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A Review On Thermal Cracking In Disc Brake Of Air Brake System

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Abstract : *The Disc Brake Is An Advance Technology In Brake System Of Any Vehicle. At The Braking Time, The Frictional Heat Generated Over Disc Surface And Lead To High Temperature. Due To Which, After Certain Number Of Brake Actuation, Cracks Are Generated And Propagated In Radial Direction On Disc Surface And Hence Overall Reduces The Performance Efficiency Of The Brake System. These Cracks Behavior Are Measured By Different Fracture Parameter Like Stress Intensity Factor, Crack Initial Life, Crack Propagation Life, Etc*

Keywords *- Crack, Disc Brake, Heat Dissipation, Paris Law, Stress Intensity Factor (SIF).*

I. Introduction

The Brake System Is Most Important Safety Control Part Of Any Vehicle. It Is Used For Stop Or Retard The Motion Of Vehicle Under Emergency Or Normal Condition [1]. During The Braking Phase, Large Amount Of Kinetic Energy Is Transform Into Heat Energy Through The Friction At Interface Of Disc And Pad. Out Of Total Heat Energy , Part Of Heat Dissipated In Disc & Pad By Conduction And Remaining Amount Of Heat Dissipates To Surrounding Atmosphere By Convection & Radiation[2].Due To The Heat Dissipation, Temperature Gradient Is Generated Through The Thickness Of Disc & Also Compressive Stresses Are Generates On Both Side Of Disc. After Release The Brake, An Outer Surface Is Cooled & Generates The Tensile Stresses. Due To These Tensile Stresses, After Certain Number Of Brake Actuation, The Cracks Are Initiated And Propagate In Radial Direction On Brake Disc Surface [2].The Generated Surface Cracks On The Disc Surface Are Analyzed By Fracture Parameters. The Relation Between Crack Length And Stress Near The Crack Tip Is Determined Using The Stress Intensity Factor. These Fracture Parameters Have Limit Depending On Fracture Toughness Of The Material, When It Exceed The Parameter Limit Then Crack Will Prorogate Over The Surface. Paris Law Is Useful To Determine The Crack Propagation Life And It Gives The Total Life Of Disc Brake Without Failure [3, 5].

II. Heat Dissipation In Brake Disc

When Brakes Are Applied, It Results In Retards The Motion Of Vehicle And Simultaneously Frictional Heat Is Generated Over The Surface Of Disc. At Normal Braking, Slowly Apply The Brake To Retards The Motion Of Vehicle And Generates Small Heat At Interface Of Disc And Pad. But In Emergency Or Sudden Braking, Large Force Is Applied And Generates Large Amount Of Heat Energy At Interface Of Disc-Pad. This Generated Heat Is Dissipates By Conduction, Convection And Radiation Shown In Below Fig.1.

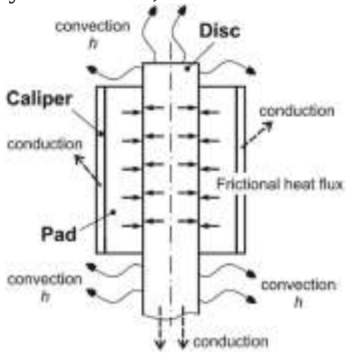

Fig.1. Heat Dissipation From Disc/Pad [2]

Out Of The Total Heat Dissipated, Most Of The Heat Dissipation Is By Conduction And Convection And Very Small Amount Of Heat Dissipatation Is By Radiation. But At Braking Time There Is Prevention To Transfer The Heat By Convection At Contact Surface And Hence Heat Dissipates By Conduction Through The Disc Thickness And Generates The Temperature Gradient In Disc.Thus Outer Surface Has The Maximum Temperature As Compared To Interior Parts Of Disc Which Helps To Generates Surface Cracks[2].

III. Cracks On Disc Surface

Due To Braking The Surface Cracks Are Generated On Disc Brake Shown In Below Fig.2. At The Braking Time, Suddenly High Frictional Heat Is Generated Over The Disc Surface And Hence Outer Surface Have Very High Temperature Compared With Interior Part Of Disc, Results In Steep Temperature Gradient Occur Through The Thickness Of Disc. Due To Which Deformation Restrained And Plastic Limit Is Not Exceeded At Interior Part And Simultaneously At Outer Surface Compressive Plastic Deformation And Thermal Contraction Is Occur. Results In Multidirectional Crack Network Are Form At Outer Surface And After Repeated Number Of Brake Actuation These Cracks Are Propagates Over Disc Surface [2].

Fig.2. Thermal Craking In Disc Brakes[2]

IV. Fracture Parameter For Analyze Crack Behavior

The Generated Cracks At Disc Surface Are Analyzed By Following Methods-
1. Stress Intensity Factor (SIF)
2. Energy Release Rate
3. J-Integral

Above Methods Define Fracture Parameters, If Its Value Exceeds The Limit Which Depends On Fracture Toughness Of The Material Then Crack Will Initiate And Propagate On Disc Surface. Out Of Which Energy Release Method And Stress Intensity Factor Method Are Used For Linear Elastic Fracture Mechanics (LEFM) And J-Integral Method Is Used For Elastic-Plastic Fracture Mechanics (EPFM).Hence In Above Methods, Stress Intensity Factor (SIF) Is Widely Used And Easier For Designer As Compared With Energy Release Method For Disc Material (I.E. Cast Iron Behaves As Linear Elastic) [5].

Stress Intensity Factor (K) – Stress Intensity Factor (K) Gives The Relation Between Crack Geometry, Crack Length And Stress Field Around The Crack Tip. There Are Three Different Modes Of Crack Propagation As Shown In Fig.3.

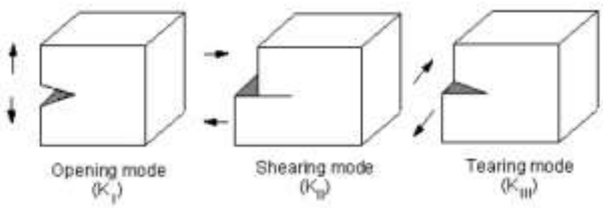

Fig.3. The Three Modes Of Loading Applied On A Crack [3]

For Opening Mode-I,

KI = F Σ ,

Where, F Is A Function Depending Only On Crack Geometry, A Is A Crack Length,

Σ Is A Stress Near The Crack Tip.

Stresses For Opening Mode At The Crack Front Are

$$\Sigma_x = \frac{K_I}{\sqrt{2\pi r}} \cos\theta \left[1 - \sin\frac{\theta}{2} \sin\frac{3\theta}{2}\right]$$

$$\Sigma_y = \frac{K_I}{\sqrt{2\pi r}} \cos\theta \left[1 + \sin\frac{\theta}{2} \sin\frac{3\theta}{2}\right]$$

$\Sigma_{xy} = \frac{K_I}{\sqrt{2\pi r}}\, sin\frac{\theta}{2} cos\frac{\theta}{2} cos\frac{3\theta}{2}$

Where, X Axis And Y Axis Are Along The Crack Length And Normal To The Crack Length Respectively Σ_x And Σ_y Are The Stresses Along X And Y Axis Direction Respectively [6]. The Fracture Toughness Is A Material Property Which Keeps The Limit On The Stress Intensity Factor. When The Stress Intensity Factor Is Greater Than The Fracture Toughness Of The Material Then Unstable Crack Propagation Will Occur. The Fracture Toughness Of The Material Is Depends On Temperature, At Elevated Temperature Brittle (Linear Behavior) Material Transforms To Ductile Material. The Disc Material (Cast Iron) Is Brittle At Room Temperature And Increase In Ductility Will Only Decrease The Crack Propagation And Hence It Is Conservative To Assume The Disc Material Have A Linear Behavior At Elevated Temperature [3]. Half Ellipse Shape Is Used For Modeling The Surface Cracks Over The Disc Brake With Its Minor Axis Into The Thickness Direction [5]. The Stress Intensity Factor For Mode-I At Crack Front Points Of A Semi-Elliptical Crack Is

$$K_I = \frac{1.12\sigma(\pi a)^{0.5}}{I_2}\left[\sin^2\theta + \left(\frac{a}{c}\right)^2 \cos^2\theta\right]^{0.25}$$

Where,

I_2 Is The Elliptical Integral Depends On Ratio Of Minor Radius To Major Radius Of Half Ellipse(A/C), Θ Is The Angle Measured From One Side Major Axis Towards The Other Side Through The Thickness.

Paris Law- At Fatigue Loading Crack Propagates Below The Critical Stress Intensity Factor Which Depending On Fracture Toughness Of The Material [3,4]. The Paris Law Gives The Relation Between The Crack Propagation Rate And Stress Intensity Factor As,

$$\frac{d\alpha}{dN} = C(\Delta K)^m$$

Where,

$\Delta K = K_{I,Max} - K_{I,Min}$, Difference In Stress Intensity Factor,

C And M Are The Material Constants. Crack Propagation Rate Increases With Increase In Stress Intensity Factor As Shown In Fig.4

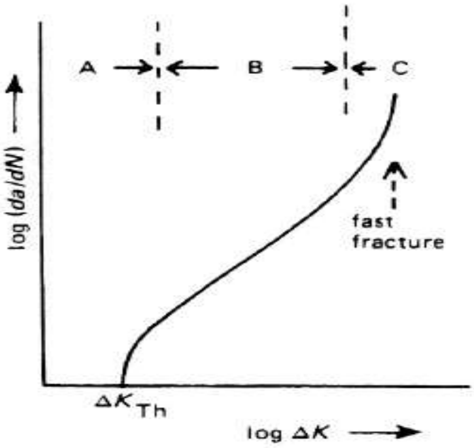

Fig.4 Crack Growth Curve For A Fatigue Loading [3]

V. Conclusion

When The Brakes Are Applied, Frictional Contact Occurs At Interface Of Disc-Pad And Hence It Retards Or Stops The Motion Of Vehicle. At Braking Time, The Kinetic Energy Of Vehicle Is Converted Into Frictional Heat At Disc Surface And It Is Dissipated By Three Modes Of Heat Transfer. Out Of Which Part Of Heat Dissipation Is By Conduction Through The Disc Thickness And Generates The Temperature Gradient In Disc And Simultaneously Apply The Compressive Stresses, Results In Surface Cracks On Disc Surface. Remaining Most Of Heat Dissipation Is By Convection And Small Amount Of Heat Dissipates By Radiation. So Design Should Be Such That Most Of Total Heat Dissipation Is By Convection And Prevent The Disc From Very High Temperature. Surface Crack Behavior Is Analyzed By Stress Intensity Factor (K) And Paris Law For Brittle Material (Cast Iron). When The Stress Intensity Factor Is Exceeding The Critical Stress Intensity Factor Then Crack Will Propagate Over The Disc Surface In Radial Direction. Determination Of The Crack Initial Life And Crack Propagation Life Using Paris Law And Thus The Total Life Of Disc Brake Without Failure Occurs Is Expected.

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