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Ceramic Matrix Composites: A Strong and Lightweight Material Solution

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Opinion Article

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DESCRIPTION

Ceramic matrix composites (CMCs) are a subclass of ceramics and composite materials in the field of materials research. They are made up of ceramic fibres that are set into a ceramic matrix. Any ceramic material can be used to make the fibres and the matrix, and carbon and carbon fibres can also be thought of as ceramic materials.

To solve the issues with traditional technical ceramics like alumina, silicon carbide, aluminium nitride, silicon nitride, or zirconia, which easily fracture under mechanical or thermo-mechanical loads due to cracks started by minute imperfections or scratches, researchers developed CMCs. As with glass, the crack resistance is very poor. Particles (also known as monocrystalline whiskers or platelets) were incorporated into the matrix to boost the fracture toughness or crack resistance. However, the enhancement was quite slight, and the items were only used in a few ceramic cutting tools. Only the incorporation of long multi-strand fibres has so far significantly improved crack resistance, elongation resistance, and thermal shock resistance and led to a number of novel applications.

In order to take use of the ceramic matrix's naturally high strength and Young's modulus, Ceramic Matrix Composites (CMC) utilise reinforcements to increase the combined material system's fracture toughness. The most frequent kind of reinforcement is a continuous-length ceramic fibre, which typically has a lower elastic modulus than the matrix. When thru-thickness cracks start to form across the CMC at higher stress levels like Proportional Limit Stress, PLS, this fiber's functional role is to

- Increase the CMC stress for the progression of microcracks through the matrix, increasing the energy expended during crack propagation,
- Bridge these cracks without fracturing, giving the CMC a high Ultimate Tensile Strength (UTS).

In this approach, ceramic fibre reinforcements help prevent the abrupt brittle failure that is typical of monolithic ceramics while simultaneously boosting the composite structure's initial resistance to crack propagation. Contrary to the behaviour of ceramic fibres in Polymer Matrix Composites (PMC) and Metal Matrix Composites (MMC), where the fibres often fracture before the matrix due to the higher failure strain capabilities of these matrices, this behaviour is unique from those of ceramic fibres in these materials.

Manufacture

The following three steps are typically included in the production processes:

- Laying out and fixing the fibres in the required component shape
- Penetration of the matrix substance
- Finishing the machining and, if necessary, adding additional treatments to the intrinsic porosity, such as coating or impregnation.

For all CMCs, the first and last steps are nearly identical: The first stage involves laying up textiles, twisting filaments, braiding, and knotting to arrange and attach the fibres, which are frequently referred to as rovings. Fiber-preform, or simply preform, is the process' end result.

- The ceramic matrix between the preform's fibres is filled in the second step using five different techniques:
- Formation from a gas combination
- Pre-ceramic polymer pyrolysis
- Elements' chemical reactions
- Sintering at a temperature between 1,830°F -2,190°F and 1,000°C -1,200°C, which is relatively low.
- A ceramic powder is deposited electrophoretically.

The first three processes are employed with non-oxide CMCs, whereas the fourth is applied to oxide CMCs. Combinations of these procedures are also used. The fifth step hasn't been included into industrial operations yet. Each process has a sub-variation with specific technical differences. A porous substance is produced by all processes.

Ceramic fibers

Similar to traditional ceramics, ceramic fibres in CMCs may have a polycrystalline structure. When organic precursors are pyrolyzed, they can also become amorphous or have an uneven chemical makeup. Organic, metallic, or glass fibres cannot be used to make CMCs because of the high process temperatures needed. Only fibres that can withstand temperatures of more than 1,000°C (1,800°F), such as those made of alumina, mullite, SiC, zirconia, or carbon, may be employed. The elongation capability of amorphous SiC fibres is greater than 2%, which is substantially higher than that of traditional ceramic materials (0.05% to 0.10%).