Characterization of Fade and Recovery Behavior of Brake Friction Material

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Abstract—The loss in braking effectiveness at elevated temperatures and the revival of the same at lower temperatures is referred to as fade and recovery, respectively. These characteristics are of great significance in the performance evaluation of friction materials. This paper deals with fade and recovery behavior of non-asbestos disc brake friction material.

Key Words—Brake, fade, friction and recovery.

I. INTRODUCTION

Disc brake friction materials consist of four classes of ingredients viz., binder - a thermo-setting resin (mostly phenolic), fibers, fillers and friction modifiers. Each class of material significantly contributes towards effective braking performance. In the passenger cars operating temperature of the rotor disc and pads can go up to 200-250° and 370° C respectively due to severe and repetitive breakings [1]. Such high interfacial temperatures lead to decrease in shear strength of the pad and consequently decrease in frictional force causing “Fade” [2]. Loss in braking effectiveness at elevated temperatures (300°C-400°C) because of reduction in friction coefficient and the revival of the same at lower temperatures is referred to as fade and recovery respectively[3],[4].

The temperature sensitivity of friction materials is a critical aspect while ensuring their smooth and reliable functioning. The temperature sensitivity of the friction materials influences the thermo-elastic-instabilities, which in turn alters the friction performance at the braking junctions [4]. In the front wheel, disc brake pads absorb a major amount (up to 80%) of the total kinetic energy of an automobile. This causes the generation of high temperature up to 370°C on the disc. The severity of such temperature rise is further manifested in the form of a very high flash temperature up to 600°C at the contacting asperities [4, 5]. At such high temperatures, pads suffer from a loss of effectiveness called “fade”. Such thermally induced friction alterations cause deviations in the Amonton’s law of friction.

The inverse temperature dependency of frictional shear loads at the interfacial zones brings out fade and reduces the braking efficiency. In this regard, the primary attributes in governing brake fade were proposed to be load fade, speed fade and temperature fade. The gas evolution at the braking interfaces as a consequence of pyrolysis and thermal degradation of the material resulting in a decrease in the applied force at elevated temperatures was also proposed to be one of the possible mechanisms of fade [7]. Fade was also reported to be strongly influenced by tribological history and shear thinning interfacial rheology at the braking junctions [8–10]. Traditionally the cause of fade has always been ascribed to the degradation of the phenolic resin [3], [4].

Hence the present paper deals with the possible mechanisms of fade and experimental study of fade and recovery behavior.

A. Types of brake fade

‘Fade’ is the term used to indicate a loss of braking effectiveness at elevated temperatures because of a reduction in the kinetic friction coefficient (μ). The fade phenomenon in friction materials represents a deviation from Amonton’s law of friction and its occurrence reduces braking efficiency and reliability. Three primary attributes governing brake fade have been identified by Rhee as load fade, speed fade and temperature fade. High interfacial temperatures can lead to a decrease in shear strength of the pad and consequently a decrease in frictional force which induces fade [9].

Anderson [7] has categorized fade phenomenon as thermal fade, delayed fade, blister fade, flash fade and contamination fade.

1) Delayed Fade

It is a phenomenon that can occur with some drum brake friction materials. During the fade recovery, brake effectiveness may drop unexpectedly, causing a temporary, but pronounced increase of brake pedal force requirement. A delayed fade is insidious in that it is unexpected. It occurs well after a period of hand brake usage and usually with no warning signs.

2) Blister Fade

New brake linings may contain volatile material from fabrication, which if not released by the end of the burnish process, could cause high internal gas pressures upon rapid heating, as during a hard brake application. In some situations, a near-surface blistering results in a rapid, brief loss of brake effectiveness. Friction is lost because of...
excessive contact pressures at the blister sites and from the evolved gases. Effectiveness is lost for a few seconds during a hard brake application, and then returns to near-normal. Repetition of the hard brake application will not produce a second blister fade, because the volatile material has been eliminated from the near-surface region.

3) **Flash Fade**

It is related to the blister and green fade, but occurs only at very high brake power levels, usually at very high speeds. The rapid decomposition of near-surface organic constituents produces a gas-pressure-lubricated braking surface. The brake lining friction may not be low, but the evolved gas pressurizes the friction material to counteract the applied force. High surface area brakes and those with high organic contents are most vulnerable. Prior brake usage at moderate to high brake lining soak temperatures reduces flash fade severity.

4) **Contamination Fade**

Water, oil or a combination of these on the surface of the brake lining or brake drum/disk can generate an elasto hydrodynamic fluid film that effectively makes a bearing from a brake. Different friction materials have different porosity, compliance and wear characteristics and thus may be quite different in sensitivity to contamination. High surface area brakes, such as drum brakes are more prone to contamination fade. However, even automotive disk brakes can exhibit such a fade, if saturated by either water or oil/water. This effect is similar to that from oil/water films on the road surface, affecting tire friction.

According to Sherwood Lee [11] Following are the types of brake fade

1. Pad fade
2. Green fade
3. Fluid fade

5) **Pad fade**

Pad fade can be caused by several factors. Friction materials are designed to work at an optimum temperature when the coefficient of friction is the highest. When brakes are used too frequently, if the pad material is not adequate for the temperature then the coefficient of friction can decrease. When the temperature is too high the material can melt and cause the coefficient of friction to rapidly decrease to the point where the material will melt and/or change its frictional characteristics and cause a lubrication effect. Some pad materials change slowly at elevated temperatures while other materials react with a sudden and dangerous loss of friction. The result is “glazed” brake pads and rotors.

6) **Green Fade**

This is the type of brake fade caused by hard braking on relatively new pads. With new pads, the resins that bind the friction material will “out-gas” at relatively low temperatures. This is caused by not “bedding” the pads rather than being caused by elevated braking temperatures. Green fade typically occurs much earlier than normal pad fade. Green fade can happen even after changing the brakes and driving normally for many hundreds of miles. The first aggressive stop may result in a loss of friction.

7) **Brake Fluid Fade**

Fluid fade is caused by overheated brake fluid. The energy converted during braking creates tremendous heat which must be handled by the rotors, calipers, brake pads and the brake fluid. When fluid reaches a critical temperature, it boils. Regular brake fluids boil around 400°F, the best ones are stable up to 500°F and higher. Whatever the rating, when brake fluid boils air bubbles are created. Fluid in a closed system cannot be compressed. However, air can be compressed and when boiling brake fluid creates air bubbles, the brake pedal and master cylinder travel is used up compressing the air and thus unable to hydraulically move the pads against the brake rotor.

II. **EXPERIMENTAL**

To evaluate the fade and recovery behavior of disc brake pad assembly intended for specified vehicle, four wheeler inertia brake dynamometer as shown in Fig. 1 and specified brake pad assembly were used.

The inertia for this test is 90 kg.m$^2$. The fixture of caliper disc brake pad assembly is mounted on the tail stock end of dynamometer. The disc is mounted. The disc pad assembly is positioned properly onto the caliper. The sequence for the fade and recovery test is given as follows:

A. **Base line check test**

Fade test starts with base line check. It is carried out for finding the friction coefficient before hot performance. The test carried out at 80 kmph and 60 bar pressure. There are three cycles for base line check. After completion of this test, immediately fade test is started.

B. **Fade test**

During the fade test 15 brake applications were done at very short interval for the speed 120 kmph to 60 kmph. The temperature versus the coefficient of friction graph was plotted. During these stops 65 bar pressure was applied which allows the pad to be tested to become very hot and as a result
one can observe the behavior of the test pad during high temperature applications. An inferior test pad will fade drastically, especially during the first seven stops after which it will recover somewhat [9].

C. Residual Stop test
Immediately after fade test the residual stop test took place. From this stop the coefficient of friction after the hot performance is calculated. It will give us percentage fade. This test was carried out at 80 kmph and pressure is 60 bar.

D. Recovery test
The return to acceptable levels of friction at lower temperatures is referred to as ‘recovery’ [9]. It is carried out immediately after residual stop test. The speed for the test was 120 to 60 kmph and pressure 65 bar.

E. Post Recovery test
Post recovery is carried out immediately after the recovery cycle is over. It gives the performance after the recovery of the coefficient of friction. Recovery behavior was studied at 80 kmph and 60 bar. Percentage recovery was calculated after this test.

III. RESULT AND DISCUSSION

For this brake friction material (Ref. Fig.2) the value of coefficient of friction dropped from 0.255 to 0.202 for first five cycles. After that there was a gain of coefficient of friction from 8th cycle to 12th cycle i.e. μ increased from 0.202 to 0.224. Further it showed drop of friction coefficient from 8th cycle to 12th cycle (i.e.μ dropped from 0.224 to 0.209). After that there was increase of coefficient of friction for next 3 cycles. For this material observed fade percentage was 9.90 %.

During fade test temperature increased drastically due to continuous action of rotor and friction material. The highest temperature of brake pad material was recorded during the fade cycle. At the end of fade cycle the temperature reached beyond 500ºC.

The recovery test is used to identify how quickly a material can recover to base line characteristics of friction level. This friction material showed the good recovery characteristics, its percentage recovery was 112 %.

IV. CONCLUSION
Tested friction material is having moderate fade characteristics but good recovery behavior.

V. REFERENCES

VI. APPENDIX

\[ \text{Percentage fade} = \frac{\text{Avg COF before fade test} - \text{COF after fade test}}{\text{Avg COF before fade test}} \]

\[ \text{Percentage Recovery} = \frac{\text{Avg COF of post recovery}}{\text{Avg. COF before fade test}} \]