

# Thermal Enhancements Using Graf+® Graphite Powders & Graf-X™ Graphene Nanoplatelet (GNP) Additives



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### Overview

This document aims to provide readers with a comprehensive understanding of NeoGraf Solution's Graf+® micronized graphite powders and Graf-X™ graphene nanoplatelets and their impact on thermal conductivity properties in foam materials. The following pages offer an overview of the foam types discussed in this paper, as well as an explanation of thermal conductivity and how NeoGraf powders enhance the thermal performance of these foams. Additionally, we will delve into topics such as graphite and graphene, foam materials, principles of thermal conductance, and suitable application methods.

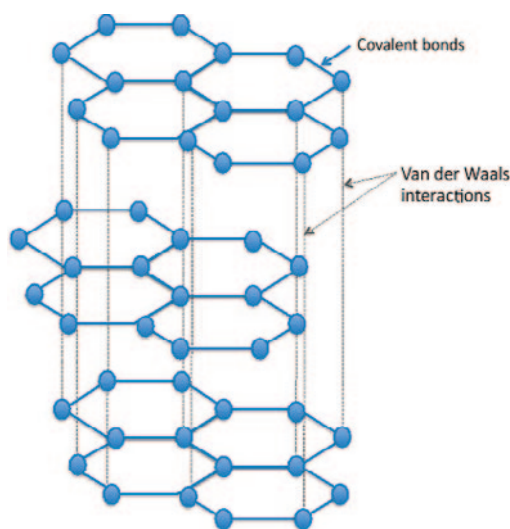
### Graphite and Graphene Nanoplatelet - Definitions and Products

The nanomaterial industry has witnessed confusion surrounding the distinction between graphene and graphite since the initial synthesis of graphene. Graphite, an allotrope of carbon, is classified as a mineral, known for its platelike crystal structure and anisotropic thermal conductivity properties.

The International Organization of Standardization (ISO) describes the differences between graphite, graphene, and nanoplatelets.

- **Graphene:** single layer of carbon atoms with each atom bound to three neighbors in a honeycomb structure
- **Nanoplatelet:** nano-object with one external dimension in the nanoscale and the other two external dimensions significantly larger
- **Graphite:** allotropic form of the element carbon, consisting of graphene layers (3.1.2.1) stacked parallel to each other in a three dimensional, crystalline, long-range order<sup>1</sup>

It is crucial to emphasize that graphene is a single layer of atoms. Figure 1 shows different layers of graphene, stacked upon each other to make a larger graphite structure, with the individual graphene layers bonding to each other via weaker, secondary Van der Waals interactions<sup>2</sup>:



— Figure 1 —

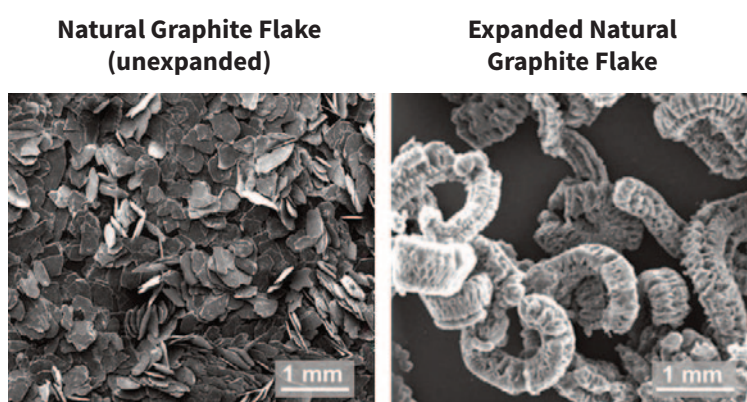
Since synthesizing a single atomic layer of a substance is extremely difficult, slow, and expensive, and applications for such a substance are incredibly niche, we can conclude that much of what is read about graphene is not technically graphene as defined by ISO. This also does not cover the multitude of different graphene synthesizing methods, differences in graphite from different mine sources, and various categorization methods that can be used on the final material to map differences between density, surface chemistry, surface area, crystallinity, purity, etc.

<sup>1</sup> <https://www.iso.org/obp/ui/#iso:std:iso:ts:80004:-13:ed-1:v1:en>

<sup>2</sup> <https://www.sciencedirect.com/topics/materials-science/graphite>

Graphene is a single atomic layer of graphite, a nanoplatelet is a series of graphene layers in a stack with a high aspect ratio, and graphite is many, many layers of graphene stacked upon one another. It is important to note that the method of processing NeoGraf uses is considered a “top-down” approach, meaning all products come from the most pristine and naturally occurring mine-sourced graphite. All the products are derived from this natural flake graphite, preserving its molecular structure without gaps in the monolayer lattices, enhancing mechanical properties.

For thermal enhancements in foam materials, we utilize two primary powder product families: Graf+ fine graphite flake powders and Graf-X graphene nanoplatelets. These products come in various sizes and shapes. Within the Graf+ family, we have natural graphite (NG) flake and expanded natural graphite (ENG) as shown in Figure 2. The term “expanded” refers to a process involving acid compound intercalation followed by thermal treatment, resulting in the exfoliation or expansion of natural graphite flakes into lower-density, more dendritic particles, which are then milled and classified for size. Figure 3 displays the typical properties of the Graf+ micronized graphite materials, while figure 4 displays the typical properties of the Graf-X nanoplatelet materials.



— Figure 2 —

The technical specifications of these two material categories are shown in Figure 3.

Typical Properties								
Property	Unit	Flake Natural Graphite Grades (NG)						
		Graf+ 4-A-NG	Graf+ 8-C-NG	Graf+ 10-A-NG	Graf+ 25-A-NG	Graf+ 25-C-NG	Graf+ 100-C-NG	Graf+ 200-C-NG
Ash	%	<0.5	<5	<0.5	<0.5	<5	<5	<5
Typical Particle Size								
D10	microns	1.2	2	5	11	11	20	80
D50	microns	4	8	10	25	25	100	200
D90	microns	9	25	20	47	47	180	400
Scott Density	g/ml	0.09	0.15	0.08	0.11	0.11	0.11	0.35
BET Surface Area	m <sup>2</sup> /g	16	13	7	4	4	3	1
Moisture	%	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Typical Properties							
Property	Unit	Expanded Natural Graphite Flakes (ENG)					
		Graf+ 10-A-NG	Graf+ 20-A-NG	Graf+ 40-A-NG	Graf+ 10-C-NG	Graf+ 20-C-NG	Graf+ 40-C-NG
Ash	%	<0.1	<0.1	<0.1	<5%	<5%	<5%
Typical Particle Size							
D10	microns	5	7	15	5	7	15
D50	microns	10	20	40	10	20	40
D90	microns	27	47	100	27	47	100
Scott Density	g/ml	0.06	0.06	0.07	0.06	0.06	0.07
BET Surface Area	m <sup>2</sup> /g	20	18	16	20	18	16
Moisture	%	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

— Figure 3 —

Naming convention is as follows (ex: 10-A-ENG): # = D50 Micron particle size, A/B/C = carbon purity content (A=99.9+%, B=97+%, C=95+%), E/NG = Expanded/Natural Graphite

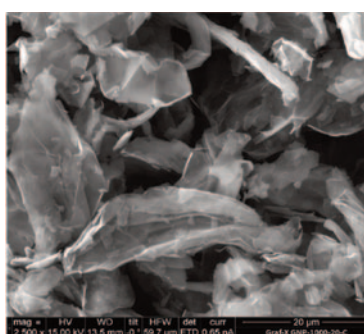
Graf-X graphene nanoplatelets, on the other hand, are more so categorized by number of graphene layers (1 graphene = 1 atomic monolayer of graphite), as well as their lateral dimensions.

Typical Properties				
Characteristic	Unit	Graf-X™ GNP-1000	Graf-X™ GNP-2000	Graf-X™ GNP-3000
Specific Surface Area	m <sup>2</sup> /g	15-20	30-40	11-17
Purity (Carbon Content)	%	99+, <99>97, <97>92, <92	<97>92	99+, <99>97
Average Lateral Dimension	µm	10, 20, 40	5, 10, 20, 50	
Scott Density	g/cm <sup>3</sup>	0.05-0.09	0.08-0.2	
Oxygen Content	%	0.2-0.3	0.9-3.3	
Number of Graphene Layers		<200	<100	<10

— Figure 4 —

Naming convention is as follows (ex: GNP-2000-40-B): 1/2/3000 = Series, # = Average Lateral Dimension, A/B/C = carbon purity

**SEM Image of Graphene Nanoplatelets**

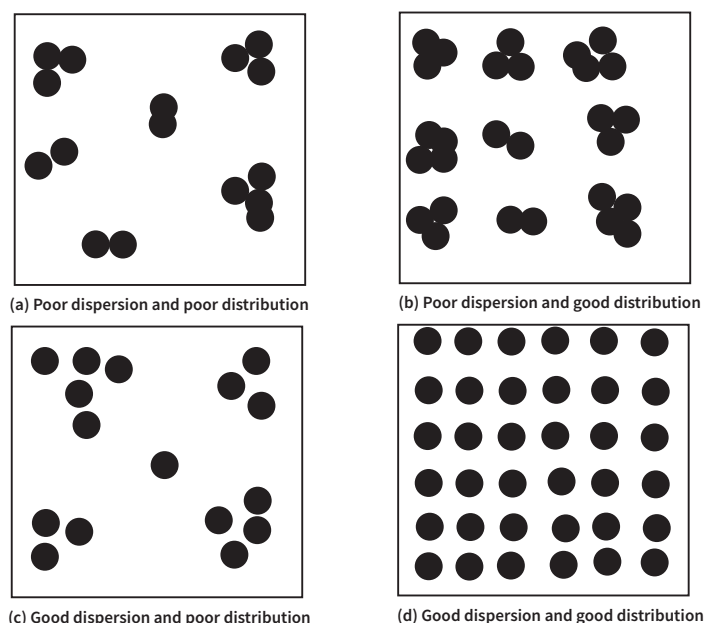


— Figure 5 —

### Importance of Dispersion and Distribution

Achieving desired results with graphite or GNP powders involves more than simply stirring them into a base resin. Proper incorporation is crucial, typically achieved through high shear mixing. Longevity and intensity of mixing are essential factors, with our applications typically involving speeds around 2,000 RPM. It is recommended to use the freshly dispersed mixture promptly to prevent premature settling of the material.

Ongoing validation of promising functionalization techniques aims to enhance dispersion stability (i.e., shelf life) before application. Several academic studies have already documented appropriate dispersion techniques, emphasizing the distinction between dispersion and distribution. Low-shear mixing can achieve good distribution but poor dispersion of graphite and GNP powders. To achieve both dispersion and distribution, additional energy from high shear mixing is required to break up agglomerations, as depicted in Figure 6.<sup>3</sup> Our test have shown that poor dispersion may yield negligible improvements or even worse performance to the control materials.



— Figure 6 —

It is also crucial to consider particle size and processing. These powders exhibit low density and high surface area, meaning particle size affects processing. In general, smaller particles have a more significant impact on the resin's viscosity. Sometimes, a combination of particle sizes helps achieve the desired filler loading level while minimizing the effect on viscosity. NeoGraf has conducted numerous tests to evaluate appropriate powder grade and loading level, enabling us to determine ideal processing parameters based on the desired thermal properties.

### Thermal Conductivity Basics

#### Definitions

Thermal conductivity refers to a material's ability to conduct or transfer heat. Heat transfer through conduction occurs when energy is transferred between different areas of a material without the material itself moving.

Conductivity arises when a temperature gradient exists in a solid or stationary fluid, resulting in heat flowing from higher to lower temperatures due to differences in molecular energy and movement. This paper focuses on graphite's thermal conductivity compared to other materials such as aluminum, gold, copper, silver, and diamond. It is essential to note the weight and density differences between graphite and these materials.

<sup>3</sup> [https://www.researchgate.net/publication/286430035\\_Acoustically-enhanced\\_particle\\_dispersion\\_in\\_polystyrenealumina\\_nanocomposites](https://www.researchgate.net/publication/286430035_Acoustically-enhanced_particle_dispersion_in_polystyrenealumina_nanocomposites)

Figure 7 shows the thermal conductivities of different commonly used materials at room temperature and pressure.

Material	Thermal Conductivity W/(m*K)
Air (still)	0.025
Water (liquid)	0.6
Stainless Steel	12 – 45
Lead	35.3
Aluminum (alloys)	120
Aluminum (pure)	237
Gold	318
Copper	380 – 401
Silver	429
Diamond	900 – 2320
Graphene (monolayer)	4840 – 5300

— Figure 7 —

Figure 8 displays commonly used materials to enhance thermal conductivity with the material's density.

Material	Density (g/cm <sup>3</sup> )
Aluminum (alloys)	2.64 – 2.81
Aluminum (pure)	2.7
Gold	18.31
Copper	8.96
Silver	10.49
Graphite	2.26
Diamond	3.51

— Figure 8 —

Regarding insulation, thermal performance is typically measured using R-values, which are derived from Lambda ( $\lambda$ ) values. Lambda values represent a product's thermal conductivity measured in units of W/mK or BTU (hr·ft·°F).<sup>4</sup>

R-values quantify a material's thermal resistance, reflecting the temperature difference between two defined surfaces of a material or construction that induces unit heat flow through a unit area.<sup>5</sup> In simpler terms, R-values indicate how effectively a material resists heat transfer (thermal conductivity) at a given thickness. Generally, R-values increase with thicker insulation. Utilizing Graf+ micronized powders and GNP nanoplatelet materials enhances the R-value of foam without increasing its thickness.

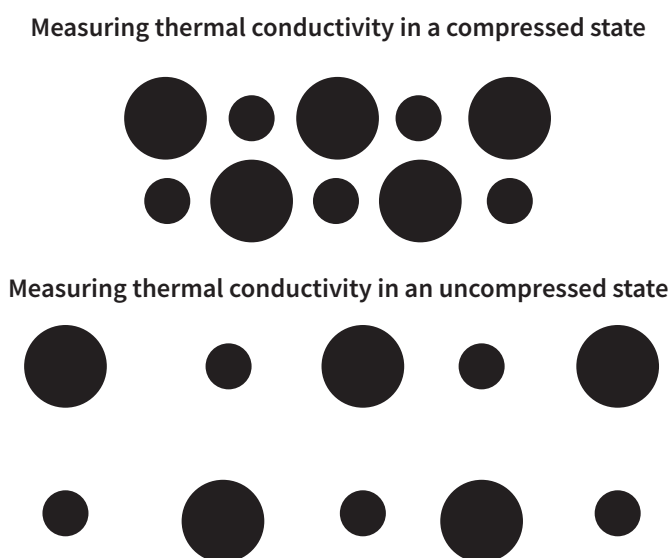
<sup>4</sup> <https://www.kingspan.com/gb/en/knowledge-articles/what-are-u-values-r-values-and-lambda-values/#:~:text=What%20is%20Lambda%20value%3F,possible%20to%20reduce%20heat%20loss>

<sup>5</sup> <https://insulation.org/io/articles/k-value-u-value-r-value-c-value/>

## Phonon Transport and Percolation Threshold

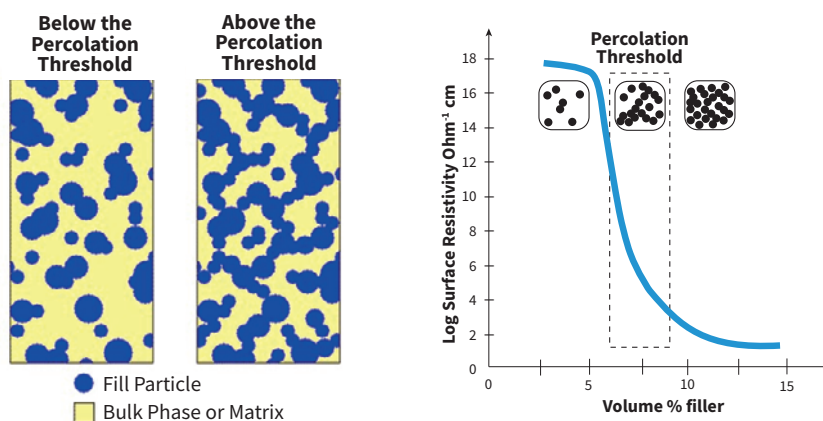
Distinguishing between electrical and thermal conductivity mechanisms is crucial. Thermal conductivity primarily relies on the transfer of heat through vibrational energy in the crystal lattice, known as phonons.<sup>6</sup>

Understanding vibratory energy transport is essential as it highlights the distinction between thermal and electrical conductivity. In electrical conductivity, particle proximity significantly affects conductivity by facilitating electron flow. Electric current flows across the surface of conductive particles. In contrast, thermal conductivity does not necessitate particles being as close to each other; thermal energy transfers through particles rather than on their surface. Consequently, thermal energy within a foam material, aided by the utilization of graphite and GNP powders, exhibits different values in compressed and uncompressed foam states due to changes in particle distance. Therefore, it is essential to document the foam state during thermal conductivity measurements. Figure 9 is a graphical depiction of the proximity of the particles in a compressed and non-compressed state, notice the difference in the spacing between particles.



— Figure 9 —

Percolation threshold is closely related to phonon energy transport. It denotes the minimum filler loading level required to achieve conductivity in a polymer medium. If the filler concentration falls below the percolation threshold, there is insufficient filler content in the polymer to create a conductive pathway. High particle crystallinity, a quality of natural graphite, also facilitates phonon transport. Once the percolation threshold is reached, a conductive pathway is established, leading to enhanced thermal conductivity, assuming proper dispersion and distribution of the filler. Figure 10 provides a visual representation of this concept.<sup>7</sup>



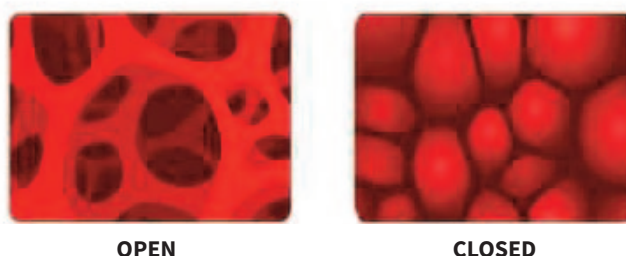
— Figure 10 —

<sup>6</sup> <http://web.mit.edu/nanoengineering/research/phonon.shtml>

<sup>7</sup> <https://polymerinnovationblog.com/thermal-interface-materials-part-four-how-to-achieve-high-thermal-conductivity/>

### Foam Material Basics

Industrial foam materials can be categorized as open cell or closed cell foams. The cell structures result from the foaming process of a liquid polymer resin, involving the introduction of a blowing agent or a reaction between chemistries. Regardless of the foam type, uniformity in cell structure is vital for quality control. Hence, thorough dispersion and distribution of graphite and GNP powder play a crucial role. Figure 11 illustrates the general differences between open and closed cell structures. Open cells are more permeable than closed cells. Closed cell foams typically have higher density and better water resistance than open cell foams.<sup>8</sup>



— Figure 11 —

The foam materials discussed in this paper are commonly used as insulation boards, valued in the building and construction industry for their thermal properties. NeoGraf has extensive experience with various foam technologies, including:

- Polyethylene (PE)
- Polyurethane (PUR)
- Polystyrene (PS, GPPS)
- Phenolic
- Polyolefin
- Polyisocyanurate (PIR)

#### Polyethylene Foam

Polyethylene foam is generally a closed-cell material with good vibration dampening and insulative properties. Typically, this type of foam is used for protective packaging of fragile or sensitive goods and automotive applications.



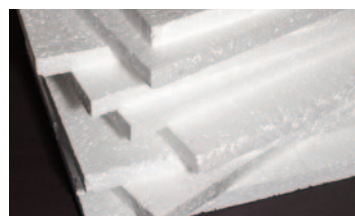
#### Polyurethane Foam

Polyurethane foam can be rigid or flexible, as well as open or closed cell. The foam is created by reacting polyols and di-isocyanates. Rigid polyurethane foam is typically used for thermal insulation. Flexible polyurethane foam is used for mattresses, furniture, car seats and other foam-based internal components, and similar types of comfort products. The process of generating the foam is a chemical interaction as opposed to the requiring of a blowing agent like the other foam technologies.



#### Polystyrene Foam

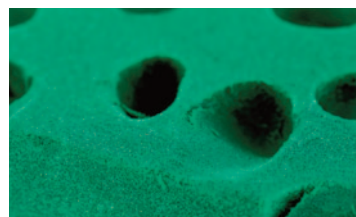
The type of polystyrene NeoGraf typically enhances are expanded polystyrene (EPS) and extruded polystyrene (XPS). XPS products (i.e. Sytrofoam) are typically used as closed-cell insulation boards for wall, roofs, and foundations. XPS foams are generated through a large-scale extrusion process generating slab-stock. This slab-stock can be cut into various thicknesses for the final application. EPS products are closed-cell and typically used for packaging and insulation applications. Expanded polystyrene foams generally first start as a bead, then are treated in a way to make the beads adhere to one another as they expand and form a desired shape in a mold.



<sup>8</sup> <https://blog.polytechinc.com/open-vs-closed-cell-foam-article/>

### Phenolic Foam

Phenolic foam is created by combining phenol-formaldehyde resin with a foaming agent, followed by adding a hardening agent which creates an exothermic reaction to activate the foaming agent. Typically, phenolic foam is used as insulation for pipework, fluid vessels, tanks, etc. Phenolic foam is typically rigid, closed-cell, and has low thermal conductivity. This material is also used for interior roofing insulation and top of the building applications where polystyrene or polyurethane do not provide enough insulation value. Phenolic foams are intrinsically fire retardant due to their high char yield from combustion.



### Polyolefin Foam

Polyolefin foam is made by utilizing a cross-linking agent and a blowing agent. Typical applications for polyolefin foam are interior casings for airplanes and automotive parts due to its light weight and good mechanical properties. Many engineered foams are based upon polyolefin foam precursors.

### PIR Foam

PIR foam is derived from combining polyols and isocyanates, and has natural flame and smoke resistance, functions as a low moisture barrier, and is generally rigid and closed-cell. PIR foam is typically used for insulating metal panels and plasterboard.



## Conclusion

NeoGraf Solutions has demonstrated experience in applying graphite and graphene powders into various foam technologies across several industries. NeoGraf has a dedicated team of product managers, application engineers, and research scientists who work directly on material science and application development. We continually enhance dispersion techniques to achieve greater success in implementing powders into customer projects. The Graf+ micronized powders and Graf-X nanoplatelets can be appropriately dispersed into most foam systems with significant performance improvements.

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### About NeoGraf Solutions

NeoGraf Solutions, a world leader in graphite materials science, has been manufacturing carbon and graphite products for over 140 years. Today, the company's high-performance products are used in a variety of demanding applications in a diverse array of industries. NeoGraf specializes in developing and manufacturing of high-quality natural and synthetic graphite sheets and powders used in the latest consumer electronic devices, building and construction materials, transportation, and sealing and gasketing. With internal research, development, and manufacturing capabilities, NeoGraf provides high-quality products, environmentally sustainable solutions, and new opportunities for our customers. For more information, visit [www.neograf.com](http://www.neograf.com).

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