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Crack Propogation and J Integral Evaluation of Surface Crack of Brake Rotar of Disc Brake

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Abstract:- Disc Brake is an essential Component of automotive braking system. Its generally subjected to high amount of temperature and pressure for continuous stopping of vehicles. The literature shows most of work is done on the structural strength and transient temperature impact on disc brake. No work is executed on crack development at high stress intensity point on the disc brake surface.

150cc Pulsar two-wheeler is considered for designing and analysis of the disc. 3D Modelling of the disc brake is done by 3D Modelling software Solidworks and All the design parameters are taken from the literature papers. Finite Element analysis software ANSYS workbench 15.0 is used for Structural, Thermal and Crack development analysis at actual working condition of the disc brake.

Finite element analysis on the disc brake shows that, Crack initiation taken place at High intensity point on the crack surface and Crack Development will happen when J Integral value of the Simulation crosses the SIF of the Material. FEA simulation also show the rate at which crack develops and direction of crack Movement.

Keywords:- *Stress Intensity Factor(SIF), J-Integral(JINT), Finite element analysis (FEA), Meshing, Brake Pads, Brake Rotor.*

I. INTRODUCTION

Generally after High braking event, Thermal cracking can be commonly detected and seen in the rotor of disk brake. These cracks are classified into two broad categories: a series of heat cracks that partially penetrate the surface of the discs and thru-cracks in which they completely pass through the disc wall. For thru-cracks, unfortunately there are no formal treatment. A failure analysis of thermal cracking in disc brake rotor is done. The analysis was motivated by thermal cracking in the trucks and taken reference to do analysis on the front disc brakes in a pulsar 150cc. Failure generally occurred after several stops, and can be indicated by an audible ping and a pronounced ticking sound during subsequent braking. Although such cracks happen in Heavy weight vehicle like trucks or in sports bike/car, the following procedure represent a general treatment of the problem that is applicable to any vehicle.

Disc brakes are manufactured from grey cast iron.

A typical geometry shown in Grey cast iron is chosen due to its relatively high thermal conductivity, high thermal diffusivity and most importantly low cost. The brake rotor has a hat, or hub connected to the wheel and axle. It has outboard braking surface which is directly attached to the hub/hat and a inboard braking surface which is attached to outboard unit through a series of cooling vanes.

Fig 1:- Thermal cracking in disc brakes.

The subsequent frictional work due to braking arrests the rotation of the wheel which induces a substantial amount of heat. Such braking last on the order of seconds, generating frictional heating in the rotors while leaving the hat near room temperature. Thermal cracking is relatively common in trucks and emergency vehicles; vehicles which are exposed to extreme conditions. It is important to note, those conditions are not considered abusive; rather they are due to the limitations of braking technology.

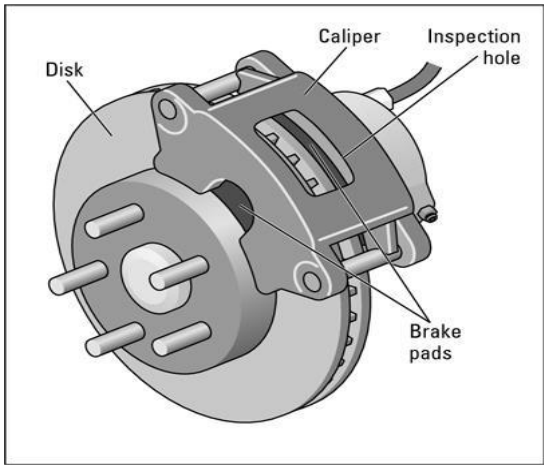

Fig 2:- Disc brake.

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A disc brake uses callipers to squeeze pairs of pads against "rotor" which creates friction. Disc brakes utilize callipers, brake rotors and brake pads. Each one of disc brake has a brake pad on both sides that are press against the brake rotor when the driver applies pressure to the brake pedal. Disc brakes offer the best stopping power as disc brakes are commonly used by high performance super bikes and cars.

- *Stress Intensity Factor*

The stress intensity factor (SIF) is primarily use in fracture mechanics.

It is used to predict the stress state ("stress intensity") near the tip of a crack when remote load or residual stresses are induced. For brittle materials, SIF is very useful in providing a failure criterion

Also, it can be use as critical technique in the discipline of damage tolerance.

- *Modes of Crack Failures*

There are linearly independent cracking modes in fracture mechanics. These load types are named as followed:-
Mode I : opening (tensile) mode.
Mode II : sliding (in-plane shear) mode.
Mode III : tearing (anti-plane shear) mode.

The stress intensity factor for the three different modes are designated by different subscripts The stress intensity factor for mode I is designated K1 and applied to the crack opening mode. The mode II stress intensity factor, K2, applies to the crack sliding mode and the mode III stress intensity factor, K3, applies to the tearing mode**.**

- *Evaluation of J-Integral*

The J-integral represents a way to calculate the strain energy release rate, or work (energy) per unit fracture surface area, in a material.[1]

The theoretical concept of J-integral was developed in 1967 by Cherepanov and in 1968 by Jim Riceindependently, who showed that an energetic contour path integral (called *J*) was independent of the path around a crack. The J-integral is equal to the strain energy release rate for a crack in a body subjected to monotonic loading.[6]

Under quasistatic conditions, it is true only if the material is linear elastic. If the material experience small-scale yielding at the crack tip, *J-Integral* can be used to compute the energy release rate. Also we can compute the strain energy release rate with the help *J-Integral* for pure power-law hardening plastic materials, as they undergo small-scale yielding at the crack tip.

II. LITERATURE SURVEY

- *Pandya Nakul Amrish. [1]*

Comparison of commonly used disc brakes in automotive vehicles viz. Solid and drilled brakes made of gray cast iron are performed. Design and analysis are thoroughly explained and based on proper mechanical calculations; the CAD model is prepared in CATIA V5 software. Steady state Thermal and Structural analysis is performed for both the models by using ANSYS Software and comparison is made for both the models. By comparing the analysis, what concluded is that Ultimate stresses were under the ultimate tensile stress of assumed material i.e. Gray Cast Iron and also that temperature variation and heat flux is slightly lesser for drilled rotor as there is increased in heat dissipation area.[1]

- *Mr. P. N. Gunjal. Prof. Hredeya Mishra.[2]*

Thermal analysis and optimization for weight reduction of two-wheel vehicles using analytical and numerical modeling of thermal effects during long-term braking for maintaining a constant speed in a downgrade railroad. CAD model of simple brake was prepared and by using ANSYS software topology function, unwanted areas were removed. Hence, a safe thermal stress free and optimized structure is obtained which can further save material cost.[2]

- *N.Balasubramanyam. Prof. Smt. G. Prasanthi. [3]*

The transient thermal analysis for thermo elastic contact problem of disc brakes by using ANSYS software and thermo elastic behavior of carbon composites are also discussed. By calculations a model was prepared on CATIA software. During the research thermo elastic instability (TIE) phenomenon was observed and its influence on material property is observed. Based on results he found that cast iron is the best material for manufacturing rather than carbon- carbon composite. [3]

- *C.Radhakrishnan Yokeswaran. Vengadeshprasah. Vishnuhasan. Vimalraj. Velusamy. [4]*

The frictional heat generated on the rotor surface during the braking phase,can influence excessive temperature rise which, in turn, leads to undesirable effects such as thermal elastic instability (TEI), premature wear, brake fluid vaporization (BFV) and thermally excited vibrations (TEV).Author tends to reduce these undesirable effects by using better thermal stability materials.CAD model was prepared in Solidworks 2013 and analysis like static structural and thermal was performed in ANSYS Workbench 14.0. For two materials i.e. Gray cast iron and Ti 550.Based on results obtained from analysis, total deformation, von mises stresses and temperature was compared and Ti 550 is suitable with its lesser deformation, stresses and surface temperature than gray cast iron. [4]

- *Sudershan. Gowda A. C. Kirthan L. J.[5]*

Estimation of fatigue crack growth rate considering the J-integral calculations for a semi-elliptical crack for gas turbine compressor blades subjected to centrifugal loading. By using static analysis, crack zone was found out and maximum Von mises stresses were recorded by using ANSYS software. Fractural module was used for evaluation of J- integral in blade with elliptical flaw. Fatigue crack growth rate at the crack length was determined and it was found that fatigue crack growth rate at the surface interception point increases with increase in crack depth and Fatigue crack growth rate at the crack depth increase with the increase in crack length.[5]

- *Zhiyong Yang. Jianmin Han. Weijing LI. Zhiqiang Li. Like Pan. Xiaoling Shi [6]*

Mechanisms of fatigue crack initiation and propagation in CRH EMU brake discs was analyzed in steady as well as braking condition and three kinds of crack propagation was noticed namely, the crackle, radial crack and circumferential crack. A finite element analysis (FEA) was performed to determine temperature and stress distribution in the brake disc as well as to estimate stress distribution during braking. Results indicate more significant residual, circumferential tensile stress on the external friction surface after emergency braking. It is also concluded that when the cracks run along the thickness direction to the specified distance, they cease to run along this direction and begin propagating mainly in the direction of the radius. [6]

- *Azadeh Haidari. Mojtaba Heidari [7]*

Surface crack growth rate by using Energy based J integral method and K factor method in FEA software ABAQUS to study 3-D semi elliptical crack growth in the railway wheel with strain hardening property, subjected to fatigue loading and its comparison. A FEA model of a wheel, with two brake shoes and a portion of rail are created and working condition loads and boundary conditions are applied to the railway wheel model. They concluded that J integral method has more accuracy to calculate of crack growth and also overcome the disadvantages of K factor method. [7]

- *Hadi Eskandari [8]*

Stress analysis of an internal crack located at an arbitrary position in a FGM disk with a concentric circular hole with graded material disk assuming the disc to be isotropic with exponentially varying elastic modulus in the radial direction. A comparison was made for different combinations of the crack length, direction, and location with the different materials. The critical values of stress intensity factors and their position in homogeneous and FGM disks are obtained and found that as large are the cracks; the larger is the stress intensity factors. [8]

- *Shreyas Deshpande. Aniket Kamat. Rohan Dalvi. Yash Deshpande [9]*

Failures caused in disc brakes of bicycles and automotive vehicles due to overheating, hotspots generation, thermal judders phenomenon occurring on the disc and crack induced was studied. During their study they found out that a large amount of heat is generated due to sudden braking in fraction of second and because of which thermal stresses are induced which leads to surface cracks and deformation in brake material. They concluded that for reduction in failures, a proper material should be selected with proper ventilation which increases airflow and improves convection rate of disc. [9]

III. PROPOSED WORK

A. Problem Definition

The brake system generates necessary force to slow the car, both for racing and emerging situations. The system must be able to easily dissipate heat and handle the energy dissipated by braking without compromising the safety or performance of the car. Failure of disc brake due to the application of the pressure on the brake, it causes to increase its temperature up to 900C for certain interval due to this Thermal Stresses is induced in the system. Due to these thermal stresses there is sudden expansion and contraction which points to system failures and inefficient braking

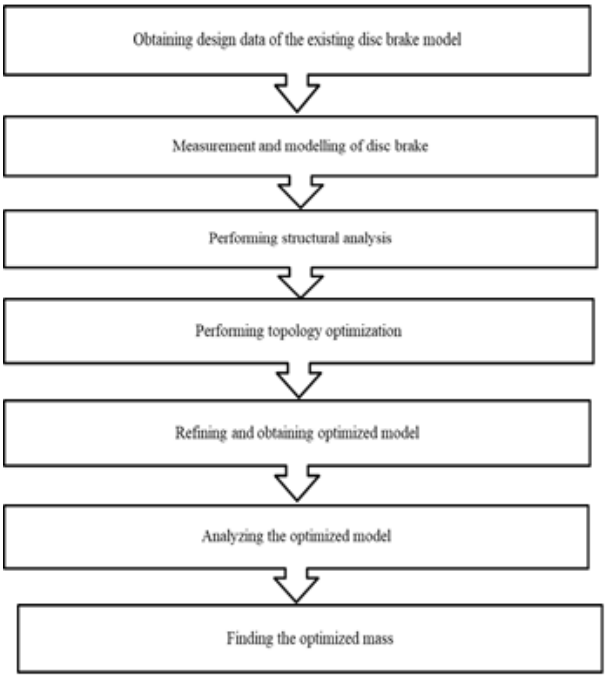

Fig 3:- Methodology of the Project.

B. Methodology

Disk brakes are an essential component of automotive braking system but due to sudden stopping temperature is reached up to 900 degrees hence thermal stresses are induced in the disc material. This thermal stress produces a crack which leads to future serious failures. To overcome these failures, crack analysis is carried out. First of all from reference papers, a dimension is selected for sketching disc brake. 3D modeling software Solidworks is used for producing a CAD model. After this CAD file is saved as .iges or .step file so ANSYS can read it as shell geometry. Structural analysis is carried out by using ANSYS Workbench 15.0.

By Structural analysis, there are where stresses are maximum. These are the spots where cracks will start to initiate. After finding these spots using ANSYS software a semi elliptical crack is generated and again transient structural is carried out to find J Integral and K factor of the model. These factors influence the crack growth rate and crack propagation rate of the model.

C. 3D Modelling using Solidworks

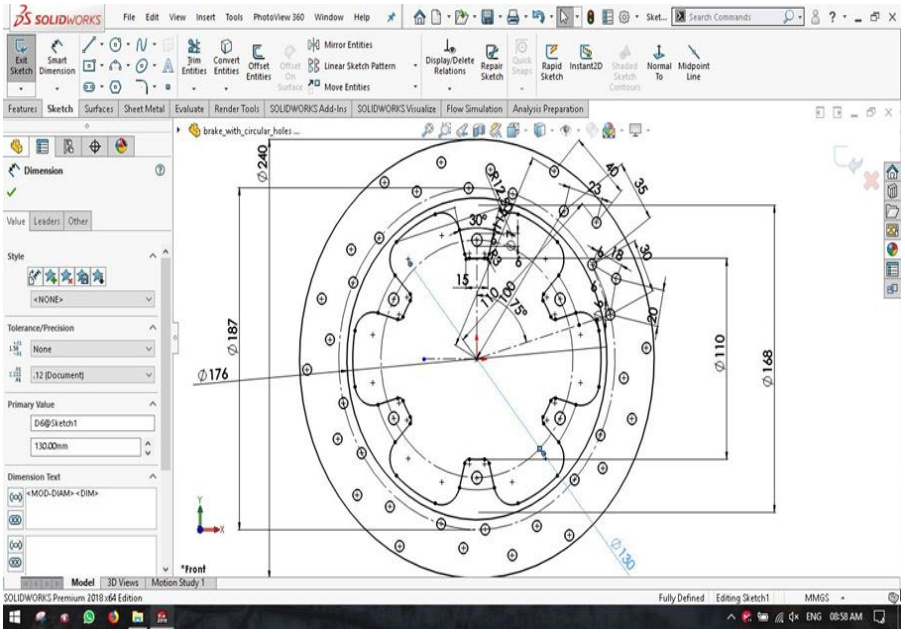

Fig 4:- Sketch feature of Brake rotor.

Fig 5:- Rendered part of Optimized model.

D. Simulation of Disc brake using FEA

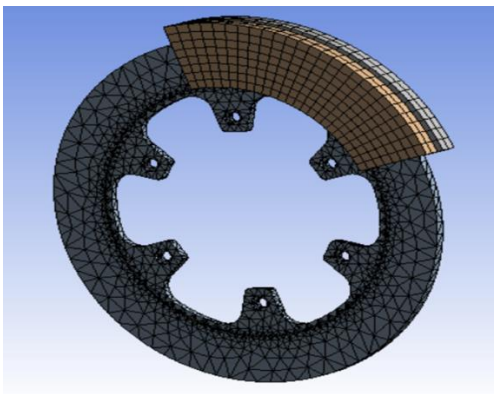

Fig 6:- Meshed part of Disk Brake.

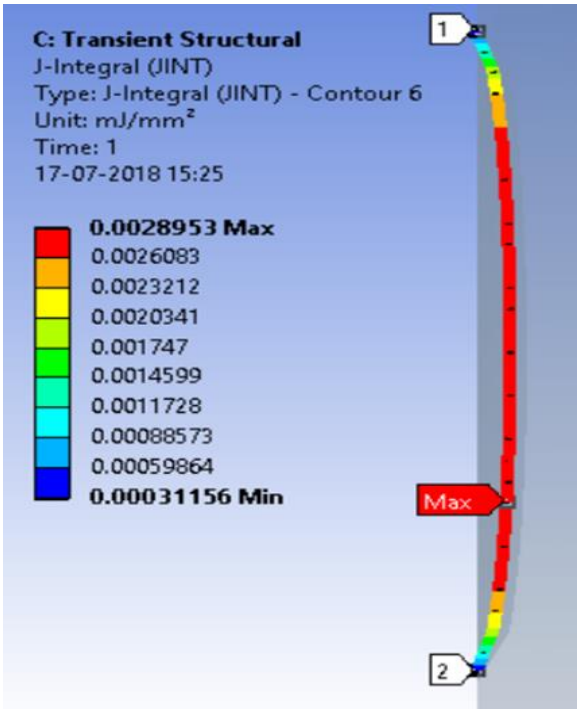

Fig 7:- JINT Analysis for Crack 1.

Crack 1:
Maximum value of J integral is 0.0028953
Minimum Value of J integral is 0.00031156

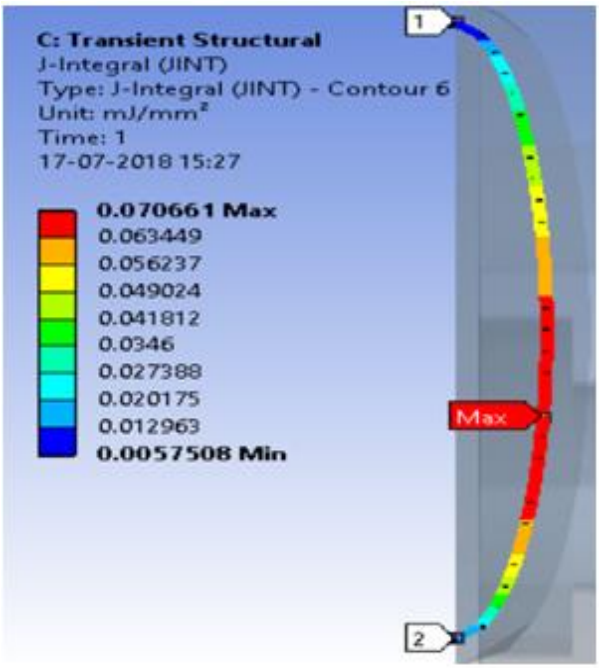

Fig 8:- JINT Analysis for Crack2.

Crack 2:
Maximum value of J integral is 0.0070661
Minimum Value of J integral is 0.0057508

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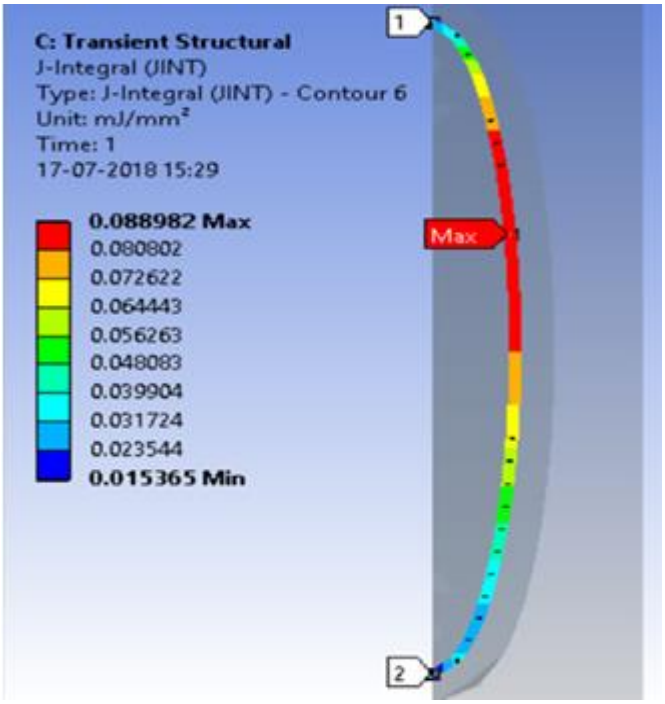

Fig 9:- JINT Analysis for Crack3.

Crack 3:
Maximum value of J integral is 0.088982
Minimum Value of J integral is 0.015365

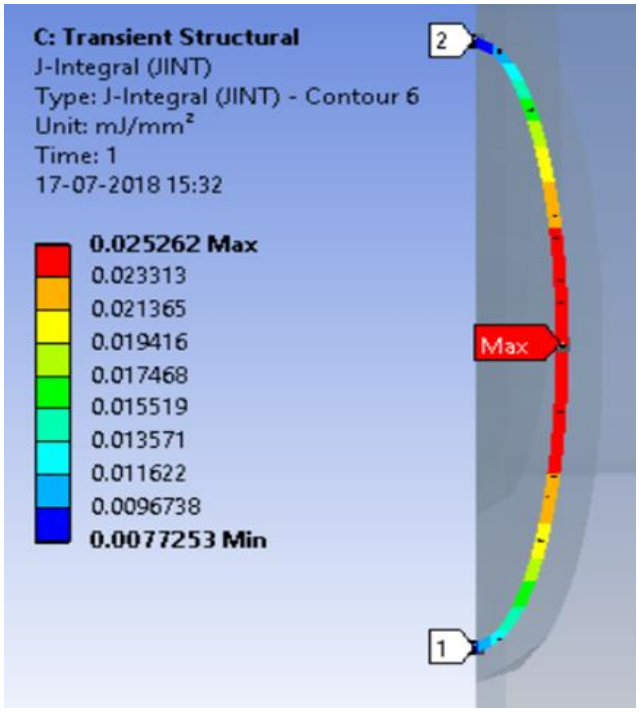

Fig 10:- JINT Analysis for Crack4.

Crack 4:
Maximum value of J integral is 0.025262
Minimum Value of J integral is 0.0077253

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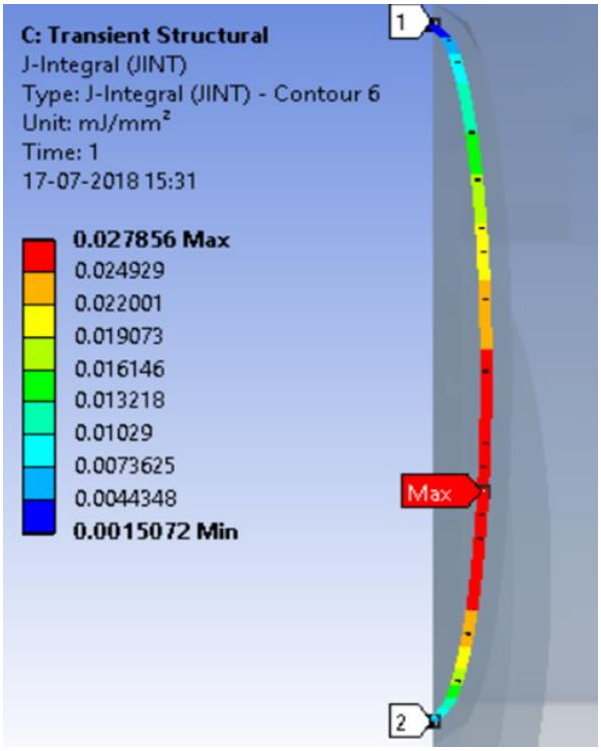

Fig 11:- JINT Analysis for Crack5.

Crack 5:
Maximum value of J integral is 0.27856
Minimum Value of J integral is 0.0015072

IV. RESULT AND CONCLUSION

A. *Result*

Cracks	SIF Mode 1 (K1)	SIF Mode 2 (K2)	SIF Mode 3 (K3)	J-Integral
Crack 1	**18.16**	**4.3**	**5.622**	**0.0028953**
Crack 2	**28.438**	**20**	**5.6211**	**0.0028953**
Crack 3	**-45.21**	**34.419**	**55.424**	**0.088982**
Crack 4	**-3.333**	**35.553**	**-12.06**	**0.025262**
Crack 5	**-2.955**	**23.376**	**46.719**	**0.027856**

Table 1

B. *Conclusion*

- A study was conducted on a Bajaj Pulsar 150cc Disc brake where we found that due to tremendous increase in temperature for a certain interval of time, there exists a sudden expansion and contraction in the disc material which leads to fatigue of the disc material.
- To study this cause a standard CAD model was prepared by using Solidworks with reference dimensions taken from research paper.
- A Steady-State Thermal Analysis was performed in ANSYS Workbench with boundary conditions stated. After which a Transient Structural Analysis was performed with randomly spotted semi-elliptical cracks of different dimensions.
- SIF Factor (K1, K2, K3) and J-Integral is evaluated from analysis and by comparing it with standard values of Gray Cast Iron we concluded that given disc brake mat initiate cracks but due to its less size it may be neglected from cracks under these conditions.
- By analysis results we can conclude that for crack 1 and crack 2, there is higher value of K1 Factor being 18.16 & 28.438 and these falls under the standard limits hence they can be neglected. Also, J-integral value are 0.0028953 & 0.0028953 hence, mode I type cracks may initiate but due to its neglected size and closure value to its standard value it can be neglected.
- Also Crack 3 and crack 5 has more chances of achieving Mode III type crack due to higher value of K3 factor and no Mode I cracks because of its negative

value. And since its J-integral value is very less being 0.088982 and 0.027856 these cracks can be neglected.

- For Crack 4, the highest value is for K2 being 35.553 Mode II type failure may initiate but J-integral value being 0.025262 these cracks can be neglected. No mode I type will be initiated due to its negative value.

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