ROTATIONAL MOLDING

Rotational molding, also called rotomolding or rotational casting, is a thermoplastic processing method for producing hollow parts, from the most simple to the very complex.

CHAPTER CONTENTS:

THE BASIC PROCESS

Rotational molding consists of six steps:

1. A predetermined amount of plastic, either in powder or liquid form, is deposited in one half of a mold.
2. The mold is closed.
3. The mold is rotated biaxially inside an oven.
4. The plastic melts and forms a coating over the inside surface of the mold.
5. The mold is removed from the oven and cooled.
6. The mold is opened and the hollow part is removed.

Polyethylene powders are the most widely used rotational molding material. Vinyls, both liquids and powders, are the second most widely used rotational molding material. Many other types of plastics are rotationally molded, but are used less often.

APPLICATIONS

Rotational molding produces parts for many different industries including automotive, furniture, industrial equipment, lawn/garden, marine, materials handling, road/highway, sporting equipment, medical, toys, and transportation.

Agriculture

Vegetable growing trays, feeding/watering troughs, chemical tanks.

Consumer Products

Baby strollers, child car seats.

Containers

Storage tanks, 55-gallon drums, carboys, septic tanks.

Furniture

Children's beds, chairs, planter pots, tables.

Industrial Equipment

Tool carts, equipment housings, safety helmets, battery containers, fluid reservoirs.

Lawn/garden

Garden tool carts, composting bins.

Marine

Boats, kayaks, sailboards, canoes, boat bumpers.

Medical

Syringes, dental chairs, testing equipment housings, anesthesia/ oxygen masks, ear syringes, squeeze bulbs.

Materials Handling

Stackable pallets, forklift containers, shipping containers.

Road/Highway

Safety barricades, lane markers, litter bins, portable toilets.

Sporting Equipment

Bike seats, athletic pads, footballs, juggling pins, helmets.

Toys

Playhouses, outdoor gym equipment, balls, rocking horses, picnic tables, wading pools, pool floatables, doll parts.

Transportation

Camper tops, motorcycle saddlebags, bicycle trailers, tool chests for trucks, truck bed liners, air ducts, fuel tanks, seat back head-restraint covers.

ADVANTAGES AND LIMITATIONS

Key advantages of rotational molding:

- Molds are relatively inexpensive.
- Rotational molding machines are much less expensive than other types of plastic processing equipment, such as injection molding machines and blow molding machines.
- Different parts can be molded at the same time.
- Straight-wall parts can be made (no draft angles).
- Very large hollow parts can be made.
- Parts are stress-free.
- Very little scrap is produced.

Limitations of rotational molding:

- Cannot make high-tolerance parts.
- Large flat surfaces are difficult to achieve.
- Molding cycles are long.
- A limited number of resins are successfully processed.

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THE BASIC PROCESS

There are many process and materials variables for rotational molding, which gives the process considerable design flexibility.

MATERIALS TESTING AND PREPARATION

The rotational molding process starts with materials preparation. For powders, this preparation can include the grinding of pellets and the dry blending of colored powders.

Rotational molding powders are purchased from materials suppliers. Molders can also buy resin pellets and produce their own powders. There are three key powder properties: mean particle size, apparent/ bulk density, and pourability.

Particle size analysis. This process uses a series of stacked screens. A 100 g powder sample is placed in the top screen, which has the largest mesh. A cover is placed over the top screen and a pan below the bottom screen and the stack is mechanically shaken. The amount of powder retained by each sieve is measured. (ASTM D-1921)

Mean particle size (MPS) in microns is determined by:

$$MPS = [\sum(P_i \times D_i)]/100 \qquad (1)$$

where:

P_i = percent of powder retained in each sieve
D_i = average particle size in microns on each sieve

Apparent/bulk density. The density of powders is determined by pouring a powder sample through a funnel. The funnel has a top opening of 3.6 in. (9.1 cm), is 4.5 in. (11.4 cm) high, and has a wall inclination of 20° and a bottom opening of 0.4 in. (1.01 cm). The funnel is placed in a ring holder and a 3.9 in. (9.9 cm) measuring cup is placed below it, with its top 15 in. (38 cm) below the bottom of the funnel. The bottom of the funnel is closed by holding a flat material against it and the funnel is filled with 115 cc of powder. The bottom of the funnel is opened and all the powder flows into the cup. Apparent density (g/cc) is determined by dividing the net weight of powder in the cup by 100. Apparent density (lbs/ft^3) is determined by multiplying sample weight by 0.6243. (ASTM D-1895)

Pourability. Checking for pourability uses the same funnel for determining apparent density. A powder sample weighing 100 times the material's molded specific gravity is poured into the funnel. The flow time(s) for the powder through the funnel is recorded. Pourability, g/min = (wt of powder in cup $\times$ 60)/seconds (sample flow time from cup). (ASTM D-1895)

Optimum particle size. This will vary depending on the material rotationally molded and processing requirements. A mean particle size of 500 micron (35 mesh) powder is the norm for polyethylenes.

Rotational molding powders generally are mechanically ground without refrigeration. If the material's properties are affected by the heat generated during grinding, the polymer (polypropylene) pellets are refrigerated (using liquid carbon dioxide, liquid nitrogen or "dry ice" [compressed carbon dioxide]).

Key physical properties of rotational molding powders are dry flow (also called pourability), particle distribution, and bulk factor. Testing for these properties is done in accordance with ASTM D-1895. Dry flow describes the relative flow property of a powder at ambient conditions. Shorter flow times indicate better flow. Particle size, distribution, shape, and surface condition also influence flow properties.

Generally, rotational molding materials contain all the additives that are needed to meet processing and performance requirements. Typical additives include heat stabilizers, ultraviolet light stabilizers, and colorants. Many molders dry and blend their own colored materials and may add other additives to help the flow.

Precolored polyethylene powders save rotational molders the difficulty of dry blending pigments with natural-colored resin powder. Also, when compared to dry blending: higher pigment loading is possible with precolored polyethylene powders; there is greater lot-to-lot color consistency; and higher levels of inherent properties are retained with precolored powders.

Drying is required with some rotational molding powders (for example, polycarbonate and some nylons) that absorb moisture from the air, that is, they are hygroscopic. Moisture can affect the processing of rotational molding powders, as well as the mechanical properties of molded parts.

Rotational molding liquids, primarily vinyl plastisols, consist of a vinyl (homopolymer or copolymer) powder suspended in a plasticizing liquid. Generally, vinyl plastisol compounds are purchased from custom compounders rather than made by processors. The majority of large processors compound their own PVC.

A starting amount of powder required to rotationally mold a polyolefin part is determined by the formula:

Shot weight = mold cavity area (in.^{2}) $\times$ nominal wall thickness of part $\times$ density (lb/in.^{3}).

To convert density (g/cc) to density (lb/in.^{3}) multiply density (g/cc) by 0.0022 (g/lb) $\times$ 0.43 (cc/in.^{3}).

Adjustments to this amount, to account for part shrinkage during cooling, are then made through trial and error.

MOLDS AND SPECIAL CONSIDERATIONS

Discussion will include:

- Construction.
- Multilayer moldings.
- Cross-linked moldings.
- Inserts.
- Decorations.

CONSTRUCTION

Generally, the walls of rotational moldings are made of one material. However, multilayer rotational moldings are made using molds equipped with a drop box. For example, there can be a foam layer, a solid layer, a layer of recycled material, a cross-linked layer, and different colored layers. The major limitation of multilayer parts is that each layer acts as an insulator and, thus, production cycles are much longer. Using the same basic resin is recommended to achieve good layer bonding and minimize differences in layer shrinkage during cooling.

MULTILAYER MOLDINGS

Multilayer rotational moldings are made in the following manner:

1. A polyolefin powder is inserted in the mold to form a solid outer layer.

2. Using a dump box in the mold, the material for the second layer is dropped into the mold.

CROSS-LINKED MOLDINGS

Cross-linked rotational moldings can be made by using materials that contain a chemical cross-linking agent. Cross-linking improves impact strength, dimensional stability, creep resistance and environmental stress crack resistance (ESCR) (see “Secondary Finishing” in this chapter).

INSERTS

Inserts for mechanical fastening are molded in place during the rotational molding process. The inserts are placed in the mold cavity prior to dispensing the material into the mold. Reinforcement inserts, such as glass fiber-reinforced plastic rods, also can be added to rotational moldings.

DECORATIONS

Decorations can be directly molded into rotational moldings or applied later (see also “Secondary Finishing” in this chapter). By embedding a graphic into the surface of a rotational molding, the graphic becomes permanent and will not peel, and cannot scratch or rub off. Molded-in Graphics® eliminate surface pretreatment required with other decorating methods.

Molded-in Graphics are printed on paper carriers. The carrier, graphic side down, is placed on the mold surface. The back of the carrier is rubbed to ensure that the graphic fits tightly against the mold surface without air pockets. Then the carrier is peeled off, leaving the graphic on the mold surface. The mold is charged with the molding powder and the part is molded. During the molding cycle, the graphic (which is made of colored polyolefin-compatible powder) becomes embedded in the surface of the part and a thin layer of the molding material forms over the graphic.

EQUIPMENT

Rotational molding systems, including both the basic molding machines and the auxiliary equipment, are significantly improved.

GRINDING

Attrition mills are a common type of equipment used to make rotational molding powders. Pellets are pulverized between two serrated or otherwise simple rough disks, which have a close tolerance between them and rotate either in opposite directions or with one stationary disk. The type of serration, the clearance between the disks, and the speed of rotation vary according to the pellets used and the required particle size.

MIXING

High-intensity shear mixers blend dry powders, colorants and additives. Other types include vertical whirlwind mixers, paddle mixers, ribbon mixers, drum tumblers, and drum rollers.

DRYING

Desiccant dryers run at high temperatures, and hot air circulating ovens remove moisture from hygroscopic rotational molding powders. Generally, a thin layer of the material is spread on large pans placed in the dryer.

MATERIAL LOADING

Usually, material is loaded manually, although the process can be automated. Accurate weighing of the material charge and distribution prior to starting the molding cycle is important especially in large molds.

MACHINE TYPES

There are seven machine types used for rotational molding:

- Clamshell.
- Turret.
- Shuttle.
- Swing.
- Vertical wheel.
- Rock and roll.
- Open flame.

CLAMSHELL MACHINES

A clamshell machine (Fig. 10-1) is a single-station machine including an oven with hinges for the cover and front panel. The mold rotation arm can swing into and out of the open oven. The cover and front panel are closed during heating and are opened for part cooling, part removal, and reloading of the mold.

TURRET MACHINES

Also known as carousel machines (Fig. 10-2), turret machines have a center pivot with three to six arms. Each arm has a mold attached to its end. The arms index individually or simultaneously from station to station. Depending upon production requirements, these machines can have two cooling stations and/or two load/unload stations. Arms can handle loads (mold and material) up to 4,000 lb (1,814 kg).

SHUTTLE MACHINES

Shuttle machines (Fig. 10-3) move the mold along an oval or straight track from the load/unload station to the oven, then to the cooling station.

SWING MACHINES

A swing machine (Fig. 10-4) has one or more pivot units with a single arm that indexes from the load/unload station, to the oven, and then to the cooling station.

VERTICAL WHEEL MACHINES

Vertical wheel machines (Fig. 10-5) operate like a ferris wheel. Molds, mounted on cradles, are indexed simultaneously from sta-

MACHINE TYPES

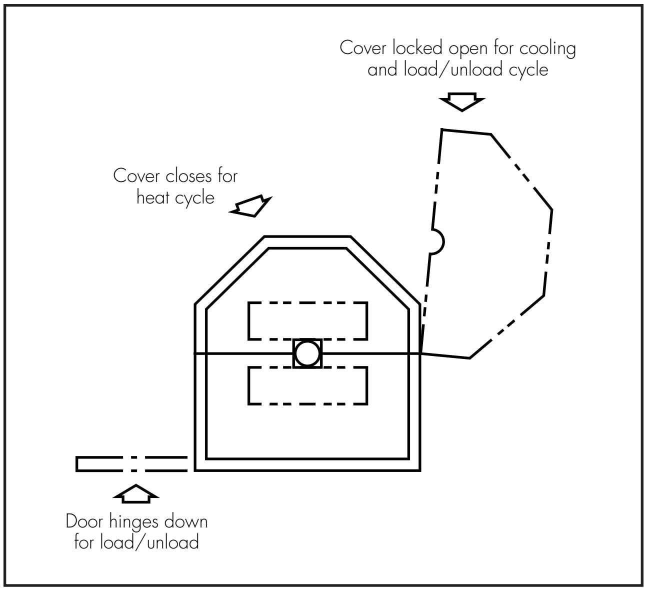

Fig. 10-1 Single-station machine with an oven (clamshell machine).

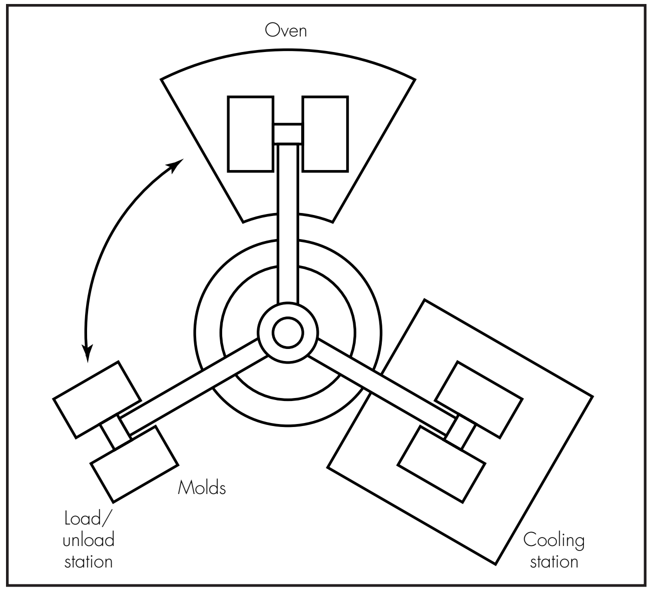

Fig. 10-2 Turret machine.

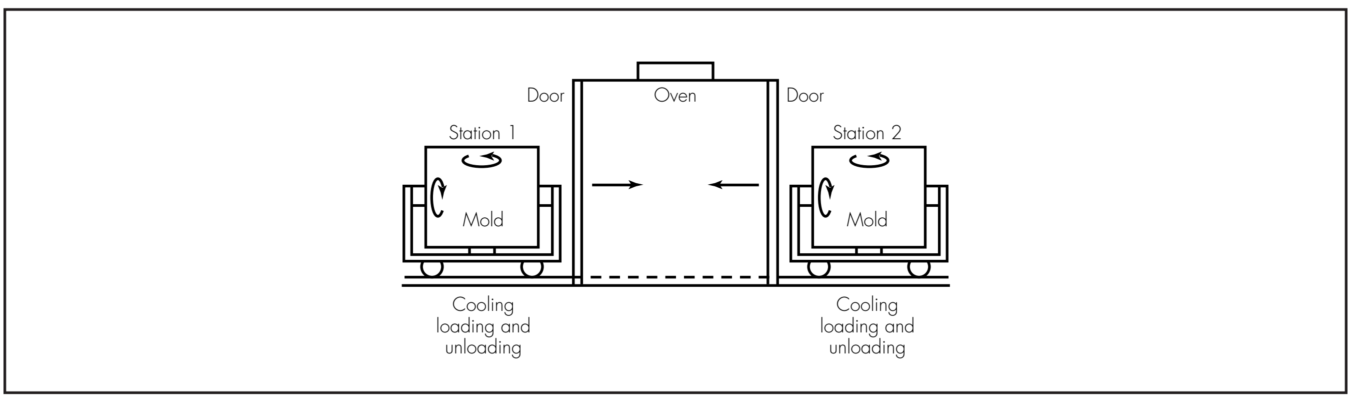

Fig. 10-3 Shuttle machine.

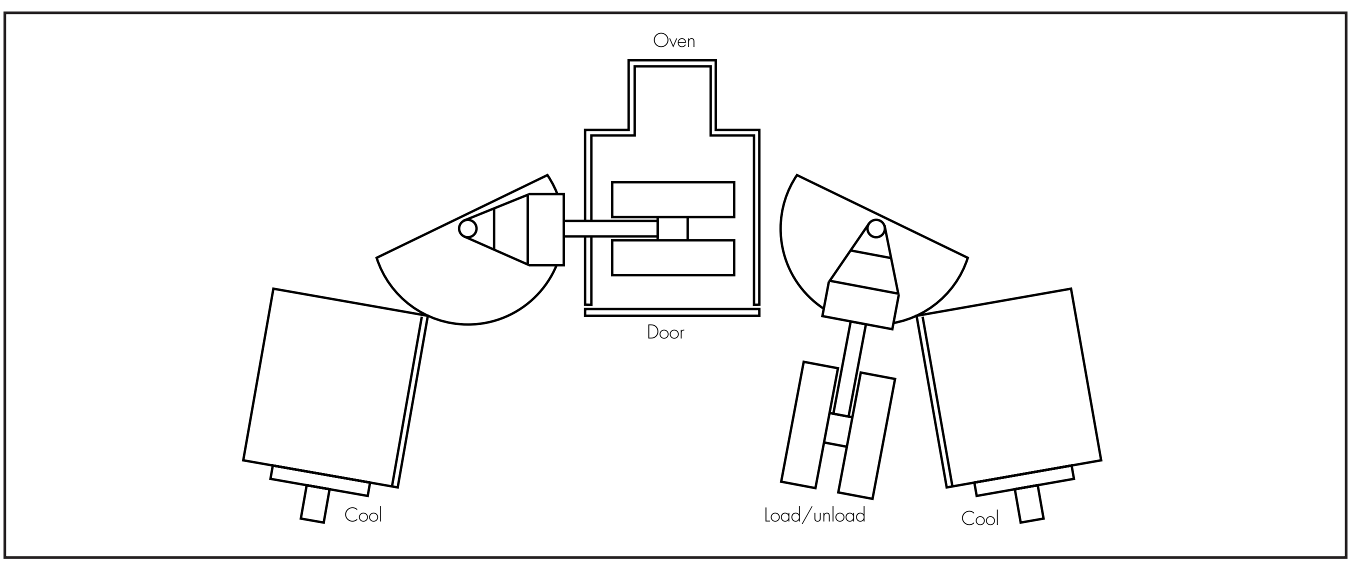

Fig. 10-4 Swing machine.

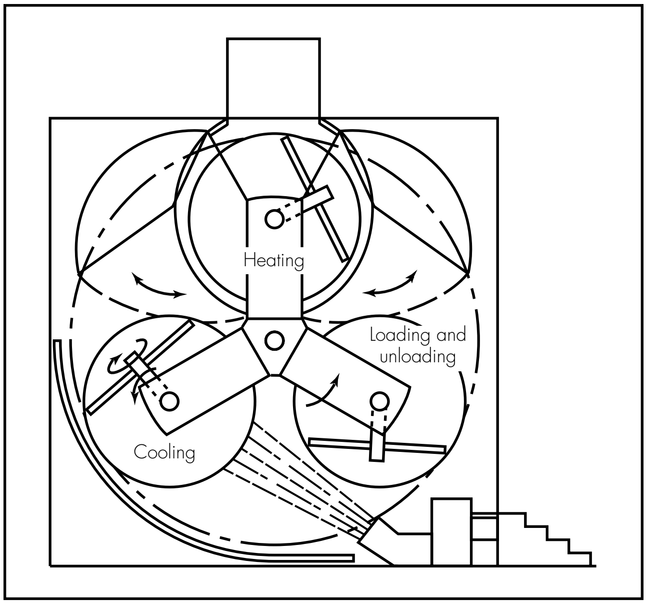

Fig. 10-5 Vertical wheel machine.

tion to station, with the load/unload station at the bottom of the wheel. Vertical wheel machines with up to six cradles can mold small- to medium-size parts. The cradles have maximum load limits of 300 lb (136 kg).

ROCK AND ROLL MACHINES

Rotational moldings with very long length to diameter ratios can be made on equipment called rock and roll machines (Fig. 10-6). The mold, mounted on a cradle, is rocked back and forth on a stationary, horizontal axis while it is rotated about a moving axis perpendicular to the rotating axis. On some machines, the oven may move. Canoes and kayaks are made with this type of machine.

OPEN-FLAME MACHINES

The oldest type of rotational molding equipment, open-flame machines, produce open-ended items such as pails and drums.

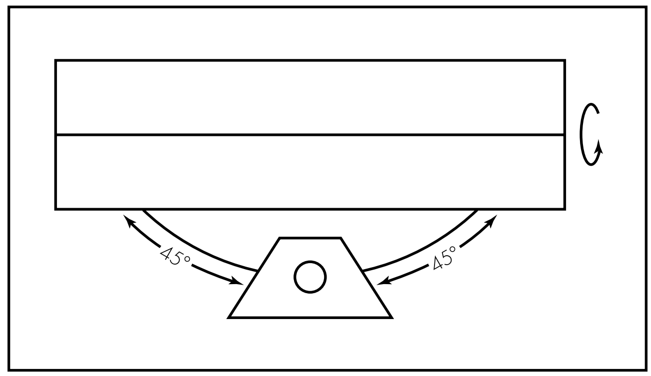

Fig. 10-6 Rock and roll machine.

PROCESS FACTORS

SINTERING

A significant part of the rotational molding heating cycle is taken up by sintering or curing of the part while the mold is still in the oven. During sintering, air pockets trapped at the mold surface or within the material collapse.

Air pockets can affect surface appearance and cause internal voids that affect the part's strength. Sintering time can be reduced by controlling the air inside the mold or by using additives that reduce the formation of air in the material.

After the sintering cycle, the rotational mold is cooled, usually by free air convection. However, forced air convection can significant-ly reduce cooling time. Quick quenching, such as by water spray, can further reduce the cooling cycle, but can increase the amorphous structure in crystalline polymers. Slow cooling, therefore, is generally preferred for crystalline polymers when resistance to warping and good low-temperature properties are needed. The cooling rate has little effect on the properties of amorphous polymers. Also, the cooling cycle is reduced by injecting cool air inside the rotational molding. This technique also improves dimensional stability.

Generally, parts removal is done manually. Release agents either periodically sprayed or wiped on mold surfaces permit easy part removal. Occasionally, an air ejection assist is used to lift a part from the inner mold surfaces.

MOLD ROTATION

Wall thickness distribution is determined by rotation ratio, that is, the number of primary rotations per minute to the number of secondary rotations. The rotation ratio is a function of part shape. A sphere or cube can be molded at a ratio of 4:1, but irregularly shaped parts can require ratios of 1:8 or 8:1. The optimum rotation ratio is determined by trial and error and molder experience.

Rotation speed varies with the melt flow properties of the material. A material with a low melt index (MI) tends to uniformly cover the mold when rotation speed is low. However, low-oven temperatures may be needed, thus making the molding cycle longer. Also, MI affects the material's properties.

Generally, ovens for rotational molding machines use forced hot air, heated by natural gas, liquid petroleum gas (LPG), oil, or electricity. Temperatures up to 900° F (482° C) are reached by some models.

Cooling units apply forced air and/or water sprays to the outside of the mold. Also, cooling air can be injected inside the part through a vent hole in the mold.

CONTROL SYSTEMS

Basic controls for rotational molding machines include heating controls/sensors, cooling controls/sensors, timers, sequence controls, rotation speed controls, and on/off buttons. Rotational molding machines can have microprocessor controls and programmable controllers. Mold cycle data can be quickly inputted, stored, retrieved, and activated. Cycle data can include cycle times, oven temperatures, major and minor axis speeds, rotation time, and cooling temperatures. Also, automatic troubleshooting is possible.

A major development is the ability to control the rotational molding process by measuring temperature inside the mold.

PROCESS FACTORS

Standard rotational molding machines have a thermocouple in a corner of the oven to control process temperatures. Temperature measurements inside the mold allow more accurate determination of when the plastic first starts to stick to the mold, when all the material has adhered to the mold, when the material has sufficiently cured, when the plastic has solidified, and when the part can be removed from the mold.

Another development is the use of a hand-held infrared thermometer to measure mold and oven temperatures.

TRIMMING

Generally, rotational moldings that have well-designed parting lines do not require trimming. However, with prolonged mold use, parting line flash may develop and require trimming. Also, molded-in holes may require some trimming.

MOLDS

One key advantage of rotational molding compared to other plastics processing methods is the low cost of molds. Generally, molds consist of two pieces, although three or more piece molds may be used to allow for removal of a complicated part.

Major factors to consider in designing a rotational mold are heat transfer of the material, where parting lines are located, where to vent the part, how the mold is clamped, how the mold is mounted for rotation, and how many parts the mold will make.

Rotational molds are subjected to large thermal stresses during the process. In a relatively short period of time, they are heated to 600˚ F (316˚ C) and higher and then cooled down to about room temperature. Selection of a mold material must consider this thermal stress, as well as design, production, and economic factors.

CAST ALUMINUM MOLDS

Cast aluminum molds are the most widely-used and are made quickly and relatively inexpensively. Aluminum has excellent thermal conductivity. Castings made from plaster foundry tooling can be made with surface texture, although high-gloss surfaces are not possible. Porosity is a concern for cast aluminum molds. As mold size gets larger, the problem of casting porosity becomes more difficult to overcome. Internal air pockets insulate heat and are stress risers.

Sheet-metal Molds

This type of mold is for making large parts that have relatively simple contours. Steel sheets 0.03-0.06 in. (0.76-1.5 mm) thick are formed and then welded together. The weld areas are then ground and polished. Parting lines are machine planed. A key advantage of sheet metal molds is uniform wall thickness and low cost compared to aluminum casting of a single mold.

Electroformed Molds

Hard nickel or copper molds have good thermal conductivity and corrosion resistance, and they are nonporous. High-gloss surfaces and excellent surface texture is achieved. Electroformed molds exactly reproduce the details of the model from which they are made.

Vapor Formed Molds

This type of mold is made by chemical vapor deposition of nickel which can be used to make rotational molds. Molds have excellent surface texture, very uniform thickness, and very good thermal conductivity.

Design

Mold design for rotational molding relies upon molder experience. There are many “tricks of the trade,” which are learned from many years of working with different types of molding machines, mold materials, and molding materials.

A basic consideration in mold design is that one half of the mold cavity must be large enough to hold the resin volume needed for molding the part. For powders, the key property needed is the material’s apparent bulk/density.

CLAMPING

Clamps ensure that rotational molds do not leak at the parting line. Clamps must be easy and fast to operate. There are numerous types of clamp designs, but vise clamps, spring loaded clamps, toggle clamps, or nuts and bolts are generally used.

Flanges

To securely clamp a mold closed, the mold has flanges located around the parting line. Flanges are mechanically fastened to the mold, welded to the mold, or included as part of a mold casting.

INSERTS

Metal inserts increase or decrease wall thickness in a particular area of a molding. Wall thickness increases as the thermal conductivity of the insert material increases. High-heat conducting inserts can improve material flow in areas where good flow is difficult to achieve, such as deep ribs or pockets.

Inserts can produce molded-in holes and generally have a nonstick coating, such as a fluoropolymer. Also, nonstick inserts are used for the cover of a drop box. These are called shielding.

MOLD ARMS

Mold arms are designed to rotate the mold 360˚ horizontally (called the primary axis). On the end of the arm there is a spindle unit that rotates the mold 360˚ in a second direction, generally vertically to the arm. Molds can be rotated at various speeds and the primary and secondary rotation speeds can be different. Rotation speeds are low (15 rpm or less).

Mold arms are straight or offset (Fig. 10-7). The offset arms mount large, single cavity molds to make maximum use of the molding machine’s capacity.

The arms of rotational molding machines can contain pipes for injecting air and/or a controlled atmosphere into the mold. Mold temperature sensors can also be run through the arms. Nylon requires a nitrogen atmosphere in the mold. Some equipment uses air-injection units that inject air inside a part to hold it against the mold surface and improve dimensional stability. Inert gas can be forced into a mold to purge the cavity and injected hot or cold air can reduce cycle time.

Mold spiders. Mold arms can hold multiple molds by using devices called spiders (Fig. 10-8). Spiders also can be double-mounted.

MOUNTING

Frames are attached to the molds so that the molds can mount on the arm(s) of the rotational molding machine. Also, frames can serve as reinforcing members to prevent mold distortion. Mounting frames can have baffles to direct hot and cold air to deep recessed areas of molds.

Molds are mounted on the end of arms so that there is minimal shielding of any surface from the heat source and the cooling medium.

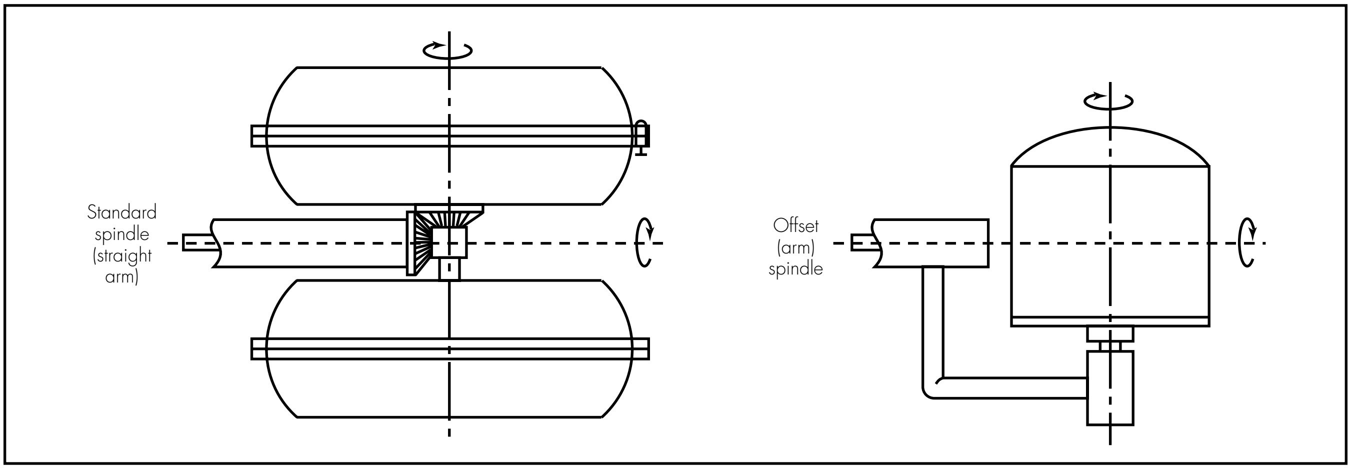

Fig. 10-7 Mold arms.

Mold parting line location is a key factor in mold design. It is located where:

- The line it produces on the part will be least visible.
- Where it allows easy part removal from the mold.
- Where it can be effectively clamped to prevent leakage.

Part shrinkage during cooling, particularly if there are internal wall surfaces, affects mold parting line location. Mold parting line surfaces are coated with nonstick materials to prevent polymer build-up which can cause leakage.

VENTING

Molds are vented to avoid pressure build-up during the heating cycle and to relieve mold vacuum during the cooling cycle. Vent tubes are made of a material that the molten polymer will not adhere to. The vent holes are placed in the mold where they will not become plugged during the rotational molding cycle. Since vent holes will leave holes in the rotational molding, their location is important both to the part's appearance and in preventing moisture from entering the part during the cooling cycle. Vent holes should have a diameter of 0.5 in. (13 mm) for each yd^3 (0.8 m^3) of volume in the part. Rotationally molded balls do not require vent holes because the spherical shape equalizes inside and outside pressure.

DROP BOX

To make multilayer rotational moldings, molds have drop boxes. After the first layer has been molded, the box is opened and the material for the next layer is dropped into the mold. The box is closed and the molding continues. The lid of the drop box has a nonstick surface.

MOLD RELEASE AGENTS

External release agents (release agents that are periodically sprayed or wiped on the mold surfaces) include waxes, soaps, silicone fluids/emulsions, and fluoropolymers. External release agents are low cost and easy to apply, but they tend to build up on mold surfaces and can cause warpage and other part problems (see "Additives" in this chapter).

As a result of the U.S. Clean Air Act of 1993, many rotational molders are switching to environmentally friendly, water-borne release agents from CFC- and solvent-borne release agents. The water-borne agents can provide comparable performance to solvent-borne in both parts removal and durability.

However, application of the water-borne release agents is slightly different. The semipermanent, water-borne release agents cannot be applied at room temperature like solvent-borne release agents. The water-borne release agents require a mold surface temperature of about 140° F (60° C). If a part is removed from its mold at this temperature or above, the water will quickly evaporate. If the parts are removed at lower temperatures, the water-borne release agent has to be heated, which can be done using a hot air gun. With the initial application of a water-borne release agent, the water can be driven off by running the mold through a dry cycle.

Improved surface gloss and smoothness, as well as reduced manufacturing costs, are possible with rotational molds coated with a fluoropolymer. The fluoropolymer coating allows the polymer melt to flow more uniformly, which can significantly reduce pin holes in the surface of molded parts.

A fluoropolymer-coated mold eliminates the need for and expense of repeatedly spraying the mold with a mold release

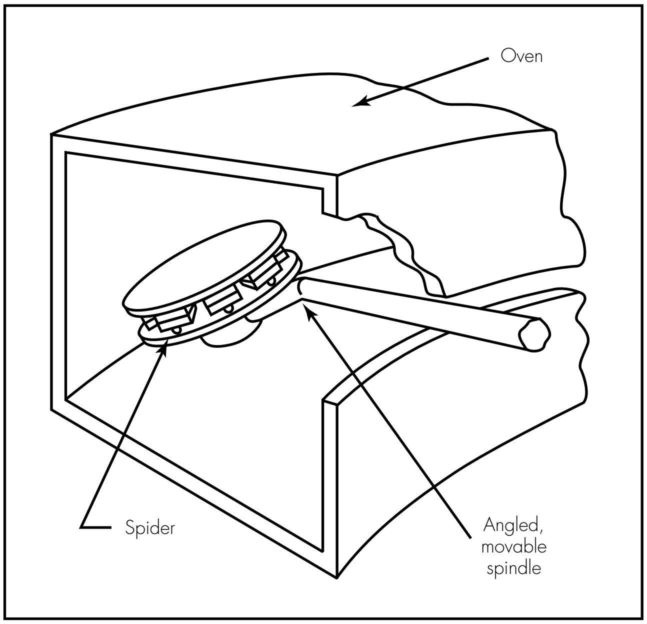

Fig. 10-8 Mold spiders.

agent. The long-lasting fluoropolymer coating is baked on the mold surface. For small- to medium-size parts, fluoropolymer coated molds reportedly have gone over 20,000 cycles without parts sticking.

Several types of fluoropolymers are available for coating rotational molds. FEP (fluorinated ethylene propylene), which is most widely used, provides fast and easy release and yields parts that have very smooth, shiny surfaces. PTFE- (polytetrafluoroethylene) modified thermoset polymer coatings yield parts with matte finishes and provide a slightly slower release. With large flat surfaces, the fluoropolymer coating helps control shrinkage and provides additional surface hardness and abrasion resistance.

Internal air may be needed when molds are PTFE-coated. The air pressure holds the polymer against the wall, preventing shrinkage and warpage. Inside the arm that holds the rotational mold is an air system that injects a stream of air into the mold during the cooling cycle.

MATERIALS

There are many thermoplastics that theoretically can be rotationally molded. However, only a few are used to make commercial products. Polyethylenes (low density, linear low density, high density, cross-link high density, and copolymers) are the most widely used materials, followed by vinyls, used less often. Typical property ranges for rotational molding materials are shown in Table 10-1.

POLYETHYLENES

Key physical properties are melt index, molecular weight distribution (MWD), and density. As melt index increases, gloss improves, heat resistance decreases, breaking tensile strength decreases and low temperature impact decreases. Resins with a narrow MWD have better physical properties and processibility. As the density increases, the stiffness, heat-deflection temperature, warpage, and shrinkage will generally increase.

Typically, polyethylene powders are rotationally molded between 572–806˚ F (300–430˚ C). Molding cycles for small- to medium-size parts average about 10–15 minutes.

LLDPE

Linear low-density polyethylene (LLDPE) is the most widely used material for rotational molding. The density of LLDPE rotational molding grades ranges from 0.923–0.940 g/cc with a melt index (MI) of 3–7 g/10 min. LLDPE rotational-molding resins offer good stiffness and low-temperature impact strength, excellent environmental stress crack resistance (ESCR) and warp resistance.

LDPE

The density of low-density polyethylene (LDPE) rotational molding grades ranges from 0.915–0.920 g/cc with an MI of 10–25 g/10 min. LDPE rotational molding resins offer good impact strength, low shrinkage, good warp resistance and good flexibility.

HDPE

The density of high-density polyethylene (HDPE) rotational molding grades ranges from 0.942–0.950 g/cc with an MI of two to eight g/10 min. HDPE rotational molding resins offer high stiffness, impact strength, and excellent chemical resistance.

Copolymers

The density of ethylene vinyl acetate (EVA) copolymers for rotational molding ranges from 0.925–0.945 g/cc with an MI of 10–25 g/10 min. EVAs offer good low-temperature impact strength and flexibility.

Cross-Linked Polyethylene

The density of cross-linked polyethylenes (XLPE) for rotational molding ranges from 0.936–0.941 g/cc. Cross-linked polyethylenes offer excellent ESCR, very good low-temperature impact strength and good heat resistance. Recent research shows that cross-linked polyethylene rotational molding scrap can be recycled as a powder filler for rotational molding. At 350.6˚ F (177˚ C), cross-linked polyethylene powders become tacky and will bond to other materials.

Recycled Polyethylene

Pressure from environmental groups, both government and private, is leading some rotational molders to incorporate post-consumer resins (PCR) into their products.

Most commercially available PCRs are made from high-density polyethylene (HDPE) blow molded containers. Thus, these HDPE PCRs have much lower melt indexes than the MI of typical

TABLE 10-1
Typical Property Ranges for Rotational Molding Materials (Natural)

Properties	ASTM	LDPE	LLDPE	HDPE	XLPE	PP	Nylon	PC	Plastisols
Flexural modulus, (1%), kpsi	D790	20-25	80-120	135-150	90-110	190-195	180-400	340	—
Tensile yield strength, kpsi	D638	1.1-1.15	2.5-2.6	3.0-3.3	2.0-2.5	4.0	7.5-11	9.0	0.8-3.0
Heat distortion temp, (66 psi load), ˚C	D648	40	50-55	67-72	60-67	58	135	280	—
Low-temperature impact strength (0.125 in.), ft-lb	ARM	30	44-51	45-52	50-60	20-30	4	70	<40
ESCR (Condition A, F_{50})	D1693								
100% Igepal, hrs		1	>1000	10-30	>1000	>1000	>1000	—	—
10% Igepal, hrs		<1	25-350	4-5	>1000	>1000	>1000	—	—

rotational molding resins. Therefore, for rotational molding, an HDPE PCR is blended with a virgin resin. HDPE PCR content in blends can range from 10–25%. The blends can be made by either melt compounding or dry blending PCR/virgin blends.

How the PCR/virgin resin blend is prepared affects the inner surfaces of rotationally molded parts. Parts rotationally molded from dry blends can have very rough inner surfaces. Parts made from HDPE PCR/virgin resin extrusion blends exhibit smooth inner surfaces.

The color of parts rotationally molded from HDPE PCR/virgin resin blends will be influenced by the type of HDPE PCR in the blend. Since some HDPE PCR is green (PCR based on HDPE copolymers), rotational molding resins made with these resins have a green tint. Other HDPE PCR is gray with black specks. Thus, parts rotationally molded from blends made with some HDPE PCR have an off-white color.

Compared to the virgin LLDPE resin, the toughness of HDPE PCR/virgin resin blends is much less, decreasing as HDPE PCR content increases.

The environmental stress crack resistance (ESCR) of HDPE PCR/virgin resin blends is considerably lower than that of the virgin polyolefin resin.

The physical properties, including impact strength and ESCR, of rotational moldings made from HDPE PCR/virgin resin blends, as well as many other rotational molding resins, can be dramatically improved using electron beam cross-linking.

Adhesive polyethylene grades can form a liner on the inside of metal pipe (called rotolining) and form a tie-layer between two resins that are rotationally molded.

NYLON

Nylon, which is used in its pellet form rather than as a powder, offers good heat resistance, toughness, good wear and abrasion resistance, high strength and stiffness, and good chemical resistance. Nylon pellets may require drying immediately before they are rotationally molded. To prevent discoloration and to achieve optimum properties, inert gas (nitrogen or carbon dioxide) is injected into the mold. Nylon is rotationally molded at 550–700° F (288–371° C). Typically, a nylon part 0.125 in. (3.2 mm) nominal wall thickness has a molding cycle of 15–20 minutes.

A liquid nylon monomer can be rotationally molded. The liquid polymerizes during heating. For larger parts, optimum wall thickness and surface appearance can be achieved using a two-shot molding process.

POLYCARBONATE

Key benefits of polycarbonate rotational molding resins are high-heat resistance, good impact strength and clarity, and more dimensional stability than polyethylenes. Polycarbonate resins must be dried immediately before they are rotationally molded. Typically, polycarbonates are rotationally molded at 680–707° F (360–375° C) and cycle times range from 10–20 minutes. Part shrinkage in the mold is less than 1%; therefore, draft is needed for all walls.

POLYPROPYLENE

Polypropylene rotational molding resins offer higher heat resistance and stiffness than polyethylenes. Typically, polypropylenes are rotationally molded at 500–550° F (260–288° C) and cycle times range from 18–28 minutes.

VINYLS

Both powder and liquid vinyl rotational molding resins are available. Vinyl plastisols are liquid rotational molding resins that offer a wide range of stiffness, from very soft (low durometer) to very rigid (high durometer).

Plasticizer level determines the properties of vinyl plastisols. Vinyl plastisols generally are rotationally molded at 450–480° F (232–249° C) and molding cycles are 5–10 minutes. Rotation-ally molded vinyl plastisol products are easily painted.

ADDITIVES

With the exception of colorants, rotational molders generally do not prepare their own compounds. Resins that contain the required additives are purchased from materials suppliers.

Colorants

Powdered colorants can be added to rotational molding resin powders and then dry blended. Precolored powders are available, as are precolored resins in pellet form, which are ground into powder.

Antistatic Agents

For some powders, antistatic agents can improve material flow during processing. Antistatic agents also reduce static buildup on the surface of molded parts.

Cross-linking Agents

Chemical cross-linking agents, most often a peroxide, can improve strength and ESCR.

Fillers

Fillers provide added stiffness, but their use can cause processing problems, including surface roughness and reduced melt flow and impact strength.

Flame Retardants

Flame retardants allow use of rotational molding materials for electrical applications covered by Underwriters Laboratories (UL) requirements.

Flow Modifiers

Complex mold designs use flow modifiers to improve polymer flow and to achieve complete and uniform filling of the mold.

Foaming Agent

When heated, rotational molding powders that contain a foaming agent generate a gas and, thus, foam the material.

Glass Fibers

Although they improve strength and stiffness, glass fibers can cause processing problems, including surface roughness and reduced melt flow.

Heat Stabilizers

Thermal degradation is prevented during processing by using heat stabilizers. Rotational molding materials contain higher levelsof heat stabilizers than resins used by other plastic processing methods.

Impact Modifiers

Most notably for elastomers, impact modifiers increase impact strength, but their use can cause processing problems, including surface roughness and reduced melt flow.

Release Agents

Internal release agents, that is, release agents mixed with the resin, include both stearates (fatty esters) and fatty amides. Internal release agents can eliminate or reduce the need for external release agents, but they also can affect mechanical properties of the rotational molding material and cause discoloration.

UV Stabilizers

Materials such as polyolefins require UV stabilizers, such as hindered-amides-light stabilizers (HALS), to protect them from the effects of sunlight.

DESIGN GUIDELINES

The following design recommendations refer to polyethylene rotational molding.

ANGLES

The minimum recommended angle is 30°.

CORNERS

Outside corners generally have thicker walls than the nominal wall thickness of a part and inside corners generally have thinner walls. The radius for outside corners should be no less than 0.060 in. (1.5 mm) and, ideally, they should be 0.250 in. (6.4 mm). The radius of inside corners should be no less than 0.125 in. (3.2 mm) and, ideally, they should be 0.500 in. (12.7 mm).

DRAFTS

An advantage of rotational molding is that parts often are made with no draft angles because when the part cools, it shrinks away from the cavity. However, if there are mold surfaces inside the part, such as the core of a doughnut shaped part, draft angles of one to two degrees are necessary.

FLATNESS

Typically, a flatness tolerance for rotationally molded parts is +0.020–0.050 in./in. (+0.020–0.050 cm/cm).

HOLES

Large holes are formed during rotational molding or are made by machining. Molded-in holes are achieved by using inserts to which the plastic melt does not adhere. Also, holes are made by rotationally molding two identical parts end-to-end and then cutting them apart.

INSERTS

If metallic inserts are heated, the molten polymer's surface adhesion is increased. Inserts should have undercuts to increase holding strength. The shrinkage that occurs during part cooling provides good gripping strength; however, it is important to avoid stress cracking.

MULTIWALL PARTS

An adequate distance between parallel walls in double-wall parts is five times the nominal wall thickness.

RIBS/BOSSES

Stiffening ribs and bosses are not designed as solid elements; they must be hollow. Rib/boss depth is at least four times the nominal wall thickness and the width at least five times the nominal wall thickness. While rounded ribs/bosses are better for material flow, rectangular-shaped ribs/bosses provide more stiffness.

Kiss-off ribbing, where two closely spaced walls are attached to each other, is a unique capability of rotational molding. Kiss-off ribbing counters warpage in large flat surfaces and provides added stiffness.

TEXTURED SURFACES

Draft angles are necessary for textured surfaces on the inside surfaces of rotational moldings. The draft angle is 1° more than the draft angle for an untextured part.

THREADS

Inside and outside threads are possible with rotational molding, but coarse forms of acme or modified buttress type threads with a thick profile are used.

TOLERANCES

Because of the shrinkage that occurs during part cooling, close tolerances are not recommended for rotationally molded parts. Although tolerances of ±0.010 in./in. (±0.010 cm/cm) are possible using special cooling fixtures, ideal tolerances are ±0.020 in./in. (±0.020 cm/cm).

UNDERCUTS

Small external undercuts are possible with rotational moldings if the material is flexible enough to allow stripping of the part from the mold cavity. Internal undercuts are not recommended since the part shrinks onto the mold as it cools, making part extraction very difficult.

WALL THICKNESS

The basic nature of the rotational molding process produces uniform wall thickness. Depending on part size and shape, a wall thickness tolerance of ±20% is generally recommended. A lower tolerance may require special processing procedures and add to part cost. Nonuniform wall thicknesses are achieved by altering the mold temperature, using inserts, or mold shielding in areas where the variance is desired.

SECONDARY FINISHING

Secondary finishing procedures are determined by the type of rotational molding material rather than the process.

DECORATING/PAINTING

There are many techniques for decorating rotationally molded parts including painting, hot stamping, silk screening, and labeling. Surfaces of polyolefin parts that are decorated or painted are oxidized by flame treatment or electronic treatment to achieve optimum adhesion. Adhesion also is improved by using surface primers either alone or with oxidation.

U.S. federal legislation is causing rotational molders to use water-borne coatings for their products. The two-step coatings (base coat and top clear coat) are available in a wide range of colors. Both airless and/or conventional air spray equipment are used with the water-borne coatings. Air drying for five to 20 min at 175 to 250° F (79–121° C) is recommended to enhance gloss and shorten production cycles.

ELECTRON BEAM CROSS-LINKING

Secondary cross-linking involves exposing the molded parts to electron beams. With electron beam cross-linking (EBXL), the degree of cross-linking is controlled; therefore, the level of property improvements is controlled. With EBXL, reject parts are recycled before they are subjected to the EB treatment. Thus, scrap losses are reduced compared to chemical cross-linking.

Another benefit of EBXL is that, unlike chemical cross-linking agents, it does not affect the U.S. Federal Drug Administration (FDA) status of a rotational molding resin. The ability to make parts that have excellent ESCR and that can meet FDA requirements makes EBXL very attractive for molding food handling products.

An EBXL facility is cost prohibitive for most rotational molders. However, electron beam cross-linking equipment is available on a tolling basis.

FOAM FILLING

In a secondary operation, rigid polyurethane (PUR) foam is injected through small holes, into the hollow space between the walls of rotational moldings. The PUR foam system is injected as a liquid and after it has risen and set, the holes are sealed with caps made of the same material as the rotational molding. The foam core adds stiffness and structural strength. Further, for products such as boat hulls, the PUR foam provides permanent buoyancy if the polyolefin skin is punctured or cut.

MACHINING

Rotationally molded parts can be drilled, sawed, milled and routed. Machining conditions will vary according to the rotational molding material.

WELDING

Various types of welding techniques are used with rotational moldings, including hot-plate welding, electromagnetic/induction welding, spin welding, hot-gas welding, thermal welding, and extrusion welding.

Hot-plate Welding

Hot-plate welding consists of holding two surfaces against a hot-plate long enough to heat and soften the joint and then forcing the two pieces together until the joint has cooled. Joints must be flat.

Electromagnetic/Induction Welding

A magnetically active material and an oscillating electromagnetic field are used to produce a weld. The magnetically active material is applied to the joint and then briefly exposed to the electromagnetic field by a set of conductive coils through which alternating current runs. Fusion temperatures are reached rapidly. The magnetic material melts and flows, filling the joint, and transfers the heat by conduction to the abutting surfaces, fusing them together. Long joints are quickly welded and joints can be in more than one plane.

Spin Welding

Frictional heat caused by rapidly spinning one surface under pressure against another is used to melt the interface and cause the two surfaces to bond together.

Hot-gas Welding

Hot-gas welding consists of beveling the edges of two parts that are joined, bringing the two edges together to form a groove, and laying and pressing a hot bead of thermoplastic into the groove. While inexpensive, this technique produces welds with uneven strengths and typically low bond strengths.

Thermal Welding

Hot-melt adhesive guns are used to apply a molten bead between two surfaces that are joined.

Extrusion Welding

Extrusion welding is similar to hot gas welding except it uses a hot-melt applicator (extruder) to apply the molten bead of thermoplastic into the groove between two surfaces that are joined.

TROUBLESHOOTING

Solutions to rotational molding problems will vary from material to material. Following are some general guidelines.

BLOW HOLES AT PARTING LINE

- Mold parting lines not clean—clean and coat with mold release.
- Poor mold parting line—repair mold.
- Plugged vent—replace vent.

BLOW HOLES AROUND INSERTS

- Material not fully adhering to insert—change insert and/or location.
- Air leakage around the insert—stop the leakage.

BLOW HOLES IN OTHER AREAS OF PART

- Impurities on mold surface—clean mold surface.

- Poor blending of fillers or reinforcement—change blending method and/or procedure.

BUBBLES ON SURFACE OR IN PART
- Moisture in resin—dry resin. Change drying procedure.
- Incompatible mold release—change mold release.
- Poor mold parting line—eliminate pockets of entrapped air.
- Inadequate venting—relocate vent. Increase vent size.

DISCOLORATION OF PART
- Oxidation on mold surface—clean mold surface and check for moisture source.
- Sintering cycle too long—reduce oven heat and/or shorten cycle.
- Resin degradation—decrease oven temperature or heating cycle. Increase or change antioxidant. Change to more thermally stable pigment.

FLASHING AT PARTING LINE
- Internal mold pressure during heating cycle—check for vent clogging. Reduce the air pressure. Relocate the vent. Increase vent size.
- Insufficient clamp pressure—increase clamp pressure or type of clamp used.

INCOMPLETE MOLD FILL
- Poor mold design—increase space between walls and corner radii and change rib design. Consider using mold inserts.
- Improper mold rotation—change ratio and speeds.
- Cold spots in mold—check for shielded areas and mold wall thickness uniformity.
- Poor powder flow—change powder particle size and/or add flow modifier.

INCOMPLETE FUSING OF MATERIAL
- Low-oven temperature—increase oven temperature.
- Poor heat transfer—use thinner mold wall thickness and/or change mold material.
- Resin powder too coarse—use finer mesh powder.
- Moisture in mold—keep molds warm and dry before charging with powder.
- Moisture in resin—dry resin before molding.
- Melt index of resin too low—use resin with higher melt index.
- Improper mold rotation—change ratio and/or speed of rotation.

LOW-IMPACT STRENGTH
- Parts improperly sintered—increase or decrease oven temperature and heat cycle.
- Improper pigment loading—change type of pigment and/or reduce pigment loading.
- Parts improperly cooled—change cooling cycle.
- Insufficient fusion of resin (see “Incomplete Fusing of Material” in this section).

LOW-PART STIFFNESS
- Wall too thin—increase powder loading.
- Poor resin choice—change resin.
- Material underfused (see “Incomplete Fusing of Material” in this section).
- Poor design—change part design.

LONG-OVEN CYCLE
- Poor heat transfer rate—reduce mold wall thickness or change mold material.
- Poor heating—increase air velocity, check oven for leaks, check oven temperature sensor and recalibrate or replace.
- Resin powder too coarse—use finer mesh powder.

MOLD BULGING
- Gas build-up in mold—relocate vent or use multiple vents.

PART STICKS IN MOLD
- Insufficient mold release—apply mold release more often and/or change application method.
- Ineffective release agent—change type of release agent.
- Mold surface roughness—refinish mold surface.
- Build-up of degraded resin on mold surface—periodically clean mold surface.
- Part shrinking onto mold surfaces—increase vertical wall tapers.
- Material too stiff to release from mold undercuts—change material or reduce undercuts.
- Material shrinkage too low—user higher density resin.

PLATE-OUT
- Additives building up on mold surface—change additive.

POCK MARKS ON PART
- Improper heating cycle—reduce heat and/or cycle time.
- Improper mold release—change mold release.

UNEVEN COLORING
- Moisture in pigment or resin — dry color blend before processing.
- Static build-up—use resin that has an antistatic agent.
- Improper pigment particle size—use precompounded resin. Change pigment particle size.
- Insufficient blending—change dry blending procedure or type of equipment used.

WALL THICKNESS UNEVEN
- Improper mold speed and rotation ratio—adjust speed and ratio.
- Uneven mold surface temperature—change wall thickness. Check for shielded areas. Use inserts with high heat transfer.
- Mold arm improperly balanced—rebalance arm.
- Fusion rate too fast — lengthen heat time and lower mold temperature.

WARPING OF PART
- Inadequate venting—increase vent size.
- Nonuniform part cooling—rotate mold during cooling cycle. Use less release agent. Reduce cooling rate during initial part of cooling cycle. Apply air pressure inside part during cooling. Increase cooling medium temperature.
- Uneven mold wall thickness—redesign mold.
- Parts of mold are shielded—change how mold is mounted to arm. Add baffles to direct heat to recessed or shielded areas.
- Part overcured—decrease oven temperature or heating cycle.
- Part underfused (see “Incomplete Fusing of Material” in this section).
- Powder contains moisture—dry powder or change drying procedure.

- Improper coloring—change pigment type and/or loading level.
- Vacuum in part during cooling—check vent for clogging. Increase vent size.

Table 10-2 shows the appearance of rotationally molded parts at different cures. The information may not relate to all resins.

TABLE 10-2
Cure Versus Appearance for Rotationally Molded Parts

State of Cure	Under	Slightly Under	Cured	Slightly Over	Over
Inside surface color	Same as outside surface			Slightly yellow	
Inside surface gloss	Dull		Shiny		
Inside surface appearance	Rough	Waxy	Smooth not sticky	Slightly sticky	Sticky
Bubbles	Many	Few	None		
Fill	Less than best to best		Best		
Tear resistance	Less than minimum		Maximum		

INDUSTRY ASSOCIATION

The rotational molding industry is represented by the Association of Rotational Molders, 2000 Spring Rd., Suite 511, Oak Brook, IL 60521 (Telephone (708) 571-0611). ARM is the major source for distributing technical literature and educational material about rotational molding. In addition, ARM annually conducts a technical conference and an exhibition at which the latest developments in rotational molding are displayed.