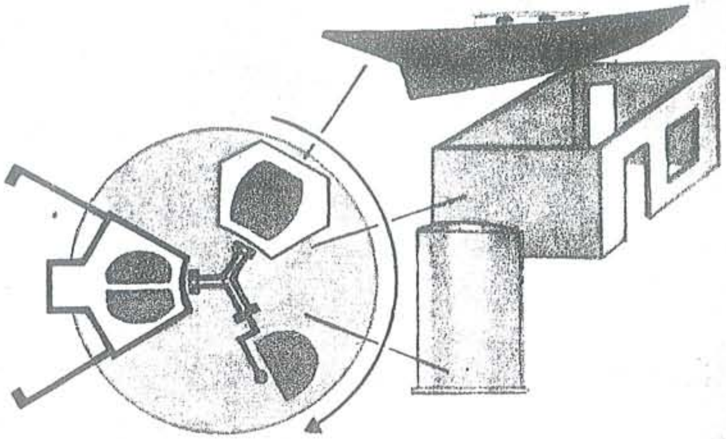
Rotational molding —a quick update



When it comes to forming large hollow parts having complex shapes, rotational molding remains unique as a process. Parts can be made from powders or liquids, in thermoplastics and, in some instances, in thermosets.

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If you are planning to manufacture large hollow parts, don't overlook rotational molding as one of the ways to go. You can mold parts in an almost endless variety of sizes and shapes, many of them virtually impossible to produce economically by other more widely used processes. One machine offered for rotocasting can produce parts measuring 10-1/2 by 10-1/2 by 8 feet—suggested product capabilities include boat hulls, storage tanks for corrosive chemicals, and large modular-room units for mass-produced housing. And machinery makers envision the possibility of building even larger machines.

The rotomolding process was originally developed to process hollow parts from liquid polyvinyl-chloride formulations (plastisols), but is now used for molding practically all thermoplastic resins, usually in dry-powder form. What's more, with the exception of powdered phenolic resins, the process can also be used with thermosetting materials such as precatalyzed epoxies and polyesters, or urethane systems and others that polymerize in the mold.

Mechanics of rotational molding

Essentially, the process starts with the precise weighing of a quantity of material that is placed in a mold which is then securely closed. The mold is rotated about two perpendicular axes while being first heated and then cooled. Finally, the mold is opened, the part removed, and the mold recharged for the next cycle. The operation can be performed with a single mold that passes successively through three machine stations—the work zone (unloading and recharging), the oven, and the cooling zone. Most commercial rotomolding machines have three arms so that the three functions can be performed simultaneously (some have five arms for greater output). Each mold is mounted on a support or carrier assembly (arm) which in turn is mounted on a central rotating hub that contains the rotational-drive mechanism for rotating the mold, and the indexing mechanism to move the molds from station to station. Other machine configurations are also used; the step-by-step functions are essentially the same.

In a three-arm setup as one mold indexes to the oven position, the other molds advance to the cooling and work zones respectively.

In the heating step (oven-residence cycle), the thermoplastic material, having been distributed over the entire inner surface of the mold, begins to fuse as the mold is heated. Initial partial fusing forms a porous skin on the mold surface which gradually melts to form a homogeneous layer of melted plastic of uniform thickness. The action is slightly different with liquid resins which flow out and coat the mold surface until their gel temperature is reached, when flow ceases. In any case, sufficient time in the oven must be scheduled for the material to be completely distributed and fused. (Thermosets require no external heating since they solidify by chemical reaction of resin and catalyst; but adequate time must be allowed to complete the reaction cycle).

At the end of the oven-residence cycle the molds are again advanced with the heated mold moving to the cooling zone. When the mold has cooled, rotation stops and the mold is indexed to the work zone where it is opened, the part is removed, and the next charge is loaded.

Fusing the resin

Thermodynamically, rotomolding is an unsteady-state heat-transfer process, in which the mold temperature is constantly rising or falling throughout the cycle, first to heat and then to cool the resin inside the mold. Since the resin is heated inward from the mold surface, the known poor heat-transmission properties of resins retard the heating of material farthest from the mold surface. Heating the mold to high temperatures to accelerate fusing of the entire resin mass is usually not possible as it entails overheating and degradation of the resin in direct contact with the mold surface.

Thus, fusion time will depend on the maximum oven temperature that can be sustained without damaging the resin; the wall thickness of the part; the type and particle size of the resin, its melt temperature, and heat of fusion. External factors relating to the mold are the mold surface-to-volume ratio, and the mold's heat capacity per unit area; the heat-transmission rate of the mold material; and the temperature and effectiveness of the heating medium in heating the mold surface.

Raising the actual oven temperature can effectively shorten the fusion time. The rate of fusion can be increased by as much as 30 percent by raising the temperature from 400 to 600°F. Possible degradation of the resin, however, can make the higher oven temperature self-defeating Such degradation is manifested by discoloration, development of strong odors, internal voids, or surface deterioration, depending on the particular polymer involved. In addition, wear and tear on the equipment may be greater, resulting in increased maintenance costs.

The heating time in the oven is generally the limiting factor in the duration of the overall molding cycle. The heating period is composed of two elements: the temperature buildup time in which the mold is heated to the melting temperature of the resin, and the actual fusion time in which the total fusing of the resin is completed. To shorten the overall cycle it is often possible to transfer the mold to the cooling station before fusion is completed, relying on heat retention by the mold and the resin itself to continue the fusion while the cooling cycle—which takes less time—is delayed. In this way, the following mold can start its heating time sooner, thereby increasing machine output.

Heating and cooling systems

Most rotational molding machines operate with a heated enclosure or oven as the heating zone. Rapid heating is obtained by spraying hot liquids—oil or molten salt—directly onto the mold, but newer machines use hot-air impingement instead, thereby eliminating the hazards of personal injury and machine deterioration often associated with the hot liquids, and the difficulties inherent in recovering the liquid media.

For mold cooling, early rotational-molding machines were simply air-cooled by large fans. Later, water-spray cooling was added to speed up cycles, and this combination remains the most popular. As mentioned above, the cooling zone is often used to continue the fusing cycle after the mold has moved from the heating oven. In this procedure, fan cooling is used to effect a gradual drop in the mold temperature before the programmed water-spray cooling is started to complete the cooling cycle.

Internal cooling of molded parts can be utilized to speed up the cooling cycle, usually by introducing a stream of chilled air or water into the mold through the machine arm. The technique has not been widely applied, probably because of its potential difficulties. With water cooling there is the possibility of steam generation as the water is heated, resulting in internal pressure that can damage the mold. Also, excessive air pressure can generate a force sufficient to distort the mold. With either cooling medium, venting of the mold is a must to protect the mold. Other problems with water cooling result from water droplets striking the inner wall of the part to produce pockmarks, and accumulation of water inside the part, which makes demolding difficult and sloppy.

Internal pressure, properly controlled, does hold the part against the mold wall and improves heat transfer from the part as it is cooling. Internal cooling speeds the part-cooling time in two ways—by direct heat extraction and by better heat transfer to the wall.

If you choose internal cooling, you must be careful to avoid exceeding the internal pressure a particular mold construction can safely withstand without distortion or other damage. Even the low 2 to 3 psi air pressure usually used, can generate a high total force on the mold (pressure multiplied by projected area of the part).

Experiments have been performed using liquid carbon dioxide as the internal-cooling medium. The high pressures generated as the liquid vaporizes inside the mold appear to be excessive for most molds in use today, and this otherwise highly effective cooling medium is not recommended at present for rotomold cooling.

The most recent advancement in heating/cooling systems is the use of jacketed molds in which liquid heating and cooling media are circulated between the mold proper and its outer jacket. Such systems have several advantages over external sprays or air:

- Higher heat-transfer coefficients—faster cycling;
- More precise control of resin temperatures—which can be measured by internal thermocouples;
- Effective use of lower molding temperatures—less likelihood of resin degradation;
- The ability to inject additives or to add more resin without interrupting the cycle;
- Lower energy consumption—with closed systems for both heating and cooling liquids.

An obvious disadvantage is the higher cost of jacketed molds, which largely limits their use to high-volume operations that can absorb the costs.

Cooling the molded part

In the early days of rotomolding, cooling was largely taken for granted—and little effort was put into understanding the potential benefits of improved cooling techniques.

With the adapting of rotomolding to the fabrication of a wide range of materials, particularly highly crystalline resins such as high-density polyethylene, nylons, and polyacetals, the effects of cooling rates on part properties became apparent. Now, slow cooling of crystalline resins is preferred when minimum part distortion and good low-temperature properties are needed, both resulting from the higher percentage of crystalline structure that results from slow cooling. On the other hand, rapid cooling inhibits large-crystal growth and produces parts with greater impact resistance and flexibility. Too rapid cooling, however, can damage molds because of the thermal shock to the metal.

In order to increase machine output, parts are sometimes stripped from the mold while they are still warm. Thus, cooling continues after the part is out of the mold. Uneven cooling rates, stresses caused by the weight of the part itself, and other seemingly insignificant parameters can cause post-stripping distortion of the parts. The distortion can often be avoided by placing the hot parts into cooling fixtures until they are completely cooled. With some parts it is possible to inject air (at 2 to 3 psi) which is held in the part until it is fully cooled to maintain its proper shape.

Rotational speed and ratio

Two important processing variables in rotational molding are the speed and ratio of rotation. Generally speaking, the speed is a function of resin flow properties, and the ratio is a function of part shape. As the cycle is made shorter, and the part-wall thickness decreases, the two parameters become more critical.

Rotational molding is not a centrifugal casting process. Since the center of gravity of most molds does not pass through both axes of rotation, and all mold surfaces are usually not equidistant from the center of rotation, any centrifugal forces generated would cause large variations in wall thickness. The forces generated by the high rotational speeds would cause the molten resin to flow toward the highest force concentration, rather than to distribute itself evenly about the entire mold surface.

The speed of rotation for a successful molding varies with the melt-flow properties of the material being molded. A material with a relatively high viscosity in its melt state will have a tendency to completely cover the mold with a uniform wall thickness when the speed of rotation is kept relatively slow, affecting the time/temperature cycle selection. Since a longer time will be needed to completely distribute the material, a lower oven temperature will be required, as the powder or liquid must pass over the mold surface enough times during the fusion period of the oven-residence cycle to result in a constant wall thickness. However, the time is not directly proportional to speed since at slower speeds the material will have a longer contact time with the hot mold and the buildup or coating rate will be higher than at higher rotational speeds.

Great care must be exercised in using high speeds because of the gyroscopic forces created by the rotation of high inertial loads about two perpendicular axes. With large molds and high speeds, these forces can be high enough to cause serious damage to the machinery.

The ratio of rotation is a function of the shape being molded. A symmetrical shape, such as a sphere or cube, will run very easily at a 4 to 1 ratio (of major- to minor-axis speed). Irregularly shaped objects may require ratios ranging between 8 to 1 and 2 to 1. The nature of the art and the complexity of many molds, point to determining the proper ratio of rotation by a combination of trial and error or on the basis of previous experience. The *Table* gives commonly used ratios for various shapes. The values should be used only as a guide when setting up a new mold. It is possible to get good moldings at other ratios as well, because of variations in mold configurations and cycle settings.

The speeds of the two axes of rotation are easily determined by installing a tachometer on each drive shaft and reading rpm directly. An alternate approach is to time the period of one revolution of the drive shafts—not the mold shaft—in seconds, then divide the result by 60 to obtain the rpm.

With speed of each axis determined, the ratio of rotation of major to minor axes can be calculated as follows:

$$\text{Ratio} = \frac{N_1}{N_2 - N_1}$$

Where N_1 is the major-axis speed and N_2 is the minor-axis speed, both in rpm.

The ratio can be reversed simply by varying one of the speeds. For example, at a minor-axis speed of 10 rpm and a major-axis speed of 2 rpm, the ratio of major- to minor-axis speed is 1 to 4. This would mean that for every rotation of the major axis, the mold-mount shaft spins four times about its axis of rotation. Now, by increasing the major-axis speed to 8 rpm and maintaining 10 rpm on the minor axis, the ratio shifts to 4 to 1, so that the mold-mounting shaft spins about its axis once for every four revolutions of the major axis.

At all speed settings where the major-axis speed is one-half the speed of the minor axis, the ratio is 1 to 1. The mold mounting shaft then rotates once for each rotation of the major axis—not a good molding condition.

As the speed of the minor axis approaches that of the major axis, the ratio tends to approach infinity. At this point, the rotation of the mold-mounting shaft relative to the major axis has stopped and the mold does not spin. Adjustment of the speed of either drive motor will again cause the mold to spin about the axis of the mold-mounting shafts. It is possible to actually reverse the direction of minor-axis spin by adjusting the speed of either shaft in the proper direction. For example, at a minor-axis setting of 10 rpm and major-axis speed of 8 rpm, the ratio is 4 to 1, as described above. Lowering the minor-axis speed increases the ratio until at 8 rpm the relative rotation stops and the ratio becomes infinity. If the minor-axis speed is dropped again to 6 rpm, the ratio becomes a negative 4 to 1, indicating the same ratio as before, but with the spin about the minor axis in the opposite direction. This condition is not really critical in a mold with a simple shape, since the ratio is the same. However, in complicated molds with areas difficult to fill, such as sharp crevices, the direction of rotation relative to the mold position on the mounting spider becomes important for good resin distribution.

Resin particle size

The selection of a resin for rotational molding not only involves consideration of the physical and chemical properties of the resin, but also the properties of the powder itself—particle shape, size, and uniformity—all of which can affect the finished product. The most desirable particle is one that will flow readily into sharp angles, undercuts, or ribbing within the mold, and melt to a bubble-free state with a minimum of heat. As a rule of thumb, thin wall sections and sharp radii or undercuts require fine grind sizes, while finer particle sizes must be used with high-viscosity or low-melt-index resins.

An ideal particle is spherical in shape, with a smooth surface, and a narrow particle-size distribution. The particle size has been found to be optional in the range of 20 to 80 mesh; if too coarse, excessive oven-residence time is required to melt the particles, possibly resulting in deterioration of the polymer's physical properties from oxidation or thermal degradation. A powdered resin with excessively fine particles, or one which is fibrous or fluffy will have poor flow in the mold, resulting in incomplete fillout, pinholed surfaces, or bridging of angles and undercuts. In all cases, tails and fines, created by poor mechanical-grinding control, must be eliminated since a narrow size distribution is critical to good molding.

Powder to solid—forming the part

During the oven-residence cycle, the powder particles gradually increase in temperature to the point where the particles reach their melt temperature and stick to the hot walls of the mold. As the cycle continues, more particles adhere to the wall until the entire inner mold surface is coated. At this time, the actual buildup of wall thickness begins until all free particles in the mold have adhered to form a coating of uniform thickness. If the oven cycle were terminated at this point, the resultant part would be a rather weak, porous structure with a thin skin on the outside surface. A homogeneous wall of solid material does not form until the entire shell of the part is formed; then, with continued heating, the particles melt completely and fuse into a single molten layer of plastic.

If a particle is allowed to reach its softening point before it sticks to the mold surface buildup, it will stick to other free particles inside the mold and will have a tendency to ball up and create uneven wall surfaces. The results: poor resin distribution and unwanted openings or heavy spots in the molded part, most often caused by poor size distribution and/or a high percentage of fines or tails in the grind.

It has been found that with some resins it is necessary to use a very fine particle size in order to obtain good mold reproduction; on the other hand, too fine a grind will promote particle sticking as mentioned above. In order to minimize this possibility, the shortest possible oven-induction time is recommended regardless of particle size.

The apparent melt viscosity of the resin (at the low stresses found in the rotomolding process) is also an important consideration in the selection of the grind size to be used. A polymer with a relatively low viscosity (high melt index) will produce good surface reproductions with quite large particle size; a material with a high viscosity will require a fairly fine grind in order to be able to pick up good surface from the mold.

Larger particle sizes, when used with a high-viscosity material, result in poor surface reproductions, voids in the part, and a tendency to trap air in the form of bubbles when a part is formed. Since the apparent melt viscosity varies greatly from resin to resin and for different temperatures used in the process, it would be impractical to recommend a single particle distribution and size which would fit all resins for all molding conditions. Therefore, molders and resin producers often favor a particular distribution and size as the best since it works with their particular application and resin. In fact, two things stand out most clearly in relation to particle size: first, the elimination of tails and fines in the ground material will, in all cases, produce better parts; second, a smooth particle with a narrow distribution of grind sizes will again produce the best parts.

Molders normally talk in terms of mesh size when discussing the grinding or pulverizing of rotational-molding resins. The mesh size is determined by screening the powder through United States standard sieves. The mesh size is designated on a particular batch of resin by running it through a series of sieves and determining the minimum sieve size which will allow 95 percent or more of the powder to pass through it. Particle-size distribution is determined by establishing the percentage of the powder that passes through each of the subsequent sieves. With this data, one can determine the particle-size distribution curve and the acceptability of a particular resin batch.

Keep in mind that the particle size decreases with increasing mesh-size number, and that the cost of grinding increases also, since the finger particles require a longer grinding time. Thus, to achieve the greatest possible economy, the largest particle size possible or usable for a part should be specified since it will cost the least to grind.

Some development work has been done on molding with 1/32-inch pellets rather than powdered resins. The process has proven successful with simple shapes molded from such materials as butyrates, polystyrene, and high-flow polyethylenes. Work is hampered in this area because of the unavailability of most resins in the small pellet size. With simple shapes, such as balls and drums, acceptable results have been obtained using standard-size polyethylene pellets. Because of the cost savings which can be realized if grinding is eliminated, it is recommended that a test run be made using pellets with any application meeting the following conditions:

- Simple part shapes with no sharp corners or undercuts.
- Materials having fairly high melt flow (6 MI or higher for polyethylene).
- The minimum part-wall thickness is at least twice the maximum pellet dimension. □

Rotation ratios and speeds for typical part shapes.

Shape	Rotation ratio	Typical speed, rpm	
		Major axis	Minor axis
Oblongs and straight tubes[a]	8 to 1	8	9
Defroster ducts	5 to 1	5	6
Balls and gloves	4.5 to 1	8	9.75
Cubes, balls, odd shapes	4 to 1	8	10
Rectangular boxes, horses with bent legs	4 to 1	10	12.5
Shapes that have overlapping lines of rotation at 4 to 1	3.3 to 1	10 to 12	12.25 to 14.5
Rings, tires, balls	2 to 1	6	9
Rectangles that show two or more thin sides at 4 to 1	2 to 1	8	12
Picture frames, mannequins, round flat shapes	2 to 1	10	15
Horses with straight legs, auto crash pads[b]	2 to 1	12	18
Parts that have thin walls at 2 to 1	1 to 2	5 to 7	15 to 21
Flat rectangles—gas tanks, suitcases, tote-bin covers	1 to 3	4 6 9.5	15 22.5 36
Tires, curved airducts	1 to 4	4	20
Pipe angles, flat rectangles	1 to 4	5	25
Cylinders,[b] balls that have thin walls at 4 to 1	1 to 4	6	30
Cylinders[b]	1 to 5	4	24

[a] Horizontal mounted, parallel to major axis.
[b] Vertical mounted, perpendicular to major axis.

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