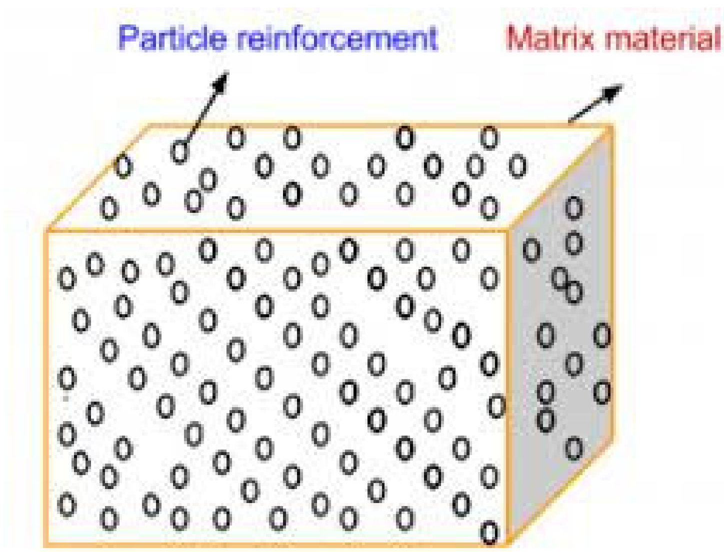
# PARTICULATE REINFORCED COMPOSITES

**A. Chennakesava Reddy**
**Professor, Department of Mechanical Engineering**
**JNTUH College of Engineering, Hyderabad**

Composites refer to a material consisting of two or more individual constituents. The reinforcing constituent is embedded in a matrix to form the composite. One form of composites is particulate reinforced composites with concrete being a good example. The aggregate of coarse rock or gravel is embedded in a matrix of cement. The aggregate provides stiffness and strength while the cement acts as the binder to hold the structure together.

There are many different forms of particulate composites. The particulates can be very small particles (< 0.25 microns), chopped fibers (such as glass), platelets, hollow spheres, or new materials such as bucky balls or carbon nano-tubes. In each case, the particulates provide desirable material properties and the matrix acts as binding medium necessary for structural applications.

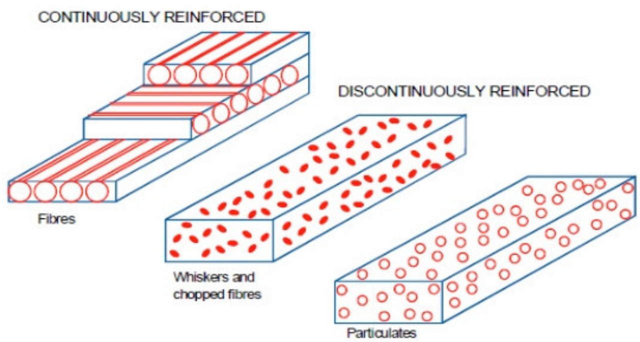



Particulate composites offer several advantages. They provide reinforcement to the matrix material thereby strengthening the material. The combination of reinforcement and matrix can provide for very specific material properties. For example, the inclusion of conductive reinforcements in a plastic can produce plastics that are somewhat conductive. Particulate composites can often use more traditional manufacturing methods such as injection molding which reduces cost.

**Role of Particulate Reinforcements:**

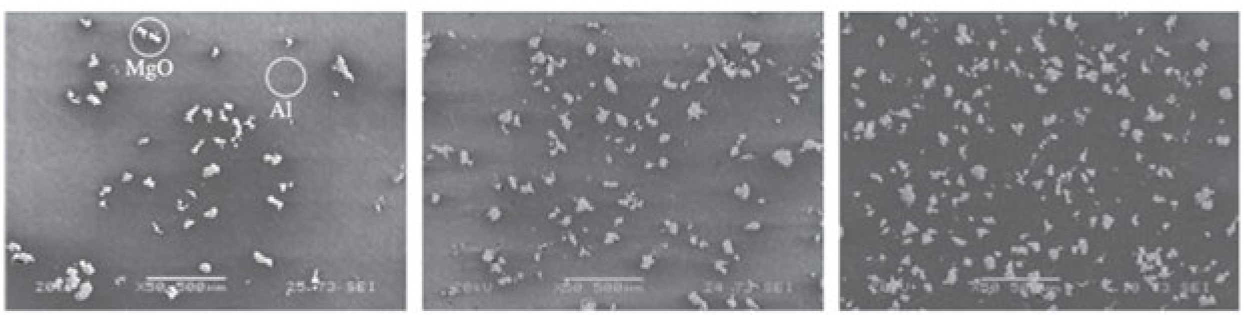
The reinforcement material is embedded into a matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging, or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystaline diamond tooling (PCD).

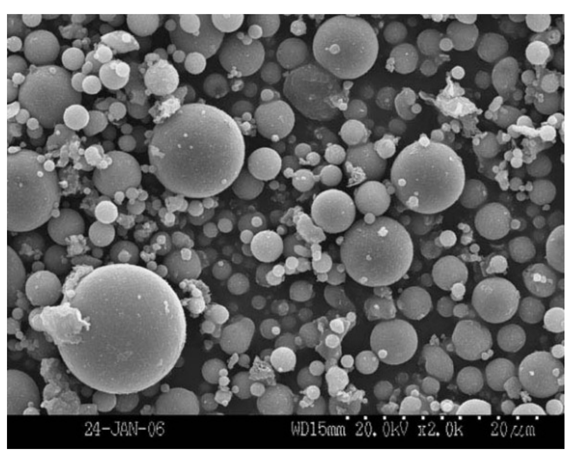
Typical Reinforcement Geometries for Composites




Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMCs used boron filament as reinforcement. Discontinuous reinforcement uses "whiskers", short fibers, or particles. The most common reinforcing materials in this category are alumina and silicon carbide.

Ceramic materials offer a number of benefits in a variety of applications. They provide high wear, heat and corrosion resistance, as well as high tensile strength, volume resistivity, dielectric strength and modulus of elasticity. These materials also offer lower thermal expansion than metals or plastics, and a longer part life at original design dimensions and tolerances.



Aluminum Oxide ($Al_2O_3$). Aluminum oxide (alumina) is the workhorse of advanced technical ceramics. It has good mechanical and electrical properties, wear resistance and corrosion resistance. It has relatively poor thermal shock resistance. It is used as an electrical insulator for a number of electrical and electronic applications, including spark plug insulators and electronic substrates. It is also used in chemical, medical and wear applications.

Zirconium Oxide ($ZrO_2$). Zirconium oxide has the highest fracture toughness of any advanced technical ceramic. Its toughness, mechanical properties and corrosion resistance make it ideal for medical and selected wear applications. Its thermal expansion coefficient is very close to steel, making it an ideal plunger for use in a steel bore. Its properties are derived from a very precise phase composition. Some environmental conditions can make the material unstable, causing it to lose its mechanical properties. Its relatively low hardness and high weight also limit its broad use in wear applications.

Fused Silica ($SiO_2$). Fused silica is an excellent thermal insulator and has essentially zero thermal expansion. It has good chemical resistance to molten metals but is limited by its very low strength. It is used for a number of refractory and glass applications, as well as radomes for missiles.

Titanium Diboride ($TiB_2$). Titanium diboride is an electrically conducting ceramic and can be machined using electron discharge machining (EDM) techniques. It is a very hard material; however, its mechanical properties are poor. Its major use is in metallurgical applications involving molten aluminum. It is also used for some limited wear applications, such as ballistic armor to stop large-diameter (>14.5 mm) projectiles.

Boron Carbide ($B_4C$). Boron carbide is the hardest material after diamond, giving it outstanding wear resistance. Its mechanical properties, especially its fracture toughness, are low, limiting its application. However, it is used extensively for ballistic armor and blast nozzles. Boron carbide is also a neutron absorber, making it a primary choice for control rods and other nuclear applications.

Silicon Carbide (SiC). Silicon carbide has outstanding wear and thermal shock resistance. It has good mechanical properties, especially at high temperatures. It is a semiconductor material with electrical resistivities in the 10^5 ohm-cm range. It can be processed to a very high purity. Silicon carbide is used extensively for mechanical seals because of its chemical and wear resistance.

Tungsten Carbide (WC). Tungsten carbide is generally made with high percentages of either cobalt or nickel as a second, metallic phase. These ceramic metals, or "cermets," have wide use as cutting tools and other metal-forming tools. Pure tungsten carbide can be made as an advanced technical ceramic using a high-temperature hot isostatic pressing process. This material has very high hardness and wear resistance and is used for abrasive water jet nozzles; however, its weight limits its use in many applications.

Aluminum Nitride (AlN). Aluminum nitride has a very high thermal conductivity while being an electrical insulator. This makes it an ideal material for use in electrical and thermal management situations.

Boron Nitride (BN). Hexagonal boron nitride is a chalky white material and is often called "white graphite." It has generally poor mechanical properties. It has outstanding high-temperature resistance (>2500$^oC$) in inert atmospheres but cannot be used above 500$^oC$ in an air atmosphere. It is used as a high-temperature insulator and in combination with TiB 2 in many ferrous and aluminum metallurgical applications.

Silicon Nitride ($Si_3N_4$). Silicon nitride has the best combination of mechanical, thermal and electrical properties of any advanced technical ceramic material. Its high strength and toughness make it the material of choice for automotive and bearing applications.

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