INFLUENCE OF MATERIAL PROPERTY CHANGES FOR BRAKE PADS UNDER MANUFACTURING PROCESS, AGING STATE AND EXPERIMENTAL BRAKE TEST

Present by: Meechai Siriwiboon Student ID: 60-090919-6006-9
Advisor: Assoc. Prof. Dr. Saiprasit Koetniyom
AUTOMOTIVE BRAKE SYSTEM

INTRODUCTION
WHAT IS BRAKE PAD AND HOW ITS WORK?

INTRODUCTION

Ref: https://www.youtube.com/watch?v=bPgLdxQbiWI
**INTRODUCTION**

**BRAKE PROBLEMS OF CAR BRANDS**

**BRAKE NOISE IS THE FIRST BRAKE ISSUE OF ALL CAR BRAND**

---

**OEM’S BRAKE INITIAL QUALITY STUDY 2014 IN THAILAND**

<table>
<thead>
<tr>
<th>BRANDS</th>
<th>BRK EFFECT POOR</th>
<th>BRK DUST</th>
<th>PARKING BRK HEAVY</th>
<th>PARKING BRK POOR</th>
<th>BRK NOISE</th>
<th>BRK JUDDER</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>5.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>6.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>7.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>8.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>9.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>10.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ref: [http://www.jdpower.com/cars/articles/jd-power-studies/vehicle-dependability-study-top-10-problems-3-year-old-vehicle-initial-quality](http://www.jdpower.com/cars/articles/jd-power-studies/vehicle-dependability-study-top-10-problems-3-year-old-vehicle-initial-quality)
Spectral Contents of Brake Noise and Vibration Problem

- Judder
- Groan
- Creep groan
- Roughness
- Moan
- Grunt
- Crunch
- Fog horn
- Hum
- Squelch
- Squeal
- Chirp
- Wire brush
- HF SQUEAL
- LF SQUEAL


SQUEAL IS THE PURE TONE BETWEEN 1,000 TO 18,000 Hz HIGH FREQUENCY RANGE

THE MOST COMMONLY CONSIDERED BRAKE NVH ISSUE
Introduction

Brake Squeal

Frequency (Hz.)
2,000  4,000  6,500  7,000  11,000  16,000

Caliper bracket induced
Pad induced
Rotor induced

INTRODUCTION
SQUEAL REDUCTION

PARAMETRIC STUDIES
on squeal reduction methods

MATERIAL MODIFICATION
1. Rotor
2. Friction material
3. Calliper
4. Anchor bracket/Abutment

PAD SHIM

GEOMETRICAL MODIFICATION
Disc Modification
1. No. of vanes
2. Hat thickness
3. Neck thickness
4. Neck height
5. Drilled rotor
6. Solid rotor
7. Hat asymmetric

Pad Modification
1. Slots
2. Chamfer
3. Friction material thickness
4. Back plate thickness

REDUCTION OF SQUEAL

COMPOSITES OF FRICTION MATERIALS

INTRODUCTION

Binders
Held the rest of ingredients in friction materials and maintain the structural integrity of the composites.

Fibers
Maintained proper shape during use (reinforcement)

Fillers
Increasing the volume of brake pad

Lubricants
Decrease friction between friction materials and rotor surface

Abrasives
Increase coefficient of friction

INTRODUCTION
FRICITION MATERIAL TYPE

LOW COPPER
- Non-ferrous Ferrous
- Organic fiber
- Rubber
- Resin
- Carbon
- Filler
- Sulphide
- Abrasive

COPPER FREE
- Lubricant
- Fillers
- Iron and iron alloy
- Resin
- Abrasive
INFLUENCE OF THE PROCESS

INTRODUCTION

SAND-BLASTING → GLUE APPLICATION

MIXING → PREFORMING

Pressing operation

HOT PRESSING

THERMAL TREATMENT

OUTGOING GOODS WAREHOUSE

PAINTING AND VISUAL CHECK

GRINDING
## TEST PLAN FOR PASSENGER CAR DISC BRAKE PAD

<table>
<thead>
<tr>
<th>Type of tests</th>
<th>Notes</th>
<th>Standard/Document</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual inspection</td>
<td></td>
<td>ISO/PAS 22574</td>
<td>D</td>
</tr>
<tr>
<td>Underlayer distribution</td>
<td></td>
<td>SAE J2772</td>
<td>D</td>
</tr>
<tr>
<td>Inspection critical dimensions</td>
<td></td>
<td>Part drawing</td>
<td>D</td>
</tr>
<tr>
<td>Full dimensional inspection</td>
<td>1</td>
<td>Part drawing</td>
<td>D</td>
</tr>
<tr>
<td><strong>Physical properties</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td></td>
<td>ISO 15484</td>
<td>E</td>
</tr>
<tr>
<td>Porosity</td>
<td></td>
<td>ISO 15484</td>
<td>E</td>
</tr>
<tr>
<td>pH-index</td>
<td></td>
<td>JASO C458-86</td>
<td>E</td>
</tr>
<tr>
<td>Compressibility, cold</td>
<td>2</td>
<td>ISO 6310</td>
<td>A, D</td>
</tr>
<tr>
<td>Compressibility, hot</td>
<td></td>
<td>ISO 6310</td>
<td>D</td>
</tr>
<tr>
<td>Swell and growth 1</td>
<td></td>
<td>ISO 6310</td>
<td>D</td>
</tr>
<tr>
<td>Thermal transmission</td>
<td></td>
<td>ISO 6310</td>
<td>D</td>
</tr>
<tr>
<td>Shear strength, cold</td>
<td></td>
<td>ISO 6312</td>
<td>A, D</td>
</tr>
<tr>
<td>Shear strength, cold (after performance dyno test)</td>
<td></td>
<td>ISO 6312</td>
<td>A, D</td>
</tr>
<tr>
<td>T-pull-test (bonded insulator)</td>
<td></td>
<td>SAE J2694</td>
<td>D</td>
</tr>
<tr>
<td>Eigenfrequency</td>
<td></td>
<td>SAE J2598</td>
<td>D, G</td>
</tr>
<tr>
<td><strong>Alternative/Regional tests</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swell and growth 2 (oven)</td>
<td></td>
<td>SAE J160</td>
<td>D</td>
</tr>
<tr>
<td>Hardness</td>
<td>2</td>
<td>JIS D4421</td>
<td>A, D</td>
</tr>
<tr>
<td><strong>Corrosion</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosion effects on painted backing plates &amp; shoe</td>
<td>3</td>
<td>ISO 27667</td>
<td>E, F</td>
</tr>
<tr>
<td>Resistance to brake fluid and mineral oil</td>
<td>3</td>
<td>ISO 2812-1</td>
<td>E, F</td>
</tr>
<tr>
<td><strong>Inertia-dynamometer tests</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance test 1/Production friction test</td>
<td></td>
<td>ISO 26867</td>
<td>A, D</td>
</tr>
<tr>
<td>Wear test</td>
<td>3</td>
<td>SAE J2707</td>
<td>D, H</td>
</tr>
<tr>
<td><strong>Alternative/Regional tests</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance test 2</td>
<td></td>
<td>SAE 2522</td>
<td>A, D</td>
</tr>
<tr>
<td>Performance test 3</td>
<td></td>
<td>JASO C-406</td>
<td>A, D</td>
</tr>
<tr>
<td>Production friction test</td>
<td></td>
<td>ECE R 90/Annex 8</td>
<td>A, D</td>
</tr>
</tbody>
</table>

---

**INTRODUCTION**

**PROCESS TEST CONTROL OF BRAKE FRICTION MATERIALS DEVELOPMENT**

test plan ISO 15484,disc brake pads PC
Disc pads for pickup truck brakes
- Low-copper and copper-free formulations
- Friction material thickness 15.5 mm
- Steel backing plate thickness 5.5 mm
- Conventional hot molding and curing process
- Cure: 200 or 220 °C for 2 or 3 hours
- No backing layer/no underlayer
- No scorching
- No noise shims
- All to minimize experimental variables

Figure 1--- Pick up truck Disc Pad
Measurement of pad physical characteristics; continuously over a period of 12 months

- Thickness
- Dynamic modulus
- Natural frequency
INTRODUCTION

ULTRASONIC METHOD RELIES ON PRECISE TIMING MEASUREMENT

Measurement configuration for ultrasonic-based dynamic modulus measurements

- Automated ToF Measurement
- Pre-load Control
- Manual Positioning
- Non-destructive
- Measures volume in Path
- Rapid

Load Applied
Steel Backing
Friction material
UT Transmitter
UT Receiver
Load Cell
INTRODUCTION

NATURAL FREQUENCY MEASUREMENT

Simulations

Impact Hammer Testing

Dynamometer
Aging effect on thickness; 2 or 3 hour cure at 200 °C

Figure 4-1 --- Pad thickness changes with aging at room temperature of Low-Copper

Pad thickness increases continuously for the first 30 days; thereafter dips slightly and then rises again slowly
Aging effect on thickness; 2 or 3 hour cure at 220 °C

Pad thickness increases continuously for the first 30 days; thereafter dips slightly and then rises again slowly.
RESULTS AND DISCUSSION

LOW COPPER

Aging effect on dynamic modulus of low-copper pads; 2 or 3 hour cure at 200 °C

Figure 5-1 --- Pad dynamic modulus changes with aging at room temperature of Low-Copper pads.

Dynamic modulus increases continuously for the first 60 days; thereafter dips slightly and then rises again slowly.
Figure 5-1 --- Pad dynamic modulus changes with aging at room temperature of Low-Copper

Dynamic modulus increases continuously for the first 60 days; thereafter dips slightly and then rises again slowly.
RESULTS AND DISCUSSION

LOW COPPER

Aging effect on natural frequency; 2 or 3 hour cure at 200 °C

Natural frequency increases continuously for the first 90 days, and then remains fairly constant thereafter.
RESULTS AND DISCUSSION
LOW COPPER

Aging effect on natural frequency; 2 or 3 hour cure at 220°C

Figure 6-1 --- Pad natural frequency changes with aging at room temperature of Low-Copper

Natural frequency increases continuously for the first 90 days, and then remains fairly constant thereafter.
Two competing processes appear to be taking place simultaneously;

1. Continuous cross-linking/curing of the resin, leading to pad shrinkage/higher modulus/higher natural frequency

2. Pad swelling due to internal stress relief, leading to lower modulus and lower natural frequency
Figure 4-2 --- Pad thickness changes with aging at room temperature of Copper-Free

**RESULTS AND DISCUSSION**

**COPPER FREE**

Aging effect on thickness; 2 or 3 hour cure at $200^\circ C$

Thickness increases rapidly for the first 90 days; thereafter dips slightly and then continues to increase again.
RESULTS AND DISCUSSION
COPPER FREE

Aging effect on thickness; 2 or 3 hour cure at 220 °C

Figure 4-2 --- Pad thickness changes with aging at room temperature of Copper-Free

Thickness increases rapidly for the first 90 days; thereafter dips slightly and then continues to increase again.
RESULTS AND DISCUSSION
COPPER FREE

Aging effect on dynamic modulus of Copper-Free pads; 2 or 3 hour cure at 200 °C

Dynamic modulus increases rapidly for the first 90 days; thereafter dips slightly and then continues to increase slightly
RESULTS AND DISCUSSION

COPPER FREE

Aging effect on dynamic modulus of Copper-Free pads; 2 or 3 hour cure at 220 °C

Dynamic modulus **increases** rapidly for the first 90 days; thereafter increases very slowly.

Figure 5-2 --- Pad dynamic modulus changes with aging at room temperature of Copper-Free
Aging effect on natural frequency; 2 or 3 hour cure at 200°C

Natural frequency increases rapidly for the first 90 days; thereafter dips slightly and then continues to increase slightly.
Aging effect on natural frequency; 2 or 3 hour cure at 220 °C

**Figure 6-2 --- Pad natural frequency changes with aging at room temperature of Copper-Free**

Natural frequency increases rapidly for the first 90 days; thereafter increases very slowly.
After 12 months of aging at room temperature, pad thickness, dynamic modulus and natural frequency all increased.

The rate of change is faster for the first 60 days or so for the low-copper formulation vs. 90 days for the copper-free formulation and thereafter the values go down slightly and then keep increasing very slowly.
SUMMARY AND CONCLUSIONS

3. It is proposed that 2 competing processes are taking place simultaneously in the pad during room temperature aging; continuous cross-linking of the resin and internal stress relief.

4. As pad properties are changing continuously with time, the timing of property measurement becomes an important issue.

5. It is recommended that the number of days passed after pad cure should be recorded at the time of property measurement.
Changing Properties of Brake Pads and Discs During Testing; AK Master/SAE J2522
INERTIA DYNAMOMETER
OF BRAKE TESTING

Ref: Andrew D., In Braking of Road Vehicle. Chapter 9 Brake Testing, 303-342
SAE J2522 DYNAMOMETER GLOBAL BRAKE EFFECTIVENESS

<table>
<thead>
<tr>
<th>Section</th>
<th>Number of Stops/sets</th>
<th>Braking-release Speed-kph</th>
<th>Control</th>
<th>Initial brake temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Effectiveness</td>
<td>30</td>
<td>60-30</td>
<td>30 bar</td>
<td>100</td>
</tr>
<tr>
<td>Burnish (or Bedding)</td>
<td>92</td>
<td>60-30</td>
<td>Various pressures</td>
<td>100</td>
</tr>
<tr>
<td>Characteristic Check</td>
<td>6</td>
<td>60-30</td>
<td>30 bar</td>
<td>100</td>
</tr>
<tr>
<td>Speed/Pressure Sensitivity</td>
<td>8</td>
<td>60-40</td>
<td>10.20...60 bar</td>
<td>100</td>
</tr>
<tr>
<td>Speed/Pressure Sensitivity</td>
<td>8</td>
<td>120-60</td>
<td>10.20...60 bar</td>
<td>100</td>
</tr>
<tr>
<td>Speed/Pressure Sensitivity</td>
<td>6</td>
<td>160-130</td>
<td>10.20...60 bar</td>
<td>100</td>
</tr>
<tr>
<td>Speed/Pressure Sensitivity</td>
<td>6</td>
<td>200-170</td>
<td>10.20...60 bar</td>
<td>100</td>
</tr>
<tr>
<td>Characteristic Check</td>
<td>6</td>
<td>80-90</td>
<td>30 bar</td>
<td>100</td>
</tr>
<tr>
<td>Cold Braking Check</td>
<td>1</td>
<td>40-5</td>
<td>30 bar</td>
<td>10</td>
</tr>
<tr>
<td>Motorway Braking Check #1</td>
<td>1</td>
<td>100-5</td>
<td>0.6 g</td>
<td>50</td>
</tr>
<tr>
<td>Motorway Braking Check #2</td>
<td>1</td>
<td>0.5-0.5 V max</td>
<td>50 g</td>
<td>10</td>
</tr>
<tr>
<td>Characteristic Check</td>
<td>6</td>
<td>80-30</td>
<td>30 bar</td>
<td>100</td>
</tr>
<tr>
<td>1st Fade (maximum 100 Bar)</td>
<td>15</td>
<td>100-15</td>
<td>0.4 g</td>
<td>100-500 disc 100-300 drum</td>
</tr>
<tr>
<td>Recovery</td>
<td>18</td>
<td>80-30</td>
<td>30 bar</td>
<td>100</td>
</tr>
<tr>
<td>Pressure Sensitivity</td>
<td>8</td>
<td>80-30</td>
<td>10.20...80 bar</td>
<td>100</td>
</tr>
<tr>
<td>Increasing Temperature Sensitivity (500 °C/300 °C)</td>
<td>9</td>
<td>80-30</td>
<td>10.20...80 bar</td>
<td>100-150...200</td>
</tr>
<tr>
<td>Pressure Sensitivity (500°C)</td>
<td>8</td>
<td>80-30</td>
<td>10.20...80 bar</td>
<td>500</td>
</tr>
<tr>
<td>Recovery 2</td>
<td>18</td>
<td>80-30</td>
<td>30 bar</td>
<td>100</td>
</tr>
<tr>
<td>2nd Fade (maximum 100 Bar)</td>
<td>15</td>
<td>100-15</td>
<td>0.4 g</td>
<td>100-500 disc 100-300 drum</td>
</tr>
<tr>
<td>Characteristic Check</td>
<td>18</td>
<td>80-30</td>
<td>30 bar</td>
<td>100</td>
</tr>
</tbody>
</table>
POSITION OF
DYNAMIC MODULUS MEASUREMENT
RESULTS AND DISCUSSION

CHANGING MODULUS OF LOW COPPER

Modulus of Position 3 at 100N Load; Low-Copper Formulation

Disc pad modulus decreases during testing
Modulus of Position 3 at 100N Load in Copper-Free Formulation

Disc pad modulus decreases during testing
RESULTS AND DISCUSSION

LOW-COPPER PAD

NATURAL FREQUENCIES OF INNER PAD BEFORE AND AFTER TESTING

Disc pad natural frequencies decrease during testing
Pad natural frequencies decrease during testing; more for the inner pad
RESULTS AND DISCUSSION

OUT-OF-PLANE MODE NATURAL FREQUENCIES OF DISC BEFORE AND AFTER TESTING

LOW-COPPER PAD

Disc natural frequencies decrease during testing
Pad natural frequencies decrease during testing
Pad natural frequencies decrease during testing; more for the outer pad.
RESULTS AND DISCUSSION

OUT-OF-PLANE MODE NATURAL FREQUENCIES OF DISC BEFORE AND AFTER TESTING

COPPER FREE PAD

Disc natural frequencies decrease during testing
DISCUSSION

Natural frequency vs. stiffness and mass

\[ F = \left[ \frac{1}{2 \times 3.14} \right] \times (k/m)^{1/2} \]

- In all cases, stiffness and mass are changing, leading to decreasing natural frequencies
- Pad stiffness goes down due to pad swelling and thickness loss
- Disc stiffness goes down to due internal residual stress relief and thickness loss
SUMMARY AND CONCLUSIONS

1. Pad properties and disc properties change during testing: inner pad and outer pad change at different rates.

2. What properties to measure and when to measure need to be defined for quality control, and for modeling/simulation.
SUMMARY AND CONCLUSIONS

3. The swelling phenomenon must be well characterized and understood for better prediction of brake performance, durability and squeal.

4. Property measurements of unused brand new pads must not be used for predicting brake performance, wear and squeal.
THANK YOU