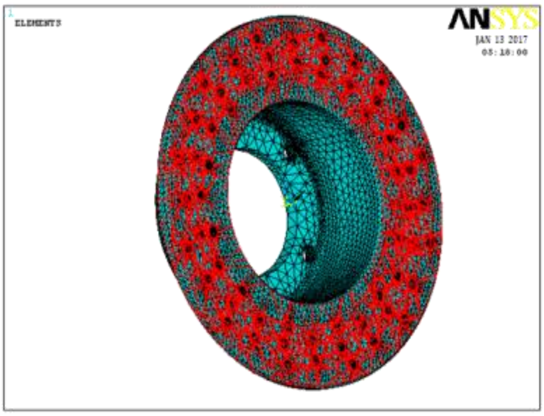

Fig. 23: Apply Load

Solution
Solution – Solve – Current LS – ok

c) Post Processor

General Post Processor – Plot Results – Contour Plot – Nodal Solution – DOF Solution – Displacement Vector Sum

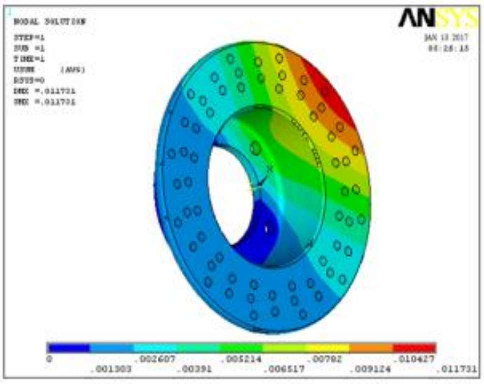

Fig. 24: Displacement

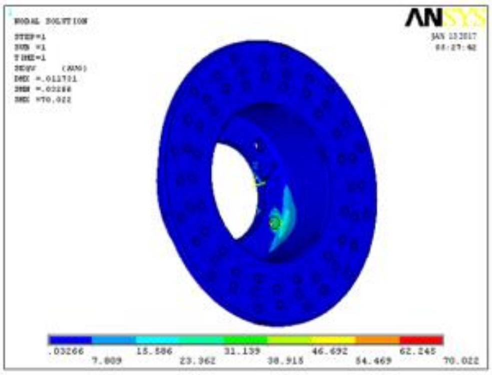

Fig. 25: Von Mises Stress

2) Cast Iron

Element Type : solid 20 nodes 95
Material Properties
Young's Modulus (EX) : 103000N/mm^2
Poisson Ratio (PRXY) : 0.211
Density : 0.0000071 kg/mm^3

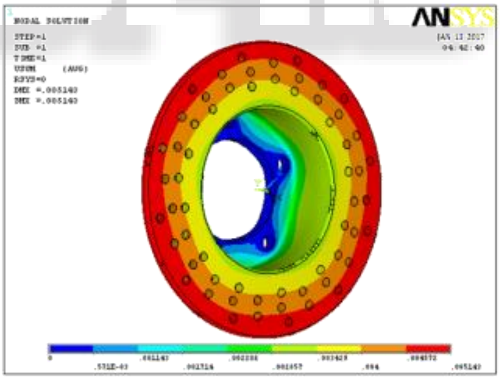

Fig. 26: Displacement

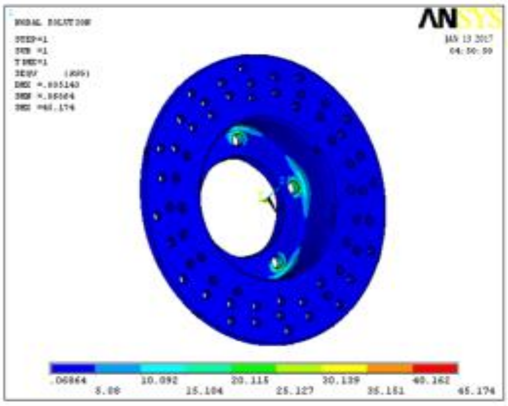

Fig. 27: Von Mises Stress

3) Aluminum Alloy

Element Type : solid 20 nodes 95

Material Properties

Young's Modulus (EX) : $70000 N/mm^2$

Poisson's Ratio (PRXY) : 0.33

Density : $0.0000028 kg/mm^3$

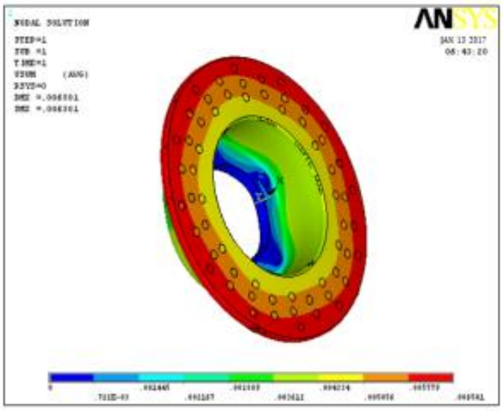

Fig. 28: Displacement

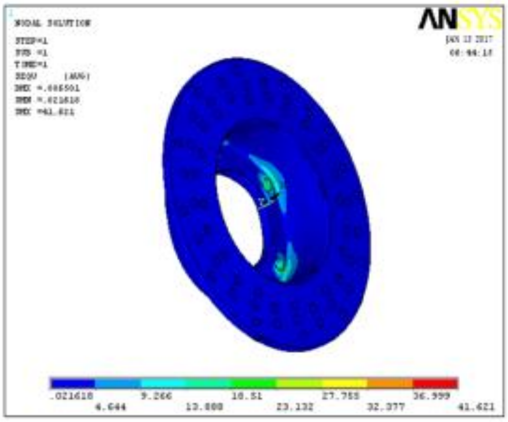

Fig. 29: Von Mises Stress

E. Thermal Analysis of Disc Brake with Drilled Holes

1) Stainless Steel

Element Type : solid 20 nodes 90

Material Properties

Thermal Conductivity : 25w/mk

Specific Heat : 460.5 j/kg k

Density : $0.000007612 kg/mm^3$

2) Apply Loads

Loads – Define Loads – Apply – Thermal – Temperature

Temperature – 353k

Loads – define Loads – Apply – Thermal – Heat flow – On nodes

Heat flow – 2kj/sec

Loads – define Loads – Apply – Thermal – Convection – on areas

Bulk Temperature – 20k

Film Coefficient – 222W/mmK

Solution

Solution – Solve – Current LS - ok

3) Post Processor

General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Nodal Temperature Vector sum

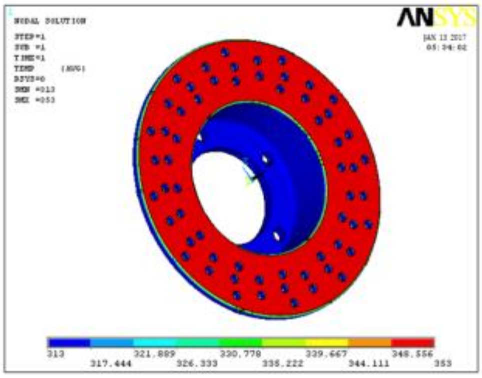

Fig. 30: Nodal temperature

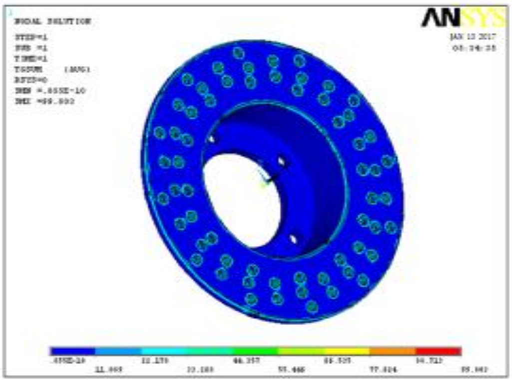

Fig. 31: Thermal gradient

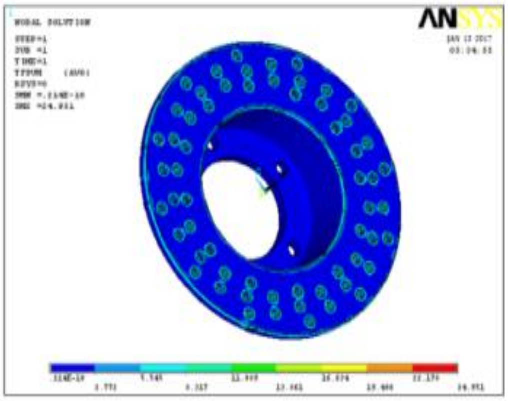

Fig. 32: Thermal flux

4) Cast Iron

Element Type : solid 20 nodes 90

Material Properties

Thermal Conductivity : 50w/mk

Specific Heat : 540j/kg k

Density : $0.0000071 kg/mm^3$

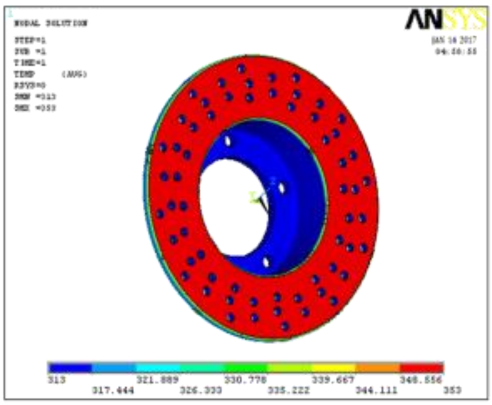

Fig. 33: Nodal temperature

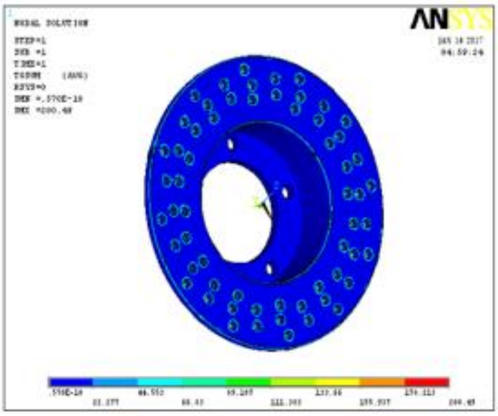

Fig. 34: Thermal gradient

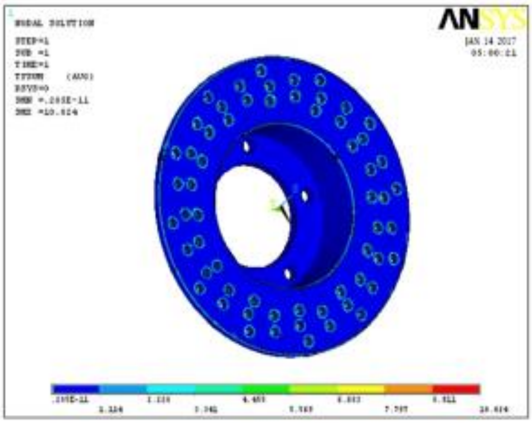

Fig. 35: Thermal flux

5) Aluminum Alloy

Element Type : solid 20 nodes 90

Material Properties

Thermal Conductivity : 113w/mk

Specific Heat : 963 j/kg k

Density : 0.0000028 kg/mm^3

a) Solution

Solution – Solve – Current LS – ok

b) Post Processor

General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Nodal Temperature Vector sum

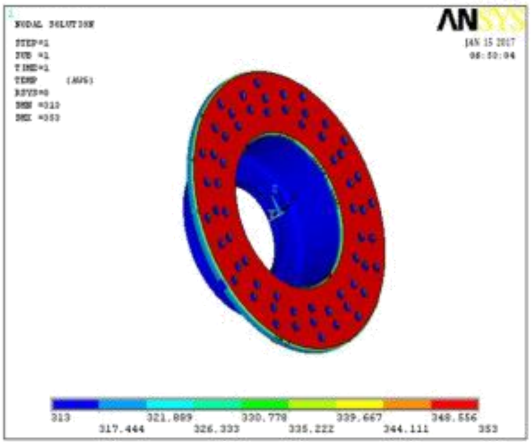

Fig. 36: Nodal temperature

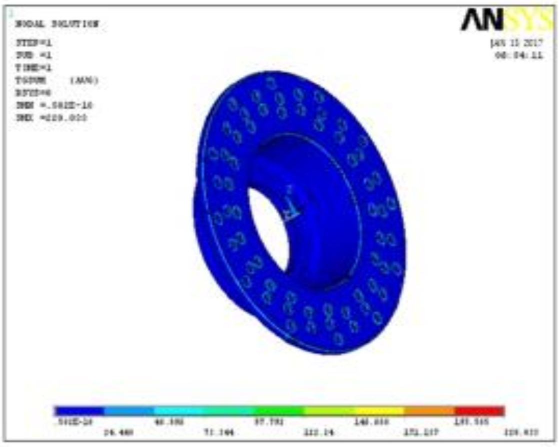

Fig. 37: Thermal gradient

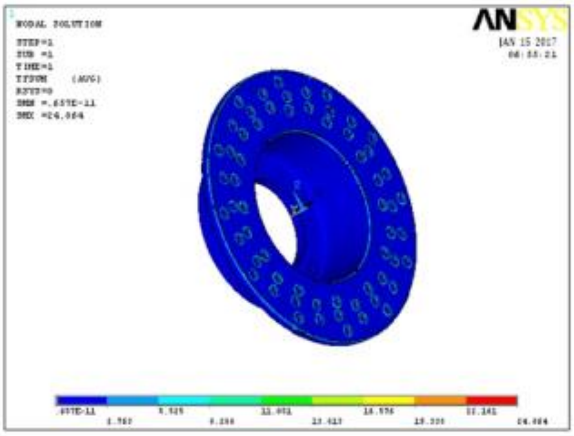

Fig. 38: Thermal flux

IV. RESULT AND DISCUSSIONS

	Displacement (mm)	**Von Mises Stress (N/mm^2)**
Stainless Steel	0.002556	44.636
Cast iron	0.005003	46.254
Aluminum Alloy	0.006332	43.338

Table 1: Structural analysis of without hole disc brake

	Nodal Temperature (K)	**Thermal Gradient (K/mm)**	**Thermal Flux (W/mm^2)**
Stainless Steel	353	84.381	21.095
Cast iron	353	98.891	0.593665
Aluminum Alloy	353	118.733	11.175

Table 2: Thermal analysis of without hole disc brake

	Displacement (mm)	**Von Mises Stress (N/mm^2)**
Stainless Steel	0.011731	70.022
Cast iron	0.005143	45.174
Aluminum Alloy	0.006501	41.621

Table 3: Structural analysis of with hole disc brake

	Nodal Temperature (K)	**Thermal Gradient (K/mm)**	**Thermal Flux (W/mm^2)**
Stainless	353	99.803	24.951

Steel			
Cast iron	353	200.49	20.024
Aluminum Alloy	353	220.033	24.864

Table 4: Thermal analysis of with hole disc brake

V. CONCLUSION

In our project we have modeled a disc brake used in Honda Civic in Pro/Engineer software.

Structural and thermal analysis is done on the disc brake for three materials stainless steel, cast iron and Aluminum alloy. Present used materials for disc brake are stainless steel and cast iron. We are replacing the material with Aluminum alloy, since its density is less than that of other two materials thereby reducing the weight of disc brake.

By observing the stress values obtained in structural analysis, they are less than the yield stress value of Aluminum alloy, so using Aluminum alloy for disc brake is safe. And also by comparing with other two materials, the stress value is less for aluminum alloy. So using Aluminum alloy is better.

By observing thermal analysis results, thermal gradient is more for Aluminum alloy that is heat transfer rate is more for Aluminum alloy by comparing with other two materials.

We also changed design of disc brake, by adding holes on disc brake. We have performed structural and thermal analysis on that model. By adding holes, thermal gradient has increased when compared with the present design.

So we can conclude that by changing the design of disc brake the heat transfer rate increases and using Aluminum alloy is better when compared to other materials.

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