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Study of Crack Propagation of Brake Disc Using Furnace

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Abstract

Because of severe operational conditions, many working components are subjected to complex combination of cyclic temperature & mechanical loading. Premature failure is the major problem encountered in the operation of brake discs. To determine the nature of cracks the failure investigation described in this study was carried out by using different experimental methods as Fatigue tester method, NDT, Bentch study braking equipment, Furnace experimental testing, Chemical Testing etc. In the furnace experimental testing stainless steel specimen with a pre-existing surface notch is exposed to a convective medium of cyclic temperature. In Batch study, braking equipment wheel-mounted forged steel brake discs are exposed to heavy thermal and mechanical loadings and subjected to high thermal shock loading during routine braking and emergency braking. The present study was carried to develop simple method for studying the crack propagation with the aim of developing brake discs with increased lifespan, so as to improve the safety and reliability of these components.

Keywords: *Crack propagation, cyclic temperature, fatigue fracture, mechanical loading, stainless steel specimen, thermal gradient*

INTRODUCTION

Some brake disc shows small cracks only after few thousands running kilometres. Friction brakes are required to transform large amounts of kinetic energy into heat energy at the contact surfaces between brake discs and pads. CRH EMU wheel-mounted forged steel brake discs are exposed to heavy thermal and mechanical loadings and subjected to high thermal shock loading during regular braking and instant braking [2]. The distribution of high temperature areas caused by thermal shock loading is not even. After some no. of braking cycles, some hot spots are generated, that shows signs of heating on friction surfaces as shown in Fig. 1. Many authors have reported that damage in car, truck and railway brake discs takes place in the form of thermal fatigue cracks. In addition, some authors have observed metallurgical phase transformations in brake discs [3] with chemical composition observation. These authors have presented high temperature levels and thermal gradients are the reasons for brake disc damage. The short lifespan of such discs has to be ascribed to the rapid decay of the mechanical properties of the manufacturing material. Material decay which is the main cause for starting cracks.

Figure 1: *Hot spots in the friction surface.*

In order to understand the different damage modes, some authors describe the behaviour of a grey cast iron brake disc combined with two semi-metallic pads under extreme conditions. A coupled numerical–experimental approach [1] was used to determine the critical thermo-mechanical loadings associated with braking-induced metallurgical phase transformations.

METHODOLOGY

Breaking Test Using Fatigue Tester

The plate samples, which were machined from the brake disc consisting of typically longer cracks as shown in Fig. 2, were broken with a fatigue tester. Observation of the fractures was done by means of fracture surface examination using a scanning electron microscope and using an X-ray energy dispersive spectroscopy method.

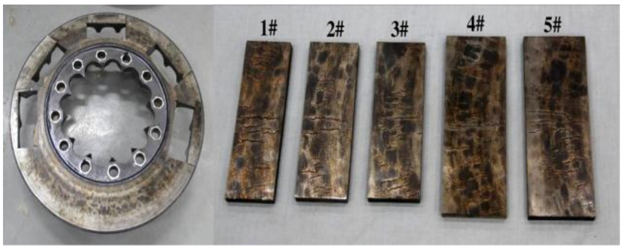

Figure 2: *Positions on the disc and shape of the three point bending samples.*

After crack fractures were produced through a breaking test, SEM analysis then shows that radial propagation of the crack occurred faster than thickness propagation; furthermore, the cracks were propagated in a semi-elliptical shape through the thickness of the friction surfaces in accordance with a thermal fatigue mechanism [2].

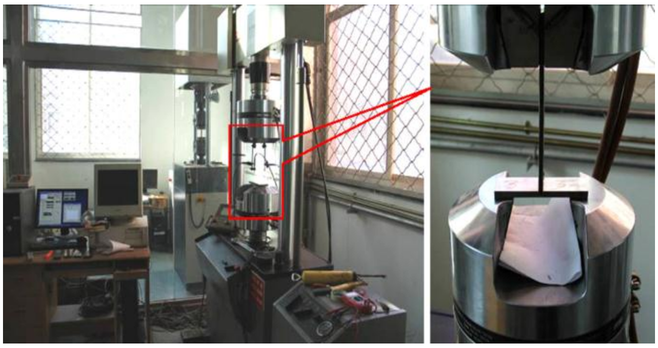

Figure 3: *Fatigue testing machine.*

Observation and Discussion

Fig. 4 shows the local friction surface of the brake disc with crack, which subjected a series of no. of braking cycles which had been subjected to higher temperatures. During braking, the energy absorbed by the brake disc was dispersed into two modes of action. Some amount of the energy was discharged in crack propagation, and the rest raised the temperature of the friction surface of the disc. Through careful observation, inferences could be made from the photos of the local friction surfaces the cracks generally initiated in the interior and at the edges of the hotspots; in addition, it has been seen that, it is necessary for crack propagation to absorb a certain amount of energy. In fact, the more crack appears in the friction surface, the more energy crack propagation would consume. As a result, the hotspot phenomenon would gradually reduce.

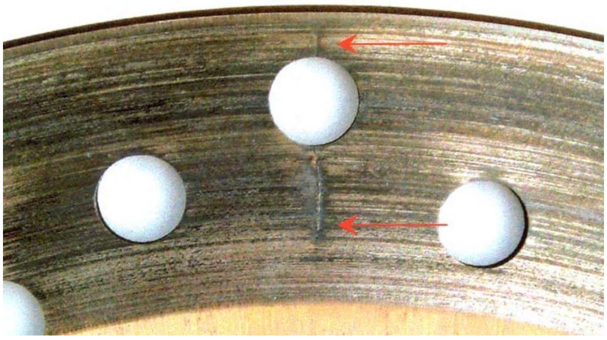

Figure 4: *Area of local friction surface with crack.*

Bench-Study Braking Test

Experimental Equipment

A rigid frame (Fig. 5) was specially designed to adapt the industrial calliper and its pneumatic actuator to the full-scale bench. The bench characteristics are specified in Table 1.

In this setup, an infrared camera was positioned in front of the half-disc in order to observe the evolution of hot areas. A trigger system made it possible to record two frames per rotation. Thermocouples were also incorporated within the disc to monitor bulk temperatures. The first thermocouple was located on the outer radius, at a depth of 2mm below the rubbing surface. The second thermocouple was positioned in the middle of a venting pillar [1].

Table 1: *Bench characteristics.*

Maximum speed (rpm)	3500
Torque (N m)	4000
Inertia (kg m^2)	220

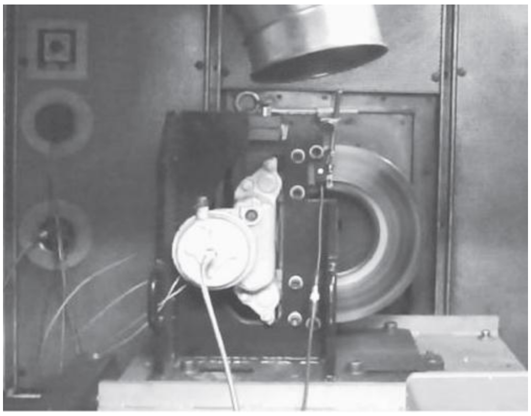

Figure 5: *Bench scale study equipment.*

PROCEDURE

Braking tests were carried out as per the sequence described in Table 2. A certain temperature condition was established in between tests the average temperature recorded by the thermo-couples had to decrease to 800°C before then extra braking test could begin. A wind tunnel was used after each braking cycle in order to reduce cooling times. Grinding was achieved through a series of 200 braking cycles at 8.1m/s (initial sliding speed) that took place over 8s.

Table 2: *Braking sequence.*

STEP NO.	STEP
1	Grinding
2	11 SB1
3	5 SB2
4	1 SSB
5	5 SB1
6	1 HB
7	Grinding
8	2 HB2
9	5 SB1
10	2 SB3

Experimental Study by Using Furnace

Material Studied

The material used in this study is a hot rolled stainless steel (SUS 410 M). Several mechanical and thermal properties, at room temperature, are listed in Table 3.The effect of continuously changing temperatures should be considered in this study. However, it was shown that the effect of material properties is small due to compensation effect of thermal and mechanical properties over the temperature range. For simplicity reasons, we assume here linear thermo-elastic behaviour, although hot rolled stainless steel (SUS 410 M) is a very ductile material. The crack growth behaviour has been identified on both SENT and CT specimen. The crack growth behaviour of the studied material can be approximated by a Paris law:

$$\frac{da}{dN} = c\Delta k^{n}$$

with $C = 6*10^{-12}$ and $n = 2.8735$ for Δk varying between 5 and 70 MPa√m.

As this Paris law is based upon the effective stress intensity factor amplitude ΔK_{eff}, it is valid for both short and long fatigue cracks. Moreover, it has been demonstrated that this law is valid for both any geometries.

Experimental Procedure

Before test, the front and back surfaces of the specimen were carefully polished (1 lm). The specimen is then placed in a resistive furnace, continuously heated at a constant temperature setting, until it reaches the temperature Tmax = 350°C. The specimen is free to expand and contract. Then, it is cooled down with spraying of water on opposite faces, until the chosen minimum temperature T min= 50°C is reached on the external surfaces. Demineralized water is used to avoid limestone layer on the surface of specimen. The procedure is repeated, to complete cyclic thermal loading on the specimen.

***Table 3:** Mechanical and thermal properties.*

Sr.No.	Properties	Value
1	Density	7.74 gm/cm3
2	Modulus Of Elasticity	$200*10^3$MPa
3	Ultimate Tensile Stress	570 MPa
4	0.2% Yield Strength	310 MPa
5	Elongation %	25
6	Rockwell Hardness	B80
7	Thermal conductivity	19W/m/K
8	CTE	$18*10^{-6}$ /K

During testing, temperature measurements of the have been made only in the vicinity of the water impact axis: this proved that the temperature evolution in the crack area is homogeneous and given by the measurements of thermocouples. The duration of the thermal cycle, revealed by thermo couples. With a very long duration of heating, it is shown that the temperature in the specimen just before cooling is nearly homogenous at 350°C. Thermal shock is the nature of our experimental facility. At the end of the test, optical observations were carried out, in order to measure crack propagation on the surface of the specimen.

DISCUSSION ON METHODOLOGIES

- The temperature evolution during braking was studied in relation to the hoop stress-hoop strain cycle. It was found that residual hoop tensile stresses appeared during cooling, which subsequently led to the development of radial micro cracks. [1] Finally, micro structural investigations of a bench-tested disc enabled us to validate the modelling results. Radial micro cracks on the disc surface and metallurgical phase transformations were observed. Never the less, such damage cannot be solely attributed to critical stop-braking, as some of it is likely to be due to the other braking tests in the sequence as well.
- During braking, the exterior of the friction surface is subjected to periodic tensile and compressive circumferential stress which leads to fatigue crack initiation and propagation [2]. The ratio of the long to the short axis of elliptically shaped cracks increased gradually. Therefore, the failure of the forged steel brake disc is mainly attributed to the radial crack length over critical value in addition, it is impossible for the cracks to run throughout the thickness of the friction surface.
- The cyclic temperature gradient induces a stress gradient inside the specimen. A tensile state near the surface and a compression state in the centre of the specimen are reported during cooling. It is shown that, with a tension state near the surface and a compression state in the centre, the crack slows down at the deepest point but accelerates at the surface point.

CONCLUSION

It is necessary to study cyclic temperature loading not only in terms of metallurgical phase transformation, chemical compositions but also fatigue failure considering stresses developed due to temperature gradient. This is short approach to study brake disc experimentally by considering sailed approaches in the paper. In this method the temperature gradient induced the stress gradient which is not shown in other two experimental methods. In furnace based experimental approach the crack propagates first in the depth and then it expands throughout the surface whereas in bench study method it is not uniform throughout the thickness. In case of method using fatigue test the damages due to critical stop braking is not attributed whereas in case of furnace test that damage are attributed. In the method of study of crack propagation using furnace the stress intensity factor (SIF) due to fatigue loading is taken into account while others was not focused in this area.

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