

A Study of Pad Properties vs. Friction, Wear and Brake Squeal: Processing/Porosity Effects

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ABSTRACT

As some brake engineers believe that brake squeal can be related to pad hardness, friction coefficient or compressibility while others disagree, a study has been undertaken to develop further insights. Two commercial formulas, one low-copper NAO and the other copper-free NAO, were made into disc pads of varying porosity without an underlayer and they were checked for specific gravity, porosity, hardness (HRS and HRR), natural frequencies, compressibility, friction, wear and squeal. With increasing porosity, the hardness and natural frequencies continue to decrease. The compressibility definitely does not increase, but rather slightly decrease or stays the same. The coefficient of friction decreases for the low-copper along with pad and disc wear reduction, and increases for the copper-free along with pad wear increase with no change in disc wear. No obvious correlation emerges between brake squeal and pad hardness, friction coefficient or compressibility. After the pads were compressed under 30, 100 and 160 bars, the hardness of the pad surface is found to increase, suggesting permanent compaction under the pressures while the interior of the pad, 5 mm deep, shows slightly increased hardness in the case of 18% and 22% porosity, not in the case of 13% porosity. The results raise a question about the meaning and usefulness of compressibility measurements.

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INTRODUCTION

Some brake engineers believe that the hardness of the pad is related to brake squeal occurrence; the higher the pad hardness, the higher the brake squeal occurrence, that lower pad compressibility (harder pads) leads to higher brake squeal occurrences, or that high coefficient of friction leads to brake squeal. Obviously there is a strong desire to relate a simple property or parameter to brake squeal. Others believe that brake squeal is not related to any of these factors [1,2].

This research is undertaken to investigate the factors in a systematic way, document relevant data and provide some insights for clarification and further open discussions.

MATERIALS, EQUIPMENT AND HARDWARE

Two production formulas were selected for the investigation; one low-copper NAO formula and one copper-free NAO formula. The underlayer was not incorporated in order to keep the experiments and

interpretations simpler. The pads were made to the size suitable for a twin-piston floating caliper (front) designed for a pick-up truck of GVW 3,200 kg and the pads had 2 vertical slots along with a radial chamfer on each end. The pads were molded at 150 °C while adjusting the molding pressure to achieve desired specific gravity/porosity. As production disc pads typically range in porosity from 12% to 24%, 13%, 18% and 22% were chosen for this investigation. The discs were 305 mm in diameter. Pad compressibility were measured using Link Compressibility Machine 1620-P/H, and an SNT dynamometer was used to measure friction, wear and squeal

RESULTS AND DISCUSSION

The specific gravity and porosity data are given in Table 1 for the low-copper NAO formula and copper-free NAO formula, respectively. The average porosities were very close to the target values of 13, 18 and 22%.

The Rockwell hardness R-scale (indentation ball size 12.70 mm, 60 kg force) as well as the S-scale (ball size 12.70 mm, 100 kg force) recommended for soft materials were used to measure pad hardness numbers. The pad hardness results are summarized in Table 2 and Appendix 1. Figure 2-1 clearly demonstrates the pad hardness decreasing with increasing porosity for the low-copper NAO, and Figure 3-1 for the copper-free NAO; all easy to detect.

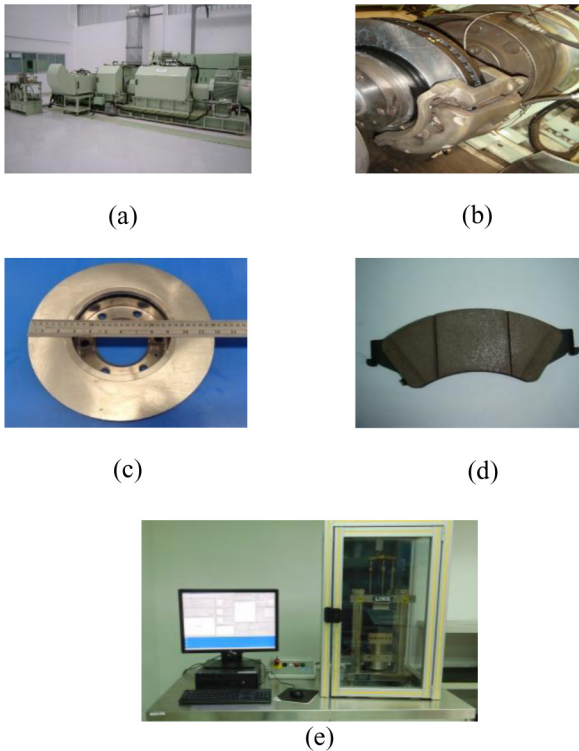


Figure 1. (a) SNT inertia dynamometer, (b) Twin piston caliper, (c) 305 mm - diameter disc, (d) Pad with two vertical slots and radial chamfers without noise shims and (e) Link Compressibility Machine 1620-P/H.

Table: 1. Pads specific gravity and porosity

Low-Copper NAO	Samples No.	Specific Gravity	% Porosity	Samples No.	Specific Gravity	% Porosity	Samples No.	Specific Gravity	% Porosity
	I-1	2.49	13.70	2-1	2.38	17.39	3-1	2.24	22.06
	I-2	2.51	13.01	2-2	2.38	17.35	3-2	2.23	22.68
	I-3	2.52	12.48	2-3	2.38	17.23	3-3	2.26	21.56
	I-4	2.51	12.98	2-4	2.37	17.69	3-4	2.26	21.48
	I-5	2.53	12.12	2-5	2.37	17.71	3-5	2.25	21.71
	I-6	2.53	12.13	2-6	2.36	17.93	3-6	2.25	21.99
	AVG	2.51 ± 0.04	12.74 ± 1.58	AVG	2.37 ± 0.02	17.55 ± 0.71	AVG	2.25 ± 0.03	21.92 ± 1.20
Copper-Free NAO	Samples No.	Specific Gravity	% Porosity	Samples No.	Specific Gravity	% Porosity	Samples No.	Specific Gravity	% Porosity
	I-1	2.43	13.04	2-1	2.31	17.08	3-1	2.15	22.93
	I-2	2.42	13.40	2-2	2.31	17.19	3-2	2.14	23.45
	I-3	2.43	12.75	2-3	2.30	17.40	3-3	2.16	22.52
	I-4	2.45	12.10	2-4	2.29	17.97	3-4	2.18	21.75
	I-5	2.44	12.63	2-5	2.29	17.77	3-5	2.18	21.91
	I-6	2.43	12.87	2-6	2.29	17.95	3-6	2.17	22.35
	AVG	2.43 ± 0.03	12.80 ± 1.30	AVG	2.30 ± 0.02	17.56 ± 0.89	AVG	2.16 ± 0.04	22.49 ± 1.70

Table: 2. Pad hardness summary

Low-Copper NAO	HR Scale & Condition of samples		LC_13%P	LC_18%P	LC_22%P
	HRS - Baseline		72.13	60.19	51.39
	HRR - Baseline		93.32	82.83	78.21
	HRR - After compression (3X) under 30 bars		95.40	88.9	83.1
	HRR - After compression (3X) under 100 bars		91.71	88.45	81.78
	HRR - After compression (3X), comp. machine under 160 bars		93.59	88.34	83.81
Copper-Free NAO	HR Scale & Condition of samples		CF_13%P	CF_18%P	CF_22%P
	HRS - Baseline		61.21	42.89	40.15
	HRR - Baseline		86.05	71.75	60.19
	HRR - After compression (3X) under 30 bars		88.48	79.59	61.6
	HRR - After compression (3X) under 100 bars		89.17	76.88	59.62
	HRR - After compression (3X), comp. machine under 160 bars		85.32	78.98	68.03
	HRR - After compression (3X), caliper on dyno under 160 bars		92.84	80.23	63.95

Pad hardness values were measured after compressing under 30 bars 3 times, and also separately under 100 bars 3 times in the compressibility machine. The hardness results are summarized in Table 2 and Figure 2-2 for the low-copper NAO, and Table 2 and Figure 3-2 for the copper-free NAO. After 30 bars or 100 bars of compression, the pad hardness increases in general with a couple of exceptions. The pads have become harder after compression under 30 bars or 100 bars, all under typical braking conditions. In other words, the pads have become denser. Similar experiments were performed under 160 bars, using the compressibility machine and also using a brake dynamometer. The hardness results are shown in Figures 2-3 and 3-3. Here again the pad hardness increases after compression. The compressibility machine and the dynamometer produce similar results.

Now one wonders about the meaning of compressibility measurement and its relationship to brake squeal.

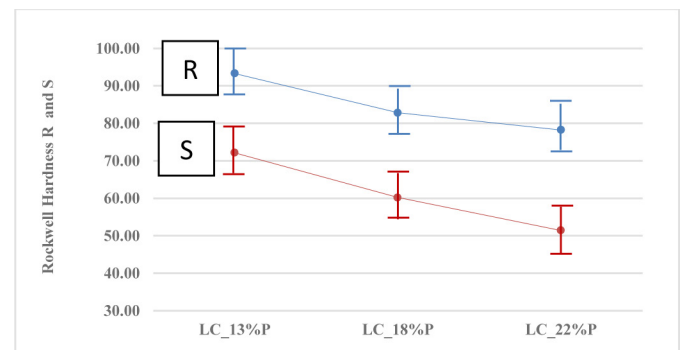


Figure 2-1. Pad porosity vs. pad hardness; Low-copper NAO

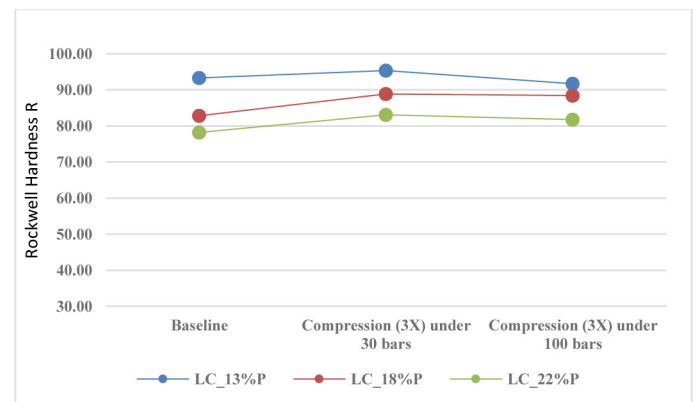


Figure 2-2. Pad hardness (HRR) after compression (3X) under 30 bars and under 100 bars using compressibility machine vs. pad porosity.

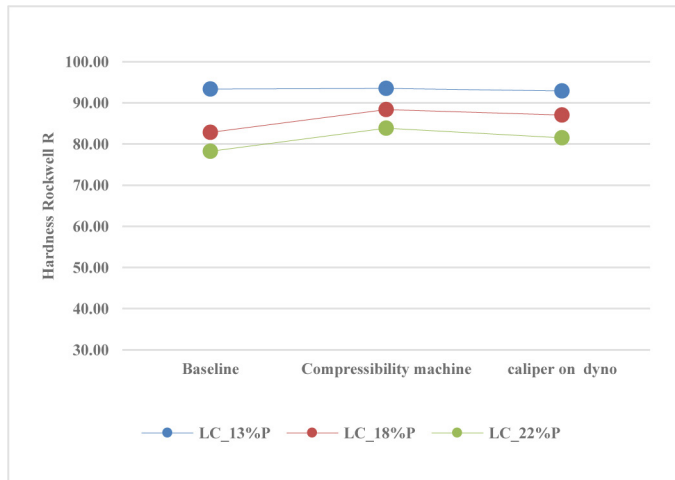


Figure 2-3. Pad hardness (HRR) after compression (3X) under 160 bars using compressibility machine or a caliper on a dynamometer vs. pad porosity; Low-copper NAO

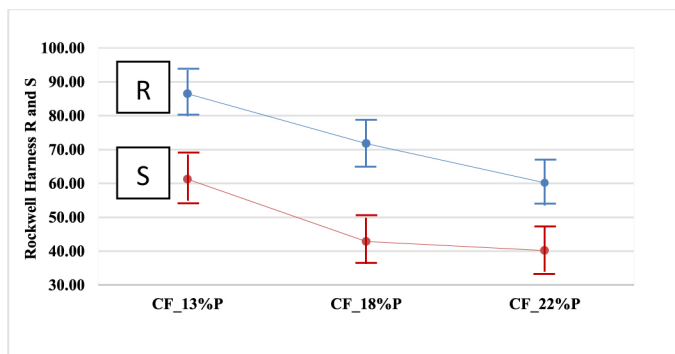


Figure 3-1. Pad porosity vs. pad hardness; Copper-free NAO

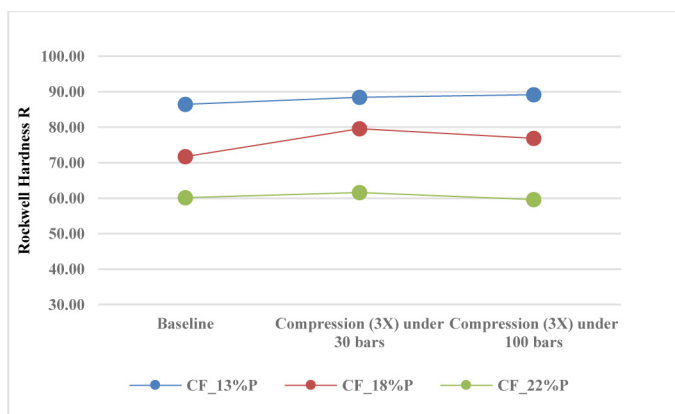


Figure 3-2. Pad hardness (HRR) after compression (3X) under 30 bars and under 100 bars using compressibility machine vs. pad porosity; Copper-free NAO

The pad samples compressed under 160 bars in the compressibility machine were checked for the pad interior hardness to determine potential compression effect. A thickness of 5 mm was ground off from the pad surface, thus reaching the mid-point of the pad in depth; 5 mm out of the original thickness of 10 mm. The HRR hardness readings are given in Table 3 for the low-copper NAO and for the

copper-free NAO. At 13% porosity, the interior hardness remains essentially the same as the surface of untested pads (see Table 2 or Appendix 1). However, at 18% and 22% porosity, the interior hardness is increased slightly, but lower than the hardness of the compressed surface. In other words, there is a hardness gradient from the compressed surface layer to the interior. One wonders how this phenomenon relates to brake squeal.

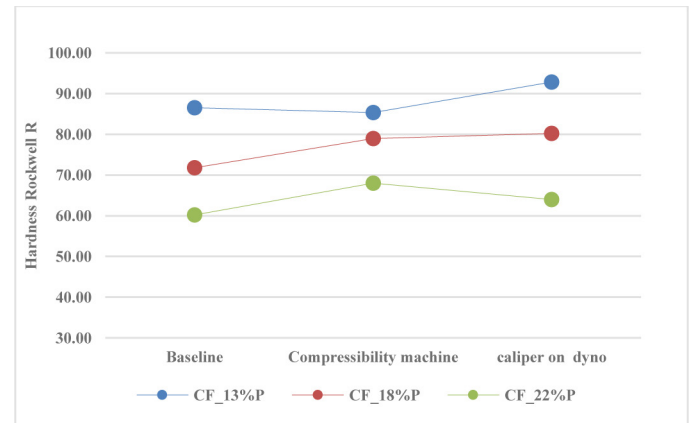


Figure 3-3. Pad hardness (HRR) after compression (3X) under 160 bars using compressibility machine or a caliper on a dynamometer vs. pad porosity; Copper-free

Table 3. Pad interior hardness (HRR) after compression under 160 bars (3X); 5 mm from the surface

Low-Copper NAO	HR Scale & Condition of samples	LC_13%P	LC_18%P	LC_22%P
	HRR - Baseline	93.32	82.83	78.21
	HRR - After compression (3X), comp. machine under 160 bars	93.59	88.34	83.81
	HRR - After compression (3X), comp. machine under 160 bars 5 mm from the surface	93.04	85.92	77.6
Copper-Free NAO	HR Scale & Condition of samples	CF_13%P	CF_18%P	CF_22%P
	HRR - Baseline	86.05	71.75	60.19
	HRR - After compression (3X), comp. machine under 160 bars	85.32	78.98	68.03
	HRR - After compression (3X), comp. machine under 160 bars 5 mm from the surface	84.44	77.28	66.42

Pad natural frequencies were measured and summarized for the 3 major peaks in Table 4. The natural frequencies decrease with increasing porosity in both formulas, which are easy to detect. After compression under 160 bars 3 times, the frequencies change slightly with no clear trends (Table 5). This outcome might be because of the pad surface density and pad stiffness changing at the same time as a natural frequency squared is proportional to the stiffness and inversely proportional to the mass.

Table 4. Pad natural frequencies

Low-Copper NAO	Natural frequencies (Hz) & Condition of samples	LC_13%P	LC_18%P	LC_22%P
	Baseline-Peak 1	1654.9	1530.4	1478.9
	Baseline-Peak 2	5598.7	5321.7	5246.5
	Baseline-Peak 3	10956.5	10643.5	10422.5
Copper-Free NAO	Natural frequencies (Hz) & Condition of samples	CF_13%P	CF_18%P	CF_22%P
	Baseline-Peak 1	1725.4	1604.3	1514.1
	Baseline-Peak 2	5845.1	5525.8	5246.5
	Baseline-Peak 3	11338.0	10980.4	10457.7