Pyrolytic Graphite: Advanced Material for Isothermal Forging

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Pyroid® Pyrolytic Graphite Features

- Light weight engineered material
- High purity > 99.999% crystalline structure
- Anisotropic structure
  - Thermally Conducting in XY planes (440 W/mK)
  - Thermally Insulating in Z plane (1.7 W/mK)
- Density: 2.25 g/cc (approaches the theoretical carbon density)

Pyroid® Pyrolytic Graphite Plate is:
- Stable at high temperature and vacuum

And Provides:
- Lowest known erosion in vacuum of any material
**Pyrolytic Graphite: Commercial Thermal Management Material**

Pyrolytic Graphite is 3 Dimensional Graphene,
- CVD deposition atom-by-atom on a substrate
- Continuous layers with hexagonal structure, like a deck of cards.

Highly anisotropic Polymorph

**Turbostratic Structure of PG**

Pyroid® CN Pyrolytic Graphite Production Process

- Large, High Temperature Vacuum Furnaces
- Pyrolytic Graphite deposition
- Plate production size (1200 sq. cm² sq up to 3 cm thick)

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Forging Operations Using Pyroid® Pyrolytic Graphite CN

Layers of Pyroid® CN plates are stacked behind the forging die. Dies at 300 - 500 C, Preform at 760 - 980 C, Speed 50 mm/sec.

Comparison of Conventional (left) and Isothermal (right) forging Processes

Source: IITRI

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Pyroid® Pyrolytic Graphite CN  Cost Effective Way to Maximize Tool Life and Optimize Production

Isothermal Forging Dies:

- Typical TZM (Mo-0.5%Ti-0.1%Zr)
- High stress – rupture and creep properties at all elevated temperatures
- Low thermal expansion coefficient
- Resist erosion (but not completely)

Isothermal forging process is optimum when the dies are at the same temperature throughout the forging operation.
Pyroid® Pyrolytic Graphite CN  Cost Effective Way to Maximize Tool Life and Optimize Production

Mosaic layers of Pyroid CN plates are stacked behind the forging die.

Pyrolytic Graphite plate insulates, **isolates the TZM from the high oxidation heat**

Result: **Enhanced Life of the TZM**.
Pyroid® Pyrolytic Graphite CN Cost Effective Way to Maximize Tool Life and Optimize Production

A Case Study: An isothermal forge stack of six layers of Pyroid® CN Pyrolytic Graphite can double the life of the TZM die material

The typical cost of 30 in.TZM die is $800,000
Normal replacement 2X per year = $1,600,000 capital outlay

The typical layer of Pyroid® CN Pyrolytic Graphite is $25,000 ($150,000 for six layers)
Doubling the life of the die saves $650,000
(TZM cost less Pyroid® CN Pyrolytic Graphite per year per forge)*

Three forge production operation can save $1.95 million/yr.

Not included are additional savings from:
Labor avoidance for TZM replacement
No loss of production down time for one changeover per year

* Estimate based on isothermal forging market study
Summary

• Pyrolytic Graphite is an Advanced Material Used in Isothermal Forging for Titanium Based Products

• Pyroid® CN Pyrolytic Graphite is a Unique Polymorph Especially Suited for Isothermal Forging Applications

• Pyrolytic Graphite Contributes Both Economic and Quality Benefits for Isothermal Forging Operations
Benefits of Pyrolytic Graphite

Pyrolytic graphite offers high thermal conduction plus insulating capability all in one material.

Using Pyroid® Pyrolytic Graphite plate ensures a very uniform heat distribution in the tool die work piece resulting in uniform temperature.

This translates into near superior net shape part quality that increases productivity for titanium and specialty alloy producers.

Insulating Property in Z Direction Yields Improved Die Life and Energy Efficiency

An Isothermal forge stack of six layers of Pyroid® CN can double the life of TZM die material

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Minerals Technologies: Overview

The Company

Minerals Technologies Inc. is a resource- and technology-based growth company that develops, produces and markets worldwide a broad range of specialty mineral, mineral-based and synthetic mineral products and related systems and services. MTI serves the paper, foundry, steel, environmental, energy, polymer and consumer products industries.
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Pyrogenics Mission: Provide engineered carbon based products for key industries requiring innovative material solutions.

**History**
Origins in 1966 (Space Age Materials Corporation)
Acquired by Pfizer (later Minerals Technologies Inc)
Major pyrolytic graphite production since 1992

**Our Operation:**
- Chemical Vapor Deposition/Chemical Vapor Infiltration
- Furnaces operating at > 2000° C (3600° F)
- Large Production Scale
- Pilot Scale and smaller development
- Mix and fill paint facility
- Analytical Laboratory Analysis Support

**Our Products:**
- Pyroid® Pyrolytic Graphite
- Carbon Composite Friction Material
- Thin Film Carbon Stripper Foil
- Firex™ Fire Protection Coatings