Ingoude University

THESIS DEFENSE

Metal Matrix Composites

Presented by:

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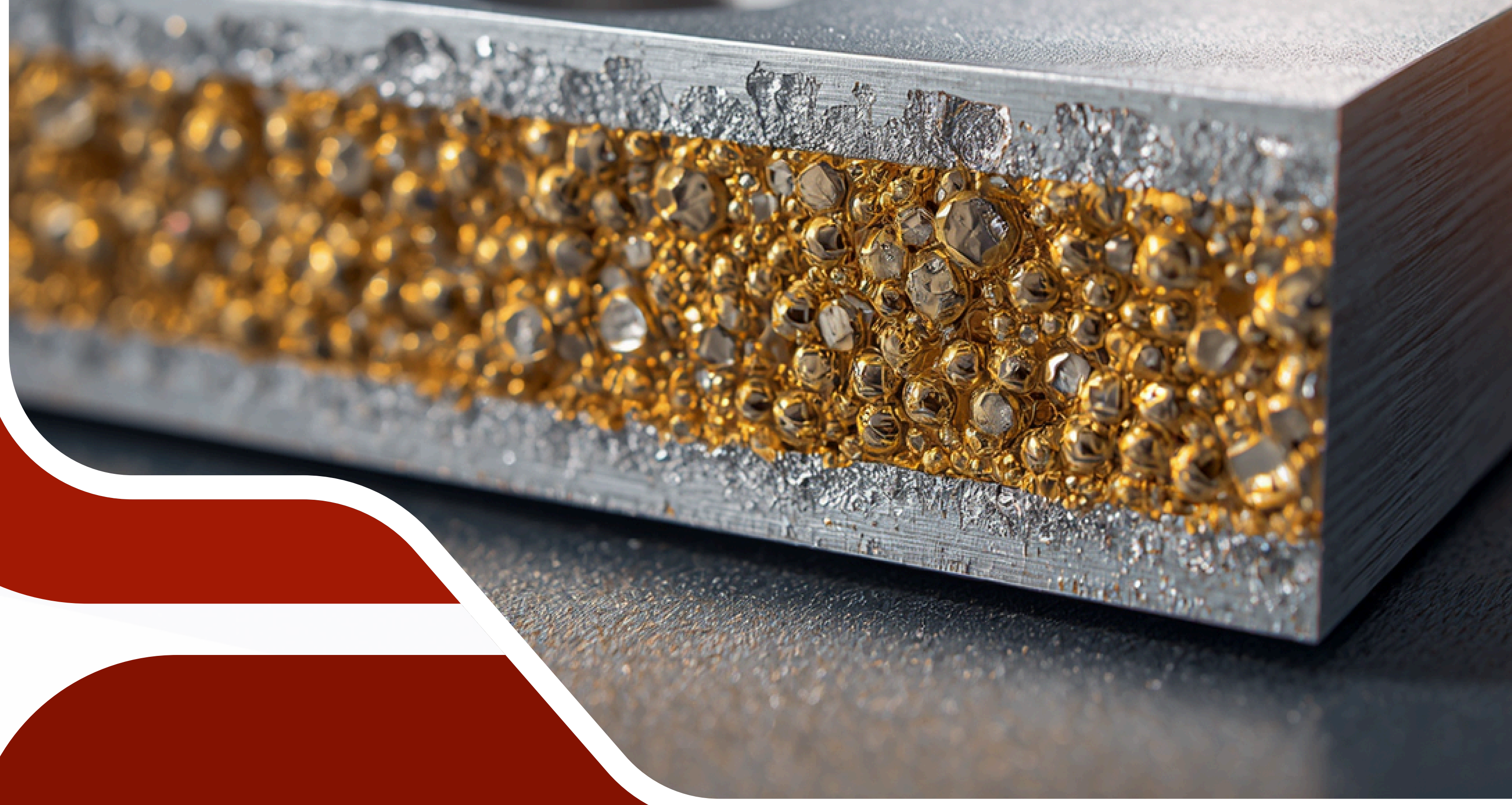
Introduction

What are Metal Matrix Composites?

Metal Matrix Composites (MMCs) are advanced engineering materials consisting of a metallic matrix reinforced with one or more constituents such as ceramic particles, fibers, or whiskers. The metallic matrix — commonly aluminum, magnesium, titanium, or copper — provides ductility and toughness, while the reinforcement imparts superior strength, stiffness, and wear resistance.

MMCs offer a unique combination of properties unattainable in conventional monolithic metals, making them indispensable in aerospace, automotive, defense, and electronics industries. Their tailorable properties, high specific strength, and excellent thermal stability position them as materials of the future for high-performance structural applications.



Topics Covered in This Course

This course provides a comprehensive study of Metal Matrix Composites covering: Fabrication techniques including solid-state, liquid-state, and in-situ methods; Interface characteristics such as mechanical and chemical bonding; Discontinuously Reinforced MMCs and their industrial applications; and Carbon Fiber Composites including fabrication, interface behavior, and performance.

Students will gain both theoretical foundations and practical insights into the processing-structure-property relationships governing MMC behavior, equipping them for advanced research and industrial problem-solving in materials engineering.

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Fabrication of Metal Matrix Composites

Solid-State Fabrication

Solid-state processes include powder metallurgy, diffusion bonding, and hot pressing. Reinforcements are blended with metal powders and consolidated under heat and pressure. These methods offer precise control over microstructure, minimal interfacial reactions, and are suitable for temperature-sensitive reinforcements like SiC and Al_2O_3 particles.

Liquid-State Fabrication

Liquid-state techniques include stir casting, squeeze casting, and infiltration. Molten metal is mixed or infiltrated with reinforcements under pressure or vacuum. These methods offer near-net-shape production, scalability, and cost-effectiveness, though wettability and interfacial reactions must be carefully controlled for uniform distribution.

In-Situ Fabrication

In-situ fabrication generates reinforcements within the metal matrix through chemical reactions during processing. Techniques include reactive sintering, reactive casting, and XD process. This results in thermodynamically stable, fine reinforcements with clean interfaces, superior bonding, and improved mechanical properties compared to ex-situ methods.

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Interface in Metal Matrix Composites

The interface in Metal Matrix Composites (MMCs) is the critical region governing stress transfer, fracture behavior, and overall mechanical performance. Three primary bonding mechanisms — mechanical, chemical, and in-situ interfacial bonding — determine the composite's structural integrity and durability under service conditions.

Chemical Bonding

Chemical bonding involves atomic-level interaction and reaction between the matrix and reinforcement at the interface. Interfacial reactions can form intermetallic compounds or reaction layers that enhance adhesion. Controlling reaction layer thickness is critical — too thin reduces bonding strength, while too thick leads to brittle phases that degrade composite performance.

Mechanical Bonding

Mechanical bonding in MMCs relies on physical interlocking between the reinforcement and matrix. Surface roughness, geometry, and residual stresses from thermal mismatch play key roles. Effective mechanical bonding improves load transfer efficiency and is influenced by the coefficient of thermal expansion difference between matrix and reinforcement phases.

Interfaces in In-Situ Composites

In in-situ MMCs, reinforcements are formed within the matrix during processing. These interfaces are thermodynamically stable, clean, and free from contamination. The in-situ formed reinforcement-matrix interface exhibits superior bonding, enhanced wettability, and improved mechanical performance compared to ex-situ composites.

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Discontinuously Reinforced MMCs

Key Properties

Discontinuously reinforced MMCs exhibit enhanced stiffness, improved strength-to-weight ratio, and superior wear resistance. Particulate and whisker reinforcements provide isotropic mechanical properties, making them suitable for structural and automotive applications.

Applications & Characteristics

These composites offer excellent thermal stability, low coefficient of thermal expansion, and high fatigue resistance. Common applications include aerospace components, brake rotors, electronic packaging, and sporting goods requiring lightweight yet durable materials.

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DRMMC Applications

Discontinuously Reinforced Metal Matrix Composites (DRMMCs) offer exceptional strength-to-weight ratio, wear resistance, and thermal stability. These properties make them highly suitable for demanding applications across aerospace, automotive, and industrial sectors where performance and durability are critical requirements.

Aerospace & Automotive

In aerospace, DRMMCs are used in structural panels, fan blades, and satellite components due to their low density and high stiffness. In automotive, they are applied in brake rotors, pistons, drive shafts, and engine components, offering improved fuel efficiency and extended component life.

Industrial Applications

Industrial applications include cutting tools, wear-resistant liners, electronic packaging, and sporting goods. DRMMCs provide superior hardness and thermal conductivity, making them ideal for high-speed machining tools, electronic substrates, and precision engineering components.

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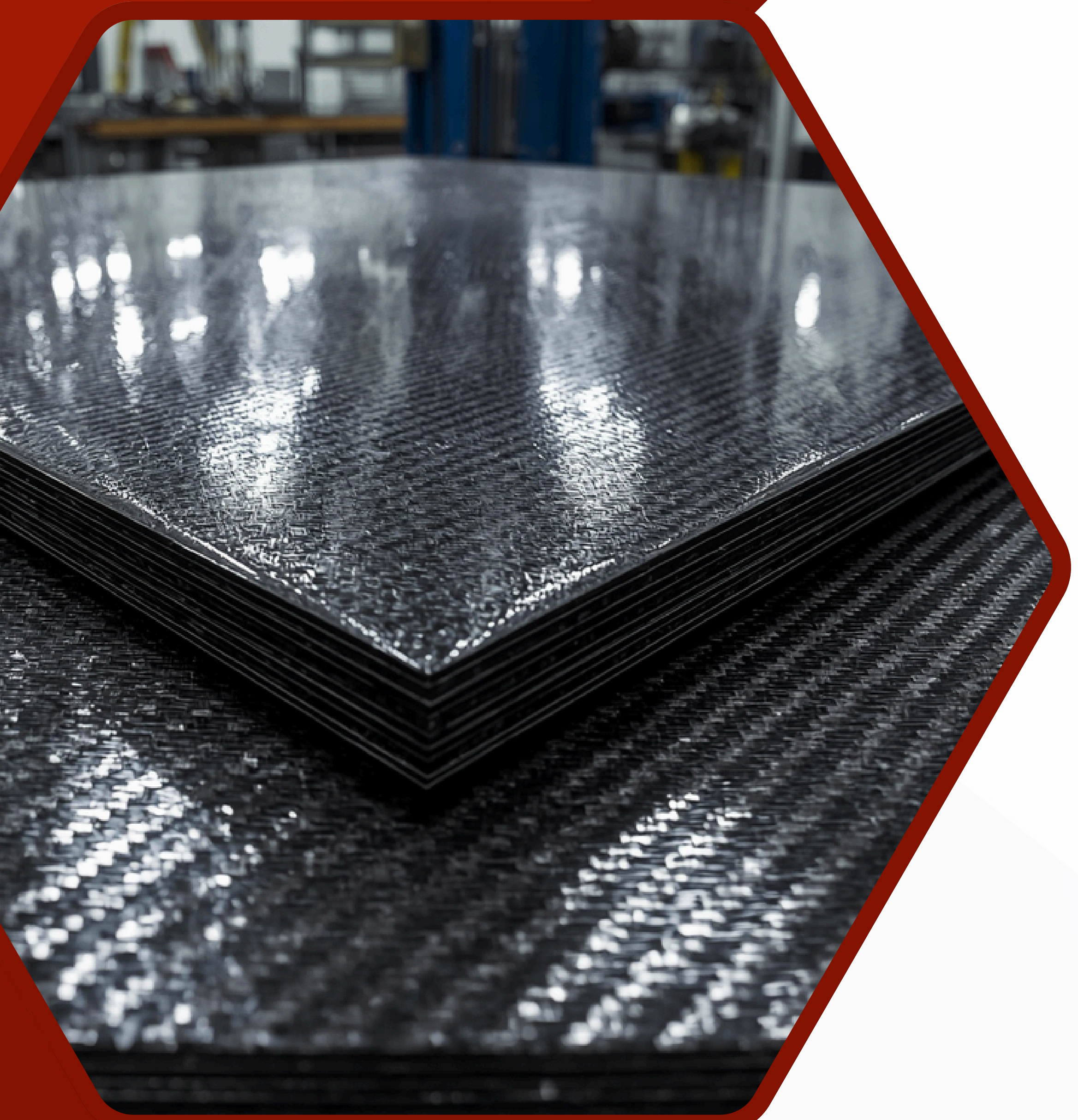
Carbon Fiber Composites



Carbon fiber composites are advanced materials formed by embedding carbon fibers in a matrix to achieve exceptional strength-to-weight ratios. Their fabrication involves specialized techniques including layup processes, resin transfer molding, and filament winding, enabling high-performance applications across aerospace, automotive, and structural engineering sectors.

Fabrication Methods

Key fabrication methods include hand layup, autoclave curing, resin transfer molding (RTM), and pultrusion. Each method offers distinct advantages in terms of fiber orientation control, void content minimization, and scalability for industrial production of composite components.

Processing Techniques

Processing techniques such as prepreg layup, filament winding, and vacuum-assisted resin infusion (VARI) ensure precise fiber volume fractions. Thermal curing cycles and post-processing steps are critical to achieving optimal mechanical properties and microstructural integrity in the final composite.

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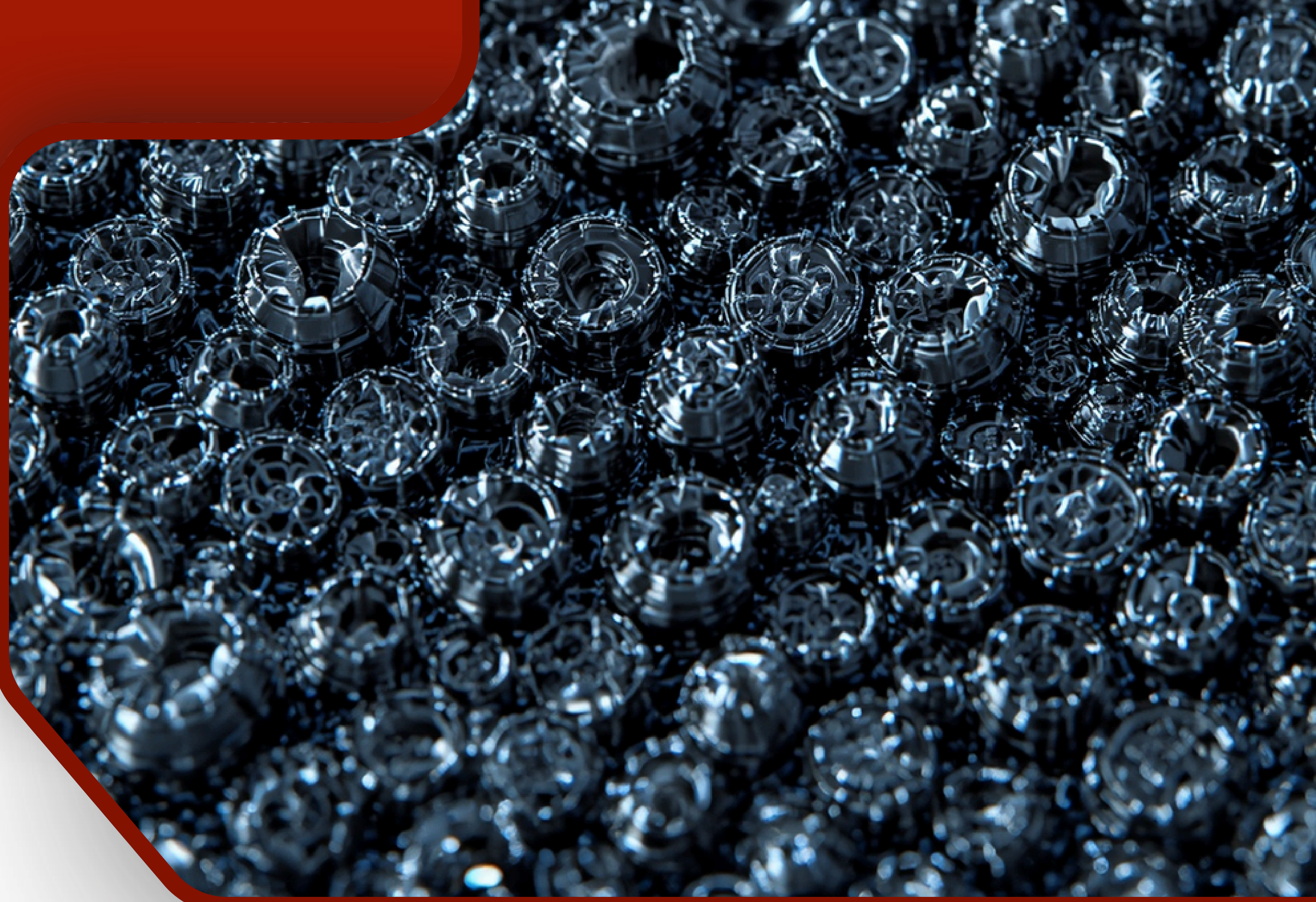
Carbon Fiber Composites



Properties of Carbon Fiber Composites

Carbon fiber composites exhibit exceptional mechanical properties including high tensile strength (3.5–7 GPa), high stiffness, and low density (~1.6 g/cm³). Their superior specific strength and specific modulus make them ideal for aerospace and structural applications. Thermal stability, low thermal expansion, and excellent fatigue resistance further distinguish these composites.

Interface Characteristics

The fiber-matrix interface in carbon fiber composites governs load transfer efficiency. Interfacial bonding is achieved through mechanical interlocking, chemical adhesion, and surface treatments such as oxidation or sizing agents. Weak interfaces cause delamination while overly strong bonding leads to brittle fracture, requiring careful optimization for balanced performance.

Microstructure & Applications

The microstructure of carbon fiber composites consists of graphitic carbon fibers embedded in polymer, metal, or ceramic matrices. Fiber orientation, volume fraction, and layup sequence control anisotropic behavior. Applications span aerospace structures, automotive components, sporting goods, biomedical implants, and civil infrastructure reinforcement due to their unmatched strength-to-weight ratio.

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Carbon Fiber Composite Applications

Aerospace & Automotive: Carbon fiber composites are extensively used in aircraft fuselages, wings, and structural panels due to their exceptional strength-to-weight ratio. In automotive engineering, they are applied in body panels, chassis components, and racing car structures, significantly reducing vehicle weight while maintaining rigidity and crashworthiness.

Key Application Areas

Sports & Structural Engineering: In sports equipment, carbon fiber composites are used in bicycle frames, tennis rackets, golf clubs, and rowing oars, offering superior stiffness and vibration damping. In civil and structural engineering, carbon fiber reinforced composites are employed for retrofitting bridges, reinforcing concrete structures, and constructing lightweight architectural elements, ensuring durability and long service life.

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THANK YOU

For Your Attention

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