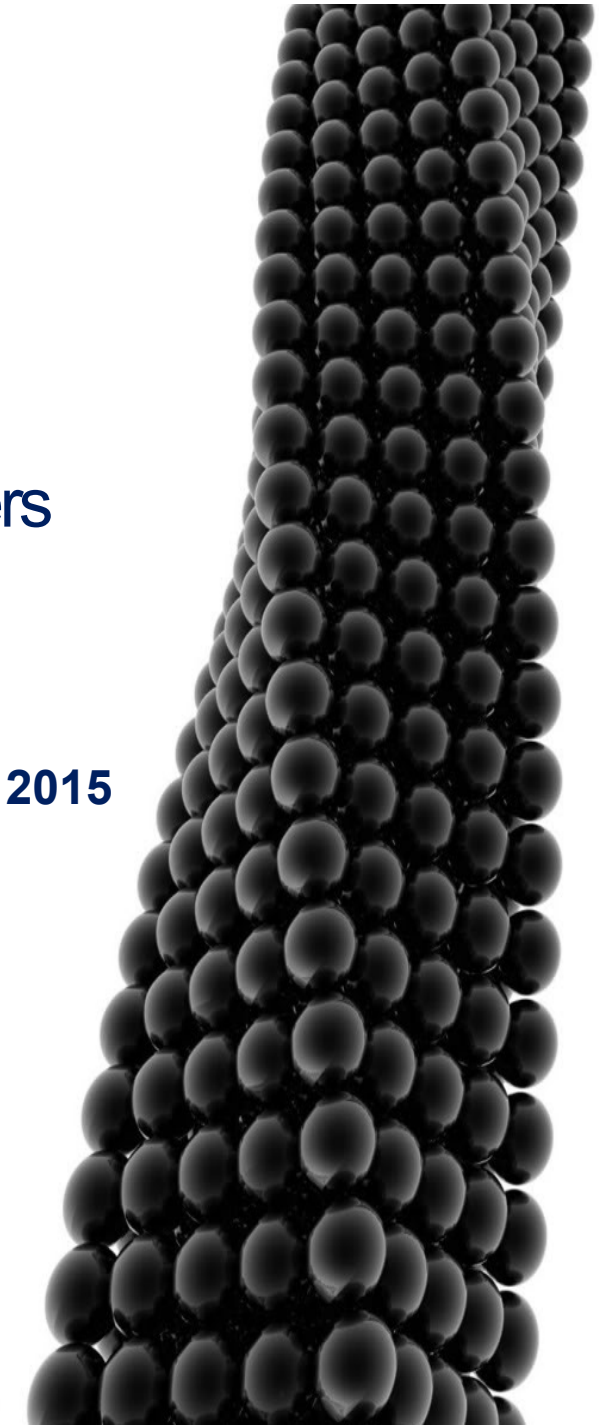
Valence Industries

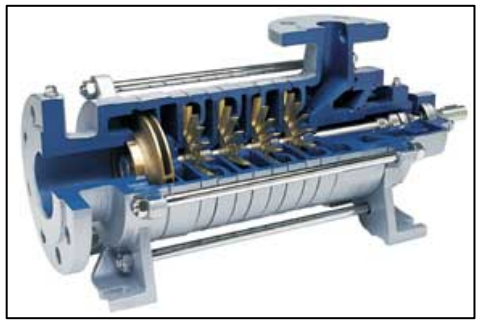
Advanced Manufacturing of Graphite Powders for High Performance Ceramics

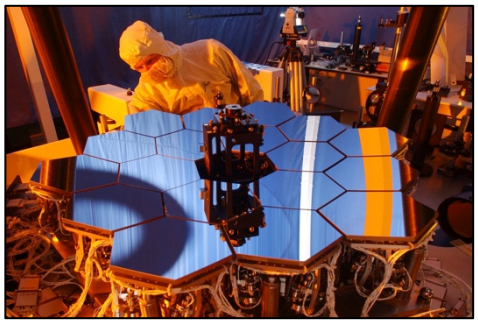
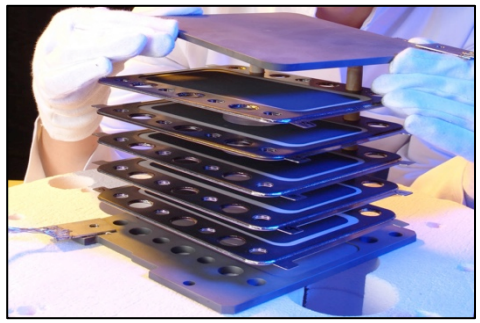
2nd International Minerals Conference September 21-22, 2015

Asia Pacific I Europe I North America



Graphite Powders Used In High Performance Ceramics



Graphite Overview

Graphite Overview

Graphite can be considered a *"universal technical mineral"*

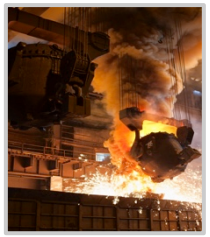
One of the few industrial minerals that can be used by a vast array of industries & applications

From refractories used in steel to graphene nano-sheets used in medical research for spinal injury treatment

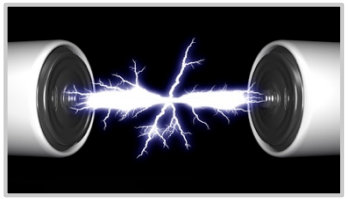
Graphite Overview

Graphite possesses three unique characteristics used by many industries

1. Thermally - refractive / conductive



2. Electrical - conductivity / resistivity



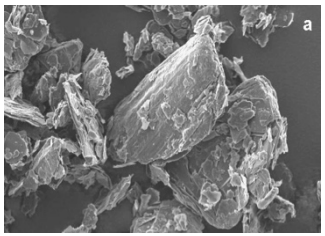
3. Lubricity – dry & suspension based

Exploring advanced graphite powders for high performance ceramics

Exploring Graphite Powders for Performance Ceramics

GRAPHITE POWDER TYPES

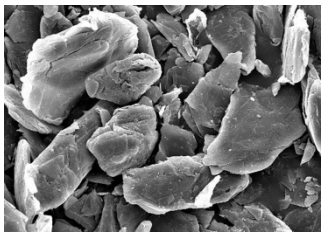
Primary Synthetic Graphite



(SEM image)

- Manufactured from select carbon precursors
- Petroleum and coal tar-based amorphous cokes
- Acheson furnace technology
- Electric / induction furnace (vertical or horizontal)
- Graphitized above 2,500C / No Oxygen
- Various morphologies & PSD's
- High crystallinity with purities ≥ 99.9%

Natural Flake (Macrocrystalline)



(SEM image)

- Mined & processed into mesh fractions & purities
- >95% purity flake micronized into specific PSD's
- Particle sizes range D90 3 µm to 150µm
- Purified – Chemical or thermal / halogen process
- Purities achieved up to 99.999% (≤100 total ppm)
- Base morphology is flake (can be mill modified)
- New purification methods create new products

Graphite powder milling, morphology modification, & purification methods

Graphite Powder Milling & Modification Processes

Micronized Primary Synthetic Graphite

Micronized Natural Flake Graphite

Graphite Powder Advanced Milling & Morphology Modification Methods

Typical Micronization Milling Methods

- Jet Mills, Hammer Mills, Modified Pin Mills
- Particle size distribution - D50 1.5µm to 45µm

Advanced Milling & Morphology Modification

- Modified Rotary Mill - Air Swept Classification
- Modified Ball / Roller Mills – Surface Area Modification (BET ≥ 80 m^2/g)
- Particle size distribution - D50 1.5µm to 28µm

Graphite Powder Purification Processes & Methods

Micronized Natural Flake Graphite

Graphite Powder Purification Processes & Methods

Typical Purification Methods

- Caustic leaching (chemical), drying, classification (up to 20% product loss) environmentally unfriendly
- Thermal / halogen purification – continuous & batch process

Purification Targets

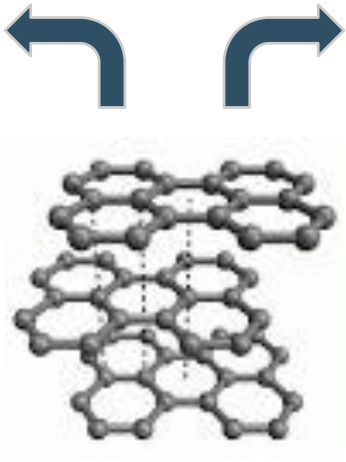
- Caustic leaching purification – purities 99.0% – 99.9%
- Thermal / halogen purification – purities 99.9% – 99.999%

Advanced graphite powders in high performance ceramics

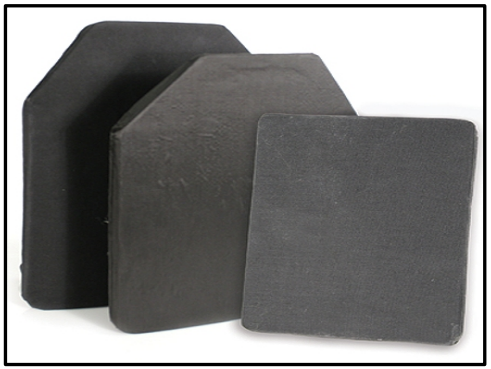
Graphite Powders In Performance Ceramic Applications

High purity graphite powder is used in a number of performance ceramics

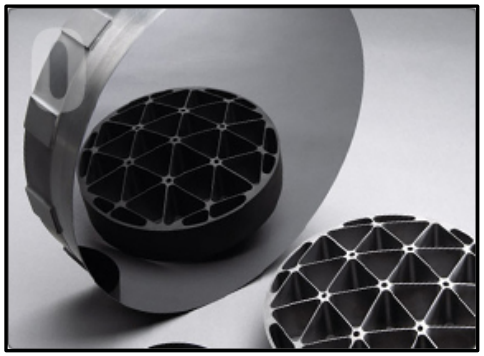
Sintered SiC Bearings & Seals



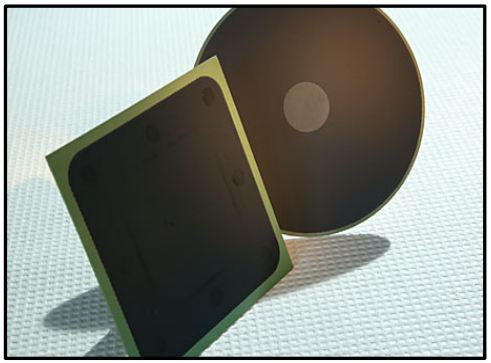
Graphite (Carbon Structure)



Sintered SiC Armor Components



Sintered SiC Optic Mirrors



SOFC Components

Graphite powders for Sintered SiC Ceramics & SOFC applications

Graphite Powders for Sintered SiC Bearings & Seals

Graphite loaded Sintered SiC parts produced by various manufacturers

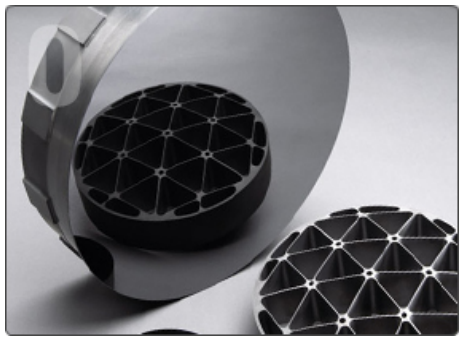
Graphite Powder Morphologies and PSD's

- Irregular (bulky) synthetic; bulky or modified shape natural graphite
- High purity – ≥ 99.9%
- Up to 20% by weight of dry lubricant (graphite or combined w/ BN; AlN)
- Dry graphite – Avg. PSD < 25µm (specific graphite lubricant inclusions)

Improvements by using graphite powders in SiC seals & bearings

- Improved lubricity at high temperatures and reduced wear
- Improved thermal gradient

Graphite Powders for Sintered SiC Optic Mirrors



Graphite loaded Sintered SiC Optic Mirror Substrates produced by few manufacturers

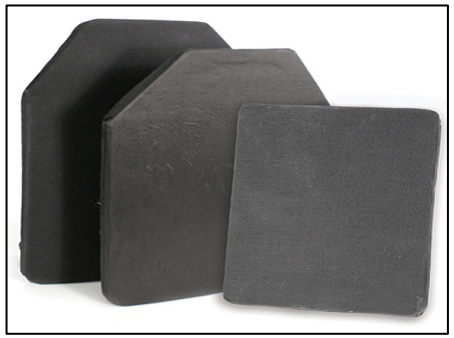
Graphite Powder Morphologies and PSD's

- Irregular (bulky) synthetic; bulky or modified shape natural graphite
- High purity – ≥ 99.9%
- Dry graphite powder up to 25% – Avg. PSD < 25µm (specific inclusions for SiC body dimensions & grain growth inhibitor)

Improvements by using graphite powders in SiC Optic Mirror Substrates

- Improved ceramic surface smoothness; inhibited SiC grain growth by graphite inclusions
- Reduced lapping machining time & cost

Graphite Powders for Sintered SiC Body Armor



Graphite loaded Sintered SiC Body Armor produced by few manufacturers

Graphite Powder Morphologies and PSD's

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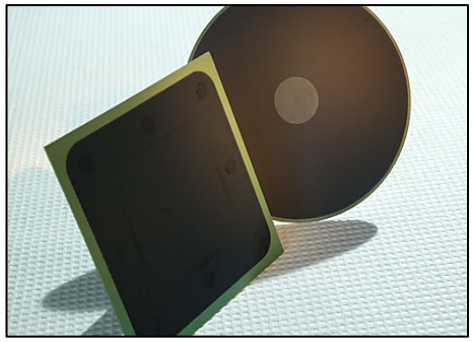
- High purity – ≥ 99.9%
- Dry graphite powder up to 25% – Avg. PSD < 25µm (specific inclusions for SiC body dimensions & grain growth inhibitor)

Improvements by using dry graphite powder in Sintered SiC Body Armor

- Improved ceramic surface smoothness; inhibited SiC grain growth by graphite inclusions
- Limited post sintering machining requirements

Graphite Powders for SOFC Ceramic Components



SOFC Ceramic components produced by various manufacturers

Graphite Powder Morphologies and PSD's

- Micronized graphite powder used as a ceramic substrate pore former
- Powder morphology & PSD ≤ 10µm – critical in microstructure porosity
- Irregular (bulky) synthetic; bulky or shaped natural graphite (5 – 50% mix)
- High purity – ≥ 99.9% (Ni, Fe, Co < 100ppm)
- Mix % of graphite depends on substrate size, configuration, & shrinkage
- Common electro-ceramic substrates – yttria-stabilized zirconia (YSZ)
- Fuel-flexible – bio-fuels, kerosene, diesel, propane, natural gas, butane

Advanced graphite powder performance summary

Advanced Graphite Powders Performance Summary

Advantages using micronized high purity graphite

Sintered SiC Ceramics

- Improve lubricity & wear (graphite loaded SiC bearings & seals)
- Improve thermal gradient (graphite loaded SiC bearings & seals)
- Inhibit surface grain growth (specialty machined critical surface applications)

SOFC Ceramic Components

- QC of PSD & purity (≥ 99.9%) is critical in SOFC substrate pore formers
- Morphology consistency is important for porosity microstructure
- Dispersibility of graphite agglomerates when combined with zirconia & binders

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Thank You