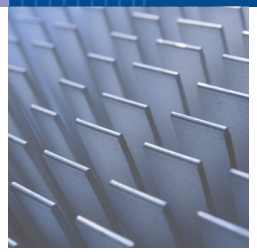
SPECIALTY CARBONS FOR **THERMALLY CONDUCTIVE POLYMERS**

TIMREX® Graphite

TIMREX® C-THERM™ Graphite

ENSACO® Carbon Black



IMERYS

IMERYS GRAPHITES & CONDUCTIVE CARBON BLACKS

THERMAL MANAGEMENT SOLUTIONS FOR YOUR POLYMER COMPOUNDS

METAL REPLACEMENT

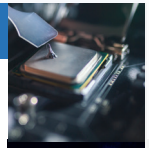
Plastics are used as metal replacements in a growing number of applications due to the following key advantages:

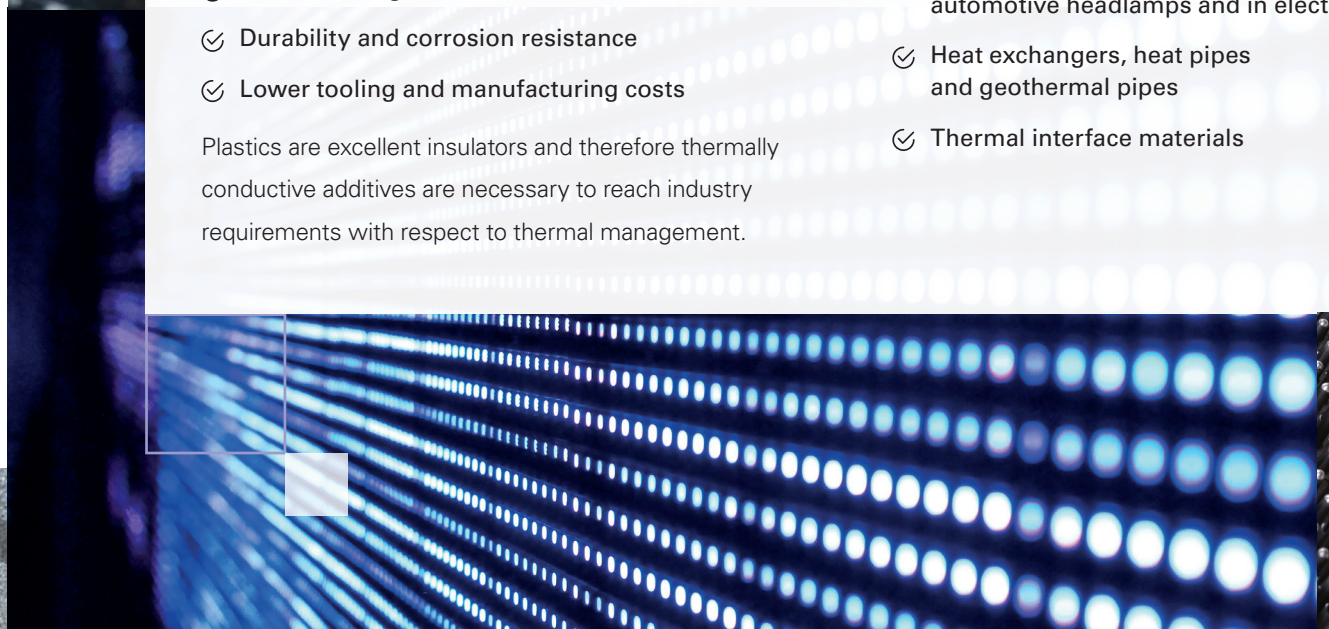
- Light-weighting
- Enables complex design geometries
- Function integration
- Durability and corrosion resistance
- Lower tooling and manufacturing costs

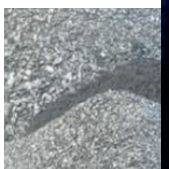
Plastics are excellent insulators and therefore thermally conductive additives are necessary to reach industry requirements with respect to thermal management.

Graphite-based solutions are high performance and cost effective additives for customized thermally conductive polymers and compounds in a wide range of applications such as:

- Heat sinks for LEDs in lighting, automotive headlamps and in electronics
- Heat exchangers, heat pipes and geothermal pipes
- Thermal interface materials



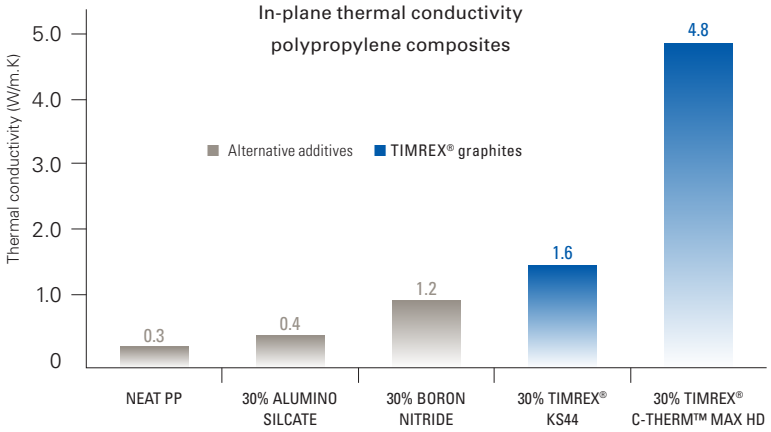




IMERYS GRAPHITE & CARBON SOLUTIONS FOR THERMALLY CONDUCTIVE POLYMERS

GRAPHITE, AN ADDITIVE WITH HIGH THERMAL CONDUCTIVITY

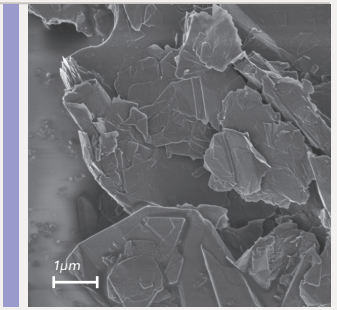
The following charts demonstrate the performance of graphites compared to alternative mineral solutions.



Polymer: Polypropylene
Compounding: Twin screw extrusion
Processing: Injection molding
Thermal conductivity measured by laser flash

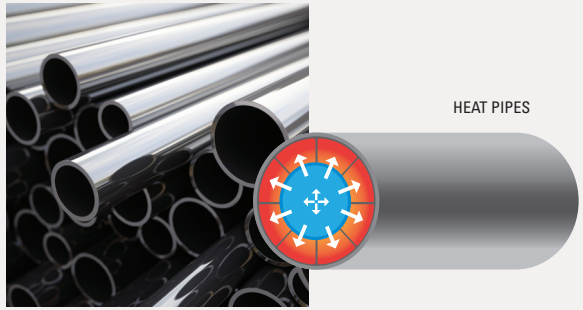
For most applications, the high thermal conductivity performance of metals is not necessary. Other thermal management factors such as convection heat transfer (air cooling) are prevalent.

Thermal conductivity targets are dependent on the application. Optimised part design, cooling technology as well as an appropriate choice of conductive additive is key to reach the different application requirements.

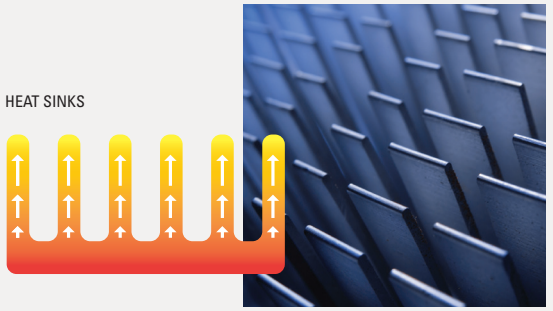


TIMREX® KS Primary Synthetic Graphite

Through-plane



In-plane



RANGE OF GRAPHITES TO MEET DIFFERENT PERFORMANCE TARGETS

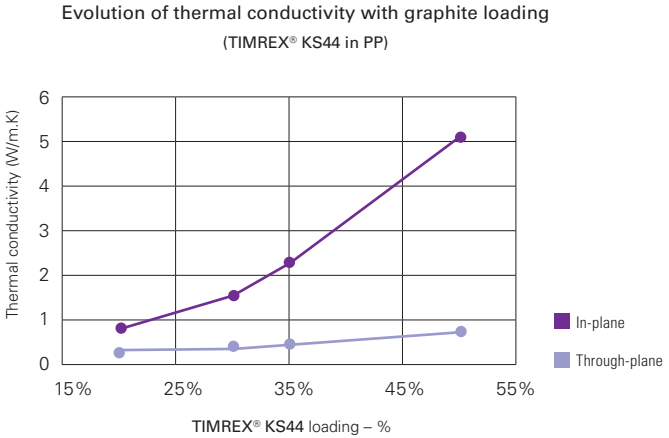
ANISOTROPIC VERSUS ISOTROPIC GRAPHITES

Imerys Graphite & Carbon produces a wide range of graphite grades with varying particle sizes and morphologies ranging from flaky, highly anisotropic graphites for high in-plane thermal conductivity to rounded, more isotropic graphites for high through-plane thermal conductivity.

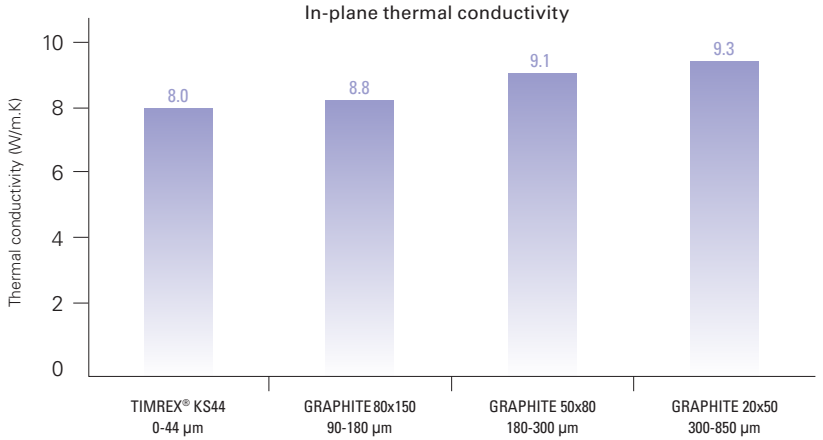
Our synthetic graphites are high purity materials, free of microcrystalline silica, suitable for the most sensitive applications. We have the expertise and work closely with our customers to find the best graphite solution to meet their thermal conductivity and mechanical property targets.

The thermal conductivity of a graphite-loaded compound:

- Increases exponentially with increasing graphite loading (graph, below)
- Increases with increasing graphite particle size (bar chart, right)

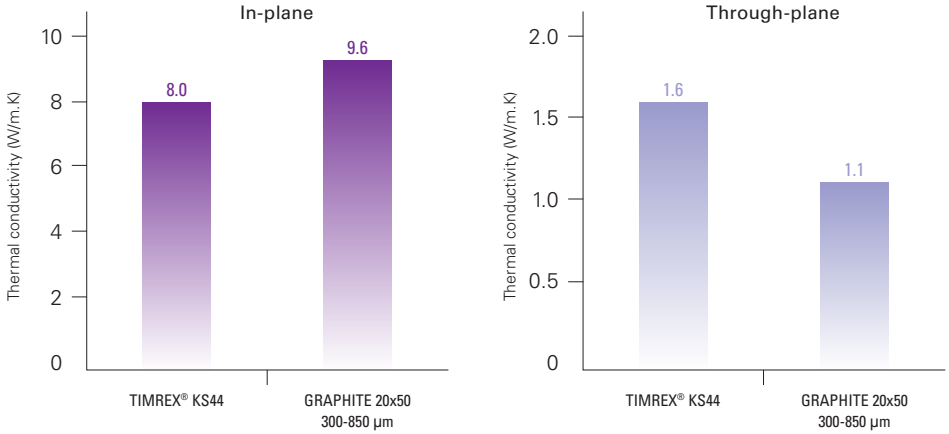


Polymer: Polypropylene copolymer *Processing: Injection molding*
Compounding: Twin screw extrusion *Thermal conductivity measured by laser flash*



Polymer: PP copolymer with 60% graphite *Processing: Compression molding*
Compounding: Twin screw extrusion *Thermal conductivity measured by laser flash*

For applications where high in-plane thermal conductivity is required, such as heat sinks or heat diffusers, highly flaky and highly crystalline natural and synthetic graphites should be favoured. Whereas in applications where high through-plane thermal conductivity is targeted such as heat exchangers and heat pipes, shaped synthetic graphites that are more rounded and isotropic are preferred.

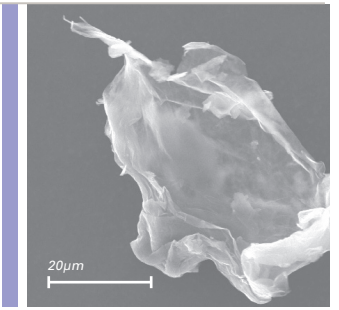


Polymer: HDPE with 60% graphite *Processing: Injection molding*
Compounding: Twin screw extrusion *Thermal conductivity measured by laser flash*

IMERYS TIMREX® C-THERM™ HIGH ASPECT RATIO GRAPHITE, YOUR SOLUTION FOR LIGHTWEIGHTING

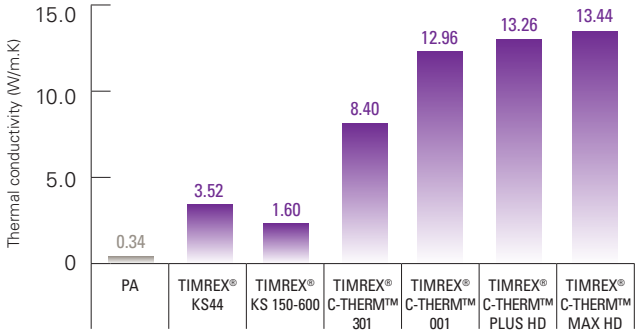
HIGH THERMAL CONDUCTIVITY AT LOW LOADING

The TIMREX® C-THERM™ family consists of high aspect ratio graphites specifically developed to provide superior thermal conductivity even at low loadings. Typically, to achieve a given level of thermal conductivity, half the loading of TIMREX® C-THERM™ is required compared to standard graphite solutions. The advantage of this is it allows for greater freedom in the final formulation design.



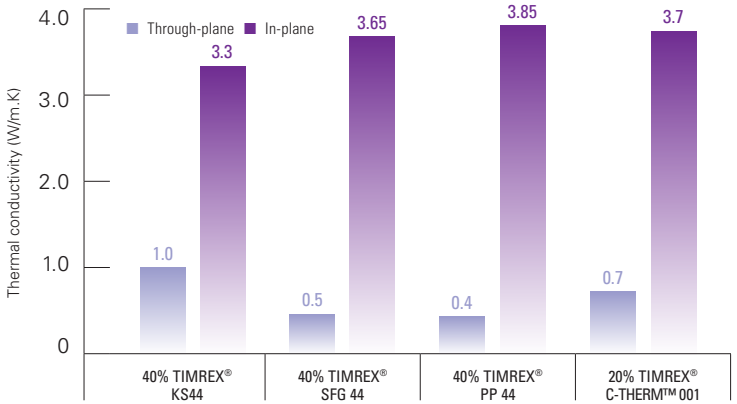
TIMREX® C-THERM™

In-plane thermal conductivity – PA6 composites



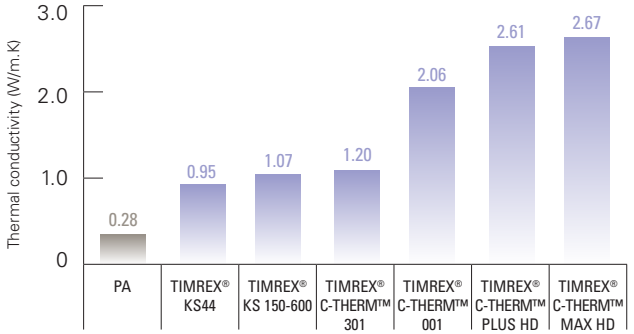
Polymer: Polyamide with 30% graphite
Compounding: Twin screw extrusion
Processing: Injection molding
Thermal conductivity measured by laser flash

Thermal conductivity – HDPE composites



Polymer: HDPE
Compounding: Twin screw extrusion
Processing: Injection molding
Thermal conductivity measured by laser flash

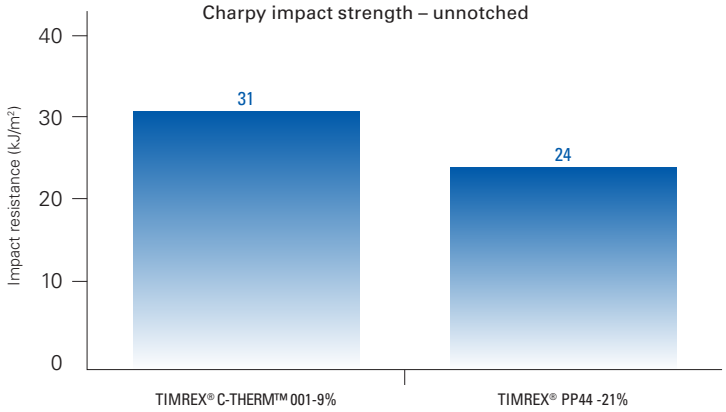
Through-plane thermal conductivity – PA6 composites



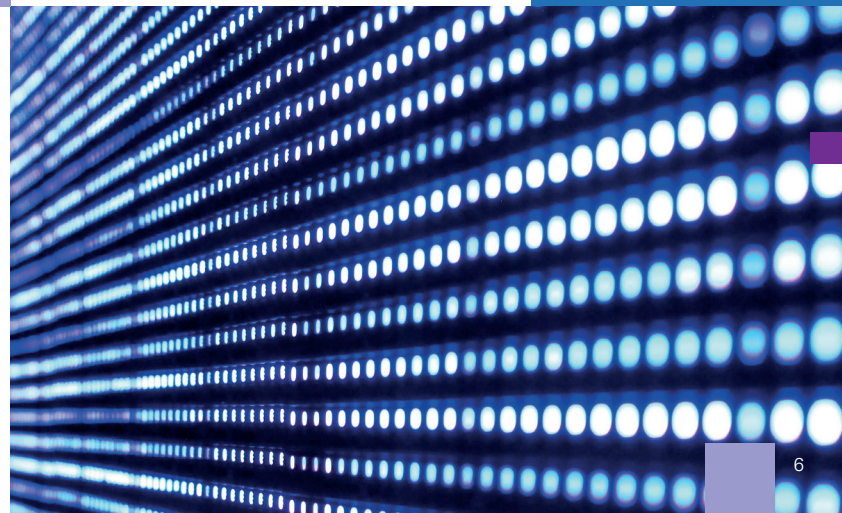
Polymer: Polyamide with 30% graphite
Compounding: Twin screw extrusion
Processing: Injection molding
Thermal conductivity measured by laser flash

Replacing standard graphite with TIMREX® C-THERM™ high aspect ratio graphite, allows for the reduction of the carbon content loading typically by 50%, resulting in the same level of thermal conductivity while ensuring better mechanical performance.

ALIPHATIC POLYKETONS, REINFORCED WITH GLASS FIBER	TENSILE STRENGTH (MPa)	TENSILE MODULUS (MPa)	ELONGATION AT BREAK (%)	IMPACT STRENGTH (CHARPY UNNOTCHED) (kJ/m^2)
TIMREX® C-THERM™ 001-9%	103	8000	2.15	31
PP44-21%	103	10000	2.15	24



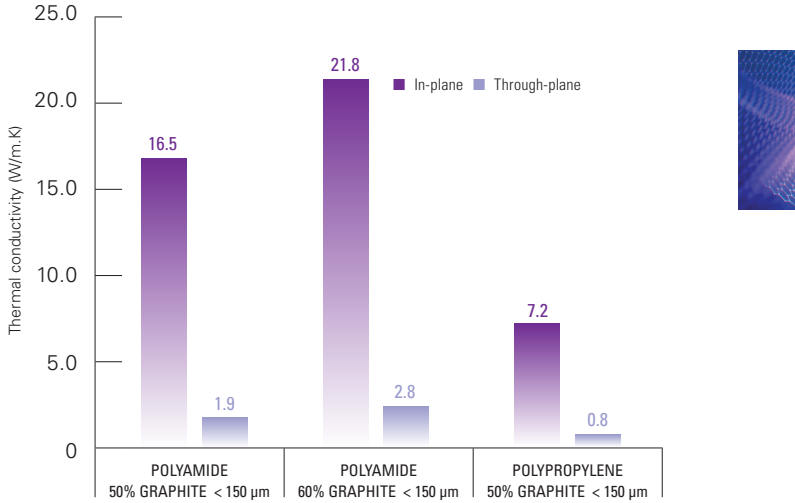
Polymer: Glass fiber reinforced aliphatic polyketones
Compound: Twin screw extrusion
Processing: Injection molding
Thermal conductivity measured by laser flash



OPTIMIZING THERMAL CONDUCTIVITY WITH APPROPRIATE SELECTION OF RESIN AND PROCESSING PARAMETERS

INFLUENCE OF POLYMER RESIN

The crystallinity and density of the polymeric resin directly influences the thermal conductivity performance of a graphite loaded compound. At the same graphite loading (in weight%), the volume percent of graphite will be higher in higher density resins which leads to higher thermal conductivity. This is illustrated in the chart on the right. The thermal conductivity of graphite-polyamide (higher resin density) compounds is higher than that of graphite-polypropylene (lower resin density) compounds at the same graphite loading (50 weight%).

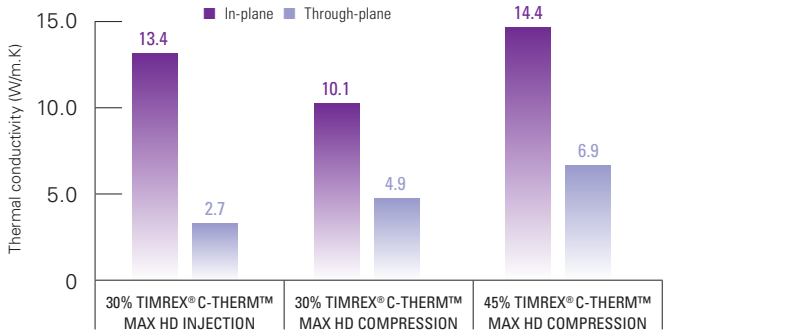


Polymer: Polyamide 6 and PP copolymer
Compound: Twin screw extrusion
Processing: Injection molding
Thermal conductivity measured by laser flash

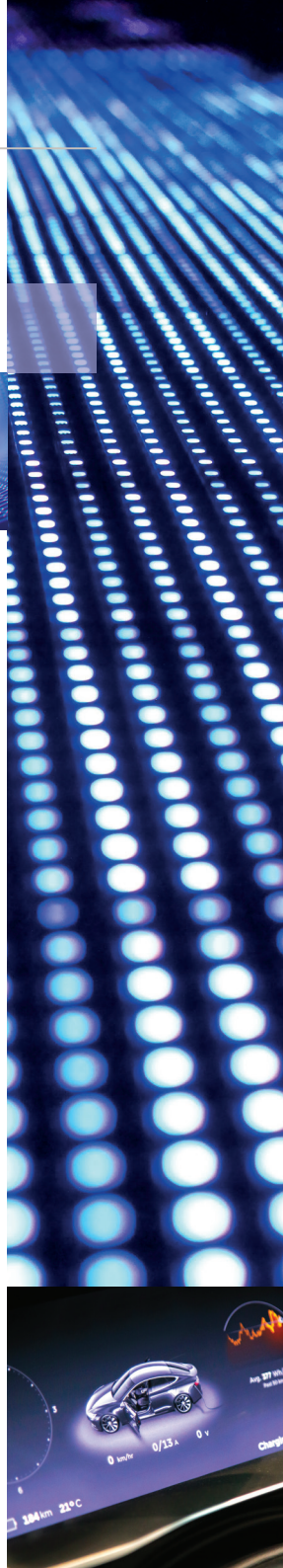
INFLUENCE OF PROCESSING

Optimised compounding parameters are key to reach excellent graphite dispersion in the polymeric matrix for the highest thermal conductivity performance.

The final processing step plays a large role in the orientation of graphite particles in the polymeric matrix, defining the thermal conductivity anisotropy in the final part. For example, injection molding leads to higher orientation of graphite particles, thus producing highly anisotropic compounds with high in-plane thermal conductivity. Lower graphite particle orientation in compression molding is favourable for superior through-plane thermal conductivity.



Polymer: PA6
Compound: Twin screw extrusion
Processing: Injection or compression molding
Thermal conductivity measured by laser flash

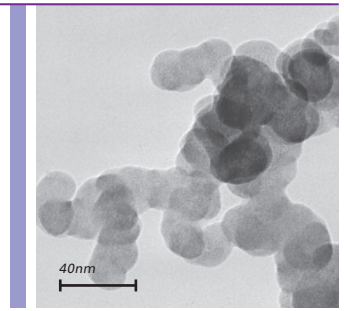


ENSACO® FOR HIGH THERMAL CONDUCTIVITY WHILE MAINTAINING EXCELLENT MECHANICAL PROPERTIES

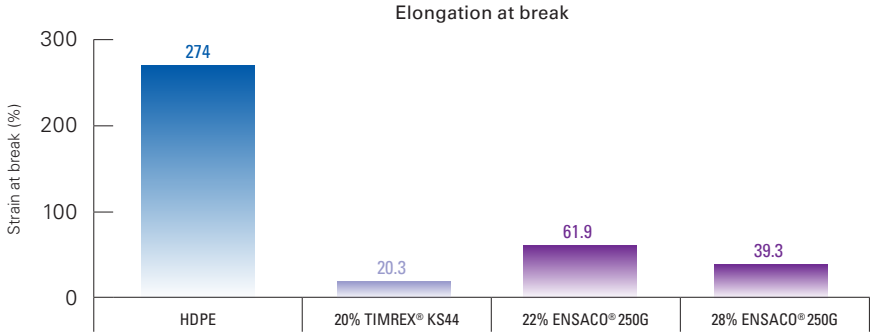
THE PERFECT BALANCE

ENSACO® conductive carbon blacks are characterised by high graphiticity, easy dispersibility and low surface area, making them an excellent choice to provide thermal conductivity while maintaining compound mechanical properties. In applications where high mechanical performance is critical, such as pressure pipes, ENSACO® provides the optimal balance between thermal conductivity and mechanical performance.

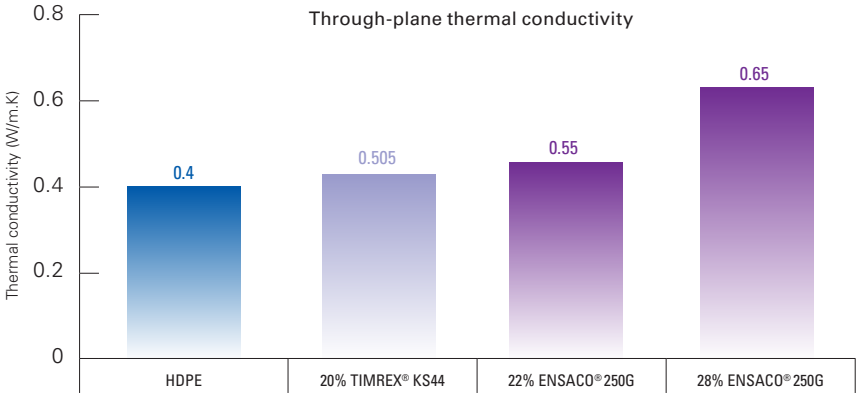
ENSACO® is an isotropic material and is therefore particularly interesting for applications where high through-plane thermal conductivity is required.



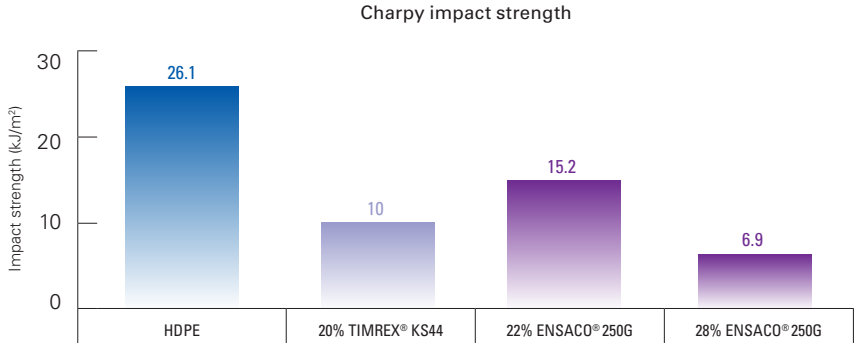
ENSACO® 250G



Polymer: HDPE
Compound: Twin screw extrusion
Processing: Injection molding
Thermal conductivity measured by laser flash



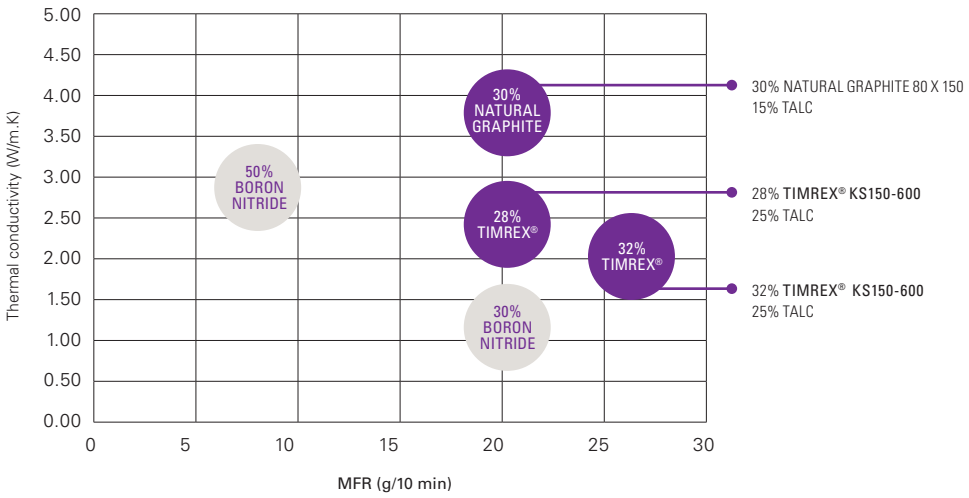
Polymer: HDPE
Compound: Twin screw extrusion
Processing: Injection molding
Thermal conductivity measured by laser flash



Polymer: HDPE
Compound: Twin screw extrusion
Processing: Injection molding
Thermal conductivity measured by laser flash

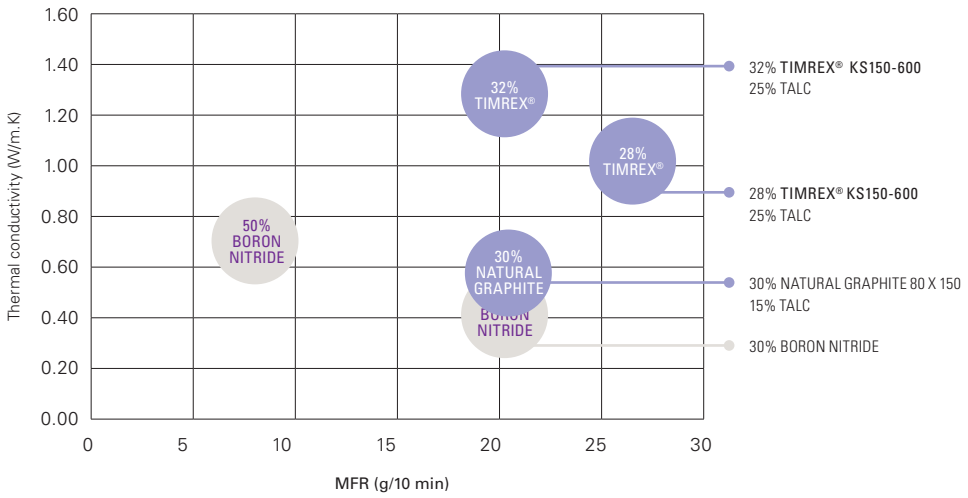
GRAPHITE AND MINERAL BLENDS FOR APPLICATIONS WHERE THERMAL CONDUCTIVITY AND ELECTRICAL INSULATION ARE CRITICAL

In-plane thermal conductivity versus melt flow rate



Polymer: PP *Processing: Injection molding*
Compound: Twin screw extrusion *Thermal conductivity measured by laser flash*

Through-plane thermal conductivity versus melt flow rate



Polymer: PP *Processing: Injection molding*
Compound: Twin screw extrusion *Thermal conductivity measured by laser flash*

Certain thermal management applications, especially in electronics, require compounds to provide both high thermal conductivity and electrical insulation for which oxides, silicates and/or boron nitride are used. These additives have the following drawbacks: high abrasiveness, limited thermal conductivity performance and high cost.

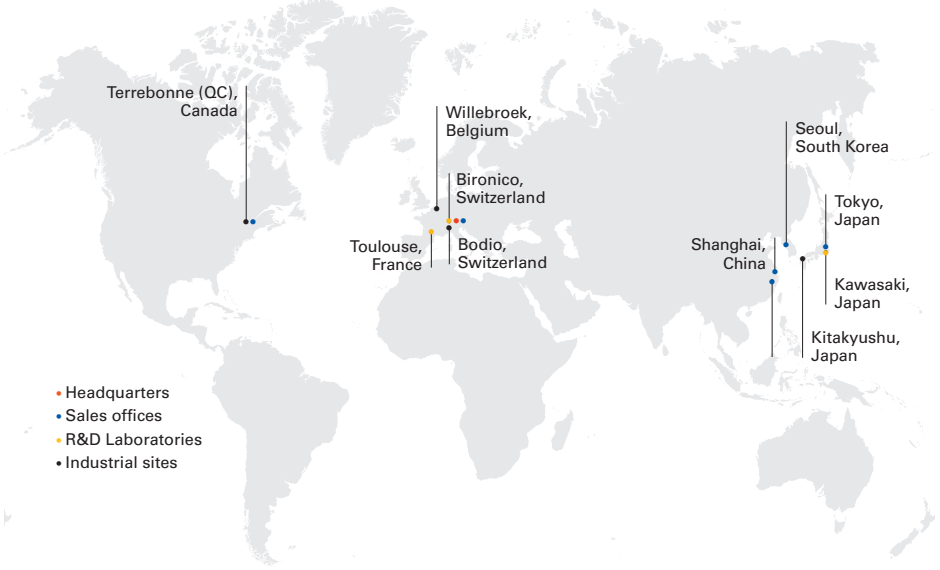
In applications where colourability is not required and where the compound can be grey or black, blends of graphite and selected minerals such as high aspect ratio **Imerys HAR® T77 talc** are a cost effective solution to provide high thermal conductivity while maintaining electrical insulation. Graphite/talc blends combine the high thermal conductivity performance as well as improved flowability, and electrical insulation.

RECOMMENDED GRAPHITE GRADES FOR THERMAL CONDUCTIVITY

GRADE	FORM	PARTICLE SIZE (APPROX)	ASH (%)	BET (m^3/g)	SCOTT DENSITY ASTM B329-98 (g/cm^3)	POUR DENSITY ASTM D1513 (kg/cm^3)
TIMREX® KS15	Graphite powder	D90<15 µm	0.1	12	0.10	–
TIMREX® KS44	Graphite powder	D90<44 µm	0.1	9	0.19	–
TIMREX® PP44	Graphite powder	D90<40 µm	4-6	4.8	0.11	–
TIMREX® C-THERM™ 301	Graphite powder	–	0.3	27	0.19*	–
TIMREX® C-THERM™ 001	Graphite nanoplatelet	–	0.3	25	0.19*	–
TIMREX® C-THERM™ 011	Graphite nanoplatelet	–	2.5	25	0.19*	–
TIMREX® C-THERM™ MAX HD	Graphite nanoplatelet	–	2.5	31	0.45*	–
TIMREX® C-THERM™ PLUS HD	Graphite nanoplatelet	–	2.5	21	0.45*	–
ENSACO® 250G	Carbon black soft granules	–	0.01	65	–	180

** Tap Density*

IMERYS GRAPHITE & CARBON – A STRONG, INNOVATIVE COMPANY.



With production sites in Europe, Canada and Japan and sales offices in Europe, America and throughout Asia we can ensure security of supply and an optimal customer experience.

OUR EXPERTISE

Imerys Graphite & Carbon is a global company focused on delivering carbon based solutions for manufacturing and industry.

We have over 100 years of experience in the development and production of a wide variety of high quality synthetic and natural graphite powders, conductive carbon blacks, silicon carbide and water based dispersions for various end applications including, but not limited to:

- Lithium-ion Batteries
- Alkaline Batteries
- Lead Acid Batteries
- Fuel Cells
- Conductive Polymers, Plastics and Rubbers
- Carbon Brushes
- Brake Pads and Clutches
- Powder Metallurgy and Hard Metals
- Refractories

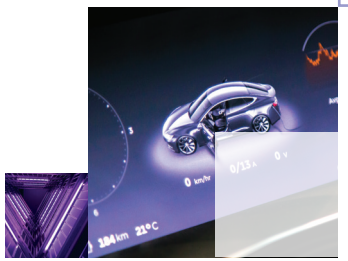
Our team of over 500 experienced professionals ensures we deliver optimal solutions for the technical challenges faced by our customers making us the market leader for:

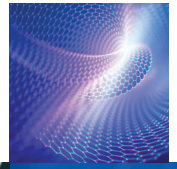
- Conductive carbon blacks and graphites for lithium-ion batteries
- Graphites for alkaline batteries
- Graphites for resin bonded carbon brushes
- Conductive carbon blacks for conductive polymers

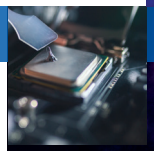
IMERYS GROUP

Imerys Graphite & Carbon belongs to Imerys Group, the world leading supplier in mineral based specialties for industry.

The Group draws on its understanding of applications, technological knowledge and expertise in material science to deliver solutions based on beneficiation of its mineral resources, synthetic minerals and formulations. These contribute essential properties to customers' products and their performance, including heat resistance, hardness, conductivity, opacity, durability, purity, lightness, filtration, absorption and water repellency.







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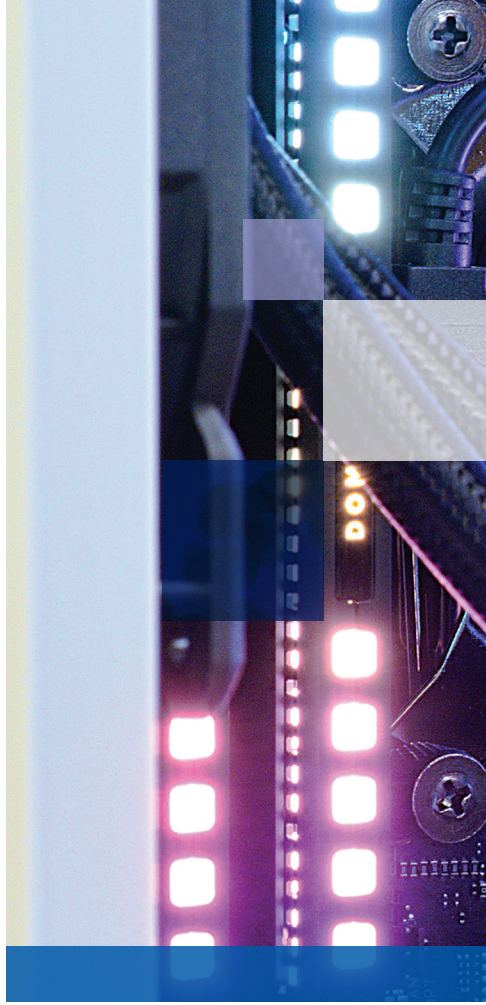

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