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REDUCTION OF DISC BRAKE SQUEAL NOISE USING CONSTRAINED LAYER DAMPERS

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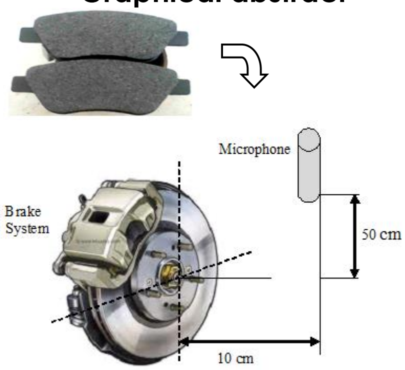
Graphical abstract



Abstract

Brakes squeal has remained to be one of the major Noise, Vibration and Harshness (NSH) challenges in brake system design and development. It has been a concern for automotive industry for decade. Brake researchers have proposed many brake squeal reduction and prevention methods in order to overcome and reduce the squeal that emanates from the brake disc systems. In this paper, the effectiveness of constrained layer dampers (CLD) in reducing disc brake squeal noise was investigated. CLD isolates the brake squeal noise through shear deformations of the viscoelastic materials. Two sets of brake tests were conducted using the brake test dynamometer with the application of CLD. Two different types of CLD were used which are three-layer constrained layer damper and four-layer constrained layer damper. Squeal tests were carried out using brake noise test rig based on the global standard procedure SAE J2521. From the test, four-layer CLD configuration works more efficient than three-layer CLD configuration. CLD made up of nitrile butadiene rubber, silicone rubber and mild steel proved to be the most effective noise insulator at hydraulic pressure range of 5 bar to 30 bar and temperature range of 50^{o}C to 200^{o}C with a maximum noise reduction of 11.3 dBA. Thus, CLD technique was proven to be an effective method in reducing brake squeal noise.

Keywords: Disc brake, squeal, constrained layer damper, viscoelastics materials

1.0 INTRODUCTION

The generation of squeal noise is a major problem for brake pad manufacturers, since they cause discomfort to the drivers and leads to unwanted warranty payouts. The warranty claims due to the noise, vibration and harshness (NVH) issues in North America alone were up to one billion US dollars per year [1]. Besides, Abendroth and Wernitz [2] have stated that many friction material suppliers had to spend up to 50 percent of their engineering budget on the NVH issues. Brake squeal noise is widely accepted as sound vibration that occurs above 1 kHz and its sound pressure level exceeds 70 dBA [3]. Till now, various methods have been proposed and implemented to reduce the propensity of generating squeal noise. They are damping layer [4-8], structural modifications [8, 9] and active noise control [10]. It is seen that damping layer is mostly preferred by car makers and brake suppliers due to its capability to suppress squeal and cost effective compared to the other techniques.

Constrained layer damping (CLD) treatment has been emerging as an excellent tool in damping mechanism. When the pad vibrates in the bending modes, a constrained layer material with a viscoelastic core bonded onto the pad backplate is submitted to mechanical deformations, converting part of the energy into heat by shear damping reducing the vibration amplitude of the component [6]. The damping layers are typically made of a viscoelastic material that sandwiched by steel plates. Singh *et al.* [5] discussed on the design, selection and implementation of a viscoelastic damping (insulator) to control disc brake squeal. Two insulator designs were investigated namely; a multi-constraining layer (insulator 1) and a single constraining layer (insulator 2) dampers. The dynamometer results shown that there was more than 25 times sound pressure level of 100 dB appear for insulator 1 while only 3 times when insulator 2 was used. This shows that insulator 2 was better in controlling disc squeal. Triches *et al.* [6] attempted to suppress squeal generation at frequency between 1 kHz to 7kHz using constrained layer damping materials or insulators. The insulators made of a viscoelastic material that sandwiched by two steel plates and was a very thin layer, which was bonded to the back plate. Several types of insulators were tested in the dynamometer and they were effectively suppressed squeal up to 20 dBA.

CLD has proven to reduce vibration of a system but its effectiveness in isolating squeal level, particularly at different hydraulic pressure and temperature needs to be examined [7]. Thus, this paper attempts to investigate the effectiveness of CLD in reducing brake squeal occurrences at different hydraulic pressure and temperature.

2.0 METHODOLOGY

The brake squeal test was carried out using a brake test rig dynamometer as shown in Figure 1, and adapted the global standard procedure SAE J2521 [8-10]. However, this test procedure has been modified to suit with the limitations of the test rig. For instance, the squeal test only employed maximum braking pressure of 30 bar. In this work, handheld devices such as IR thermometer, tachometer, pressure gauge and noise meter were used to measure temperature, sliding speed, pressure and sound pressure level, respectively. The brake squeal test was divided into two sections which are, before and after application of CLD. Bedding-in procedure was carried out before starting the real test. Bedding-in is done to ensure brake pad makes complete contact with the rotor. In the bedding-in process, the rotor was made to run for one and half hours at 6 rad/s (57 RPM) and applying braking pressure of 10 bar.

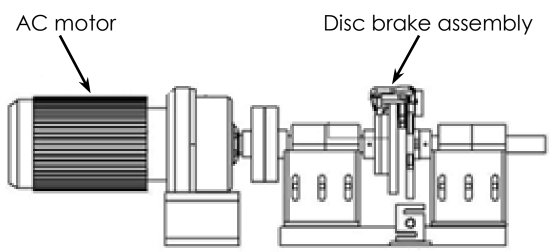


Figure 1 Schematic diagram of a brake test dynamometer

The baseline brake test was conducted at two different sliding speeds which are 3 km/h and 10 km/h. The pressures applied on the rotor surface are 5, 10, 15, 20, 25 and 30 bar. For each speed and pressure condition, different initial temperatures were applied, which are 50, 75, 100, 125, 150, 175 and 200°C. The cooling of the rotor to the desired temperature was made with the aid of a blower. A sound pressure level of 70 dBA was kept as the threshold to describe the squeal noise [11-14].

The thickness of the viscoelastic material is 1.1 mm, whereas the thickness of the steel sheets is 0.55 mm. Therefore, the total thickness of the CLD is 2.2 mm. The thickness of all the viscoelastic material has been kept constant because different thickness will provide varying damping behaviour. The viscoelastic rubber and the steel sheets have been fabricated based on the shape of the brake pad back plate. This was done so that maximum noise damping can be achieved [15-16].

The CLDs were bonded using adhesives and installed on the back of the brake pad at piston side. Three and four layers CLD configuration have been used to investigate the squeal reduction effect. The best two viscoelastic materials in three layers CLD squeal test were opted to be used in four layers CLD test. The experimental procedure for the CLD squeal test is similar to the baseline brake test.

3.0 RESULTS AND DISCUSSION

The baseline brake test shows that the maximum sound pressure level achieved at the speed of 3km/h and 10km/h were 56.1dBA and 73.2 dBA. Therefore, it can be implied that squeal event did not occur at 3 km/h as the pressure level is below the threshold limit for squeal which is about 70 dBA. The squeal only occurs at sliding speed of 10km/h as illustrated in Figure 2. So, CLD test was carried out at that particular speed. Mild steel and stainless steel have been used as the constraining layer whereby silicone rubber, Ethylene Propylene Monomer Rubber (EPDM) and Nitrile Butadiene Rubber (NBR) were used as the viscoelastic material.

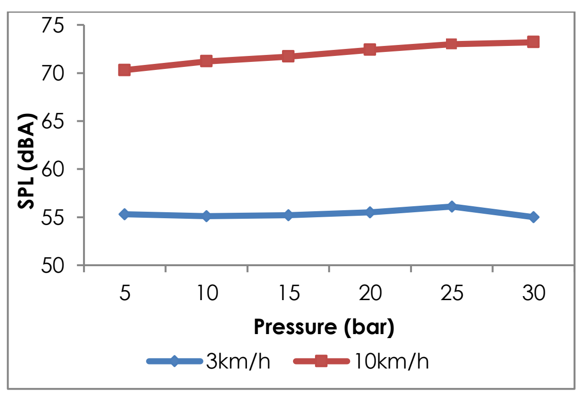
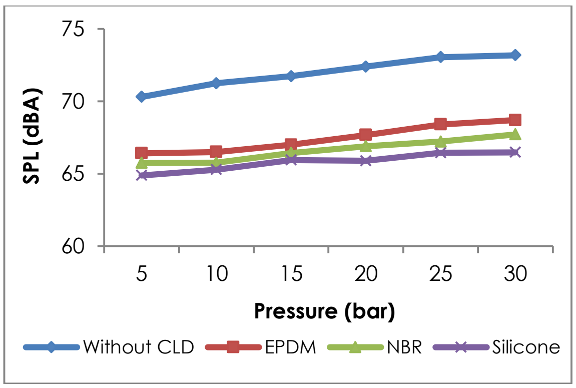
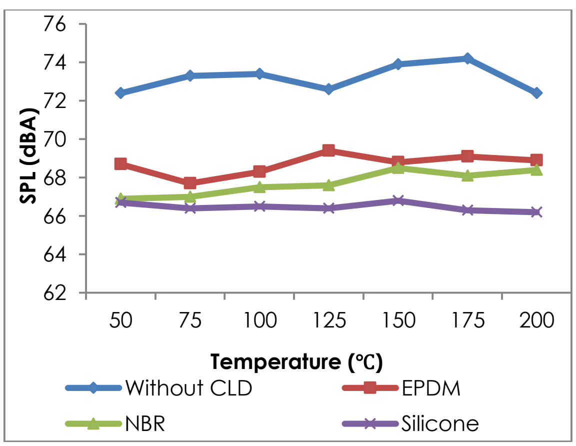


Figure 2 Squeal test results at two different speeds

Based on the CLD test, it has been found that all the viscoelastic materials were stable at the tested temperature regime. However, a detailed analysis shows that CLD works efficiently at opposite temperature and pressure conditions, i.e. low pressure and high temperature condition. Therefore, all the noise levels of a particular temperature were averaged and plotted as in Figure 3(a). When stainless steel was used as the constraining layer, silicone outperforms NBR and EPDM rubber in noise damping performance. Silicone rubber has observed noise reduction of 6.7 dBA at a pressure of 20bar. Viscoelastic materials work great at higher pressure because the high compression force causes greater shear deformation [17], which leads to higher energy dissipation [18-19].



(a)



(b)

Figure 3 Relationship between SPL and: (a) braking pressure and (b) temperature at 30 bar for three layers CLD with stainless steel as the constraining layer

At braking pressure of 30 bar, the baseline brake condition experienced a sudden dip in sound pressure level at 125℃ as shown in Figure 3(b). On the other hand, application of EPDM caused a drastic increase at the stated temperature. EPDM does not exhibit good noise damping behavior at 125℃ because it only able to reduce 3.2 dBA at that temperature. EPDM behaves better at 75℃ where it reduced a maximum of 5.6dBA; from 73.3 dBA to 67.7dBA.

Besides, NBR and silicone produced almost a similar plot trend as in pressure condition of 20bar and 25bar. However, at pressure 30 bar, NBR does not provide better noise damping compared to the one at pressure 20 bar and 25 bar. The maximum noise reduced at this pressure was 6.3 dBA, occurring at 75℃, where it reduced from 73.3 dBA to 67 dBA. Silicone again has topped the list in noise damping at this pressure. It has reduced a maximum of 7.9dBA at 175℃, which means silicone is 20.3% better compared with NBR and 29.1% better than EPDM.

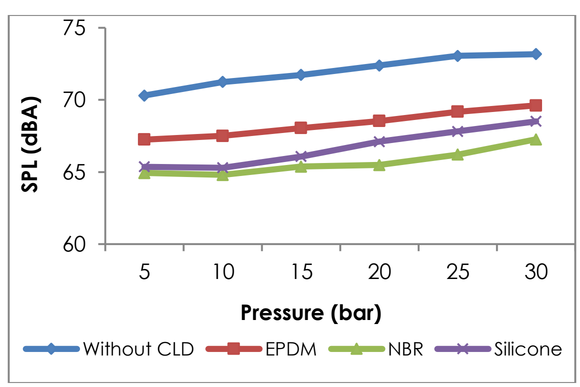
Figure 4(a) depicts the relationship between sound pressure level and braking pressure when mild steel used as the constraining layer for three layers CLD. The results indicated that NBR interacts better with mild steel compared with silicone rubber and EPDM rubber. NBR rubber has achieved maximum noise reduction of 6.9dBA at braking pressure of 20 bar.

When applying pressure of 30 bar, EPDM worked excellent at 150℃ because it has provided a noise reduction of 4.2 dBA as seen in Figure 4(b). However, at a similar temperature condition, EPDM works better when using stainless steel as the constraining layer. When stainless steel used as the constraining layer, noise reduction of 5.1 dBA was observed, this means 17.6% better than mild steel.

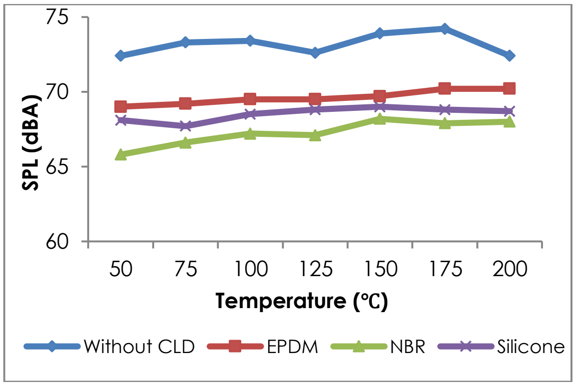
On the other hand, NBR and silicone rubber has shown good noise damping performance at 75℃. At this temperature, silicon rubber has achieved a noise reduction of 5.6 dBA. This noise reduction was observed to be from 73.3 dBA to 67.7 dBA.

However, silicone has shown better noise reduction when using stainless steel as the constraining layer. Usage of stainless steel as constraining layer has provided better noise suppression by 18.8%. The graphical pattern of NBR shows that it works better at temperature lower than 100℃. NBR has shown great performance at 75℃, with noise reduction of 6.7dBA. Given at the temperature of 75℃, NBR worked better than silicone by 16.4%. Furthermore, NBR also has performed better when using mild steel instead of stainless steel as the constraining layer.

Three layers CLD squeal test has shown that EPDM rubber does not work efficiently compared with NBR rubber and silicone rubber. Therefore, NBR rubber and silicone rubber were employed in the construction of four layers CLD. Due to contradicting interaction with constraining layers, NBR rubber and silicone rubber were tested with both mild steel and stainless steel.



(a)

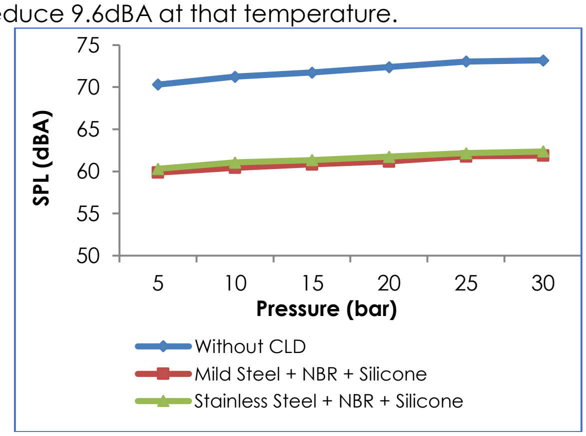


(b)

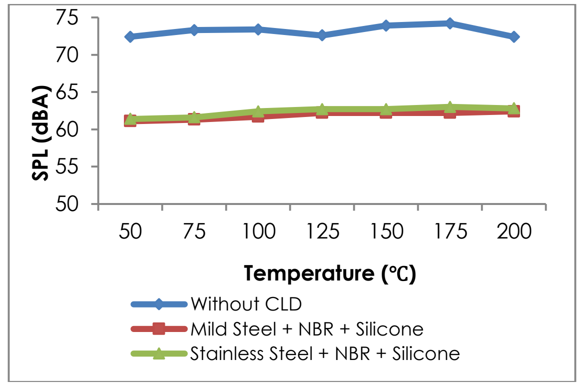
Figure 4 Relationship between SPL and: (a)braking pressure and (b) temperature at 30 bar for three layers CLD with mild steel as the constraining layer

Based on Figure 5(a), both mild steel and stainless steel CLD worked efficiently at high braking pressure. By adding another layer in the CLD, damping level will increase and hence, it will be able to absorb more vibration energy [20-22]. This agrees with the review made by Lakkam and Koetniyom [7] that brake squeal could be suppressed with the optimized damping. Mild steel CLD has provided maximum noise reduction of 11.3 dBA at 30 bar, whereas stainless steel CLD has shown maximum noise reduction of 10.9 dBA. This implies that mild steel CLD possesses better noise damping capability compared with stainless steel CLD.

The plot trend of mild steel CLD in Figure 5(b) shows that, it experienced increasing value only from 50°C to 100°C. Thereafter, the noise level stays constant at 62.2 dBA and rises again after reaching temperature of 175°C. The mild steel CLD has worked efficiently at two different temperatures which are 75°C and 175°C. However, mild steel CLD did not perform quite well at temperature of 200°C. This is because it only able to reduce 10dBA at the stated temperature. On the other hand, stainless steel CLD has worked efficiently at the temperature of 75°C. It has reduced squeal noise from 73.3 dBA to 61.6 dBA, which is a reduction of 11.7 dBA. Similar to mild steel CLD, stainless steel CLD also failed to perform well at 200°C. This is because it only able to reduce 9.6dBA at that temperature.



(a)



(b)

Figure 5 Relationship between SPL and: (a) braking pressure and (b) temperature at 30 bar for the four-layer CLD

4.0 CONCLUSION

Based on baseline brake test, squeal noise tends to generate at sliding speed of 10km/h. Three layers CLD test showed that NBR rubber and silicone rubber damped squeal noise were better than EPDM rubber. The viscoelastic materials work efficiently at opposite temperature and pressure condition. The four layers CLD proven to be a better configuration than three layers CLD because it shows maximum noise reduction of 11.3 dBA. Thus, constrained layer damping technique can be considered to be an effective method in reducing brake squeal noise.

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