World Academy of Science, Engineering and Technology
International Journal of Transport and Vehicle Engineering
Vol:11, No:11, 2017

Effect of Compressibility of Brake Friction Materials on Vibration Occurrence

Mostafa Makrahy, Nouby Ghazaly, Ahmad Moaaz

***Abstract*—**Brakes are one of the most important safety and performance components in automobiles and airplanes. Development of brakes has mainly focused on increasing braking power and stability. Nowadays, brake noise, vibration and harshness (NVH) together with brake dust emission and pad life are very important to vehicle drivers. The main objective of this research is to define the relationship between compressibility of friction materials and their tendency to generate vibration. An experimental study of the friction-induced vibration obtained by the disc brake system of a passenger car is conducted. Three commercial brake pad materials from different manufacturers are tested and evaluated under various brake conditions against cast iron disc brake. First of all, compressibility test for the brake friction material are measured for each pad. Then, brake dynamometer is used to simulate and reproduce actual vehicle braking conditions. Finally, a comparison between the three pad specimens is conducted. The results showed that compressibility have a very significant effect on reduction the vibration occurrence.

***Keywords*—**Automotive brake, friction material, brake dynamometer, compressibility test.

I. INTRODUCTION

THE friction material in the brake system has been considered as one of the key components for the performance of automobile. This is because it plays essential roles in various scenes of the brake performance such as a stopping distance, pedal feel, counter disk wear, and brake induced vibrations. The friction materials are demanded to supply a low wear rate and a stable friction coefficient at several operating temperatures, speeds, pressures and environmental conditions. Furthermore, these materials must also be compatible with the rotor material in order to reduce its extensive wear, vibration, and noise during braking [1], [2].

A commercial brake pad usually contains 10 to 20 different ingredients in order to obtain the best friction characteristics [3]. The lining materials of automotive brakes are often categorized into four classes of ingredients: binders, fillers, friction modifiers, and reinforcements. It is obvious that the characteristics of roughness characterizations, surface topography, physical properties of contact areas and the debris materials between the surfaces have a strong influence on the generation of brake vibration [4].

Farhang et al. [5] presented that noise can be related to specific surface roughness parameters, properties from micro- and macroscopically of the contact when properties of friction material (such as compressibility, stiffness and modulus of elasticity) and friction layer fit into certain specific value ranges, noisy behavior occurs.

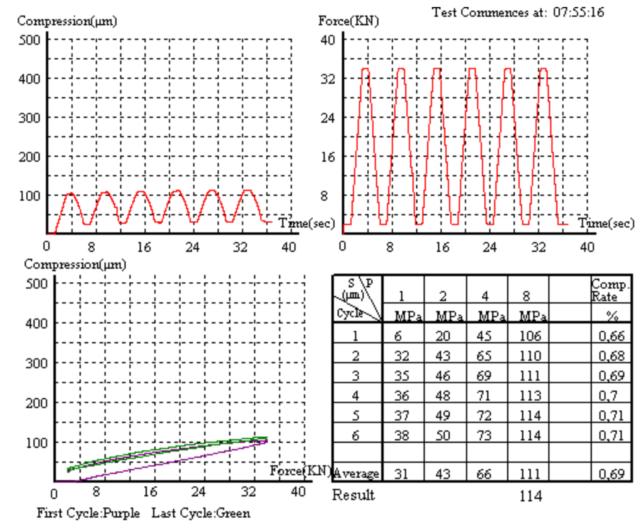
Wegmann et al. [6] define a pad's compressibility as being due to the combined physical effects of relating the elastic and plastic deformations of the lining material after a series of load cycles. Compressibility is not a friction material-specific characteristic but describes a property of the whole pad assembly which depends on its material composition, number of layers and geometry. Sanders et al. [7] study cyclic compressibility as a function of the pre-load, temperature and velocity of a semi-metallic brake lining by means of a full factorial design analysis. Increasing the temperature from 20 to 300 ◦C, or lowering the pre-load from 8 to 4 kN, halves its compressibility. Decreasing the frequency of rotation from 20 Hz to 1 Hz reduces compressibility by 10% which is almost the same as the effect of an increase in stiffness. Jeong et al. [8] measured compressibility of shims trough different parameters, for example, of adhesive shims (bonding spec., steel and rubber thickness), piston's shapes (different contact areas to the shims), and the numbers of durability. The optimization for brake feeling was determined by design for six sigma. They believe that the results should serve a useful guideline for designing braking feeling system better without brake noise.

In this research paper, the main aim is to address the relationship between compressibility of friction pad materials and their propensity to friction induced vibration generation. The compressibility of three different brake pads is measured. The vibration amplitude for each brake pad under various vehicle speed and brake pressure is investigated through brake dynamometer. Comparison between the three pads is conducted and analyzed.

II. COMPRESSIBILITY TEST

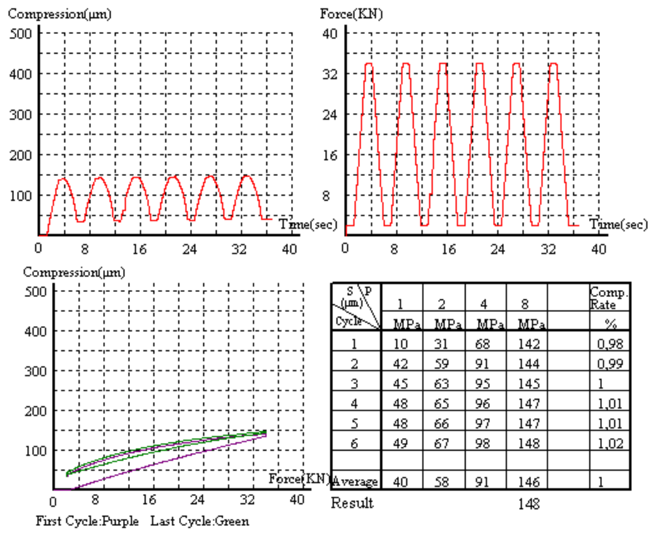
Fig. 1 Compressibility tester type KP10-C

Nouby Ghazaly is with the South Valley University,Qena- Egypt (phone: 00201010561818, e-mail: noubyluxor@eng.svu.edu.eg).
Mostafa Makrahy is with the Minia University, Minia-Egypt (e-mail: engmakrahy@yahoo.com).
Ahmad Moaaz is with the Beni-suef University, Beni-suef- Egypt (e-mail: moaz777@eng.bsu.edu.eg).



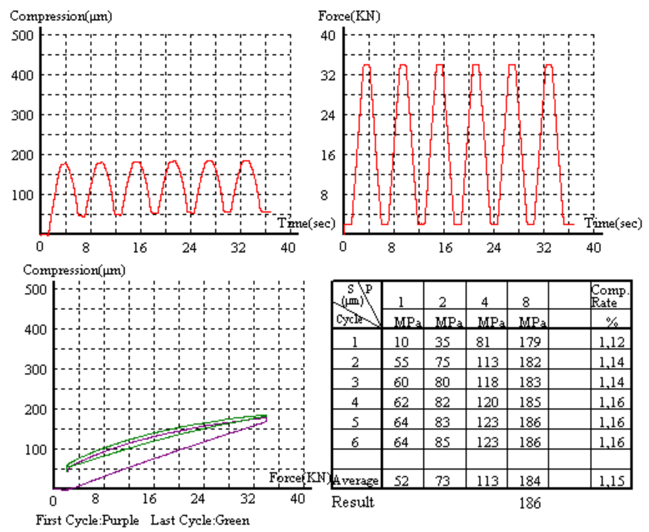
S (µm) \ P / Cycle	1 MPa	2 MPa	4 MPa	8 MPa		Comp. Rate %
1	6	20	45	106		0,66
2	32	43	65	110		0,68
3	35	46	69	111		0,69
4	36	48	71	113		0,7
5	37	49	72	114		0,71
6	38	50	73	114		0,71
Average	31	43	66	111		0,69
Result				114		

Brake Pad A



S (µm) \ P / Cycle	1 MPa	2 MPa	4 MPa	8 MPa		Comp. Rate %
1	10	31	68	142		0,98
2	42	59	91	144		0,99
3	45	63	95	145		1
4	48	65	96	147		1,01
5	48	66	97	147		1,01
6	49	67	98	148		1,02
Average	40	58	91	146		1
Result				148		

Brake Pad B



S (µm) \ P / Cycle	1 MPa	2 MPa	4 MPa	8 MPa		Comp. Rate %
1	10	35	81	179		1,12
2	55	75	113	182		1,14
3	60	80	118	183		1,14
4	62	82	120	185		1,16
5	64	83	123	186		1,16
6	64	85	123	186		1,16
Average	52	73	113	184		1,15
Result				186		

Brake Pad C

Fig. 2 Compressibility test for each pad specimen

The properties of compressibility for the friction material which is used in vehicle should be within certain limits. The main properties are minimal wear rate, sufficient power transfer from the friction pads to the rotating disc brake and must be hard enough to provide suitable pedal feel. In addition, it should be elastic to ensure sufficient grip on several disc surfaces that is indicated the quality of final products. In this work, Compressibility Tester Type KP10-C is used to examine the three friction pads material as shown in Fig. 1. Compressibility Tester according to ISO 6310 – 1980 and ISO 6310 – 2000 is used. Fig. 2 shows the results for compressibility tests performed for three different brake pads namely; (A, B and C). To easily compare between compressibility of the different brake pads, average compressibility of the three specimens is plotted under different pressure, as shown in Fig. 3. It can be observed that the **A** specimen exhibits the lowest compressibility value of these three specimens.

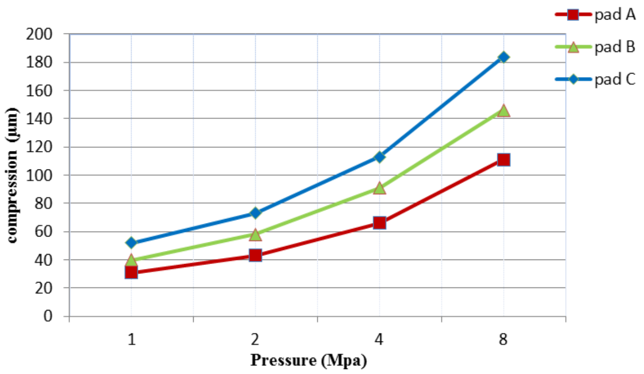


Fig. 3 Average compressibility of the three specimens

III. Dynamometer Testing

A simple brake dynamometer is prepared to provide the demand disc rotation speed and apply brake pressure to various brake applications. It can be depicted as the following: The braking system, the driving system and the measurement instruments. Fig. 4 shows the main components of the brake test rig with its different parts. The main driving unit consists of an A.C. motor of 14.9 KW with 1500 rpm that feeds the rotation speed for the driving shaft with various values. This is accomplished with the help of a manual gearbox. The braking unit contains the front disc brake components of the passenger car. The ventilating disc with its floating brake caliper is selected. A hydraulic jack is fixed to provide the required pressure. The measurement instruments included tachometer which is used to measure the rotating speed, pressure gauge which is measured applied pressure, brake acceleration is measured using accelerometer and charge amplifier, temperature is recorded by a thermocouple and tangential force is evaluated by load cell.

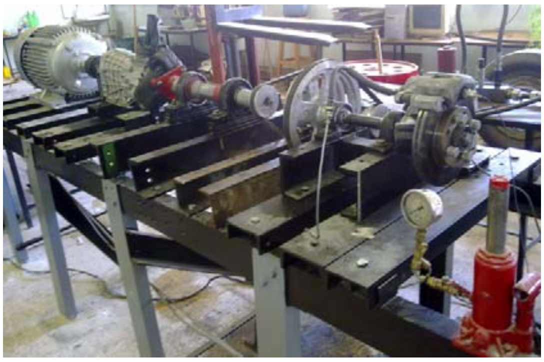
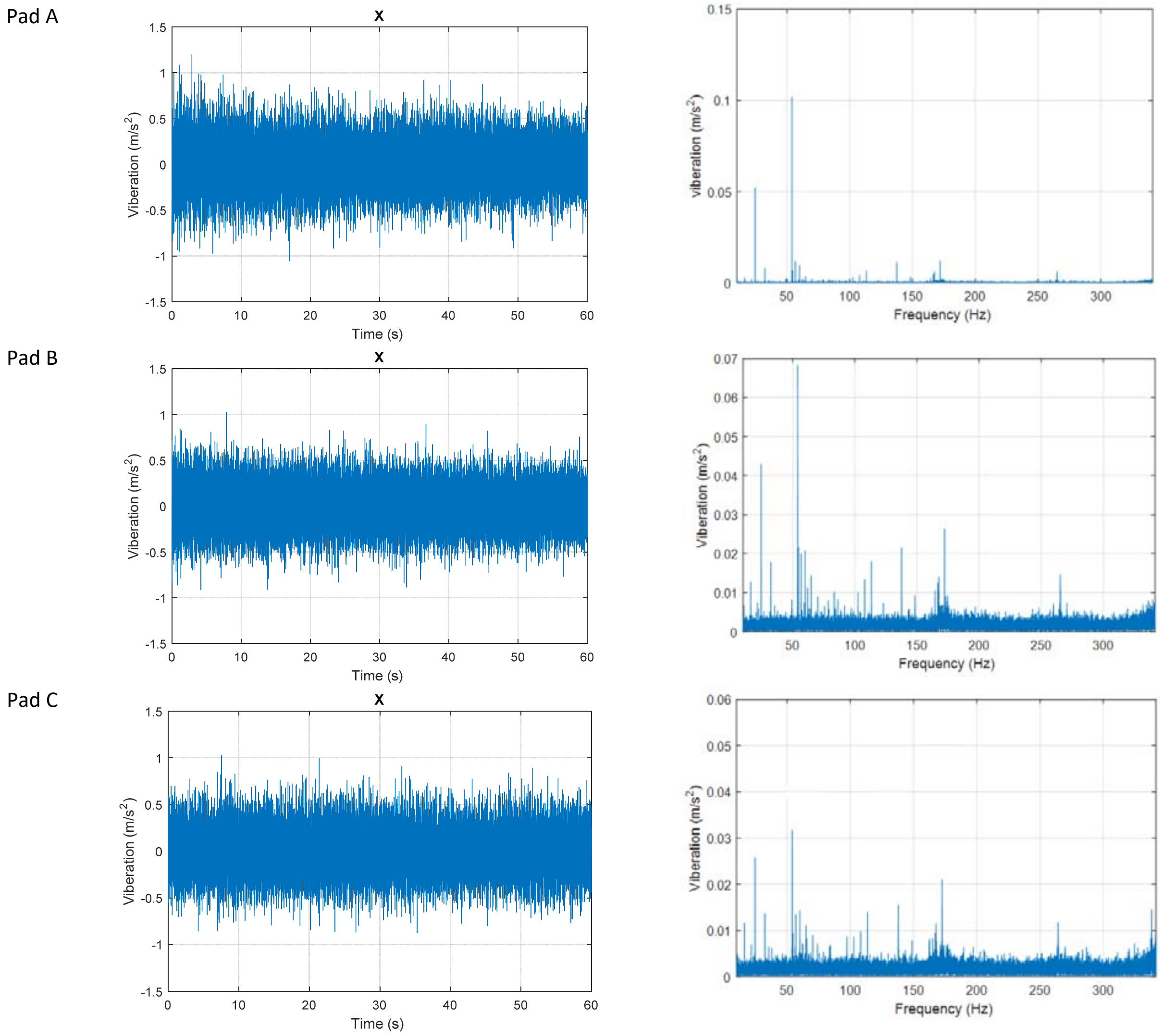


Fig. 4 Brake Test rig

IV. Vibration Measurement

Vibration measurements are conducted for three vehicle speeds 90. 170 and 250 rpm under different brake pressure in the range 0.1 to 0.7 Mpa. The output signal from the accelerometer is imported to the data acquisition signal after amplifed by a B&K charge amplifier. The amplified signals are saved in PC computer in digital form for further analysis. In order to show the comparison between vibration amplitudes of three brake pads, frequency domain signal is considered and plotted. Hence, it must be converted from the time domain to the frequency domain using a Fast Fourier Transform (FFT). Fig. 5 is one example of time domain data received from test brake pad collected by accelerometer at vehicle speed of 90 rpm and applied pressure of 0.1 Mpa. The equivalent frequency domains for all tests are recorded. Measurements are conducted three times for each test condition. Small variations; which were neglected, in the amplitude of vibration were noticed hence, the three measured vibration signals were averaged and reported. It is observed that the peak value of the pad vibration amplitude emanates from all tests are dominant at approximately frequency of 55 Hz.



Time Domain data of accelerometer *Frequency Domain data of FFT*

Fig. 5 Vibration measurement at 0.1 Mpa and 90rpm for three pads

V. RESULT AND DISCUSSIONS

Under various operating conditions of applied pressure and sliding speed, 12 vibration tests are applied to the disc brake assembly for each brake pad. Vibration frequencies are captured through accelerometer and analyzed using FFT for the three pads A, B and C. Vibration magnitudes for each brake pad at different speed are plotted as shown in Figs. 6-8. It is observed that the peak value of the pad vibration amplitude emanates from all tests are dominant at frequency of 55 Hz. Moreover, the vibration amplitude is dependent on the brake pressure and the vehicle speed. The results showed that the brake pad A generates more vibration than the brake pads B and C at the same operation conditions. It may be referred to the compressibility properties which act as the damping for vibration. It is found that A exhibits the lowest compressibility value of these three specimens. Briefly, it can be concluded that the vibration level decreases with the increase of pad compressibility. Furthermore, it is shown that the vibration level decreases with increase of applied pressure.

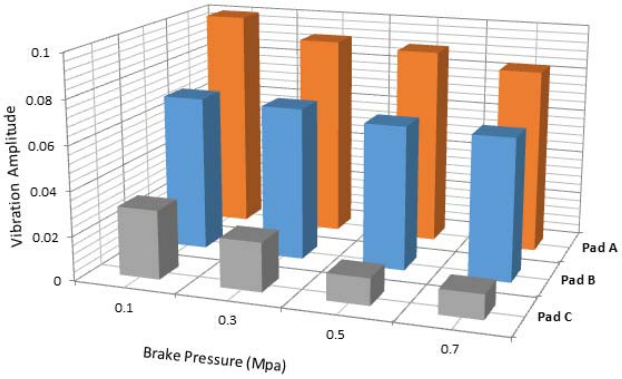


Fig. 6 Vibration amplitude versus applied pressure at speed 90 rpm

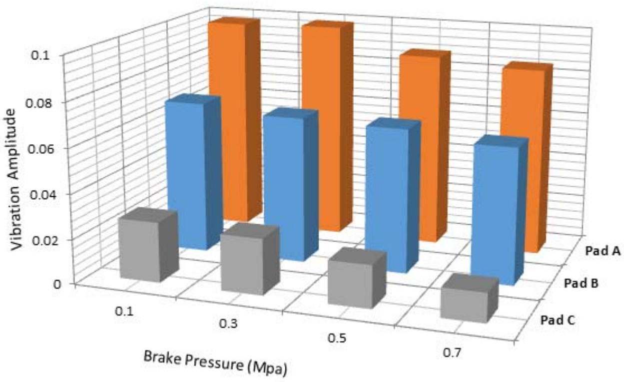


Fig. 7 Vibration amplitude versus applied pressure at speed 170 rpm

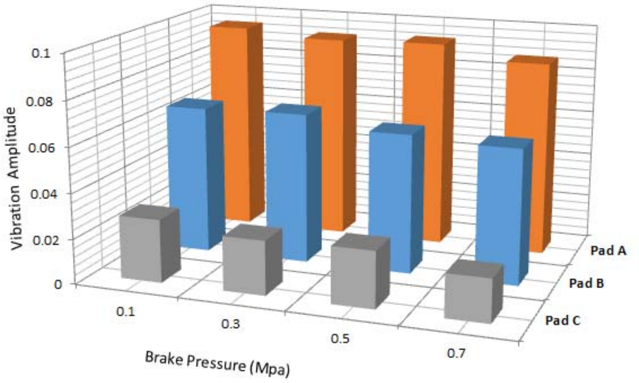


Fig. 8 Vibration amplitude versus applied pressure at speed 250 rpm

VI. CONCLUSIONS

This study is planned to identify the effects of pad compressibility on vibration generation. First, the pad compressibility of several brake pads obtained from different manufacturers is tested. The experimental results showed that the pad compressibility for pad A is less than pad C and pad B. Second, the vibration measurements for the three pads are measured using brake dynamometer under different operation conditions. It is noticed that the peak value of the pad vibration amplitude emanated from all experimental tests are dominant at 5.5 Hz. In addition, the vibration amplitude is dependent on the brake pressure and the vehicle speed. It is also shown that the vibration level decreases with the increase in applied pressure. Moreover, the results showed that the pad vibration decreased as pad compressibility increased, Finally, based on experimental measurement, it can be concluded that compressibility of brake specimens have strong influences on the occurrence of brake vibration.

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