LECTURE NOTES

ON

SPECIAL MANUFACTURING PROCESS

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UNIT-I

SURFACE TREATMENT

Surface Treatment Type	**Concepts and Applications of the process**
Electroplating	A method of forming metallic coatings (plating films) on subject metal surfaces submerged in solutions containing ions by utilizing electrical reduction effects. Electoplating is employed in a wide variety of fields from micro components to large products in information equipment, automobiles, and home appliances for ornamental plating, anti-corrosive plating, and functional plating.
Electroless Plating	A plating method that does not use electricity. The reduction agent that replaces the electricity is contained in the plating solution. With proper re-processing, virtually any material such as paper, fabrics, plastic and metals can be plated, and the distribution of the film thickness is more uniform, but slower than electroplating. This is different from chemical plating by substitution reaction.
Chemical Process (Chemical Coating)	The process creates thin films of sulfide and oxide films by chemical reactions such as post zinc plating chromate treatment, phosphate film coating (Parkerizing), black oxide treatments on iron and steels, and chromic acid coating on aluminum. It is used for metal coloring, corrosion protection, and priming of surfaces to be painted to improve paint adhesion.
Anodic Oxidation Process	This is a surface treatment for light metals such as aluminum and titanium, and oxide films are formed by electrolysis of the products made into anodes in electrolytic solutions. Because the coating (anodizing film) is porous, dyeing and coloring are applied to be used as construction materials such as sashes, and vessels. There is low temperature treated hard coating also.
Hot Dipping	Products are dipped in dissolved tin, lead, zinc, aluminum, and solder to form surface metallic films. It is also called Dobuzuke plating and Tempura plating. Familiar example is zinc plating on steel towers.

Vacuum Plating	Gasified or ionized metals, oxides, and nitrides in vacuum chambers are vapor deposited with this method. Methods are vacuum vapor deposition, sputtering, ion plating, ion nitriding, and ion implantation. Titanium nitride is of gold color.
Painting	There are spray painting, electrostatic painting, electrodeposition painting, powder painting methods, and are generally used for surface decorations, anti-rusting and anti-corrosion. Recently, functional painting such as electro-conductive painting, non-adhesive painting, and lubricating painting are in active uses.
Thermal Spraying	Metals and ceramics (oxides, carbides, nitrides) powders are jetted into flames, arcs, plasma streams to be dissolved and be sprayed onto surfaces. Typically used as paint primer bases on larger structural objects, and ceramic thermal spraying for wear prevention.
Surface Hardening	This is a process of metal surface alteration, such as carburizing, nitriding, and induction hardening of steel. The processes improve anti-wear properties and fatigue strength by altering metal surface properties.
Metallic Cementation	This is a method of forming surface alloy layers by covering the surfaces of heated metals and metal diffusion at the same time. There is a method of heating the pre-plated products, as well as heating the products in powdered form of metal to be coated.

Surface coating, any mixture of film-forming materials plus pigments, solvents, and other additives, which, when applied to a surface and cured or dried, yields a thin film that is functional and often decorative. Surface coatings include paints, drying oils and varnishes, syntheticclear coatings, and other products whose primary function is to protect the surface of an object from the environment. These products can also enhance the aesthetic appeal of an object by accentuating its surface features or even by concealing them from view.

Most surface coatings employed in industry and by consumers are based on synthetic polymers—that is, industrially produced substances composed of extremely large, often interconnected molecules that form tough, flexible, adhesive films when applied to surfaces. The other component materials of surface coatings are pigments, which provide colour, opacity, gloss, and other properties; solvents or carrier liquids, which provide a liquid medium for applying the film-forming ingredients; and additives, which provide a number of special properties. This article reviews the composition and film-forming properties of polymer-based surface coatings, beginning with the polymer ingredients and continuing through the pigments, liquids, and additives. The emphasis is on paints (by far the most common type of coating), though occasional reference is made to other types of coatings such as drying oils and varnishes. For a fuller understanding of polymeric compounds, which form the basis of surface coatings, the reader is advised to begin with the article industrial polymers, chemistry of. For an overview of the position of surface coatings within the broader field of industrial polymers, see Industrial Polymers: Outline of Coverage.

***Organic Coating*:**

An organic coating is a type of coating whose primary ingredients are derived from either vegetable or animal matter or from compounds rich in carbon. These coatings are primarily used to provide additive type finishes on the materials on which they are applied. Organic coatings can be monolithic (consisting of only one layer) or two or more layers.

Organic coatings act as a protective barrier against corrosion and oxidation. These are durable coatings applied to a substrate for their decorative or specific technical properties. Organic coatings depend primarily on their chemical inertness and impermeability. Various types of organic coatings are available for industrial purposes including primers, adhesive cements and topcoats (enamel, varnish and paints).

Organic coatings are easy to apply with the help of brushes, sprays, rollers, dips, or by electrostatic means. Brush application is a slow and lengthy procedure. The coating cures or dries by evaporation or loss of solvent, polymerization and oxidation.

Ceramic Coatings

Ceramic coatings can provide high-performance oxide layers on metals and alloys to solve the problems of corrosion, wear, heat, insulation and friction. Some ceramic coatings include thermal spray coating, plasma spray coating, sputter coating, dry-film lubricants and other wet chemical and electrochemical coatings.The thickness of ceramic films can range from 50 nm to several micron meters, depending on the application and coating processes. Recently, new nanoscale ceramic coatings such as Si_3N_4, silicon carbide, a diamond-like coating, boron nitride and cerium oxide have been considered in metal and alloy coatings to produce promising high-temperature structural materials due to their excellent thermo-mechanical properties.

Ceramic coatings have various advantages: they increase the lifetime of parts, prevent corrosion, reduce heat on high-temperature components, reduce friction, stop thermal and acidic corrosion and improve the appearance of surfaces. Although ceramic coatings have several advantages, they have some disadvantages as well: they are extremely brittle and hard to repair; de-bonding can occur during the expansion and shrinkage; corrosion easily forms at the cracks; they are heavier than organic coatings; and the coating involves additional equipment, supplies and labor.[48]

Economics of Coating

Economics of surface coatings on metals are discussed with emphasis on surface preparation, especially when large scale coating operations are conducted. ... Tabulated data on area costs of various modes a location for surface preparation and coating costs for various metal configurations are provided.

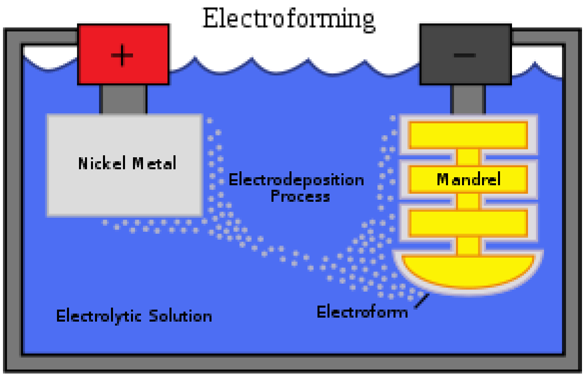
Costs are based on typical system recommendations using airless spray equipment and conservative life expectancy projections generally accepted by the coatings industry as reasonable. The intent of this data is to convey concepts useful to the professional person charged with corrosion control responsibilities.

Electroforming

Electroforming is a metal forming process that forms parts through electrodeposition on a model, known in the industry as a mandrel. Conductive (metallic) mandrels are passivated (chemically) to preclude 'plating' and thereby to allow subsequent separation of the finished electroform.

Non-conductive (glass, silicon, plastic) mandrels require the deposition of a conductive layer prior to electrodeposition. Conductive layers can be deposited chemically, or using vacuum deposition techniques (e.g., gold sputtering). The outer surface of the mandrel forms the inner surface of the form.

The process involves high current through very clean water, having no more than about 5 parts per million organic contamination. The 'thrown' ions find their missing electrons on the mandrel, which is in electrical contact with the cathode of the electroforming tank. The ions deposit as neutral metal atoms, which bind to each other. Metal is electrodeposited until it is strong enough to be self-supporting. The mandrel is most often separated intact or dissolved away after forming, but occasionally (as in the case in decorative electroforming) left in place.



Electroforming process

Chemical vapor deposition (**CVD**) is a deposition method used to produce high quality, high-performance, solid materials, typically under vacuum. The process is often used in the semiconductor industry to produce thin films.

In typical CVD, the wafer (substrate) is exposed to one or more volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit. Frequently, volatile by-products are also produced, which are removed by gas flow through the reaction chamber.

Microfabrication processes widely use CVD to deposit materials in various forms, including: monocrystalline, polycrystalline, amorphous, and epitaxial. These materials include: silicon (dioxide, carbide, nitride, oxynitride),carbon(fiber, nanofibers, nanotubes, diamond and graphene), fluorocarbons, filaments, tungsten, titanium nitride and various high-k dielectrics.

Thermal spraying is an industrial coating process that consists of a heat source (**flame** or other) and a coating material in a powder or wire form which is literally melted into tiny droplets and **sprayed** onto surfaces at high velocity.

Thermal spraying techniques are coating processes in which melted (or heated) materials are sprayed onto a surface. The "feedstock" (coating precursor) is heated by electrical (plasma or arc) or chemical means (combustion flame).

Thermal spraying can provide thick coatings (approx. thickness range is 20 microns to several mm, depending on the process and feedstock), over a large area at high deposition rate as compared to other coating processes such as electroplating, physical and chemical vapor deposition. Coating materials available for thermal spraying include metals, alloys, ceramics, plastics and composites. They are fed in powder or wire form, heated to a molten or semimolten state and accelerated towards substrates in the form of micrometer-size particles. Combustion or electrical arc discharge is usually used as the source of energy for thermal spraying. Resulting coatings are made by the accumulation of numerous sprayed particles. The surface may not heat up significantly, allowing the coating of flammable substances.

Coating quality is usually assessed by measuring its porosity, oxide content, macro and micro-hardness, bond strength and surface roughness. Generally, the coating quality increases with increasing particle velocities.

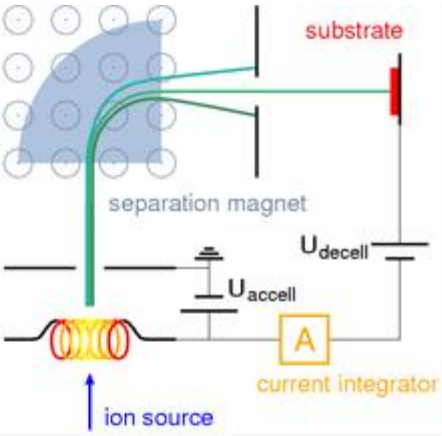
Several variations of thermal spraying are distinguished:

- Plasma spraying
- Detonation spraying
- Wire arc spraying
- Flame spraying
- High velocity oxy-fuel coating spraying (HVOF)
- High velocity air fuel (HVAF)
- Warm spraying
- Cold spraying

In classical (developed between 1910 and 1920) but still widely used processes such as flame spraying and wire arc spraying, the particle velocities are generally low (< 150 m/s), and raw materials must be molten to be deposited. Plasma spraying, developed in the 1970s, uses a high-temperature plasma jet generated by arc discharge with typical temperatures >15000 K, which makes it possible to spray refractory materials such as oxides, molybdenum, etc.

Ion implantation is a low-temperature process by which ions of one element are accelerated into a solid target, thereby changing the physical, chemical, or electrical properties of the target. Ion implantation is used in semiconductor device fabrication and in metal finishing, as well as in materials science research. The ions can alter the elemental composition of the target (if the ions differ in composition from the target) if they stop and remain in the target. Ion implantation also causes chemical and physical changes when the ions impinge on the target at high energy. The crystal structure of the target can be damaged or even destroyed by the energetic collision cascades, and ions of sufficiently high energy (10s of MeV) can cause nuclear transmutation.

General principle



Ion implantation setup with mass separator

Ion implantation equipment typically consists of an ion source, where ions of the desired element are produced, an accelerator, where the ions are electrostatically accelerated to a high energy, and a target chamber, where the ions impinge on a target, which is the material to be implanted. Thus ion implantation is a special case of particle radiation. Each ion is typically a single atom or molecule, and thus the actual amount of material implanted in the target is the integral over time of the ion current. This amount is called the dose. The currents supplied by implants are typically small (micro-amperes), and thus the dose which can be implanted in a reasonable amount of time is small. Therefore, ion implantation finds application in cases where the amount of chemical change required is small.

Typical ion energies are in the range of 10 to 500 keV (1,600 to 80,000 aJ). Energies in the range 1 to 10 keV (160 to 1,600 aJ) can be used, but result in a penetration of only a few nanometers or less. Energies lower than this result in very little damage to the target, and fall under the designation ion beam deposition. Higher energies can also be used: accelerators capable of 5 MeV (800,000 aJ) are common. However, there is often great structural damage to the target, and because the depth distribution is broad (Bragg peak), the net composition change at any point in the target will be small.

The energy of the ions, as well as the ion species and the composition of the target determine the depth of penetration of the ions in the solid: A monoenergetic ion beam will generally have a broad depth distribution. The average penetration depth is called the range of the ions. Under typical circumstances ion ranges will be between 10 nanometers and 1 micrometer. Thus, ion implantation is especially useful in cases where the chemical or structural change is desired to be near the surface of the target. Ions gradually lose their energy as they travel through the solid, both from occasional collisions with target atoms (which cause abrupt energy transfers) and from a mild drag from overlap of electron orbitals, which is a continuous process. The loss of ion energy in the target is called stopping and can be simulated with the binary collision approximation method.

Accelerator systems for ion implantation are generally classified into medium current (ion beam currents between 10 μA and ~2 mA), high current (ion beam currents up to ~30 mA), high energy (ion energies above 200 keV and up to 10 MeV), and very high dose (efficient implant of dose greater than 10^{16} ions/cm^2)

All varieties of ion implantation beamline designs contain certain general groups of functional components (see image). The first major segment of an ion beamline includes a device known as an ion source to generate the ion species. The source is closely coupled to biased electrodes for extraction of the ions into the beamline and most often to some means of selecting a particular ion species for transport into the main accelerator section. The "mass" selection is often accompanied by passage of the extracted ion beam through a magnetic field region with an exit path restricted by blocking apertures, or "slits", that allow only ions with a specific value of the product of mass and velocity/charge to continue down the beamline. If the target surface is larger than the ion beam diameter and a uniform distribution of implanted dose is desired over the target surface, then some combination of beam scanning and wafer motion is used. Finally, the implanted surface is coupled with some method for collecting the accumulated charge of the implanted ions so that the delivered dose can be measured in a continuous fashion and the implant process stopped at the desired dose level.

Diffusion coating is a process in which metal components that will be subjected to high temperature conditions and highly corrosive environments are coated with a non-corrosive material. The process is normally done at elevated temperatures in a controlled chamber.

The most widely used coatings are chromium, aluminum or silicon material. Substrate materials usually coated include cobalt and nickel-based super alloys, steels (including carbon, alloy and stainless steels) and refractory metals, among other alloys. As a result, the base metal develops extreme resistance to corrosion, oxidation and erosion in its severe working conditions. This makes the process highly reliable, enhancing the manufacture of critical components. Diffusion coating is normally used to process gas turbine engine components (vanes, blades and cases), pump impellers, gate valves and power generation components.

Diffusion coating is also called surface alloying.

Diffusion coating can be done using three processes:

- Solid state diffusion
- Liquid state diffusion
- Chemical vapor diffusion

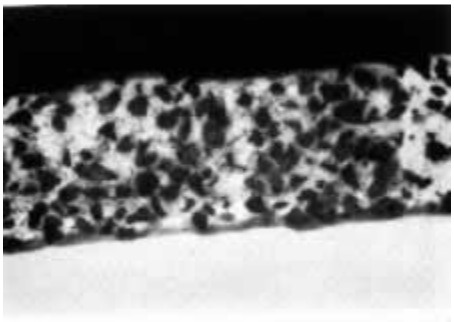
Solid state diffusion is used with nickel, titanium and iron, among other metals, and the vapor pressure of the coating metal must be lower than the base metal. The process is normally performed in a hermetically sealed container with the base metal covered with the powdered coating material. The container is then heated in a vacuum, at a temperature of 1000°C 1500°C (1800°F to 2700°F). The coating metal melts to cover the entire surface of the base metal. This process is also referred to as pack cementation.

Zinc, chrome and copper are normally coated through liquid diffusion. Liquid diffusion is performed in tank furnaces in which the diffusing metal interacts with the base metal's surface at 800°C to 1300°C (1400°F to 2300°F). Complex diffusion coating can be achieved through this process, such as chrome calorization as well as chrome-nickel plating.

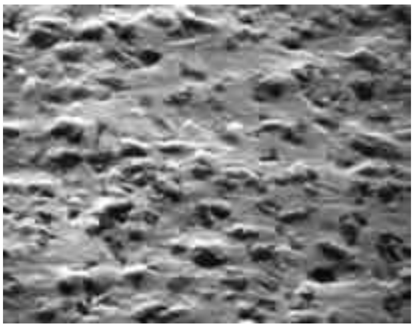
In chemical gas diffusion or out-of-contact gas phase diffusion, the coating material is heated into a gaseous form at a distance from the surface being saturated. The gaseous chemical compounds of the coating element react with the basic metal, resulting in diffusion of the metal. This gaseous phase consists of halides to ensure sublimation of the diffusing metal on the base metal's surface. The process is usually performed in specially designed furnaces at a temperature of 700°C to 1000°C (1300°F to 1800°F).

Composite Diamond Coating is a unique, patented coating with ultra-fine diamond particles contained within hard electroless nickel metal with numerous benefits including:

- Exceptional wear resistance
- Excellent hardness
- Enhanced corrosion resistance
- Perfect conformity to complex geometries including non-line-sight applications
- Increased thermal transfer
- Applicability to all common metals and alloys
- Coverage of entire surfaces or selected critical areas



1000x Cross Section of
Composite Diamond Coating



Photograph of the surface of
Composite Diamond Coating

These features allow increased lifetime and minimize maintenance related downtime due to the replacement of high wear parts. In addition, any process parts enhanced by Composite Diamond Coating will produce more consistent product over an extended period of time. The presence of this unique coating may also allow new materials with other performance or cost advantages to be utilized.

Composite Diamond Coating has long been a standard and economical solution to the extreme wear conditions in the high-speed textile industry. Composite Diamond Coating has also proven to be advantageous in the following industries:

- Gear
- Paper
- Molding
- Tool and die
- Plastics
- Packaging
- Petrochemical

- Automotive

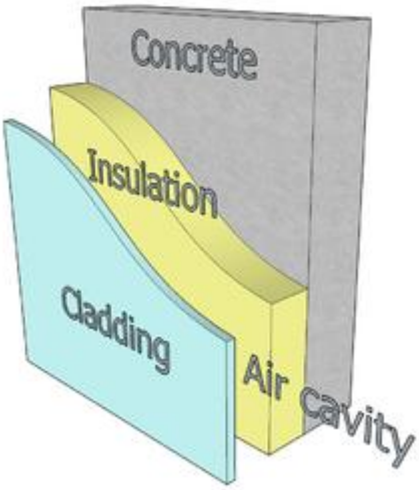
Composite Diamond Coating has received a positive review from the U.S. Food and Drug Administration (FDA) Department of Health and Human Services.

Cladding is the application of one material over another to provide a skin or layer. In construction, cladding is used to provide a degree of thermal insulation and weather resistance, and to improve the appearance of buildings.[1] Cladding can be made of any of a wide range of materials including wood, metal, brick, vinyl, and composite materials that can include aluminium, wood, blends of cement and recycled polystyrene, wheat/rice straw fibres.[2] Rainscreen cladding is a form of weather cladding designed to protect against the elements, but also offers thermal insulation. The cladding does not itself need to be waterproof, merely a control element: it may serve only to direct water or wind safely away in order to control run-off and prevent its infiltration into the building structure. Cladding may also be a control element for noise, either entering or escaping. Cladding can become a fire risk by design or material.

Rainscreen cladding is a form of weather cladding designed to protect against the elements, but also offers thermal insulation. The cladding does not need, itself, to be waterproof, merely a control element: it may serve only to direct water or wind safely away in order to control run-off and prevent its infiltration into the building structure.

Cladding may also be a control element for noise, either entering or escaping.

Cladding applied to windows is often referred to as window capping and is a specialized field.



An example of cladding

UNIT-II

PROCESSING OF CERAMICS

Ceramic processing is used to produce commercial products that are very diverse in size, shape, detail, complexity, and material composition, structure, and cost. The purpose of ceramics processing to an applied science is the natural result of an increasing ability to refine, develop, and characterize ceramic materials.

Ceramics are typically produced by the application of heat upon processed clays and other natural raw materials to form a rigid product. Ceramic products that use naturally occurring rocks and minerals as a starting material must undergo special processing in order to control purity, particle size, particle size distribution, and heterogeneity. These attributes play a big role in the final properties of the finished ceramic. Chemically prepared powders also are used as starting materials for some ceramic products. These synthetic materials can be controlled to produce powders with precise chemical compositions and particle size.

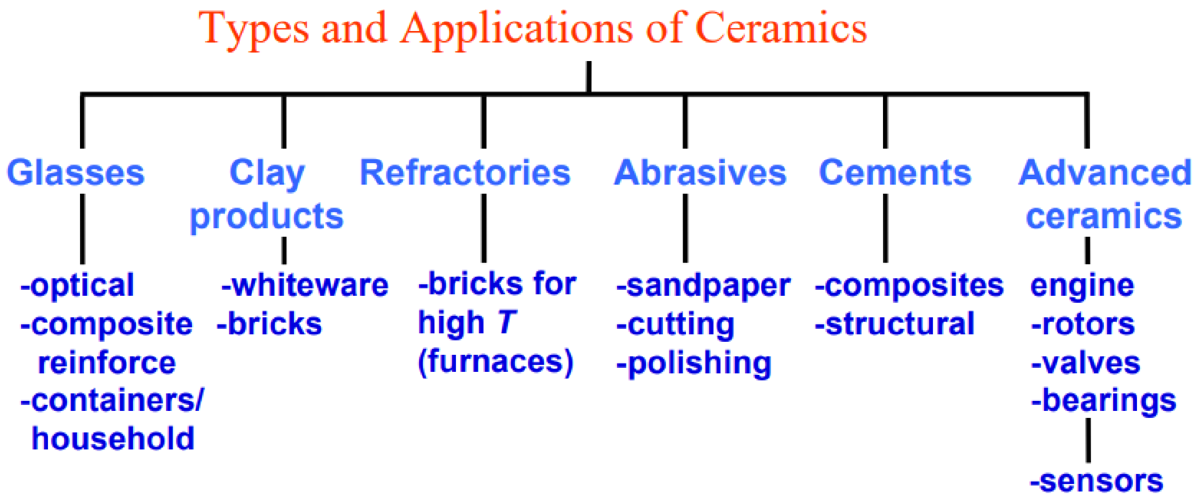
The next step is to form the ceramic particles into a desired shape. This is accomplished by the addition of water and/or additives such as binders, followed by a shape forming process. Some of the most common forming methods for ceramics include extrusion, slip casting, pressing, tape casting and injection molding. After the particles are formed, these "green" ceramics undergo a heat-treatment (called firing or sintering) to produce a rigid, finished product. Some ceramic products such as electrical insulators, dinnerware and tile may then undergo a glazing process. Some ceramics for advanced applications may undergo a machining and/or polishing step in order meet specific engineering design criteria.

The properties of ceramic materials, like all materials, are dictated by the types of atoms present, the types of bonding between the atoms, and the way the atoms are packed together. This is known as the atomic scale structure. Most ceramics are made up of two or more elements. This is called a compound. For example, alumina (Al_2O_3), is a compound made up of aluminum atoms and oxygen atoms.

The atoms in ceramic materials are held together by a chemical bond. The two most common chemical bonds for ceramic materials are covalent and ionic. For metals, the chemical bond is called the metallic bond. The bonding of atoms together is much stronger in covalent and ionic bonding than in metallic. That is why, generally speaking, metals are ductile and ceramics are brittle. Due to ceramic materials wide range of properties, they are used for a multitude of applications. In general, most ceramics are:

- hard,
- wear-resistant,

- brittle,
- refractory,
- thermal insulators,
- electrical insulators,
- nonmagnetic,
- oxidation resistant,
- prone to thermal shock, and
- chemically stable.



One is chemical processing of powders using the products of chemical reaction which are in the form of powders. Second processing technique is mechanicalpreparation methods in which a direct contact of particles takes place with some agents (such as Grinding /milling).

The processing of raw ceramics into ceramic products requires the preparation of ceramic powders. The application and quality of the product defines the type of powder preparation required. The application spectrum of ceramics ranges from household items to space-shuttle. The raw materials for powder preparation are generally natural minerals such as Quartz, Zircon, fireclay. The raw materials need to be processed in order to convert them into the desired products with special characteristics. The type and nature of processing may be different for different products and applications. Characteristics of powders Every raw material should possess some desirable characteristics for further processing. Some of the important characteristics of powders which define the quality of the final ceramic product should be kept in mind. Desirable characteristics depend upon the quality of product and application.

These characteristics are:

- Chemical composition
- Phase composition

- Particle size
- Particle size distribution
- Particle shape
- Agglomeration

Ceramic powder processing

Ceramic powder processing can be broadly divided into two categories. One is chemical processing of powders using the products of chemical reaction which are in the form of powders. Second processing technique is mechanical preparation methods in which a direct contact of particles takes place with some agents (such as Grinding /milling).

Mechanical preparation method: Milling/Crushing/Grinding

Mechanical preparation method involves crushing, milling in a ball mill or grinding ceramic raw materials into small particles. A ball mill is a machine with a rotating hollow cylinder partly filled with steel or white cast iron balls. Depending on the powder amount and the powder properties, different types of mills are used for dry and wet grinding.

Ball Milling

Ball Mill grinds a material by rotating a cylinder with hard balls, causing them to fall back into the cylinder and onto the material to be ground. The impact of balls is important for reduction in size of the particles. Ball milling is mostly used for brittle materials. The diameter of the mill decides the speed of the mill. Generally, the rotational speed does not exceed 20 RPM. Diameter of cylinder is inversely proportional to the rotational speed. The larger the diameter, the slower the rotation. If the speed is too high, it begins to act like a centrifuge and the balls do not fall back, but stay on the perimeter of the mill. Figure 1 shows the schematic of various mechanisms of crushing the ceramic powder. These are roll crushing (figure 1a), ball mill (figure 1b) and hammer milling (figure 1c). In roll crushing method, there are basically two rollers; one is fixed roller and the other is adjustable roller on which the lumps of ceramic raw material are dropped through hopper. When roller starts rotating, the raw material is pressed inside the roller as shown in figure 1a and fine particles of ceramic powder are obtained on the other side. The size of the powder can be varied as per the requirement. This can be done by changing the space between the rollers through adjustable roller using adjustable screw. In case of ball milling as shown in figure 1b, black sphere represents balls of some harder material and the green balls represent the ceramic particles. The ball mill rotates continuously and the collision between harder balls and ceramic particles occurs repeatedly and ceramic powder is prepared. In hammer milling process, a hammer is rotated inside the chamber and large size lumps of raw ceramic are crushed into very fine ceramic powder. As shown in the figure 1c, there is a grain hopper from where raw material is moved into the chamber through delivery device. There are four independent hammers attached to the rotor. Raw material is hammered down and fine ceramic powder is taken away.

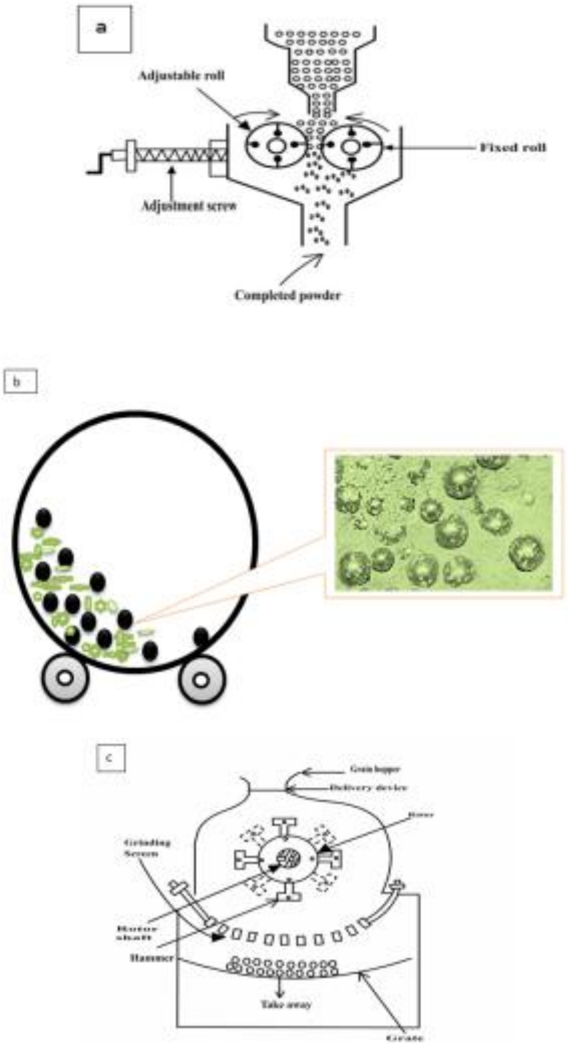


Figure 1 Mechanical preparation method, to obtain ceramic particles: (a) roll crushing (b) ball mill and (c) hammer milling

Consolidation Processes

Consolidation processes consist of the assembly of smaller objects into a single product in order to achieve a desired geometry, structure, or property. These processes rely on the application of mechanical, chemical, or thermal energy to effect consolidation and achieve bonding between objects. Interaction between the material and the energy that produces the consolidation is a key feature of the process. This interaction can be either beneficial or detrimental to the final product. In some cases, the consolidation energy enhances the structure or properties of the material and is an integral part of the process. For example, in the forging of powder preforms, the mechanical energy not only consolidates the powder but also imparts macroscopic geometry to the part while improving the microstructure of the material. In other cases, the energy used to effect consolidation is detrimental to the structure or properties of the product. For example, in fusion welding, the heat of melting achieves bonding between the objects but also can create an undesired microstructure in the heat-affected zone of the joint, causing distortion and detrimental residual stresses.

Consolidation processes are employed throughout the manufacturing sequence, from the initial production of the raw material to modification of the final assembly. One group of consolidation processes involves the production of parts from particulate or powders of metals, ceramics, or composite mixtures. These consolidated products are typically semifinished and require final thermal or machining processes. In some material systems, consolidation of powders produces feedstock billets for extensive processing into continuous mill products of bar, rod, wire, plate, or sheet. Other consolidation processes produce composites, with either polymer, graphite, metal, or ceramic matrices. Welding and joining processes, a unique group of consolidation processes, are used to combine subcomponents, often of dissimilar materials, into permanent assemblies. The performance of the final component is often governed by the quality of the joining process. This chapter presents an overview of the research needs and Bottom of Form

opportunities in powder processing, consolidation of polymeric composites, and welding/joining unit processes.

Drying:

In this day of wonderful technological achievements and automatic devices for drying, it can be difficult to remember what it is we are trying to accomplish. We must not forget that the point of drying is simply to remove water from the ceramic without causing any damage. Of course, this process must be done both efficiently and economically.

No matter what kind of drying we do whether basic air drying or sophisticated electronic drying water can only leave the surface of the ceramic at a given rate. The real trick to drying is to use a method that removes the water from the inside of the ceramic as fast as that surface water is evaporated. To accomplish this process, we must first understand 1) the factors that control how quickly the water can leave the surface, and 2) the factors that control how quickly the water can move from the inside of the piece to the surface. Understanding these principles will then enable us to make informed decisions about the type of dryer we purchase for our facility.

Sintering is the process of compacting and forming a solid mass of material by heat or pressure without melting it to the point of liquefaction.

Sintering happens naturally in mineral deposits or as a manufacturing process used with metals, ceramics, plastics, and other materials. The atoms in the materials diffuse across the boundaries of the particles, fusing the particles together and creating one solid piece. Because the sintering temperature does not have to reach the melting point of the material, sintering is often chosen as the shaping process for materials with extremely high melting points such as tungsten and molybdenum. The study of sintering in metallurgy powder-related processes is known as powder metallurgy. An example of sintering can be observed when ice cubes in a glass of water adhere to each other, which is driven by the temperature difference between the water and the ice. Examples of pressure-driven sintering are the compacting of snowfall to a glacier, or the forming of a hard snowball by pressing loose snow together.

The word "sinter" comes from the Middle High German *sinter*, a cognate of English "cinder".

Hot Compaction

The **hot compaction** process early studies on melt spun polyethylene fibres. The essence of the **hot compaction** process, developed at Leeds University, is to **heat** an array of oriented polymer fibres or tapes to a temperature where a thin skin of material on the surface of each fibre or tape is melted.

Finishing

Another frequently used secondary operation is finishing process. Various ceramic products need some finishing to achieve the required dimensional tolerance or surface finish. Since ceramics powders generally have high hardness, the conventional machining used for finishing metals cannot be used.

The finishing processes used can be one or more of the following;

(a) Diamond cut

(b) Lapping

(c) Honing

(d) Grinding

(e) Core drilling is the most common finishing techniques, but ultrasonic cutting and laser drilling and cutting are frequently used.

Advantage of finishing

(a) Increased dimensional accuracy

(b) Improved surface finish

(c) Make minor changes in part geometry

Processing of composites:

There are numerous methods for fabricating composite components. Some methods have been borrowed (injection molding from the plastic industry, for example), but many were developed to meet specific design or manufacturing challenges faced with *fiber-reinforced* polymers. Selection of a method for a particular part, therefore, will depend on the materials, the part design and end-use or applications.

Composite fabrication processes typically involve some form of molding, to shape the resin and reinforcement. A mold tool is required to give the unformed resin/fiber combination its shape prior to and during cure. Click on “Tooling” for an overview of mold types as well as materials and methods used to make mold tools.

Lightning Strike Protection for Composite Aircraft

The most basic fabrication method for thermoset composites is ***hand layup***, which typically consists of placing layers, called plies of either dry fabrics, or prepreg (fabric pre-impregnated with resin), by hand onto a tool to form a laminate stack. Resin is applied to the dry plies after layup is complete (e.g., by means of resin infusion). In a variation known as wet layup, each ply is coated with resin and *debulked* (compacted) after it is placed. Although debulk can be done by hand with rollers, most fabricators today use a *vacuum-bagging* technique that involves placing plastic sheet materials over the layup, sealing it at the tool’s edges, adding one or more ports for air hoses and then evacuating air from the space between the sheet and the layup using a vacuum pump). Debulking not only consolidates the layup but also removes air trapped in the resin matrix that would otherwise create undesirable *voids* (air pockets) in the laminate that could weaken the composite.

Several ***curing methods*** are available. The most basic is simply to allow cure (intiated by a catalyst or hardener additive premixed into the resin) to occur at room temperature. Cure can be accelerated, however, by applying heat, typically with an oven, and pressure, by means of a vacuum. For the latter, a vacuum bag, with breather assemblies, is placed over the layup and attached to the tool (in similar fashion to that used in debulking), then a vacuum is pulled prior to initiation of cure.

Pressure. Many high-performance thermoset parts require heat and high consolidation pressure to cure — conditions that require the use of an autoclave. Autoclaves, generally, are expensive to buy and operate. Manufacturers that are equipped with autoclaves usually cure a number of parts simultaneously. Computer systems monitor and control autoclave temperature, pressure, vacuum and inert atmosphere, which allows unattended and/or remote supervision of the cure process and maximizes efficient use of the technique.

Heat. When heat is required for cure, the part temperature is “ramped up” in small increments, maintained at cure level for a specified period of time defined by the resin system, then “ramped down” to room temperature, to avoid part distortion or warp caused by uneven expansion and contraction. When this curing cycle is complete and after parts are demolded, some parts go through a secondary freestanding postcure, during which they are subjected for a specific period of time to a temperature higher than that of the initial cure to enhance chemical crosslink density.

Alternative curing methods. Electron-beam (E-beam) curing has been explored as an efficient curing method for thin laminates. In E-beam curing, the composite layup is exposed to a stream of electrons that provide ionizing radiation, causing polymerization and crosslinking in radiation-sensitive resins. X-ray and microwave curing technologies work in a similar manner. A fourth alternative, ultraviolet (UV) curing, involves the use of UV radiation to activate a photoinitiator added to a thermoset resin, which, when activated, sets off a crosslinking reaction. UV curing requires light-permeable resin and reinforcements.

Cure monitoring. An emerging technology is the monitoring of the cure itself. Dielectric cure monitors measure the extent of cure by gauging the conductivity of ions — small, polarized, relatively insignificant impurities that are resident in resins. Ions tend to migrate toward an electrode of opposite polarity, but the speed of migration is limited by the viscosity of the resin — the higher the viscosity, the slower the speed. As crosslinking proceeds during cure, resin viscosity increases. Other methods include dipole monitoring within the resin, the monitoring of micro-voltage produced by the crosslinking, monitoring of the exothermic reaction in the polymer during cure and, potentially, the use of infrared monitoring via fiber-optic technology (see "Monitoring the cure itself.”)

Out-of-autoclave (OOA) curing is a notable phenomenon gaining momentum in the industry for high-performance composite components. The high cost and limited size of autoclave systems has prompted many processors, particularly in aerospace, to call for OOA resins that can be cured with heat only in an oven (less capital-intensive and less expensive to operate than an autoclave, particularly with very large parts), or at room temperature. Cytec Aerospace Materials HQ (Tempe, AZ, US) introduced the first OOA resin, an epoxy designed for aerospace applications. OOA tooling epoxies and adhesives also are coming to market (see “Autoclave quality outside the autoclave?”)

Open molding

Open contact molding in one-sided molds is a low-cost, common process for making fiberglass composite products. Typically used for boat hulls and decks, RV components, truck cabs and fenders, spas, bathtubs, shower stalls and other relatively large, noncomplex shapes, open molding involves either hand layup or a semi-automated alternative, sprayup.

In an open-moldsprayup application, the mold is first treated with mold release. If a gel coat is used, it is typically sprayed into the mold after the mold release has been applied. The gel coat then is cured and the mold is ready for fabrication to begin. In the sprayup process, catalyzed resin (viscosity of 500-1,000 cps) and glass fiber are sprayed into the mold using a chopper gun, which chops continuous fiber into short lengths, then blows the short fibers directly into the sprayed resin stream so that both materials are applied simultaneously. To reduce VOCs, piston pump-activated, non-atomizing spray guns and fluid-impingement spray heads dispense gel coats and, after gel coat cure, resins in larger droplets at low pressure. Another option is a roller impregnator, which pumps resin into a roller similar to a paint roller.

In the final steps of the sprayup process, workers compact the laminate by hand with rollers. Wood, foam or other core material may then be added, and a second sprayup layer imbeds the core between the laminate skins. The part is then cured, cooled and removed from the typically reusable mold.

Hand layup and sprayup methods are often used in tandem to reduce labor. For example, fabric might first be placed in an area exposed to high stress; then, a spray gun might be used to apply chopped glass and resin to build up the rest of the laminate. Balsa or foam cores may be inserted between the laminate layers in either process. Typical glass fiber volume is 15% with sprayup and 25% with hand layup.

Sprayup processing, once a very prevalent manufacturing method, has begun to fall out of favor. Federal regulations in the U.S. and similar rules in the EU have mandated limits on worker exposure to, and emission into the environment of VOCs and hazardous air pollutants (HAPs). Styrene, the most common monomer used as a diluent in thermoset resins, is on both lists. Because worker exposure to and emission of styrene is difficult and expensive to control in the sprayup process, many composites manufacturers have migrated to closed mold, infusion-based processes, which better contain and manage styrenes.

Although open molding via hand layup is being replaced by faster and more technically precise methods (as the following makes clear), it is still widely used in the repair of damaged parts, including parts made form other commonly used materials, such as steel and concrete. For more information, click on “Composites for repair.”

Resin infusion processes

Ever-increasing demand for faster production rates has pressed the industry to replace hand layup with alternative fabrication processes and has encouraged fabricators to automate those processes wherever possible.

A common alternative is ***resin transfer molding (RTM)***, sometimes referred to as liquid molding. RTM is a fairly simple process: It begins with a two-part, matched, closed mold that is made of either metal or composite material. Dry reinforcement (typically a preform) is placed into the mold and the mold is closed. Resin and catalyst are metered and mixed in dispensing equipment, then pumped into the mold under low to moderate pressure through injection ports, following predesigned paths through the preform. Extremely low-viscosity resin is used in RTM applications, especially with for thick parts, to ensure that the resin permeates the preform quickly and thoroughly before the onset of cure. Both mold and resin can be preheated, as necessary, for particular applications.

RTM produces high-quality parts without the necessity of an autoclave. However, when cured and demolded, a part destined for a high-temperature application usually undergoes postcure.

Most RTM applications use a two-part epoxy formulation. The two parts are mixed just before they are injected. Bismaleimide and polyimide resins also are available in RTM formulations.

Light RTM is a variant of RTM that is growing in popularity. In Light RTM, low injection pressure, coupled with vacuum, allow the use of less-expensive, lightweight two-part molds or a very lightweight, flexible upper mold.

The benefits of RTM are impressive. Generally, the dry preforms and resins used in RTM are less expensive than prepreg material and can be stored at room temperature. The process can produce thick, near-net shape parts, eliminating most post-fabrication work. It also yields dimensionally accurate complex parts with good surface detail and, unlike open molding techniques, which typically yield a contoured but planar part with A nd B sides (finished and unfinished surfaces, respectively) RTM can deliver a desired cosmetic finish on all exposed surfaces of complex, three-dimensional components. It is also possible to place inserts inside the preform before the mold is closed, allowing the RTM process to accommodate core materials and integrate “molded in” fittings and other hardware into the part structure. Moreover, void content on RTM’d parts is low, measuring ≤2%. Finally, RTM significantly cuts cycle times and can be adapted for use as one stage in an automated, repeatable manufacturing process for even greater efficiency, reducing cycle time from what can be several days, typical of hand layup, to just hours — or even minutes.

A recent variant of RTM, called high-pressure RTM (HP-RTM), is gaining attention for its potential to quickly produce automotive parts. Typically designed into a completely automated system that includes mold shuttles, HP-RTM’s ability to rapidly fill a mold loaded with a preform with a very fast curing resin shows promise for high production. HP-RTM still comprises a fiber preform, a closed mold, a press and a resin injection system, but the latter is now an impingement mixing head, like that first developed for polyurethane (PU) foam applications in the 1960s. In fact, metering/mixing/injection suppliers for the PU and reaction injection molding (RIM, see next item) processes were among the early developers of HP-RTM, including KraussMaffei Technologies GmbH (Munich, Germany), Hennecke Inc. (Sankt Augustin, Germany), Frimo Inc. (Lotte, Germany) and Cannon USA Inc. and Cannon SpA (Cranberry Township, PA US and Borromeo, Italy).

In contrast to RTM, where resin and catalyst are premixed prior to injection under pressure into the mold, ***reaction injection molding (RIM)*** injects a rapid-cure resin and a catalyst into the mold in two separate streams. Mixing, and the resulting chemical reaction, occur *in the mold*instead of in a dispensing head. Automotive industry suppliers have combined structural

RIM (SRIM) with rapid preforming methods to fabricate structural parts that don’t require a Class A finish. Programmable robots have become a common means to spray a chopped fiberglass/binder combination onto a vacuum-equipped preform screen or mold. Robotic sprayup can be directed to control fiber orientation. A related technology, dry fiber placement, combines stitched preforms and RTM. Fiber volumes of up to 68% are possible, and automated controls ensure low voids and consistent preform reproduction, without the need for trimming.

Vacuum-assisted resin transfer molding (VARTM) refers to a variety of related processes that represent a still fastest-growing molding technology. The salient difference between VARTM-type processes and RTM is that in VARTM, resin is drawn into a preform through use of a vacuum only, rather than pumped in under pressure. VARTM does not require high heat or pressure. For that reason, VARTM operates with low-cost tooling, making it possible to inexpensively produce large, complex parts in one shot.

In the VARTM process, fiber reinforcements are placed in a one-sided mold, and a cover (typically a plastic bagging film) is placed over the top to form a vacuum-tight seal. The resin typically enters the structure through strategically placed ports and feed lines, termed a “manifold.” It is drawn by vacuum through the reinforcements by means of a series of designed-in channels that facilitate wetout of the fibers. Fiber content in the finished part can run as high as 70%. Current applications include marine, ground transportation and infrastructure parts.

Resin infusion has found significant application in boatbuilding, because it permits fabricators to infuse entire hulls, deck structures and planar contoured parts in a single step. But aerospace structures, another group of often large parts, are also being developed using VARTM.

One resin-infusion twist is the use of two bags, termed double-bag infusion, which uses one vacuum pump attached to the inner bag to extract volatiles and entrapped air, and a second vacuum pump on the outer bag to compact the laminate. This method has been employed by The Boeing Co. (Chicago, IL, US) and NASA, as well as small fabricating firms, to produce aerospace-quality laminates without an autoclave. Aerospace quality has also been achieved in the development of an out-of-autoclave (OOA) CFRP wing for the *MS-21* single-aisle jetliner produced by Russian OEM Irkut and fabricator Aerocomposit, both based in Moscow. A key step was FACC AG’s (RiedimInnkreis, Austria) award-winning development of an integral CFRP wing box using its proprietary membrane assisted resin infusion (MARI) process, which uses a semipermeable membrane to enable a consistent, robust process delivering 100% impregnation (no dry spots or voids). OOA infusion has also been demonstrated on large tooling and structures for NASA’s Space Launch System (SLS) program using epoxy and bismaleimide (BMI) resins and similar work with benzoxazine resins is moving apace.

Resin film infusion (RFI) is a hybrid process in which a dry preform is placed in a mold on top of a layer, or interleaved with multiple layers, of high-viscosity resin film. Under applied heat, vacuum and pressure, the resin liquefies and is drawn into the preform, resulting in uniform resin distribution, even with high-viscosity, toughened resins, because of the short flow distance.

High-volume molding methods

Compression molding is a high-volume thermoset molding process that employs expensive but very durable metal dies. It is an appropriate choice when production quantities exceed 10,000 parts. As many as 200,000 parts can be turned out on a set of forged steel dies, using sheet molding compound (SMC), a composite sheet material made by sandwiching chopped fiberglass between two layers of thick resin paste. To form the sheet, the resin paste transfers from a metering device onto a moving film carrier. Chopped glass fibers drop onto the paste, and a second film carrier places another layer of resin on top of the glass. Rollers compact the sheet to saturate the glass with resin and squeeze out entrapped air. The resin paste initially is the consistency of molasses (20,000-40,000 cps); over the next three to five days, its viscosity increases and the sheet becomes leather-like (about 25 million cps), ideal for handling.

When the SMC is ready for molding, it is cut into smaller sheets and the *charge pattern* (ply schedule) is assembled on a heated mold (121°C to 262°C). The mold is closed and clamped, and pressure is applied at 24.5 to 172.4 bar. As material viscosity drops, the SMC flows to fill the mold cavity. After cure, the part is demolded manually or by integral ejector pins.

A typical low-profile (less than 0.05% shrinkage) SMC formulation for a Class A finish consists, by weight, of 25% polyester resin, 25% chopped glass, 45% fillers and 5 percent additives. Fiberglass thermoset SMC cures in 30-150 seconds and overall cycle time can be as low as 60 seconds. Other grades of SMC include low-density, flexible and pigmented formulations. Low-pressure SMC formulations that are now on the market offer open molders low-capital-investment entry into closed-mold processing with near-zero VOC emissions and the potential for very high-quality surface finish.

Automakers are exploring carbon fiber-reinforced SMC, hoping to take advantage of carbon’s high strength- and stiffness-to-weight ratios in exterior body panels and other parts. Newer, toughened SMC formulations help prevent microcracking, a phenomenon that previously caused paint “pops” during the painting process (surface craters caused by outgassing, the release of gasses trapped in the microcracks during oven cure).

Composites manufacturers in industrial markets are formulating their own resins and compounding SMC in-house to meet needs in specific applications that require UV, impact and moisture resistance and have surface-quality demands that drive the need for customized material development.

Injection molding is a fast, high-volume, low-pressure, closed process using, most commonly, filled thermoplastics, such as nylon with chopped glass fiber. In the past 20 years, however, automated injection molding of BMC has taken over some markets previously held by thermoplastic and metal casting manufacturers. For example, the first-ever BMC-based electronic throttle control (ETC) valves (previously molded only from die-cast aluminum) debuted on engines in the BMW *Mini* and the Peugeot *207*, taking advantage of dimensional stability offered by a specially-formulated BMC supplied by TetraDUR GmbH (Hamburg, Germany), a subsidiary of Bulk Molding Compounds Inc. (BMCI, West Chicago, IL, US).

In the BMC injection molding process, a ram- or screw-type plunger forces a metered shot of material through a heated barrel and injects it (at 34.47-82.74 MPa) into a closed, heated mold. In the mold, the liquefied BMC flows easily along runner channels and into the closed mold. After cure and ejection, parts need only minimal finishing. Injection speeds are typically one to five seconds, and as many as 2,000 small parts can be produced per hour in some multiple-cavity molds.

Parts with thick cross-sections can be compression molded or transfer molded with BMC. Transfer molding is a closed-mold process wherein a measured charge of BMC is placed in a pot with runners that lead to the mold cavities. A plunger forces the material into the cavities, where the product cures under heat and pressure**.**

Hybrid injection-molding/thermoforming is one example of the automotive industry's quest for short mold cycles (<2 minutes) by mixing plastics and composites processes. SpriForm — a process developed by HBW-Gubesch Thermoforming GmbH (Wilhelmsdorf, Germany) and used in the CAMISMA auto seat back project led by Johnson Controls (JCI, Burscheid, Germany) — preheats tailored blanks made from carbon fiber (CF)-reinforced polyamide 12 (PA12) organosheets, compression molds them in a matched metal die and tool, and then injection molds a 30% short glass fiber-reinforced PA12 compound that fills the mold cavity to create fully overmolded edges as well as ribs and other functional elements. The process is easily automated using two robots and achieves a 40-50% weight savings vs. a steel seat back and adds less than US$5/kg incremental cost for weight saved. Though continuous CF/PA12 tapes provide tailored stiffness and strength, lower cost injection molding material makes up half of the seat back mass. The one-shot process takes roughly 90 seconds, producing a geometrically detailed part with no secondary operations. The base layer of the organosheet preform was a PA12-impregnated mat made from recycled carbon fiber (RCF), also a means for lowering part cost and carbon footprint. (Read more by clicking on "CAMISMA's car seat back: Hybrid composite for high volume.")

Filament winding is a continuous fabrication method that can be highly automated and repeatable, with relatively low material costs. A long, cylindrical tool called a mandrel is suspended horizontally between end supports, while the "head" — the fiber application instrument — moves back and forth along the length of a rotating mandrel, placing fiber onto the tool in a predetermined configuration. Computer-controlled filament-winding machines are available, equipped with from 2 to 12 axes of motion.

In most thermoset applications, the filament winding apparatus passes the fiber material through a resin "bath" just before the material touches the mandrel. This is called *wet winding*. However, a variation uses towpreg, that is, continuous fiber pre-impregnated with resin. This eliminates the need for an onsite resin bath. In a slightly different process, fiber is wound without resin (*dry winding*). The dry shape is then used as a preform in another molding process, such as RTM.

Following oven or autoclave curing, the mandrel either remains in place to become part of the wound component or, typically, it is removed. One-piece cylindrical or tapered mandrels, usually of simple shape, are pulled out of the part with mandrel extraction equipment. Some mandrels, particularly in more complex parts, are made of soluble material and may be dissolved and washed out of the part. Others are collapsible or built from several parts that allow its disassembly and removal in smaller pieces. Filament-winding manufacturers often "tweak" or slightly modify off-the-shelf resin to meet specific application requirements. Some composite part manufacturers develop their own resin formulations.

In thermoplastics winding, all material is in prepreg form, so a resin bath is not needed. Material is heated as it is wound onto the mandrel — a process known as curing "on the fly" or in-situ consolidation. The prepreg is heated, layed down, compacted, consolidated and cooled in a single, continuous operation. Thermoplastic prepregs eliminate autoclave curing (cutting costs and size limitations) and reduce raw material costs, and the resulting parts can be reprocessed to correct flaws.

Filament winding yields parts with exceptional circumferential or “hoop” strength. The highest-volume single application of filament winding is golf club shafts. Fishing rods, pipe, pressure vessels and other cylindrical parts comprise most of the remaining business.

Pultrusion, like RTM, has been used for decades with glass fiber and polyester resins, but in the last 10 years the process also has found application in advanced composites applications. In this relatively simple, low-cost, continuous process, the reinforcing fiber (usually roving, tow or continuous mat) is typically pulled through a heated resin bath and then formed into specific shapes as it passes through one or more forming guides or bushings. The material then moves through a heated die, where it takes its net shape and cures. Further downstream, after cooling, the resulting profile is cut to desired length. Pultrusion yields smooth finished parts that typically do not require postprocessing. A wide range of continuous, consistent, solid and hollow profiles are pultruded, and the process can be custom-tailored to fit specific applications.

Tube rolling is a longstanding composites manufacturing process that can produce finite-length tubes and rods. It is particularly applicable to small-diameter cylindrical or tapered tubes in lengths as great as 6.2m. Tubing diameters up to 152 mm can be rolled efficiently. Typically, a tacky prepreg fabric or unidirectional tape is used, depending on the part. The material is precut in patterns that have been designed to achieve the requisite ply schedule and fiber architecture for the application. The pattern pieces are laid out on a flat surface and a mandrel is rolled over each one under applied pressure, which compacts and debulks the material. When rolling a tapered mandrel — e.g., for a fishing rod or golf shaft — only the first row of longitudinal fibers falls on the true 0° axis. To impart bending strength to the tube, therefore, the fibers must be continuously reoriented by repositioning the pattern pieces at regular intervals.

Automated fiber placement (AFP). The fiber placement process automatically places multiple individual prepreg tows onto a mandrel at high speed, using a numerically controlled, articulating robotic placement head to dispense, clamp, cut and restart as many as 32 tows simultaneously. Minimum cut length (the shortest tow length a machine can lay down) is the essential ply-shape determinant. The fiber placement heads can be attached to a 5-axis gantry, retrofitted to a filament winder or delivered as a turnkey custom system. Machines are available with dual mandrel stations to increase productivity. Advantages of fiber placement include processing speed, reduced material scrap and labor costs, parts consolidation and improved part-to-part uniformity. Often, the process is used to produce large thermoset parts with complex shapes.

Automated tape laying (ATL) is an even speedier automated process in which prepreg tape, rather than single tows, is laid down continuously to form parts. It is often used for parts with highly complex contours or angles. Tape layup is versatile, allowing breaks in the process and easy direction changes, and it can be adapted for both thermoset and thermoplastic materials. The head includes a spool or spools of tape, a winder, winder guides, a compaction shoe, a position sensor and a tape cutter or slitter. In either case, the head may be located on the end of a multiaxis articulating robot that moves around the tool or mandrel to which material is being applied, or the head may be located on a gantry suspended above the tool. Alternatively, the tool or mandrel can be moved or rotated to provide the head access to different sections of the tool. Tape or fiber is applied to a tool in courses, which consist of one row of material of any length at any angle. Multiple courses are usually applied together over an area or pattern and are defined and controlled by machine-control software that is programmed with numerical input derived from part design and analysis. Capital expenditures for computer-driven, automated equipment can be significant.

Although ATL generally is faster than AFP and can place more material over longer distances, AFP is better suited to shorter courses and can place material more effectively over contoured surfaces. These technologies grew out of the machine tool industry and have seen extensive use in the manufacture of the fuselage, wingskin panels, wingbox, tail and other structures on the forthcoming Boeing 787 *Dreamliner* and the Airbus A350 XWB. ATL and AFP also are used extensively to produce parts for the F-35 *Lightning II* fighter jet the V-22 *Osprey* tiltrotor troop transport and a variety of other aircraft. The latest equipment trend enables both AFP and ATL, switching between in a matter of minutes by swapping out dockable heads. Another development area is the pursuit of out of autoclave (OOA) primary CFRP aircraft structures via high-performance thermoplastics. Airbus (Toulouse, France) is working with both FIDAMC (Madrid, Spain) supported by MTorres (Navarra, Spain) and Technocampus EMC2 (Nantes, France) supported by Coriolis Composites SAS (Queven, France) to develop stringer-stiffened fuselage skin panels which are places and in situ cured via laser using automated machinery. FIDAMC and MTorres announced at JEC 2014 a CF/polyetheretherketone (PEEK) fuselage panel achieving 35-40% crystallinity in the matrix and a degree of consolidation (DOC) sufficient to require no further heat, vacuum bag or autoclave processing. Real-time temperature control is being integrated into the equipment. Materials have been supplied by Cytec Aerospace Materials HQ (Woodland Park, NJ, US) and Toho Tenax Europe GmbH(Wuppertal, Germany).

Centrifugal casting of pipe from 25 mm to 356 mm in diameter is an alternative to filament winding for high-performance, corrosion-resistant service. In cast pipe, 0°/90° woven fiberglass provides both longitudinal and hoop strength throughout the pipe wall and brings greater strength at equal wall thickness compared to multiaxial fiberglass wound pipe. In the casting process, epoxy or vinyl ester resin is injected into a 150G centrifugally spinning mold, permeating the woven fabric wrapped around the mold’s interior surface. The centrifugal force pushes the resin through the layers of fabric, creating a smooth finish on the outside of the pipe, and excess resin pumped into the mold creates a resin-rich, corrosion- and abrasion-resistant interior liner.

Fiber-reinforced thermoplastic components now can be produced by ***extrusion***, as well. Breakthrough material and process technology has been developed with long-fiber glass-reinforced thermoplastic (ABS, PVC or polypropylene) composites to provide profiles that offer a tough, low-cost alternative to wood, metal and injection-molded plastic parts used in office furniture, appliances, semitrailers and sporting goods. A huge market has emerged in the past decade for extruded thermoplastic/wood flour (or other additives, such as bastfibers or fly ash) composites. These wood plastic composites, or WPCs, used to simulate wood decking, siding, window and door frames, and fencing.

Additive manufacturing

Also known as 3D printing, this more recent form of composite part production grew out of efforts to reduce the costs in the design-to-prototype phase of product development, taking aim particularly at the material-, labor- and and time-intensive area of toolmaking. Additive manufacturing is a step change in the development of rapid prototyping concepts that were introduced more than 20 years ago — a collection of similar, but separately developed additive fabrication technologies — that is, automated processes that assemble a three-dimensional (3D) object from a series of nominally two-dimensional (2D), cross-sectional layers of specialized materials.

All additive fabrication techniques begin with a CAD drawing. Solid-model CAD data is converted, using special software, into a file format that represents a 3D surface as an assembly of planar triangles. Additional, and typically proprietary, software then is used to "slice" this virtual image into very thin 2D cross-sectional patterns. This layer data is used to instruct additive fabrication machinery as it builds a 3D physical model by "stacking" the 2D slices.

Today, five additive fabrication methods are in use:

Stereolithography (SLA), patented in 1986, was the first fully commercial rapid prototyping technology and is still the most widely used. In the SLA process, the part model is built on a platform positioned just below the surface in a vat of liquid, photocurable polymer, usually an epoxy or acrylate resin. A low-powered ultraviolet (UV) laser, programmed with the previously created CAD slice data, traces out the first layer of the part with its highly focused UV light beam, scanning and curing the resin within the boundaries of the slice outline until the entire area within the slice cross section is solidified. An elevator then incrementally lowers the platform into the liquid polymer to a depth equal to the slice thickness, and a sweeper recoats the solidified layer with liquid polymer. The laser then traces out a second layer on top of the first. The process is repeated until the part is complete. Depending on the geometry of the part, mechanical supports may need to be built into the part during the build to contain the liquid. After removal from the vat, supports are removed from the part, which then is placed in an UV oven for additional curing.

Fused Deposition Modeling (FDM), is the second most widely used AM process. FDM builds parts of ABS (acrylonitrile butadiene styrene), polycarbonate and other resins noted for toughness. Often, it is chosen when part durability is paramount.

FDM builds a 3-D object one layer at a time. A plastic filament is unwound from a coil, supplying material to a heated extrusion nozzle, which controls the flow. The nozzle is mounted over a mechanical stage, and can be moved horizontally and/or vertically. The nozzle moves over the stage, which is coated with a support material, depositing a thin bead of extruded plastic. For ABS, the thickness of that layer is typically 0.25 mm/0.010 inch, which roughly defines the tolerance one can expect to hold on an FDM part. Successive extruded layers bond with the previous layers, then harden immediately. The entire system is contained in a chamber held at a temperature just below the melting point of the plastic. No postprocessing is required after the part is removed from the chamber.

Laser Sintering (LS) was developed in the late 1980s by Austin, TX, US-based DTM Corp. The technology was purchased by 3D Systems in 2001. In a method similar to that employed in stereolithography, 3D's Selective Laser Sintering (SLS) process uses the heat of a

CO_2 laser to process a variety of materials in powdered rather than liquid form, including nylon, and glass fiber- or carbon fiber-filled nylons. In an enclosed unit about the size of a print shop photocopy machine, a CO_2 laser and a mirrored reflector system are mounted over a build table or pedestal, which supports the part. A roller distributes a thin layer of powdered material over the pedestal surface, and then the mirror system directs the laser beam onto the powder layer. As the beam scans back and forth across the material, the laser turns on and off, selectively sintering the powder (heating the powder grains to melt or fusion temperature) in a pattern identical in size and shape to the cross-sectional slice derived from the converted CAD file. The pedestal is then lowered the distance of the layer thickness, another layer of powder is rolled over the cooled and now solidified first layer, and the sintering process is repeated, bonding the second layer to the first. The process repeats, in layers of 0.08 mm to 0.15 mm (0.003 inch to 0.006 inch) thickness, until the part is complete.

Digital Light Processing (DLP), developed by Austin, TX, US-based Texas Instruments Inc., supports a line of Computer Aided Modeling Devices (CAMOD) developed by EnvisionTEC (Ferndale, MI, US). This technology, like the stereolithography platforms, uses light-curable resins, but reportedly processes them faster (about 25-mm/1-inch per hour) using a continuous process (rather than incremental layering) that involves Mask Projection, that is, projecting the entire image onto a liquid photopolymer bath rather than scanning over successively applied layers of powdered or liquid resin with a point energy source or depositing layers of material and applying heat. Further, the continuous-build technique eliminates the visible and tactile stair-stepped part surface that is characteristic of layer-based additive fabrication. EnvisionTEC'sPerfactoryXede machines use single or multiple DLP-based projectors to produce multiple parts within a comparatively small 457- by 304- by 508-mm (18- by 12- by 20-inch) build envelope. Finished parts reportedly have the same properties as engineering plastics, such as ABS, high-density polyethylene or polypropylene.

3-D Printing is the most recent entry into this market, making its debut in late 2007 when Objet Geometries (Rehovot, Israel) launched its Connex500 3D system, which builds 3-D parts by jetting successive layers of material. Designed to print one or two build materials simultaneously, the system is based on Objet'sPolyJet Matrix printing technology, an advanced version of what most are familiar with as inkjet technology. Objet Studio for Connex software manages the process, using converted CAD data to create print files.

In operation, the system funnels either one or two materials to a dedicated liquid system connected to the PolyJet Matrix block, which contains eight printing heads, each containing 96 nozzles. Two perfectly synchronized printing heads are designated for each material, including an easily removed, water-soluble, gel-like support material.

These processes were originally intended and still enable part designers and engineers to bypass the need for prototype tooling, enabling them to make a prototype in a few hours to evaluate form and fit characteristics and, in some cases, to serve as test articles, such as those for wind tunnel evaluation of part aerodynamics. However, designers have realized that there is the potential to use additive fabrication systems to make production parts as well.

Fused DepositonModeling is the method that has emerged as the mode for most applicatiosn of fiber-reinforced plastics applications for part production. Read more about this method of 3D printing by clicking on the following articles:

"3D Printing: Niche or next step to manufacturing on demand?"

"3D Printing continuous carbon fiber composites?"

"Additive manufacturing: Can you print a car?"

Safety and environmental protection

Fabricators and OEMs must address health, safety and environmental concerns when producing and handling composite materials. Their methods for maintaining a safe workplace include periodic training, adherence to detailed handling procedures, maintenance of current toxicity information, use of protective equipment (gloves, aprons, dust-control systems and respirators) and development of company-wide monitoring policies. Both suppliers and OEMs are working to reduce emissions of highly volatile organic compounds (VOCs) by reformulating resins and prepregs and switching to water-dispersible cleaning agents.

The US Environmental Protection Agency has continued to strengthen its requirements to meet the mandates of the Clean Air Act Amendments, passed by Congress in 1990. Specifically, the agency's goal is to reduce the emission of hazardous air pollutants (HAPs), a list of approximately 180 volatile chemicals that are considered to pose health risks. Some of the compounds used in resins and released during cure contain HAPs. In early 2003, the EPA enacted regulations specifically for the composites industry, requiring emission controls using maximum achievable control technology, or MACT. The regulations took effect in early 2006.

A **fiber-reinforced composite** (FRC) is a composite building material that consists of three components: (i) the fibers as the discontinuous or dispersed phase, (ii) the matrix as the continuous phase, and (iii) the fine interphase region, also known as the interface. This is a type of advanced composite group, which makes use of rice husk, rice hull, and plastic as ingredients. This technology involves a method of refining, blending, and compounding natural fibers from cellulosic waste streams to form a high-strength fiber composite material in a polymer matrix. The designated waste or base raw materials used in this instance are those of waste thermoplastics and various categories of cellulosic waste including rice husk and saw dust.

Fiber-reinforced composite

FRC is high-performance fiber composite achieved and made possible by cross-linking cellulosic fiber molecules with resins in the FRC material matrix through a proprietary molecular re-engineering process, yielding a product of exceptional structural properties.

Through this feat of molecular re-engineering selected physical and structural properties of wood are successfully cloned and vested in the FRC product, in addition to other critical attributes to yield performance properties superior to contemporary wood.

This material, unlike other composites, can be recycled up to 20 times, allowing scrap FRC to be reused again and again.

The failure mechanisms in FRC materials include delamination, intralaminar matrix cracking, longitudinal matrix splitting, fiber/matrix debonding, fiber pull-out, and fiber fracture

A **metal matrix composite (MMC)** is composite material with at least two constituent parts, one being a metal necessarily, the other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite. An MMC is complementary to a cermet.

Composition

MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. For example, carbon fibers are commonly used in aluminium matrix to synthesize composites showing low density and high strength. However, carbon reacts with aluminium to generate a brittle and water-soluble compound Al_4C_3 on the surface of the fibre. To prevent this reaction, the carbon fibres are coated with nickel or titanium boride.

Matrix

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high-temperature applications, cobalt and cobalt–nickel alloy matrices are common.

Reinforcement

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).

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 matrix composites (CMCs) are a subgroup of composite materials as well as a subgroup of ceramics. They consist of ceramic fibres embedded in a ceramic matrix. The matrix and fibres can consist of any ceramic material, whereby carbon and carbon fibres can also be considered a ceramic material.

The motivation to develop CMCs was to overcome the problems associated with the conventional technical ceramics like alumina, silicon carbide, aluminium nitride, silicon nitride or zirconia – they fracture easily under mechanical or thermo-mechanical loads because of cracks initiated by small defects or scratches. The crack resistance is – like in glass – very low. To increase the crack resistance or fracture toughness, particles (so-called monocrystalline *whiskers* or *platelets*) were embedded into the matrix. However, the improvement was limited, and the products have found application only in some ceramic cutting tools. So far only the integration of long multi-strand fibres has drastically increased the crack resistance, elongation and thermal shock resistance, and resulted in several new applications. The reinforcements used in ceramic matrix composites (CMC) serve to enhance the fracture toughness of the combined material system while still taking advantage of the inherent high strength and Young's modulus of the ceramic matrix. The most common reinforcement embodiment is a continuous-length ceramic fiber, with an elastic modulus that is typically somewhat higher than the matrix. The functional role of this fiber is (1) to increase the CMC stress for progress of micro-cracks through the matrix, thereby increasing the energy expended during crack propagation; and then (2) when thru-thickness cracks begin to form across the CMC at a higher stress (proportional limit stress, PLS), to bridge these cracks without fracturing, thereby providing the CMC with a high ultimate tensile strength (UTS). In this way, ceramic fiber reinforcements not only increase the composite structure's initial resistance to crack propagation, but also allow the CMC to avoid abrupt brittle failure that is characteristic of monolithic ceramics. This behavior is distinct from the behavior of ceramic fibers in polymer matrix composites (PMC) and metal matrix composites (MMC), where the fibers typically fracture prior to the matrix due to the higher failure strain capabilities of these matrices.

Carbon (C), special silicon carbide (SiC), alumina (Al_2O_3) and mullite (Al_2O_3–SiO_2) fibres are most commonly used for CMCs. The matrix materials are usually the same, that is C, SiC, alumina and mullite. Recently Ultra-high-temperature ceramics (UHTCs) were investigated as ceramic matrix in a new class of CMC so-called Ultra-high Temperature Ceramic Matrix Composites (UHTCMC) or Ultra-high Temperature Ceramic Composites (UHTCC).[1][2][3][4]

Generally, CMC names include a combination of *type of fibre/type of matrix*. For example, *C/C* stands for carbon-fibre-reinforced carbon (carbon/carbon), or *C/SiC* for carbon-fibre-reinforced silicon carbide. Sometimes the manufacturing process is included, and a C/SiC composite manufactured with the liquid polymer infiltration (LPI) process (see below) is abbreviated as *LPI-C/SiC*.

The important commercially available CMCs are C/C, C/SiC, SiC/SiC and Al_2O_3/Al_2O_3. They differ from conventional ceramics in the following properties, presented in more detail below:

- Elongation to rupture up to 1%
- Strongly increased fracture toughness
- Extreme thermal shock resistance
- Improved dynamical load capability
- Anisotropic properties following the orientation of fibers

A **polymer matrix composite** (PMC) is a composite material composed of a variety of short or continuous fibers bound together by an organic polymer matrix. PMCs are designed to transfer loads between fibers through the matrix. Some of the advantages with PMCs include their lightweight, high stiffness and their high strength along the direction of their reinforcements. Other advantages are good abrasion resistance and good corrosion resistance.[1]

Introduction

PMCs are divided into two categories: reinforced plastics, and advanced composites. The two categories differ in their level of mechanical properties. **Reinforced plastics** typically consists of polyester resins reinforced with low-stiffness glass fibers. **Advanced Composites** consist of fiber and matrix combinations that yield superior strength and stiffness. The PMC is designed so that the mechanical loads that are being applied to the material is being supported by the reinforcements. The function of the matrix is to bond the fibers together and to transfer loads between them.[1]

Composition

Fibers

PMCs contain about 60 percent reinforcing fiber by volume. The fibers that are commonly found and used within PMCs include fiberglass, graphite and aramid. Fiberglass has a relatively low stiffness at the same time exhibits a competitive tensile strength compared to other fibers. The cost of fiberglass is also dramatically lower than the other fibers which is why fiberglass is one of the most widely used fiber.[1] The reinforcing fibers have their highest mechanical properties along their lengths rather than their widths. Thus, the reinforcing fibers maybe arranged and oriented in different forms and directions to provide different physical properties and advantages based on the application.

Matrix

The properties of the matrix determines the resistance of the PMC to processes that includes impact damage, water absorption, chemical attack, and high-temperature creep. This means that the matrix of the PMC is typically the weak link. The matrix of PMCs consists of resin that are either thermosets or thermoplastics.

UNIT-III

Fabrication of microelectronic devices:

The purpose of this section is to give you a simplified overview of the manufacture of microelectronic devices. The process is far more complex than will be described here. Still, you will be able to see that microelectronics is not magic, but a highly developed technology.

Development of a microelectronic device begins with a demand from industry or as the result of research. A device that is needed by industry may be a simple diode network or a complex circuit consisting of thousands of components. No matter how complex the device, the basic steps of production are similar. Each type of device requires circuit design, component arrangement, preparation of a substrate, and the depositing of proper materials on the substrate.

The first consideration in the development of a new device is to determine what the device is to accomplish. Once this has been decided, engineers can design the device. During the design phase, the engineers will determine the numbers and types of components and the interconnections, needed to complete the planned circuit.

COMPONENT ARRANGEMENT

Planning the component arrangement for a microelectronic device is a very critical phase of production. Care must be taken to ensure the most efficient use of space available. With simple devices, this can be accomplished by hand. In other words, the engineers can prepare drawings of component placement. However, a computer is used to prepare the layout for complex devices. The computer is able to store the characteristics of thousands of components and can provide a printout of the most efficient component placement. Component placement is then transferred to extremely large drawings. During this step, care is taken to maintain the patterns as they will appear on the substrate.

Figure 1-7 shows a fairly simple IC MASK PATTERN. If this pattern were being prepared for production, it would be drawn several hundred times the size shown and then photographed. The photo would then be reduced in size until it was the actual desired size. At that time, the pattern would be used to produce several hundred patterns that would be used on one substrate. Figure 1-8 illustrates how the patterns would be distributed to act as a WAFER MASK for manufacturing.

Figure 1-7. - IC mask pattern.

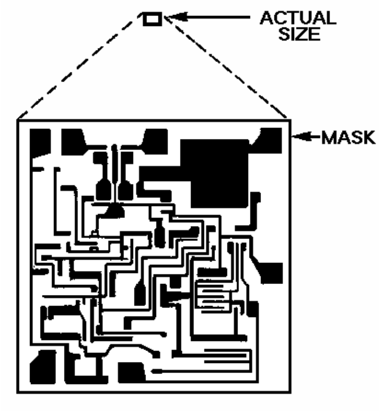
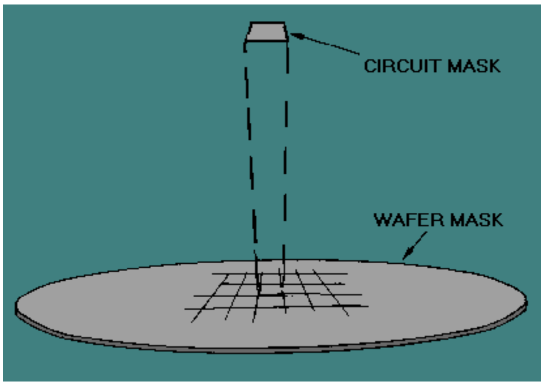


Figure 1-8. - Wafer mask distribution.



A wafer mask is a device used to deposit materials on a substrate. It allows material to be deposited in certain areas, but not in others. By changing the pattern of the mask, we can change the component arrangement of the circuit. Several different masks may be used to produce a simple microelectronicdevice. When used in proper sequence, conductor, semiconductor, or insulator materials may be applied to the substrate to form transistors, resistors, capacitors, and interconnecting leads.

SUBSTRATE PRODUCTION

As was mentioned earlier in this topic, microelectronic devices are produced on a substrate. This substrate will be of either insulator or semiconductor material, depending on the type of device. Film and hybrid ICs are normally constructed on a glass or ceramic substrate. Ceramic is usually the preferred material because of its durability.

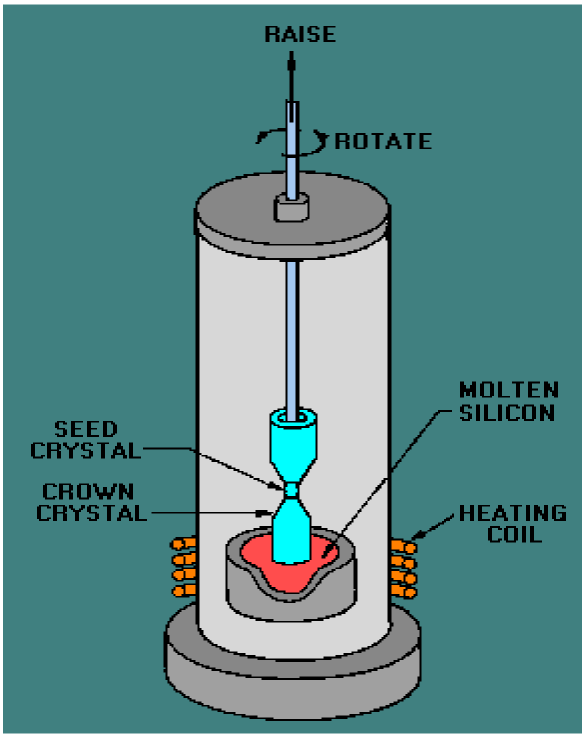
Substrates used in monolithic ICs are of semiconductor material, usually silicon. In this type of IC, the substrate can be an active part of the IC. Glass or ceramic substrates are used only to provide support for the components.

Semiconductor substrates are produced by ARTIFICIALLY GROWING cylindrical CRYSTALS of pure silicon or germanium. Crystals are "grown" on a SEED CRYSTAL from molten material by slowly lifting and cooling the material repeatedly. This process takes place under rigidly controlled atmospheric and temperature conditions.

Figure 1-9 shows a typical CRYSTAL FURNACE.

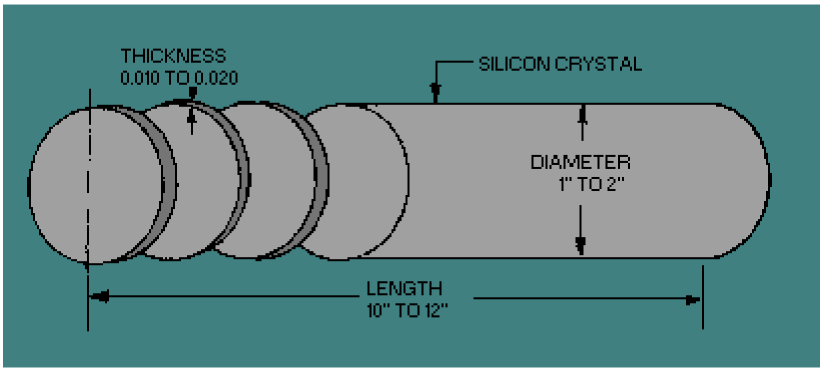
The seed crystal is lowered until it comes in contact with the molten material-silicon in this case. It is then rotated and raised very slowly. The seed crystal is at a lower temperature than the molten material. When the molten material is in contact with the seed, it solidifies around the seed as the seed is lifted. This process continues until the grown crystal is of the desired length. A typical crystal is about 2 inches in diameter and 10 to 12 inches long. Larger diameter crystals can be grown to meet the needs of the industry. The purity of the material is strictly controlled to maintain specific semiconductor properties. Depending on the need, n or p impurities are added to produce the desired characteristics. Several other methods of growing crystals exist, but the basic concept of crystal production is the same.

Figure 1-9. - Crystal furnace.



The cylinder of semiconductor material that is grown is sliced into thicknesses of .010 to .020 inch in the first step of preparation, as shown in figure 1-10. These wafers are ground and polished to remove any irregularities and to provide the smoothest surface possible. Although both sides are polished, only the side that will receive the components must have a perfect finish.

Figure 1-10. - Silicon crystal and wafers.



Film Deposition Processes

One of the basic building blocks in MEMS processing is the ability to deposit thin films of material. In this text we assume a thin film to have a thickness anywhere between a few nanometer to about 100 micrometer. The film can subsequently be locally etched using processes described in the Lithography and Etching sections of this guide.

MEMS deposition technology can be classified in two groups:

1. Depositions that happen because of a **chemical** reaction:
   - **C**hemical **V**apor **D**eposition (CVD)
   - Electrodeposition
   - Epitaxy
   - Thermal oxidation

   These processes exploit the creation of solid materials directly from chemical reactions in gas and/or liquid compositions or with the substrate material. The solid material is usually not the only product formed by the reaction. Byproducts can include gases, liquids and even other solids.

2. Depositions that happen because of a **physical** reaction:
   - **P**hysical **V**apor **D**eposition (PVD)
   - Casting

   Common for all these processes are that the material deposited is physically moved on to the substrate. In other words, there is no chemical reaction which forms the material on the substrate. This is not completely correct for casting processes, though it is more convenient to think of them that way.

This is by no means an exhaustive list since technologies evolve continuously.

Lithography (from Ancient Greek λίθος, *lithos*, meaning 'stone', and γράφειν, *graphein*, meaning 'to write')[1] is a method of printingoriginally based on the immiscibility of oil and water.[2] The printing is from a stone (lithographic limestone) or a metal plate with a smooth surface. It was invented in 1796 by German author and actor Alois Senefelder as a cheap method of publishing theatrical works.[3][4] Lithography can be used to print text or artwork onto paper or other suitable material.[5]

Lithography originally used an image drawn with oil, fat, or wax onto the surface of a smooth, level lithographic limestone plate. The stone was treated with a mixture of acid and gum arabic, *etching* the portions of the stone that were not protected by the grease-based image. When the stone was subsequently moistened, these etched areas retained water; an oil-based ink could then be applied and would be repelled by the water, sticking only to the original drawing. The ink would finally be transferred to a blank papersheet, producing a printed page. This traditional technique is still used in some fine art printmaking applications.

In modern lithography, the image is made of a polymer coating applied to a flexible plastic or metal plate.[6] The image can be printed directly from the plate (the orientation of the image is reversed), or it can be offset, by transferring the image onto a flexible sheet (rubber) for printing and publication.

As a printing technology, lithography is different from intaglio printing (gravure), wherein a plate is either engraved, etched, or stippledto score cavities to contain the printing ink; and woodblock printing or letterpress printing, wherein ink is applied to the raised surfaces of letters or images. Today, most types of high-volume books and magazines, especially when illustrated in colour, are printed with offset lithography, which has become the most common form of printing technology since the 1960s.

The related term "photolithography" refers to when photographic images are used in lithographic printing, whether these images are printed directly from a stone or from a metal plate, as in offset printing. "Photolithography" is used synonymously with "offset printing". The technique as well as the term were introduced in Europe in the 1850s. Beginning in the 1960s, photolithography has played an important role in the fabrication and mass production of integrated circuits in the microelectronics industry.

A **printed circuit board** (**PCB**) mechanically supports and electrically connects electronic components or electrical components using conductive tracks, pads and other features etched from one or more sheet layers of copper laminated onto and/or between sheet layers of a non-conductive substrate. Components are generally soldered onto the PCB to both electrically connect and mechanically fasten them to it.

Printed circuit boards are used in all but the simplest electronic products. They are also used in some electrical products, such as passive switch boxes.

Alternatives to PCBs include wire wrap and point-to-point construction, both once popular but now rarely used. PCBs require additional design effort to lay out the circuit, but manufacturing and assembly can be automated. Specialized CAD software is available to do much of the work of layout. Mass-producing circuits with PCBs is cheaper and faster than with other wiring methods, as components are mounted and wired in one operation. Large numbers of PCBs can be fabricated at the same time, and the layout only has to be done once. PCBs can also be made manually in small quantities, with reduced benefits.

PCBs can be single-sided (one copper layer), double-sided (two copper layers on both sides of one substrate layer), or multi-layer (outer and inner layers of copper, alternating with layers of substrate). Multi-layer PCBs allow for much higher component density, because circuit traces on the inner layers would otherwise take up surface space between components. The rise in popularity of multilayer PCBs with more than two, and especially with more than four, copper planes was concurrent with the adoption of surface mount technology. However, multilayer PCBs make repair, analysis, and field modification of circuits much more difficult and usually impractical.

COMPUTER AIDED DESIGN IN MICRO ELECTRONICS

Objectives

Basic principles of computer-aided design for electronic systems (Electronic Design Automation).

Electronic system design at high levels of abstraction.

Synthesis and optimization algorithms.

Test and design for testability techniques.

The hardware description language VHDL and its use in the design/synthesis process.

Surface-mount technology (**SMT**) is a method for producing electronic circuits in which the components are mounted or placed directly onto the surface of printed circuit boards (PCBs). An electronic device so made is called a **surface-mount device** (**SMD**). In industry, it has largely replaced the through-hole technology construction method of fitting components with wire leads into holes in the circuit board. Both technologies can be used on the same board, with the through-hole technology used for components not suitable for surface mounting such as large transformers and heat-sinked power semiconductors.

By employing SMT, the production process speeds up, but the risk of defects also increases due to component miniaturization and to the denser packing of boards. In those conditions, detection of failures has become critical for any SMT manufacturing process.

An SMT component is usually smaller than its through-hole counterpart because it has either smaller leads or no leads at all. It may have short pins or leads of various styles, flat contacts, a matrix of solder balls (BGAs), or terminations on the body of the component.

An **integrated circuit** or **monolithic integrated circuit** (also referred to as an **IC**, a **chip**, or a **microchip**) is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material that is normally silicon. The integration of large numbers of tiny transistors into a small chip results in circuits that are orders of magnitude smaller, cheaper, and faster than those constructed of discrete electronic components. The IC's mass production capability, reliability and building-block approach to circuit design has ensured the rapid adoption of standardized ICs in place of designs using discrete transistors. ICs are now used in virtually all electronic equipment and have revolutionized the world of electronics. Computers, mobile phones, and other digital home appliances are now inextricable parts of the structure of modern societies, made possible by the small size and low cost of ICs.

Integrated circuits were made practical by mid-20th-century technology advancements in semiconductor device fabrication. Since their origins in the 1960s, the size, speed, and capacity of chips have progressed enormously, driven by technical advances that fit more and more transistors on chips of the same size – a modern chip may have many billions of transistors in an area the size of a human fingernail. These advances, roughly following Moore's law, make computer chips of today possess millions of times the capacity and thousands of times the speed of the computer chips of the early 1970s.

ICs have two main advantages over discrete circuits: cost and performance. Cost is low because the chips, with all their components, are printed as a unit by photolithography rather than being constructed one transistor at a time. Furthermore, packaged ICs use much less material than discrete circuits. Performance is high because the IC's components switch quickly and consume comparatively little power because of their small size and close proximity. The main disadvantage of ICs is the high cost to design them and fabricate the required photomasks. This high initial cost means ICs are only practical when high production volumes are anticipated.

UNIT-IV

E-MANUFACTURING

e-Manufacturing is a transformation system that enables the manufacturing operations to achieve predictive near-zero-downtime performance as well as to synchronize with the business systems through the use of web-enabled and tether-free (i.e., wireless, web, etc.) infotronics technologies. It integrated information and decision-making among data flow (of machine/process level), information flow (of factory and supply system level), and cash flow (of business system level). e-Manufacturing is a business strategy as well as a core competency for companies to compete in today’s e-business environment. It is aimed to complete integration of all the elements of a business including suppliers, customer service network, manufacturing enterprise, and plant floor assets with connectivity and intelligence brought by the web-enabled and tether-free technologies and intelligent computing to meet the demands of e-business/e-commerce practices that gained great acceptance and momentum over the last decade. e-Manufacturing is a transformation system that enables e-Business systems to meet the increasing demands through tightly coupled supply chain management (SCM), enterprise resource planning (ERP), and customer relation management (CRM) systems as well as environmental and labor regulations and awareness, (Figure 97.3).

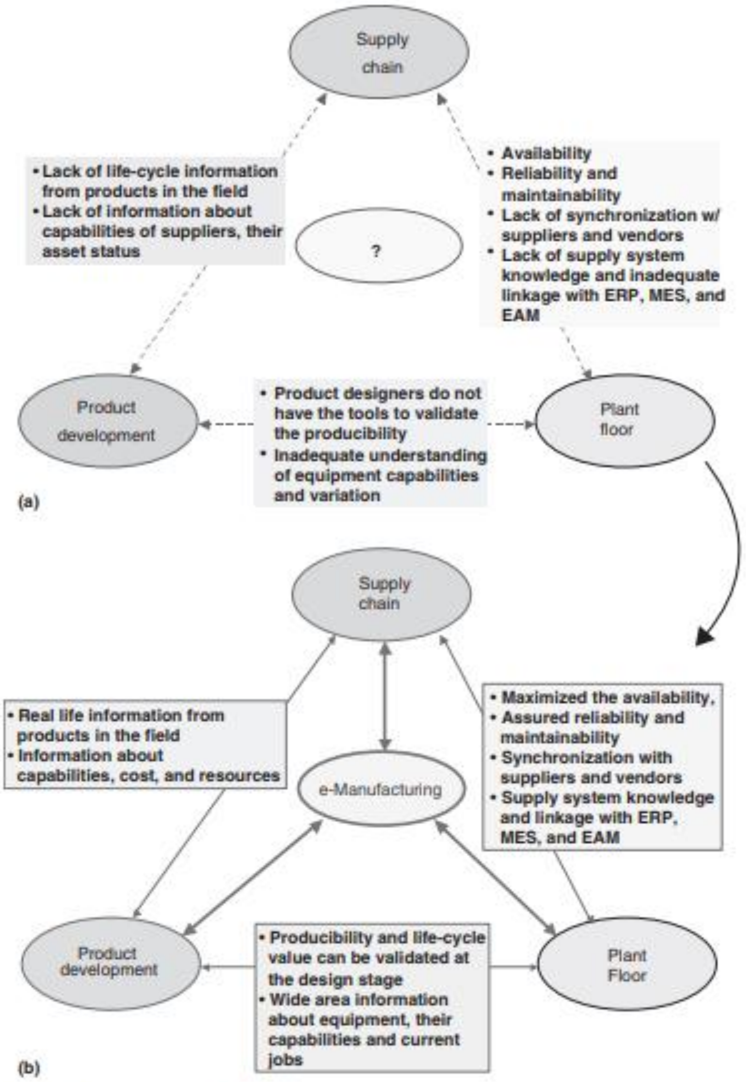


FIGURE 97.2 The transformation of e-Manufacturing for unmet needs.

e-Manufacturing includes the ability to monitor the plant floor assets, predict the variation of product quality and performance loss of any equipment for dynamic rescheduling of production and maintenance operations, and synchronize with related business services to achieve a seamless integration between manufacturing and higher level enterprise systems. Dynamically updated information and knowledge about the capabilities, limits, and variation of manufacturing assets for various suppliers guarantee the best decisions for outsourcing at the early stages of design. In addition, it enables customer orders autonomously across the supply chain, bringing unprecedented levels of speed, flexibility, and visibility to the production process reducing inventory, excess capacity, and uncertainties. The intrinsic value of an e-Manufacturing system is to enable real-time decision making among product designers, process capabilities, and suppliers as illustrated in Figure 97.4. It provides tools to access life-cycle information of a product or equipment for continuous design improvement. Traditionally, product design or changes take weeks or months to be validated with suppliers. With the e-Manufacturing system platform, designers can validate product attributes within hours using the actual process characteristics and machine capabilities. It also provides efficient configurable information exchanges and synchronization with various e-business systems.

Nanomanufacturing is both the production of nanoscaled materials, which can be powders or fluids, and the manufacturing of parts "bottom up" from nanoscaled materials or "top down" in smallest steps for high precision, used in several technologies such as laser ablation, etching and others. Nanomanufacturing differs from molecular manufacturing, which is the manufacture of complex, nanoscale structures by means of nonbiological mechanosynthesis (and subsequent assembly).

The term "nanomanufacturing" is widely used, e.g. by the European Technology Platform MINAM and the U.S. National Nanotechnology Initiative (NNI). The NNI refers to the sub-domain of nanotechnology as one of its five "priority areas." There is also a nanomanufacturing program at the U.S. National Science Foundation, through which the National Nanomanufacturing Network (NNN) has been established. The NNN is an organization that works to expedite the transition of nanotechnologies from laboratory research to production manufacturing and it does so through information exchange, strategic workshops, and roadmap development.

The NNI has defined nanotechnology very broadly, to include a wide range of tiny structures, including those created by large and imprecise tools. However, nanomanufacturing is not defined in the NNI's recent report, *Instrumentation and Metrology for Nanotechnology*. In contrast, another "priority area," nanofabrication, is defined as "the ability to fabricate, by directed or self-assembly methods, functional structures or devices at the atomic or molecular level" (p. 67). Nanomanufacturing appears to be the near-term, industrial-scale manufacture of nanotechnology-based objects, with emphasis on low cost and reliability. Many professional societies have formed Nanotechnology technical groups. The Society of Manufacturing Engineers, for example, has formed a Nanomanufacturing Technical Group to both inform members of the developing technologies and to address the organizational and IP (intellectual property) legal issues that must be addressed for broader commercialization.

In 2014 the Government Accountability Office noted that America's leadership in nanotechnology was put at risk by a failure of the government to invest in preparing basic research for commercial application.

Micromachining may refer to:

The technique for fabrication of 3D and 2D structures on the micrometer scale.

- Superfinishing, a metalworking process for producing very fine surface finishes
- Various microelectromechanical systems
  - Bulk micromachining
  - Surface micromachining
  - High-aspect-ratio microstructure technologies

Bulk micromachining: is a process used toproduce micromachinery or microelectromechanical systems (MEMS).

- Unlike surface micromachining, which uses a succession of thin film deposition and selective etching, bulk micromachining defines structures by selectively etching inside a substrate. Whereas surface micromachining creates structures *on top* of a substrate, bulk micromachining produces structures *inside* a substrate.

- Usually, silicon wafers are used as substrates for bulk micromachining, as they can be anisotropically wet etched, forming highly regular structures. Wet etching typically uses alkaline liquid solvents, such as potassium hydroxide (KOH) or tetramethylammonium hydroxide (TMAH) to dissolve silicon which has been left exposed by the photolithography masking step. These alkali solvents dissolve the silicon in a highly anisotropic way, with some crystallographic orientations dissolving up to 1000 times faster than others. Such an approach is often used with very specific crystallographic orientations in the raw silicon to produce V-shaped grooves. The surface of these grooves can be atomically smooth if the etch is carried out correctly, and the dimensions and angles can be precisely defined. Pressure sensors are usually created by bulk micromachining technique.
- Bulk micromachining starts with a silicon wafer or other substrates which is selectively etched, using photolithography to transfer a pattern from a mask to the surface. Like surface micromachining, bulk micromachining can be performed with wet or dry etches, although the most common etch in silicon is the anisotropic wet etch. This etch takes advantage of the fact that silicon has a crystal structure, which means its atoms are all arranged periodically in lines and planes. Certain planes have weaker bonds and are more susceptible to etching. The etch results in pits that have angled walls, with the angle being a function of the crystal orientation of the substrate. This type of etching is inexpensive and is generally used in early, low-budget research.

Surface micromachining builds microstructures by deposition and etching structural layers over a substrate. This is different from Bulk micromachining, in which a silicon substrate wafer is selectively etched to produce structures.

Layers

Generally, polysilicon is used as one of the substrate layers while silicon dioxide is used as a *sacrificial layer*. The sacrificial layer is removed or etched out to create any necessary void in the thickness direction. Added layers tend to be vary in size from 2-5 micrometres. The main advantage of this machining process is the ability to build electronic and mechanical components (functions) on the same substrate. Surface micro-machined components are smaller compared to their bulk micro-machined counterparts.

As the structures are built on top of the substrate and not inside it, the substrate's properties are not as important as in bulk micro-machining. Expensive silicon wafers can be replaced by cheaper substrates, such as glass or plastic. The size of the substrates may be larger than a silicon wafer, and surface micro-machining is used to produce thin-film transistors on large area glass substrates for flat panel displays. This technology can also be used for the manufacture of thin film solar cells, which can be deposited on glass, polyethylene terepthalate substrates or other non-rigid materials.

Fabrication process

Micro-machining starts with a silicon wafer or other substrate upon which new layers are grown. These layers are selectively etched by photo-lithography; either a wet etch involving an acid, or a dry etch involving an ionized gas (or plasma). Dry etching can combine chemical etching with physical etching or ion bombardment. Surface micro-machining involves as many layers as are needed with a different mask (producing a different pattern) on each layer. Modern integrated circuit fabrication uses this technique and can use as many as 100 layers. Micro-machining is a younger technology and usually uses no more than 5 or 6 layers. Surface micro-machining uses developed technology (although sometimes not enough for demanding applications) which is easily repeatable for volume production.

Sacrificial layers

A sacrificial layer is used to build complicated components, such as movable parts. For example, a suspended cantilever can be built by depositing and structuring a sacrificial layer, which is then selectively removed at the locations where the future beams must be attached to the substrate (i.e. the anchor points). A structural layer is then deposited on top of the polymer and structured to define the beams. Finally, the sacrificial layer is removed to release the beams, using a selective etch process that does not not damage the structural layer.

Many combinations of structural and sacrificial layers are possible. The combination chosen depends on the process. For example, it is important for the structural layer not to be damaged by the process used to remove the sacrificial layer.

HARMST is an acronym for **H**igh **A**spect **R**atio **M**icrostructure **T**echnology that describes fabrication technologies, used to create high-aspect-ratio microstructures with heights between tens of micrometers up to a centimeter and aspect ratios greater than 10:1. Examples include the LIGA fabrication process, advanced silicon etch, and deep reactive ion etching.

High-speed machining:

High-speed machining, specifically milling, has the same variables as traditional milling. There are speeds and feeds to set and a depth of cut to be determined. However, in a high-speed machining operation, slow, heavy cuts are replaced by fast, lighter cuts.

While it may seem counterproductive to take lighter cuts when heavy cuts are possible, shops that can make this switch in thinking will produce accurate parts faster.

Defining high-speed machining is difficult because it can be one of many operations, or a combination of them. It can be defined as:

- Machining at a high cutting speed (vc).
- Machining with a high spindle speed (n).
- Machining with a high feed rate (vf).
- Machining with a high removal rate (Q).

High-speed machining is not defined, however, as machining with a high material removal rate using a large axial depth of cut (Ap) or large radial depth of cut (Ae).

“High-speed machining typically is a combination of fast movements,” explained Kevin Burton, product specialist for Sandvik Coromant Canada. “To achieve the best results possible, these applications need to be well planned out. If you are using a high-speed process, but tool life and part quality are not within acceptable levels, you have implemented it improperly.”

Five areas require consideration before the tool ever meets the workpiece. They are:

1. Material type and features

2. Machine and machining strategy
3. Cutter style selection
4. Cutting data, tool selection, and tool balancing
5. CAM programming

Hot machining :

Hot machining is one of the unusual approaches in machining of difficult-to-cut materials like heat-resistant alloys, superalloys, hardened steels and various metal alloys. The external heat source is applied to cutting zone during machining process that will assist to increase machining performance. The achievement of hot machining is now remarkable and will extent the position in machining operations in future. Many external heating techniques are available and each type has advantages/disadvantages. The objective of the present paper is to examine various hot machining studies and provide useful information for finding optimum possible heating technique for particular machining process.

UNIT-V

Rapid prototyping is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three-dimensional computer aided design (CAD) data. Construction of the part or assembly is usually done using 3D printing or "additive layer manufacturing" technology.

The first methods for rapid prototyping became available in the late 1980s and were used to produce models and prototypeparts. Today, they are used for a wide range of applications[4] and are used to manufacture production-quality parts in relatively small numbers if desired without the typical unfavorable short-run economics. This economy has encouraged online service bureaus. Historical surveys of RP technology start with discussions of simulacra production techniques used by 19th-century sculptors. Some modern sculptors use the progeny technology to produce exhibitions. The ability to reproduce designs from a dataset has given rise to issues of rights, as it is now possible to interpolate volumetric data from one-dimensional images.

As with CNC subtractive methods, the computer-aided-design – computer-aided manufacturing CAD -CAM workflow in the traditional Rapid Prototyping process starts with the creation of geometric data, either as a 3D solid using a CAD workstation, or 2D slices using a scanning device. For Rapid prototyping this data must represent a valid geometric model; namely, one whose boundary surfaces enclose a finite volume, contain no holes exposing the interior, and do not fold back on themselves. In other words, the object must have an "inside". The model is valid if for each point in 3D space the computer can determine uniquely whether that point lies inside, on, or outside the boundary surface of the model. CAD post-processors will approximate the application vendors' internal CAD geometric forms (e.g., B-splines) with a simplified mathematical form, which in turn is expressed in a specified data format which is a common feature in additive manufacturing: STL (stereolithography) a de facto standard for transferring solid geometric models to SFF machines. To obtain the necessary motion control trajectories to drive the actual SFF, rapid prototyping, 3D printing or additive manufacturing mechanism, the prepared geometric model is typically sliced into layers, and the slices are scanned into lines (producing a "2D drawing" used to generate trajectory as in CNC's toolpath), mimicking in reverse the layer-to-layer physical building process.

Techniques

- 3D printing (3DP)
- Ballistic particle manufacturing (BPM)
- Directed light fabrication (DLF)
- Direct-shell production casting (DSPC)
- Fused deposition modeling (FDM)
- Laminated object manufacturing (LOM)
- Laminated resin printing (LRP)
- Shape deposition manufacturing (SDM) (and Mold SDM)
- Solid ground curing (SGC)
- Selective laser sintering (SLS)
- Selective laser melting (SLM)
- Stereo lithography (SLA)

Methods For Making 3D Rapid Prototypes

There are new additive manufacturing techniques being developed all the time. Some are best for consumer applications and others for industrial environments, but not all of them are suited for rapid prototyping. Let’s take a look at the top 7 methods for 3D prototyping and their strengths and weaknesses so that you can decide what might be best for your next project.

Stereolithography (SLA)

- Stereolithography was the first successful commercial 3D printing method. A bath of photosensitive liquid is solidified one layer at a time using a UV light controlled by a computer. These layers are derived from two-dimensional cross sections of the 3D CAD model and controlled with a software file format called .stl.

SLA printers often use an orange filter to screen out unwanted UV light.

- This is noteworthy because, being the first, .stl has become the default computer language used by most modern 3D printers, regardless of the printing technology employed.
- Stereolithography is best for prototypes and to make master patterns for vacuum casting. SLA is fast and inexpensive and the finished product is strong with a good surface finish. Supports may or may not be needed depending on the machine.

Selective Laser Sintering (SLS)

- This is a form of powder bed fusion. Parts are formed on a build plate one layer at a time, using a laser to sinter the powder media. Because the support is surrounded on all sides be the powder medium, it is self-supporting and additional structures are not needed.

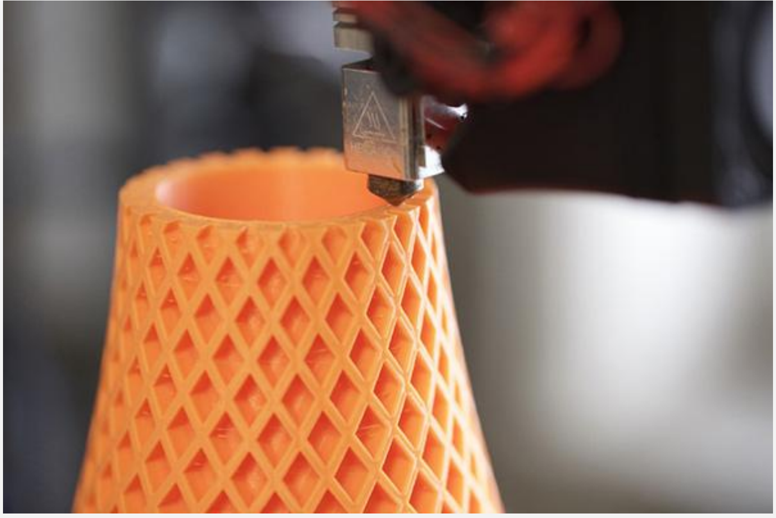
Excess powder being cleared away after SLS printing.

- SLS can work for either plastic or metal prototypes. Like many other 3D printing processes, the great advantage here is that parts can be made with complex geometries like internal lattice structures that would be difficult or impossible to do any other way.

- However, the surface finish is usually rough and may require secondary work to complete it, especially if it's used as a master pattern for later casting. The strength is also not as good as SLA printed parts.

Fused Deposition Modeling (FDM)

- This is the kind of 3D plastic printing often found in desktop machines in a home or small shop. It uses a spool of plastic filament that is melted inside the barrel of a printing nozzle. This hot liquid resin is then laid down layer-by-layer, again controlled by an .stl cutting program.



FDM printers are commonly found in small shops and even in the home.

- FDM printing is inexpensive, easy-to-use, and can accomodate different types and colors of plastic combined in a single build. It's also safe enough that even children can use it in a classroom. FDM printed parts have poor resolution and finish quality compared to industrial techniques, and the parts are not very strong. However it can be ideal for making prototypes and models during the development stage.

Selective Laser Melting (SLM)

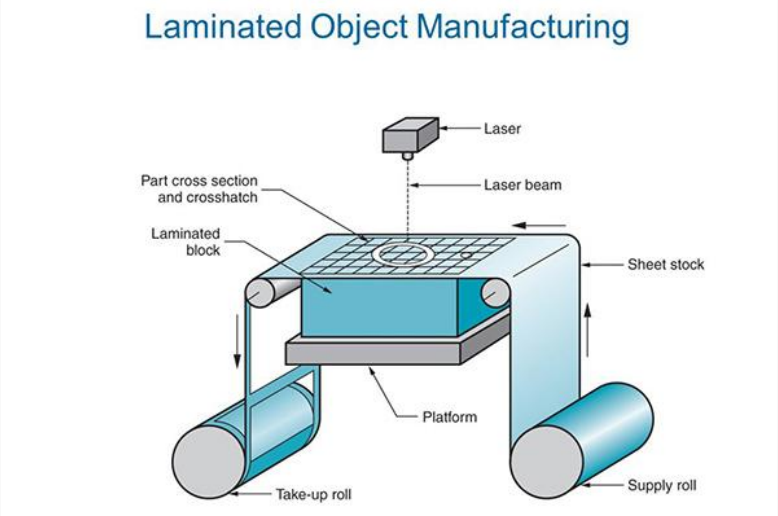
- Another form of powder bed fusion, SLM is an industrial process that requires carefully controlled conditions. Very fine metal powder of a uniform size and shape is fully welded onto a build plate using a high-powered laser inside of a sealed chamber. Common metal powders may include titanium, stainless steel, maraging steel and cobalt chrome.

These bike frame components were made with SLS prototyping technology.

- SLM is the preferred technique for making sophisticated parts of the highest strength, durability and complexity and this is what we use at Star Rapid for our DMLM service.
- The process can be expensive and must be controlled by a skilled engineer, but the results are ideal for the most demanding applications in aerospace, automotive, defense and medical parts.

Laminated Object Manufacturing

- Here a series of thin laminates are laid out on a build platform. The laminates can be paper, plastic sheet or metal foil. With each layer, a computer controlled laser or other cutting device traces out the pattern. The platform then drops by the thickness of one layer, a new laminate is glued on top and the process continues.

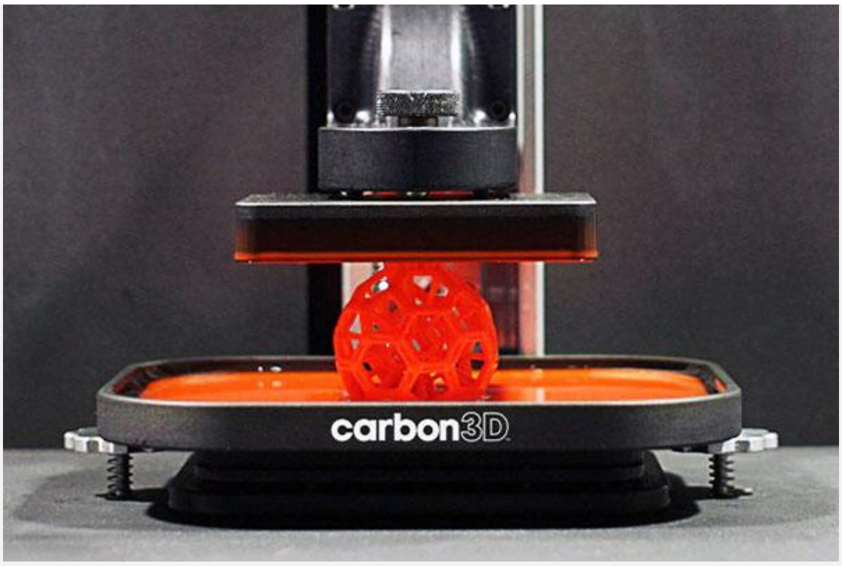


Laminated 3D printing can be used with a variety of thin, flat media.

- This stacking process makes a finished part which is less sophisticated than a SLS or SLM equivalent, but it is cheaper and does not require specially controlled working conditions. Also, if paper is used as the laminate the finished part will be similar to solid wood and can be worked accordingly.

Digital Light Processing

- Another variation on the polymerization of a curable resin, this process is very similar to SLA printing. It cures the resin with a more conventional light source, but it also requires support structures and post-build curing.
- The process is generally faster and a more shallow reservoir of photoresin can be used which also saves on cost. Like with SLA, the finished part has excellent dimensional tolerances and surface finish.



Carbon3D is showing great promise for very rapid digital light processing.

- An interesting variation of this process is called **CLIP (Continuous Liquid Interface Production).** Here the part is pulled from the vat in a continuous motion – there are no layers, it is an uninterrupted process. As the part is withdrawn it crosses a light barrier that is programmed to alter its configuration to produce the requisite cross-sectional pattern on the plastic.

Binder Jetting

- A relatively new 3D process, this has the potential to be a true high-volume mass production technique. Over a horizontal print bed covered in metal powder, hundreds of nozzles spray micro-fine droplets of a liquid binder to form a single layer. This layer is then compacted with a roller, re-coated with powder, and then sprayed for the next layer.

Binder jetting may be the high-volume solution for large scale 3D printing in metal.

- When semi-finished parts are removed from the build chamber, they must still be cured in an oven to burn off the binding resin and fuse the metal powder together into a solid.
- The advantage here is that many parts can be printed at one time, and the full volume of the chamber used. Such parts are not as strong as fully-welded SLS parts but they

can work as mechanical fittings. This technology is still under development but it may be up to 100x more cost-effective than previous techniques

Stereolithography (**SLA** or **SL**; also known as **stereolithography apparatus**, **optical fabrication**, **photo-solidification**, or **resin printing**) is a form of 3D printing technology used for creating models, prototypes, patterns, and production parts in a layer by layer fashion using photopolymerization, a process by which light causes chains of molecules to link, forming polymers.[1] Those polymers then make up the body of a three-dimensional solid. Research in the area had been conducted during the 1970s, but the term was coined by Chuck Hull in 1984 when he applied for a patent on the process, which was granted in 1986.[*citation needed*]Stereolithography can be used to create things such as prototypes for products in development, medical models, and computer hardware, as well as in many other applications. While stereolithography is fast and can produce almost any design, it can be expensive.

LASER SINTERING

Process description

A thin layer of plastic powder is selectively melted by a laser. The parts are built up layer by layer in the powder bed.

Advantages / disadvantages

Laser sintering can manufacture parts in standard plastics with good mechanical properties. There is a constantly growing set of materials available. However, parts do not have exactly the same properties as their injection molded counterparts.

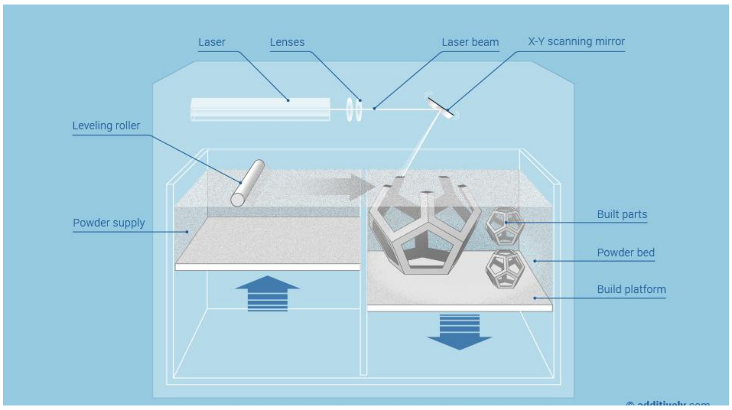
Application areas

- Prototypes are built by laser sintering in standard materials for form / fit and functional testing
- Support parts (jigs, fixtures, helps) are produced
- Small series parts are manufactured in standard materials

Characteristics / restrictions

- Maximal build envelope: 550x550x750 mm^3
- Minimum feature size: 0.15 mm
- Typical tolerance: +/-0.25 mm (can be improved through post-processing)
- Minimum layer thickness: 0.1 mm

Characteristics are only indicative, as there are different types of machines available.



Process chain

When planning the build, the entire build volume can be utilized and filled with parts. Orientation of the parts has an impact on the mechanical properties. Laser sintering parts can be further processed in order to improve tolerances and surface finish.

Pre-build planning

The production of parts is planned in a build preparation software. One or several parts are placed in the build, using the digital 3D files (typically in the STL file format). These can be arranged to fill the entire volume of the build envelope.

Post-processing

Removal of build envelope: The build envelope is removed from the machine

- Remove powder: Parts are broken out of the powder cake. Afterwards excess powder is removed from the parts by sand blasting. This is usually straight forward, however might require some extra effort for parts with complex geometric features (e.g. trapped powder)
- Post-machining: Parts might be selectively post-machined in order to fulfil critical tolerances.
- Surface finish: Often, parts need to be further processed to improve surface finish by removing material (e.g. polishing, grinding, peening) or by adding material (e.g. painting, coating). Functional coatings are also possible (EMC, anti-bacterial etc.).

Fused filament fabrication (***FFF***), also known under the trademarked term **fused deposition modeling** (***FDM***), sometimes also called *filament freeform fabrication*, is a 3D printing process that uses a continuous filament of a thermoplastic material.[1] Filament is fed from a large coil through a moving, heated printer extruder head, and is deposited on the growing work. The print head is moved under computer control to define the printed shape. Usually the head moves in two dimensions to deposit one horizontal plane, or layer, at a time; the work or the print head is then moved vertically by a small amount to begin a new layer. The speed of the extruder head may also be controlled to stop and start deposition and form an interrupted plane without stringing or dribbling between sections. "Fused filament fabrication" was coined by the members of the RepRap project to give a phrase that would be legally unconstrained in its use, given patents covering "fused deposition modeling".[*citation needed*]

- Fused filament printing is now the most popular process (by number of machines) for hobbyist-grade 3D printing.[2] Other techniques such as photopolymerisation and powder sintering may offer better results, but they are much more costly.

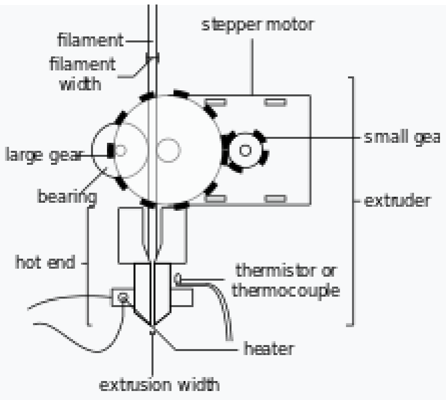


Illustration of an extruder which shows the name of parts.

- The 3D printer head or 3D printer extruder is a part in material extrusion additive manufacturing responsible for raw material melting and forming it into a continuous profile. A wide variety of filament materials are extruded, including thermoplastics such as *acrylonitrile butadiene styrene* (ABS)[3], *polylactic acid* (PLA), *high-impact polystyrene* (HIPS), *thermoplastic polyurethane* (TPU) and *aliphatic polyamides*(nylon).[4]

Rapid prototyping techniques allow the rapid and flexible generation of single design models as well as fabrication tools for the replication of small scale series, at present mainlyin the macroworld. A current internet search using one of the established search engines reveals the following typical results:•445000 links for “rapid prototyping”•55000 links for “rapid” and “prototyping” and “micro”•5100 links for “micro” and “stereolithography”•70 links for “microstereolithography”•50 links for “rapid” and “nano” and “prototyping”•0 links for “Nano stereolithography”. Approximately half a million of hits for “rapid prototyping” can be found, a significantreduction by a factor of 10 in the number of hits occurs if “rapid prototyping” is combinedwith “micro”, a factor of 10000 in case of “nano”. A similar trend can be observed using “stereolithography” as the fundamental rapid prototyping technology in combination with “micro”, the expression “Nano stereolithography” is unknown, despite the fact that several approaches for the realization of nanosized structures using stereolithographic methods are underinvestigation. In the macroscopic world a large number of different rapid prototyping (RP) techniques have been established for a rapid product development with respect to a significant reduction of the time-to-market-factor, covering the time from the first idea until product launching.

During product development certain factors strongly affect the developing time andthe resulting costs:

•Upcoming new fabrication technologies

•Material properties

•Environmental aspects

•Reduced product life time

•Maximum acceptable product price

•Product design

•Market trends

•National and international governmental laws and regulations

•Product liability aspects.

An overview of the established rapid prototypingtechniques in the macroworld, the basic technological features arising using the top-downapproach in realizing micro and nano rapid prototyping processes and the combinationof established technologies with the application of new physical effects like two photonabsorption a.o.