Engineering Materials

# SPECIALTY CARBONS FOR FRICTION MATERIALS

**TIMREX®**
TIMCAL Graphite

**TIMREX®**
TIMCAL Coke

**TIMREX® C-THERM™**
TIMCAL Graphite

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IMERYS
Graphite & Carbon

# Imerys Graphite & Carbon

**WHO ARE WE?**

Imerys Graphite & Carbon has a strong tradition and history in carbon manufacturing. Its first manufacturing operation was founded in 1908.
Today, Imerys Graphite & Carbon facilities produce and market a large variety of synthetic and natural graphite powders, conductive carbon blacks and water-based dispersions of consistent high quality.
Adhering to a philosophy of Total Quality Management and continuous process improvement, all Imerys Graphite & Carbon manufacturing plants comply with ISO 9001:2008.
Imerys Graphite & Carbon is committed to produce highly specialized graphite and carbon materials for today's and tomorrow's customers needs.
Imerys Graphite & Carbon belongs to Imerys, the world leader in mineral-based specialties for industry.

**WHERE ARE WE LOCATED?**

With headquarters located in Switzerland, Imerys Graphite & Carbon has an international presence with production facilities and commercial offices located in key markets around the globe. The Group's industrial and commercial activities are managed by an experienced multinational team of more than 430 employees from many countries on three continents.

For the updated list of commercial offices and distributors please visit www.imerys-graphite-and-carbon.com

**Lac-des-Îles, Canada**
Mining, purification and sieving of natural graphite flakes

**Bodio, Switzerland**
Graphitization and processing of synthetic graphite, manufacturing of water-based dispersions, processing of natural graphite and coke, and manufacturing and processing of silicon carbide

**Terrebonne, Canada**
Exfoliation of natural graphite, processing of natural and synthetic graphite

**Willebroek, Belgium**
Manufacturing and processing of conductive carbon black

**WHAT IS OUR MISSION?**
To promote our economic, social and cultural advancement with enthusiasm, efficiency and dynamism by offering value, reliability and quality to ensure the lasting success of our customers.

**WHAT IS OUR VISION?**
To be the worldwide leader and to be recognized as the reference for innovative capability in the field of carbon powder-based solutions.



# Our value proposition

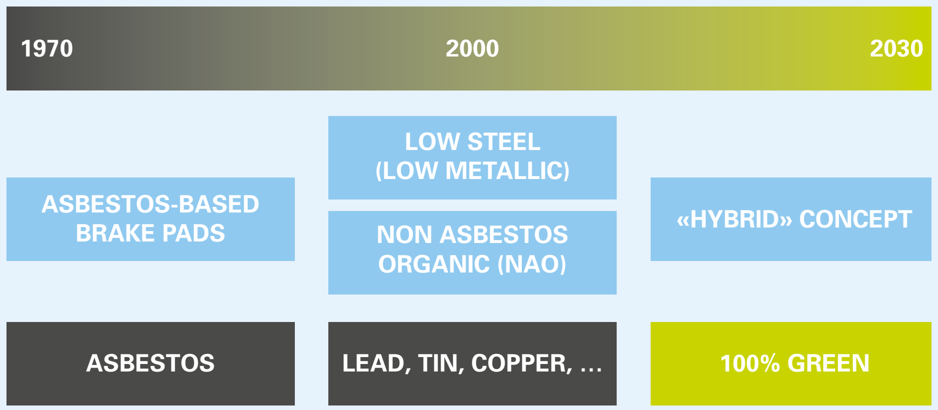
We at Imerys Graphite & Carbon deliver tailor made solutions for friction materials applications with superior consistency of key products' parameters: purity, crystallinity, particle size distribution, oversize control.

We at Imerys Graphite & Carbon address with our portfolio and with our R&D efforts the key requirements of friction materials industry:

| APPLICATION REQUIREMENTS | RELATED ISSUE | FRICTION MATERIALS' TECHNICAL REQUIREMENTS INVOLVED | BENEFITS FROM IMERYS GRAPHITE PORTFOLIO |
|---|---|---|---|
| Low NVH (noise-vibration harshness) | Braking system's/ vehicle's perceived quality | Hot spots; balanced friction coefficient (μ); presence/absence of noise dampers. | High thermal conductivity (C-THERM™); noise damping effect. |
| Higher wear resistance | Friction material's lifetime; matching heavy duty applications; Copper substitution (USA regulation, Copper fluctuating Price) | Hardness & density; increased thermal conductivity. | Various levels of compressibility; stable friction coefficient (μ) at high temperature; good thermal conductivity (C-THERM™). |
| Short braking distance | Safety | Friction coefficient (μ); thermal conductivity; | High/low (μ); μ at high temperature; high thermal conductivity (C-THERM™). |

# Overview of resin-bonded friction materials

Efforts to develop environmentally friendly friction materials have started in the 1980’s, when asbestos was confirmed to be carcinogenic. Later on, other toxic materials like lead and tin have been banned from brake pads. Recently, the use of Copper is being questioned because of the potential environmental impact of Cu wear debris. In USA, the use of Copper in automotive brake pads will be strongly restricted in the future and will limit the use of Cu in all of its forms.
Since the elimination of asbestos, many different types of friction materials have been developed, which are typically classified by their raw material constituents. For automotive applications, two main classes of friction materials are currently used: low steel (also called low metallic) and non-asbestos organic (NAO). Both low steel and NAO materials have very complex formulations with several different ingredients that can be categorized in five groups: binder, fibers, abrasives, lubricants and fillers. Low steel brake pads contain small concentrations of steel fibers (compared to semi-metallic materials) and are mainly used in Europe, where high braking performance is required. NAO brake pads do not contain ferrous metals and are commonly used in USA and Japan, where comfort (low noise) is more important.
Ongoing developments target an “hybrid” concept of environmentally friendly brake pads that combine the high performance of low steel formulations with the high comfort of NAO formulations.




| INGREDIENTS | NAO FORMULATIONS | LOW STEEL FORMULATIONS | «HYBRID» FORMULATIONS |
|---|---|---|---|
| Binder | Phenolic resin | Phenolic resin | Phenolic resin |
| Fibers | Organic and inorganic fibers, metallic fibers (non ferrous, e.g. Copper, Brass) | Organic and inorganic fibers, metallic fibers (non ferrous, e.g. Copper, Brass & ferrous, e.g. Steel) | Organic and inorganic fibers, metallic fibers (Cu-free, new alloys) |
| Abrasives | Aluminum oxide, silicon carbide, … | Aluminum oxide, silicon carbide, … | Aluminum oxide, silicon carbide, … |
| Lubricants | Graphite, metal sulfides, … | Graphite, metal sulfides, … | Special graphite, metal sulfides, … |
| Fillers | Baryte, … | Baryte, … | Baryte, … |
| Properties | Low noise<br>Low wear | High fricton coefficient | Low noise<br>Low wear<br>High fricton coefficient |
| Benefits | High comfort | High performance | High comfort<br>High performance<br>“Green” |



# Specialty carbons’ validation by experimental tests

Imerys Graphite and Carbon has recently been collaborating both with universities and OEM producers to validate its solutions for NVH and Copper substitution (see literature references, pag. 13). Formulations used in the tests are presented below. Tests results will be displayed in the following pages.

**NAO: SIMPLIFIED FORMULATION**

For NAO type brake pads, model friction materials with a known formulation and a reduced number of components have been produced and tested on lab scale. Several graphite grades and particle size distributions have been investigated.

| FORMULATIONS (%wt.) | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Resin | Phenolic | 18 | | | | | |
| Fibers | Mineral fibers | 10 | | | | | |
| | Aramid pulp | 5 | | | | | |
| Friction particles | Cashew friction dust | 10 | | | | | |
| Filler | Barite | 57 | 49 | | | | |
| Graphite | KS150-600 SP | – | 8 | – | – | – | – |
| | T150-600 | – | – | 8 | – | – | 4 |
| | T800 | – | – | – | 8 | – | – |
| | T200-2000 | – | – | – | – | 8 | – |
| | C-THERM™ | – | – | – | – | – | 4 |

**LOW STEEL: MODIFIED OEM FORMULATION**

For low-steel type brake pads, an existing commercial OEM formulation has been modified according to the following table.

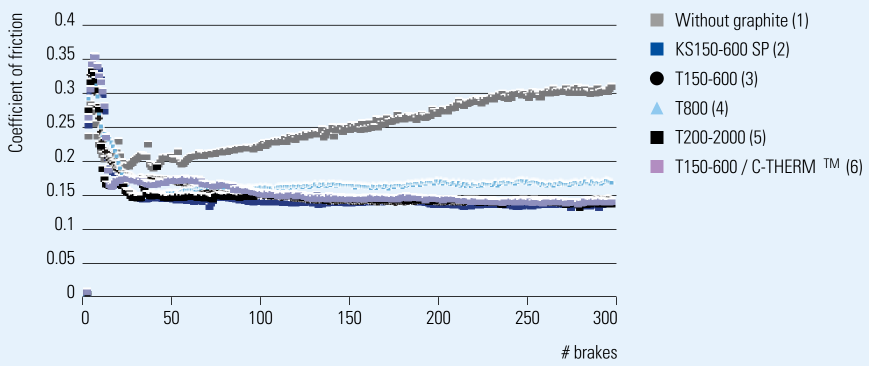
| FORMULATION (%wt.) | A | B | C | D |
|---|---|---|---|---|
| DESCRIPTION | OEM brake pad for Euro Car segment B | Without Cu alloy | Without Cu-alloy, NG replaced with C-THERM™ | Cu-free, with new alloy, increased % graphite, with C-THERM™ |
| Cu | 10 | 10 | 10 | 0 |
| Cu-alloy | 10 | 0 | 0 | 0 |
| Steel | X | X+10 | X+10 | X+10 |
| Alloy + sulfide modification | 0 | 0 | 0 | 8.5 |
| TIMREX coke | Y | Y | Y | Y |
| Primary synthetic graphite (T150-600) | 3.0 | 3.0 | 3.0 | 3.5 |
| Natural graphite (NG) | 2.5 | 2.5 | 0 | 0 |
| Special graphite (C-THERM™) | 0 | 0 | 2.5 | 3.5 |
| Total Graphite | 5.5 | 5.5 | 5.5 | 7 |

# Specialty carbons and friction coefficient

## NAO: SIMPLIFIED FORMULATION

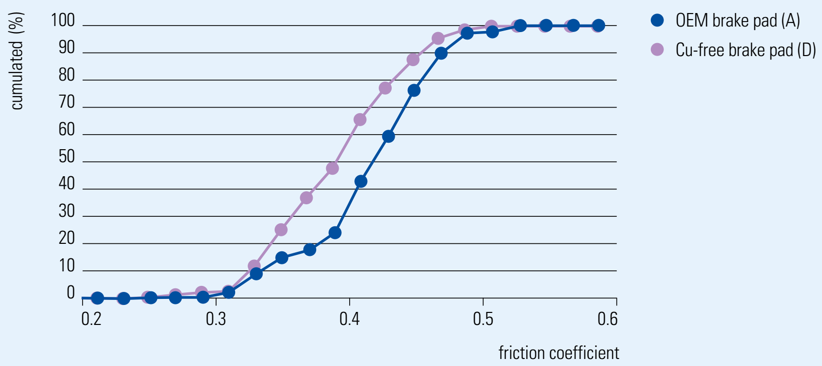
Fading test by Reduced Scale Prototype (RSP) test setup of Indian Institute of Technology (New Delhi): 300 brakes at 4 MPa, 1200 rpm.

- Graphite is helpful to stabilize the friction coefficient.
- Friction coefficient slightly higher for T800.
- C-THERM™ has no impact on the brake performance (friction coefficient).




## LOW STEEL: MODIFIED OEM FORMULATION

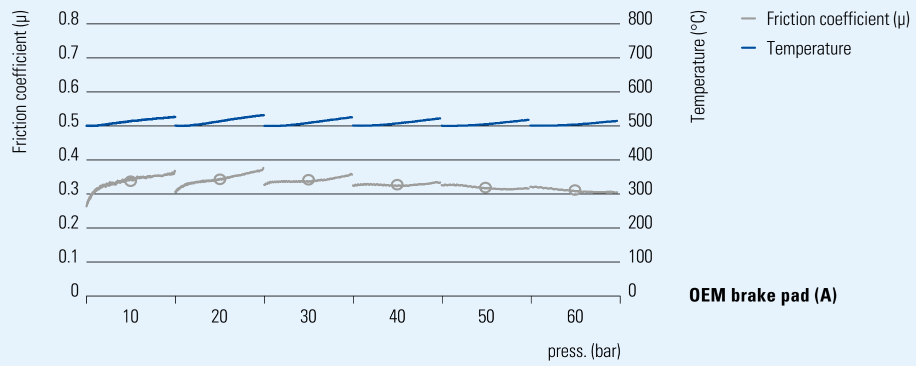
Friction distribution (total performance) according to ISO 26867 (Road vehicles – Brake lining friction materials – Friction behavior assessment for automotive brake systems).

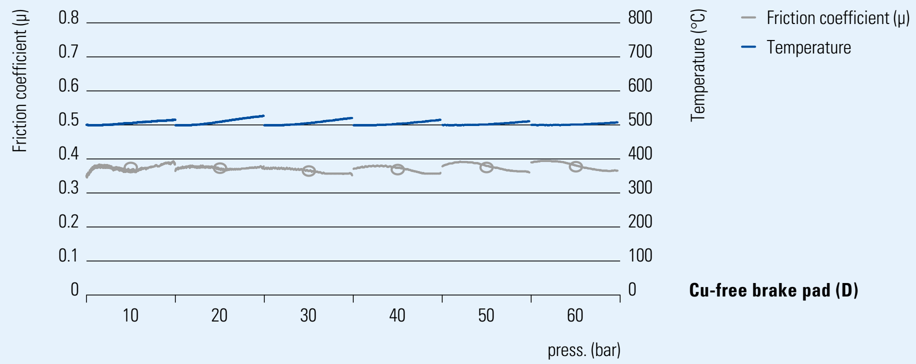


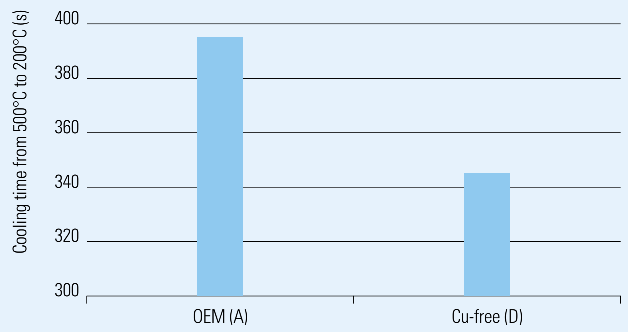

Cu-free formulation with C-Therm™ (D) has slightly lower friction coefficient compared to OEM brake pad.



Hot performance according to ISO 26867 (road vehicles – Brake lining friction materials – friction behavior assessment for automotive brake systems).
Section 14 (hot performance): friction coefficient and brake disc temperature is measured during 6 stops from 80 km/h to 40 km/h at different pressures from 10 bar to 60 bar (initial brake disc temperature=500 °C).



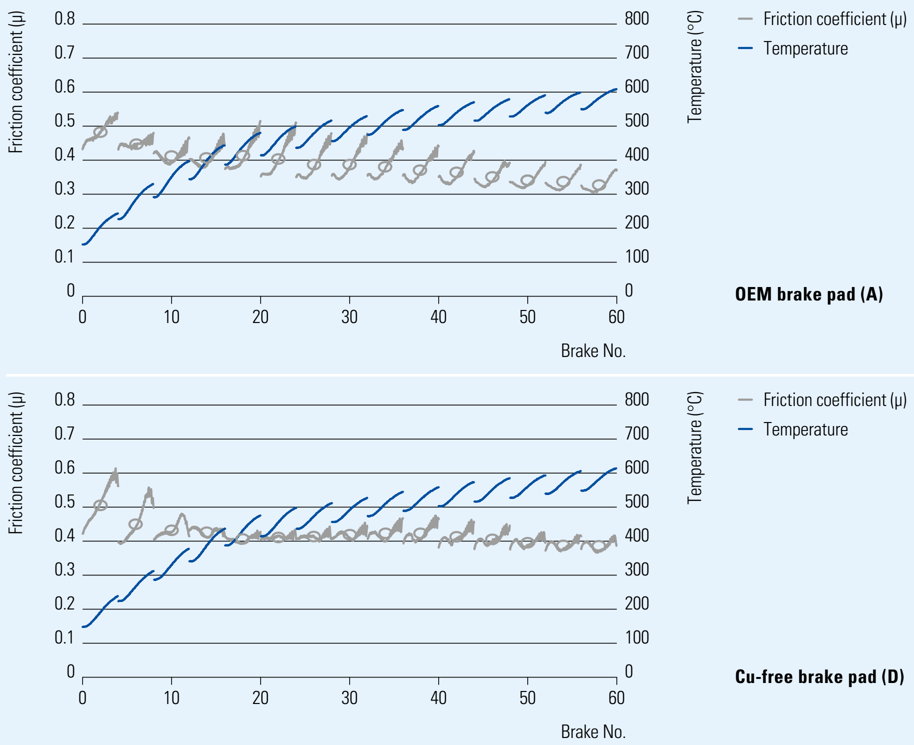




Cu-free formulation with C-Therm™ (D) shows higher minimum friction coefficient and more stable friction coefficient at different pressure levels.

# Specialty carbons and friction coefficient

Fading behaviour according to ISO 26867 (road vehicles – brake lining friction materials – friction behavior assessment for automotive brake systems).
Section 18 (second fade): friction coefficient and brake disc temperature is measured during 15 stops from 100 km/h to 0.5 km/h with deceleration of 0.4 g and increasing initial temperature of brake disc.




Cu-free formulation with T150-600 and C-THERM™ has better fading behaviour compared to OEM formulation. In particular, the friction coefficient at high temperatures is higher and more stable. This can be explained by the higher thermal conductivity of Cu-free formulation (due to higher amount of graphite and C-THERM™) that leads to a better heat dissipation and lower cooling time between different brake stops.

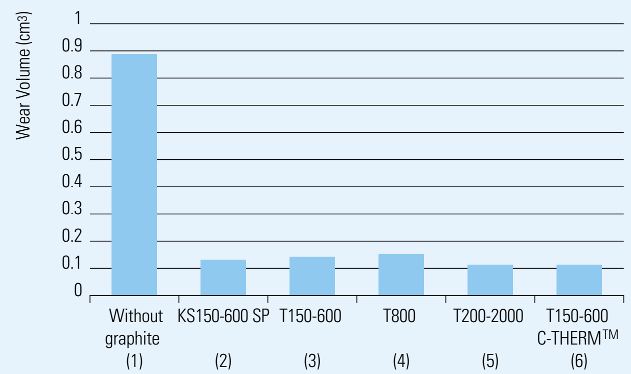


# Specialty carbons for wear resistance

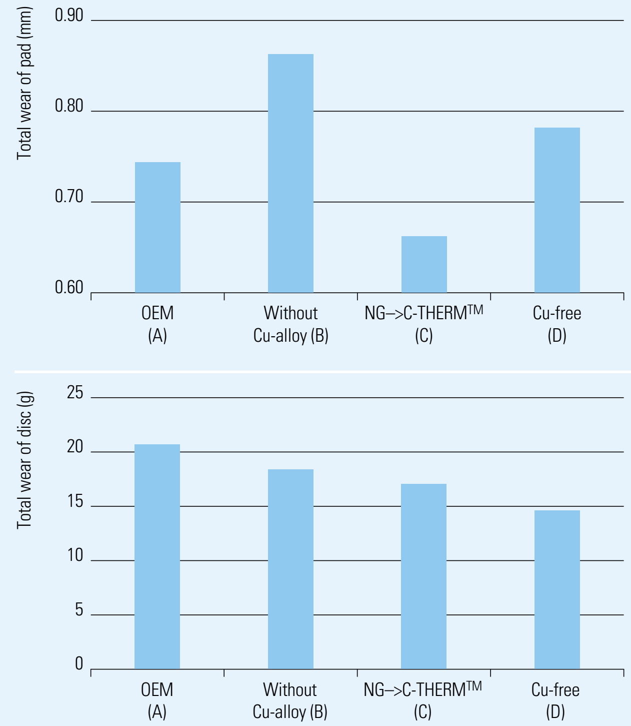
**NAO: SIMPLIFIED FORMULATION**

Fading test by Reduced Scale Prototype (RSP) test setup of Indian Institute of Technology (New Dellhi): 300 brakes at 4 MPa, 1200 rpm.

- Graphite is helpful to decrease the wear rate.
- Wear rate similar for all tested graphite, much lower than without graphite.
- C-THERM™ has no negative impact on wear.




**LOW STEEL: MODIFIED OEM FORMULATION**




- Formulation with C-THERM™ (C) shows best results in terms of brake pad wear.
- Cu-free formulation with C-THERM™ (D) shows the best performance in terms of brake disc wear and comparable performance to original OEM (A) in terms of brake pad wear.

Replacement of natural graphite with C-THERM™ reduces the wear of both brake pad and brake disc.

# Specialty carbons for improved NVH

## NAO: SIMPLIFIED FORMULATION

Noise measurements using test setup of Polytech Lille [1].
Description of noise test procedure applied for each sample of the different brake pad formulations:

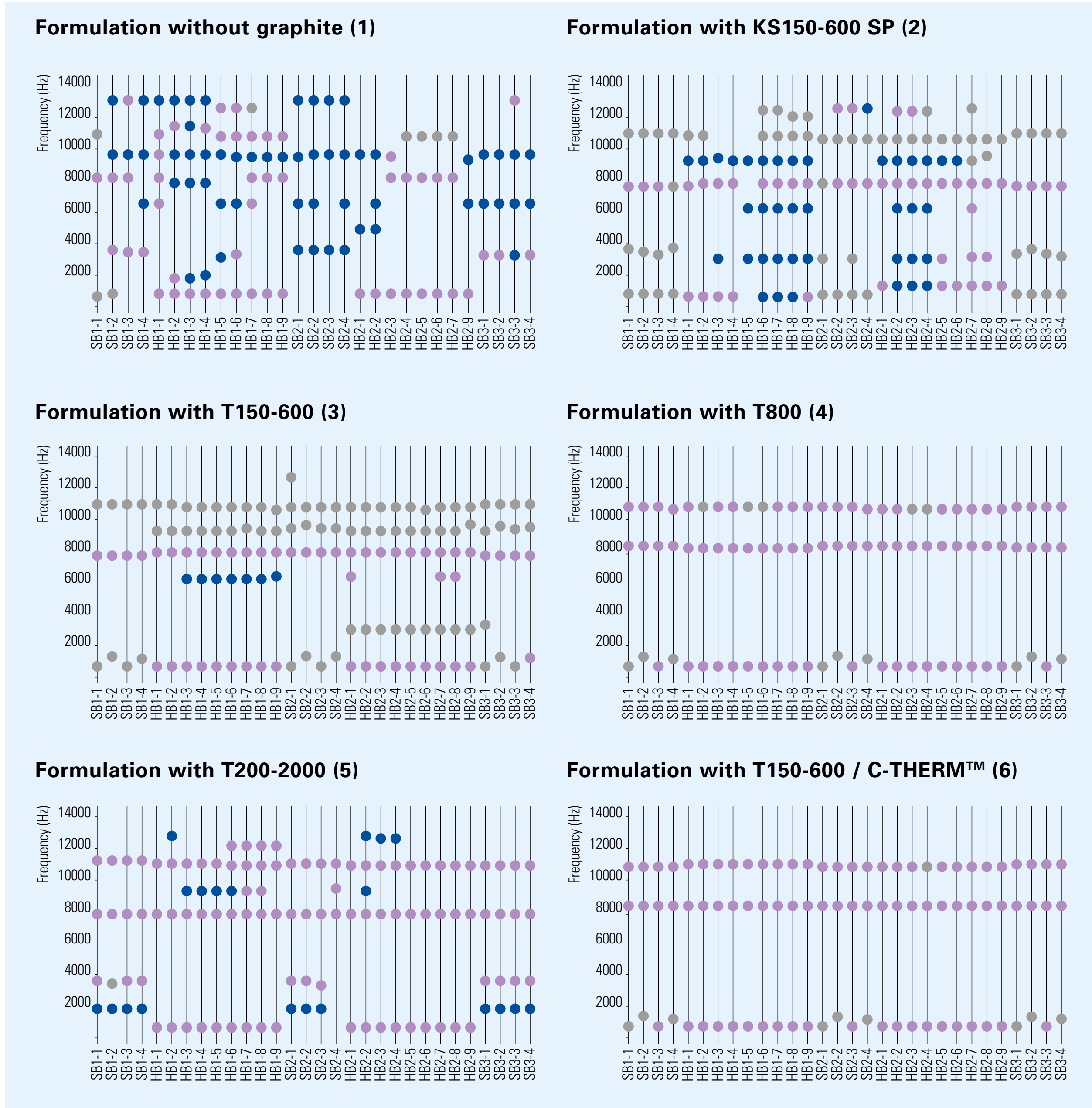
| PHASE | DETAILS | CODE |
|---|---|---|
| Linear decreasing speed | 250 N at 500 rpm | SB1-1 |
| | 250 N at 1000 rpm | SB1-2 |
| | 500 N at 500 rpm | SB1-3 |
| | 500 N at 1000 rpm | SB1-4 |
| Constant speed | 250 N at 500 rpm during 15 min | HB1-1 to HB1-9 |
| Linear decreasing speed | 250 N at 500 rpm | SB2-1 |
| | 250 N at 1000 rpm | SB2-2 |
| | 500 N at 500 rpm | SB2-3 |
| | 500 N at 1000 rpm | SB2-4 |
| Constant speed | 500 N at 1000 rpm during 20 min | HB2-1 to HB2-9 |
| Linear decreasing speed | 250 N at 500 rpm | SB3-1 |
| | 250 N at 1000 rpm | SB3-2 |
| | 500 N at 500 rpm | SB3-3 |
| | 500 N at 1000 rpm | SB3-4 |

## SUMMARIZE OF NVH TEST RESULTS:

| BRAKE PAD TYPE | CONSTANT SPEED | L. D. SPEED |
|---|---|---|
| Without graphite | 12700 Hz – 92 dB<br>9300 Hz – 106 dB<br>4600 Hz – 90 dB<br>1700 Hz – 96 dB | 12700 Hz – 95 dB<br>9300 Hz – 106 dB<br>6200 Hz – 91 dB<br>3400 Hz – 86 dB |
| KS150-600 SP | 9300 Hz – 107 dB<br>6200 Hz – 103 dB<br>3000 Hz – 88 dB | 12700 Hz – 84 dB |
| T150-600 | 6200 Hz – 91 dB | No noise |
| T800 | No noise | No noise |
| T200-2000 | 12700 Hz – 99 dB<br>9300 Hz – 105 dB | 1750 Hz – 97 dB |
| T150-600/C-THERM™ | No noise | No noise |

Conclusions:

- Graphite has positive effect on noise reduction.
- T graphite (especially T800) gives lower noise compared to KS graphite.
- C-THERM™ special graphite has no negative effect on the occurrence of squeal and shows good noise behavior in combination with T150-600.



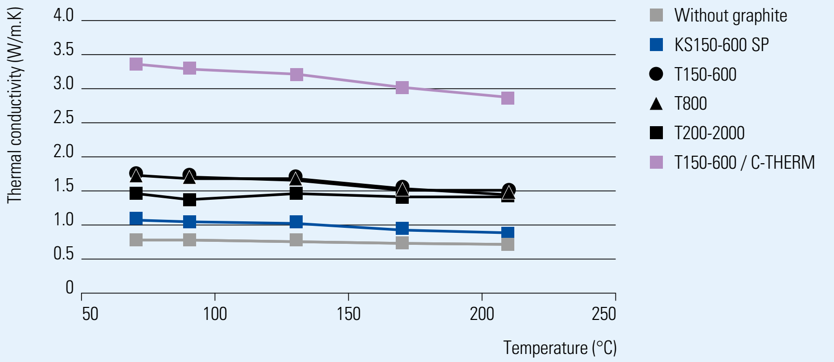

● > 80 dB
● 60 dB < 80 dB
● < 60 dB

Copper and Copper alloys are present in both NAO and low-steel formulations as fibers and powders. Copper contributes to the friction stability, wear resistance, heat dissipation and noise damping of brake pads. There is no single material that can replace Copper, and Cu-free brake pad formulations have to be significantly modified in order to keep the same performance. Graphite has some similar functions as Copper, like high thermal conductivity for heat dissipation, stabilization of friction coefficient and wear reduction. In this section we'll discuss the effect of graphite on the thermal conductivity of brake pads.

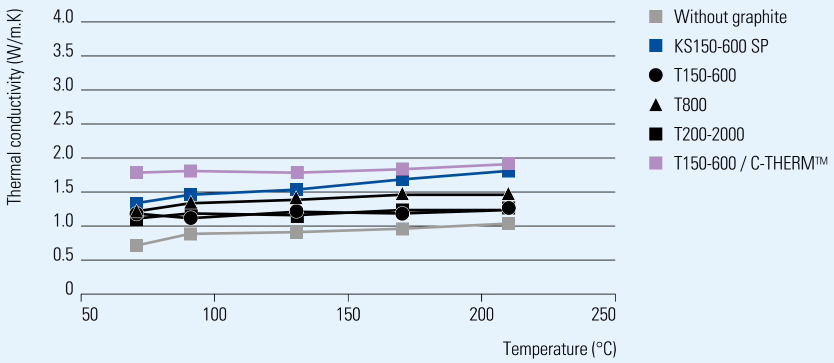
## NAO: SIMPLIFIED FORMULATION

From the brake pads, 10 × 10 × 3 $mm^3$ samples have been cut both parallel ("through-plane") and perpendicular ("in-plane") to the direction of compression for thermal conductivity measurements with Laserflash equipment (Netzsch LFA447, ASTM E1461).

**In-plane thermal conductivity**



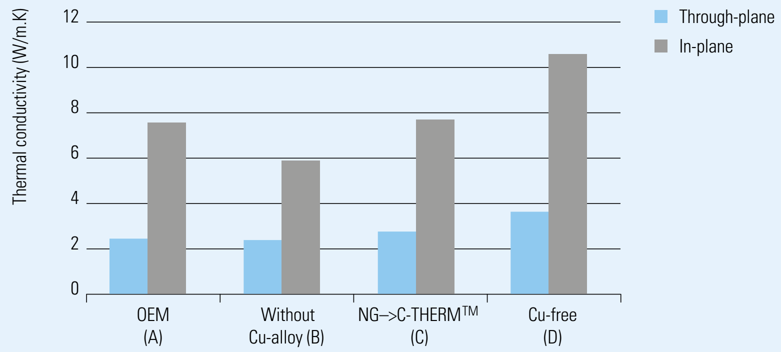

**Through-plane thermal conductivity**




- Graphite increases the thermal conductivity of brake pads.
- Particle size distribution (of T-type synthetic graphite) has small influence of on thermal conductivity.
- Synthetic graphite T150-600 gives higher in-plane / lower through-plane thermal conductivity compared to synthetic graphite KS150-600 SP.
- C-THERM™ special graphite clearly outperforms all other graphite types in terms of thermal conductivity.
- The high thermal conductivity anisotropy of brake pads containing C-THERM™ is beneficial for an efficient heat dissipation without overheating of caliper and brake fluid.



## LOW STEEL: MODIFIED OEM FORMULATION




- Replacement of natural graphite with C-THERM™ can compensate the loss of thermal conductivity in the formulation without Cu-alloy.
- Increased amount of graphite and C-THERM™ overcompensate the thermal conductivity of Copper in Copper-free formulation (D).

## LITERATURE REFERENCES AND ACKNOWLEDGMENTS

Imerys graphite and carbon has recently published the following works in collaboration with its partners:

[1] R. Gilardi , L. Alzati et alii, «Copper Substitution and Noise Reduction in Brake Pads: Graphite Type Selection», Materials 2012, 5, 2258-2269.
[2] R. Gilardi, L. Alzati et alii, «Selection of Graphite types for optimizes friction materials", SAE Brake Colloquium 2012, San Diego CA (USA).
[3] R. Gilardi, L. Alzati et alii, "Copper Substitution and Noise Reduction in Brake Pads addressed by Graphite Type Selection", Eurobrake 2013, Dresden (Germany).
[4] R. Gilardi, D. Sarocchi, L. Alzati, "Copper substitution and improved wear resistance at high temperatures in OEM friction formulations by means of graphite-based products", SAE Brake Colloquium 2013, Jacksonville FL (USA).
[5] R. Gilardi, D. Sarocchi, L. Alzati, "Carbon-Based Products for Copper-Free Low-Steel Brake Pads", Eurobrake 2014, Lille (France).
[6] R. Gilardi et alii, "Green automotive brake pads based on graphite powders", ASIATRIB 2014, Agra (India)

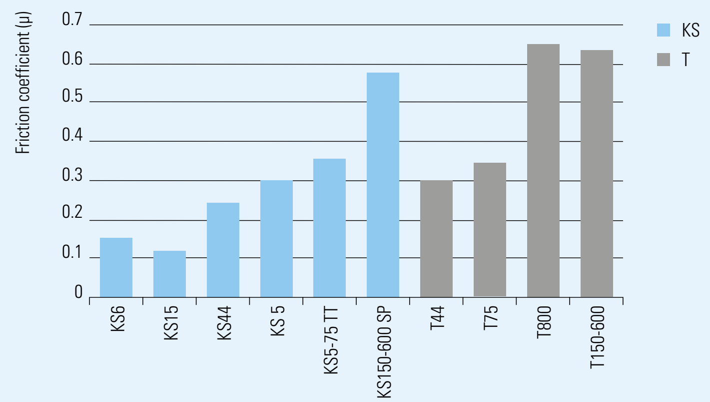
Imerys graphite and carbon would like to thank its partners for the data presented in this brochure.
In alphabetic order:
Indian Institute of Technology, New Delhi (India) – professor Jayashree Bijwe (www.iitd.ac.in);
Laboratoire de Mécanique de Lille (France) – professor Philippe Dufrénoy (http://lml.univ-lille1.fr);
Raicam Group – Ing. Davide Sarocchi (www.raicam.it).

**COPPER SINTERED FRICTION MATERIALS**

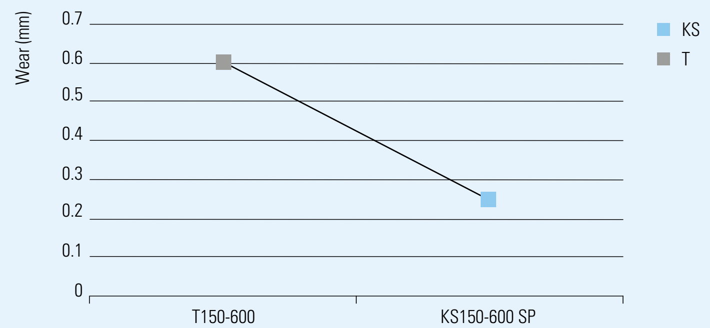
Imerys Graphite & Carbon can supply a large variety of particles size distributions to satisfy the demands of Copper sintered friction material performance. Also, graphite powders showing different levels of compressibility are available (see KC-materials, pag. 15).

In order to investigate the effect of particles size distribution on friction coefficient, Copper and graphite/coke have been mixed (90% Copper, 10% carbon), pressed and sintered for 3 hours at 850 °C (sintered density: 55% of theoretical density). The Cu-C sintered specimen (disc with diameter=37 mm and height=18 mm) have been tested on a gyrating mass dynamometer at constant speed (42 km/h) and constant pressure (67 N/cm²). Friction coefficient and wear have been measured.

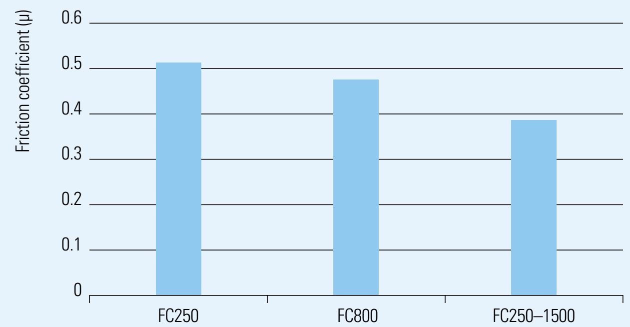
**Friction coefficient as a function of the particle size distribution of graphite**




**Wear resitance as a function of the graphite type**




**Effect of particles size distribution of Coke on friction coefficient**

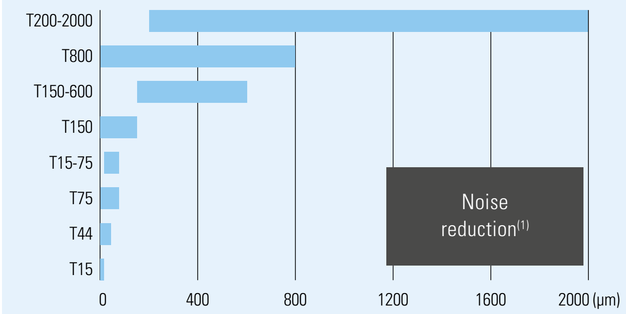


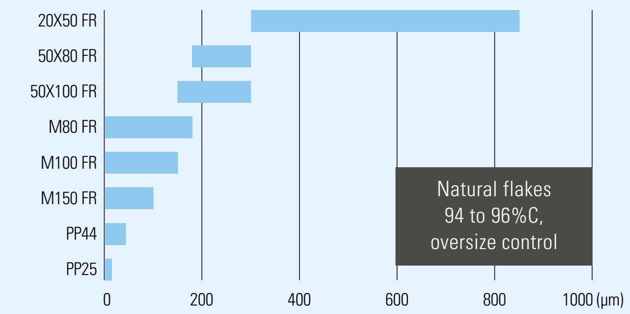


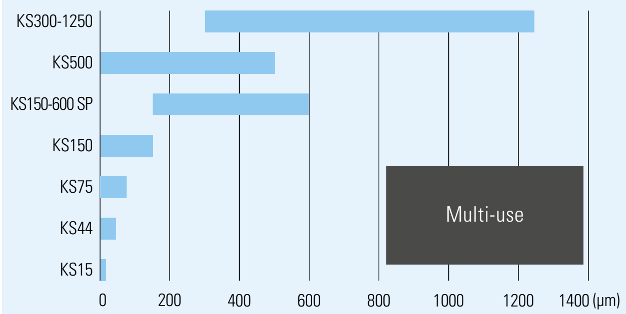


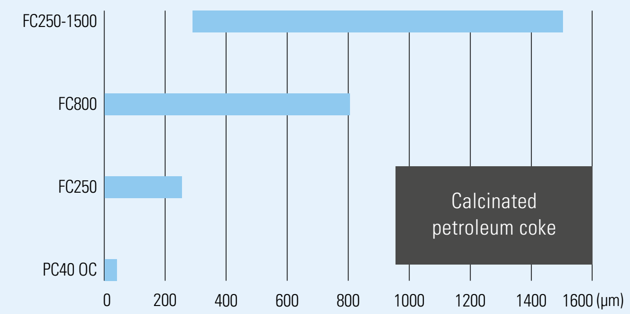

| | | | FRICTION MATERIALS | |
|---|---|---|---|---|
| | | %C min. | Resin/paper bonded | Copper sintered |
| Primary synthetic graphite | T | 99.9% | ○ | |
| | KS | 99.9% | ○ | ● |
| | KC | 99.9% | ● | ○ |
| Natural graphite flakes | | 94.0 - 96.0% | ○ | ○ |
| Petroleum coke | | 99.5 - 99.7% | ○ | ○ |
| C-THERM™ | | 97.5 - 99.7% | ○ | |

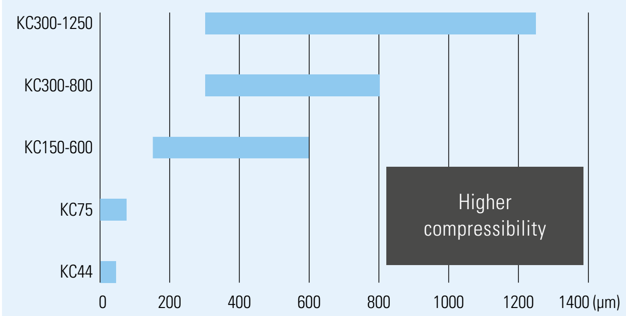
○ Especially recommended ● Recommended




**Carbon based solutions for increased wear resistance:**

C-THERM™001
C-THERM™011
(Patent pending)

Copper free friction materials[1]

Hot-spots reduction

Heavy-duty friction materials

IMERYS
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