

# METAL MATRIX COMPOSITES

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# Classification of Composite Materials by Primary Phase (Matrix Material)

1. *Metal Matrix Composites* (MMCs) - mixtures of ceramics and metals, such as cemented carbides and other cermets
2. *Ceramic Matrix Composites* (CMCs) -  $\text{Al}_2\text{O}_3$  and SiC imbedded with fibers to improve properties, especially in high temperature applications
  - The least common composite matrix
3. *Polymer Matrix Composites* (PMCs) - thermosetting resins are widely used in PMCs
  - Examples: epoxy and polyester with fiber reinforcement, and phenolic with powders

# Functions of the Matrix Material (Primary Phase)

- ✓ Provides the bulk form of the part or product made of the composite material
- ✓ Holds the imbedded phase in place, usually enclosing and often concealing it
- ✓ When a load is applied, the matrix shares the load with the secondary phase, in some cases deforming so that the stress is essentially born by the reinforcing agent

# Functions of the Reinforcing Phase (Secondary Phase)

- ✓ Function is to reinforce the primary phase
- ✓ Imbedded phase is most commonly one of the following shapes:
  - ✓ Fibers
  - ✓ Particles
  - ✓ Flakes
- ✓ In addition, the secondary phase can take the form of an infiltrated phase in a skeletal or porous matrix
  - Example: a powder metallurgy part infiltrated with polymer

# Metal Matrix Composites (MMCs)

A *metal* matrix reinforced by a second phase

- Reinforcing phases:
  1. *Particles* of ceramic (these MMCs are commonly called *cermets*)
  2. *Fibers* of various materials: other metals, ceramics, carbon, and boron

# Metal Matrix Composites (MMCs)

- Materials consisting of metallic matrices, reinforced with ceramic particles or fibers, are known as metal matrix composites or MMCs
- The volume fraction of the reinforcement is typically in the range 10-70%.
- MMCs can offer a range of property enhancement over monolithic alloys.

# Metal Matrix Composites (MMCs)

- Metal matrix composite materials have found application in many areas of daily life for quite some time.
- Materials like cast iron with graphite or steel with a high carbide content, as well as tungsten carbides, consisting of carbides and metallic binders, also belong to this group of composite materials.
- Metal matrix composites become interesting for use as constructional and functional materials, if the property profile of conventional materials either does not reach the increased standards of specific demands, or is the solution of the problem.

# Metal Matrix Composites (MMCs)

The reinforcement of metals can have many different objectives;

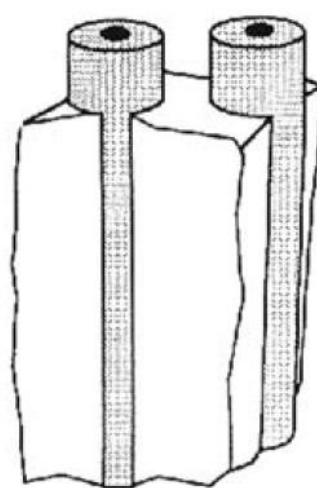
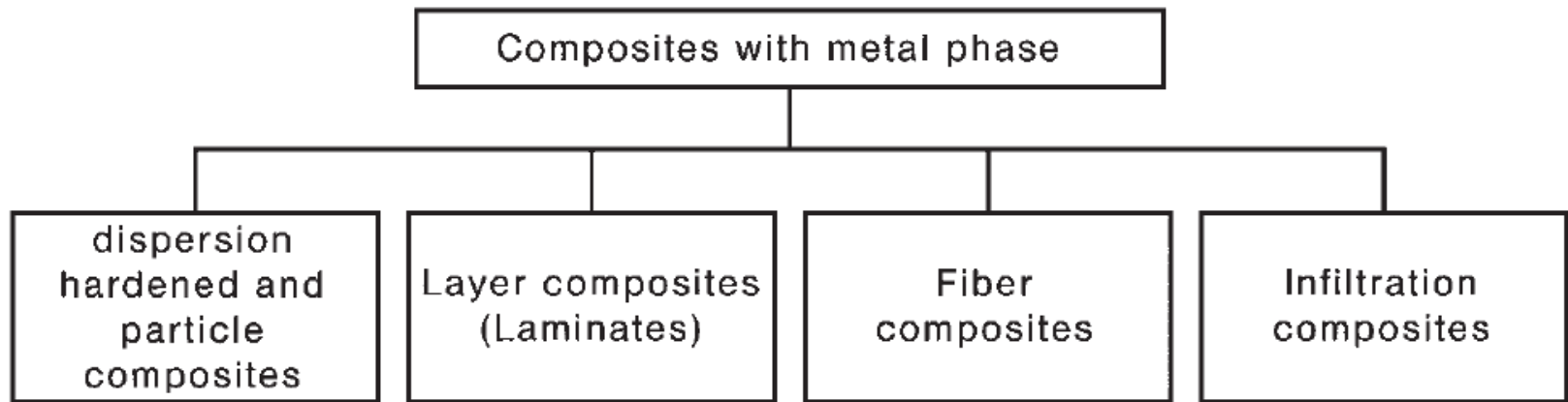
- ✓ Increase in yield strength and tensile strength at room temperature and above while maintaining the minimum ductility or rather toughness,
- ✓ Increase in creep resistance at higher temperatures compared to that of conventional alloys,
- ✓ Increase in fatigue strength, especially at higher temperatures,
- ✓ Improvement of thermal shock resistance,
- ✓ Improvement of corrosion resistance,
- ✓ Increase in Young's modulus,
- ✓ Reduction of thermal elongation.



# Advantages

- ✓ Light Weight
- ✓ Performance at higher temperatures
- ✓ High Strength
- ✓ Low Density, Better wear resistance

# Classification of Metal Matrix Composites



Mono filaments



Whiskers/  
Short fibers



Particle

# Reinforcements for Metal Matrix Composites

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

- ✓ low density
- ✓ mechanical compatibility (a thermal expansion coefficient which is low but adapted to the matrix)
- ✓ chemical compatibility
- ✓ thermal stability
- ✓ high Young's modulus
- ✓ high compression and tensile strength
- ✓ good processability
- ✓ economic efficiency

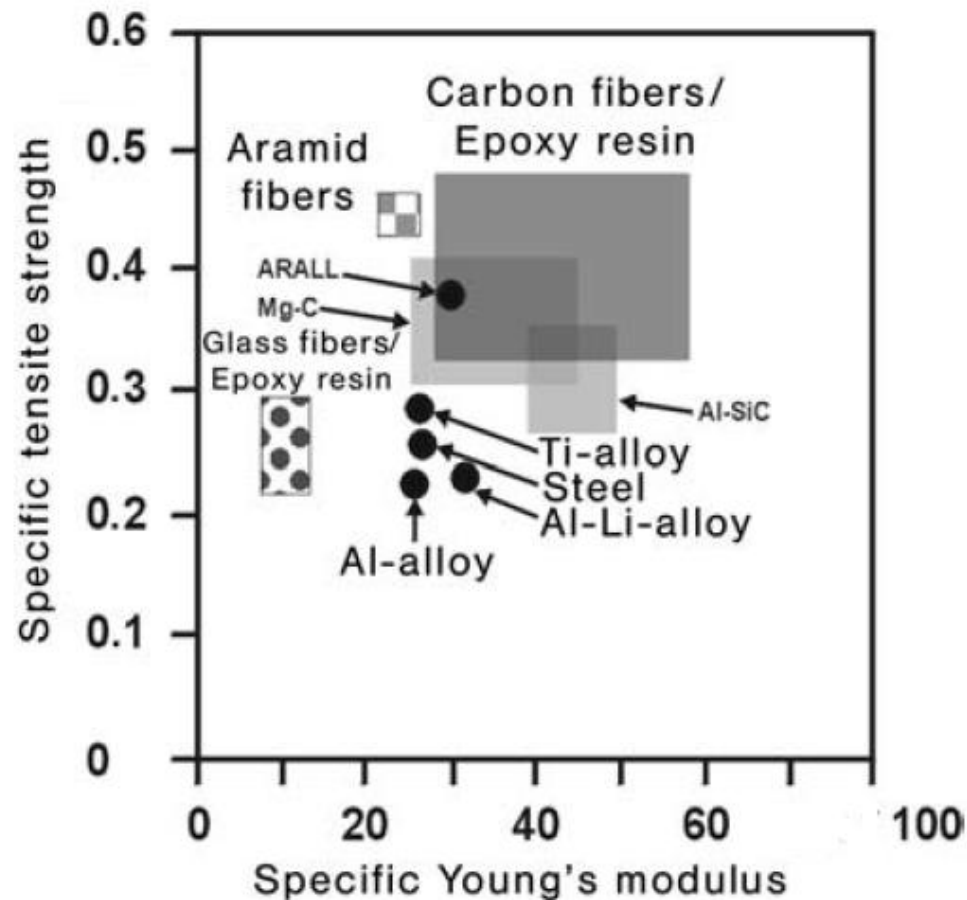
# Reinforcements for Metal Matrix Composites

- These demands can be achieved only by using non-metal inorganic reinforcement components. For metal reinforcement ceramic particles or, rather, fibers or carbon fibers are often used.

Property potential of different metal matrix composites

<i>MMC type</i>	<i>Properties Strength</i>	<i>Young's modulus</i>	<i>High temperature properties</i>	<i>Wear</i>	<i>Expansion coefficient</i>	<i>Costs</i>
mineral wool: MMC	*	*	**	**	*	medium
discontinuous reinforced MMC	**	**	*	***	**	low
long fiber reinforced MMC: C fibers	**	**	**	*	***	high
other fibers	***	***	***	*	**	high

# Reinforcements for Metal Matrix Composites



Specific tensile strength and specific Young's modulus of different quasi-isotropic fiber composite materials in comparison to some metal alloys

# Processing of Metal Matrix Composites

- ✓ Metal matrix composite materials can be produced by many different techniques.
- ✓ The focus of the selection of suitable process engineering 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.

# Liquid-State Processes

## Casting or liquid infiltration

- ✓ **Casting or liquid infiltration** involves infiltration of a fibrous or particulate reinforcement preform by a liquid metal.
- ✓ Liquid-phase infiltration of MMCs is not straightforward, mainly because of difficulties with wetting the ceramic reinforcement by the molten metal.
- ✓ When the infiltration of a fiber preform occurs readily, reactions between the fiber and the molten metal may take place which significantly degrade the properties of the fiber.

# Liquid-State Processes

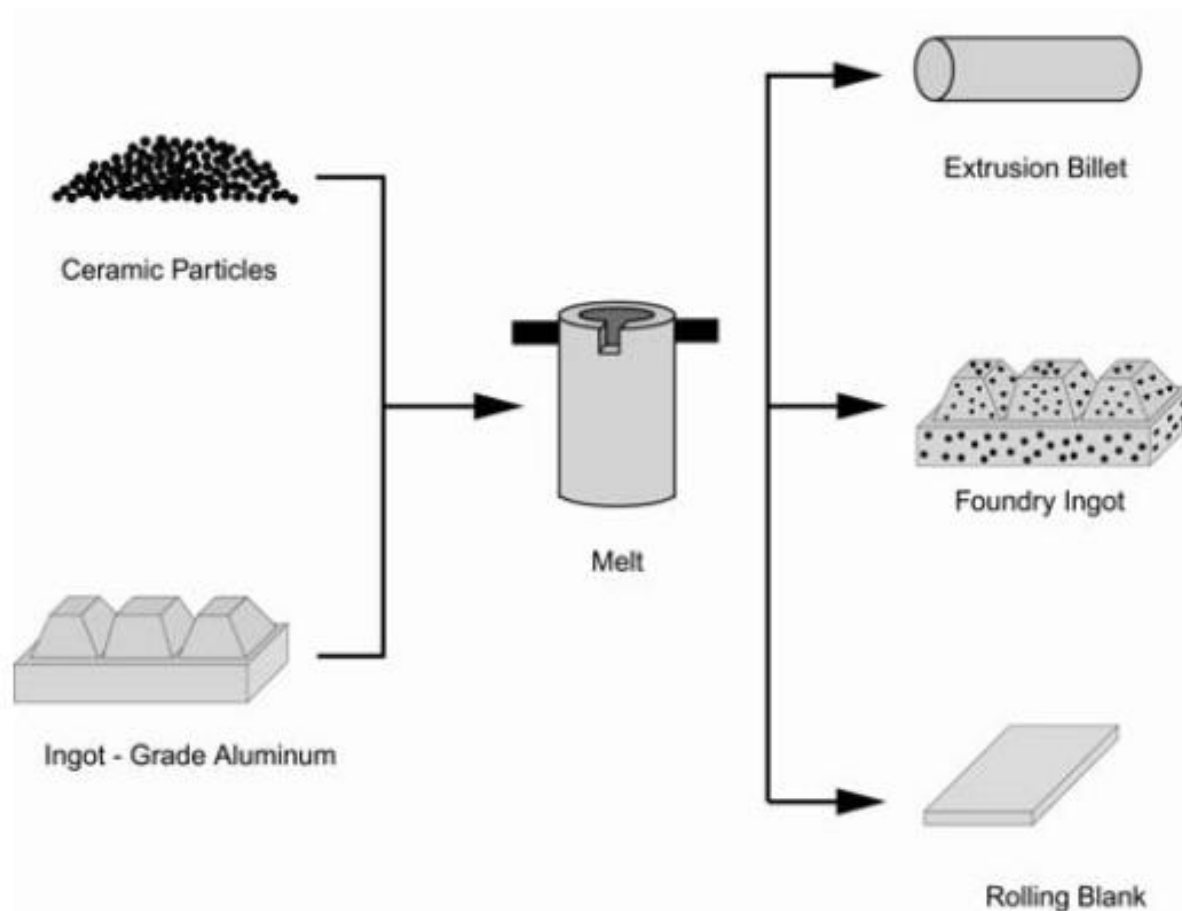
## Casting or liquid infiltration

- ✓ A liquid infiltration process called the Duralcan process involving particulate reinforcement, has been successfully used for MMC synthesis.
- ✓ Ceramic particles and ingot-grade aluminum are mixed and melted.
- ✓ The melt is stirred slightly above the liquidus temperature (600–700°C).
- ✓ The solidified ingot may also undergo secondary processing by extrusion or rolling.
- ✓ The Duralcan process of making particulate composites by a liquid metal casting route involves the use of 8–12  $\mu\text{m}$  particles.



# Liquid-State Processes

## Casting or liquid infiltration



Duralcan process for particulate or short fiber MMCs.

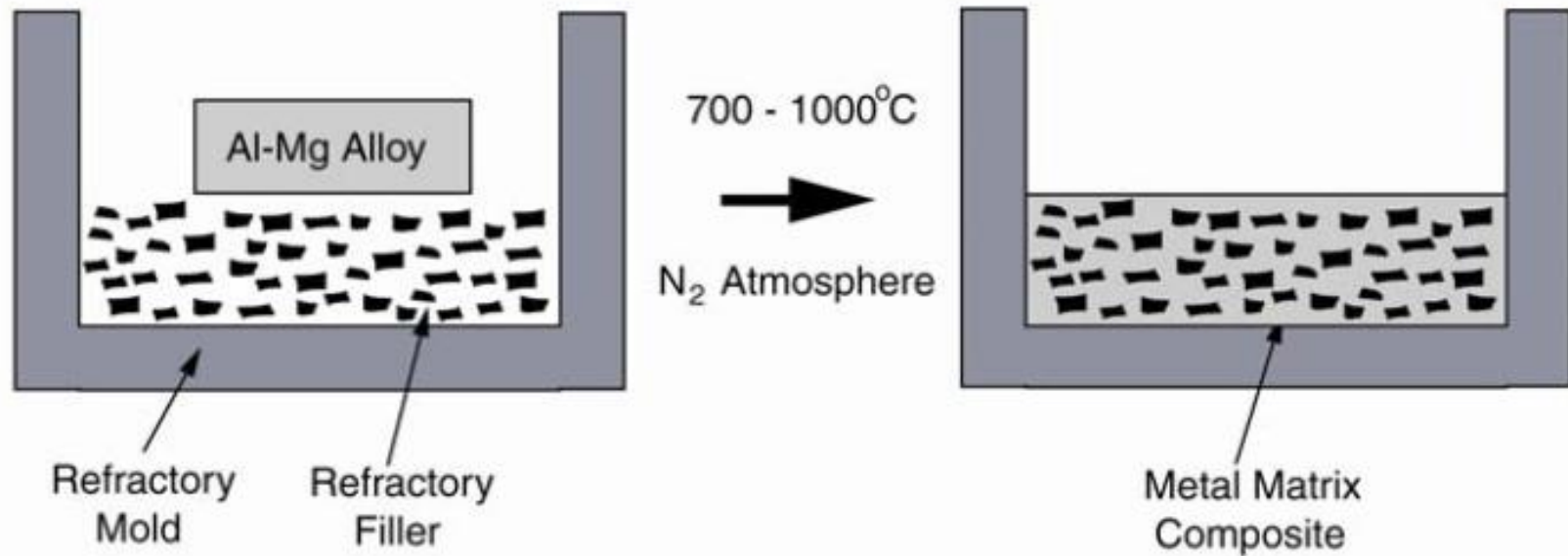
# Liquid-State Processes

## Casting or liquid infiltration

- ✓ Another pressureless liquid metal infiltration process of making MMCs is the Primex process (Lanxide), which can be used with certain reactive metal alloys such as Al– Mg to infiltrate ceramic preforms
- ✓ For an Al– Mg alloy, the process takes place between 750–1000°C in a nitrogen-rich atmosphere, and typical infiltration rates are less than 25 cm/h.

# Liquid-State Processes

## Casting or liquid infiltration



Reactive liquid metal infiltration process.

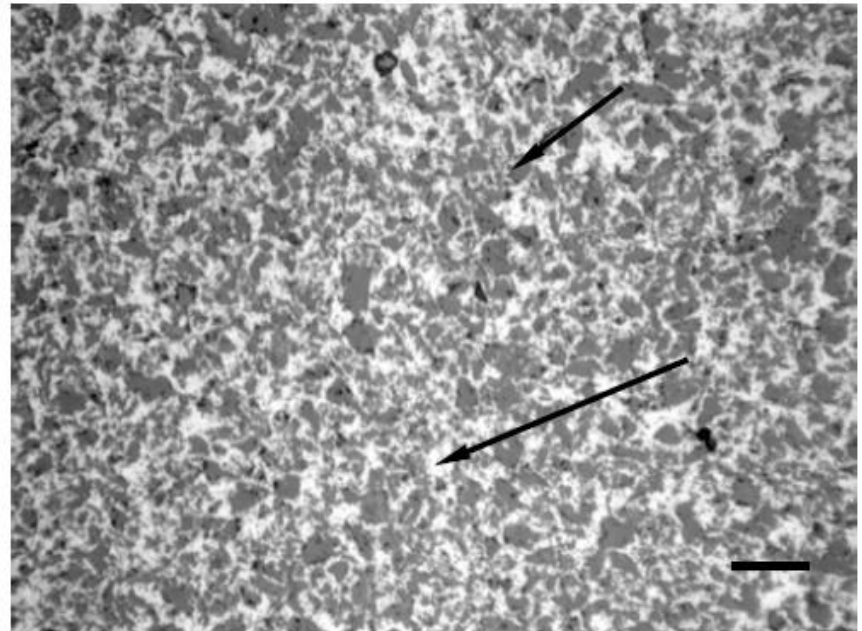
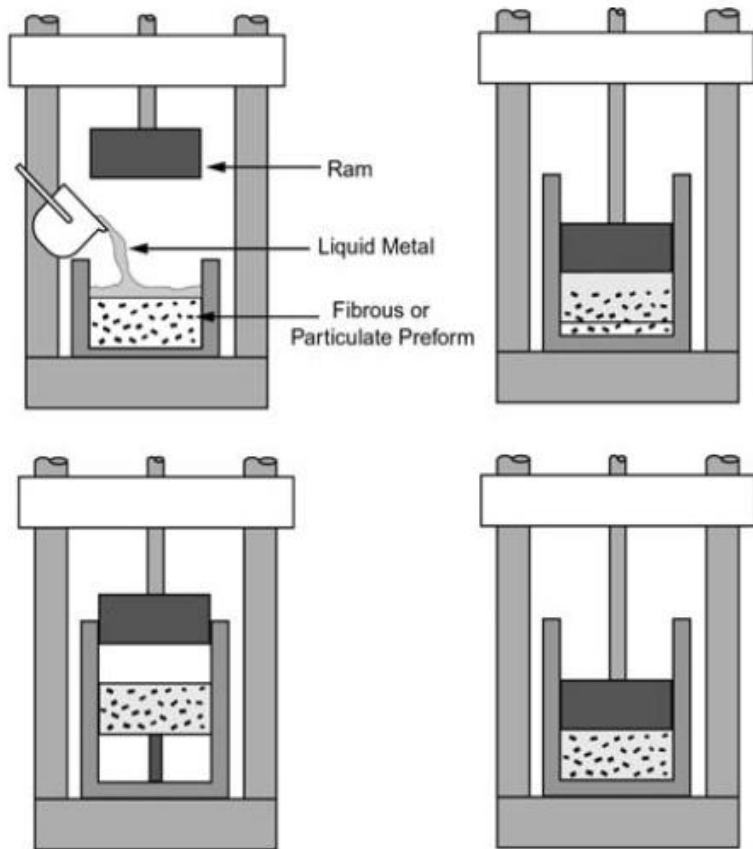
# Liquid-State Processes

## Squeeze casting or pressure infiltration

- ✓ Involves forcing a liquid metal into a fibrous or particulate preform. Pressure is applied until solidification is complete.
- ✓ By forcing the molten metal through small pores of the fibrous preform, this method obviates the requirement of good wettability of the reinforcement by the molten metal.
- ✓ Composites fabricated with this method have the advantage of minimal reaction between the reinforcement and molten metal because of the short processing time involved.
- ✓ The process is conducted in the controlled environment of a pressure vessel and rather high fiber volume fractions; complex shaped structures are obtainable .
- ✓ Alumina fiber reinforced intermetallic matrix composites, e.g., TiAl, Ni<sub>3</sub>Al, and Fe<sub>3</sub>Al matrix materials, have also been prepared by pressure casting

# Liquid-State Processes

## Squeeze casting or pressure infiltration



(a) Squeeze casting or pressure infiltration process and  
(b) microstructure of Al 6061/SiC composite

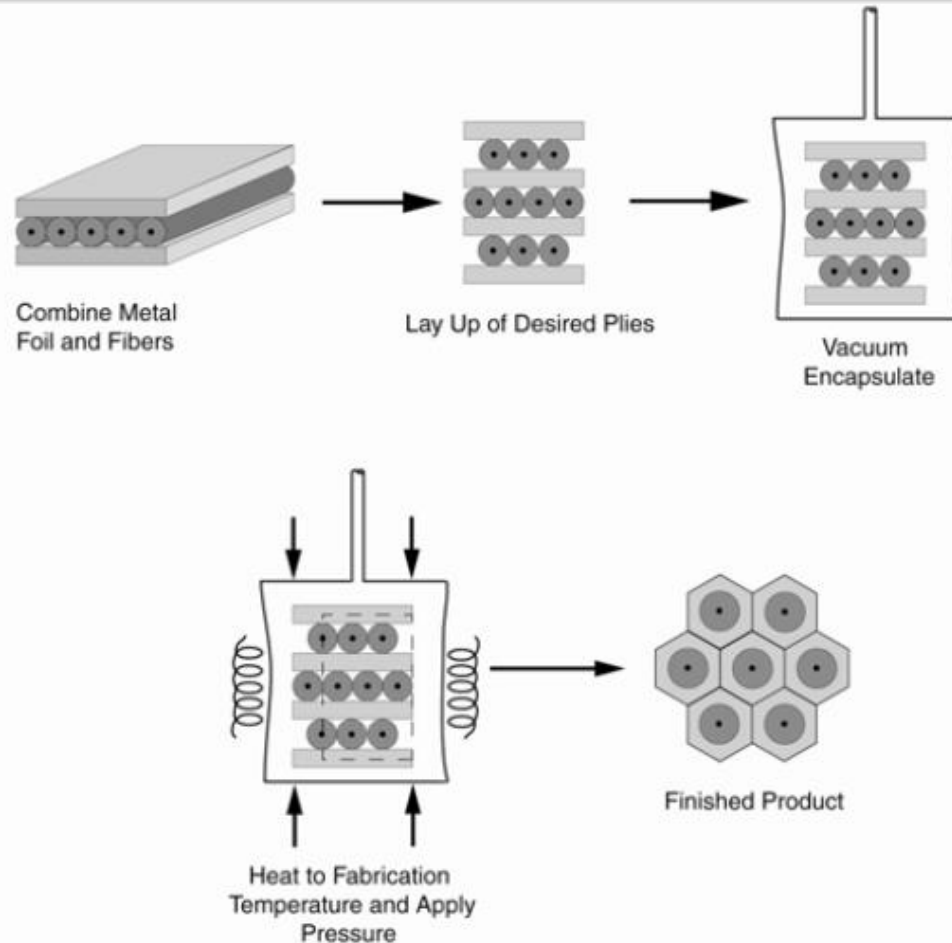
# Solid-State Processes

## Diffusion Bonding

- ✓ ***Diffusion bonding*** is a common solid-state processing technique for joining similar or dissimilar metals. Interdiffusion of atoms between clean metallic surfaces, in contact at an elevated temperature, leads to bonding.
- ✓ The principal advantages of this technique are the ability to process a wide variety of metal matrices and control of fiber orientation and volume fraction.
- ✓ Among the disadvantages are long processing times, high processing temperatures and pressures (which makes the process expensive), and a limitation on the complexity of shapes that can be produced.
- ✓ There are many variants of the basic diffusion bonding process, although all of them involve simultaneous application of pressure and high temperature.
- ✓ Vacuum hot pressing is an important step in the diffusion bonding processes for metalmatrix composites. Hot isostatic pressing (HIP), instead of uniaxial pressing, can also be used.

# Solid-State Processes

## Diffusion Bonding



Diffusion bonding process: **(a)** apply metal foil and cut to shape, **(b)** lay up desired plies, **(c)** vacuum encapsulate and heat to fabrication temperature, **(d)** apply pressure and hold for consolidation cycle, and **(e)** cool, remove, and clean part.

# Solid-State Processes

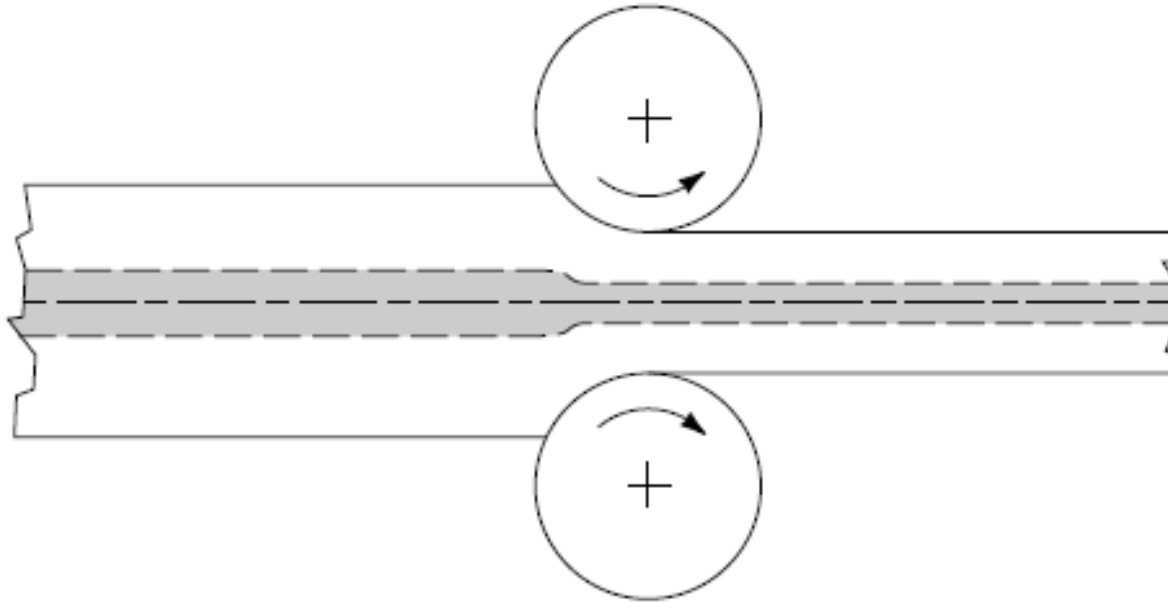
## Deformation Processing

- ✓ **Deformation processing** can also be used to deform and/or densify the composite material.
- ✓ In metal–metal composites mechanical processing (swaging, extrusion, drawing, or rolling) of a ductile two-phase material causes the two phases to co-deform, causing one of the phases to elongate and become fibrous in nature within the other phase.
- ✓ The properties of a deformation processed composite depend largely on the characteristics of the starting material, which is usually a billet of a two-phase alloy that has been prepared by casting or powder metallurgy methods.
- ✓ Roll bonding is a common technique used to produce a laminated composite consisting of different metals in layered form. Such composites are called sheet laminated metal-matrix composites.



# Solid-State Processes

## Deformation Processing



Roll bonding process of making a laminated MMC; a metallurgical bond is produced

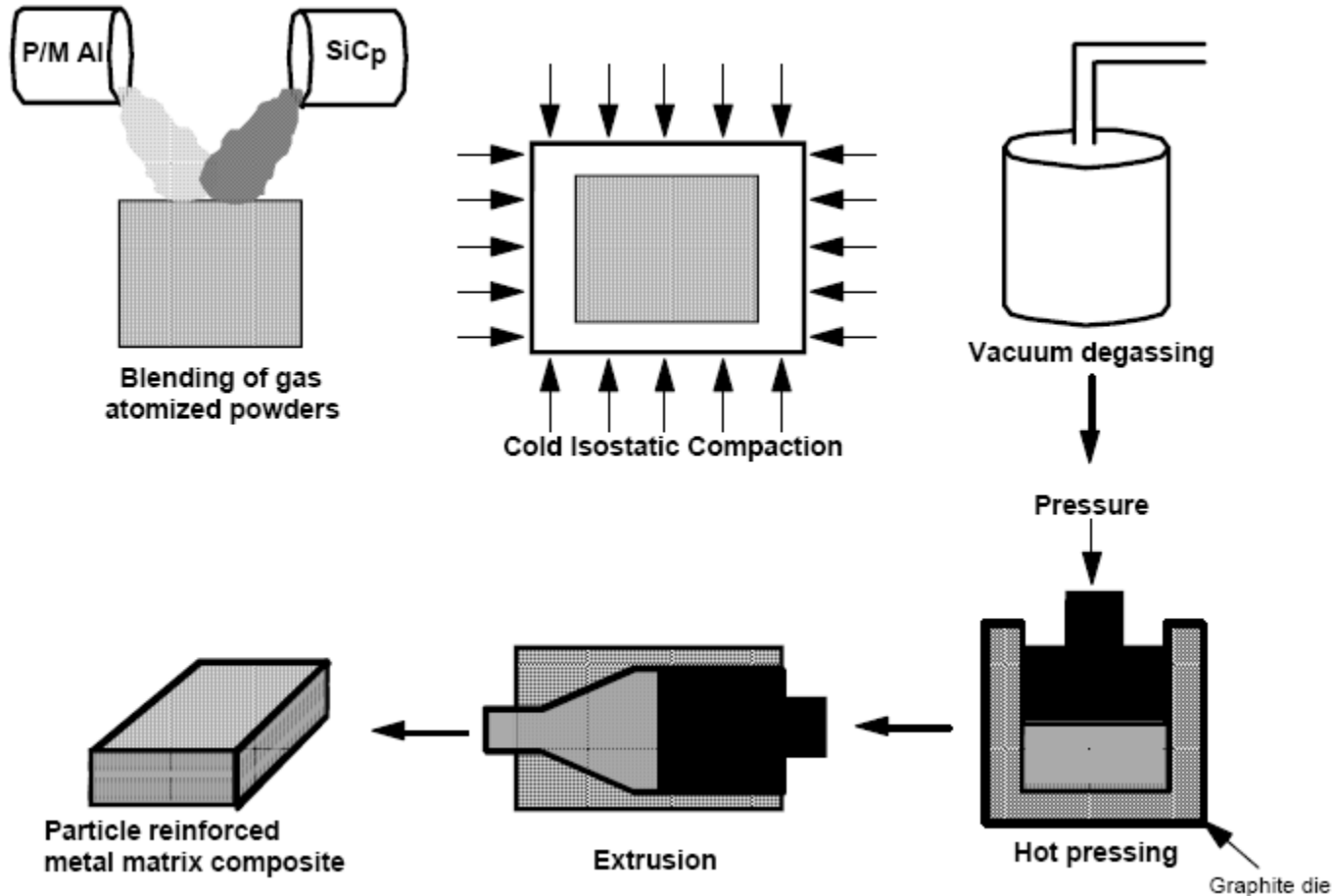
# Solid-State Processes

## Powder Processing

- ***Powder processing*** methods in conjunction with deformation processing are used to fabricate particulate or short fiber reinforced composites.
- This typically involves cold pressing and sintering, or hot pressing to fabricate primarily particle- or whisker-reinforced MMCs.
- The matrix and the reinforcement powders are blended to produce a homogeneous distribution.
- The blending stage is followed by cold pressing to produce what is called a green body, which is about 80% dense and can be easily handled.
- The cold pressed green body is canned in a sealed container and degassed to remove any absorbed moisture from the particle surfaces.
- The material is hot pressed, uniaxially or isostatically, to produce a fully dense composite and extruded. The rigid particles or fibers cause the matrix to be deformed significantly.

# Solid-State Processes

## Powder Processing

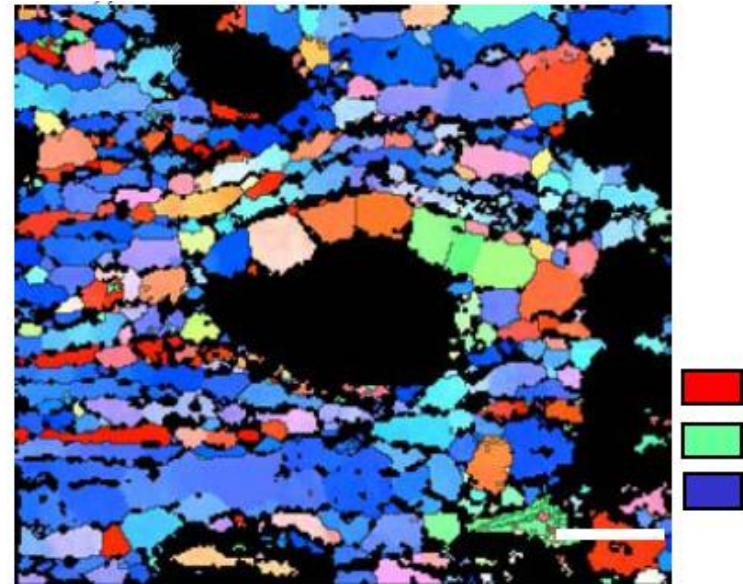
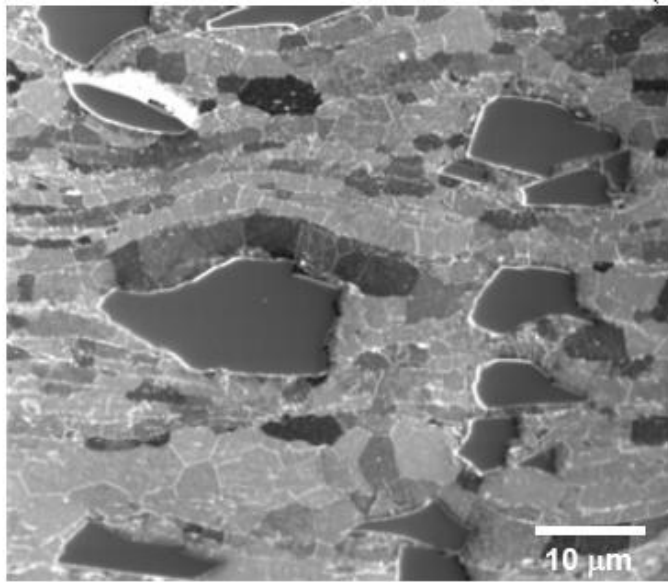


Powder processing, hot pressing, and extrusion process for fabricating particulate or short fiber reinforced MMCs

# Solid-State Processes

## Powder Processing

During hot extrusion, dynamic recrystallization takes place at the particle/matrix interface, yielding randomly oriented grains near the interface, and relatively textured grains far from the interface.



(a) Microstructure of SiC particle reinforced 2080 Al matrix composite after hot extrusion and (b) Orientation image map showing random orientation of grains at the particle/matrix interface due to dynamic recrystallization, and textured grains away from the interface

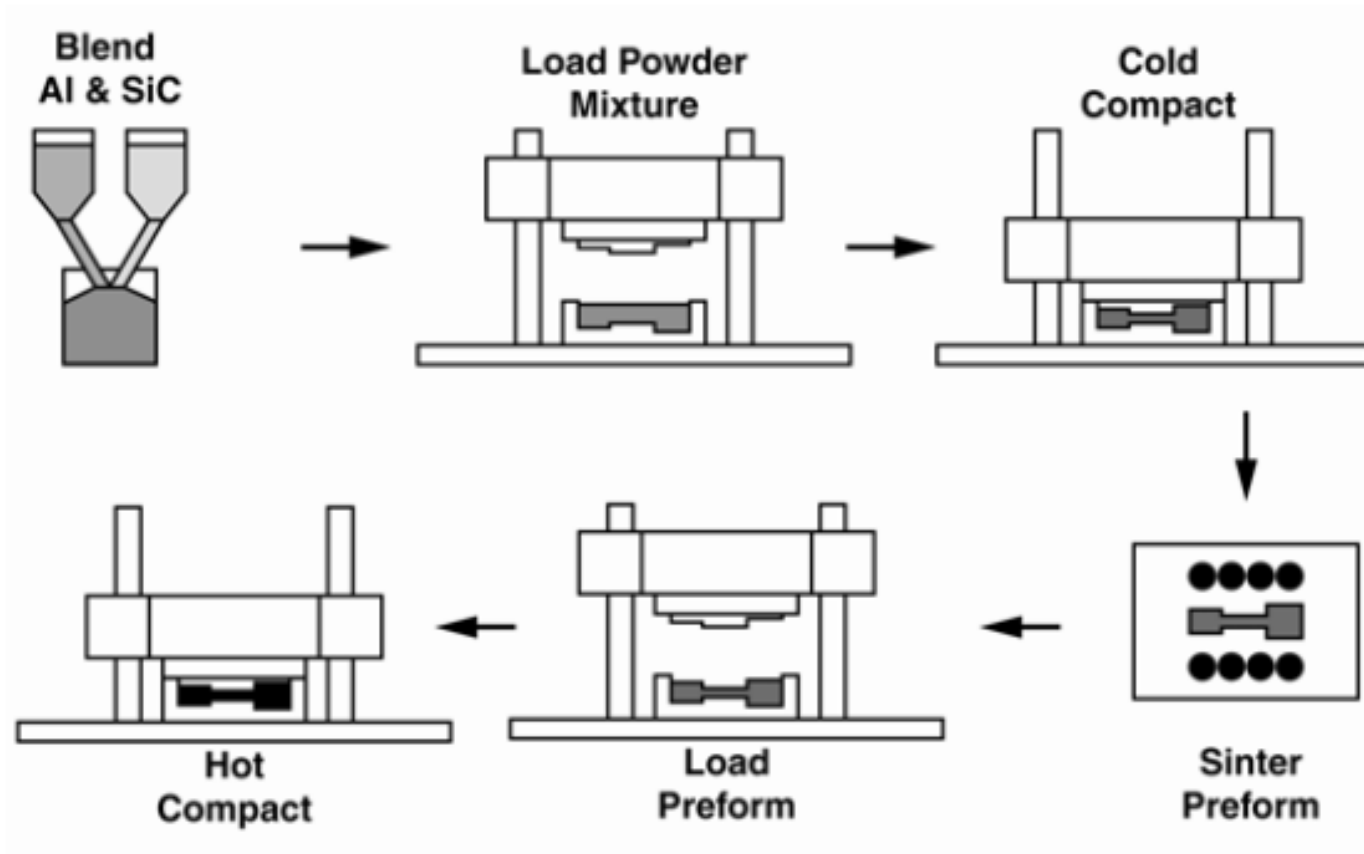
# Solid-State Processes

## Sinter-Forging

- ✓ ***Sinter-forging*** is a novel and low cost deformation processing technique.
- ✓ In sinter-forging, a powder mixture of reinforcement and matrix is cold compacted, sintered, and forged to nearly full density.
- ✓ The main advantage of this technique is that forging is conducted to produce a near-net shape material, and machining operations and material waste are minimized.
- ✓ The low cost, sinter-forged composites have tensile and fatigue properties that are comparable to those of materials produced by extrusion.

# Solid-State Processes

## Sinter-Forging



Sinter-forging technique for producing near-net shape, low cost MMCs

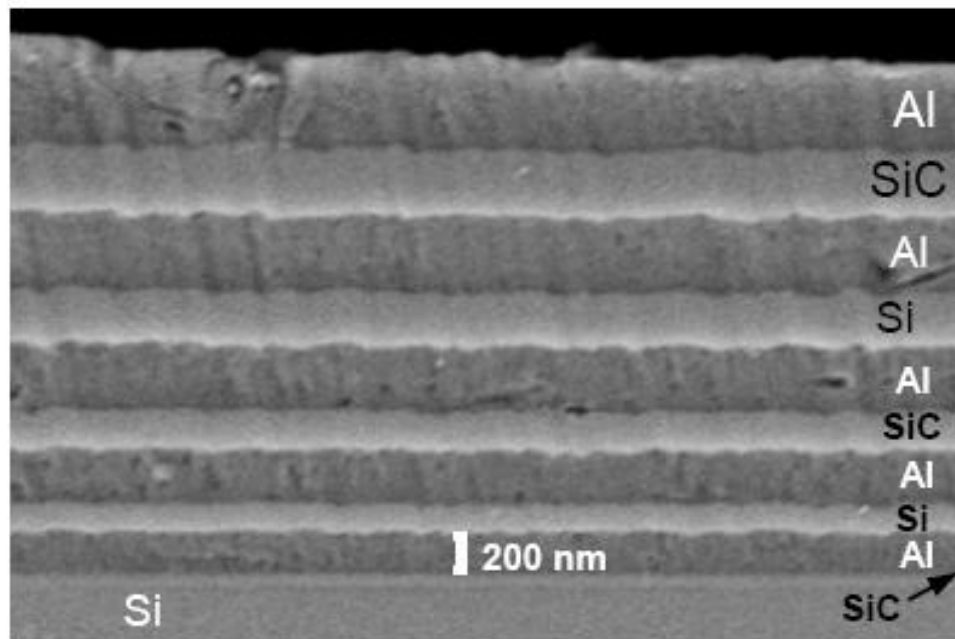
# Solid-State Processes

## Deposition Techniques

- ✓ ***Deposition techniques*** for metal-matrix composite fabrication involve coating individual fibers with the matrix material needed to form the composite followed by diffusion bonding to form a consolidated composite plate or structural shape
- ✓ Several deposition techniques are available: immersion plating, electroplating, spray deposition, chemical vapor deposition (CVD), and physical vapor deposition (PVD)
- ✓ PVD may also be used to produce multilayered MMCs, particularly at the nanometer scale

# Solid-State Processes Deposition Techniques

- Thin film MMC microstructure with individual layers on the nanometer scale



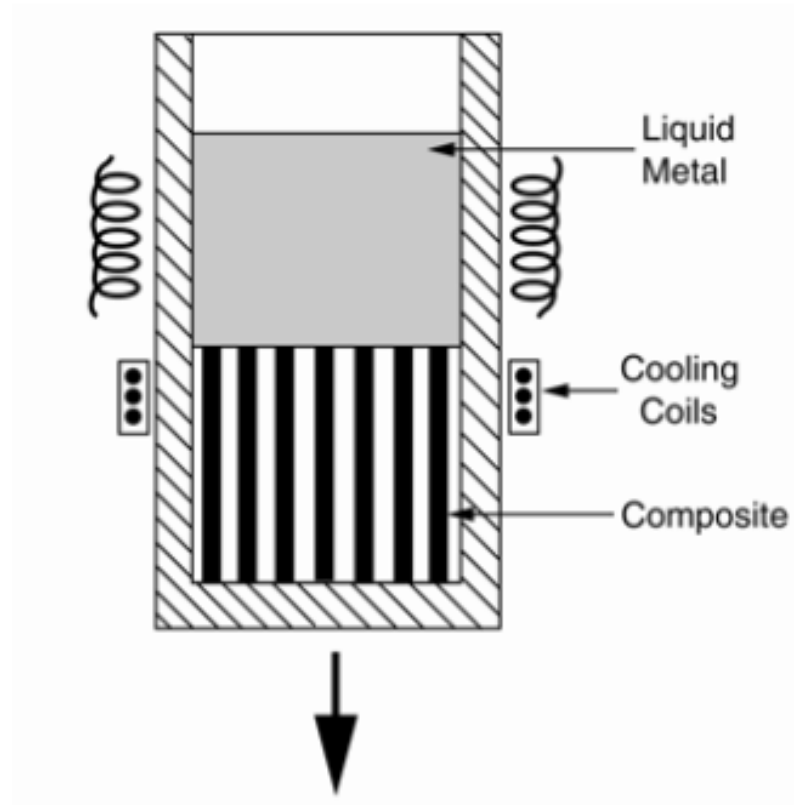
Microstructure of multilayered Al/SiC composite deposited by PVD. The thickness of the layers increases progressively with distance from the Si substrate.



# In Situ Processes

- ✓ In these techniques, the reinforcement phase is formed *in situ*.
- ✓ The composite material is produced in one step from an appropriate starting alloy, thus avoiding the difficulties inherent in combining the separate components as done in a typical composite processing.
- ✓ Controlled unidirectional solidification of a eutectic alloy is a classic example of *in situ* processing. Unidirectional solidification of a eutectic alloy typically results in one phase being distributed in the form of fibers or ribbon in the matrix phase.
- ✓ The relative size and spacing of the reinforcement phase can be controlled by simply controlling the solidification rate, although the volume fraction of reinforcement will always be constant.

# In Situ Processes

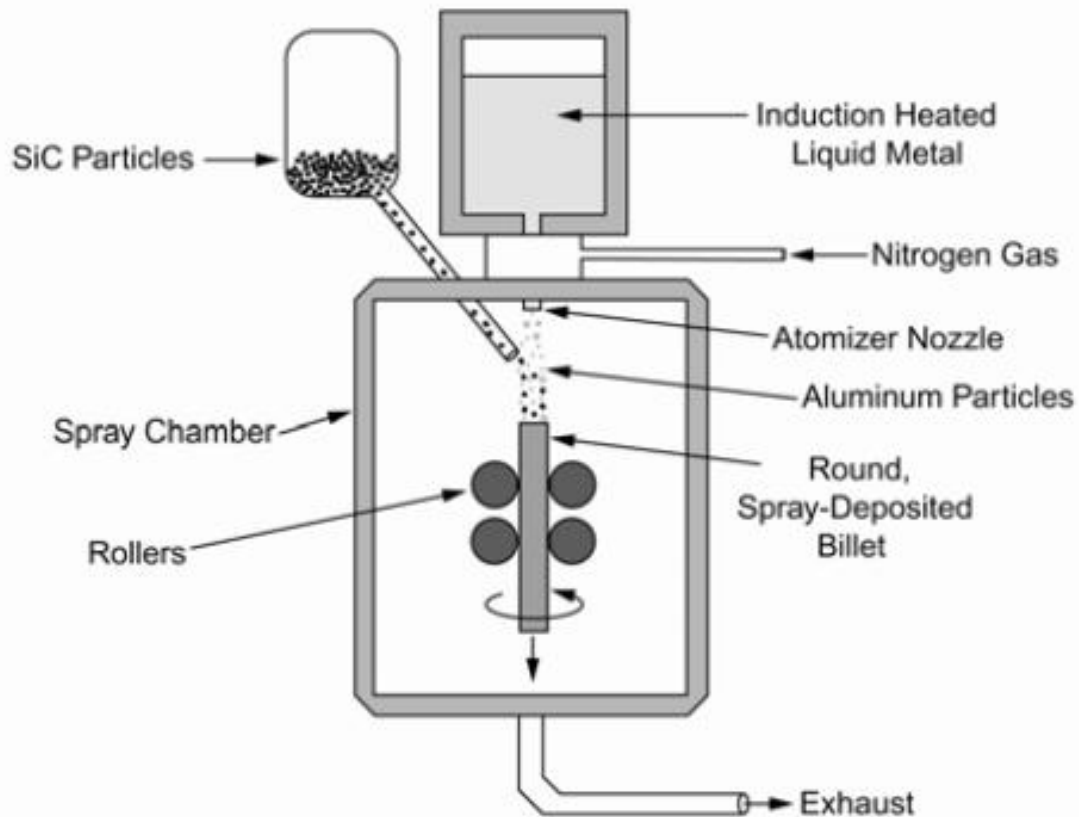


*In situ* processing by controlled unidirectional solidification of a eutectic alloy.

# Spray-Forming of Particulate MMCs

- ✓ Another process for making particle-reinforced MMCs involves the use of modified spray forming techniques that have been used to produce monolithic alloys.
- ✓ One particular example of this, a co-spray process, uses a spray gun to atomize a molten aluminum alloy matrix, into which heated silicon carbide particles are injected.
- ✓ Silicon carbide particles with volume fractions up to 20% have been incorporated into aluminum alloys.
- ✓ An advantage of the process is the flexibility it provides in making different types of composites, eg, *in situ* laminates can be made using two sprayers or by selective reinforcement.
- ✓ This process is quite expensive, however, mainly because of the costly capital equipment.

# Spray-Forming of Particulate MMCs



The spray-forming process