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

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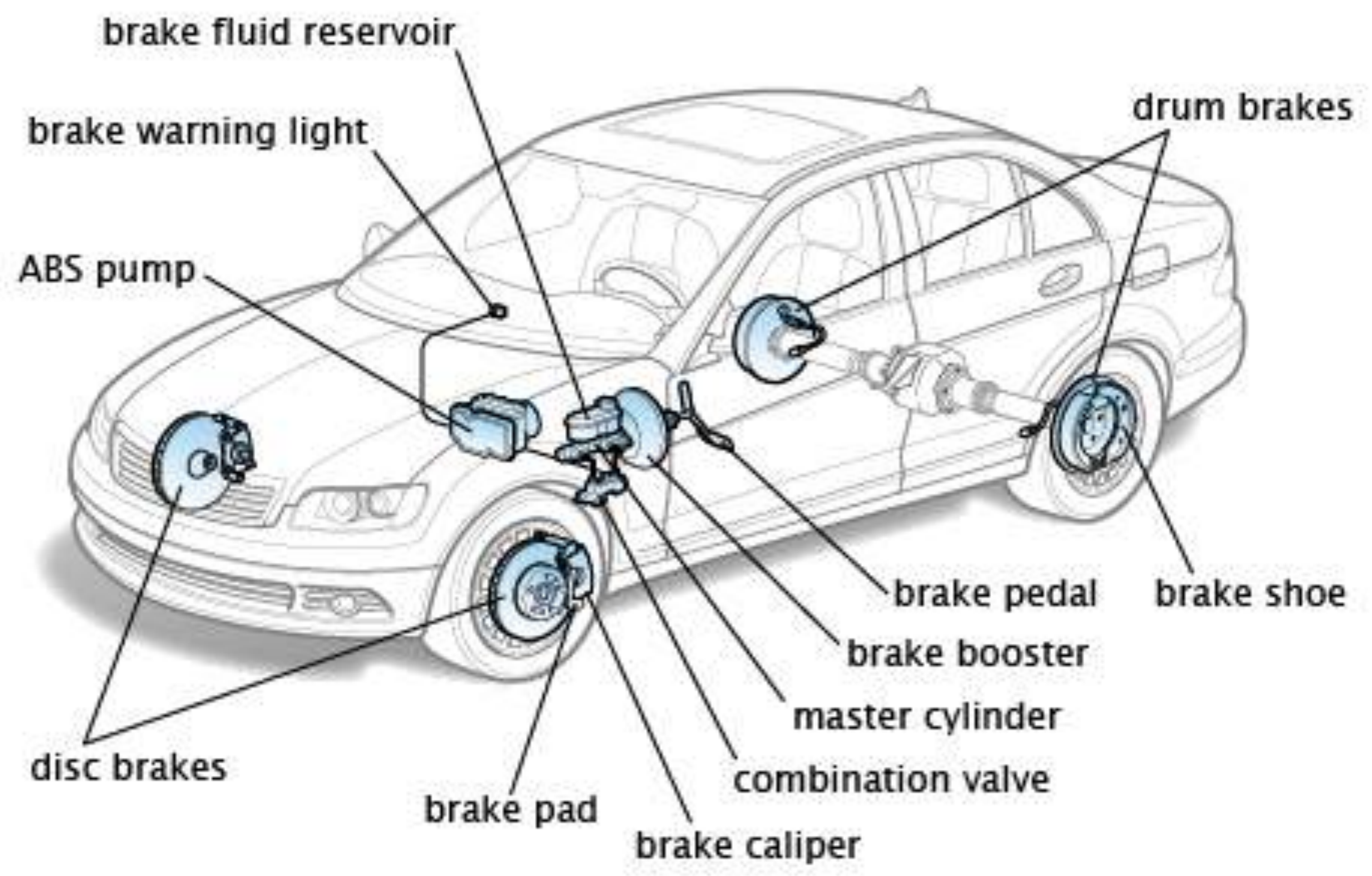
The Sirindhorn International Thai-German Graduate School of Engineering (TGGS)
Industry-Oriented Graduate Education and Research in Thailand based on the RWTH Aachen Model

NOISE

INTRODUCTION

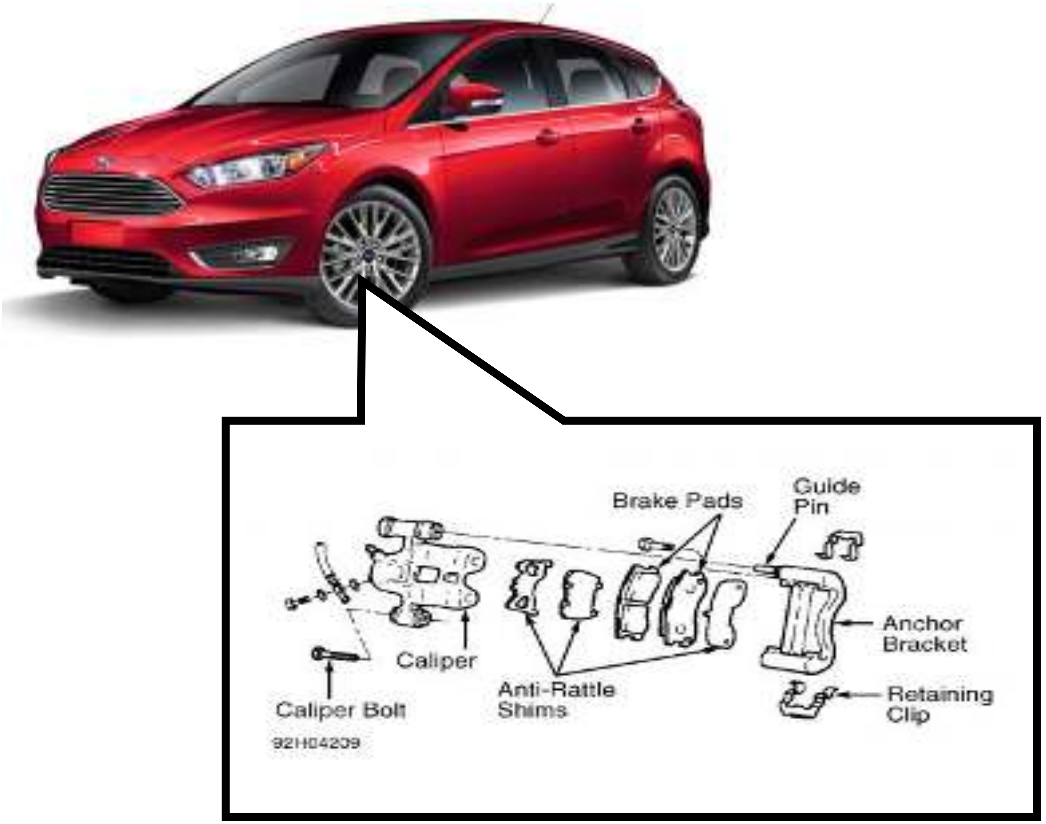
# AUTOMOTIVE BRAKE SYSTEM



INTRODUCTION

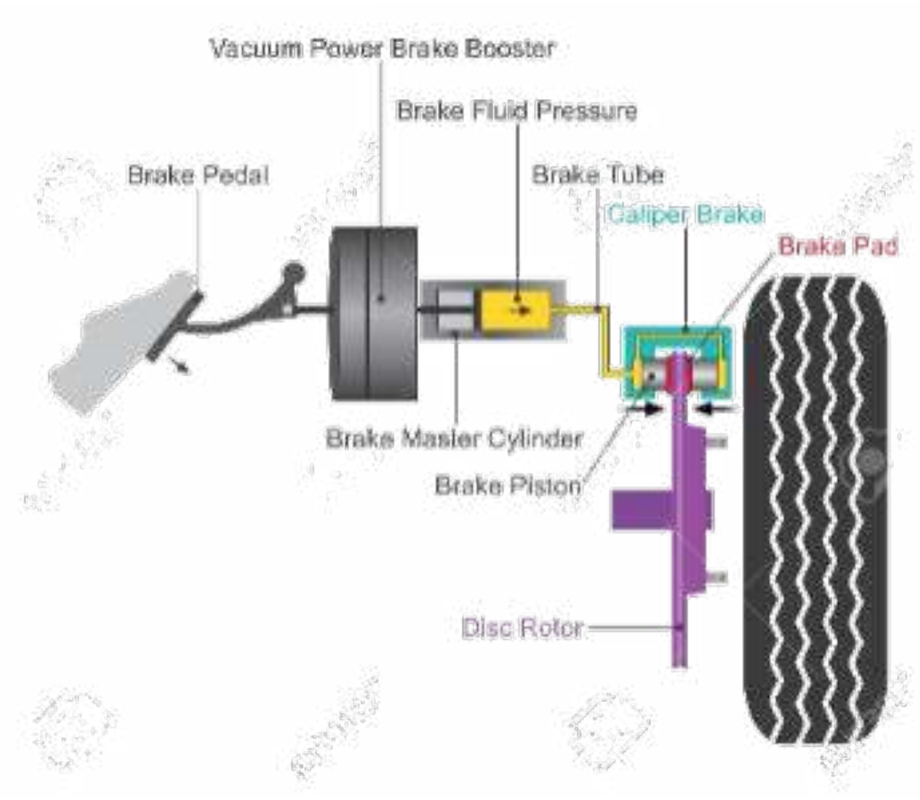
# AUTOMOTIVE BRAKE ASSEMBLY

## Disc brake




Ref: https://www.2carpros.com/questions/ford-probe-1995-ford-probe-how-to-replace-rear-brake-pads-and-discs

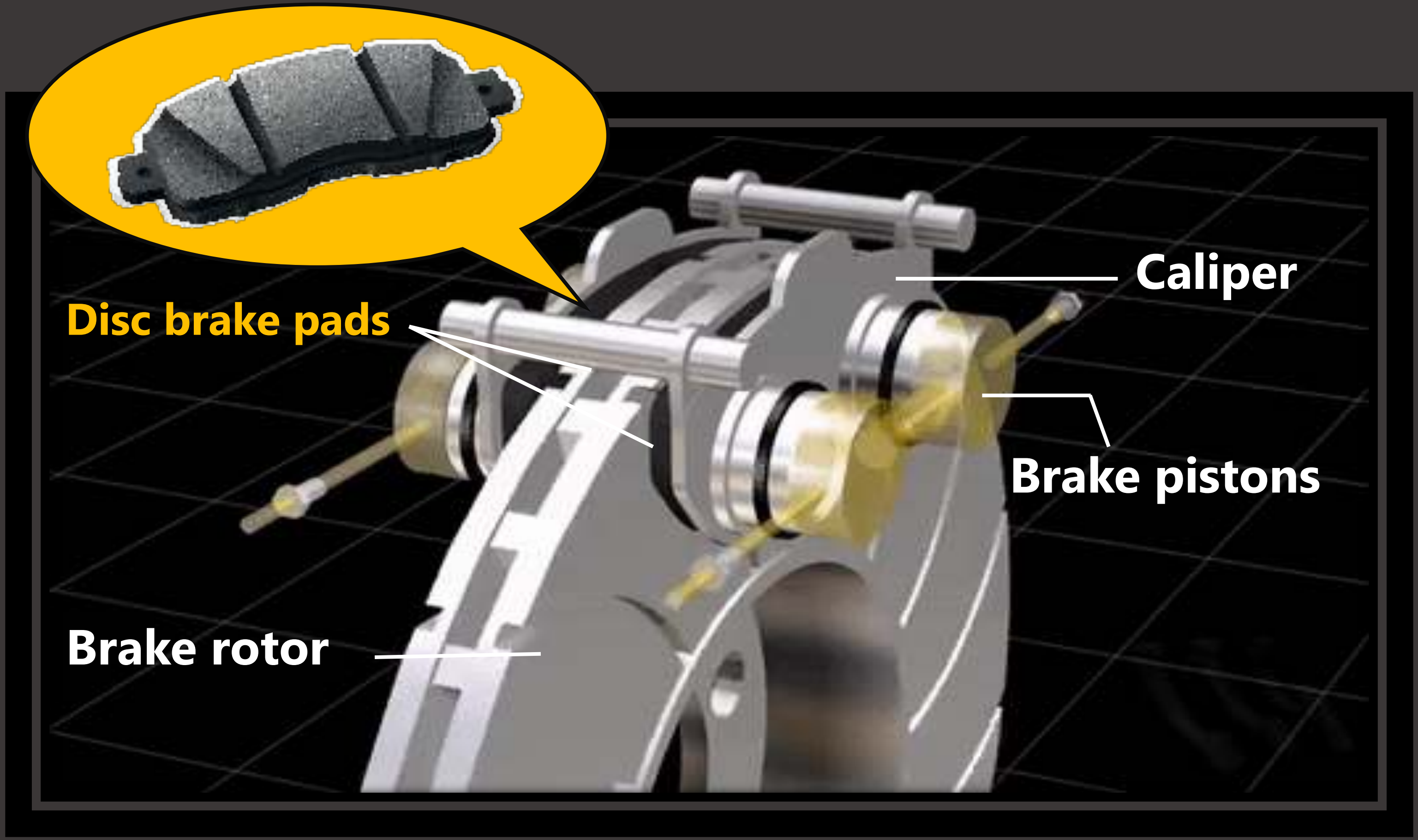
## Hydraulic brake system




Ref: https://www.123rf.com/photo_98082209_stock-vector-hydraulic-brake-system-when-the-brake-pedal-is-pressed-a-push-rod-exerts-force-on-the-piston-in-the-

INTRODUCTION

# WHAT IS BRAKE PAD AND HOW ITS WORK ?

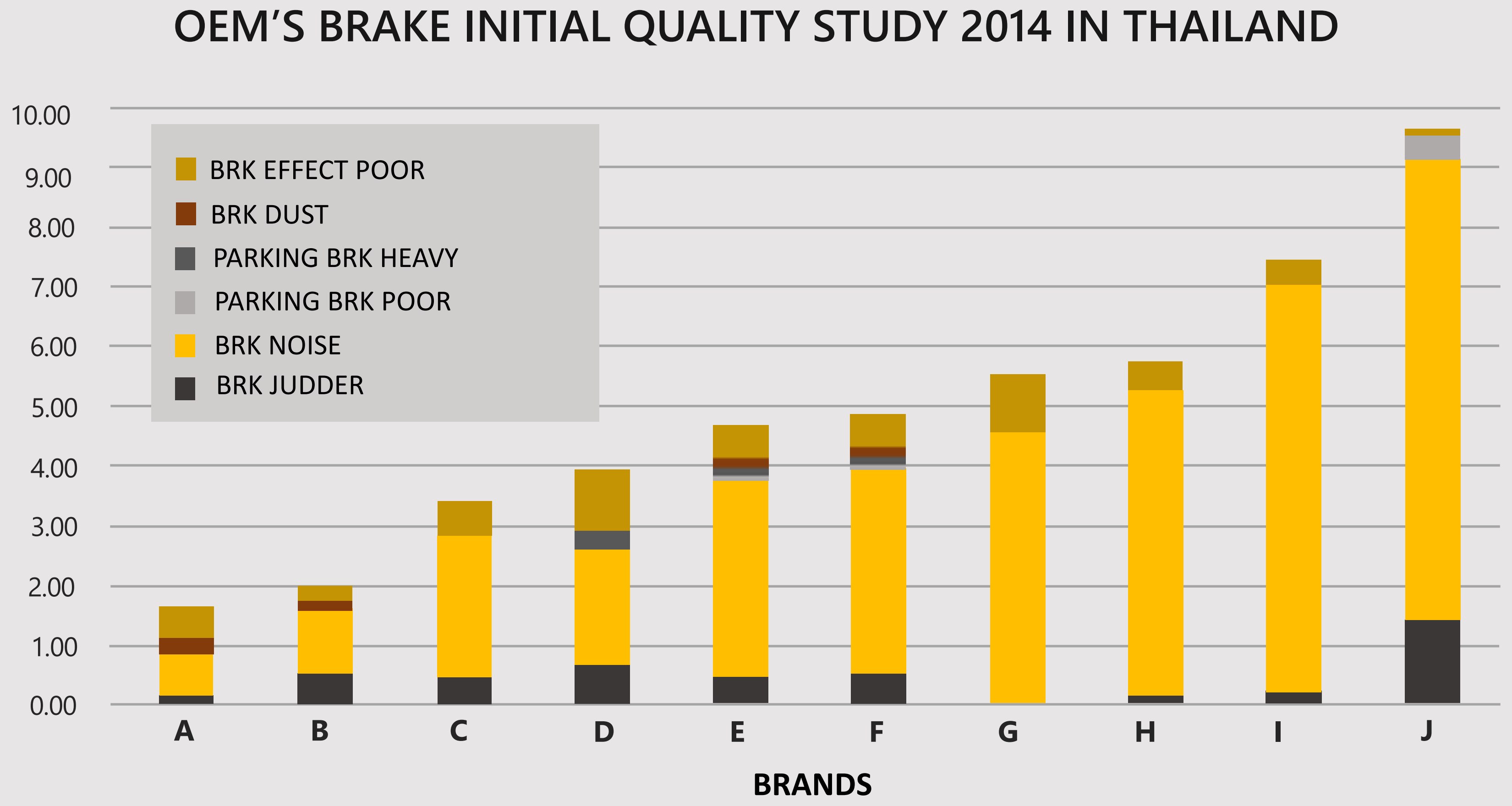



*Ref: https://www.youtube.com/watch?v=bPgLdxQbiWI*

INTRODUCTION

# BRAKE PROBLEMS OF CAR BRANDS

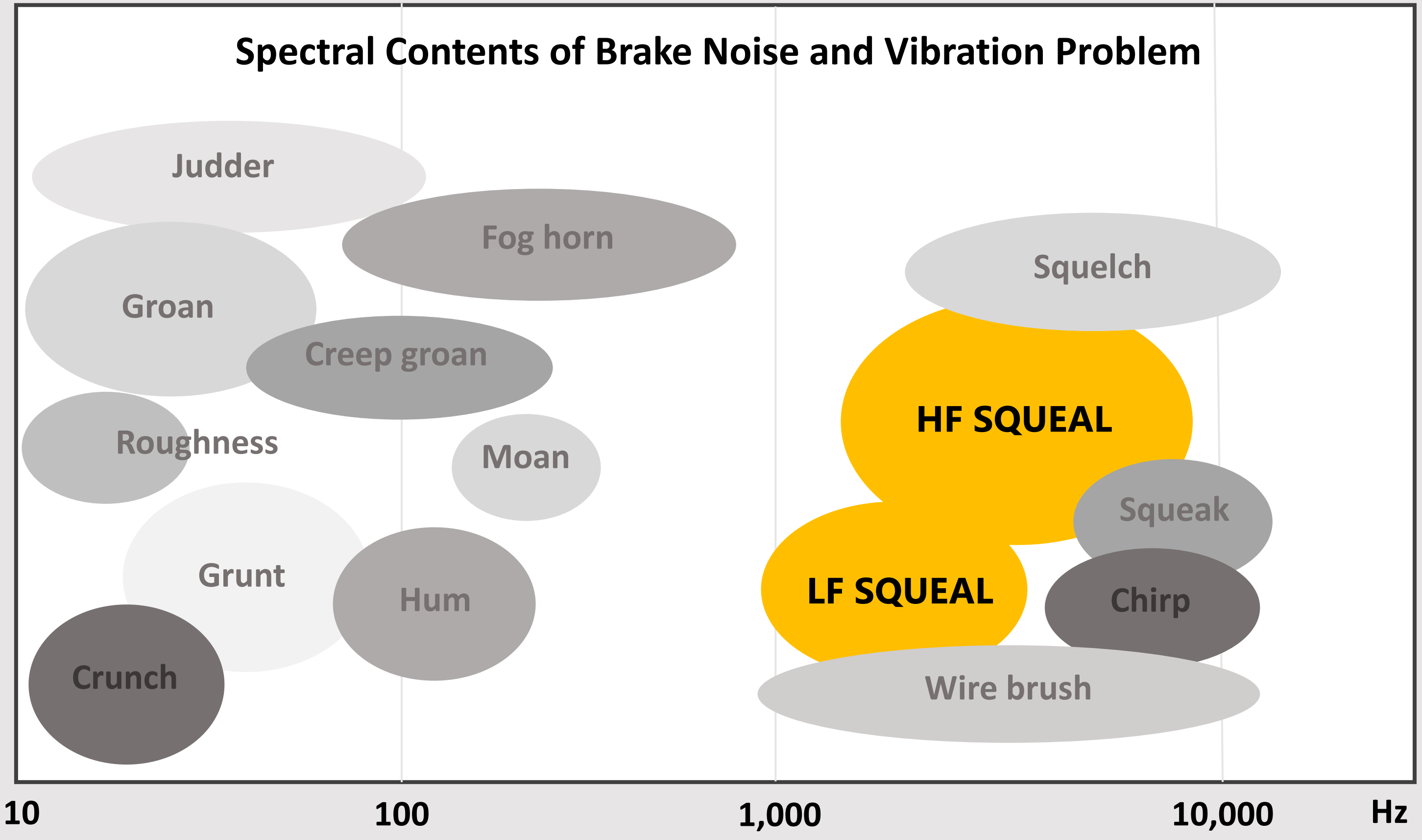
**BRAKE NOISE** IS THE **FIRST** BRAKE **ISSUE** OF ALL CAR BRAND




Ref: http://www.jdpower.com/cars/articles/jd-power-studies/vehicle-dependability-study-top-10-problems-3-year-old-ve

INTRODUCTION

# BRAKE NOISE




Ref. https://www.researchgate.net/figure/Spectral-contents-of-brake-noise-and-vibration-problems_fig2_315690874

SQUEAL IS THE PURE TONE BETWEEN

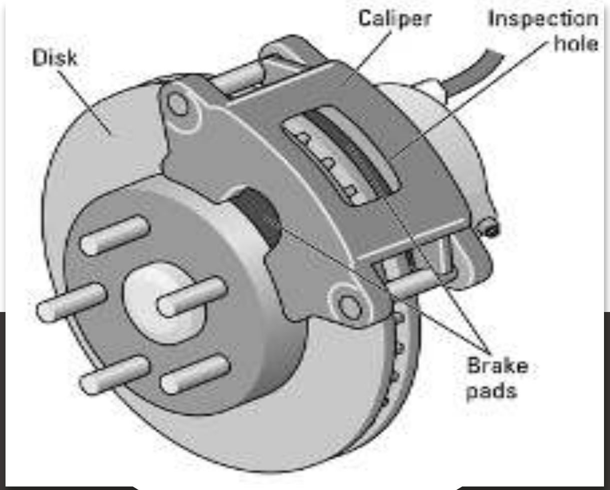
**1,000 TO 18,000 Hz**

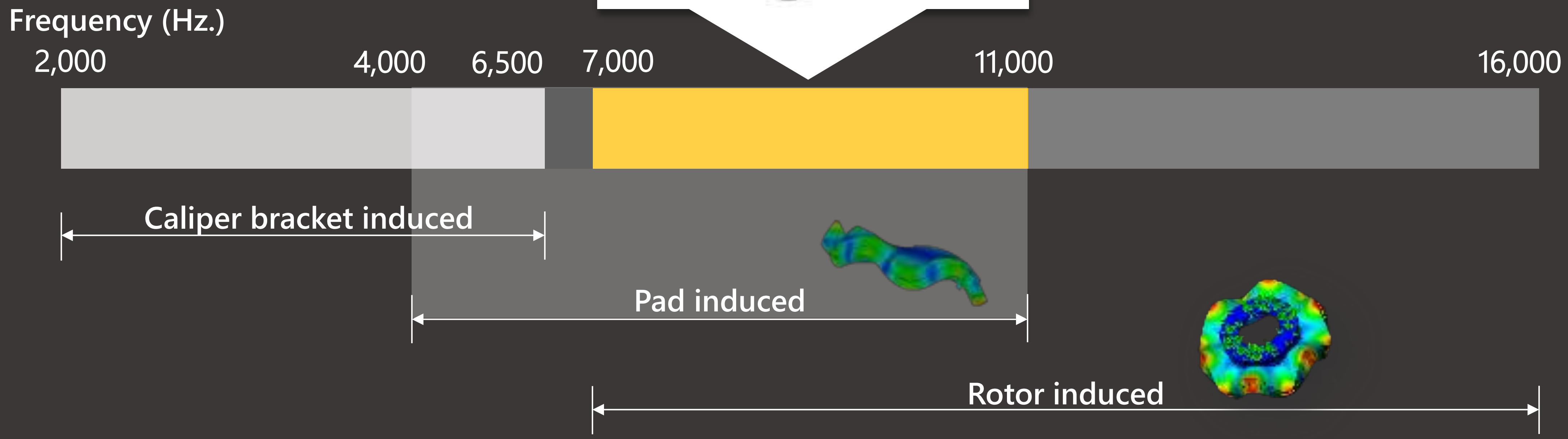
HIGH FREQUENCY RANGE

THE MOST COMMONLY CONSIDERED BRAKE NVH ISSUE

INTRODUCTION

# BRAKE SQUEAL




*Ref: Nouby M. Ghazaly, Mohamed El-Sharkawy, Ibrahim Ahmed, A Review of Automotive Brake Squeal Mechanisms*

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**

*Ref: Nouby M. Ghazaly, Mohamed El-Sharkawy, Ibrahim Ahmed, A Review of Automotive Brake Squeal Mechanisms*

INTRODUCTION

# COMPOSITES OF FRICTION MATERIALS

**Binders**

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

**Fillers**

Increasing the volume of brake pad

**Fibers**

Maintained proper shape during use(reinforcement)

**Lubricants**

Decrease friction between friction materials and rotor surface

**Abrasives**

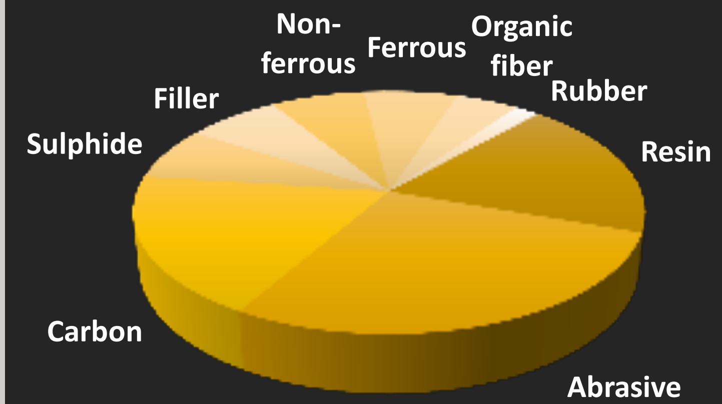
Increase coefficient of friction

*Ref: Nicholson, G. (1995). Raw Materials. In Facts About Friction: A Friction Material Manual Almost All You Need to Know About Manufacturing; 100 Years of Brake Lining & Clutch Facing, 167-186.*

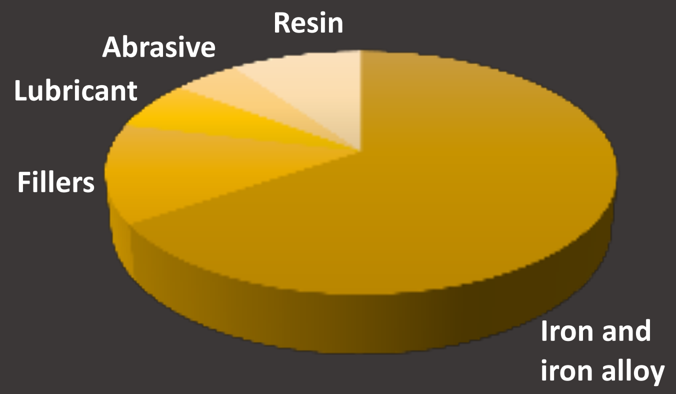
INTRODUCTION

# FRICTION MATERIAL TYPE

## LOW COPPER

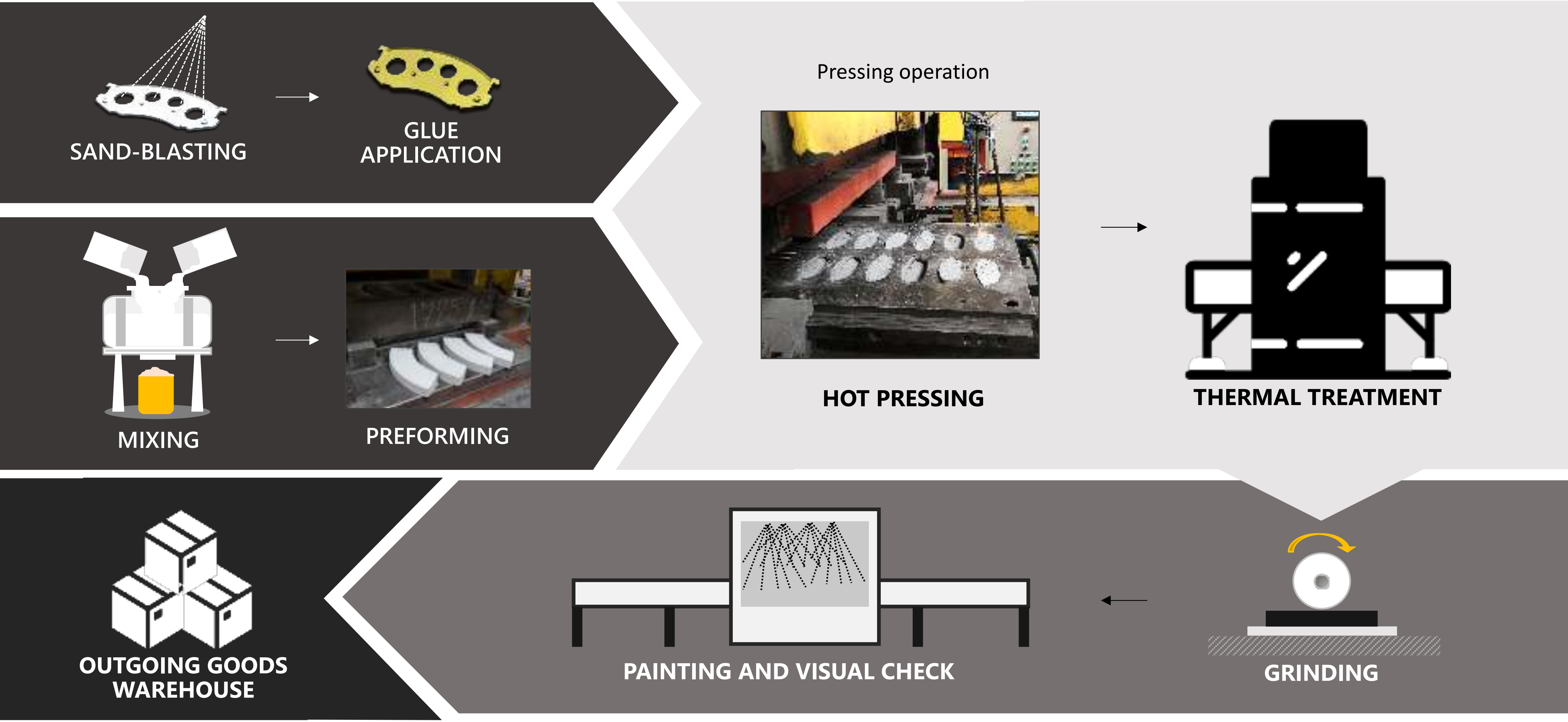



## COPPER FREE



INTRODUCTION

# INFLUENCE OF THE PROCESS



INTRODUCTION

# PROCESS TEST CONTROL OF BRAKE FRICTION MATERIALS DEVELOPMENT

test plan ISO 15484 ,disc brake pads PC

## TEST PLAN FOR PASSENGER CAR DISC BRAKE PAD

| Type of tests | Notes | Standard/ Document | Index | |
|---|---|---|---|---|
| **General** | | | | Kick-off Meeting |
| Visual inspection | | ISO/PAS 22574 | D | |
| Underlayer distribution | | SAE J2724 | D | |
| Inspection critical dimensions | | Part drawing | D | |
| Full dimensional inspection | 1 | Part drawing | D | |
| **Physical properties** | | | | |
| Density | | ISO 15484 | E | |
| Porosity | | ISO 15484 | E | |
| pH-index | | JASO C458-86 | E | |
| Compressibility, cold | 2 | ISO 6310 | A, D | |
| Compressibility, hot | | ISO 6310 | D | |
| Swell and growth 1 | | ISO 6310 | D | |
| Thermal transmission | | ISO 6310 | D | |
| Shear strength, cold | | ISO 6312 | A, D | |
| Shear strength, cold (after performance dyno test) | | ISO 6312 | | |
| T-pull-test (bonded insulator) | | SAE J2694 | D | |
| Eigenfrequency | | SAE J2598 | D, G | |
| **Alternative/ Regional tests** | | | | |
| Swell and growth 2 (oven) | | SAE J160 | D | |
| Hardness | 2 | JIS D4421 | A, D | |
| **Corrosion** | | | | |
| Corrosion effects on painted backing plates & shoe | 3 | ISO 27667 | E, F | |
| Resistance to brake fluid and mineral oil | 3 | ISO 2812-1 | E, F | |
| **Inertia-dynamometer tests** | | | | |
| Performance test 1/ Production friction test | | ISO 26867 | A, D | |
| Wear test | 3 | SAE J2707 | D, H | |
| **Alternative/ Regional tests** | | | | |
| Performance test 2 | | SAE 2522 | A, D | |
| Performance test 3 | | JASO C-406 | A, D | |
| Production friction test | | ECE R 90/Annex 8 | A, D | |

INTRODUCTION

# EXPERIMENTAL

Figure 1--- Pick up truck Disc Pad

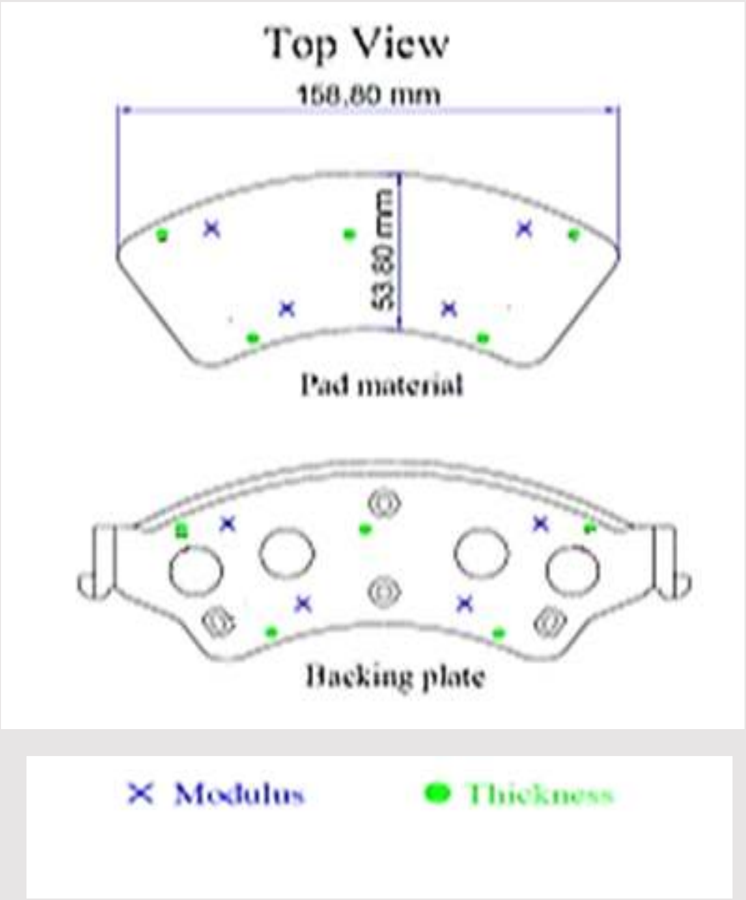
- Disc pads for pickup truck brakes
- Low-copper and copper-free formulations
- Friction material thickness 15.5 mm
- Steel backing plate thickness 5.5 mm
- Conventional hot molding and curing process
- Cure: 200 or 220 $^{0}$C for 2 or 3 hours
- No backing layer/no underlayer
- No scorching
- No noise shims
- All to minimize experimental variables

# EXPERIMENTAL

Measurement of pad physical characteristics;

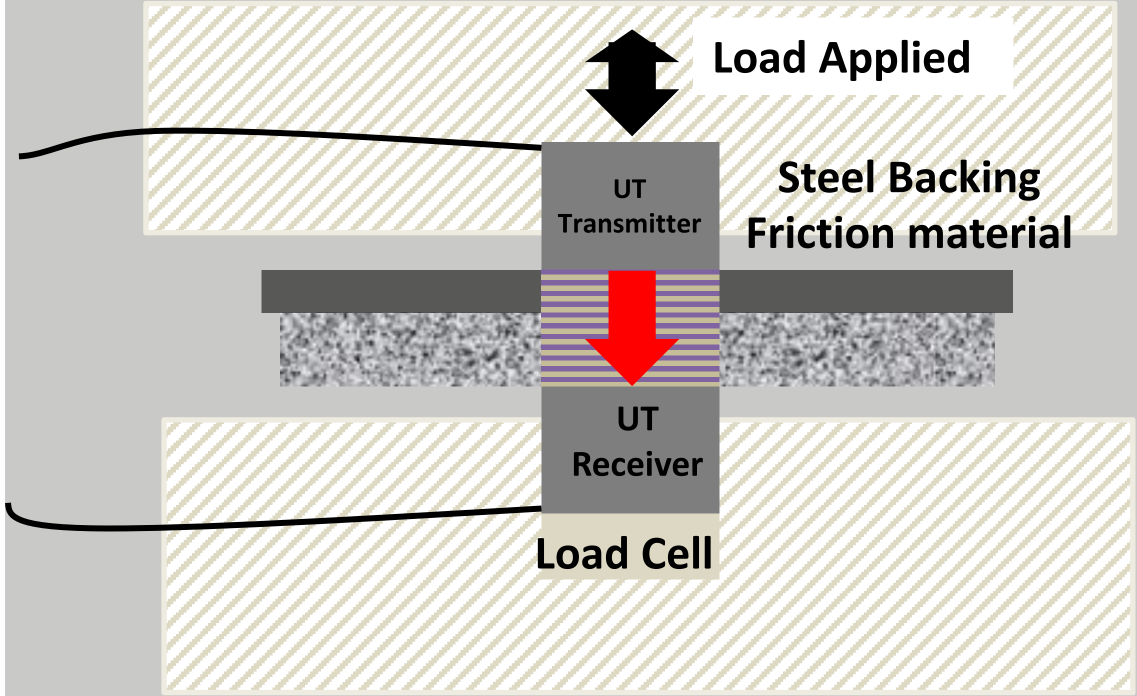
continuously over a period of 12 months

- Thickness
- Dynamic modulus
- Natural frequency



# ULTRASONIC METHOD RELIES ON PRECISE TIMING MEASUREMENT

- Automated ToF Measurement
- Pre-load Control
- Manual Positioning

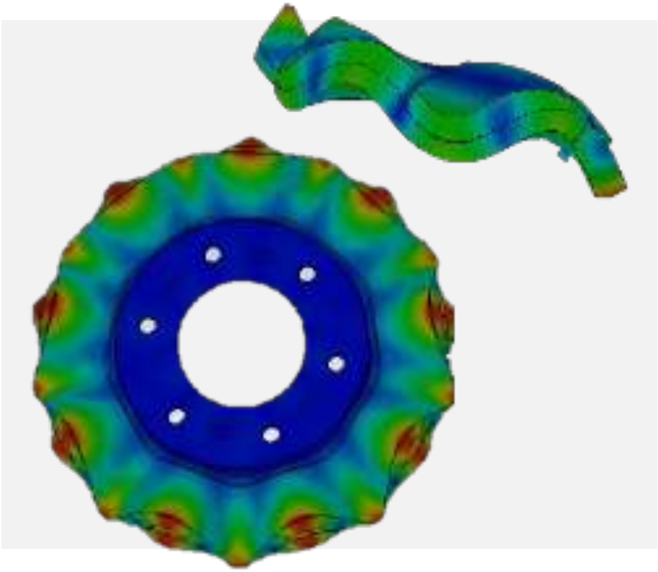
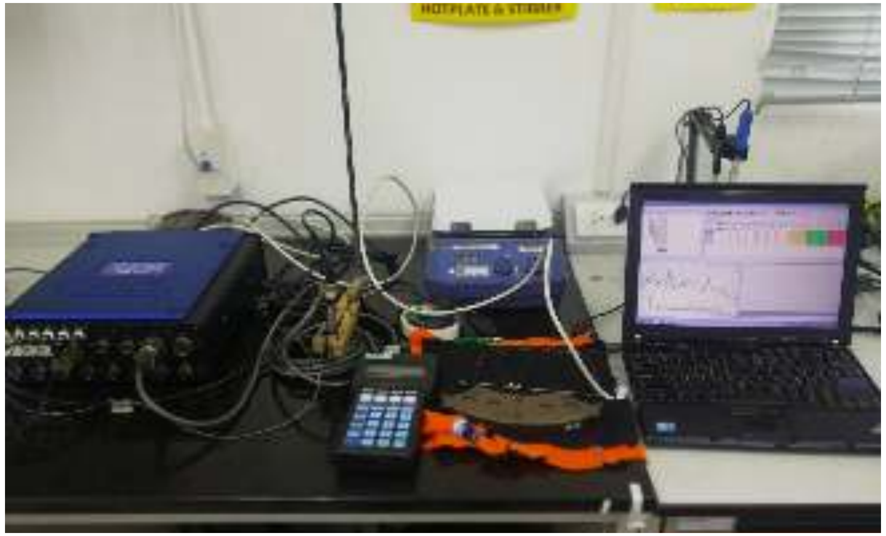



- Non-destructive
- Measures volume in Path
- Rapid

**Measurement configuration for ultrasonic-based dynamic modulus measurements**

INTRODUCTION

# NATURAL FREQUENCY MEASUREMENT

| Simulations | Impact Hammer Testing | Dynamometer |
| --- | --- | --- |
|  |  |  |

RESULTS AND DISCUSSION

# LOW COPPER

## Aging effect on thickness; 2 or 3 hour cure at 200 $^{0}$C

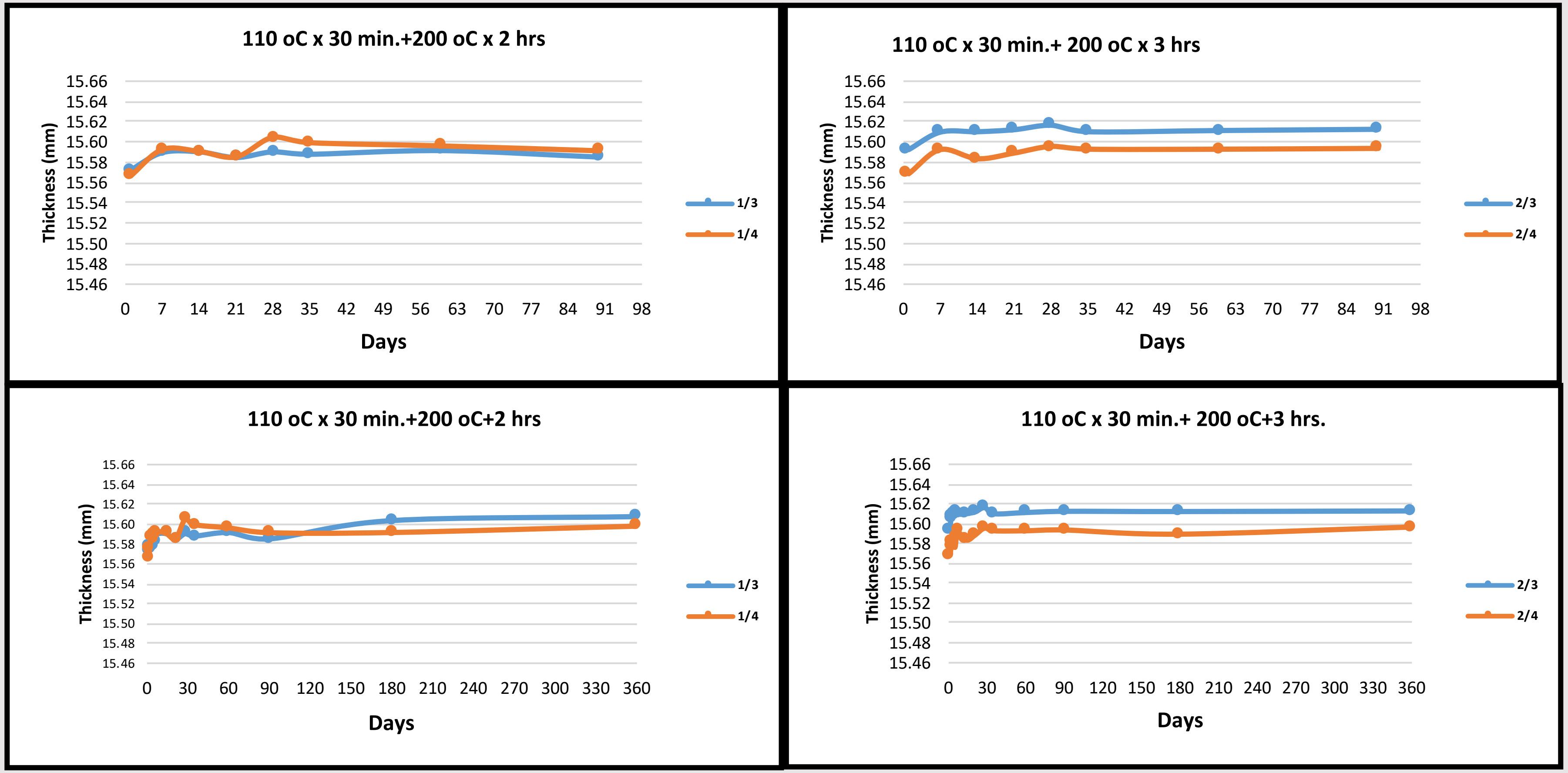



Figure 4-1 --- Pad thickness changes with aging at room temperature of Low-Copper

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

RESULTS AND DISCUSSION

# LOW COPPER

## Aging effect on thickness; 2 or 3 hour cure at 220 $^0$C

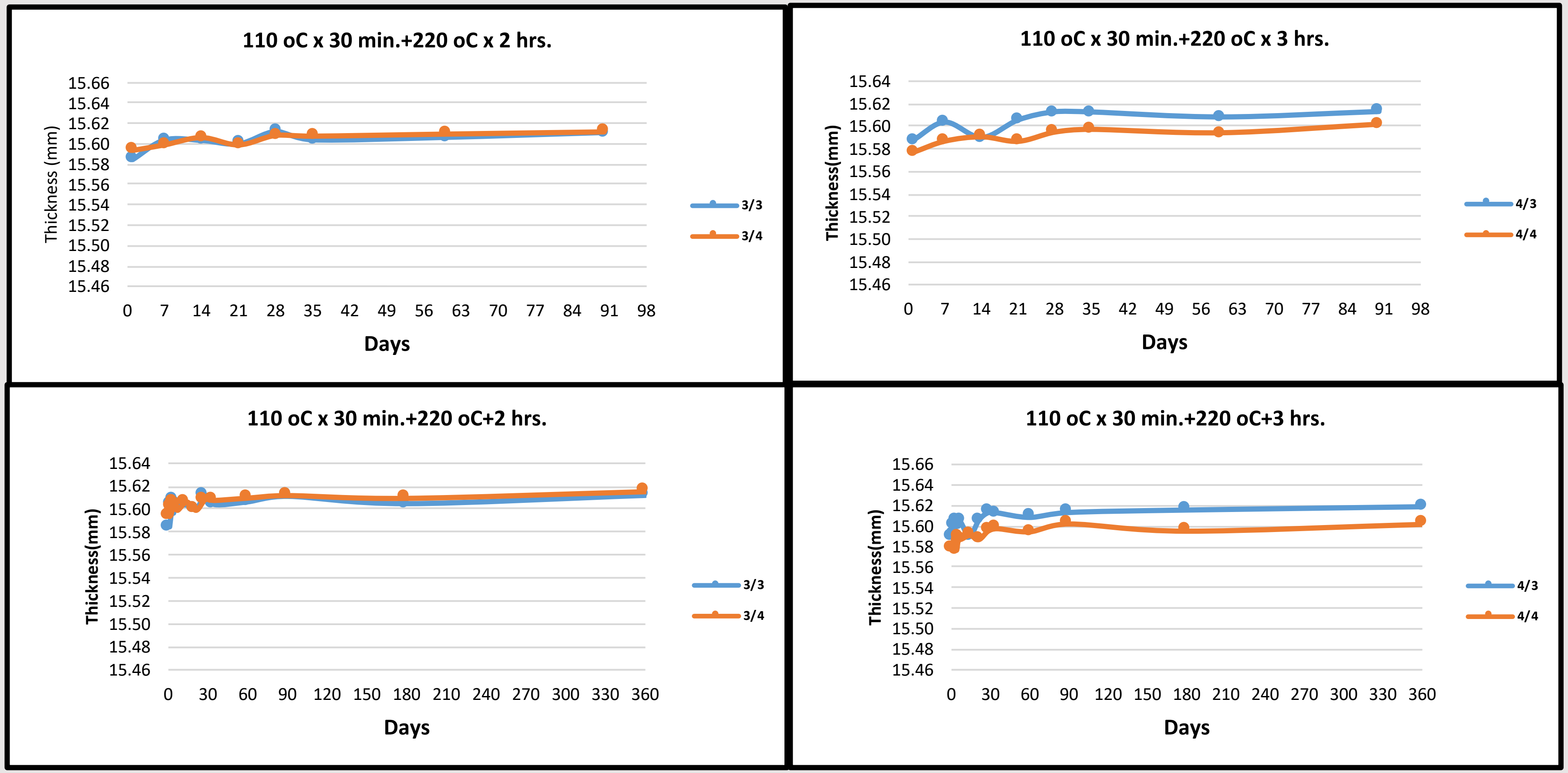



Figure 4-1 --- Pad thickness changes with aging at room temperature of Low-Copper

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RESULTS AND DISCUSSION

# LOW COPPER

## Aging effect on dynamic modulus of low-copper pads; 2 or 3 hour cure at 200 $^0$C

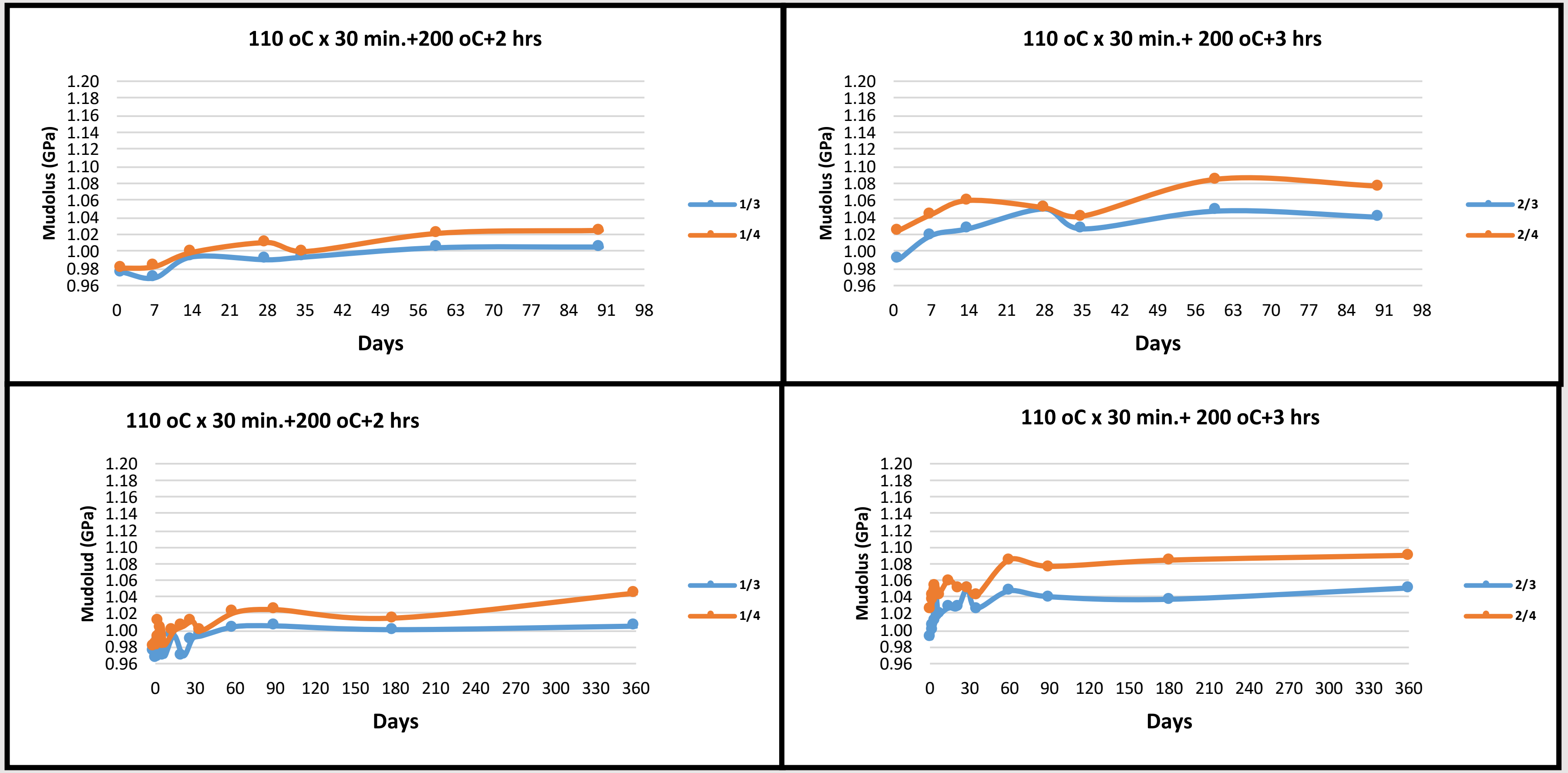


Figure 5-1 --- Pad dynamic modulus changes with aging at room temperature of Low-Copper

**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 dynamic modulus of low-copper pads; 2 or 3 hour cure at 220 ⁰C

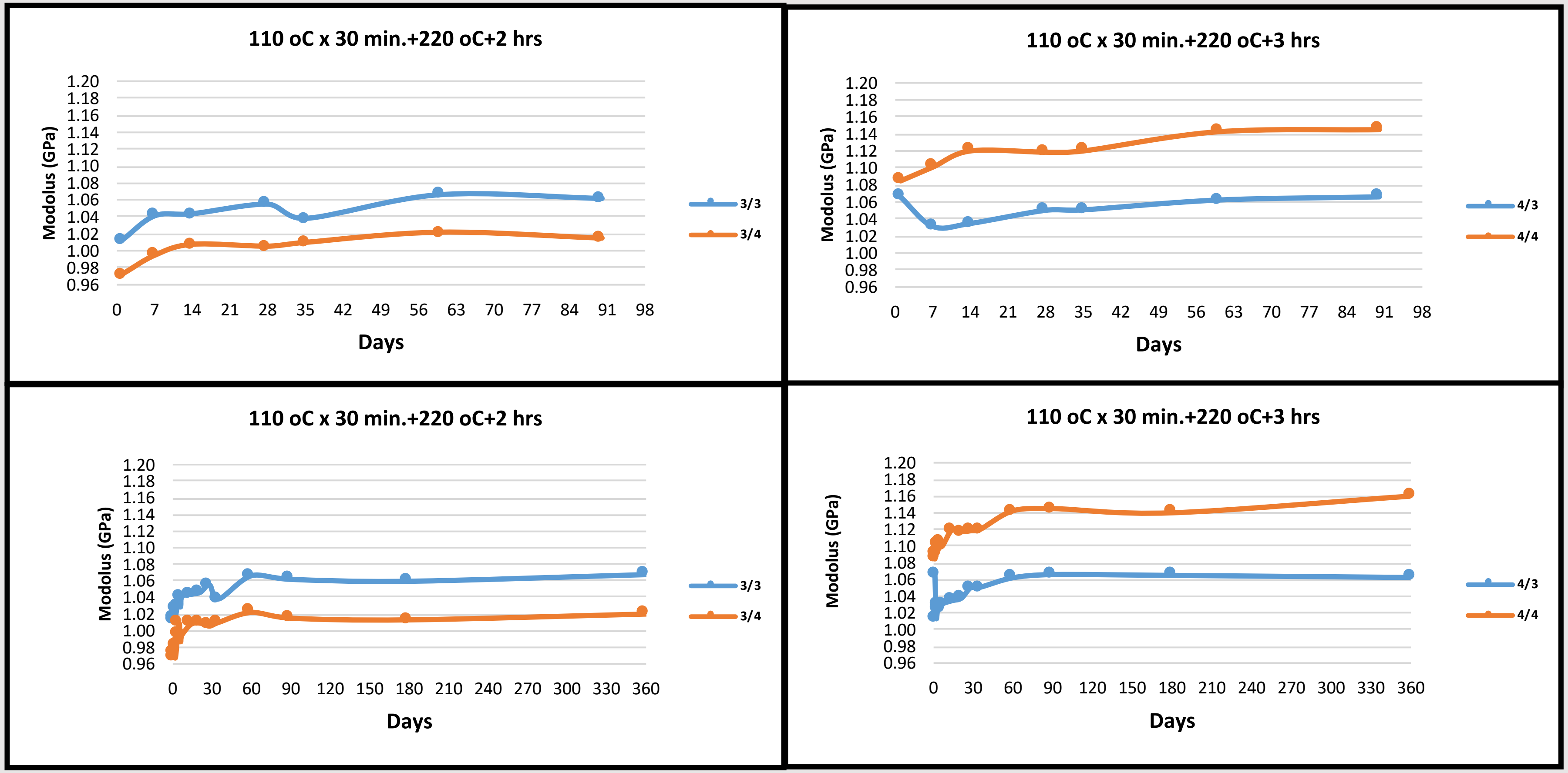


Figure 5-1 --- Pad dynamic modulus changes with aging at room temperature of Low-Copper

**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 $^0$C

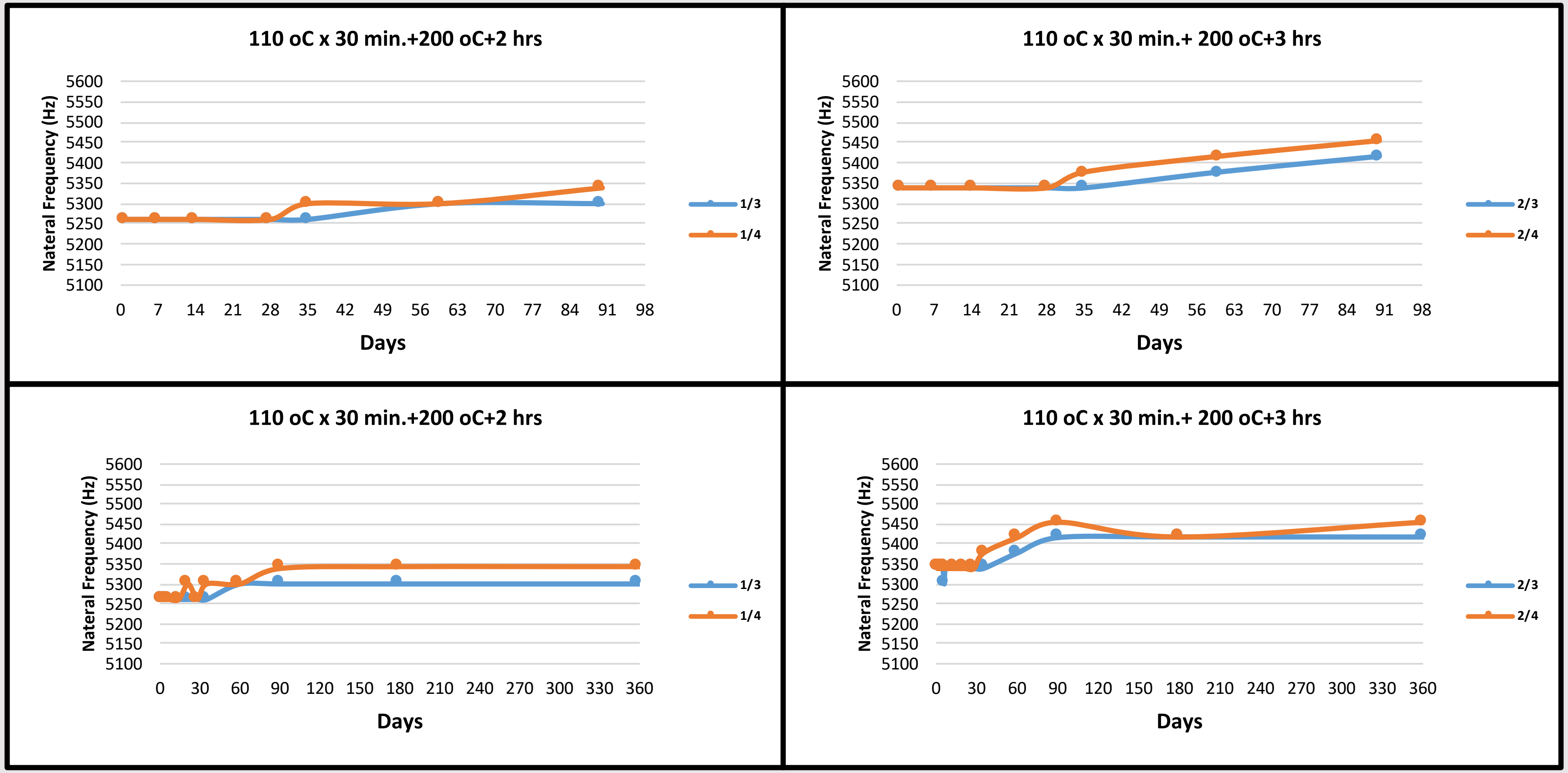


Figure 6-1 --- Pad natural frequency changes with aging at room temperature of Low-Copper

Natural frequency increases continuously for the first 90 days,
and then remains fairly constant thereafter

RESULTS AND DISCUSSION

# LOW COPPER

## Aging effect on natural frequency; 2 or 3 hour cure at 220 $^0$C

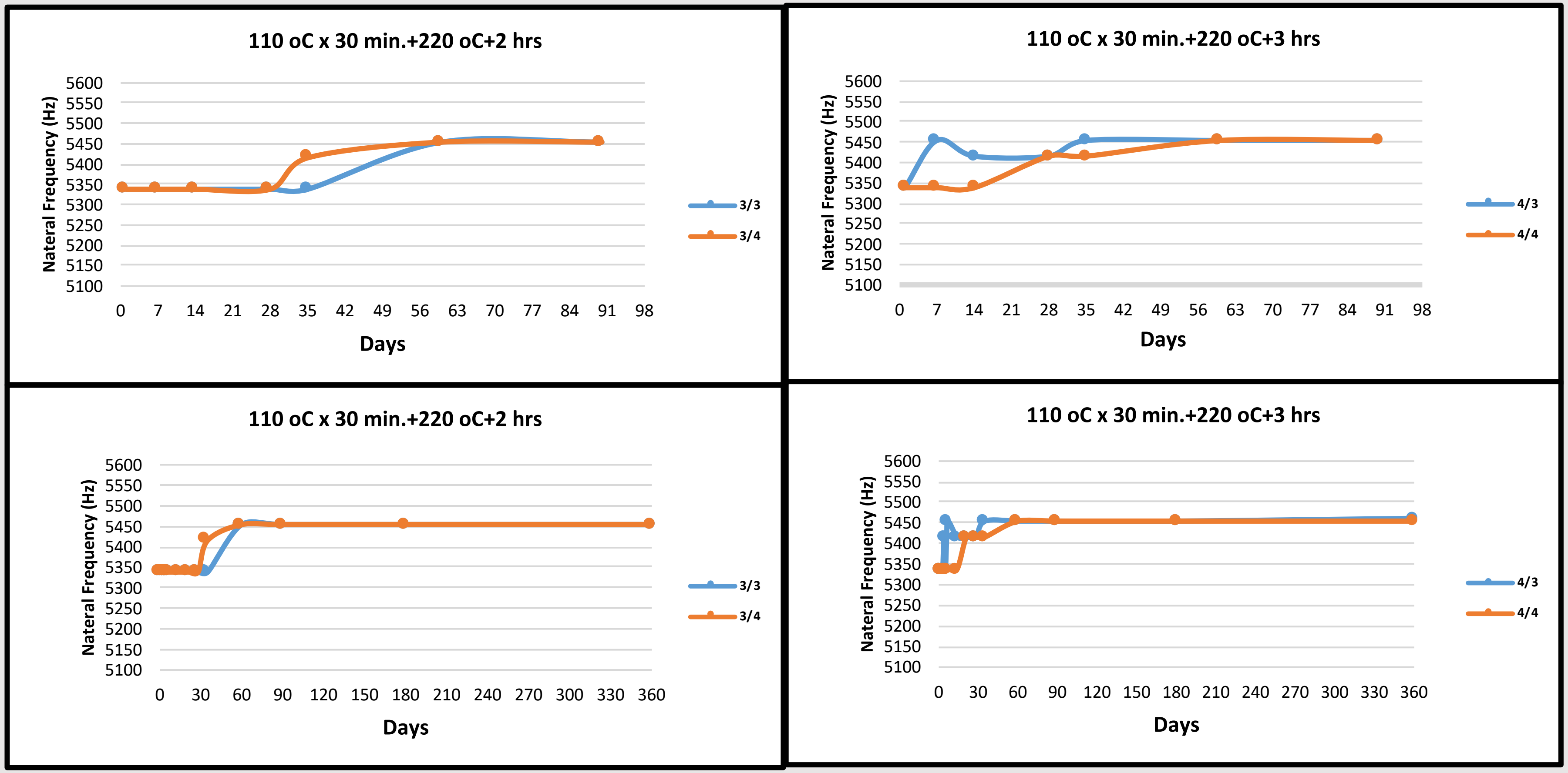


Figure 6-1 --- Pad natural frequency changes with aging at room temperature of Low-Copper

**Natural frequency increases continuously for the first 90 days, and then remains fairly constant thereafter**

# LOW COPPER

1. Two competing processes appear to be taking place simultaneously;

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

3. Pad swelling due to internal stress relief, leading to lower modulus and lower natural frequency

RESULTS AND DISCUSSION

# COPPER FREE

## Aging effect on thickness; 2 or 3 hour cure at 200 $^{0}$C

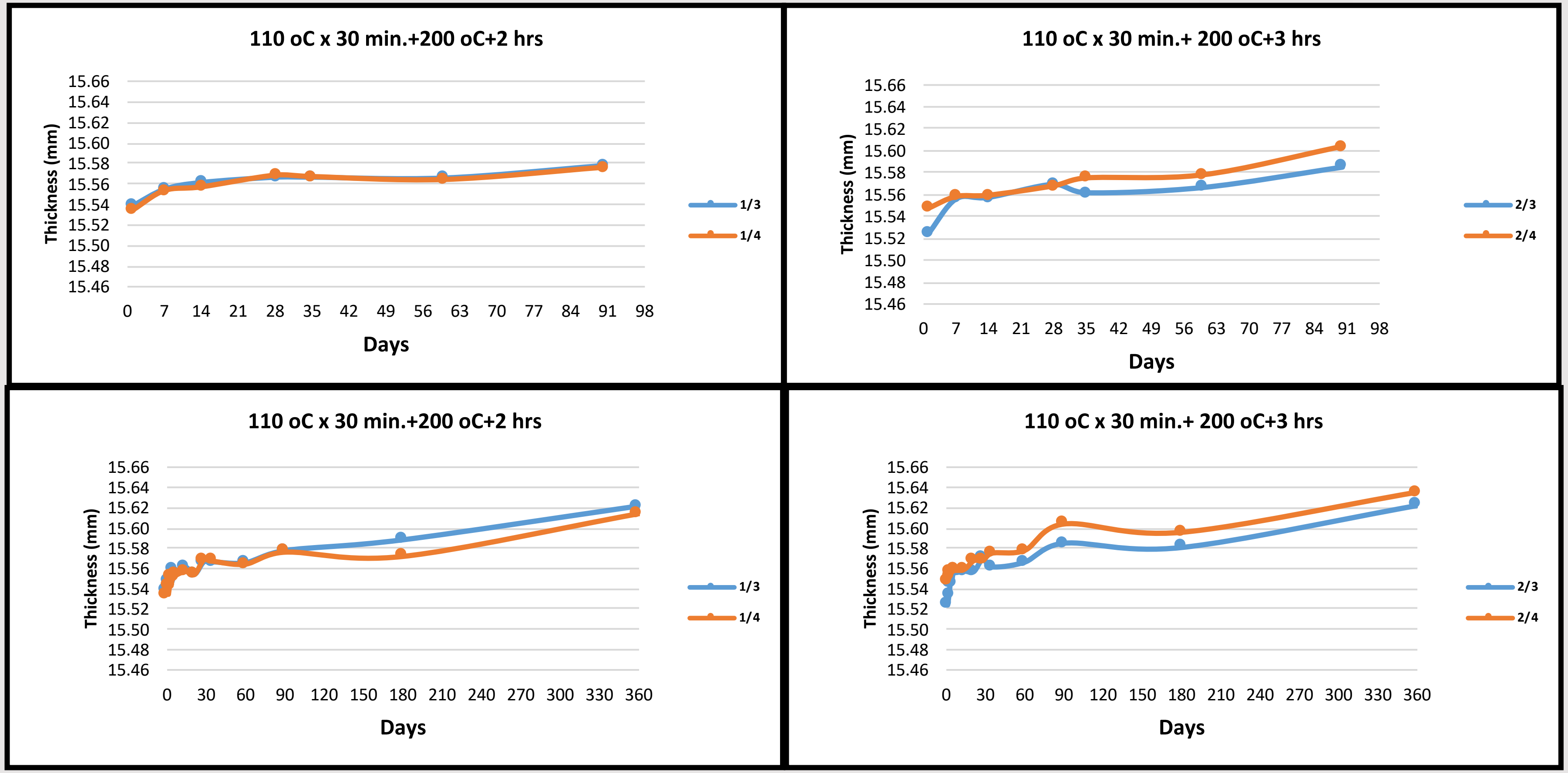


Figure 4-2 --- Pad thickness changes with aging at room temperature of Copper-Free

**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 thickness; 2 or 3 hour cure at 220 $^0$C

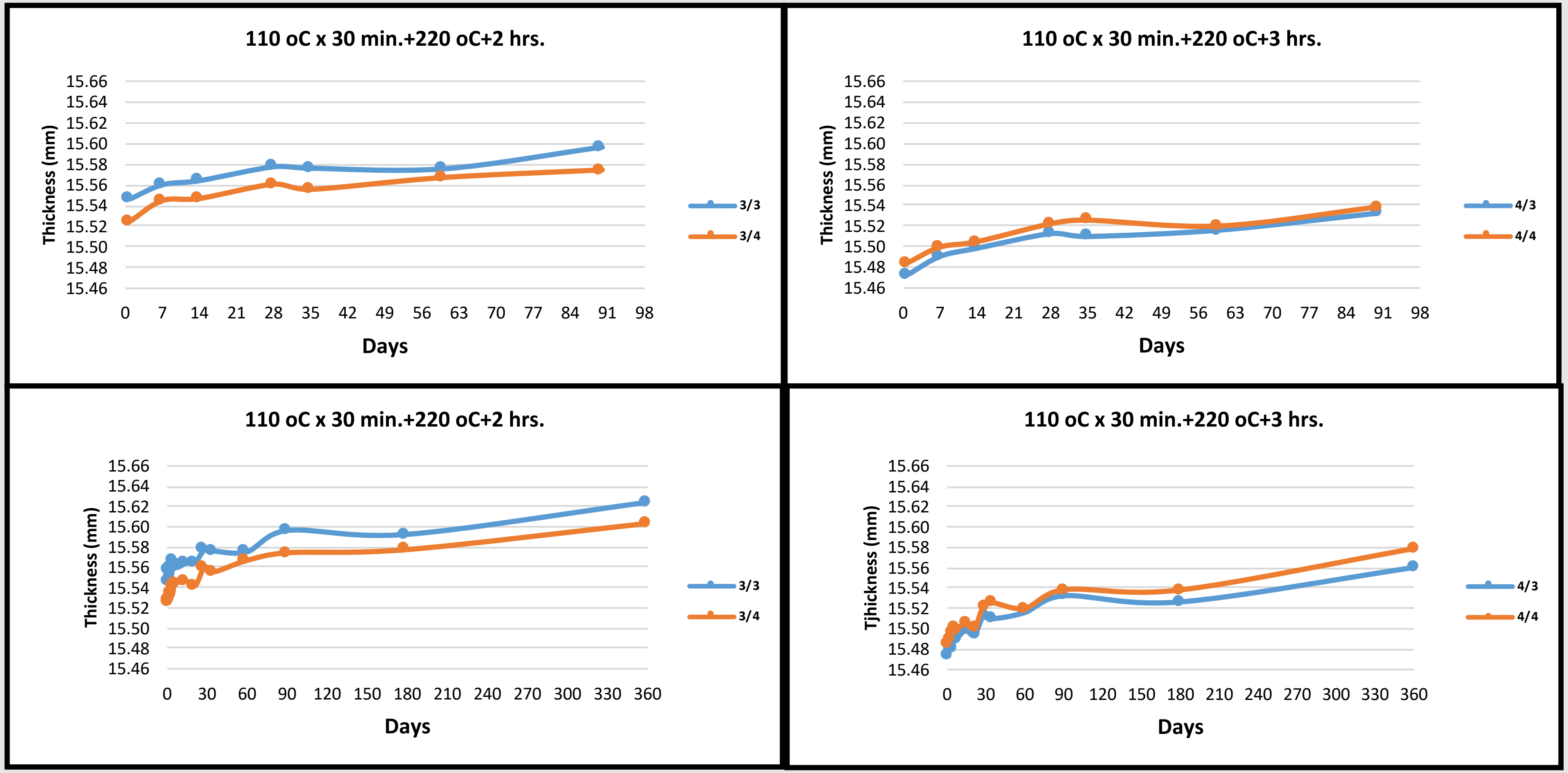


Figure 4-2 --- Pad thickness changes with aging at room temperature of Copper-Free

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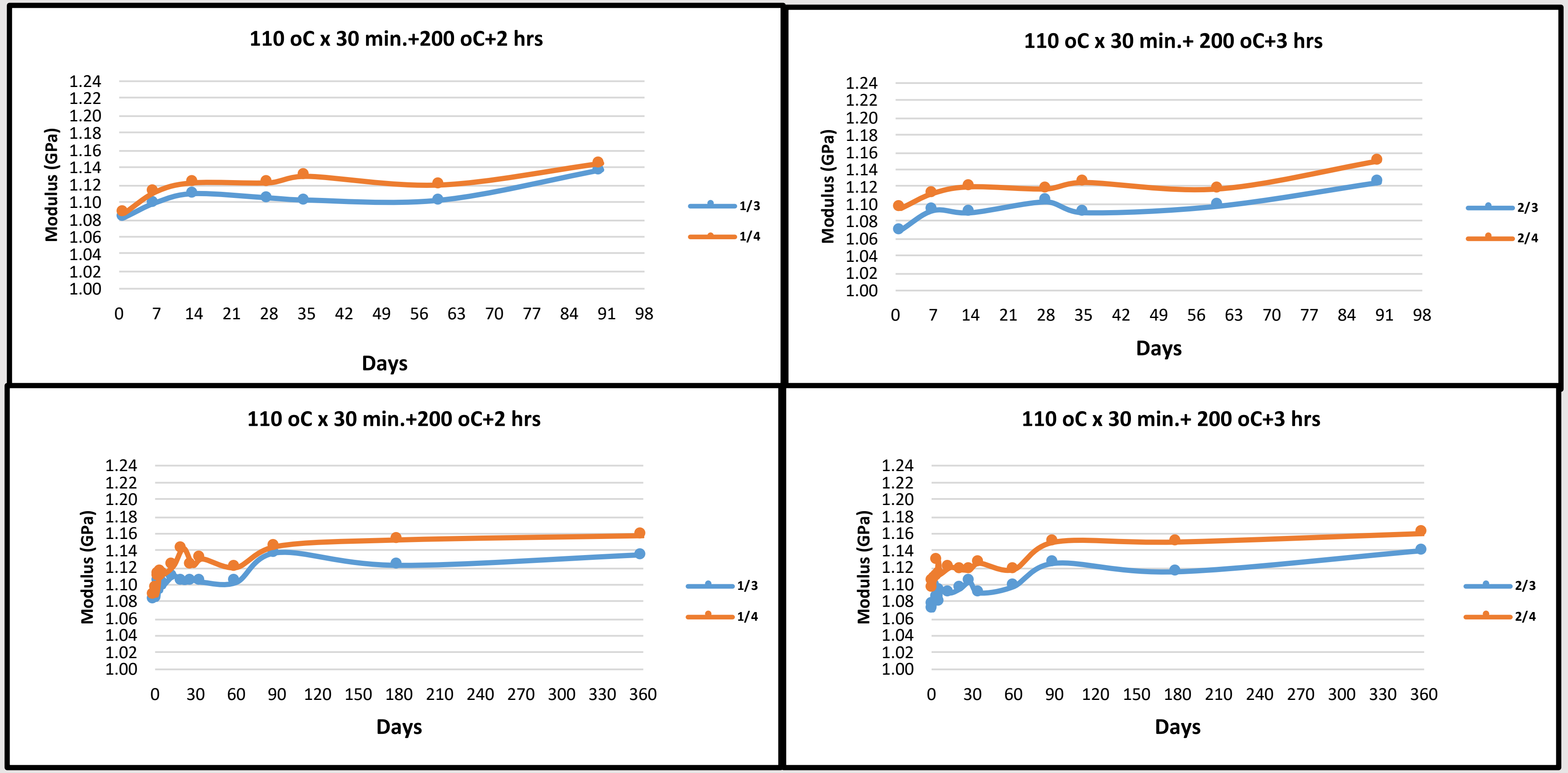
RESULTS AND DISCUSSION

# COPPER FREE

## Aging effect on dynamic modulus of Copper-Free pads; 2 or 3 hour cure at 200 $^{0}$C

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RESULTS AND DISCUSSION

# COPPER FREE

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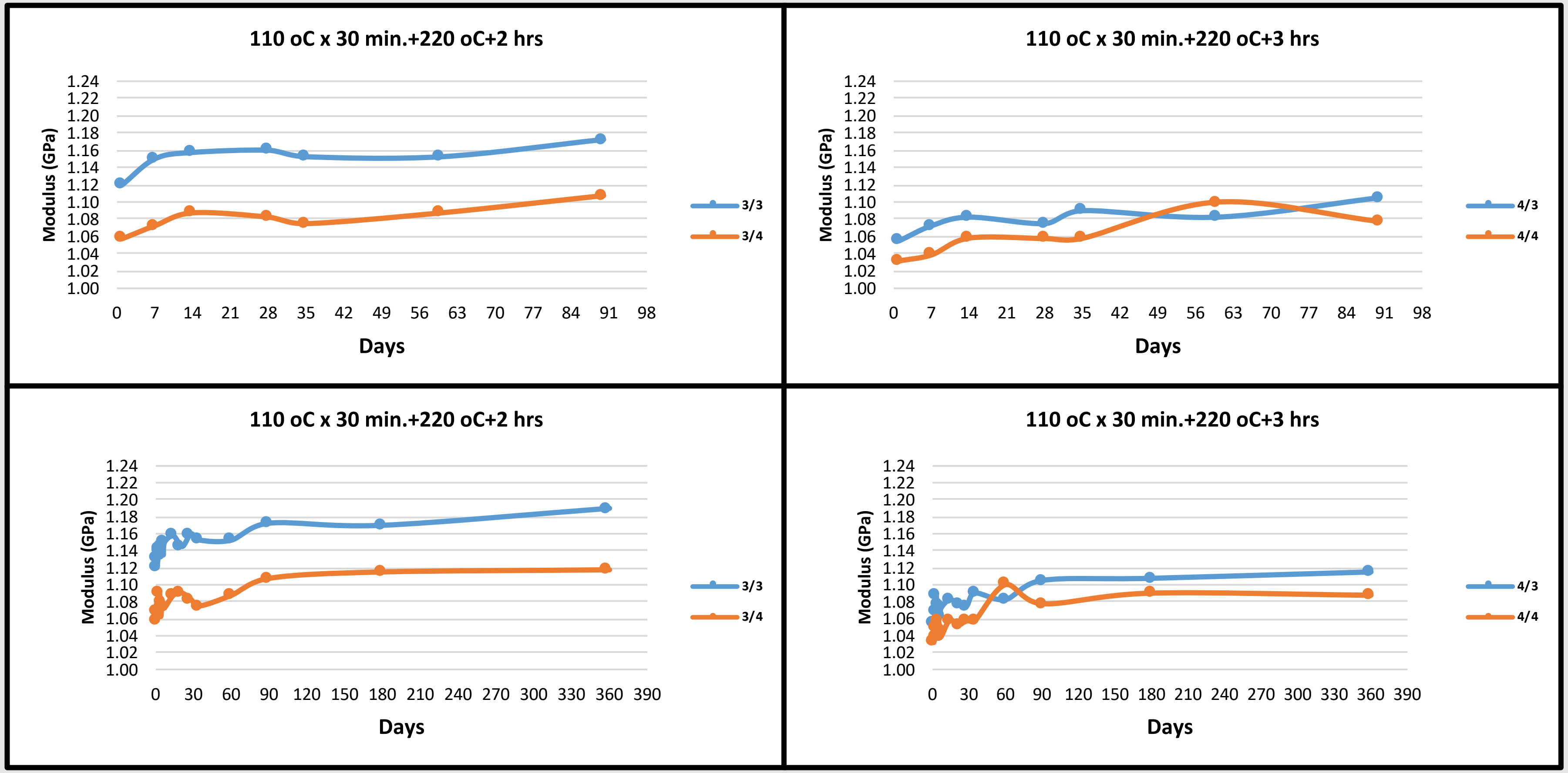



Figure 5-2 --- Pad dynamic modulus changes with aging at room temperature of Copper-Free

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

RESULTS AND DISCUSSION

# COPPER FREE

## Aging effect on natural frequency; 2 or 3 hour cure at 200 $^0C$

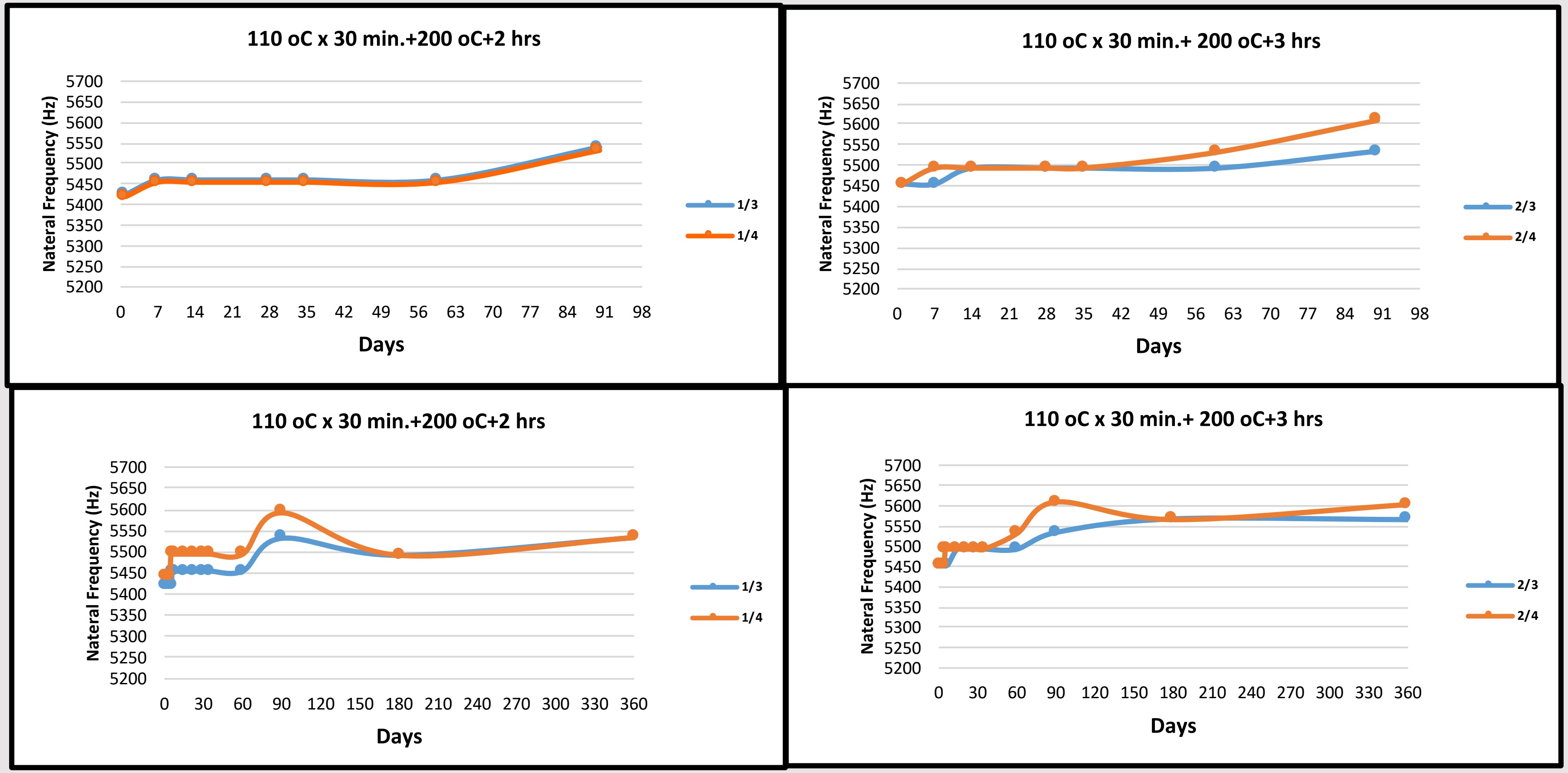



Figure 6-2 --- Pad natural frequency changes with aging at room temperature of Copper-Free

Natural frequency increases rapidly for the first 90 days;
thereafter dips slightly and then continues to increase slightly

RESULTS AND DISCUSSION

# COPPER FREE

## Aging effect on natural frequency; 2 or 3 hour cure at 220 $^{0}$C

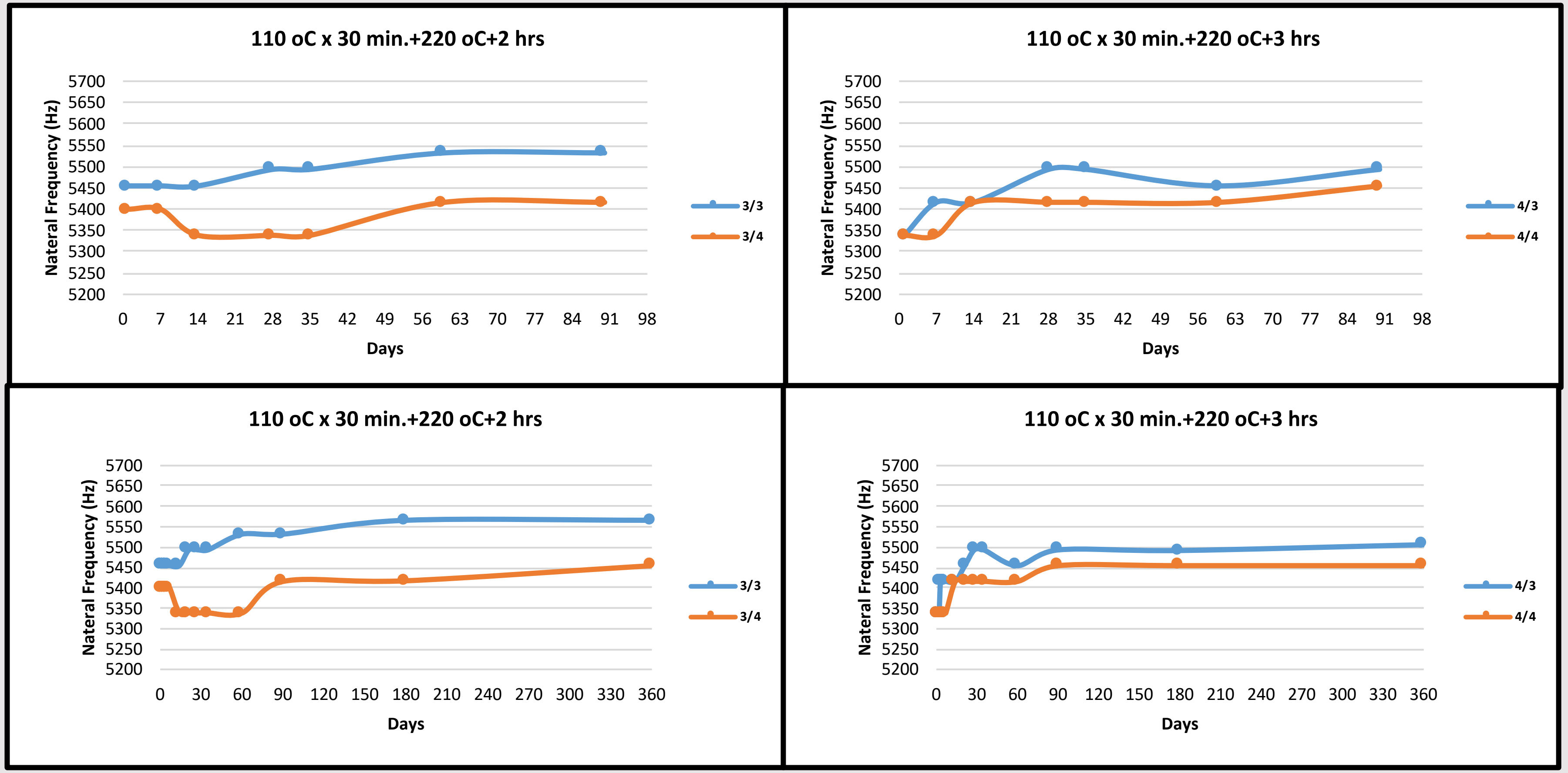



Figure 6-2 --- Pad natural frequency changes with aging at room temperature of Copper-Free

Natural frequency increases rapidly for the first 90 days;
thereafter increases very slowly

# SUMMARY AND CONCLUSIONS

1. After 12 months of aging at room temperature, pad thickness, dynamic modulus and natural frequency all increased.

2. 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 process is 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

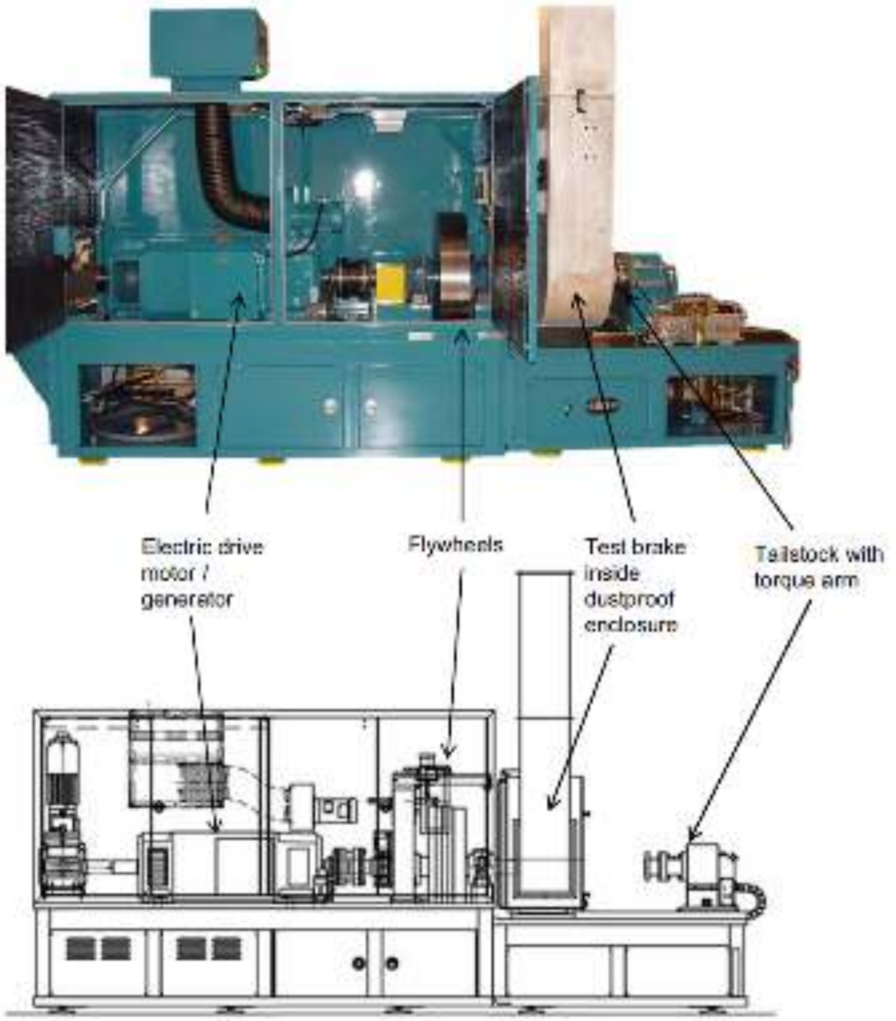



Figure 9.4: Inertia Dynamometer for Brake Testing (Courtesy of Link Engineering).

Ref: Andrew D., In *Braking of Road Vehicle.* Chapter 9 Brake Testing, 303-342

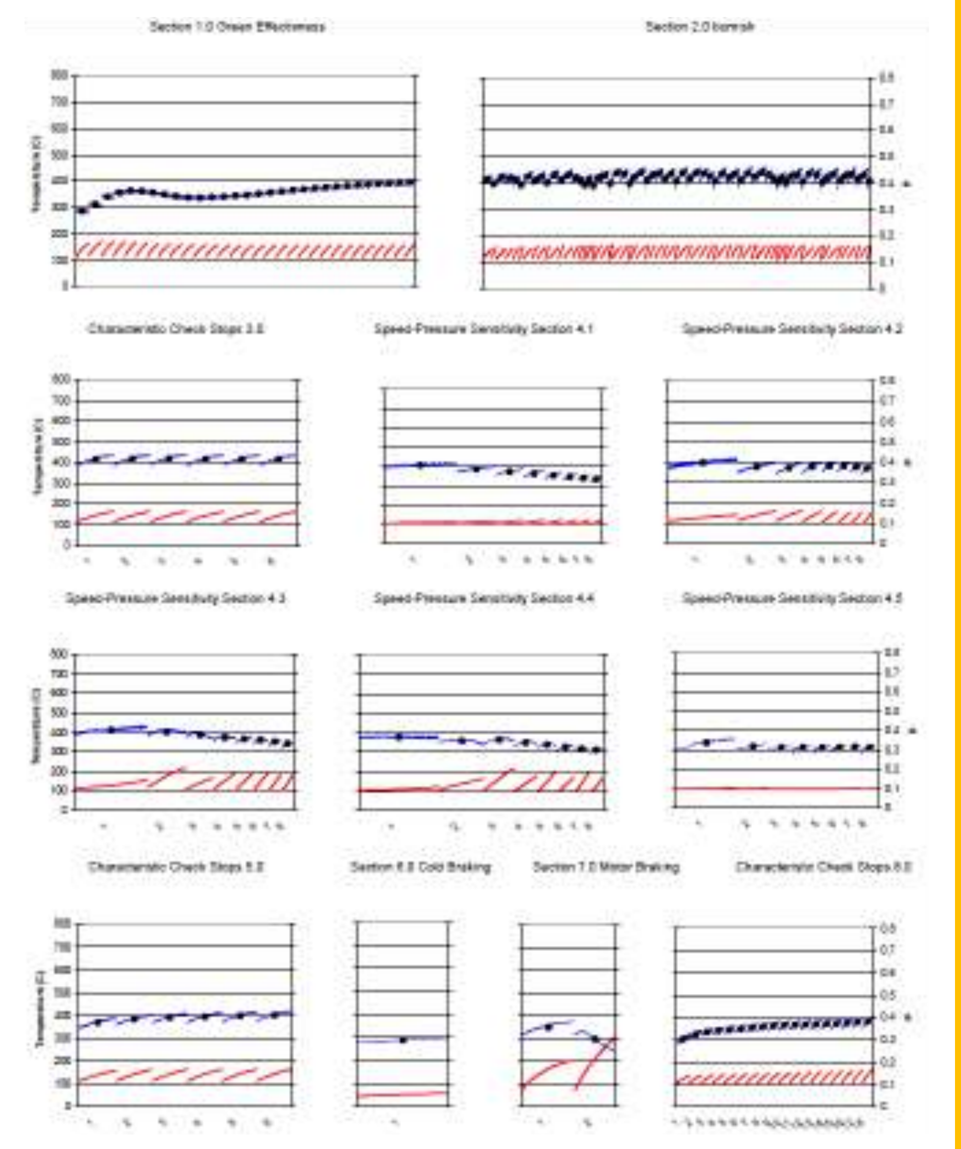
# TECHNICAL OVERVIEW OF BRAKE PERFORMANCE TESTING FOR OE AND AFTERMARKET INDUSTRIES IN THE US AND EUROPEAN MARKETS

Calos E. Agudelo, Eduardo South America

## SAE J2522

DYNAMOMETER GLOBAL BRAKE EFFECTIVENESS

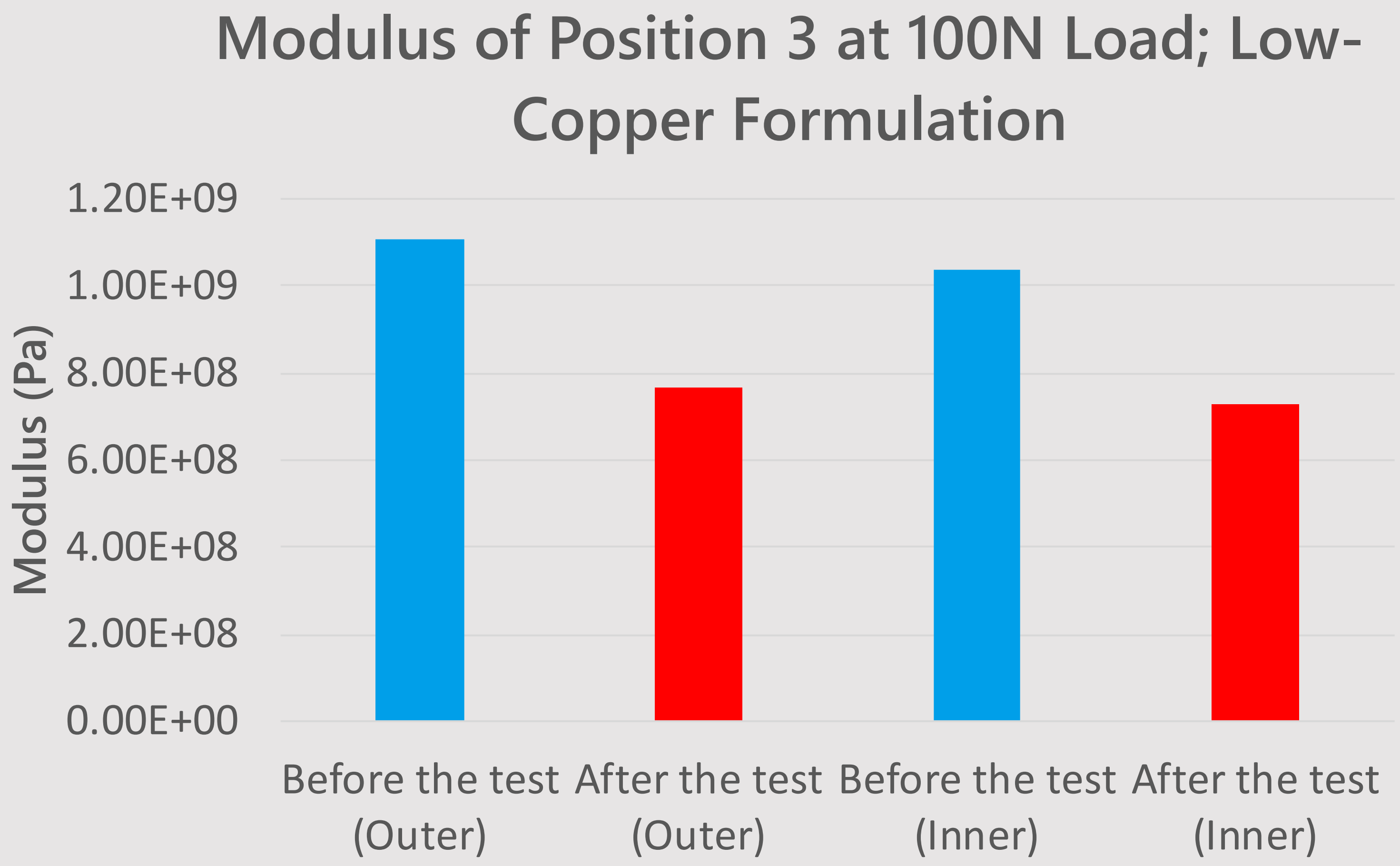
| Section | Number of Stops/snubs | Braking-release Speed -kph | Control | Initial brake temperature -°C |
|---|---|---|---|---|
| Green Effectiveness | 30 | 80-30 | 30 bar | 100 |
| Burnish (or Bedding) | 192 | 80-30 | Various pressures | 100 |
| Characteristic Check | 6 | 80-30 | 30 bar | 100 |
| Speed/Pressure Sensitivity | 8 | 40-<5 | 10,20, … 80 bar | 100 |
| Speed/Pressure Sensitivity | 8 | 80-40 | 10,20, … 80 bar | 100 |
| Speed/Pressure Sensitivity | 8 | 120-80 | 10,20, … 80 bar | 100 |
| Speed/Pressure Sensitivity | 8 | 160-130 | 10,20, … 80 bar | 100 |
| Speed/Pressure Sensitivity | 8 | 200-170 | 10,20, … 80 bar | 100 |
| Characteristic Check | 6 | 80-30 | 30 bar | 100 |
| Cold Braking Check | 1 | 40-<5 | 30 bar | 40 |
| Motorway Braking Check #1 | 1 | 100-5 | 0.6 g | 50 |
| Motorway Braking Check #2 | 1 | 0.9-0.5 $V_{max}$ | 0.6 g | 50 |
| Characteristic Check | 6 | 80-30 | 30 bar | 100 |
| 1st Fade (maximum 160 Bar) | 15 | 100 -<5 | 0.4 g | 100-500 disc<br>100-300 drum |
| Recovery | 18 | 80-30 | 30 bar | 100 |
| Pressure Sensitivity | 8 | 80-30 | 10,20, … 80 bar | 100 |
| Increasing Temperature Sensitivity (500 °C/300 °C) | 9 | 80-30 | 30 bar | 100,150, … 500 |
| Pressure Sensitivity (500 °C) | 8 | 80-30 | 10,20, … 80 bar | 500 |
| Recovery 2 | 18 | 80-30 | 30 bar | 100 |
| 2nd Fade (maximum 160 Bar) | 15 | 100 -<5 | 0.4 g | 100-500 disc<br>100-300 drum |
| Characteristic Check | 18 | 80-30 | 30 bar | 100 |



POSITION OF
# DYNAMIC MODULUS MEASUREMENT

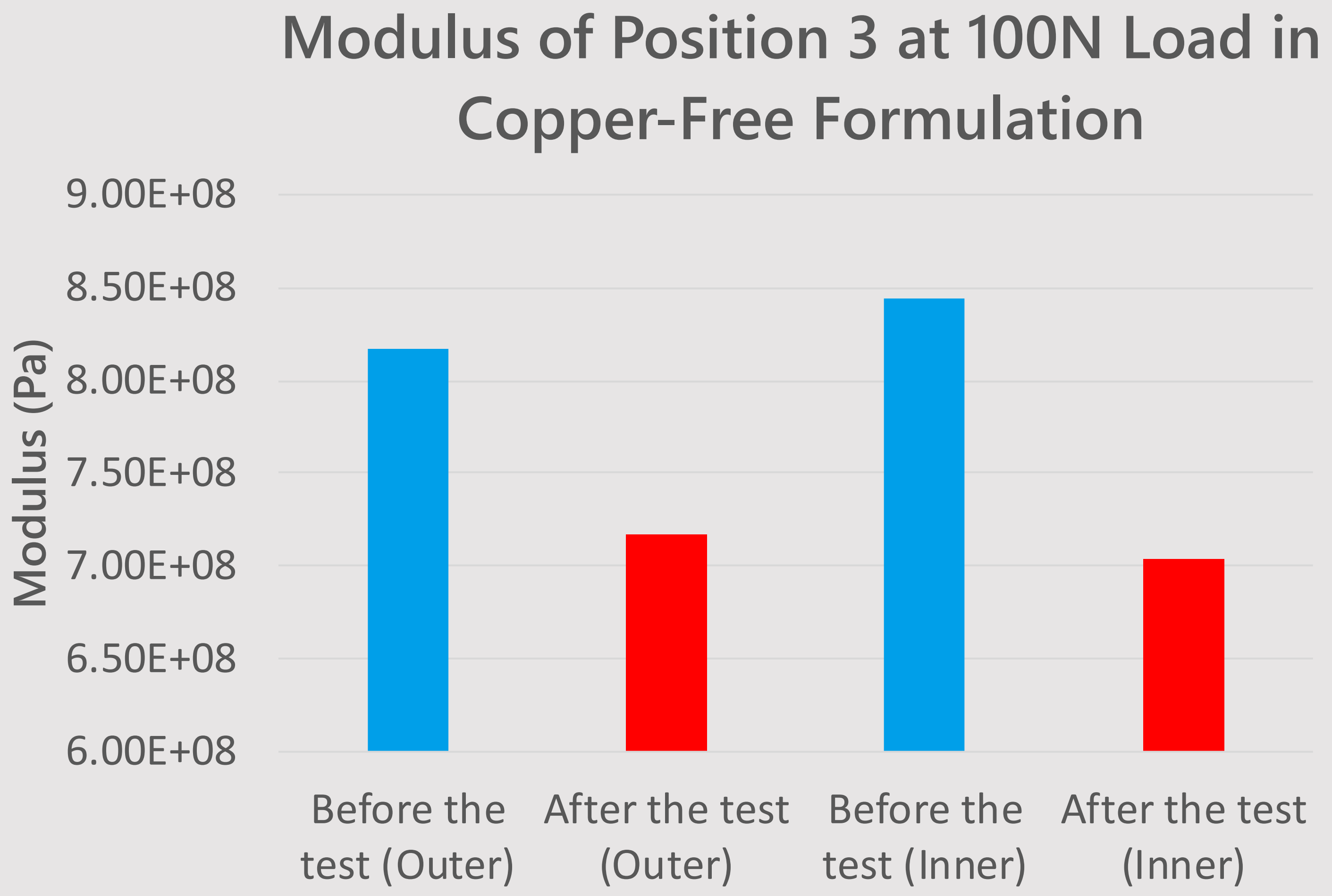
RESULTS AND DISCUSSION

# CHANGING MODULUS OF LOW COPPER




**Disc pad modulus decreases during testing**

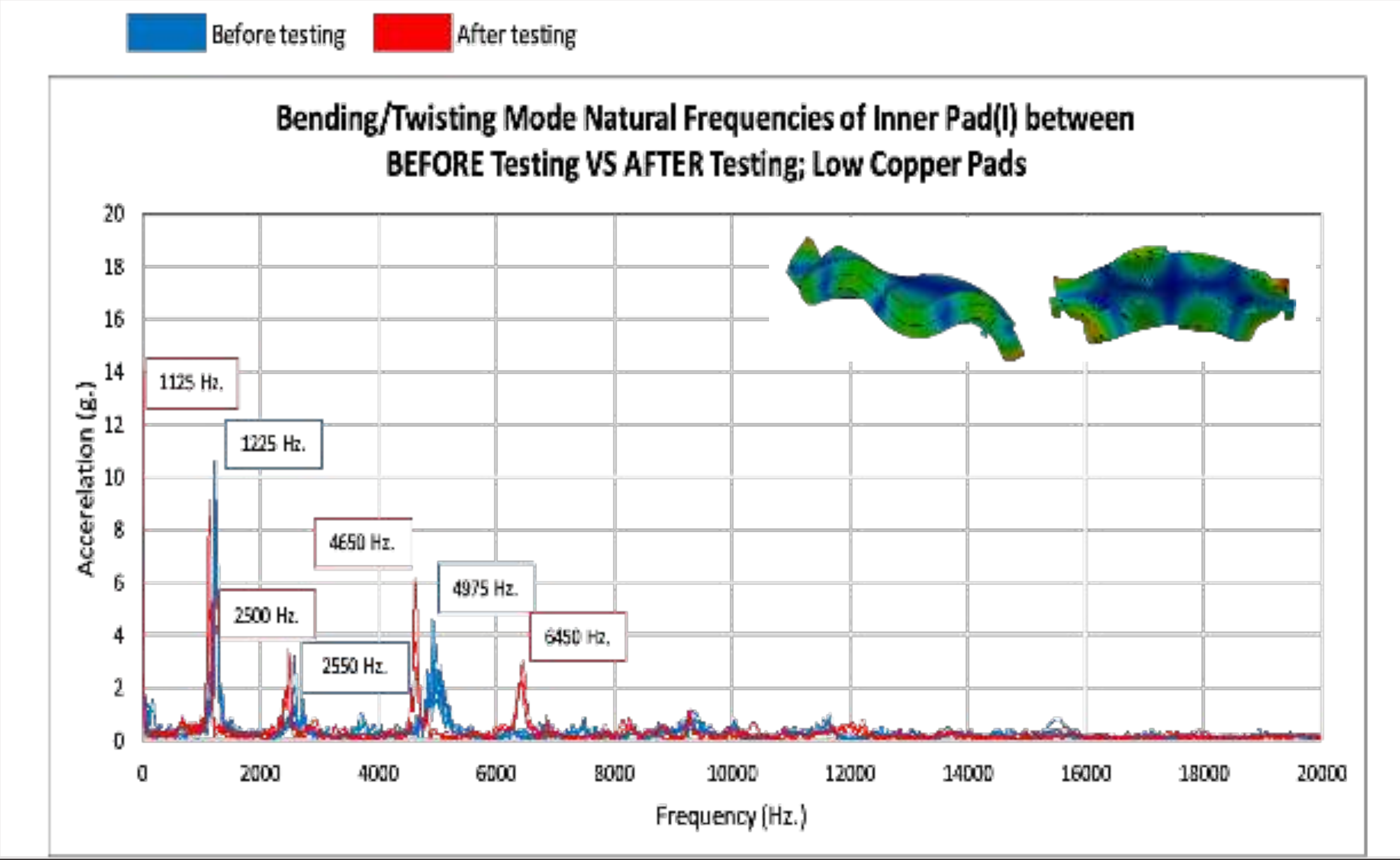
# CHANGING MODULUS OF COPPER FREE




**Disc pad modulus decreases during testing**

NATURAL FREQUENCIES OF INNER PAD BEFORE AND AFTER TESTING

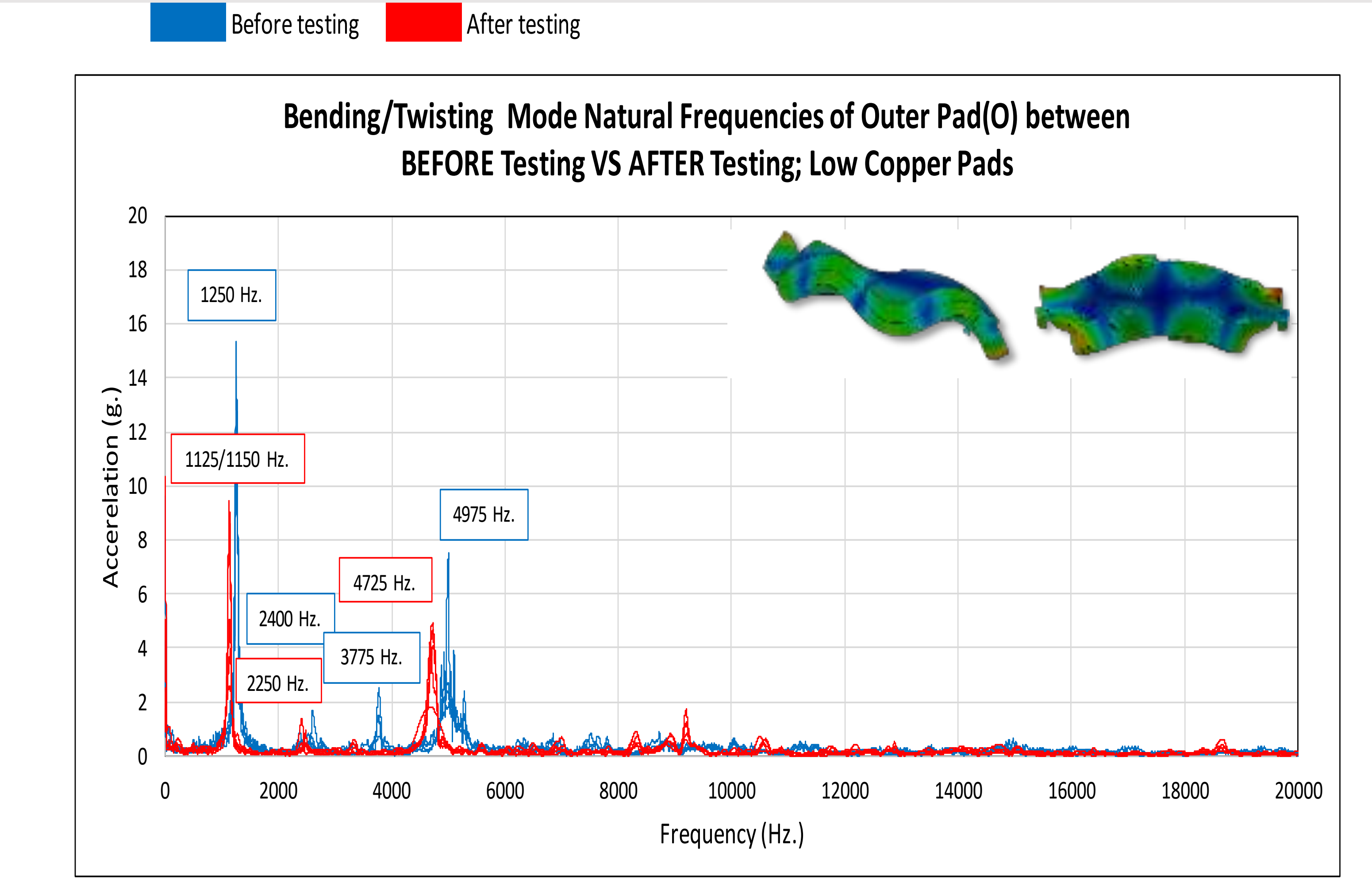
# LOW-COPPER PAD




**Disc pad natural frequencies decrease during testing**

NATURAL FREQUENCIES OF OUTER PAD BEFORE AND AFTER TESTING

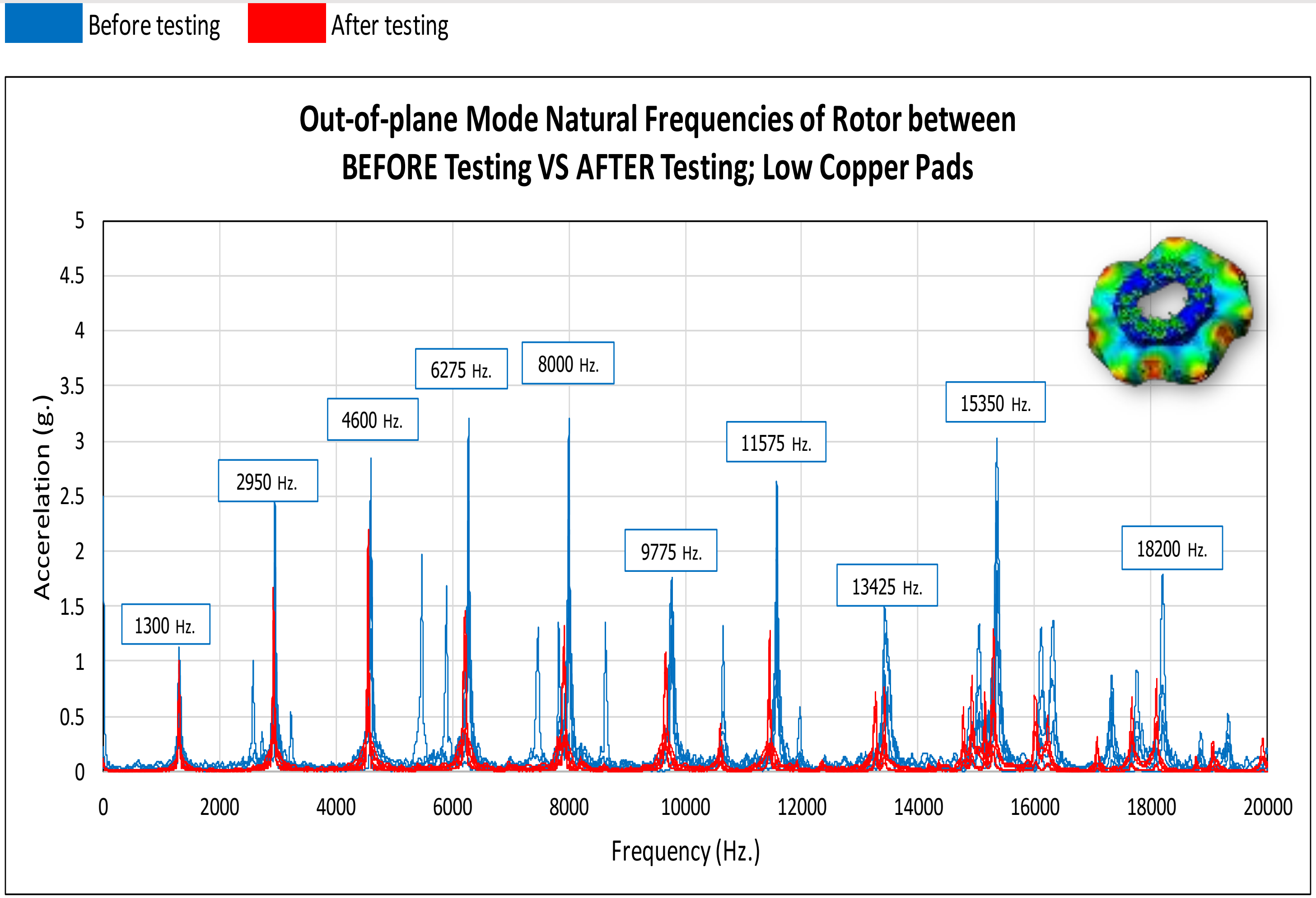
# LOW-COPPER PAD




**Pad natural frequencies decrease during testing; more for the inner pad**

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

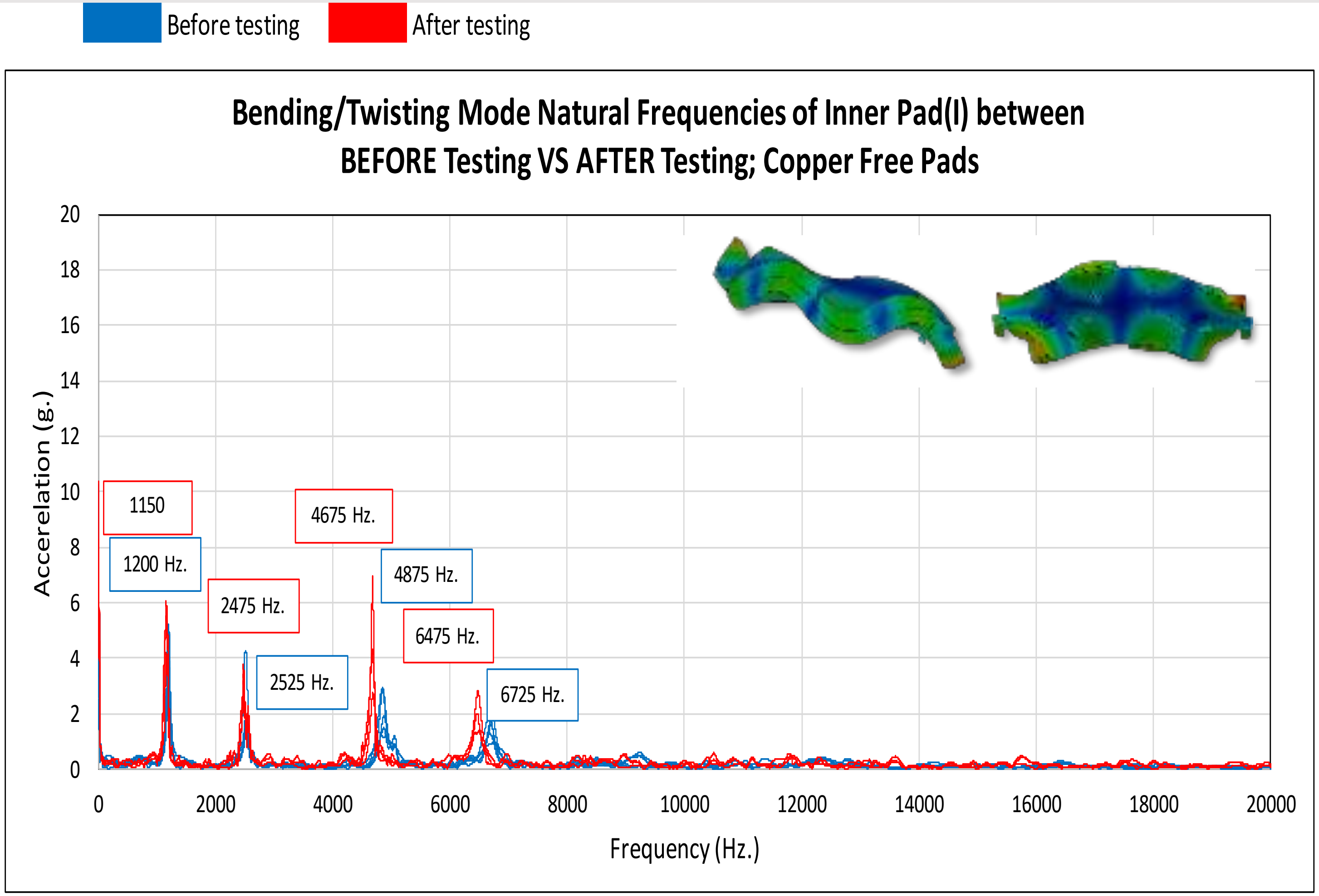
# LOW-COPPER PAD




**Disc natural frequencies decrease during testing**

NATURAL FREQUENCIES OF INNER PAD BEFORE AND AFTER TESTING

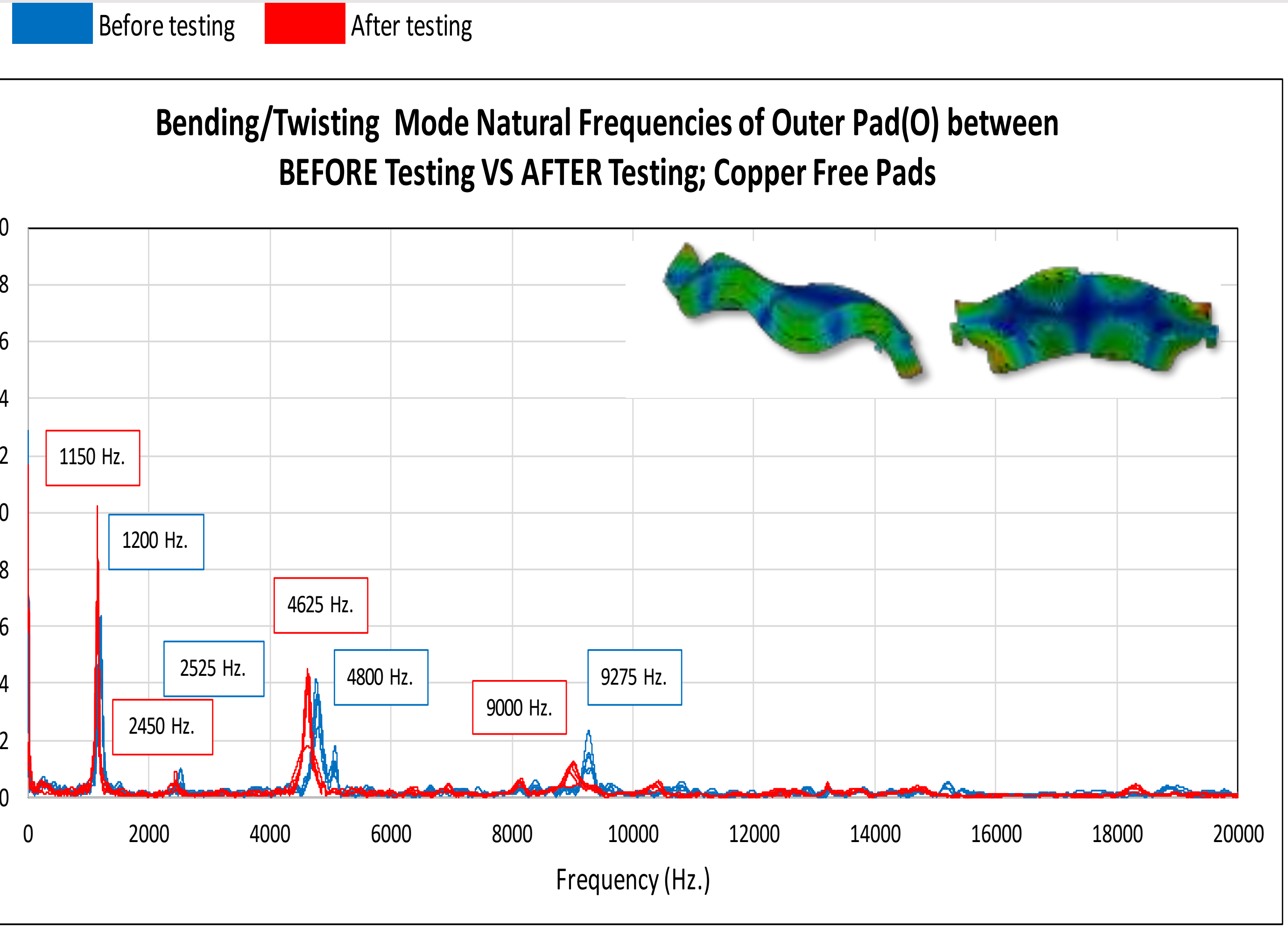
# COPPER FREE PAD




**Pad natural frequencies decrease during testing**

NATURAL FREQUENCIES OF OUTER PAD BEFORE AND AFTER TESTING

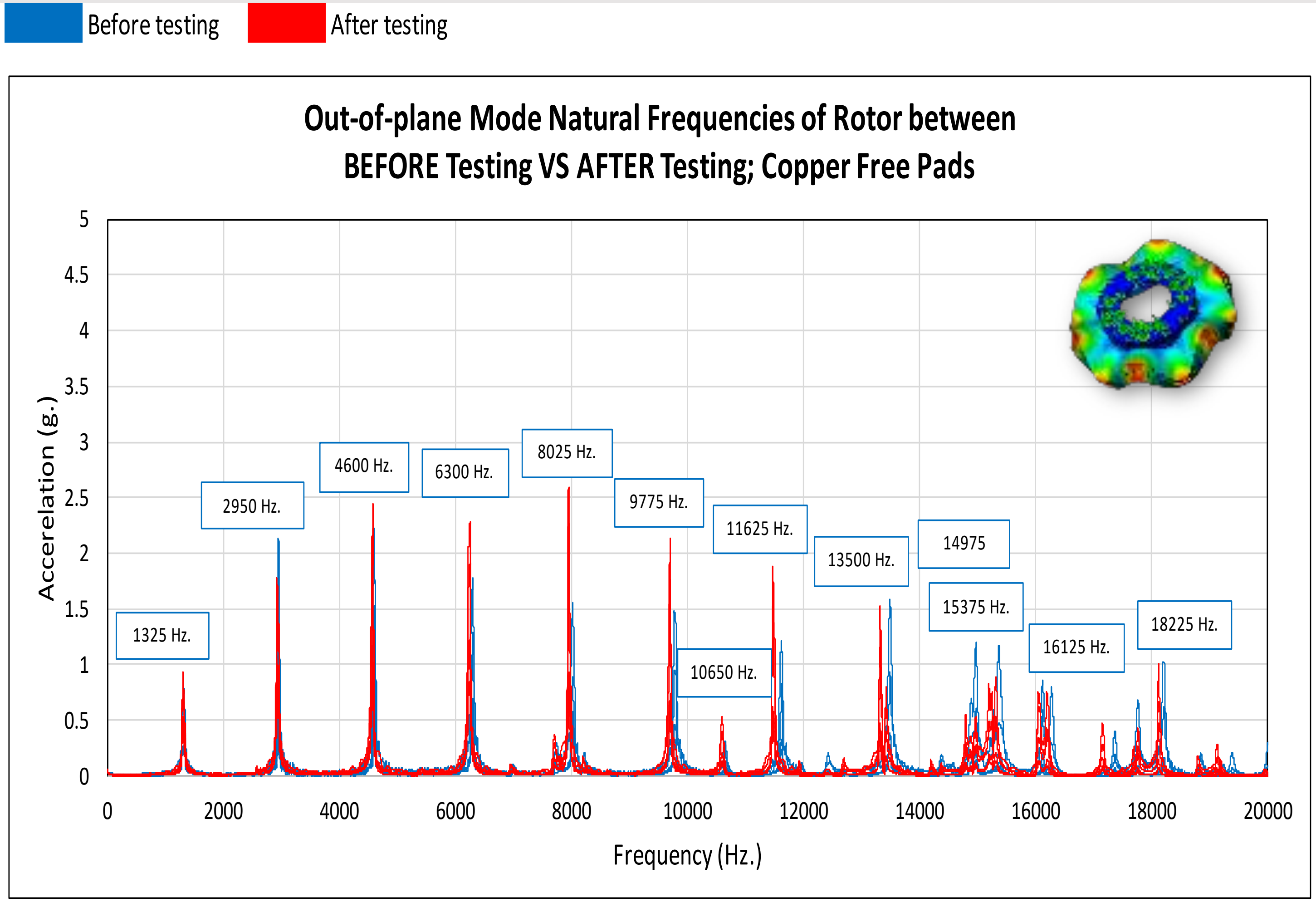
# COPPER FREE PAD




**Pad natural frequencies decrease during testing; more for the outer pad**

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

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

F = natural frequency in Hertz
k = stiffness of the spring (N/m)
m = mass (kg)

- 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