METAL–MATRIX COMPOSITES

MMCs are made by dispersing a reinforcing material into a metal matrix. As the name implies, for metal-matrix composites (MMCs), the matrix is a ductile metal. These materials may be utilized at higher service temperatures than their base metal counterparts; furthermore, the reinforcement may improve specific stiffness, specific strength, abrasion resistance, creep resistance, thermal conductivity, and dimensional stability. Some of the advantages of these materials over the polymer matrix composites include:

- higher operating temperatures,
- no flammability,
- do not absorb moisture,
- have better electrical and thermal conductivity,
- are resistant to radiation damage,
- greater resistance to degradation by organic fluids.
- Low cost, therefore, their (MMC) use is somewhat restricted.

In polymeric composites, matrix materials play important but secondary role of holding the fibers in place and providing proper load dispersion in the fibers, while material strength and stiffness are controlled by the reinforcements. By contrast, mechanical properties of metal matrix composites are controlled by the matrix to a considerably larger extent, though fibers still provide the main contribution to strength and stiffness of the material.

The superalloys, as well as alloys of aluminum, magnesium, titanium, and copper, are employed as matrix materials. The reinforcement may be in the form of particulates, both continuous and discontinuous fibers, and whiskers; concentrations normally range between 10 and 60 vol%. Continuous fiber
materials include carbon, silicon carbide, boron, alumina, and the refractory metals. On the other hand, discontinuous reinforcements consist primarily of silicon carbide whiskers, chopped fibers of alumina and carbon, and particulates of silicon carbide and alumina. In a sense, the cermets fall within this MMC scheme.

In the automotive industry, MMCs have been used commercially in fiber reinforced pistons and particle-strengthened brake disks. Recently, some of the automobile manufacturers have introduced engine components consisting of an aluminum-alloy matrix that is reinforced with alumina and carbon fibers; this MMC is light in weight and resists wear and thermal distortion.

Aerospace structural applications include advanced aluminum alloy metal-matrix composites; boron fibers are used as the reinforcement for the Space Shuttle Orbiter, and continuous graphite fibers for the Hubble Telescope. Reinforcements for metal matrix composites have a manifold demand profile, which is determined by production and processing and by the matrix system of the composite material. The following demands are generally applicable

1. low density,
2. mechanical compatibility (a thermal expansion coefficient which is low but adapted to the matrix),
3. chemical compatibility,
4. thermal stability,
5. high Young’s modulus,
6. high compression and tensile strength,
7. good processability,
8. Economic efficiency.
Which components are finally used, depends on the selected matrix and on the demand profile of the intended application.

**Processing of Metal Matrix Composites**

Metal matrix composite materials can be produced by many different techniques. The focus of the selection of suitable process is the desired kind, quantity and distribution of the reinforcement components (particles and fibers), the matrix alloy and the application. By altering the manufacturing method, the processing and the finishing, as well as by the form of the reinforcement components it is possible to obtain different characteristic profiles, although the same composition and amounts of the components are involved.

**Powder metallurgy:** Is a forming and fabrication technique consisting of three major processing stages. First powdered metal and dispersed metal or ceramic powder or discontinuous fibers are mixed. Next, the powder is injected into a mold or passed through a die to produce a compact of weakly cohesive structure. Finally, the end part which formed by applying pressure may be sintered in a proper temperature and atmosphere to produce a final composite compact. This compact may need to undergo a secondary manufacturing process like rolling or extrusion to produce the desired shape to suite the application. The process may be represented by the following:
Diffusion bonding: In this technique layers of metal foil are sandwiched with long fibers, and then pressed through to form a composites. Also this technique is used for making multi-layer metal sheets. One of applications is the bi-metal. In this process two different thin sheets are brought into contact with each other in an alternative manner. This arrangement may be pressed strongly for a long period while keeping their temperature slightly high. This forced contact would lead to the atoms of individual metals to diffuse into the neighboring metal. The amount of interdiffusion of any metal atom into the other will be decided by the value of diffusion coefficient of one metal atom into the other metal. Hence, the sheets will stick together quite tightly.
Impregnation process: In this technique a bundle of fibers tightly bound together in cylindrical shape and immersed in a molten metal, which temperature is lower than the softening point of the fibers. The molten metal would be attracted to impregnate and climb-up the voids between the fibers due to capillary action. The bundle is left in the molten metal until all the voids are filled with the molten metal. This is usually done in a relatively short period, thus the fibers will not damage and their shape will remain. It is possible to extrude or draw of metal matrix composite to modify the outer shape or cross section, or to reduce the diameter which might be needed to undergo such secondary processes for more than one pass to ensure final dimension and good quality.

Electrochemical forming: This process is mainly used to reinforce the metal matrix with long continuous fibers. The process depends on aligning the long fibers in a (non-conductive frame) such as plastic frame to hold the long and electrically conductive fibers. All types of metallic fibers as well as graphite fibers that are conductive to electrical currents are used in this process. The frame with the long fibers is immersed in a bath containing a solution of certain chemical compound. Such compounds are used in electroplating, where metallic layers are precipitated onto metal surfaces, like Ni-plating, Chrome-plating, or copper plating. This process is quite common in industry. The proper salt is chosen in order to precipitate the desired metallic matrix. A d.c. current is passed, with the proper value of current density for a relatively long period of time. During this the metallic matrix will be precipitated around the fibers, and this precipitation will accumulate and form a plate shape matrix.
The density of the matrix would depend on the preparation factors like current density, salt-bath temperature. The resulting sheet composite may treated by secondary forming process to control the final dimensions by rolling. This may also affect the final microstructure and reduce the voids of the bulk of the metal matrix that may form during the precipitation process.

**Plasma spraying methods:** This process used only for long fibers of all kinds conductive and non-conductive. Molten metal is sprayed onto a continuous fiber substrate.

**Stir casting:** Discontinuous reinforcement is stirred into molten metal, which is allowed to solidify. The particles are often tending to form agglomerates, which can be only dissolved by intense stirring. However, here gas access into the melt must be absolutely avoided, since this could lead to unwanted porosities or reactions. The melt can be cast directly or processed with alternative procedures such as squeeze casting.

![Schematic operational sequence during melt stirring.](image)

**Fig. (1), schematic operational sequence during melt stirring.**

**Squeeze casting:** Squeeze casting or pressure casting are the most common manufacturing variants for MMCs. Molten metal is injected into a form with
fibers or particles preplaced inside it. A two-stage process is often used. In the first stage the melt is pressed into the form at low pressure and then at high pressure for the solidification phase. This prevents damage to the preform by too fast infiltration. The squeeze casting permits the use of relatively reactive materials, since the duration of the infiltration and thus the response time, are relatively short. A further advantage is the possibility to manufacture difficultly shaped construction units.

![Diagram of Direct Squeeze Casting](image)

**Fig. 2, Direct squeeze casting.**

**Physical vapor deposition:** The fiber is passed through a thick cloud of vaporized metal, coating it.

Melting metallurgy for the production of MMCs is at present of greater technical importance than powder metallurgy. It is more economical and has the advantage of being able to use well proven casting processes for the production of MMCs.