# GLOSSARY

**MANUFACTURING TECHNOLOGY** is power-driven manufacturing machinery, not portable by hand, used in the process of transforming materials into discrete durable goods (i.e., automated systems, laser systems, measurement systems, assembly or robotic systems, machine tools, and other machines and systems.) The industry is classified into the following major product types:

***Material Removal:*** Any machining process that uses some form of cutting tool to cut or shape metal or material into a new form, or give a workpiece a new configuration.

**Boring Machine:** a turning machine that is used to enlarge drilled or cored holes with a single- or multi-point cutting tool.

**Broaching Machine:** a machine that uses a specially shaped broaching tool having a series of progressively larger teeth to cut internal or external shapes on a workpiece. The broach is pulled or pushed through or over the part by mechanical or hydraulic means to reproduce its size and shape.

**Drilling:** an operation of using a hardened rotating tool to produce a round hole in a workpiece where none existed before. Drilling is generally performed before the machining operations of boring, reaming, tapping, counterboring, countersinking, and spotfacing.

**Electrical Discharge Machining (EDM):** a metal removal process that uses an electric spark for the removal of metal. The most commonly used EDM machines are the plunge, ram, and the wire-cut.

**Gear Cutting:** a specially designed milling operation used to form gear teeth on a cylindrically shaped gear blank.

**Grinding:** removes material from the workpiece by a powered abrasive wheel, stone, belt, paste, sheet, compound, slurry, or other agent. The most common forms of grinding are surface grinding (produces flat and/or squared surfaces) and cylindrical grinding (used to grind internal and external parts).

**Centerless Grinding:** a grinding operation for long, thin parts or shafts where the workpiece rests on a knife-edge support, rotates through contact with a regulating or feed wheel, and is ground by a grinding wheel.

**Creep Feed Grinding:** an operation in which the grinding wheel is set to the full depth of the form required, and then slowly fed into the work at a slow speed to finish the form in one pass.

**Disk Grinding:** an operation in which the workpiece is held and ground against the side of a wheel, rather than on the wheel's periphery.

**Laser:** ***L***ight ***A***mplification by ***S***timulated ***E***mission of ***R***adiation. A tool which amplifies and intensifies light into a narrow beam that can be used to cut, melt, and vaporize materials.

**$CO_2$ Laser:** a type of gas laser that uses a mixture of $CO_2$, nitrogen, and helium to produce a continuous output of laser light at a wavelength of 10.6 mm. $CO_2$ lasers are used to produce holes in plastic pipes, baby-bottle nipples, and aerosol can spray tips.

**Continuous-wave Laser:** a laser that produces light beams continuously rather than as a series of pulses. The continuous mode is preferred for straight and mildly contoured cuts.

**Excimer Laser:** a type of pulsed-gas laser that emits light in the ultraviolet (UV) region of the spectrum that produces high-quality edges on parts with little or no micro-cracking or thermal damage. Lasing gases are a mixture of a noble gas (argon, krypton, or xenon) and a halogen gas.

**Gas Laser:** a laser that uses a gas or gas mixture such as carbon dioxide ($CO_2$), argon, or other gases as the lasing medium. Gas lasers can be used for hole production, perforating, and welding.

**Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) Laser**: a solid-state laser that uses a crystal of yttrium aluminum garnet (YAG) doped with neodymium (Nd) as the lasing medium.

**Pulsed Laser**: a laser that emits a light beam in a series of pulses rather than continuously. The pulsed mode is preferred for thin materials because it allows tight corners and intricate details to be cut without excessive burning.

**Ruby Laser**: a solid-state laser that uses a synthetic ruby crystal doped with chromium impurity as the lasing medium. Ruby lasers are used to produce precise holes in diamonds for wire-drawing dies. They are restricted in their applications because of their relatively short wavelength.

**Solid-State Laser:** a laser that uses a crystal or glass as a host to an impurity, such as neodymium or chromium, which produces the lasing action. Solid-state lasers have proved very useful in the fields of surgery, atomic fusion, drilling diamond dies, measurement, and spot welding.

**Yttrium Aluminum Garnet (YAG) Laser:** a laser used in manufacturing with power ranges from a few milliwatts to more than 400 W. Low-power models are used for the manufacture of integrated circuit-mounted resistors. High-power YAG lasers are used for cutting, drilling, heat-treating, and welding operations.

**Lathe:** a machine designed to remove material and produce external or internal forms by rotating a round workpiece against a stationary cutting tool. The axis of workpiece rotation may be either parallel to the floor as in a horizontal lathe, or perpendicular to the floor as in a vertical lathe.

**Machining Center:** a machine tool that is CNC-controlled to perform a wide variety of machining operations (typically combining boring-drilling-milling tasks) automatically under the control of the part program. Machining centers have three or more axes of motion, have a contouring type numerical control and an automatic tool changer.

**Milling:** an operation designed to remove material using a rotating cutter which is also moved laterally with respect to the workpiece.

**End Mill:** a vertical or horizontal milling machine operation in which an end-milling cutter is mounted in the machine's spindle, rather than on an arbor. Common end-mill cutters have two, three, or four flutes that cut on the end and also on the periphery.

**Face Milling:** a form of milling that produces a flat surface, generally at right angles to the rotating axis of a cutter. The cutter has teeth or inserts on its periphery and on its end face.

**Gang Cutting, Milling, Slitting:** milling operations that use several cutters mounted on a single arbor, generally for simultaneous cutting of a form or contour.

**Peripheral Milling:** a type of milling operation that machines a finished surface parallel to the rotating axis of a multi-tooth cutter.

**Spiral Milling:** an operation in which the table of a milling machine is set at an angle and the workpiece is rotated and fed under a revolving formed cutter to create a spiral form; commonly used for cutting helical flutes on drills, taps, reamers, end mills, and so on. Also called helical milling.

**Plasma Cutting:** a process that uses a high velocity jet of ionized gas that is delivered from a constricting orifice. The high velocity ionized gas, that is, the plasma, conducts electricity from the torch of the plasma cutter to the work piece. The plasma heats the workpiece, melting the material. The high velocity stream of ionized gas mechanically blows the molten metal away, severing the material.

**Sawing:** an operation in which a machine using a cutting blade with hardened teeth is used to cut material to length and/or a new shape.

**Abrasive sawing:** abrasive grains attached to a fiber- or metal-backing wheel cut material similar to a grinding cutoff operation.

**Bandsawing:** a continuous flexible-toothed blade rides on driving and driven pulleys (wheels) under tension and is guided through the work.

**Cold or Circular Sawing:** a rotating, circular, toothed blade, similar to a table or radial-arm saw blade, is used as the cutting tool.

**Diamond Bandsawing:** an operation in which a band coated with diamond abrasives is used to machine carbides, ceramics, and other extremely hard materials.

**Friction Sawing:** a high-speed sawing operation, using a special band machine capable of achieving band velocities of 15,000 sf/min or more, to cut hard alloy steels. Frictional heat softens the metal at the point where the band contacts the metal surface; then the teeth remove the molten material.

**Hacksawing:** in a power or manual operation, the blade is moved back and forth through the work; the cutting generally occurs on the forward stroke.

**Station-Type Machine:** provide several work processing locations (stations) in a single machine. The processes provided may include drilling, boring, milling, and finishing. Material handling capabilities are built-in to transport the workpiece from one work station to another. A transfer line is a type of station machine.

**Tapping:** an operation where a tap, with teeth on its periphery, cuts internal threads in a predrilled hole having a smaller diameter than the tap diameter so that a matching piece (e.g., a screw) will fit. Hand taps have a square on the riving end for a tap wrench; machine taps are fitted into a driving chuck and have spiral flutes to assist in removing chips from a hole.

**Threading:** an operation of producing a helical ridge of uniform cross section (thread) around an external or internal form by cutting, turning, and rolling of threads into some type of material. Threading machines are designed to take a turned workpiece and cut grooves into its sides (thus threading it in such a manner that it could fit into a tapped piece).

**Turning:** the operation of revolving a piece of round stock held in a chuck, between centers, or mounted on a faceplate against a stationary cutting tool, to create a cylindrical shape. Turning operations can be performed on lathes, machining centers, or other machine tools where the rotating work is fed past a stationary cutting tool.

**Turning Center:** a machine tool, similar to a lathe, that is CNC-controlled to perform a wide variety of machining operations automatically under the control of the part program.

**Waterjet Cutting:** a process that uses a fine, high-pressure, high-velocity jet of water directed by a small nozzle to cut hard or soft materials. This type of cutting is limited to material with naturally occurring small cracks or softer material.

**Abrasive Water Suspension Jet System:** accelerates a suspension of abrasive in water through the system. This type of system appears to be more efficient than previously developed abrasive waterjet systems.

**Abrasive Waterjet Slurry System:** mixes the abrasive with the water jet early in the system. This is done before the water is pressurized. Slurry systems then accelerate the abrasive particles with the water throughout the system. This causes more wear on the internal parts than an entrainment system.

**Abrasive Waterjet Entrainment System:** mixes the abrasive with the waterjet in a mixing chamber just after the nozzle. In most systems being built today, a venturi effect is utilized to pull the abrasive into the waterjet. The abrasive particles are accelerated into the stream and then with the stream out the orifice.

***Material Forming:*** Any manufacturing process in which products are given new shapes by casting, or by some form of mechanical deformation such as forging, stamping, or bending.

**Bending Machines:** designed to strain (bend) material which is usually in the form of bars or tubes.

**Die-Forming Machines:** metal forming machines employing a pair of mating dies which, when forced against the interposed sheet of material, impart their contour on the otherwise flat sheet.

**Extrusion:** a process used to force metal, plastic, or other materials, by compression, through a die.

**Forging Machines:** used to deform the workpiece into desired shapes by compressive forces exerted through a die, generally at elevated temperatures.

**Hydro-forming:** The use of liquid pressure to mold material. In metal forming, the fluid pressure is used to actuate the ram for both open- and closed-die forging. In plastic molding, the molding force is created by the pressure exerted by the fluid material itself.

**Presses:** machines having a stationary bed and a slide (ram) which has a controlled reciprocating motion toward and away from the bed surface and perpendicular to it. They are used to form and/or shear the workpiece (usually from flat sheet).

**Punch Presses:** cuts holes in stock using special punches and dies. Operations such as nibbling, notching, piercing, perforating, slotting, pointing, and marking are very similar to punching.

**Roll Forming:** a continuous process of feeding metal sheet, strip, or coiled stock, between successive pairs of rolls that progressively shape it unti the desired cross section is produced.

**Shearing Machines:** designed for straight-line cutting, involving the action of two opposing blades, one or both of which move during the shearing operation.

**Spin forming:** a device that uses one or more high-strength working rollers moving against a rotating sheet metal disc (workpiece) which is formed over a spinning chuck to shape a part. During the operation, there is no deliberate reduction in wall thickness. It may also be referred to as the spinning machine.

**Stamping:** the process of cutting and shaping metal alloys into specific forms, especially to be used as components for large machinery or structures. Metal sheets can be molded into different pre-determined shapes for use as regular products like pans and cans.

**Stretch Forming:** A forming process widely used in the aircraft industry to produce parts with large radius of curvature by primarily applying tensile forces to stretch the sheet metal over a tool or form block.

## *Additive Processes*

**3D Printing:** a manufacturing process for rapid and flexible production of prototype parts and tooling, layer by layer, directly from a CAD model. It can create parts of any geometry, including undercuts, overhangs, and internal volumes. A thin distribution of powder is spread over the surface of a powder bed and the computer calculates the information for the layers. A binder material joins particles where the object is to be formed. A piston then lowers so that the next powder layer can be spread and selectively joined, this process is repeated until the part is completed.

**Rapid Prototyping:** The speedy fabrication of sample parts for demonstration, evaluation, or testing. It typically utilizes advanced layer manufacturing technologies that can quickly generate complex three-dimensional objects directly from computer-based models devised by Computer Aided Design (CAD). This computer representation is sliced into two-dimensional layers, whose descriptions are sent to the fabrication equipment to build the part layer by layer. Rapid prototyping includes many different fabrication technologies:

**Fused Deposition Modeling (FDM):** a process which forms three-dimensional objects from CAD-generated solid or surface models. FDM patterns are generally used when an acrylonitrile-butadiene-styrene thermal plastic part is required for a working prototype.

**Laminated Object Manufacturing (LOM):** process that creates models from inexpensive, solid-sheet materials. It is similar to stereolithography in that it slices a three-dimensional electronic file from the computer to the LOM machine to produce parts for visualization models, casting patterns, and designs.

**Selective Laser Sintering (SLS):** a flexible technology that uses a $CO_2$ laser beam to fuse (sinter) layers of nylon, metal, or trueform powdered materials into a three-dimensional model. It is a leading rapid prototyping technology, providing more choices of materials for flexibility, and more applications than other technologies.

**Stereolithography (SL):** A layer manufacturing technology in which the layers are formed by using a laser to cure the surface of a bath of photo-sensitive polymer resin in the desired shape. The process takes a CAD design and makes a solid three-dimensional prototype (model) using a combination of laser, photochemistry, optical scanning, and computer software technology.

## *Controls/Software*

**CAD/CAM:** Results when computer-aided design (CAD) systems in engineering and computer-aided manufacturing (CAM) systems in manufacturing are joined together to produce a product.

**Closed-loop Servo-controlled System:** a control system which compares the system output to the system input, and can make corrections for any variations that exist.

**Computer-Aided Design (CAD):** the use of a computer and specialized graphics software to design a part or workpiece. A machine program may also be obtained as an output of the software.

**Computer-Aided Engineering (CAE):** the application of computers, special software, and various peripherals to accomplish such engineering tasks as analysis and modeling.

**Computer-Aided Manufacturing (CAM):** the use of a computer and specialized graphics software to prepare a machine program for a computer numerically controlled (CNC) machine.

**Computer-Integrated Manufacturing (CIM):** the total integration of such individual concepts as NC, robotics, and materials handling into one large automated system.

**Computer Numerical Controls (CNC):** a numerical control system where the data handling sequence, the control functions and the response to data input are determined primarily by a computer program executed by a computer. It provides electrical signals to coordinate and move the various slides or axes of the machine.

**Control System:** a system of hardware and software that controls the operation of a CNC machine tool. For motion control, it may use either nonservo techniques that control endpoints only, or a servo control of the path and speed.

**Direct Numerical Control (DNC):** the direct control of a number of separate CNC machine tools by a large central hose computer. The part programs are down-loaded from a host computer directly into the memory of a CNC machine tool as required.

**Distributed Numerical Control:** a hierarchical control in which the machine tool control units are connected to a central plant computer and the controllers are themselves CNC units.

**Numerical Control (NC):** a form of programmable automation in which the machine tool is controlled by means of a predetermined program of coded instructions and commands which consist of numbers, letters, and other symbols.

**Programmable Logic Control (PLC):** a digital electronic stored program device used in sequencing, timing, counting, and arithmetic to control – through digital or analog input/output modules – various types of machines or processes.

**Servo Control:** an industrial robot control system in which sensing devices monitor movement, and report any deviation between commands as issued and movement as monitored. Deviations will automatically cause corrective action to be taken.

**Tool Changer:** mechanisms that automatically change cutting tools on a CNC machine under program control. It may take the form of a carousel with a variety of cutting tools for machining centers, or a special device at the end of a robot arm that provides for quick changes of the end-effector or tool.

***Tooling:*** the tools and equipment that help industrial personnel make product parts of consistent size, shape, and quality.

**Arbors:** milling accessories that are used to mount milling cutters. They are inserted and held in the spindle by a draw bolt or a quick-change adapter.

**Boring Bar:** usually a round bar, used mainly on lathes, mills, and boring and drilling machines, that holds one or more cutting tools during a boring operation. It can be held stationary and moved axially while the workpiece revolves around the cutting tool, or it c an be revolved and moved axially while the workpiece is held stationary.

**Boring Tool:** a cutting tool mounted in the boring bar that is used to true and enlarge a previously drilled or cored hole. Each successive tooth removes a small amount of metal to enlarge a hole or slot to a size or shape.

**Broach:** a tapered tool having a series of teeth increasing in size and/or shape that is pushed or pulled into a workpiece.

**Ceramics:** a class of hard, brittle, and high-melting nonmetallic cutting tool materials made from aluminum oxide, zirconium oxide, and beryllium oxide. Ceramics are generally used for machining hard ferrous materials and cast iron at cutting speeds higher than those possible with the use of high-speed steel tools.

**Cermets:** inserts composed of solid titanium carbide (TiC) and titanium nitride (TiN) with a superalloy metal binder; used for high-velocity precision machining of cast irons and steels where high temperatures are encountered.

**Counterbore:** an end-cutting tool with a pilot on its end to keep the tool in line with the hole being counterbored. Some types of counterbore tools have interchangeable pilots to suit various-size holes.

**Countersink:** a tool with an angular cutting surface used to enlarge the start of a hole to allow a screwhead or other object to sit flush with the surface of the workpiece.

**Dies:** hardened cutting tools used to produce external threads on round work. The most common types are solid, adjustable, and adjustable screw-plate dies.

**Drills:** a rotary end-cutting tool used to produce holes in most types of materials. Two helical flutes are cut lengthwise around the body of a standard drill to provide cutting edges and space for the cutting to escape while drilling.

**End Mill:** a milling cutter with teeth on its end as well as on the periphery. End mills are manufactured in a variety of sizes and styles to suit a wide variety of milling operations.

**Gear Cutter:** a formed cutter having the exact shape of the space between the teeth of the gear to be cut.

**Gear Hob:** a formed gear cutter used for continuous cutting of gear teeth on gear-generating machines.

**Grinding Wheel:** a cutting tool composed of natural or manufactured abrasive grains that are held together in a desired form with a suitable bond material. Grinding wheels are manufactured in a variety of sizes and shapes to suit various grinding operations or different types of work material. The most commonly used grinding wheel is made of aluminum oxide grains that are held together with a vitrified bond.

**Helical Cutter:** a milling cutter having right- or left-handed spiral flutes cut at helix angles of 45° to 60°. This gives the teeth a shearing action, reduces chatter, and produces a good surface finish. These cutters are suited for milling wide and intermittent surfaces.

**Indexable Insert:** a replaceable geometric-shaped tool, made of carbide, ceramic, cermet, polycrystalline cubic boron nitride, or polycrystalline diamond that is mechanically held in special holders. Indexable inserts usually have multiple cutting edges that can be used and resharpened when all the edges are dull.

**Milling Cutter:** any type of rotary cutting tool with one or more teeth; used on a milling machine to remove material as the workpiece is moved past the rotating center.

**Modular Tooling:** A complete tooling system which combines the flexibility and versatility to build a series of tools necessary to produce a part. Modular systems combine accuracy and quick-change capabilities to increase productivity.

**Punch:** the male part of a die, fastened to the punch holder, which is moved directly or indirectly by the press slide.

**Reamer:** a rotary cutting tool with straight or helical cutting edges along its body. It is used to accurately size and smooth ah ole that has been previously drilled or bored.

**Superabrasive Tools:** cutting tool inserts made from diamond or cubic boron nitride (CNB) that can be used for the high-speed cutting of hard, abrasive materials. Diamond insert tools are used for machining hard, abrasive nonferrous or nonmetallic materials. Cubic Boron nitride insert tools are used for machining hard, abrasive ferrous materials through a chemical vapor deposition process.

**Tap:** a cylindrical fluted, hardened cutting tool that is used to produce internal threads. Machine taps are designed for use on machine tools such as lathes, drill presses, and milling machines. The most common are the stub and spiral-flute taps.

**Toolholder:** a holding device used to hold a cutting tool during a machining operation. They are available in a variety of styles and shapes such as straight, left-, and right-hand lathe toolholders and parting, threading, and boring toolholders.

## *Workholding Devices*

**Angle plates:** a t-slotted or blank form usually made from strong iron castings. Adjustable angle plates may tilt in one direction only or have a swivel base. They are very useful for milling workpieces that are irregular in shape and cannot be held easily in a vise.

**Blocks:** a locator that provides a wall for a part or fixture to be held against

**Bushings:** mechanisms used to guide the tool and keep it in proper location in relation to the workpiece, so that operations such as drilling and reaming can be performed accurately on many similar parts.

**Chucks:** universal holding device capable of OD and /or ID clamping. A chuck may be actuated manually, pneumatically, hydraulically or electrically.

**Clamps:** A stationary workholding device having one or more moveable jaws that is used to clamp a workpiece.

**Jig:** a tool or device that positions and clamps a workpiece; also guides or controls the location of the cutting tool.

**Fixture:** a device used to locate or support material, workpiece(s), or tool(s) during machining operations. Usually custom designed to hold a specific workpiece.

**Tooling Columns:** a device used in association with clamping device to hold workpiece in position (horizontal or vertical).

**Vise:** a mechanical device used to clamp work for hand or machining operations. Vises are generally made of malleable iron or steel and have two jaws: one fixed and one movable.

## *Material Handling*

**Automated Guided Vehicles:** a computer-controlled robotic handling system used to move tools and materials from a storage-retrieval area to a machine station, or vice versa.

**Automated Storage-and-Retrieval System:** a computer-controlled system used for storing and retrieving parts from a warehouse as they are required in manufacturing, through the use of automated guided vehicles.

**Automatic Tool Changer:** a mechanical armlike device on the CNC machine tool for automatically changing cutting tools under the control of a part program.

**Conveyors:** a machine used to move parts and materials along an assembly line at a constant rate of speed.

**Flexible Manufacturing System (FMS):** a group of processors or workstations connected by an automated materials-handling system and operated as an integrated system under computer control.

**Robot:** a computerized or electromechanical automatic, general-purpose device, whose primary function is to produce motion in order to accomplish some task. Computerized robots usually consist of three main components: the machinery or mechanical parts, the controller/computer system, and the software. An industrial robot is designed especially for industrial use such as materials handling, tool changing, assembly, welding, and measuring. An industrial robot can be programmed or taught by using a digitizing system which translates movements into commands for the robot to understand. The five basic types of industrial robots are:

**Antropomorphic, or Articulated Robot:** has movements such as the human arm, with rotating shoulder, bending elbow, and rotating wrist.

**Cylindrical Robot:** similar to the Cartesian model except that it rotates about a stationary base instead of moving from side to side.

**Overhead, or Gantry Robot:** moves on a crane or bridge-type support; the arm can have a number of axial movements.

**Polar, or Spherical Envelope Robot:** rotates about a perpendicular axis; its arm is capable of moving in and out and through an up-and-down arc.

**Rectilinear, or Cartesian Robot:** moves in straight lines, the X, Y, and Z axes.

**Robotics:** computer-aided manufacturing, where robots are used for repetitive manufacturing operations such as assembly, painting, and welding.

## *Automated Systems & Testing*

**Coordinate Measuring Machines:** a numerically controlled machine for measuring shapes and dimensions of solid objects, which consists of a contact probe and a means of positioning the probe in three-dimensional space relative to the surfaces and features of a workpiece to be measured. The locations of the tip of the probe can be accurately and precisely recorded to obtain dimensional data concerning the workpiece geometry.

**Flexible Manufacturing Systems (FMS):** An automated manufacturing system consisting of a number of CNC machine tools, serviced by a materials handling system, under the control of one or more dedicated computers. It is designed to produce parts with a minimum of production changeover time.

**In-process Gaging:** A system using probes, lasers, optical devices, or similar instruments to measure or inspect work while it is being machined.

**Optical Comparator:** a device that projects an enlarged shadow of an object onto a screen where it may be compared to lines on a grid or to a master form that indicates the limits of the dimensions or the contour of the part being checked.

## *Plastics Technology*

**Blow Molding:** the process of fabricating hollow products by forcing a hot plastic (melt) into the shape of the mold cavity by internal air pressure. There are three main types of blow molding:

**Extrusion Blow Molding (EBM):** uses an unsupported parison (hollow plastic tube that is extruded from the die head and expanded within the cavity by air pressure to produce blown objects.)

**Injection Blow Molding (IBM):** uses a perform supported by a metal core pin.

**Stretched Blow Molding:** used for EBM or IBM to obtain bioriented products.

**Co-Injection Molding:** a special multimaterial injection process in which a mold cavity is first partially filled with one plastic and then a second shot is injected to enclose the first shot.

**Compression Molding:** a thermoset plastic molding technique in which the preheated molding compound is placed in a heated open-mold cavity. The mold is closed under pressure, causing the material to flow and completely fill the cavity where the pressure is held until the material has cured.

**Die:** in plastics technology, the terms die, mold, and tool are sometimes considered the same in that they have a female or negative cavity through, or into, which a molten plastic moves under heat and pressure.

**Extrusion:** the compacting and forcing of heated plastic material through a shaping orifice (a die) in one continuous flow.

**Injection Molding:** a molding procedure in which heat-softened plastic is forced from a cylinder into a relatively cool cavity that gives the item the desired shape.

**Thermoforming:** any process that forms thermoplastic sheet by heating the sheet and forcing it onto the mold surface by vacuum or air pressure, mechanical means, or a combination of both.