

SIAMC Advanced Material Co., Ltd.

**SIAMC**

# Development of Individual Nuclear-Grade Graphite Materials for both HTGR and MSR Reactors

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VP)

June, 2026

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Strive to become a globally leading carbon material technology enterprise



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## Company Mission

### Drive Tech Innovation in:

- Isotropic graphite processing technologies
- Billet manufacturing equipment
- Surface engineering solutions

### Deliver Expertise in:

- Tailored graphite applications
- Hybrid material design
- Failure analysis for sustainable closed-loop innovation

### Create Value for:

- End users of graphite components
- Upstream suppliers and downstream partners
- Shareholders, employees, and stakeholders

## Manufacture Sites

### SIAMC Advanced Materials Co. Ltd.

- Established in Changxing, Zhejiang Province (2007)
- Specializes in isostatic moulding graphite billet manufacturing
- Precision machining of graphite components for the semiconductor and nuclear industries

### SIAMC Advanced Materials (Ningxia) Co. Ltd.

- Established in Yongning, Ningxia Province (2021)
- Comprehensive processing: billet baking, impregnation, and graphitization
- Manufacture of vibration moulding graphite billets
- Machining of graphite and carbon for the PV and nuclear industries



## Core Business

### Nuclear Graphite

- **HTGR & MSR:** Cores, reflectors, and shielding (Commercial mass production achieved for HTR-PM and experimental MSR).
- **Fuel & Shielding:** High-purity graphite powder for pebble fuels and shields for fast neutron reactors (Commercial mass production achieved).

### Semiconductor Graphite

- **Czochralski (CZ) silicon Crystal Growth Hot-Zones**
- **Physical Vapor Transport (PVT) silicon carbide (SiC) Crystal Growth Hot-Zones**

### Industrial Graphite

- **Wafer processing components**
- **Process equipment for mechanical and chemical industries**

## Manufacture Capabilities

### Isotropic fine-grained graphite billets via isostatic moulding

- Annual production capacity: **15-20,000 tons**
- Billet dimension limits:  **$\phi 1400 \times 1100$  mm**  
**3000 (length)  $\times$  800 (width)  $\times$  700 mm**

**(thickness)**

### Isotropic/near-isotropic medium-grained graphite, carbon or carbon dispersed with boron carbide via vibration moulding

- Annual production capacity: **10,000 tons**
- Billet dimension limits:  **$\phi 1800 \times 480$  mm**  
**2770 (length)  $\times$  1330 (width)  $\times$  480 mm**

**(thickness)**



# Manufacture Flow Chart



## Key Facilities

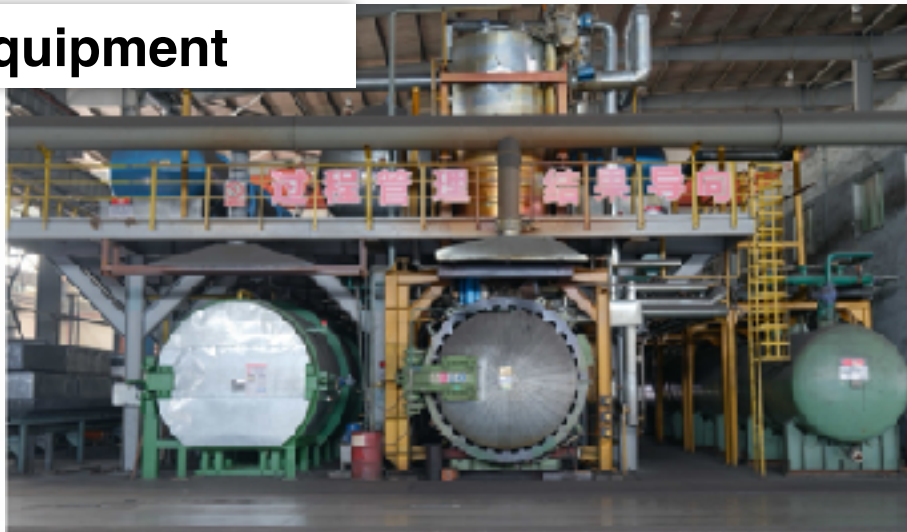
CIP equipment



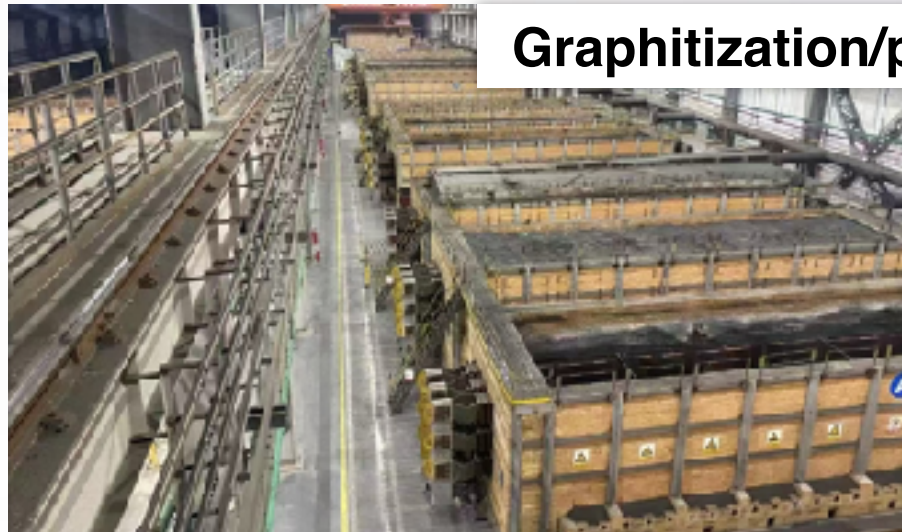
Baking equipment



PI equipment



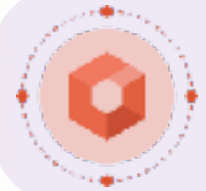
Graphitization/purification



# Section 03



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**05** Physical Property for a Single Production Batch



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**06** Physical Property for All Accumulated Production Batches



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**10** High Purity Silicon Carbide / Graphite Composites

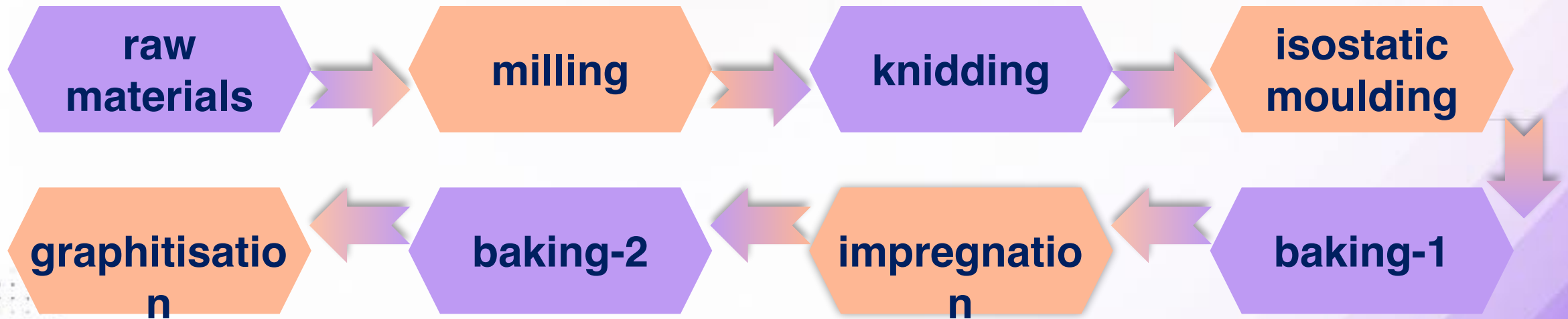


**12** Summary 2



## Manufacture information highlight

- Filler type: petroleum coke
- Filler size: 15-20  $\mu\text{m}$
- Billet size: 2100  $\times$  625  $\times$  400 mm, ~1 ton; customization available
- Batch size: > 20 tons



# Key Characteristics in Processing

## Raw Material Control

Petroleum coke is utilized as the primary feedstock. Rigorous technical specifications are enforced to ensure consistent quality and adherence to target indicators.

## Particle Size Control

The particle size distribution of the ground powder is tightly controlled, maintaining the average particle size within a narrow tolerance range.

## Mixing and Kneading

Continuous feeding combined with intensive kneading ensures effective impregnation and uniform coating of coke particles with pitch.

## Forming Process

One-step isostatic pressing is utilized to guarantee homogeneous density and structural uniformity in all directions.

# Key Characteristics in Processing (cont.)

## Baking Regime

- **First Baking:** Car-bottom furnaces are employed to ensure temperature uniformity.
- **Second Baking:** Pressurized baking is applied to maximize pitch carbon yield and enhance product density.

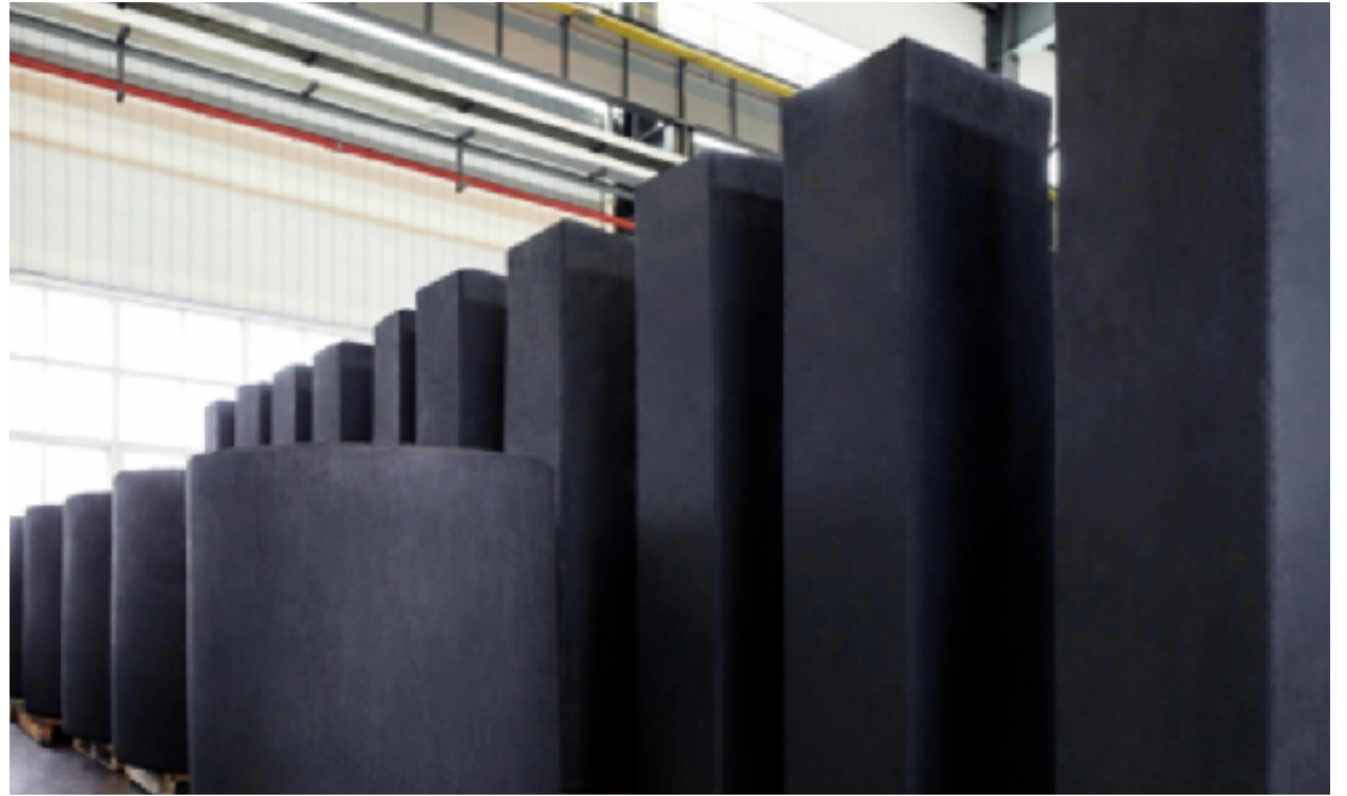
## Impregnation

- Vacuum and high-pressure cycles are utilized to ensure the pitch fully penetrates and fills internal voids within the product.

## Graphitisation







- High-temperature halogen purification is implemented to reduce the boron equivalent to the required level during graphitisation.

# As-manufactured billets



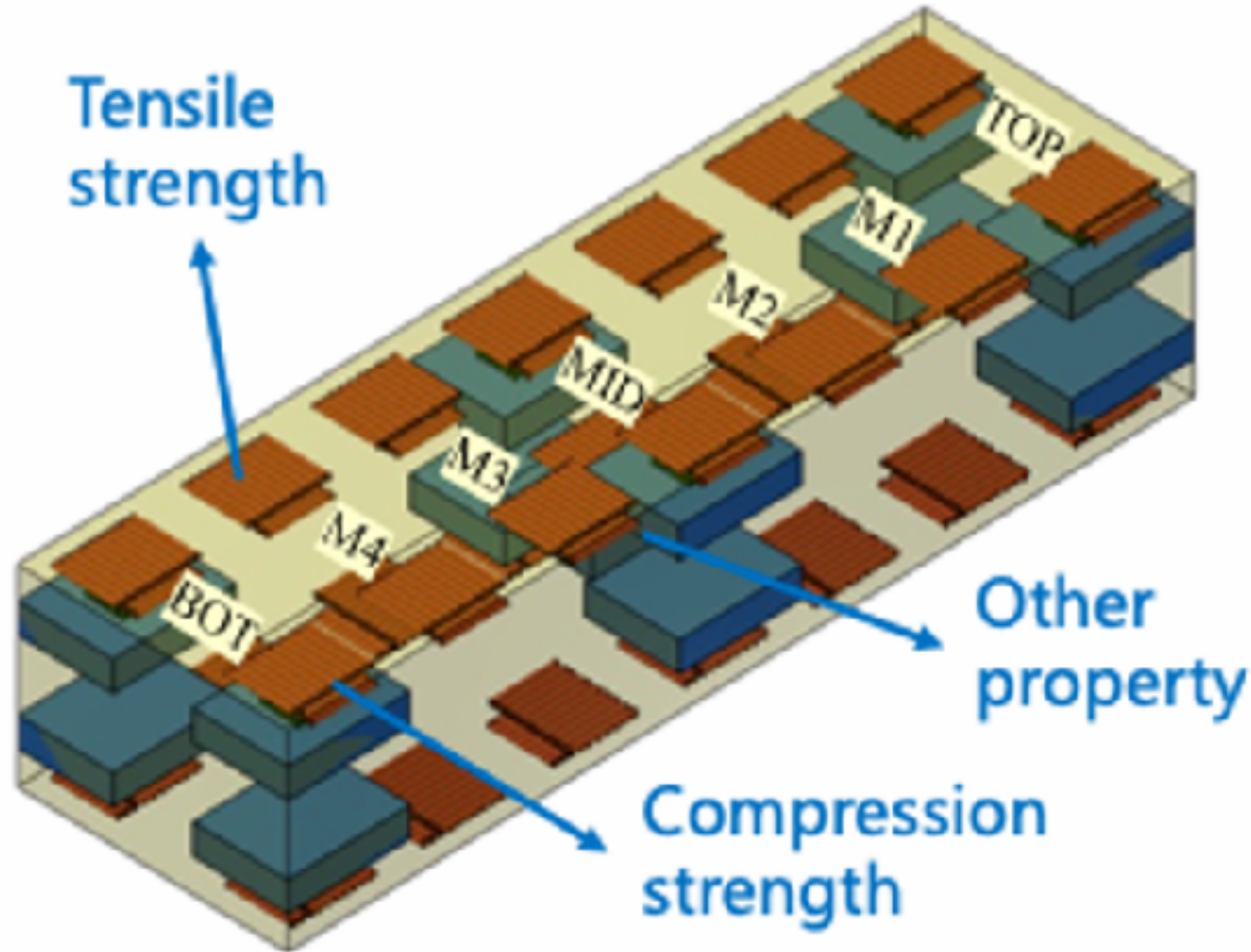
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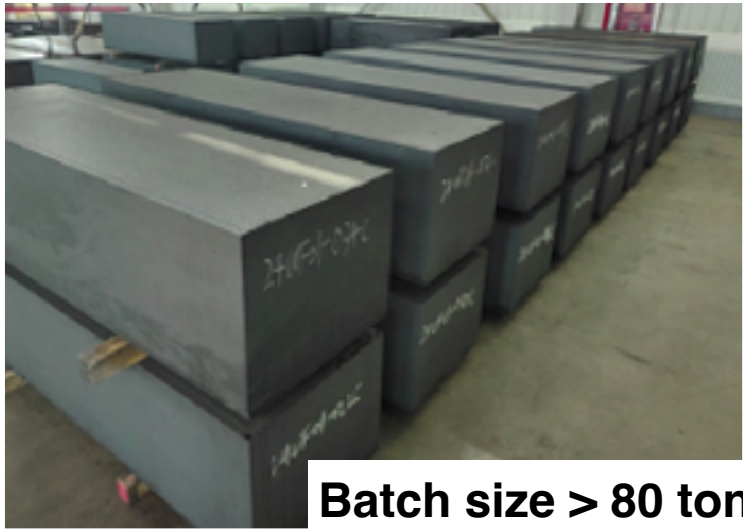
-  **02** Nuclear Graphite Billets Manufacture
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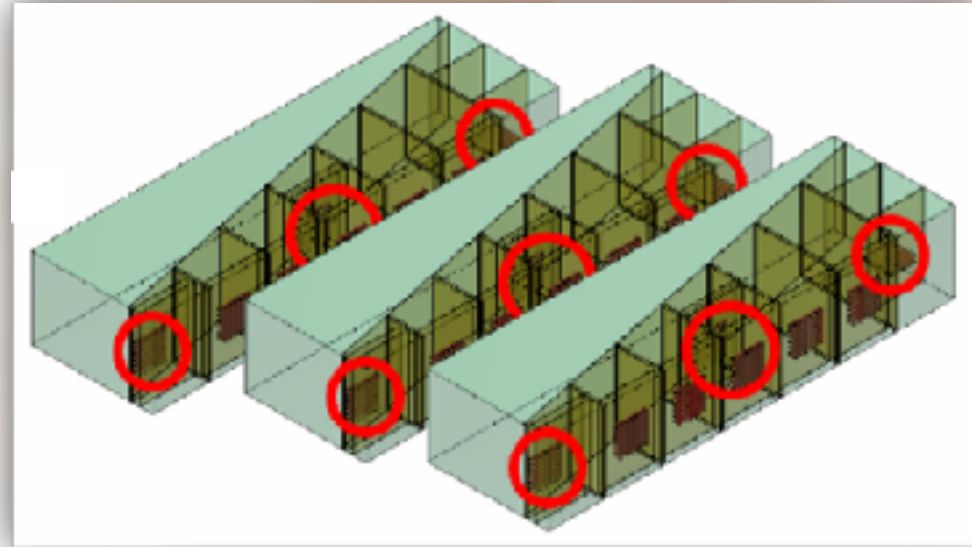
# Sampling Protocol for a Single Billet



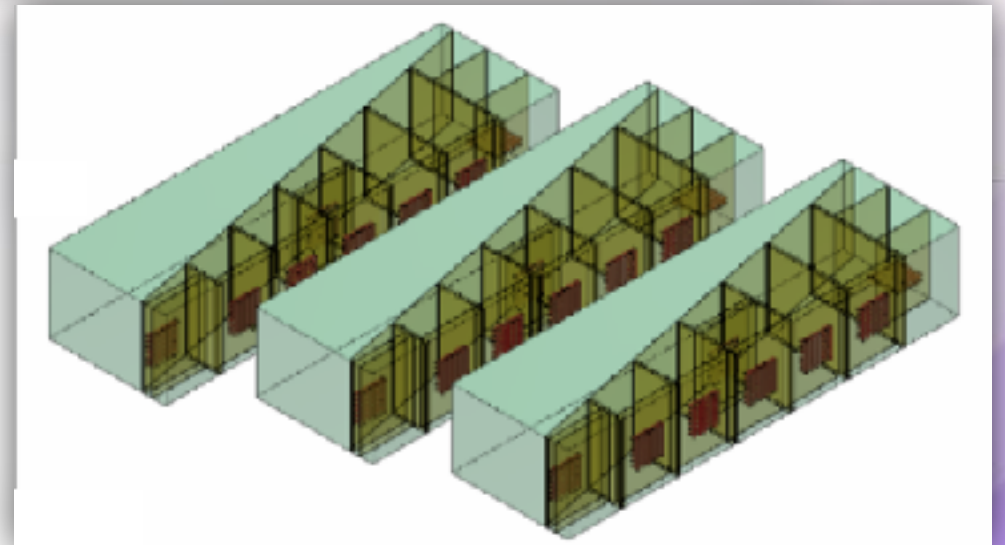
# Sampling Protocol for Multiple Billets for Each Batch



random selection



random selection



# Section 05



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**12** Summary 2



## Summary of Properties for a Single Batch-I

Property	Unit	Sample no in AG & WG	Value in AG & WG
Tensile strength (RT)	MPa	⊥ : 80,    : 80	⊥ : 32.46,    : 35.16
Tensile strength (300°C)	MPa	⊥ : 5,    : 5	⊥ : 29.96,    : 33.72
Tensile strength (450°C)	MPa	⊥ : 5,    : 5	⊥ : 32.19,    : 34.34
Tensile strength (600°C)	MPa	⊥ : 5,    : 5	⊥ : 32.23,    : 35.06
Tensile strength (750°C)	MPa	⊥ : 5,    : 5	⊥ : 31.55,    : 33.54
Compressive strength (RT)	MPa	⊥ : 80,    : 80	⊥ : 83.0,    : 82.6
4-p bending strength (RT)	MPa	⊥ : 10,    : 10	⊥ : 43.0,    : 43.8

## Summary of Properties for a Single Batch-II

Property	Unit	Sample no in AG & WG	Value in AG & WG
Static Young's modulus (RT)	GPa	⊥ : 10, ∥ : 10	⊥ : 7.8, ∥ : 8.3
Dynami Young's modulus (RT)	GPa	⊥ : 10, ∥ : 10	⊥ : 9.8, ∥ : 10.1
Poison ratio	/	10	0.13
Fracture toughness, $K_{1C}$	MPa·m <sup>1/2</sup>	⊥ : 10, ∥ : 10	⊥ : 0.92, ∥ : 0.92
Strain energy releasing rate, $G_{1C}$	J/m <sup>2</sup>	⊥ : 10, ∥ : 10	⊥ : 190, ∥ : 189
Weibull modulus of tensile strength, m	/	( ⊥ + ∥ ) : 396	16.2
Shaw's hardness	HSD	10	49.83

## Summary of Properties for a Single Batch-III

Property	Unit	Sample no in AG & WG	Value in AG & WG
Density	g/cm <sup>3</sup>	10	1.79
BET specific area	m <sup>2</sup> /g	10	0.35
Permiability	10 <sup>-9</sup> m <sup>2</sup>	10	0.022
Porosity	%	10	13.88
Electrical resistance rate	μΩ·m	10	10.34

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## Summary of Properties for Accumulated Batches-I

Property	Unit	Sample no in AG & WG	Value in AG & WG
Tensile strength (RT)	MPa	⊥ : 3020,    : 3020	⊥ : 33.57,    : 35.99
Compressive strength (RT)	MPa	⊥ : 1218,    : 1218	⊥ : 86.5,    : 86.9
4-p bending strength (RT)	MPa	⊥ : 125,    : 125	⊥ : 44.3,    : 46.3
Static Young's modulus (RT)	GPa	⊥ : 78,    : 78	⊥ : 8.4,    : 8.7
Density	g/cm <sup>3</sup>	415	1.80
Fracture toughness, K <sub>1C</sub>	MPa·m <sup>1/2</sup>	⊥ : 156,    : 156	⊥ : 0.93,    : 0.93

## Summary of Properties for Accumulated Batches-II

Property	Unit	Sample no in AG & WG	Value in AG & WG
CTE (RT-200°C)	10 <sup>-6</sup> /°C	⊥ : 165, ∥ : 165	⊥ : 3.22, ∥ : 3.07
Anisotropy	/	165	1.05
Thermal conductivity (RT)	W/(m·K)	⊥ : 81, ∥ : 81	⊥ : 126.3, ∥ : 130.5
EBC	wt.ppm	156	0.14
Ash	wt.ppm	78	6.7
Weibull modulus of tensile strength, m (95% confidence level)	/	( ⊥ + ∥ ) : 6040	16.7

# Section 07



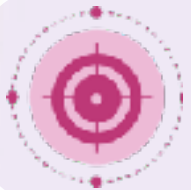
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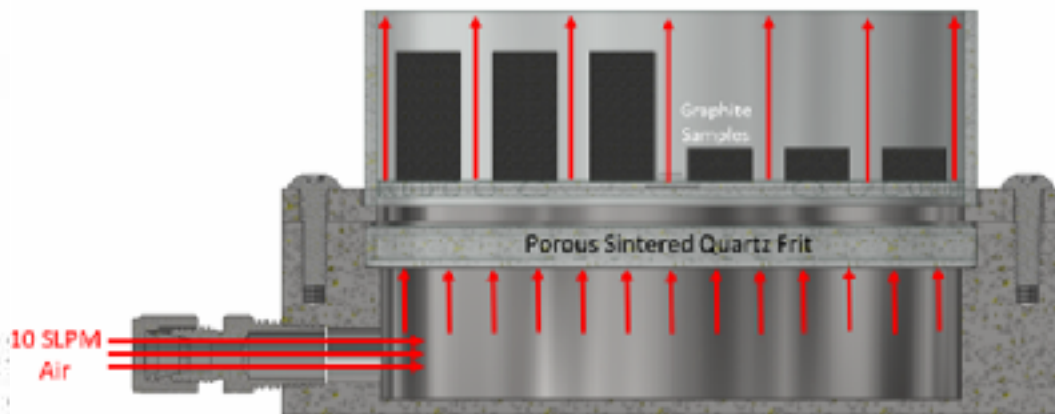
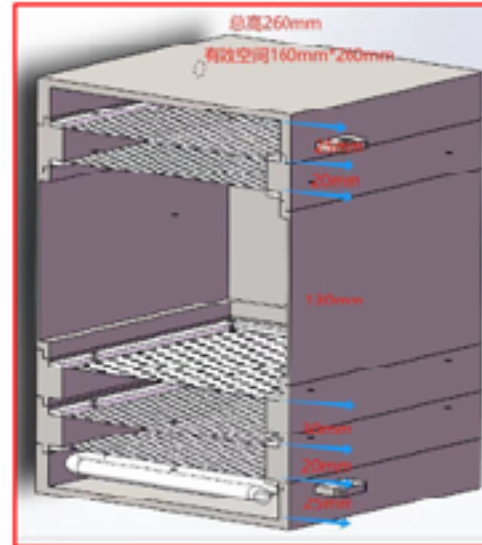
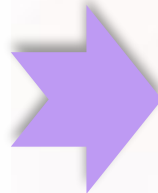
**10** High Purity Silicon Carbide / Graphite Composites



**12** Summary 2



# Oxidation Test Setup



(Austin C. Matthews et. al, Journal of Nuclear Materials, 2026)

# Oxidation Conditions

- **Continuous air flow rate:** 10 litres/min

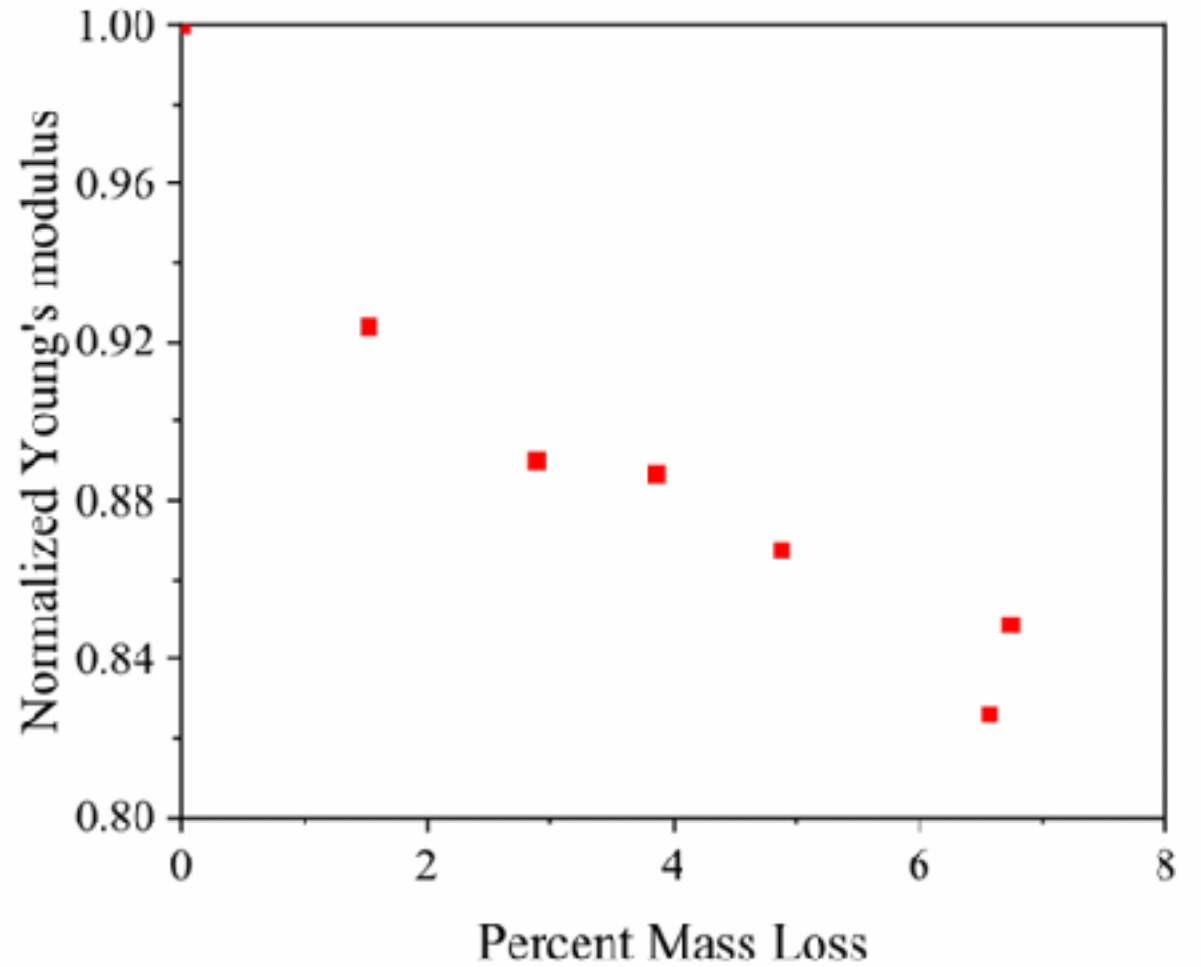
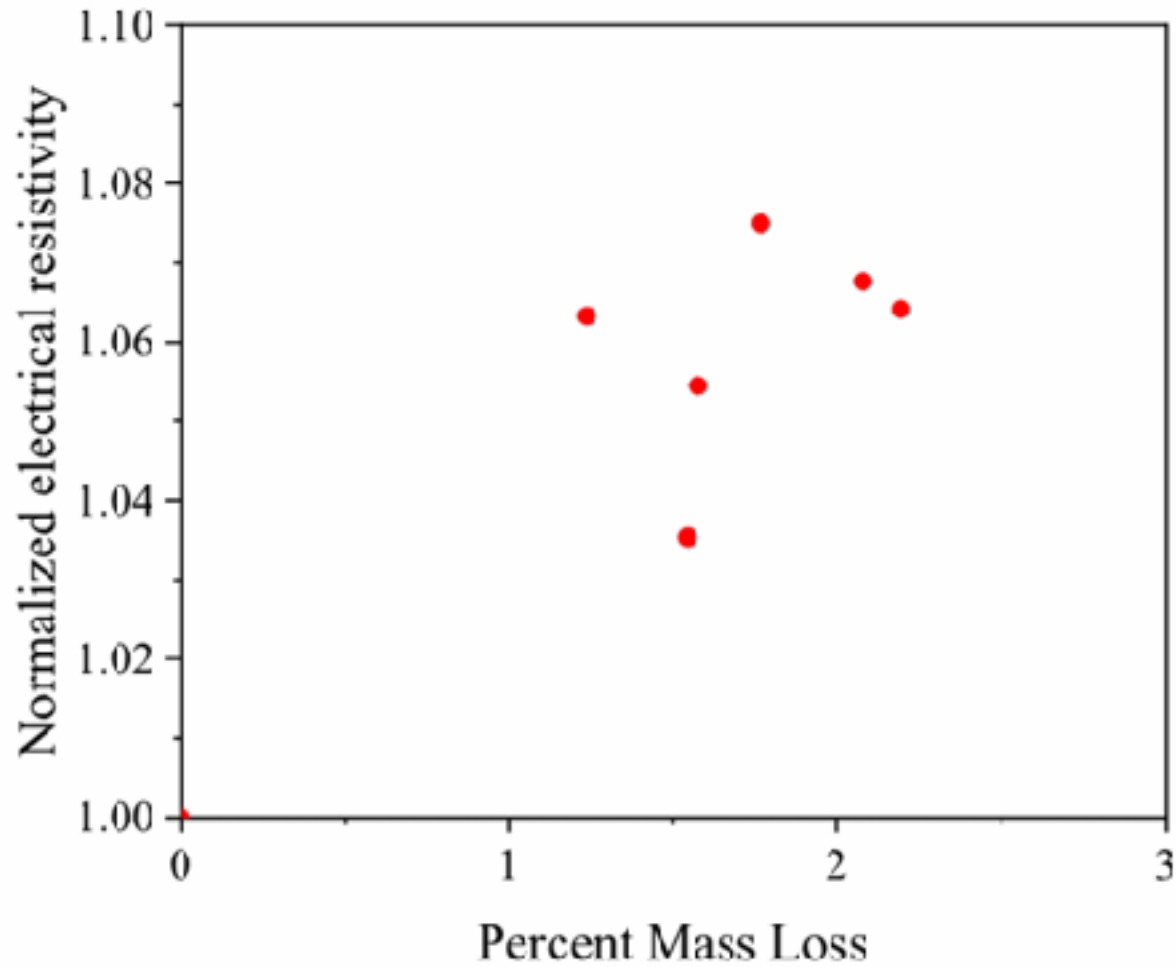
- **Oxidation temperature 1:**

1. 485 °C, the temperature used in the INL publication
2. oxidation time: 24 hrs
3. weight loss rate: 0.12%, smaller than the reported rate in INL publication

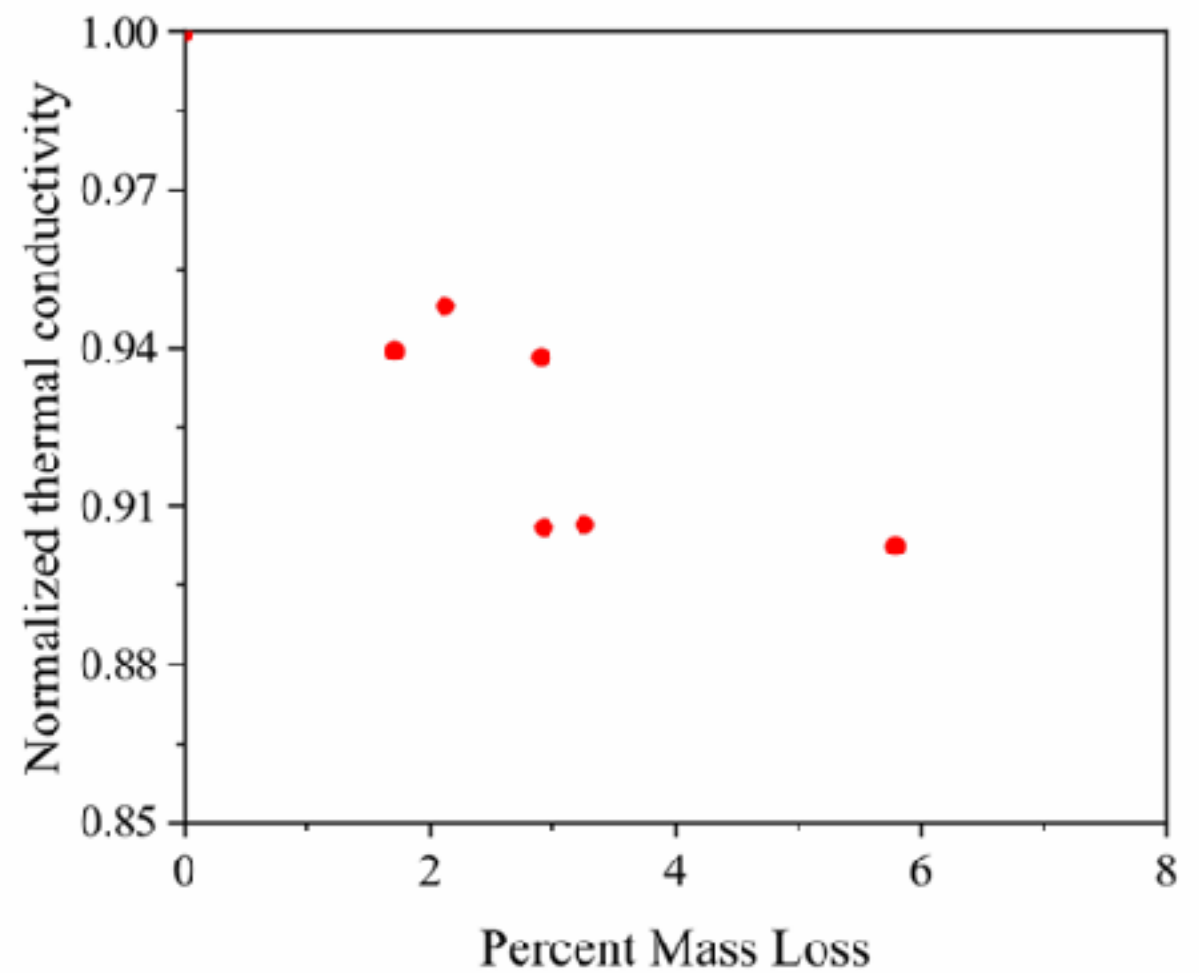
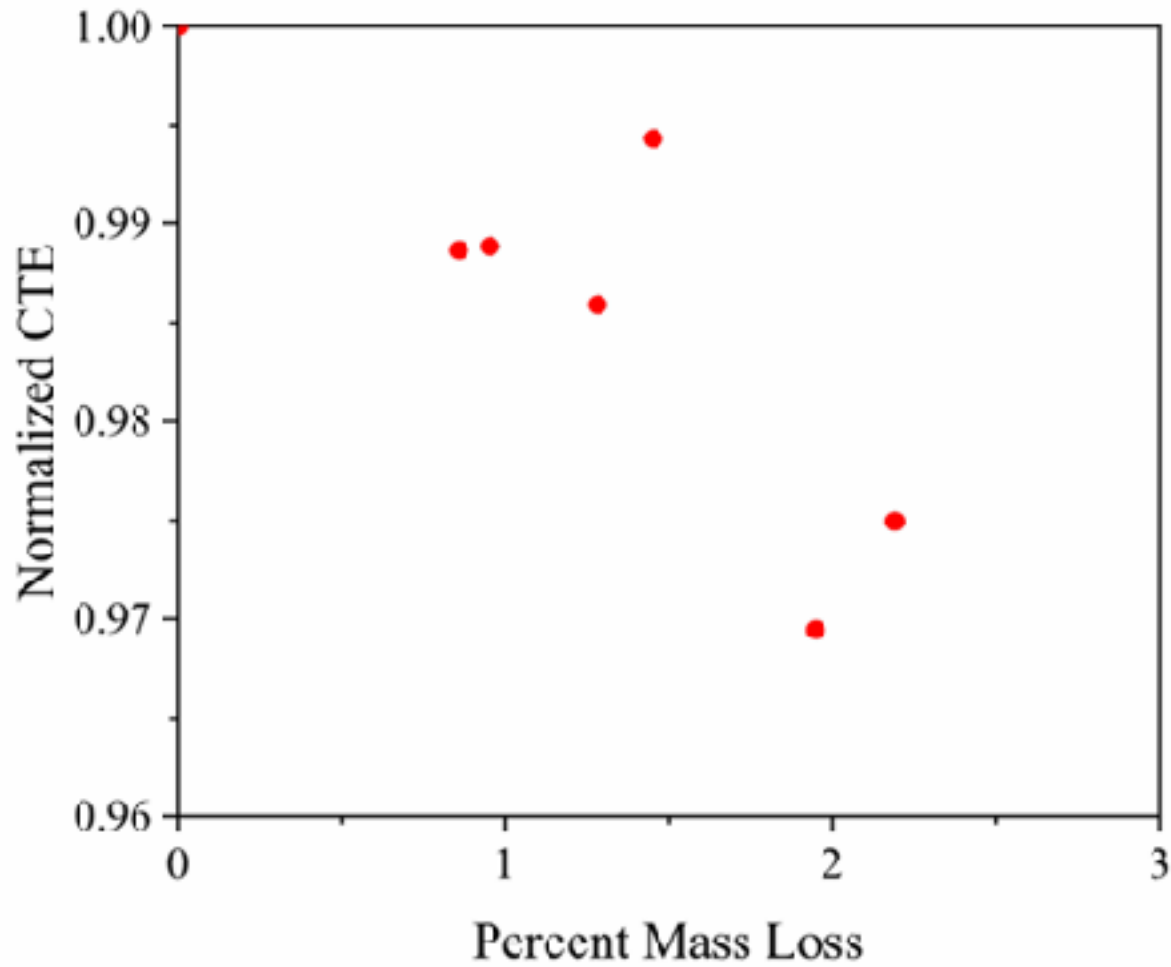
- **Oxidation temperature 2:**

1. 550 °C, higher temperature than the one used in the INL publication.
2. oxidation time: 24 hrs
3. weight loss: testable
4. measured changes in Young's modulus, electrical resistance, CTE, and thermal conductivity
5. mechanical property tests in progress

# Change of Electrical Resistivity & Young's Modulus



# Change of CTE & Thermal Conductivity



# Summary 1

- 1. All pre-irradiation properties of mass-produced billets comply with the HTR-PM technical specifications.**
- 2. Tensile strength testing across all manufactured batches demonstrates high strength and consistency (Weibull modulus > 16).**
- 3. To date, approximately 10,000 tons of SNG742 billets have been produced.**
- 4. Impact of oxidation on electrical resistivity, Young's modulus, CTE and thermal conductivity has been tested.**
- 5. Impact of oxidation on mechanical properties is in progress.**
- 6. Following neutron irradiation screening test in ORNL, full neutron irradiation qualification in NRG has been progressing well since 2019. Updated data are available.**

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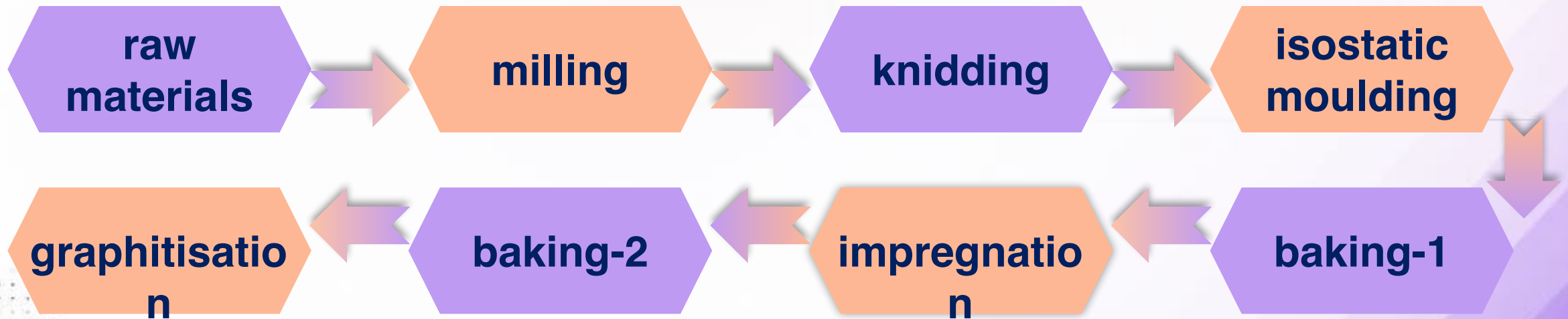


**12** Summary 2



## Manufacture information highlight

- Filler type: Pitch coke
- Filler size: 5  $\mu\text{m}$
- Billet size: 760  $\times$  575  $\times$  390 mm; customisation available
- Batch size: > 20 tons



# Summary of Properties-I

Property	Unit	Sample no in AG & WG	Value in AG & WG
Tensile strength (RT)	MPa	⊥ : 24,    : 24	⊥ : 32.81,    : 33.56
Compressive strength (RT)	MPa	⊥ : 48,    : 48	⊥ : 120.6,    : 119.2
4-p bending strength (RT)	MPa	⊥ : 48,    : 48	⊥ : 40.55,    : 42.92
Dynamic Young's modulus (RT)	GPa	⊥ : 10,    : 10	⊥ : 12.25,    : 12.40
Density	g/cm <sup>3</sup>	96	1.88
Porosity	%	/	8
Fracture toughness, K <sub>1C</sub>	MPa·m <sup>1/2</sup>	⊥ : 24,    : 24	⊥ : 0.92,    : 0.91

## Summary of Properties-II

Property	Unit	Sample no in AG & WG	Value in AG & WG
CTE (RT-200°C)	$10^{-6}/^{\circ}\text{C}$	⊥ : 24,    : 24	⊥ : 4.31,    : 4.19
Anisotropy	/	24	1.03
Thermal conductivity (RT)	W/(m·K)	⊥ : 48,    : 48	⊥ : 79.75,    : 80.80
EBC	wt.ppm	9	0.654
Ash	wt.ppm	10	49.9
Weibull modulus of tensile strength, m	/	( ⊥ +    ) : 47	12.7

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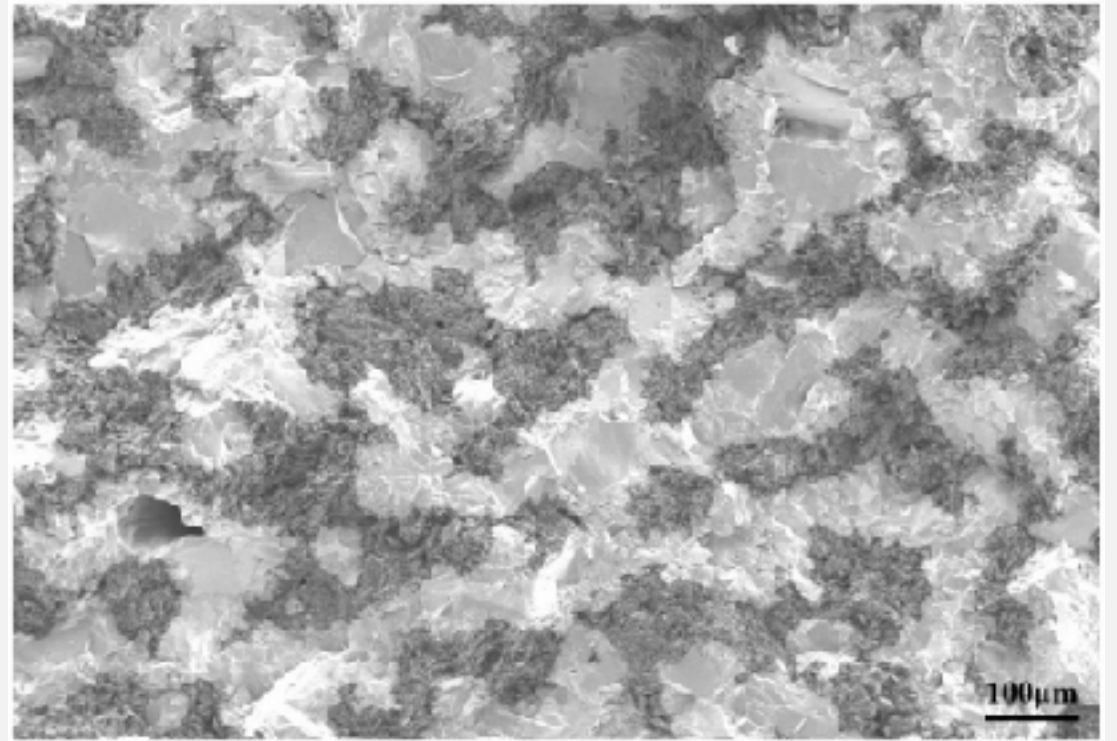
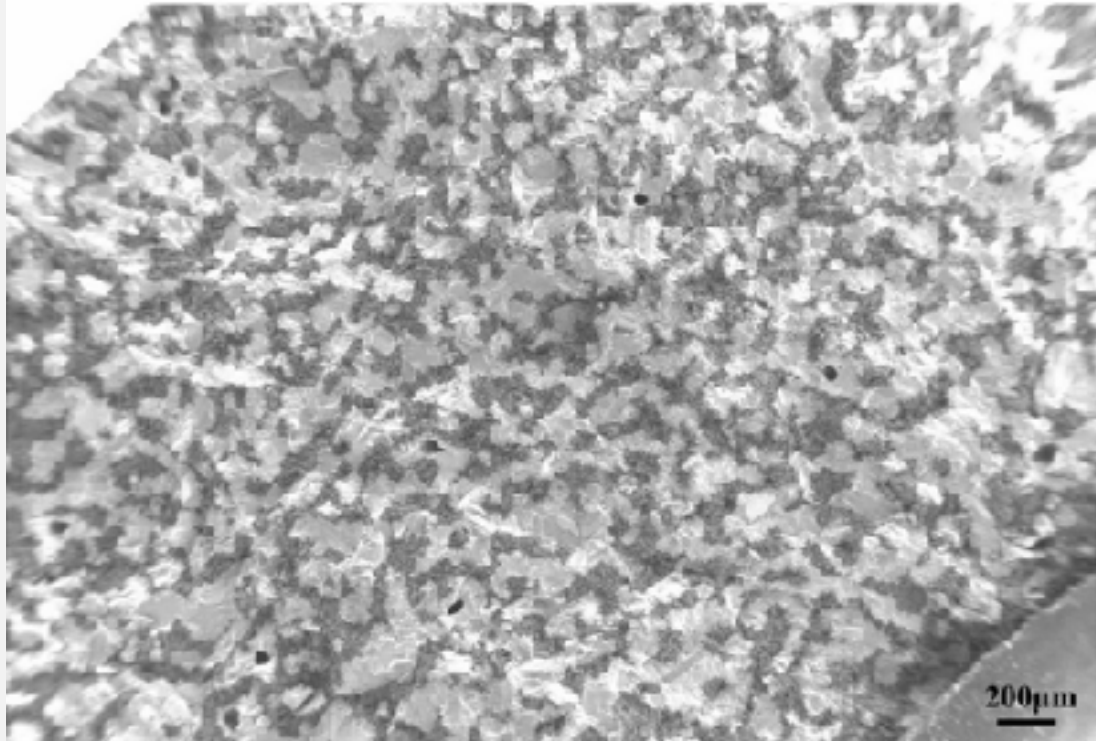
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# Motivation

- 1. Combine the advantages of high-purity graphite and silicon carbide in neutron irradiation resistance, and excellent high temperature behaviour**
- 2. Enhanced thermal and mechanical properties**
- 3. Suitable for manufacturing large-size blocks for reactors**
- 4. Block size available: Normally in near-net shape and customisation available**

# Representative Microstructure



# Representative Properties

- **Density:** 2.5–2.8 g/cm<sup>3</sup>
- **Porosity:** 0.5%-10%
- **3-Point Bending Strength:** 125 MPa
- **Coefficient of Thermal Expansion (CTE):**  $3.6-4.1 \times 10^{-6} \text{ K}^{-1}$  (RT–200°C)
- **Thermal Conductivity:**
  - 180 W/(m·K) at RT
  - 141 W/(m·K) at 200°C
  - 112 W/(m·K) at 400 °C
  - 92 W/(m·K) at 600 °C

# Section 11



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**12** Summary 2



# Graphite machining capabilities

## A range of machines for different tasks

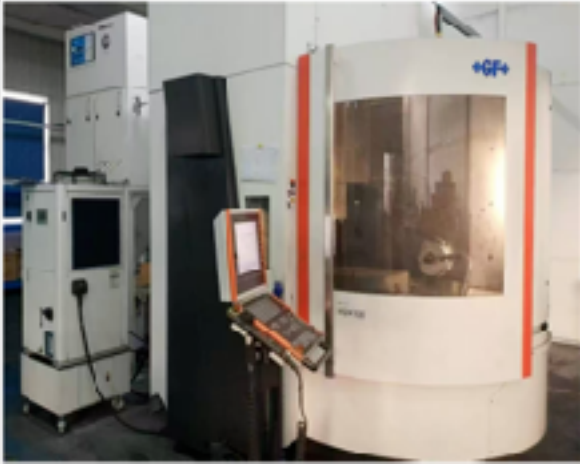
- High-speed CNC milling machines
- Universal machining centre (UMC)
- Multi-task machining centre (MTM)
- All sorts of saws, drills, etc.

## Typical components machined

- Graphite core for HTR-PM, MSR
- Carbon, carbon+B4C blocks for HTR-PM
- Components for semi, PV and other industries

# Typical machines

High-speed CNC Milling Machine



Universal Machining Centre (UMC)



Multi-Task Machining Centre (MTM)



High-speed CNC Milling Machine



Universal Machining Centre (UMC)



Multi-Task Machining Centre (MTM)



# UMC Production Line



# CNC Precision Machining Line



# MTM Production Line



# Metrological Capability

1. Standard inspection instruments
2. Various dedicated go/no-go gauges and ring gauges
3. 10 HEXAGON CMMs:
  - Precision 2.3 to 2.9  $\mu\text{m}$
  - Travel range from 900 to 3000 mm
4. All instruments undergo regular calibration by a certified agency



Coordinate Measuring Machines (CMMs)

## Summary 2

- 1. SIAMC has successfully developed multiple high quality nuclear-grade graphite, graphite/silicon carbide composite, carbon, and carbon/boron carbide composite suitable for different HTGR and MSR designs.**
- 2. SIAMC has established machining capabilities of nuclear graphite, carbon and their composite components from small to large sizes in a mass-production manner.**

**SIAMC**

**Thank you for your**  
**Look forward to working together with**  
**attention**  
**you !**

**SIAMC Advanced Material Co., Ltd.**

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Strive to become a globally leading carbon material technology enterprise