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Design Evaluation and Optimization of a Disc Brake

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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 paper 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.

Keywords:

Disc Brake, Ceramic Composites, Brake Pads, Materials, Design

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. Still other 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 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 mechansims, 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.

Characteristics:

Brakes are often described according to several characteristics including:

- Peak force - The peak force is the maximum decelerating effect that can be obtained. The peak force is often greater than the traction limit of the tires, in which case the brake can cause a wheel skid.

- Continuous power dissipation - Brakes typically get hot in use, and fail when the temperature gets too high. The greatest amount of power (energy per unit time) that can be dissipated through the brake without failure is the continuous power dissipation. Continuous power dissipation often depends on e.g., the temperature and speed of ambient cooling air.

- Fade - As a brake heats, it may become less effective, called brake fade. Some designs are inherently prone to fade, while other designs are relatively immune. Further, use considerations, such as cooling, often have a big effect on fade.

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• Smoothness - A brake that is grabby, pulses, has chatter, or otherwise exerts varying brake force may lead to skids. For example, railroad wheels have little traction, and friction brakes without an anti-skid mechanism often lead to skids, which increases maintenance costs and leads to a "thump thump" feeling for riders inside.

• Power - Brakes are often described as "powerful" when a small human application force leads to a braking force that is higher than typical for other brakes in the same class. This notion of "powerful" does not relate to continuous power dissipation, and may be confusing in that a brake may be "powerful" and brake strongly with a gentle brake application, yet have lower (worse) peak force than a less "powerful" brake.

• Durability - Friction brakes have wear surfaces that must be renewed periodically. Wear surfaces include the brake shoes or pads, and also the brake disc or drum. There may be tradeoffs, for example a wear surface that generates high peak force may also wear quickly.

• Weight - Brakes are often "added weight" in that they serve no other function. Further, brakes are often mounted on wheels, and unsprung weight can significantly hurt traction in some circumstances. "Weight" may mean the brake itself, or may include additional support structure.

• Noise - Brakes usually create some minor noise when applied, but often create squeal or grinding noises that are quite loud.

Design Evaluation and Optimization of a Disc Brake

Pistons and cylinders:

The most common caliper design uses a single hydraulically actuated piston within a cylinder, although high performance brakes use as many as twelve. Modern cars use different hydraulic circuits to actuate the brakes on each set of wheels as a safety measure. The hydraulic design also helps multiply braking force. The number of pistons in a caliper is often referred to as the number of 'pots', so if a vehicle has 'six pot' calipers it means that each caliper houses six pistons.

Brake failure can occur due to failure of the piston to retract - this is usually a consequence of not operating the vehicle during a time that it is stored outdoors in adverse conditions. On high mileage vehicles the piston seals may leak, which must be promptly corrected.

The brake disc must have enough surface to perform well and the co-efficient of friction is the most important factor to be consider when designing a brake system.

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Brake pads:The brake pads are designed for high friction with brake pad material embedded in the disc in the process of bedding while wearing evenly. Although it is commonly thought that the pad material contacts the metal of the disc to stop the car, the pads work with a very thin layer of their own material and generate a semi-liquid friction boundary that creates the actual braking force.[Of course, depending on the properties of the material, disc wear rates may vary. The properties that determine material wear involve trade-offs between performance and longevity.

The brake pads must usually be replaced regularly (depending on pad material), and some are equipped with a mechanism that alerts drivers that replacement is needed. Some have a thin piece of soft metal that rubs against the disc when the pads are too thin, causing the brakes to squeal, while others have a soft metal tab embedded in the pad material that closes an electric circuit and lights a warning light when the brake pad gets thin. More expensive cars may use an electronic sensor.Generally road-going vehicles have two brake pads per caliper, while up to six are installed on each racing caliper, with varying frictional properties in a staggered pattern for optimum performance.

Steps involved in ANSYS:

In general, a finite element solution can be broken into the following these categories.

1. Preprocessing module: Defining the problem
The major steps in preprocessing are given below
- defining key points /lines/areas/volumes
- define element type and material /geometric /properties
- mesh lines/areas/volumes/are required
The amount of detail required will depend on the dimensionality of the analysis (i.e. 1D, 2D, axis, symmetric)
2. Solution processor module: assigning the loads ,constraints and solving. Here we specify the loads (point or pressure), constraints (translation, rotational) and finally solve the resulting set of equations.
3. Post processing module: further processing and viewing of results
In this stage we can see: List of nodal displacement ,Elements forces and moments,Deflection plots ,Stress contour diagrams.

STRUCTURAL ANALYSIS OF DISC BRAKE WITHOUT CROSS DRILLED HOLES STAINLESS STEEL

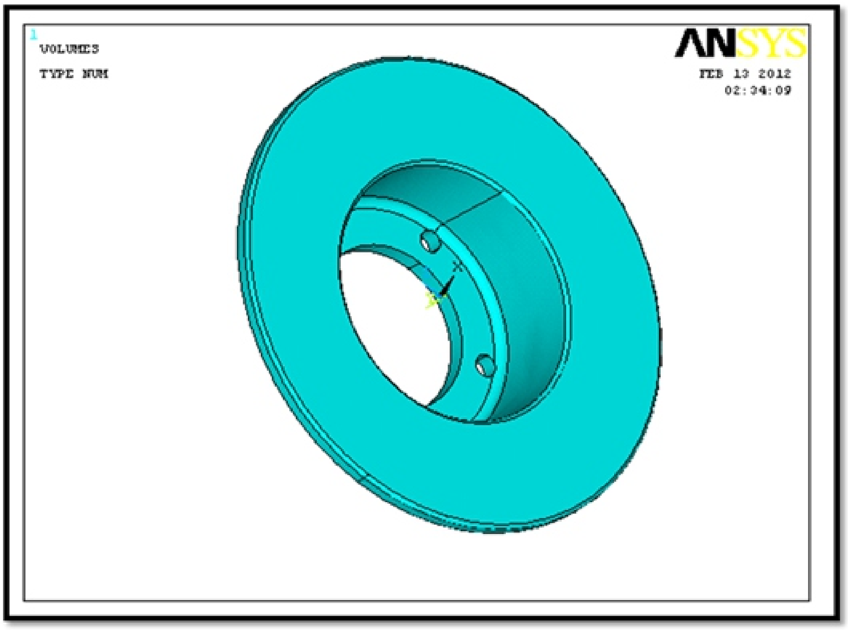

Fig.1 Imported Model from Pro/Engineer

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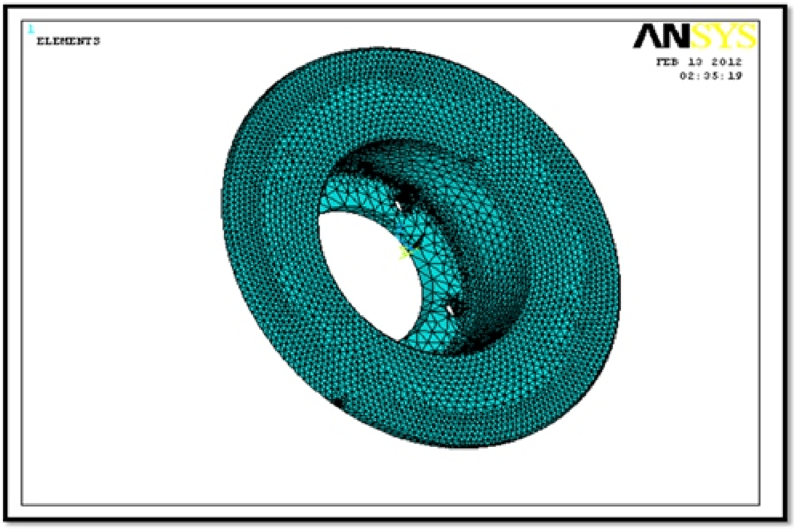
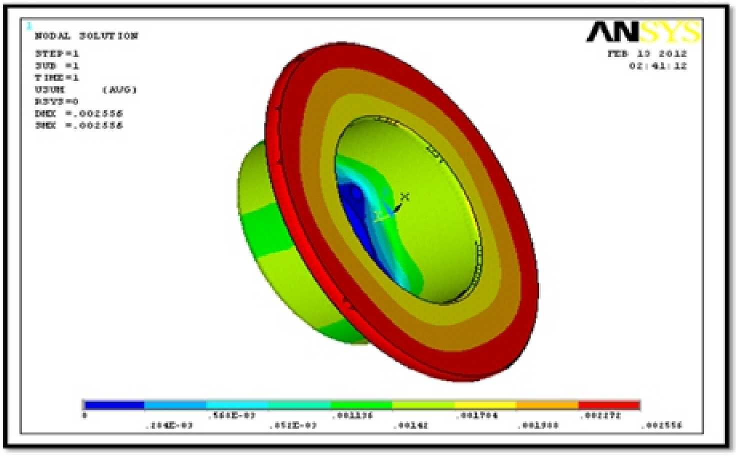
Element Type: Solid 20 node 95
Material Properties: Youngs Modulus (EX) : 200000N/mm2
Poissons Ratio (PRXY) : 0.28
Density: 0.000007612 kg/mm3

Meshed Model

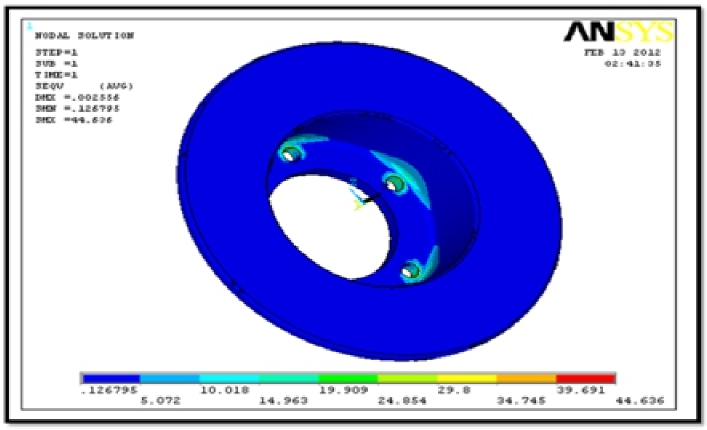


Post Processor

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



General Post Processor – Plot Results – Contour Plot – Nodal Solution – Stress – Von Mises Stress



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CAST IRON

Element Type: Solid 20 node 95

Material Properties: Youngs Modulus (EX) : 103000N/mm2

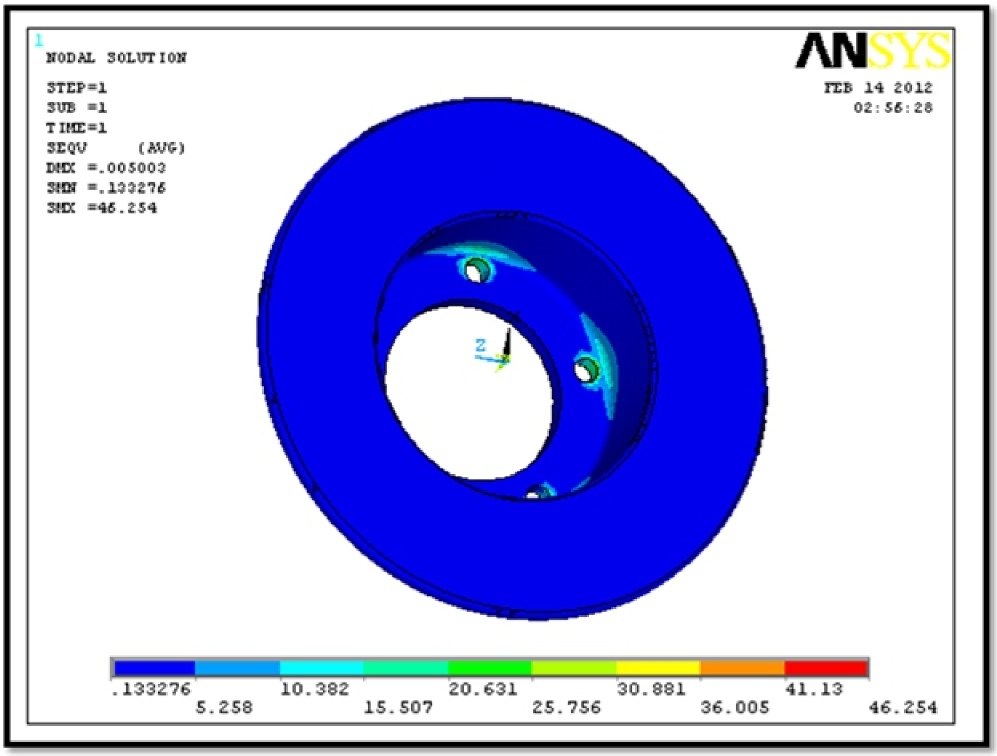
Poissons Ratio (PRXY) : 0.211

Density:0.0000071 kg/mm3

Fig: Post Processor

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

Fig: General Post Processor – Plot Results – Contour Plot – Nodal Solution – Stress – Von Mises Stress



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ALUMINUM ALLOY

Element Type: Solid 20 node 95
Material Properties: Youngs Modulus (EX) : 70000N/mm2
Poissons Ratio (PRXY) : 0.33
Density :0.0000028kg/mm3
Fig.: Post Processor
General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Displacement Vector Sum

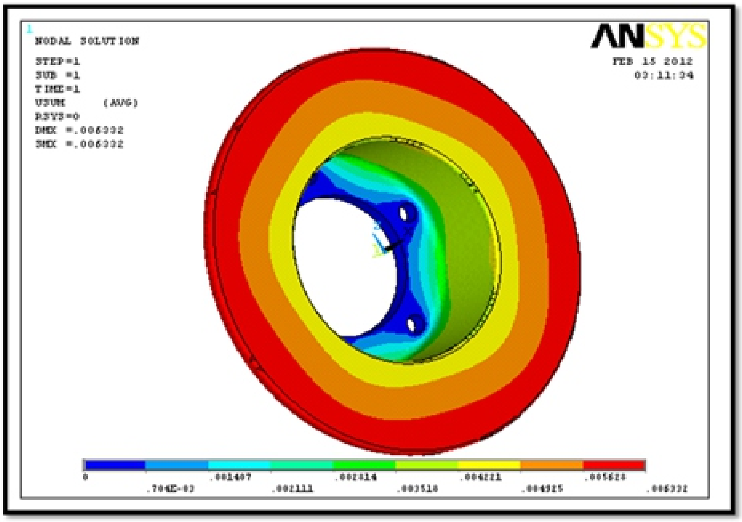
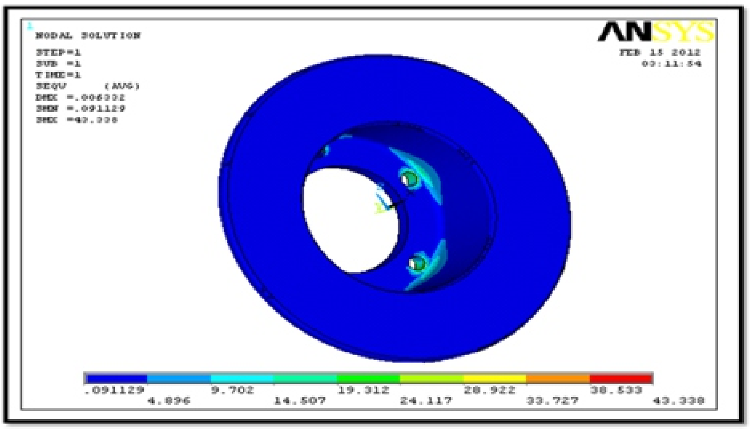


Fig.: General Post Processor – Plot Results – Contour Plot – Nodal Solution – Stress – Von Mises Stress



OVERVIEW OF THERMAL ANALYSIS:

A thermal analysis calculates the temperature distribution and related thermal quantities in a system or component. Typical thermal quantities of interest are:

- The temperature distributions
- The amount of heat lost or gained
- Thermal gradients
- Thermal fluxes.

Thermal simulations play an important role in the design of many engineering applications, including internal combustion engines, turbines, heat exchangers, piping systems, and electronic components. In many cases, engineers follow a thermal analysis with a stress analysis to calculate thermal stresses (that is, stresses caused by thermal expansions or contractions).

STAINLESS STEEL:

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

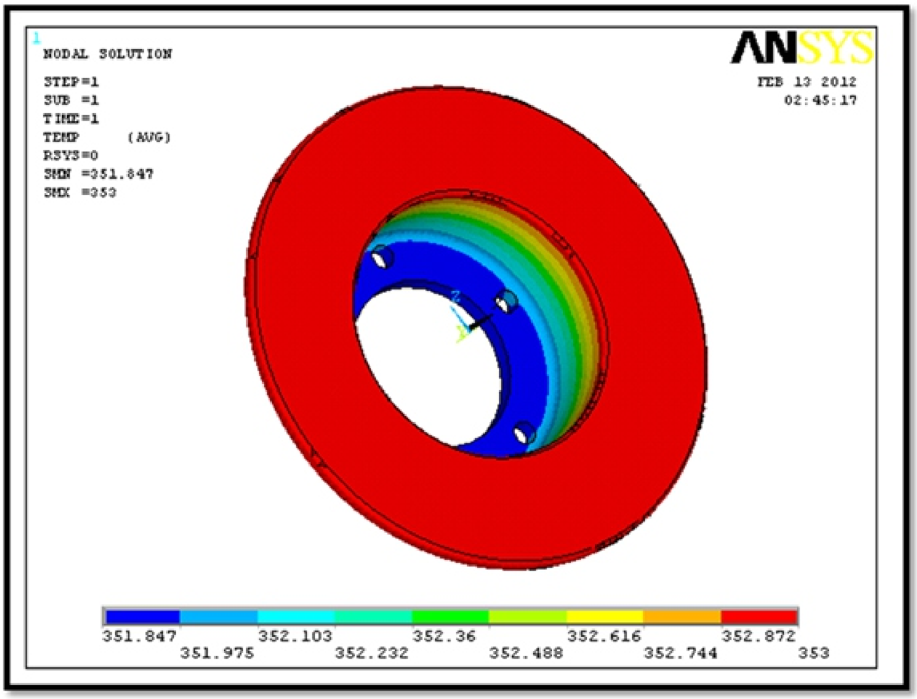


Fig. General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal Gradient Vector sum

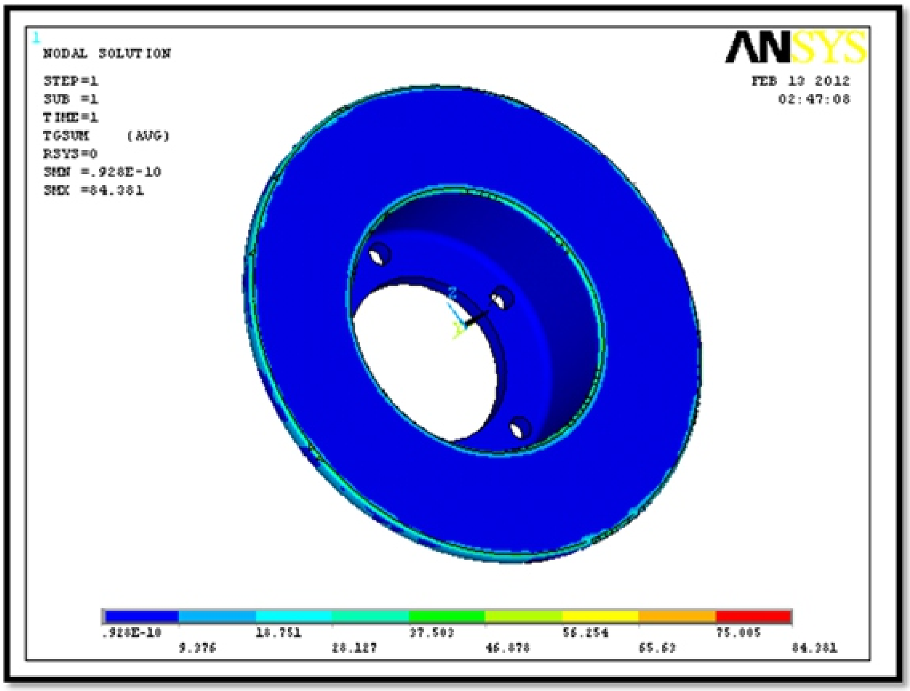


Fig. General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal flux vector sum

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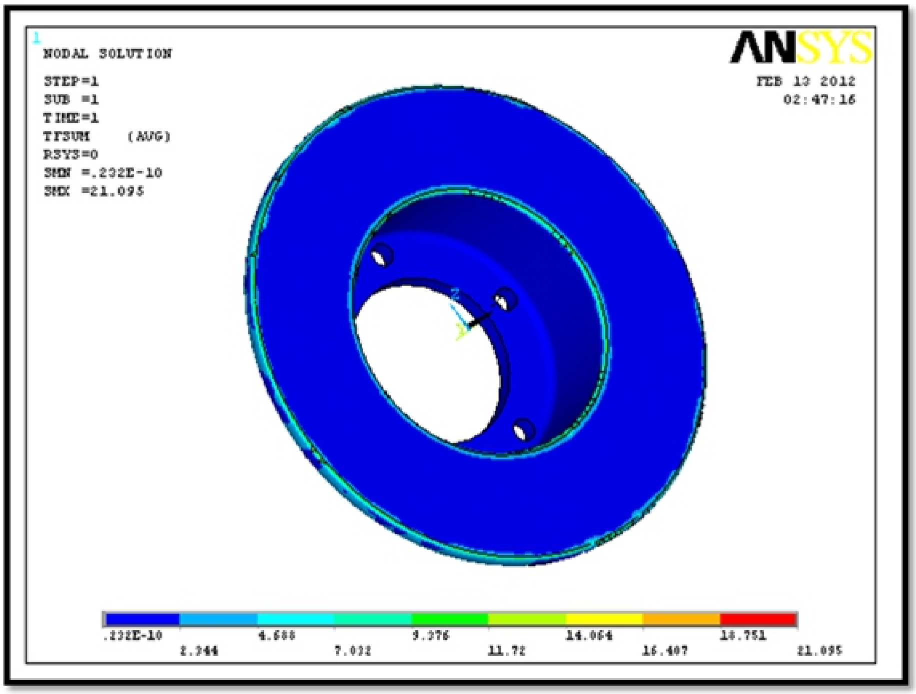

CAST IRON

Post Processor

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

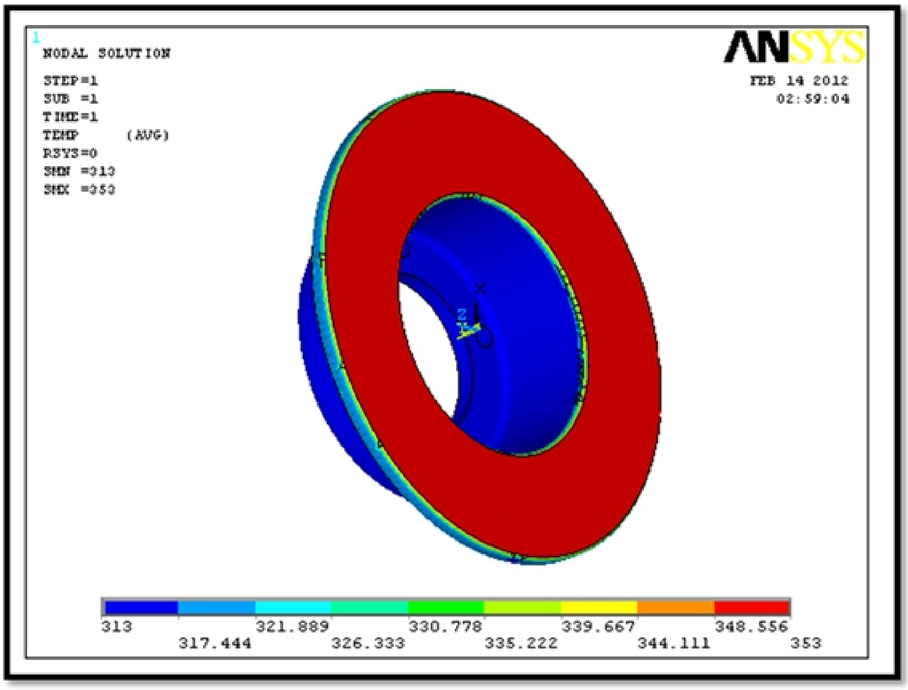

Fig: General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal Gradient Vector sum

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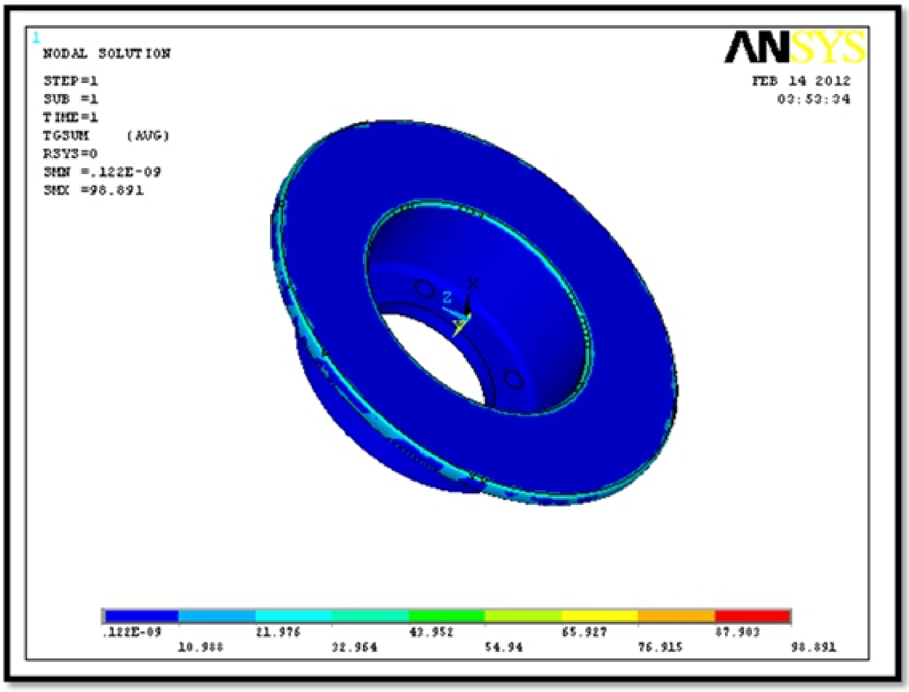
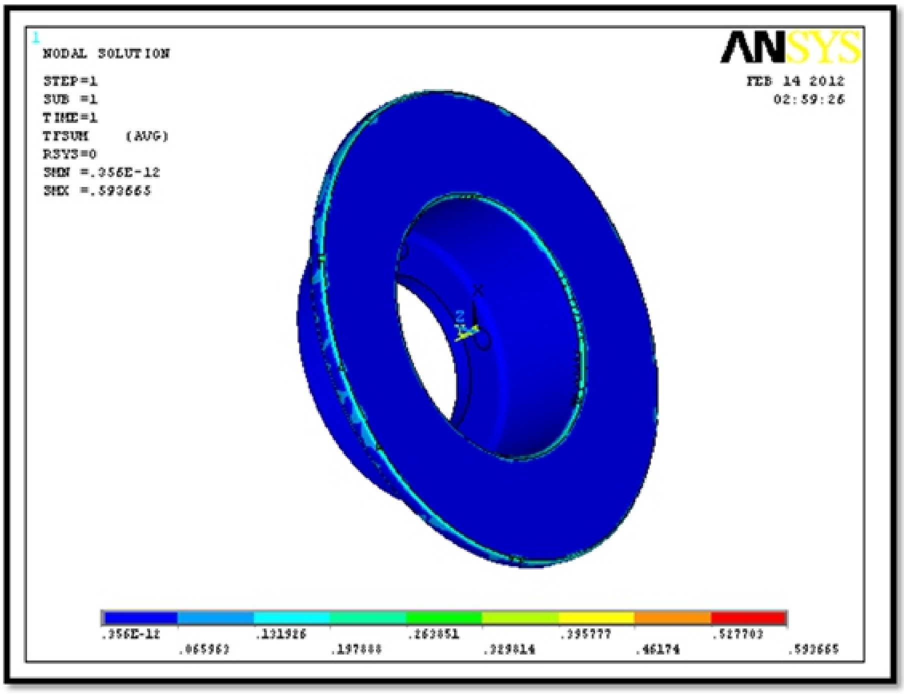


Fig.General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal flux vector sum



ALUMINUM ALLOY

Fig. Post Processor

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

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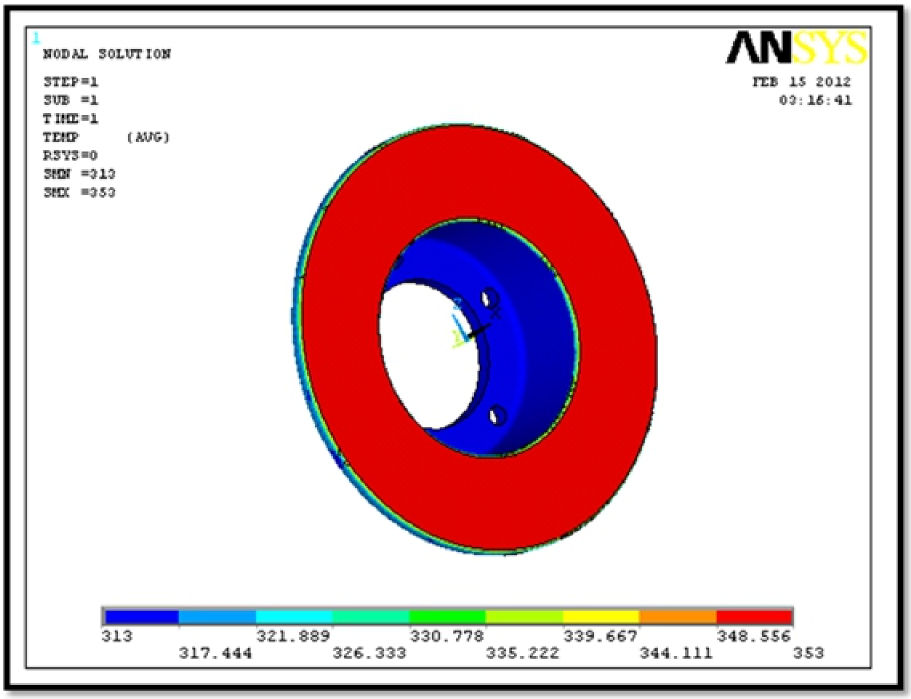

Fig. General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal Gradient Vector sum

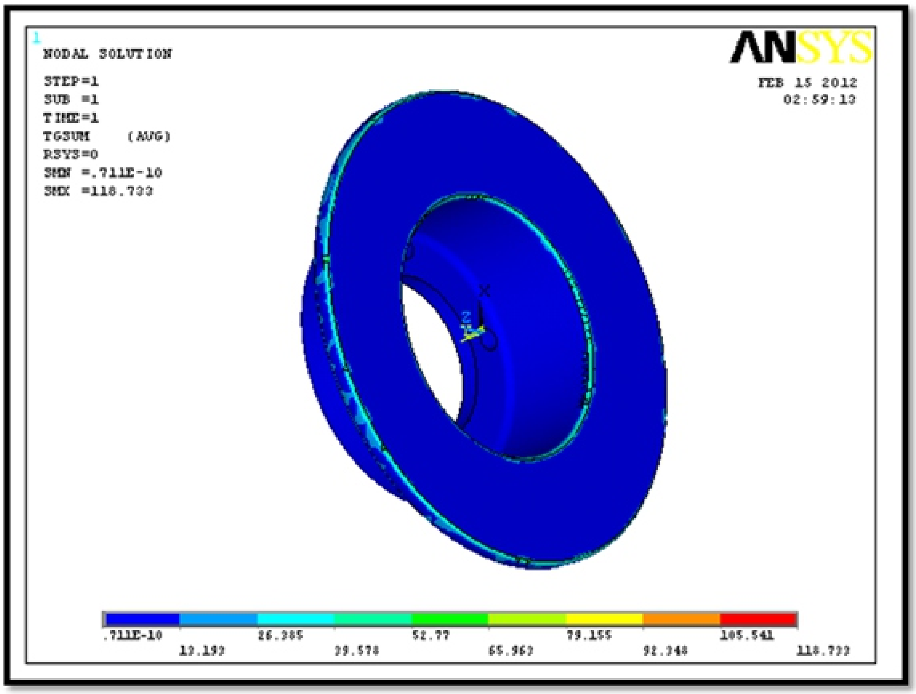

Fig.General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal flux vector sum

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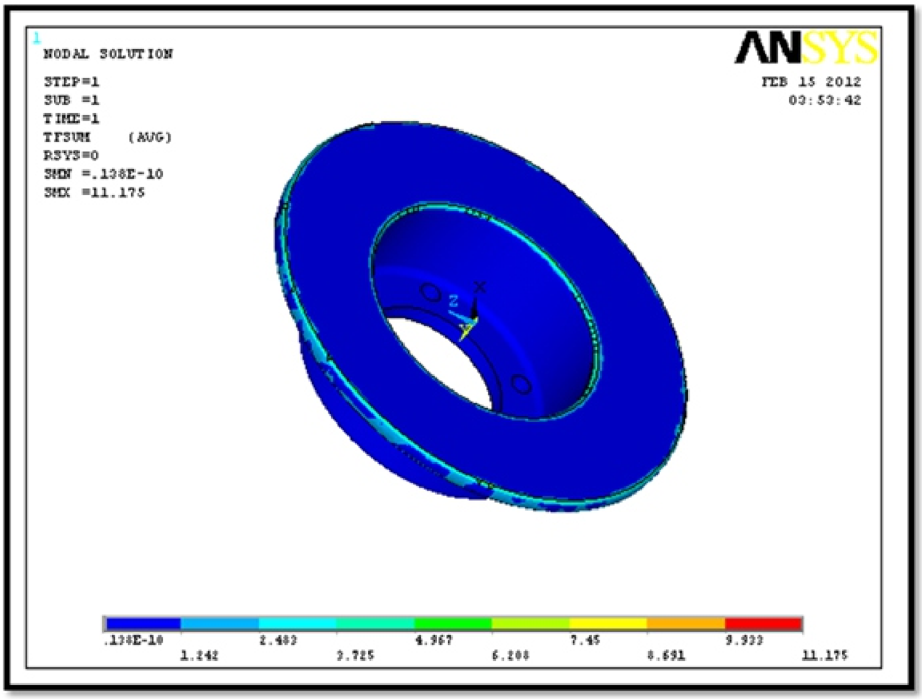

Similarly, THERMAL ANALYSIS OF DISC BRAKE DRILLED HOLES and STRUCTURAL ANALYSIS OF DISC BRAKE DRILLED HOLES is done.

RESULTS TABLE

As per the analysis images

	Displacement (mm)	Von Mises Stress (N/mm^2)	Nodal Temperature (K)	Thermal Gradient (K/mm)	Thermal Flux (W/mm^2)
Stainless Steel	0.002556	44.636	353	84.381	21.095
Cast iron	0.005003	46.254	353	98.891	20.195
Aluminum Alloy	0.006332	43.338	353	118.733	11.175

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4 RESULTS TABLE

As per the analysis images

	Displacement (mm)	Von Mises Stress (N/mm^2)	Nodal Temperature (K)	Thermal Gradient (K/mm)	Thermal Flux (W/mm^2)
Stainless Steel	0.011731	70.022	353	99.803	24.951
Cast iron	0.005143	45.174	353	200.49	20.024
Aluminum Alloy	0.006501	41.621	353	220.033	24.864

CONCLUSION:

In our project we have modeled a disc brake used in Honda Civic in Pro/Engineer software. Structural and thermal analyses are 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.

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