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

P. P. Patil¹, U. S. Chavan²

¹²(Department Of Mechanical Engineering, Vishwakarma Institute Of Technology, S. P. Pune University, India)

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


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 Dissipation 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].

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.

For opening mode-I,

\[ K_I = F \Sigma A \]

Where, \( F \) is a function depending only on crack geometry, \( A \) is a crack length, \( \Sigma \) is a stress near the crack tip.

Stresses for opening mode at the crack front are

\[ \Sigma_x = \frac{K}{\sqrt{\pi a}} \cos \theta \left[ 1 - \sin \frac{\theta}{2} \sin \frac{\theta}{2} \right] \]

\[ \Sigma_y = \frac{K}{\sqrt{\pi a}} \cos \theta \left[ 1 + \sin \frac{\theta}{2} \sin \frac{\theta}{2} \right] \]
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\[ \Sigma_{XY} = \frac{k}{\sqrt{2\pi}} \sin^2 \frac{\delta}{2} \cos^2 \frac{\delta}{2} \]

Where, X Axis And Y Axis Are Along The Crack Length And Normal To The Crack Length Respectively. \( \Sigma_1 \) And \( \Sigma_2 \) 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

\[ K_1 = \frac{1.122\langle\pi\rangle^{0.5}}{b^2} \left[ \sin^2 \theta + \left( \frac{a}{b} \right)^2 \cos^2 \theta \right]^{0.25} \]

Where,

\( I_2 \) Is The Elliptical Integral Depends On Ratio Of Minor Radius To Major Radius Of Half Ellipse(A/C), \( \Theta \) 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,

\[ \frac{da}{dn} = C(\Delta K)^m \]

Where,

\( \Delta K = K_{1,\text{Max}} - K_{1,\text{Min}} \), 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](image)

**V. Conclusion**

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References


