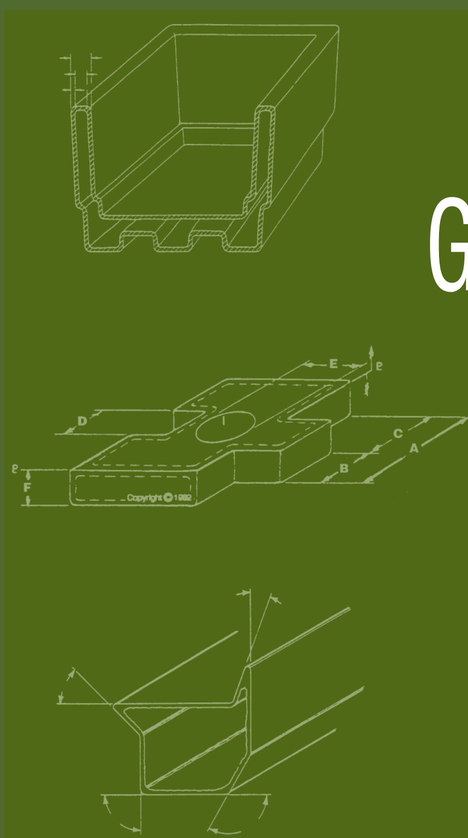


The Introductory Guide to Designing Rotationally Molded Plastic Parts

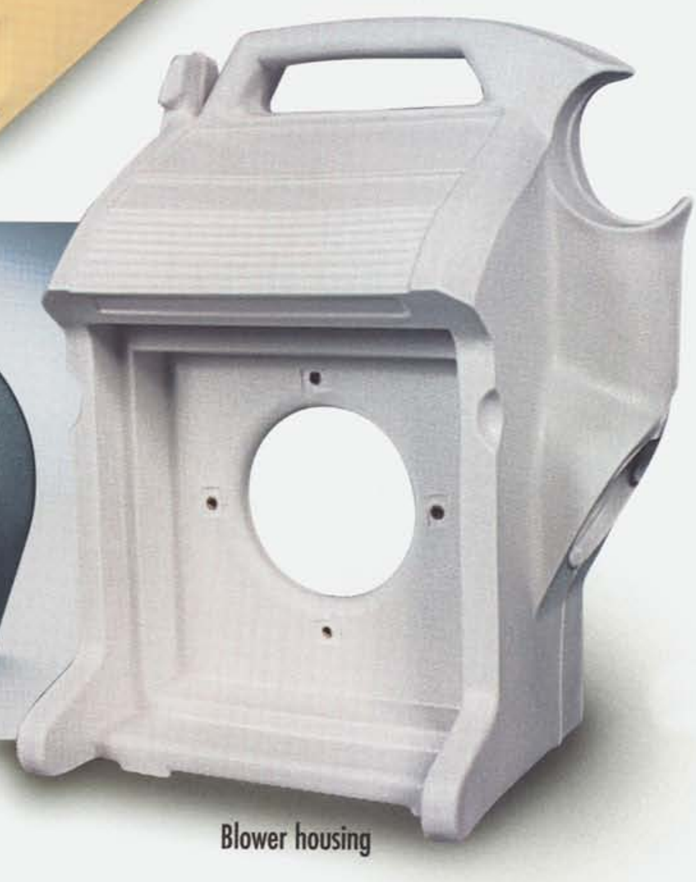
Association of Rotational Molders Internaional

Medical specimen case

Traffic sign

Sample compartment for chemical analyzing machine

Cymbal case



Blower housing

A Word about the Data Being Presented

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Introduction

This booklet has been prepared as a guide for design engineers and for other professionals in the plastics field who want to know how to design high quality, low cost rotationally molded plastic parts.

Contents

Advantages of Rotational Molding

What is the rotational molding process?

What are its advantages to users?

How do you design rotationally molded parts?

What plastics are being molded?

This booklet answers these four basic questions and more. You will find it useful whether you are a designer, a specifier, or a buyer.

Rotational molding is a plastics processing technique that is ideally suited to producing relatively large, hollow, seamless parts which are partially or totally enclosed.

This process has been in existence since the early 1930s. The introduction of micronized polyethylene in the late 1950s has provided the industry with an ideal material for the rotational molding process. Since that time, the industry has continued to grow at a steady rate.

Designers of plastic parts turn to rotational molding to produce small or large parts of unusual shape that cannot be produced as one piece by other processes. Parts as small as a ping pong ball or as large as a 22,500-gallon tank can be made by rotational molding.

Relative to their size, rotationally molded parts can have thinner walls than similar parts made by other processes. Rotational molding tends to produce an increasing wall thickness on outside corners of parts, which gives the process a distinct advantage over blow molding and thermoforming since these processes tend to produce thin outside corners. The added thickness and corresponding increase in strength at the outside corners is usually an advantage, especially in large parts.

Rotational molding is a low-pressure process, and the strength required from the molds is minimal. This results in its ability to produce large or complex parts on short notice, using low cost molds. Due to the low tooling cost, rotational molding is ideally suited to producing prototypes, small or large quantities of production parts and the initial production of parts that will eventually be made by some other more capital-intense process, when the required quantities justify such an expenditure.

The low processing pressure involved in rotational molding has the added advantage of producing parts which are relatively stress free, as compared to other high pressure processes. This advantage of the process is especially important when considering large, load-bearing parts in applications which must provide corrosion or stress-crack resistance.

The surface finish, which includes sandblast, shot peen texture, even wood grain and color through dry blending or compounding of rotationally molded parts, can be tailored to suit the product's requirements.

Metal inserts or integrally molded-in threads are possible with rotationally molded parts.

Reversal parts with closely spaced double walls are common, enabling foam injection for insulation and structural purposes. Many parts are molded with little or no draft angle. With some materials, it is possible to produce parts with undercuts.

Many thermoplastics and some thermosetting plastics can be rotationally molded; however, the most commonly molded plastics are thermoplastic, polyethylene, polyvinylchloride, nylon and polycarbonate. Unsaturated polyester and cross-linked polyethylene are the most often used thermosetting plastics.

The following pages will give the design engineer a better understanding of the rotational molding process and its own unique capabilities.

Rotational molding is well known for its ability to produce tanks of all kinds. This process, however, is also ideally suited to producing other types of products as well. Rotationally molded parts are used in the health and science field as instrument housing, carrying cases, dental chairs and other types of furniture.

In the recreational field, boats, truck cabs, motorcycle shields, swimming pool filter housings, surfboards and balls of all kinds are made by the rotational molding process. Riding toys such as hobbyhorses and car bodies are common. Climb-on, -over, -through and slide-down toys have been made by the rotational molding process.

The point-of-sale advertising industry uses rotational molding to produce a wide range of mannequins and other types of advertising devices which both display and store the products.

Safety devices such as marker floats and buoys, highway safety barriers, and road markers are rotationally molded products.

In the industrial field, rotationally molded parts find use as instrument housings, carrying cases, instrument carts, lighting globes and gasoline tanks for all kinds of vehicles.

Household products such as planters, serving trays and carts, room dividers, refuse containers and picnic tables are made by rotational molding.

Agricultural, chemical-processing and specialty tanks of unusual shape for boats and recreational vehicles are major markets for rotational molding.

Rotational Molding Process

Figure IC

Figure I

Figure IB

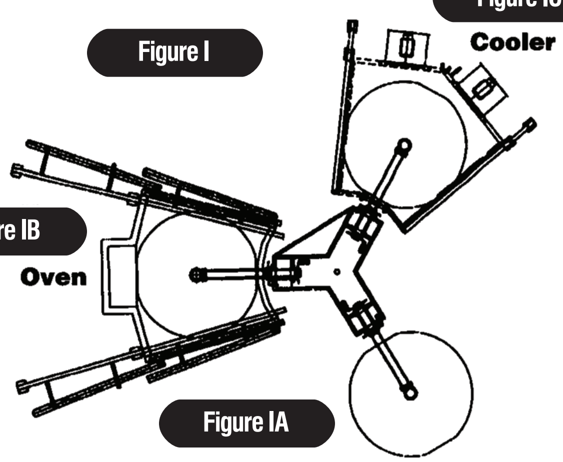


Figure IA

In rotational molding, a premeasured amount of plastic material in liquid or powder form is placed in a cavity and the mold is closed. The amount of material required is determined by the wall thickness desired.

The molding machine then indexes the mold into an oven (Figure 1B) where the mold and subsequently, the plastic is brought up to the molding temperature. As the mold is heated, it is rotated continuously about its vertical and horizontal axes. Usually a four (major) to one (minor) rotation ratio between 6-8 r.p.m. is used. A reverse rotation can also be achieved to fill small intricacies and hidden areas of the mold. The biaxial rotation brings

Figure II

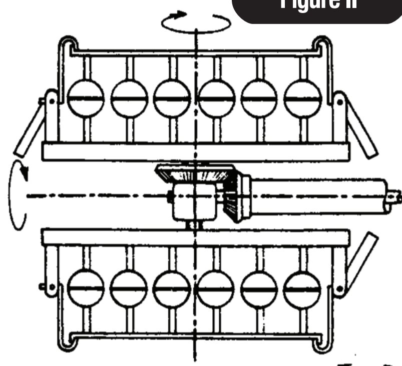
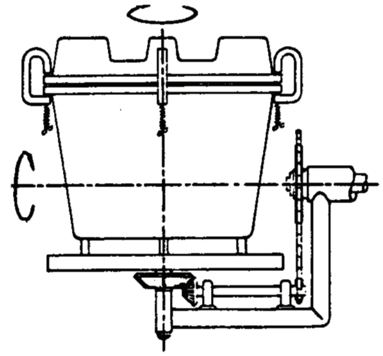


Figure IIA

Figure IIB



all surfaces of the mold into contact with the puddle of plastic material. The mold continues to rotate within the oven until all the plastic material has been picked up by the hot inside surfaces of the cavity. The mold continues to rotate until the plastic material densifies into a uniform layer of melt.

While continuing to rotate, the machine moves the mold out of the oven and into a cooling chamber (Figure 1C). Air or a mixture of air and water cools the mold and the layer of molten plastic material. This cooling process continues until the part has cooled sufficiently to retain its shape. The machine then indexes the mold to the loading and unloading station (Figure 1A). The mold is then opened and the part removed. A new batch of material is then placed in the cavity, the mold is closed and the process is repeated.

There are several different kinds of rotational molding equipment currently in use, but the three-station layout shown in Figure 1 is the most common.

The biaxial rotation is usually achieved by a series of gears or chains and sprockets such as are shown in Figures 11A and 11B. Small, multiple cavity molds of the same parts are usually centrally mounted (as shown in Figure 11A).

Large, single-cavity molds are frequently mounted offset (as shown in Figure 11B) in order to make maximum utilization of the molding machine's capacity.

Plastic parts of totally dissimilar shape, such as small doll heads and large refuse containers can sometimes be molded simultaneously on the same machine. The only limiting factor is that the oven temperature and cycle time must be compatible with the wall thickness of the various parts and the materials being used. The arm must also be balanced to achieve uniform wall thickness and to prevent wear on motors, gears and chains.

For a given part size, rotational molding equipment is relatively low in cost, compared to other more capital intense processes, such as injection or blow molding. However, long cycles, quantity of resin, finishing and shipping could increase piece part price.

Molds for Rotational Molding

Rotational molding is a low pressure process and molds are primarily a thin hollow shell that defines the outside shape and surface of the part. The inside surface of the part is formed by the thickness of the nominal wall and does not require internal cores. In many cases, rotational molding molds are relatively low in cost when compared to other type molds such as those used for blow or injection molding.

There are many different approaches to producing molds for rotational molding. Determining which type of mold to use depends upon several factors: tolerances, aesthetics of the part, geometry, lead-time, and budget.

Cast Molds

Cast aluminum molds are widely used in the rotational molding industry because they offer a convenient means of creating complex shapes. Casting offers excellent repeatability for multiple molds and parts varying from the very small to the large (e.g. kayaks and 400 gallon containers) can be produced. Cast molds are particularly suited to products requiring great detail or intricate shapes.

There are a number of ways to design and enhance cast tools for longevity, molder ease, and the construction and design of specific products. While much detail can be cast into the mold from the model or pattern, many textures and finishes can be added to the casting through glass bead or shot peening blasting and polishing, with relative ease, due to the strength and malleability of cast aluminum. Multiple piece molds can be designed to allow part removal for undercuts or unusual shapes. Mold wall thickness can be varied or heat fins cast into the tool to produce desired heat transfer requirements, thus producing thicker/thinner walls.

One of the greatest advantages of cast aluminum molds is the ease of revising the tool to incorporate design changes or revisions. Cast aluminum molds can be updated and refurbished many times at a comparatively low cost compared to purchasing new tools. For numerous changes or ones that entail a lot of work, the pattern can be revised and the mold recasted.

Machined Molds

CNC machined molds are typically used when extreme accuracy, short lead-times, acid etched surface and/or complex geometry are required. These tools are machined from forged aluminum directly from solid model CAD data. With today's high-speed machining technology, this is one of the fastest ways to produce rotational molds.

The forged aluminum provides increased durability over cast molds and an excellent surface for acid etching. The machined parting lines result in minimal witness lines. Machined molds are ideal when complex part geometry requires multiple piece molds and extensive parting lines on highly aesthetic products. The typical overall tolerance on a machined aluminum mold is ±0.010".

Fabricated Molds

Fabricated molds from carbon steel, stainless steel and aluminum are widely used for parts of simple geometry and are particularly suited to very large parts. Complex shapes can be fabricated with some limitations. Duplicate molds can be made within the tolerances of human ability because a pattern is not used to make the mold.

Steel fabricated molds have the advantage of not experiencing the heat expansion differences between aluminum and the steel mounting structures. Generally, the completed units are lighter weight than cast aluminum molds. A lower cost may be realized because of not requiring the expense of a full size pattern.

Fabricated steel molds are very durable. Aluminum and stainless steel will not rust like carbon steel in the harsh environment of heating and cooling. The strength and toughness of steel is an advantage in any maintenance requirements as well as revising because of design changes. Revising is at least as low cost as cast molds.

The production of surface textures in steel molds is difficult, although embossed patterns and logo plates are available.

Electroformed Nickel Molds

Electroformed cavities are less common, but they have the advantage of being able to reproduce faithfully fine details such as wood or leather graining which would be difficult to achieve by other techniques. Figurine molds are a good example of an application where large numbers of identical cavities can be made economically.

Electroformed cavities are frequently used to produce hollow undercut cavities for the molding of flexible materials such as polyvinylchloride. Doll head molds, in which the entire part is pulled out through the neck opening, are a good example of this approach. The size of the electroformed molds is limited by the size of the plating tanks. Electroformed molds have been used to produce items as small as a doll's head and as large as a canoe or boat hull.

Vapor-Formed Nickel Molds

Although similar to electroformed molds, vapor-formed nickel molds are more costly. They have the advantage of producing a more uniform cavity wall thickness with less buildup of nickel on sharp outside corners.

Non-Metallic Molds

Liquid thermosetting polyester and epoxy materials are formed and cured at room temperature. The molds used for these types of materials can be fabricated by using room temperature curing silicone and fiberglass fabrication techniques. Temperatures at which these molds are run usually do not exceed 450°F.; therefore, cycle times are extended. In a typical gas oven, this type of mold will yield up to 100 parts, making this a method for prototyping. Some new types of composite molds (CMT) have electrical heating elements embedded in the mold material so that the mold can be heated without the need for an oven.

Summary

To a great extent, the quality and especially the tolerances on a rotationally molded part, like plastic parts made by other processes, are dependent upon the quality and precision incorporated into the mold. There is no substitute for a good quality mold. Each of the various types of molds described here has its own unique advantages and disadvantages. A rotational molder can provide advice as to which type of mold will be the best for a particular application. Also, new technology is being researched in mold construction to shorten cycle times and increase efficiency.

Plastic Material Considerations

Any plastic material can, theoretically, be rotationally molded. This includes both thermoplastics, which melt or soften and flow when heated (and harden when cooled) and thermosets, which crosslink or cure (and harden when heated) and cannot be remelted.

There are two primary requirements for a material for rotational molding. First, it must flow adequately to coat the cavity evenly as the mold is rotated. Second, it must be thermally stable at the oven temperature at which it is processed and for the oven cycle time required.

Most plastic materials for rotational molding are special formulations which were developed to have high flow, superior thermal stability, and narrow molecular weight distribution for excellent physical properties. Most bulk resins have a melt between 3-6 g/10 minutes, although "engineered resins" reach above or below that. Most resins are supplied in a fine powder (35 mesh) but some resins are in liquids or very small pellets known as micropellets.

Common Rotationally Moldable Materials

The following list is comprised of the more commonly used plastic materials and their general characteristics.

Polyethylene

LLDPE (Linear Low Density Polyethylene) – Flexible to medium stiffness, excellent impact, chemical, and environmental stress crack resistance, easy to process and most are available with UV stabilizer. Most will meet the requirements of FDA, USDA, NSF and UL (Horizontal Burn). Applications include tanks, containers, toys and playground equipment.

HDPE (High Density Polyethylene) – Stiffest of all polyethylene. Excellent chemical resistance and good impact. Easy to process and most available with a UV stabilizer. Most will meet the requirements of FDA, USDA, NSF, and UL (Horizontal Burn). Applications include tanks, ducting, and parts requiring maximum rigidity.

XLPE (Crosslink Polyethylene) – Contains a cross linking agent which reacts with the material during the molding cycle forming a crosslinked molecular structure similar to thermoset. Properly crosslinked resins provide excellent impact, environmental stress crack resistance, and weatherability. Applications include gas and oil storage tanks, trash containers, as well as parts requiring maximum toughness. Also good for parts being used in cold temperatures. Most do not meet FDA, USDA or NSF requirements.

Specialty Polyethylenes – Polyethylenes can be modified to provide specific properties.

Flame retardant additives can be incorporated into polyethylene to allow parts to pass the stringent UL vertical burn. Applications can include hospital, airline and military containers.

Foaming or blowing agents can be incorporated into a small to medium size pellet and used with powder in a system that can mold a part in one step that has an outer skin of polyethylene and a foam filled core. Applications requiring floatation, insulation or sound reductions can be molded with this resin system.

Polyethylenes can be chemically modified to allow the resin to adhere to metals or other resins. These resins, commonly known as rotolining resins, can be used to line metal vessels for corrosion and chemical resistance. A rotolining resin can also serve as a bonding or tie layer for co-rotational molding in which two dissimilar resins are joined.

EVA Copolymer – Excellent low temperature flexibility. Available in UV stabilized and FDA approvable grades. Applications include soft toys and blending with other materials to improve impact strength.

Polyvinylchloride

PVC compounds can be molded in either liquid or powder form. The liquid plastisols are fluid suspensions of fine particle size resins in plasticizing liquid.

PVC compounds are moderate in cost and are easily processed. They can be formulated to produce parts ranging from flexible to semi-rigid with Durometer hardness ranges of 60 Shore A to 65 Shore D. Applications include balls, doll heads, teething rings, planters, novelty items and flexible bellows.

Nylon

Type 6 – Excellent tensile strength, stiffness and impact strength. High heat resistance, so properties are maintained at elevated temperatures. Excellent chemical resistance. Moderate in cost. Applications include military fuel tanks, hydraulic oil and solvent tanks, grain buckets, and air ducts.

Type 12 – Moisture absorption, melting point, and mechanical properties are lower than Nylon 6 but more easily processed. Applications include heating and air conditioning ducts, gasoline tanks and chemical tanks.

Polycarbonate

Excellent mechanical properties including stiffness, tensile strength and creep resistance. Highest impact strength of all rigid plastics. High heat resistance. Can be molded clear. Applications include light fixture globes, snowmobile engine hoods, shipping containers and other applications where high heat resistance and toughness are required.

Polypropylene

Stiffer than most polyethylene with higher heat distortion temperature, autoclavable and has excellent environmental stress crack resistance. Polypropylene requires cryogenic grinding to be used in a powder. Applications include bio-chemical vessels, solar panels, and medical storage containers.

Special Plastic Materials and Composites

At one time or another, virtually all thermoplastics and most thermosetting plastic materials have been rotationally molded, at least experimentally. In most of these special cases, markets have not grown large enough to justify the development of the specially compounded plastics that would be suitable for the rotational molding process. The following list of plastic materials are used occasionally for the rotational molding of specialty products:

1. LDPE	**8.** Polybutylene
2. Acetal	**9.** Other Grades of Nylon
3. Acrylic	**10.** Polyurethane
4. Cellulosics	**11.** SAN
5. Epoxy	**12.** Silicon
6. Fluorocarbon	**13.** Polyesters
7. Phenolic	**14.** EBA

The physical properties of the plastics referred to in this manual are summarized in the Modern Plastics Encyclopedia and the Gordura Company's Desktop Data Bank. This information may be available from other databank sources.

Additives

The properties and appearance of any material can be changed with additives. Most materials already have an antioxidant, which prevents degradation during processing, and a UV stabilizer for long term outdoor protection. Colorants, known as dyes or pigments, are very common to material used in rotomolding. The colorant can be dry blended into the powdered resin by the rotomolder or be hot melt compounded into the resin using pellets or powder.

Other common additives are flow lubricants and antistatic agents which are used for the purpose their name implies. The rotomolder can also choose to use a blowing or foaming agent in its neat form if they do not prefer to use a one step system previously discussed. These agents can be introduced during the molding cycle or used as a post molding product.

Another common group of additives are reinforcements. Although not often used, glass fiber or other reinforcements can be added to increase stiffness.

Fillers and extenders can also be added to the plastic resin. These are generally low-cost inorganic materials which are added to increase to bulkiness and thereby reduce the material cost. Since properties of an extended material often suffer, they are generally used for less critical applications. However, some fillers enhance specific properties such as reducing material shrinkage, increasing stiffness, increasing heat deflection temperature or thermal conductivity or reducing tensile strength. Like the other additives, the fillers and extenders are fine powders and can be dry blended with the plastic powder or compounded into the pellets.

The design engineer should also recognize that all of these additives and special molding techniques could be combined to produce very sophisticated parts. For example, it is technically feasible to compound a plastic material which is colored, foamed, reinforced and fortified to provide ultraviolet light stability and fire retardancy, which can be molded with two or more layers of material for special effects.

Product Design Considerations

The design of a rotationally molded plastic part, like any other part, must simultaneously satisfy three basic requirements. First, the part must provide the end-use functional requirements. While designing the part, the design engineer must also take into account the part design requirements or limitations of the material and process which has been specified. While satisfying these first two requirements, the designer must not lose sight of the fact that the product must also fall within a specified cost range in order to be economically feasible. Most design projects are a compromise between these basic requirements.

Once the design engineer has created a basic shape that will satisfy the functional requirements of the product, his attention should then be given to finalizing the design of each detail on the part in order to put the overall part design into the best condition for the material and process that has been chosen. The correct handling of design details such as wall thicknesses, corner radiuses, draft angles, etc., can mean the difference between success and failure.

The following design guidelines will help the design engineer to create high quality rotationally molded plastic parts which will be economical to produce.

Rotational molding, like all other plastic-processing techniques, has its own unique advantages, disadvantages and part design requirements. The design engineer must recognize that there are no forces which push the plastic material through the mold as is the case with thermoforming and injection or blow molding. In rotational molding, the mold rotates through a puddle of liquid or powdered plastic and the plastic adheres to the hot surfaces of the cavity to build up the desired wall thickness. Considering this situation, the ideal design for a rotationally molded part is any hollow shape where the various elements in the part design are smoothly blended from one contour to the next.

The smooth blending of contours will result in a finished product which has increased strength, is easier to produce, and is more economical.

The successful design of any plastic product is dependent, to some extent at least, on proportioning the design of the part to accommodate the specific plastic material that is to be used.

A rigid, high temperature, low mold shrinkage, hard flow, amorphous material, such as polycarbonate, has different design and processing requirements than a softer, low temperature, high mold shrinkage, easy flowing material, such as crystalline polyethylene. Each plastic material has its own unique design requirements. In relationship to some of the older plastics processing techniques, rotational molding is comparatively new. Some of the design guidelines are just now being formulated into rules and there still remain many unanswered questions.

The following design guidelines would be good practice to apply to any plastic material that will be rotationally molded. Some of the plastics have special design requirements. This data has been included in these guidelines, as it was available.

Nominal Wall Thickness

The nominal wall of the part is its basic frame which defines its shape. Once the basic shape has been established, other details can be added to it in order to provide other features in the finished part. The nominal wall (or the frame of the part) is the single most important element in the design and it must be handled correctly.

Once the outside shape has been defined, the designer must remind himself that the inside of the part will be free-formed and that its size and shape will be dependent upon the outside size and shape minus the wall thickness.

The type of plastic material used and the thickness of the nominal wall will determine the strength and load bearing capability of the finished part. The wall thickness required to sustain a given load can be determined by the conventional techniques that are applied to other plastic parts; however, as molded physical properties must be used in these calculations.

The nominal wall thickness will have a direct effect on the cost of the finished part. In addition to the added cost of the material used in a thicker wall, the cycle time and the energy required to heat and cool the plastic will be directly related to the wall thickness. For example, a .030 inch increase in the wall thickness of a Nylon 6 part will result in an increased oven time of approximately two minutes.

An ideal nominal wall thickness for most materials would be in the range of .125 inch. A .125 inch wall thickness provides a good compromise with cycle time, ease of processing, strength and cost. Other wall thicknesses can be provided if the functional requirements of the product justify them.

Wall thicknesses as thin as .030 inch have been produced successfully in polyvinylchloride and thermoplastic polyester materials for such applications as medical drainage bags and waterbed mattresses.

It is generally agreed that parts to be produced in nylon should be limited to a wall thickness of .060 inch to .750 inch, but 1.25 inch thick parts are possible.

Polycarbonate wall thicknesses are typically in the range of .060 inch to .375 inch, with .125 inch being an ideal thickness.

Polyethylene wall thicknesses are usually in the range of .125 inch to .25 inch. However, large parts in cross-linked polyethylene have been made with wall thicknesses as great as two-plus inches. A wall thickness of one inch is not uncommon.

The designer must remember that these thick walls can be made; however, the cycle time will be very long. Consideration must be given to thermal degradation of the plastic material because of the prolonged oven heating cycle required for thick walls. This is especially true with heat sensitive materials.

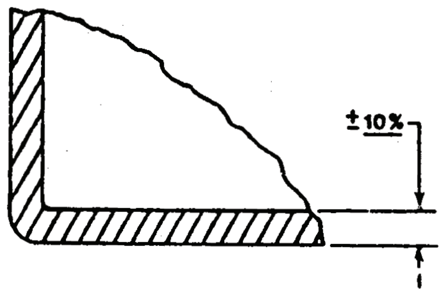
Rotational molding provides the design engineer with the unique capability to increase or decrease the wall thickness of a part after the mold has been built and sampled. The final wall thickness of the part can therefore be established after actual in-use testing of the part. Few other plastics processing techniques offer the designer this advantage.

Wall Thickness Uniformity

As far as wall thickness uniformity is concerned, rotational molding is a designer's 'dream come true.' The nature of the process automatically produces uniform wall thickness, even in the most unusual shapes, which is a distinct advantage over other processes such as blow molding or thermoforming.

The ideal way in which to specify the wall thickness on a part that is to be rotationally molded is to specify the nominal wall thickness and to indicate the minimum allowable wall thickness that can exist anywhere on the finished part. These specifications allow the molder the maximum latitude in producing a good quality, low cost part.

Depending upon the part's size and shape and the material being molded, a commercially acceptable wall thickness tolerance of $\pm$20 percent is usually possible. A wall thickness specification of $\pm$10 percent would be considered to be a precision tolerance that could be achieved only with added cost and difficulty.



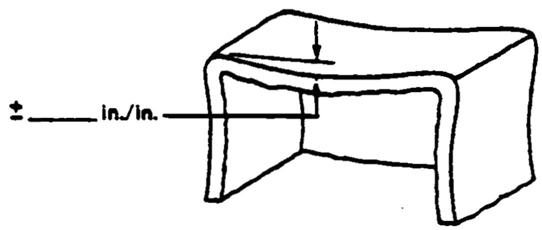
Rotationally molded parts usually contain gradually thickening walls on the outside corners and slightly thinner walls on the sharp inside corners. Because of this fact, wall thickness tolerances are usually understood to refer to the nominal wall only and not the corners of the part. This subject will be covered in greater detail in the section concerning radiuses.

Varying Wall Thicknesses

Non-uniform wall thicknesses can be produced within limits. Advanced techniques, such as varying the wall thickness of the mold or changing the mold construction material to achieve increased or decreased thermal conductivity, have been used successfully. Preheating or shielding specific portions of the mold from the oven's heat have also proved effective. In each case, the molder has used the fact that the portion of the mold which reaches molding temperature first will accumulate the thickest layer of plastic. These techniques have been put to good use in producing vertical storage tanks with gradually thickening walls near the bottom of the tank where the loads are greater.

Flatness Considerations

Rotationally molded parts, like blow-molded parts, are formed in hollow molds with no internal cores. This makes it difficult to guarantee flatness on large flat panels. A commercially acceptable flatness tolerance on a polyethylene or polyvinylchloride part would be in the range of $\pm$.020 inches per inch. An ideal tolerance would be more like $\pm$.050 inches per inch. A precision tolerance of $\pm$.010 inches per inch could be achieved if flatness were more important than part cost.



It is generally agreed that flatness can be controlled more closely when molding parts in nylon or polycarbonate. In these cases, a commercially acceptable tolerance would be ±.005 inches per inch. An ideal tolerance would be ±.010 inches per inch and a precision tolerance would be in the range of ±.003 inches per inch.

Experienced designers of rotationally molded parts avoid large flat surfaces where possible. Where large flat surfaces cannot be avoided, these surfaces should be supported with reinforcing ribs (Fig. IV, pg. 9). Another approach is to provide a .015 inch-per-inch crown on large flat surfaces. Some designers have incorporated decoration or lettering on flat surfaces in order to draw attention away from the lack of flatness.

Minimum Wall Separation

Considering the nature of the rotational molding process, the designer must provide an adequate distance between parallel walls to allow the puddle of liquid or powdered plastic to come into contact with all surfaces of the cavity. Parallel walls which are too close to each other will bridge over the space between the wall and prevent the cavity from filling completely, thereby producing a dike composed of a solid wall of plastic. These solid sections take longer to cool, which results in longer molding cycles and increased cost. Excessive mold shrinkage and a tendency toward part warpage and molded-in stress can also result from these non-uniform wall thicknesses.

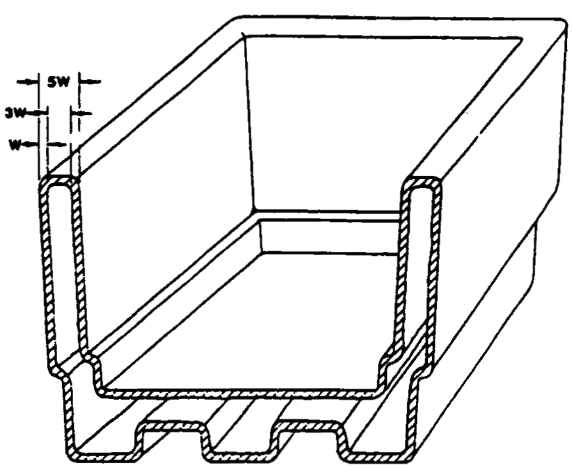


Figure III

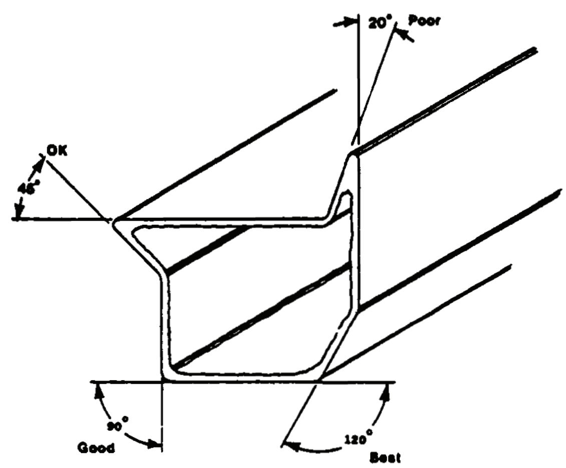
A separation between parallel walls of five times the nominal wall thickness (outside part wall surface to outside part wall surface) of the part will allow the molding of good quality parts with little or no difficulty. (Fig. III)

Wall separations of as little as three times the nominal wall thickness have been molded successfully, with only an occasional bridging over. However, parallel walls which are this close to each other require extra care and attention. Solid walls cannot be produced by reducing the wall separation to less than that recommended.

The bulk factor of powdered plastics is approximately three times that of the solid molded part. In designing parts with a minimum wall separation, the designer must allow adequate volume in the cavity to receive the charge of powder.

Corner Angle Limits

Another consideration, which has requirements similar to those described for minimal wall separations, is the angle at the corners of a three-dimensional part.



Considering the way in which the hot surfaces of the mold pass through the puddle of liquid or powdered plastic, it is obvious that a perfectly round part would be ideal for the rotational molding process. In the real world, however, very few parts are perfectly spherical.

Irregularly shaped parts with corner angles of 90° or greater can be molded with relative ease in any plastic material suitable for the end-use requirements of a part.

Corner angles of less than 90° begin to require greater care and attention by the molder. Corner angles of 45° can be produced on parts which are molded in polyethylene, polyvinylchloride and nylon, but they are more difficult to achieve with the harder flow materials such as polycarbonate.

The minimum recommended angle for polyethylene and polyvinylchloride is 30°. Corner angles which are as small as 20° have been produced successfully in the easy flowing nylon materials. Polycarbonate will be difficult to mold in corners which have an angle of less than 45°.

The limiting factor on corner angles is that there must be an adequate radius at the point where the two walls meet. The design guidelines given for "minimum wall separations" and "corner radiuses" also apply to corner angles.

Corner angles that are less than those recommended result in parts which are not completely filled out. The plastic tends to bridge over into these restricted areas, thereby producing a solid part with increased porosity, excessive mold shrinkage and warpage. These conditions cause processing difficulties which result in additional rejects and added part cost.

Reinforcing Ribs

Stiffening ribs are an especially important design detail on rotationally molded plastic parts. Relatively speaking, rotationally molded parts frequently have walls which are quite thin in comparison to their size. The skillful use of stiffening ribs can increase the part's stiffness while keeping the nominal wall to a minimum. The correct use of stiffening ribs can result in strong, lightweight parts that can be produced on short molding cycles at low cost.

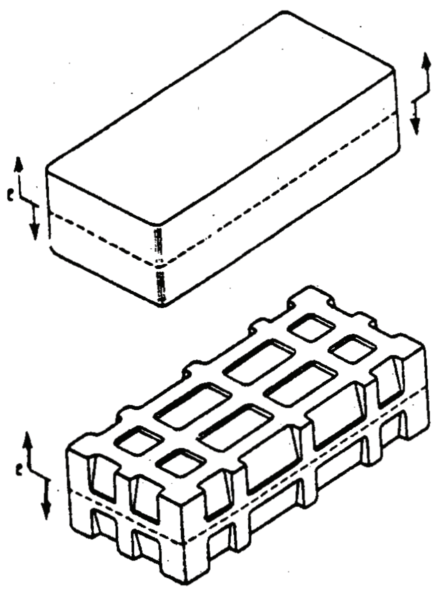


Figure IV

Stiffening ribs can be designed to almost any configuration that is in keeping with good molding proportions. Deep, narrow ribs are actually closely spaced parallel walls, and they cannot exceed the design guidelines for parallel walls. As a general rule, several shallow ribs will be easier to produce than one deep rib.

Stiffening ribs on rotationally molded plastic parts cannot be designed as solid elements as is the case with injection or compression molded parts. In this case, the stiffening ribs must be designed as hollow design elements which are similar to corrugated sheet or thermoformed parts.

Good average proportions for rotationally molded stiffening ribs are shown in Figure V, where the depth (Y) of the rib is at least four times the nominal wall (W) thickness and the width (X) is at least five times the nominal wall.

The "Y" portion of the rib provides the added stiffness, and the greater stiffness will be achieved by increasing this dimension. It must be remembered that increasing this dimension in relation to the "X" dimension will result in complicating the molding procedures. For best results "X" dimension should be greater than "Y" dimension.

Rounded stiffening ribs, as shown in Fig. V, are frequently specified, as they are easier to produce in the mold. However, for the same amount of added plastic material used, the rectangular-shaped reinforcing rib shown in this figure will provide more stiffness, due to the perpendicular positioning of dimension "Y".

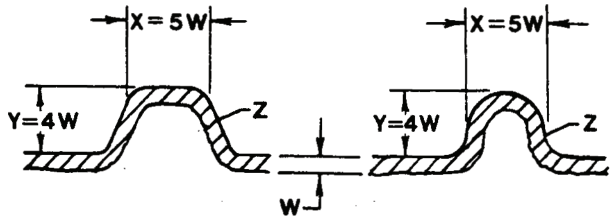


Figure V

The side walls (Z) of stiffening ribs should be provided with tapers to improve their release from the cavity. The tapers should be proportioned according to the design guidelines for draft angles, which will be reviewed later.

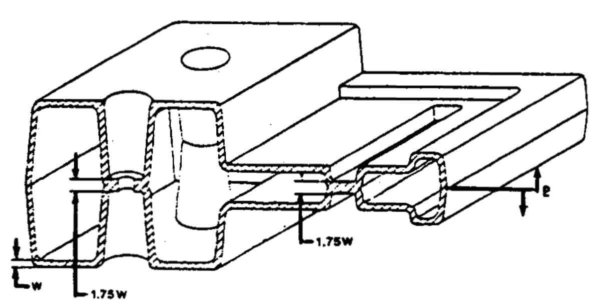
Kiss-Off Ribbing

Kiss-off ribbing is another unique capability of the rotational molding process. With this form of reinforcement, two closely spaced walls are attached to each other to provide added strength and dimensional stability.

Kiss-off ribbing of this type has been used effectively to counteract warpage in large, flat surfaces and to provide added strength and baffeling inside military fuel tanks.

The thickness in the kiss-off area is usually established by the trial-and-error method; however, 175 percent of the nominal wall (W) thickness is a good starting point. These proportions will provide a good weldline, while leaving space enough for the plastic to move over all surfaces of the mold.

Care must be exercised when attempting this type of reinforcement when the two nominal walls are located a great distance apart. In these cases, it is difficult and sometimes time consuming to heat the mold surfaces adequately in the kiss-off area. This situation can be improved by designing the maximum width of the kiss-off area that is practical, within keeping with the rest of the design. Designing a hole through the mold and the part in the kiss-off area will help bring hot oven air down into contact with the kiss-off surface. Constructing the kiss-off mold areas with a high thermal-conductivity metal has also been found to be effective.



Draft Angles

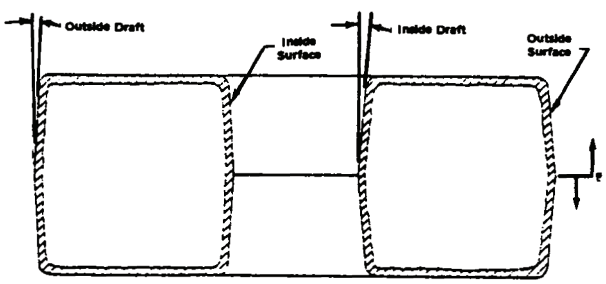
Draft angles are tapers that are placed on the surfaces of parts that will be perpendicular to the parting line of the mold. Draft angles are used to make it easier to remove the molded part from the cavity.

The limiting factor on a part's cooling cycle time is that the part must be cooled enough to have regained sufficient strength to retain its shape after being removed from the mold. The part must also have regained sufficient strength to resist the forces required to remove the part from the mold. The liberal use of draft angle, wherever possible, will reduce the forces applied to the part during removal from the mold. In reducing these forces, the cooling time, cost, induced stress and part warpage will be minimized.

One of rotational molding's advantages over other processes is that many types of parts can be molded straight up and down, with no draft angle at all. This is made possible by the fact that these hollow parts are molded without internal cores. As the formed part is cooled, it shrinks and draws away from the cavity, which makes it easy to remove from the cavity.

A donut-shaped part would shrink as it cools and would draw away from the cavity on its outside surfaces. However, those surfaces that form the hole in the center of the part would shrink down tightly onto the mold. Removal of the part from the mold would be made easier by providing sufficient draft angle on these inside surfaces.

Each of the various plastic materials has its own mold shrinkage characteristics. Those materials which have a high mold shrinkage factor, such as polyethylene or nylon, will pull away from the cavity wall more than the materials with a lower mold shrinkage factor, such as polycarbonate.



The softer, self-lubricating materials such as polyethylene are always easiest to remove from cavities that have a minimal draft angle.

It is difficult to state hard and fast rules for draft angles on rotationally molded parts, as some parts with no draft angles can be produced if ease of processing and part cost are of secondary importance.

It is safe to say, however, that liberal draft angles should be incorporated into the design of plastic parts that will be rotationally molded. This is especially true for inside surfaces that will shrink down tightly onto the mold as the part cools, making demolding difficult.

It is generally agreed that the draft angles shown in Chart I should be applied to rotationally molded parts where their presence will not interfere with the functional requirements of the part in its final use environment. Parts of large size or unusual shape may require larger draft angles. This is especially true for deep draw parts.

Chart I

Recommended Draft angles in Degrees Per Side

	Outside Surfaces		Inside Surfaces	
	Minimum	**Better**	**Minimum**	**Better**
Polyethylene	0°	1°	2°	4°
PVC	0°	1.5°	1°	3°
Nylon	1°	1.5°	1.5°	3°
Polycarbonate	1.5°	2°	2°	4°
Polyester	1°	1.5°	1.5°	3°

A smoothly polished cavity with no tool marks or undercuts will improve the part's release from the mold. Care must be exercised so as not to over-specify mold polish since it adds significantly to the mold cost. However, inside surfaces should be smoothly polished to improve part demolding.

Textured surfaces and other features are frequently applied to rotationally molded parts in order to achieve a decorative effect or to improve the image of quality. The designer must remember that these surface finishes are achieved by providing the reverse details in the cavity. The rough surface on cavity walls which are perpendicular to the parting line of the mold makes it difficult to remove the molded part from the cavity. Parts that incorporate special finishes of this type must be designed with proportionally greater draft angles. A good rule of thumb to remember is that the draft angle on these surfaces should be shown in Chart I, plus one additional degree per side of draft angle for each.001 inch of textured depth.

Corner Radiuses

Radiuses on the corners of plastic parts have two primary functions in a part design: 1) Radiuses distribute the corner stress on a part over a broader area and add to the part's strength; and 2) Radiuses improve the molding of corners.

It is a well publicized fact that a plastic part will be highly stressed whenever the radius on an inside corner is less than 25 percent of the nominal wall thickness. There will be an increase of strength in the corner as the dimension of the radius is increased up to 75 percent of the nominal wall thickness. Little additional strength will be realized with a larger radius. The relationship between radius size and part strength is shown in Figure VI, pg. 11.

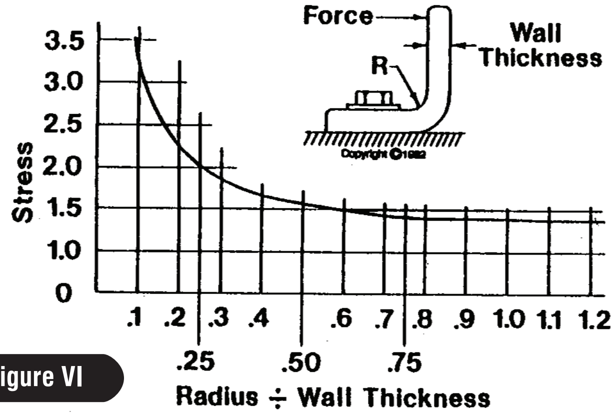
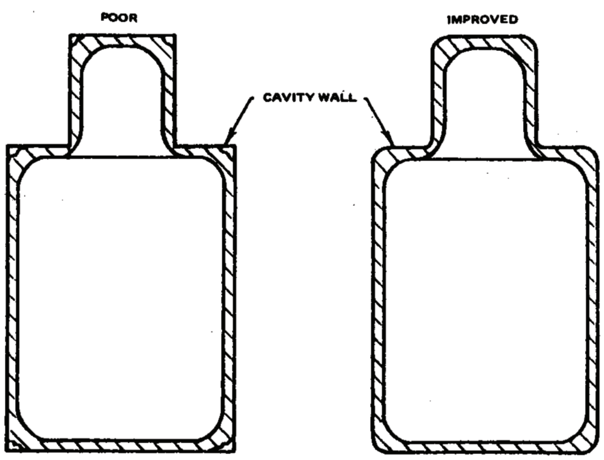


Figure VI

In the case of rotational molding, radiuses improve the ease of molding good-quality parts. Sharp inside corners on the mold tend to be one of the last portions on the mold to reach molding temperature. The plastic also has a tendency to migrate away from sharp inside corners. These two actions combine to produce a reduction in wall thickness at sharp inside corners on the molded part.

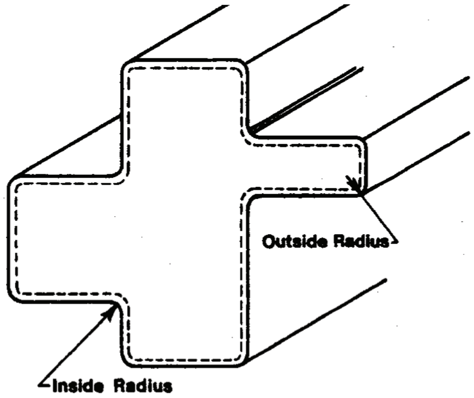
Sharp outside corners of the type that are sometimes formed by low-cost sheet-metal molds are also troublesome. The corresponding outside corners on the molds are usually the closest to the source of the oven heat. Outside corners reach molding temperature first and start to pick up plastic before the other mold surfaces. As the mold turns through the puddle of the liquid or powdered plastic, there is a tendency for the plastic to accumulate in outside corners. These two actions result in a situation where the outside corners on rotationally molded plastic parts are almost always somewhat thicker than the rest of the part. The outside corners of a part are frequently heavily loaded, and the added thickness in these corners is considered to be an advantage of the rotational molding process.



Another problem associated with sharp outside corners is that the corner cannot always be filled out completely. In some cases, the first layer of plastic which is picked up by mold will bridge across the sharp corner and create a freeformed radius. The plastic on the surface of these freeformed radiuses is not in contact with the mold. This sometimes results in a condition where the plastic in these corners is not adequately heated or cooled.

Considering these potential difficulties, it is highly desirable to radius the inside and outside corners of plastic parts generously if the parts are to be rotationally molded. The use of radii will improve molding and minimize the increases and decreases of the wall thickness at the corners.

Because of the differing molding characteristics of the various types of plastics, corner radii must be specified for the particular material being molded. Chart II lists the recommended radii for plastic materials which are commonly used for rotational molding. For thick-walled parts, the minimum radius should equal the wall thickness.



As can be seen in Chart II, the recommended radius sizes are quite large. The designer who is specifying radiuses on rotationally molded plastic parts would be well advised to review the chart and the graph (Figure VI) and specify whichever radius is the larger. This approach will result in strong, good-quality, low-cost parts which are easy to mold.

Chart II

	Inside Radius (in inches)	Outside Radius (in inches)
Polyethylene		
Ideal	.250	.250
Commercial	.187	.187
Minimum	.060	.125
Polyvinylchloride		
Ideal	.375	.250
Commercial	.250	.125
Minimum	.125	.080
Nylon		
Ideal	.750	.500
Commercial	.375	.375
Minimum	.187	.187
Polycarbonate		
Ideal	.500	.750
Commercial	.375	.375
Minimum	.125	.250

Holes

Rotational molding is an ideal process for producing hollow, seamless plastic parts. However, most parts require a vent opening through the wall of the part in order to equalize the pressure on the inside and outside of the molded part as the mold is heated and cooled. Spherical parts such as balls can be produced without a vent hole, as their shape resists the forces of the cooling and contracting air inside the completely closed part. Plastic parts which have large, flat, unsupported surfaces must be vented to minimize part warpage.

In many cases, the design engineer can utilize the vent holes as part of the final part design. In these cases, it is mandatory that the molder be advised of the designer's intentions.

Blind holes can be provided on rotationally molded parts if the hole projects into the part, as shown in Figure VII, example A. Their depth, however, should be kept as small as possible in order to minimize the problems associated with inadequate heat at the tip of the core pin which forms the hole.

Outwardly projecting blind holes of the type shown in Fig. VI, example B are not recommended, as the plastic will not flow down into the restricted walls around the core pin. A hole of this type could be produced with the double-walled structure shown by the broken lines, but that is, in effect, the same as the hole shown in Figure VII, example A.

Outwardly-projecting through holes or bosses of the type shown in Fig. VII, example C can be produced by over-designing the projection and cutting off the tip after molding. The inside diameters of these holes cannot be controlled as well as those shown in Fig. VII, example A, since they are free-formed rather than molded over a core pin. The outside diameter of this type of hole must be a minimum of six times the nominal wall thickness. However, small bosses can be molded as long as the boss diameter is greater than the boss length.

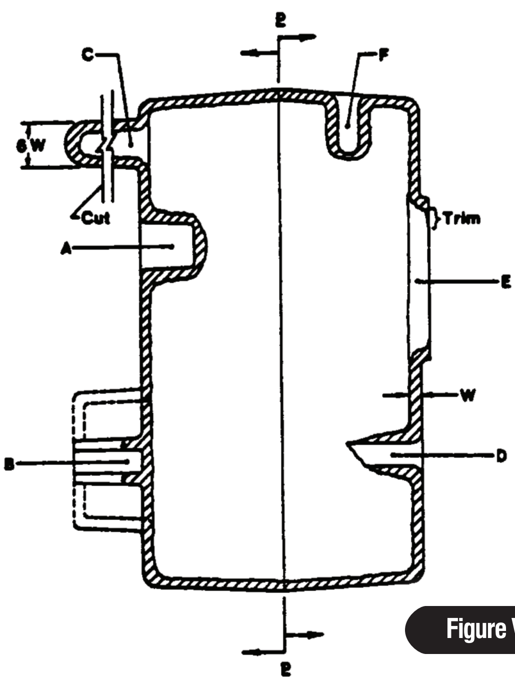


Figure VII

Through-holes of the type shown in Fig. VII-D can be produced by the use of a vent tube or by mounting a long core pin in the mold. These pins are normally fabricated by the use of a metal with low thermal conductivity. In some cases, the core pins are coated with baked-on silicone or Teflon in order to discourage the plastic from adhering to the core pin. In these cases, there will be some inward extension of the hole beyond the nominal wall of the part.

Large holes through the wall, as shown in Fig. VII-E, can be produced by a similar technique. In these cases, a section of the cavity, which is the same shape as the desired hole, is designed so that there is insufficient heat on the inside cavity wall for the plastic to adhere to it. A small amount of plastic will usually creep a short distance into the hole. These areas are trimmed after molding. A hole of this type is shown in Fig. VII.

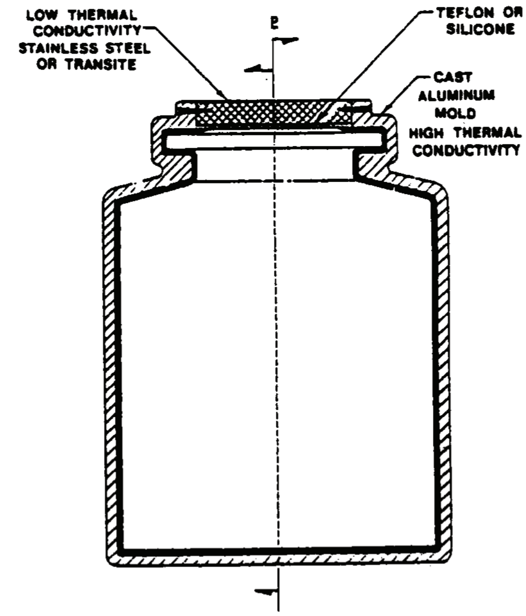


Figure VIII

All of the holes that have been discussed so far have been perpendicular to the parting line of the mold. The same types of techniques can be employed to provide holes which have an axis parallel to the parting line of the mold. However, holes in these locations represent undercuts, as can be seen in Fig. VII-F.

Undercut holes of this type can be produced with side-acting molds or removable inserts. Where possible, holes in these locations should be avoided, because they increase the cost of the mold as well as the molding of the part significantly.

Another interesting approach to producing large openings in rotationally molded parts is to mold two identical or dissimilar parts as one piece and then cut them apart after molding to produce two separate parts.

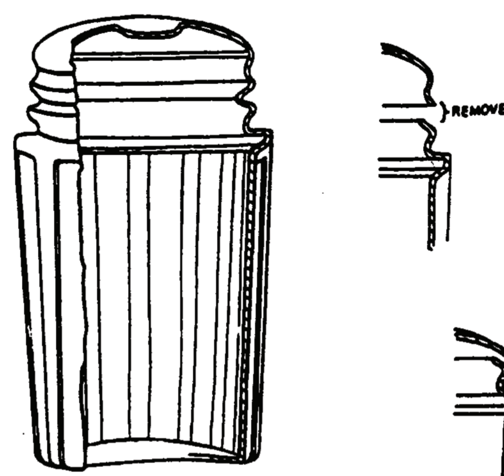


Figure IX

Two tote bins can be produced in this manner. A refuse container body and cover, as shown in Figure IX, pg. 12, is another possibility. Instrument housings have been produced by cutting the part into two pieces to produce the top and bottom of the housing simultaneously.

Secondary operations, such as the cutting apart of a piece as described above, or the machining of holes through the walls of rotationally molded parts are common. The accuracy and costs of these cutting operations have been greatly improved with the advent of numerically controlled routing equipment.

Undercuts

An undercut on a rotationally molded plastic part is any inwardly or outwardly projecting wall that is parallel to the parting line of the mold which must be deformed in order to be removed from the mold.

It is difficult to be specific about the design of undercuts on plastic parts which will be rotationally molded. This process, which molds hollow parts with no inside cores, does allow the walls of the molded part to be deformed inwardly to free the undercut. However, there are limitations on both the design of the parts and the plastic material that is molded.

The hypothetical part, shown in cross-section in Figure X, contains four different types of undercuts. The possible undercut "A" can be avoided by locating the parting line of the mold as shown at "W-W."

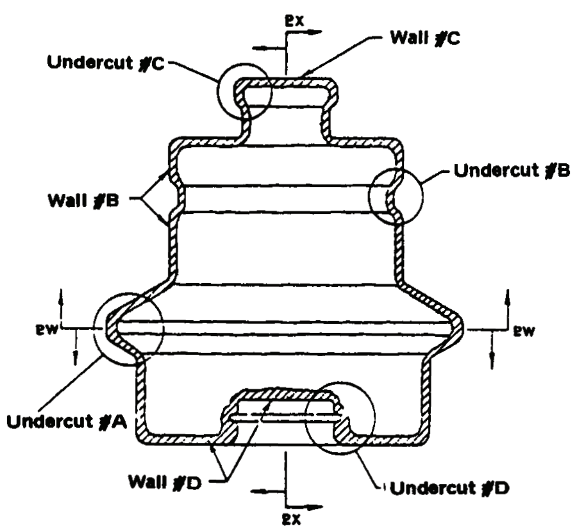


Figure X

The undercut "B" can be stripped from the cavity if the plastic material will deform sufficiently to accommodate the depth of the undercut. Removal from the mold will be enhanced if the shape of the undercut encourages the inward deformation of walls "B."

The undercut "C" will be difficult or impossible to remove from the cavity in all but the very flexible plastics such as low-density polyethylene, polyvinylchloride or the polyester elastomers. The location of Wall "C" reinforces the undercut and makes it difficult to deform inwardly. The walls "B" in the previous example are free to bend.

The undercut "D" is similar to "C". Whether or not it can be stripped from the mold is dependent upon the flexibility of the plastic material, the depth and shape of the undercut, and its location in relationship to the two reinforcing walls "D" and material shrinkage.

Internal undercuts of the type shown in "D" are always more difficult to remove than external undercuts of the same proportions. This is due in part to the fact that, as the plastic cools, it shrinks and draws down tightly onto the core pin that forms the undercut. External undercuts, on the other hand, tend to free themselves from the cavity by the shrinkage of the plastic. Internal undercuts of this type should be avoided where possible. When they must be specified, their depth must be kept to a minimum and their use limited to flexible or semi-rigid plastic materials only.

The potential undercuts shown at locations "A", "B", and "C" can be avoided if the parting line of the mold were relocated to position "X-X". In some cases, this will add to the cost of the mold, but the molding of the part and especially the removal of the part from the mold will be improved.

The majority of rotational molds are of a two-piece construction; however, three or more movable parts can be built into a mold in order to accommodate special details such as undercuts, side-cored holes or molded-in inserts. These extra mold components will add significantly to the mold's construction and overall maintenance costs.

Tolerances

The very important subject of which dimensional tolerances are possible for a given plastics-processing technique is always difficult to reduce to hard, fast numbers. Attainable tolerances are a very individualistic thing that is dependent upon the design of the part, the plastic material used for molding, the dimensions of the cavity and the processing technique which is used. Each combination of these four factors is an individual case which must be studied separately.

Design Factors

In finalizing a design, the engineer must remember that small parts can be held to closer tolerances than large parts. Thin-walled parts will be of more precision than the same size and shape of a part with a thicker wall.

The outside dimensions (Figure XI – "A", "B", "C", and "F") on a rotationally molded plastic part are free to draw away from the inside surfaces of the cavity as the plastic cools and shrinks. These dimensions will always vary more than inside dimensions (Figure XI – "D" and "E"). These inside dimensions will be stabilized by the presence of the mold and will not shrink as much as outside dimensions.

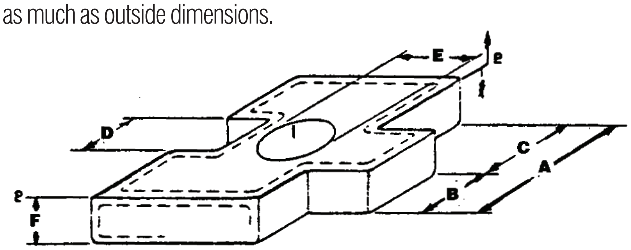


Figure XI

Dimensions and tolerances are usually not applied to the inside of hollow rotationally molded parts. These free-formed surfaces are not in contact with the cavity and they cannot be controlled with any repetitive degree of accuracy. In this regard, rotational molding is similar to blow molding and female thermoforming.

Plastic Material Factors

It is generally agreed that plastic materials which have the smallest mold-shrinkage factors will produce the more dimensionally stable parts.

Amorphous materials such as polyvinylchloride and polycarbonate are less susceptible to molding cycle variations than are crystalline materials such as high-density polyethylene and nylon.

There are always some minor variations in the batch-to-batch uniformity of the plastic material as received from the material supplier. However, in more recent years, these variations are becoming less of a factor. Greater dimensional and processing variables can be encountered by using reprocessed, offgrade or improperly ground plastic materials.

Mold Design & Construction Factors

To a great extent, the ability of a molder to produce a part within drawing specification is dependent upon the design, construction and precision of the mold. There is no substitute for a good quality, precision mold. For cast molds, the accuracy of the wood pattern has the greatest affect on mold dimensions and therefore part dimensions.

In the case of multiple-cavity molds, the dimensional uniformity of the molded parts must also allow for the dimensional variations among the various cavities.

Theoretically, there is no limit to the level of precision that can be built into a cavity, assuming that the cost of the mold is of secondary importance.

Rotational molding is a low-pressure process, and the two halves of the mold do not require the high-pressure clamping which is common to blow or injection molding. As a result, larger tolerances are required on part dimensions (Figure XI-F, pg. 13) that are perpendicular to the mold's parting line. Routine mold maintenance and cleaning of the parting line surfaces will minimize these dimensional variations.

The type, amount and frequency of mold release usage will also affect a part's size. Molds with Teflon coating will produce a more consistent part because the release is constant.

It is important that the designer identify critical dimensions and if needed, a shrink fixture can be made to keep that dimension.

Processing Factors

It is generally agreed that processing variables account for the majority of dimensional differences in rotationally molded plastic parts. This condition is improving as the process is more clearly understood and as more sophisticated controls are applied to the various segments of the molding cycle.

If an exact dimensional reproduction is absolutely mandatory, the molder can devote all his skill and experience to that one requirement so that precision parts can be produced. The resultant part cost may be prohibitive, however, the design engineer must exercise care in applying tolerances to part-drawing dimensions, as overspecification will have a direct and adverse effect on the cost of the mold and the molded parts. As with all other plastics processing techniques, the best tolerance is the broadest tolerance that will satisfy the end-use functional requirement of that part.

The following table can be used as a design guide for applying dimensional tolerances to rotationally molded plastic parts. However, each part design and material section is a special case which must be given individual consideration. The knowledge and experience of a custom processor can be very helpful in determining which tolerances will be practical for a specific part design.

Chart III

Recommended Tolerances

(Values in inches/inch. Does not include tolerance of cavity.)

DIMENSION FROM FIGURE XI:

	A	B	C	D	E	F
POLYETHYLENE						
Ideal	±.020	±.020	±.020	±.015	±.010	±.020*
Commercial	±.010	±.010	±.010	±.008	±.008	±.010*
Precision	±.005	±.005	±.005	±.004	±.004	±.005*
POLYVINYLCHLORIDE						
Ideal	±.025	±.025	±.025	±.015	±.015	±.025*
Commercial	±.020	±.020	±.020	±.010	±.010	±.020*
Precision	±.010	±.010	±.010	±.005	±.006	±.010*
NYLON						
Ideal	±.010	±.010	±.010	±.008	±.008	±.010*
Commercial	±.006	±.006	±.006	±.005	±.005	±.006*
Precision	±.004	±.004	±.004	±.003	±.003	±.004*
POLYCARBONATE						
Ideal	±.008	±.008	±.008	±.006	±.005	±.008*
Commercial	±.005	±.005	±.005	±.003	±.003	±.005*
Precision	±.003	±.003	±.003	±.002	±.002	±.003

NOTE: Ideal Tolerance = Minimum care required
Commercial Tolerance = Possible with reasonable care
Precision Tolerance = Possible with difficulty & added cost

*Plus .010 inch for parting line variations

Molded-In Threads

Inside and outside threads are routinely molded into rotationally molded plastic parts. All types of threads have been molded; however, coarse thread forms of the Acme or modified buttress type, with a thick profile, are preferred for rotationally molded parts.

Threads with sharp profiles such as the American Standard or tapered pipe threads are difficult to produce without bridging over of the tips of the thread cavities which results in underfilled parts. When these types of threads must be provided, they should be machined into the part after molding.

Small, fine-pitched threads which are difficult to mold are sometimes provided as metal inserts molded into the part during the normal molding cycle.

Recommended thread profiles that have been successfully molded are shown in Figure XII.

In designing inside and outside threads, the designer must follow the design guidelines already established for closely spaced parallel walls, holes and draft angles.

The designer must recognize that, in specifying threads on a part, it will increase the cost and complexity of the mold and, in some cases, the molding cost. Threads should not be specified unless they provide some definite end-use benefit that justifies their cost.

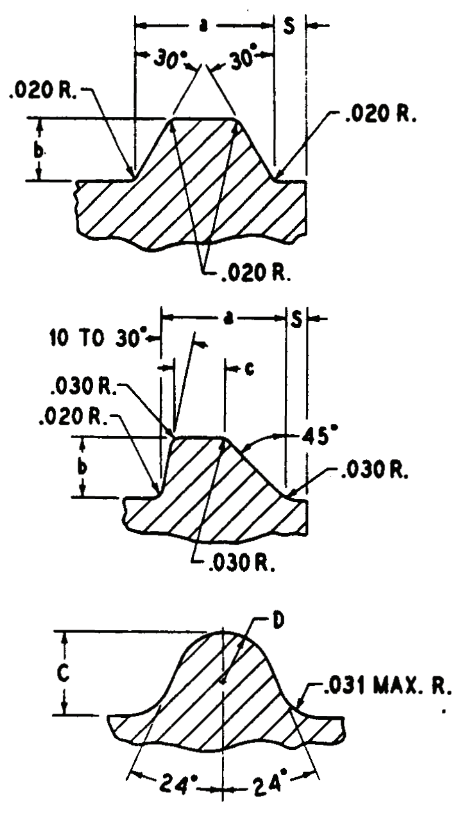


Figure XII

Molded-In Inserts

Molded-in inserts can be incorporated into rotationally molded plastic parts. In this process, the insert is mounted inside the cavity and the plastic material molds around the insert to lock it into the molded part.

It is ideal for the insert to be capable of absorbing heat from the surface of the cavity and conducting it along the length of the insert. This will allow the plastic to melt and form around the insert. The best results are achieved when the shape of the insert provides undercuts into which the plastic can flow to lock the insert into the part.

Inserts of many different kinds of material have been molded successfully. The only requirements are that the insert must be chemically compatible with the plastic and it must have temperature resistance enough to resist deformation at molding temperatures. The reverse is true in some cases where plastic inserts are allowed to partially melt on their outside surfaces so that they adhere to the finished part.

The insert must provide a method by which it can be mounted inside the cavity.

Care must be exercised in choosing the size, shape and location of inserts. As the plastic material cools and shrinks, it draws down tightly on molded-in inserts, which normally have a lower coefficient of thermal expansion. This condition can result in stress cracking of the plastic around the insert. In this regard, large inserts are more troublesome than small inserts. Inserts with sharp edges will encourage stress cracking.

When more than one insert is to be used, the distance between the inserts should be kept as small as possible. Shrinkage of the plastic between widely spaced inserts can cause high stress at the fitment between the insert and the plastic. This condition can also result in difficulties in removing the finished part from the cavity.

One of rotational molding's advantages is that it is a low-pressure process. This is helpful when inserts are being used, as there are no high forces available to deform or break inserts such as are present in injection and compression molding.

Finishing and Decorating

Many industrial-type rotationally molded plastic parts are ready to use as they come out of the mold. In these cases, no additional finishing is required. This is another advantage to rotational molding as opposed to other processes such as thermoforming and extrusion blow molding, which nearly always require postmold trimming and reprocessing of the scrap material.

Appearance-type parts may require light trimming at parting lines or mold shutoffs. Many parts have special decorating requirements such as painting, hot stamping, silkscreening, labeling, etc. Other decorative effects such as textured and engraved surfaces can be molded directly into the part. All of these decorating procedures are performed in the same manner as other types of plastic parts.

Appearance-type parts can also be decorated with multi-colored graphics that can be molded-in during the molding process or applied after the part is molded. These "molded-in" or "post-molded" methods result in extremely durable graphics because they are bonded to the plastic.

Rotationally molded parts can be heat sealed or postmold formed the same as other types of parts. Spin welding is a common method of plugging vent holes or attaching fittings of various kinds. Inserts of different materials are commonly added to parts by ultrasonic heating or force-fitting.

Some double-walled parts (see page 8) are filled with foam for added stiffness or thermal-insulating properties.

Many rotationally molded parts are drilled, sawed, milled and routed to provide openings through the nominal wall or to separate one molded part into two pieces (see Figure IX, pg. 12).

Computer-Aided Design

Computer-aided design is changing and improving the way rotationally molded products are developed. 2D CAD improved the design drawings but 3D CAD is improving the entire new product development process. This in turn improves the finished rotationally molded products.

The advantages for developing rotationally molded products with 3D CAD systems all relate to the different uses for the electronic date that represents the 3D model.

1. Computer models can be reviewed before the wood patterns are made. Design changes can be made easier and quicker to the computer models. The use of color renderings help non-technical personnel to understand the design.

2. Drawings are improved since all drawing views are created from the 3D model. All drawing views are an exact representation of the 3D model. Difficult cross-sections can be easily made and this can aid in checking the distance between two adjacent walls and assembly issues.

3. Tolerances can be improved by using the 3D CAD file to directly make the wood model or the mold. This also allows for more complex geometry in parts using CNC machinery.

4. 3D CAD can create parts with complex geometry or "3-Dimensional" shapes that would be difficult to do with any other method. This is especially true with parts involving difficult assembly issues.

5. The 3D CAD software calculates physical properties such as volume and weight. This results in more accurate tanks and containers. Knowing the exact weight allows for more accurate costing. Mold volume can be accurately calculated to determine if there is sufficient space for the powdered material.

6. Finite Element Analysis (FEA) can be used to determine the stresses in a part due to the forces applied during its use. FEA requires a 3D model.

7. The electronic CAD file can be transferred over the Internet to improve communications with vendors.

3D CAD is rapidly changing the way that we develop our products. These changes are leading to improvements in traditional products, as well as creating new opportunities for the design of rotationally molded products. 3D CAD can improve part accuracy and parts with complex geometry. 3D models can better communicate the details and design concept of a product or part. All of these advantages are expanding the use of rotationally molded products.

Volume of Mold Cavity Versus Volume of Powder Shot Weight

Applicable in determining if mold cavity is large enough to accept shot weight to mold a part of desired wall thickness.

Formulas

Vmc = Mold length x mold width x mold height
Vpp = Surface area (part) x desired wall thickness (part)
SW = Vpp x density (resin)
Vsw = Powder shot weight ÷ bulk density

Where

Vmc = Volume of mold cavity
Vpp = Volume of the plastic of the part
Sw = Powder shot weight
Vsw = Volume of powder shot weight

American Standard

Sample Calculation

Mold dimensions 24 in L x 24 in W x 2 in H
Density (resin) 0.94 g/cm^3 (940 kg/m^3)

Bulk density 23 lb/ft^3
Desired wall thickness 0.186 in

Step 1 Convert bulk density to lb/in^3

$$\text{Bulk density} = 23\ \text{lb/ft}^3 \times \frac{1}{1728\ \text{in/ft}^3} = 0.0133\ \text{lb/in}^3$$

Step 2 Convert density (resin) to lb/in^3

$$\text{Density} = 0.94\ \text{g/cm}^3 \times \frac{1}{454\ \text{g/lb}} \times 16.39\ \text{cm}^3/\text{in}^3 = 0.0339\ \text{lb/in}^3$$

Step 3 Surface area = 2 (24 x 24) + 4 (2 x 24)
= 1344 in^2

Step 4 SW = 1344 in^2 x 0.186 in x 0.0339 lb/in^3
= 8.48 lbs

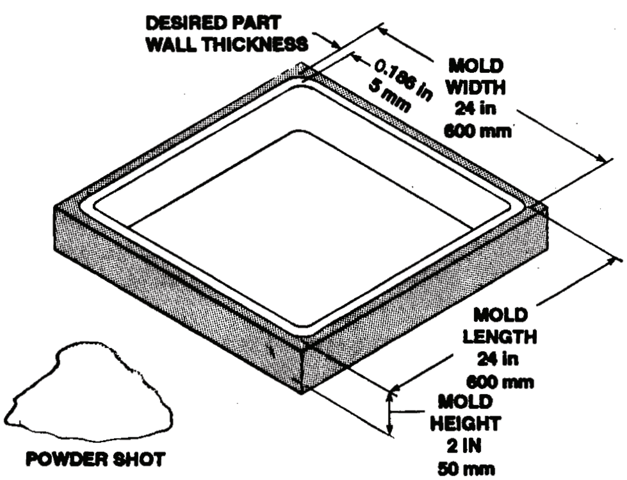
Step 5

$$\text{Vsw} = \frac{8.48\ \text{lb.}}{0.0133\ \text{lb/in}^3} = 637.6\ \text{in}^3$$

Step 6 Vmc = 24 x 24 x 2
= 1152 in^3

Comparison Vmc versus Vsw
1152 in^3 versus 637.6 in^3

Summary Volume mold cavity is large enough to accept volume of shot weight required to produce part of desired wall thickness.



Metric Standard

Mold dimensions 600 mm L x 600 mm W x 50 mm H
Density (resin) 0.94/cm^3 (940 kg/m^3)

Bulk density 0.370 g/cm^3 (370 kg/m^3)
Desired wall thickness 5 mm

Surface area = 2(600 x 600) + 4 (50 x 600)
= 840000 mm^2

Vpp = 840000 mm^2 x 5 mm = 4200000 mm^3 = 4200 cm^3

Sw = 4200 cm^3 x 0.94 g/cm^3
= 3948 g

$$\text{Vsw} = \frac{3948\ \text{g}}{0.370\ \text{g/cm}^3} = 10670\ \text{cm}^3$$

Vmc = 600 x 600 x 50
= 18000000 mm^3 = 18000 cm^3

Vmc versus Vsw
18000 cm^3 versus 10670 cm^3

Volume mold cavity is large enough to accept volume of shot weight required to produce part of desired wall thickness.

Note:
In order to have reliable comparisons, it is suggested to use the following margin of error:
1.) +20% to Vsw, because bulk density is never constant
2.) −10% to Vmc, because the volume is not always usable in its totality (especially when there are elaborate dimensions).

Product Dimensional Change Due to Heating or Cooling

Applicable in evaluating the effects of expansion or contraction due to heating or cooling a product against compliance with dimensional tolerances.

Formula Dimensional change = Coe x D_1 x T_1

Where Coe = resin coefficient of expansion
D_1 = original dimension
T_1 = temperature change

Coe must be calculated for any specific resin selected using ASTM D-696.
Test is normally conducted over the temperature range -30°C to + 30°C. Values will vary for different temperature ranges.

American Standard

Sample Calculation

D_1 = 48 in

Coe = 0.8 x 10^{-4} in/in/°F

T_1 = 10°F

Dimensional Change

= Coe x D_1 x T_1

= 0.8 x 10^{-4} in/in/°F x 48 in x 10°F

=0.038 in

Metric Standard

D_1 = 120 cm

Coe = 144 x 10^{-6} cm/cm/° C

T_1 = 10° C

= Coe x D_1 x T_1

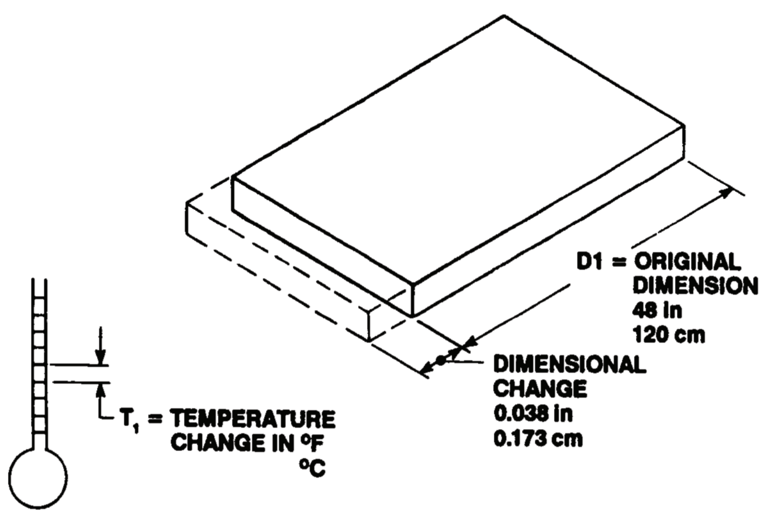
= 144 x 10^{-6} cm/cm/° C x 120 cm x 10° C

= 0.173 cm

Note:

To determine expansion or contraction in area, multiply original area by a doubled coefficient.

To determine expansion or contractoin in volume, multiply original volume by a tirpled coefficient.



Design Wall Thickness Cylindrical Tank

Applicable in determining wall thickness of a cylindrical tank when the diameter and height are known.
Only applicable for the following conditions:

(a) Atmospheric pressure
(b) Ambient Temperature 60-85° F (16-28° C)
(c) Vertical cylindrical tanks

American Standard

Formulas

$$T = \frac{P \times OD}{2\,Sd}$$

$$P = SG \times 0.433\ (\text{psi/ft } H_2O) \times H\ (\text{ft})$$

$$SG = \frac{\text{Density fluid (lb/gal)}}{\text{Density water (8.33 lb/gal)}}$$

Where

T = Tank wall thickness (in)
P = Pressure (psi)
OD = Tank outside diameter (in)
*Sd = Design hoop stress for resin (psi)
SG = Specific gravity of fluid
H = Fluid head or tank height (ft)

Sample Calculatoin

Tank diameter = 9 ft 11 in (119 in)
Tank height = 13 ft
Fluid density = 12 lb/gal (US)
Sd = 600 psi for resin in question

$$P = SG \times 0.433 \times H$$

$$= \frac{12\ \text{lb/gal} \times 0.433 \times 13\ \text{ft}}{8.33\ \text{lb/gal}}$$

$$= 8.1\ \text{psi}$$

$$T = \frac{P \times OD}{2\,Sd} = \frac{8.1\ \text{psi} \times 119\ \text{in}}{2 \times 600\ \text{psi}}$$

$$T = 0.803\ \text{in}$$

*Obtain Sd value from resin supplier for specific resin

Metric Standard

$$T = \frac{P \times OD}{2\,Sd}$$

$$P = SG \times 0.0098\ (\text{kPa/mm } H_20) \times H\ (\text{mm})$$

$$SG = \frac{\text{Density fluid (kg/litre)}}{\text{Density water (0.987 kg/litre)}}$$

T = Tank wall thickness (mm)
P = Pressure (kPa)
OD = Tank outside diameter (mm)
*Sd = Design hoop stress for resin (kPa)
SG = Specific gravity of fluid
H = Fluid head or tank height (mm)

Tank diameter = 3000 mm
Tank height = 4000 mm
Fluid density = 1.5 kg/l
Sd = 4000 kPa for resin in question

$$P = SG \times 0.0098 \times H$$

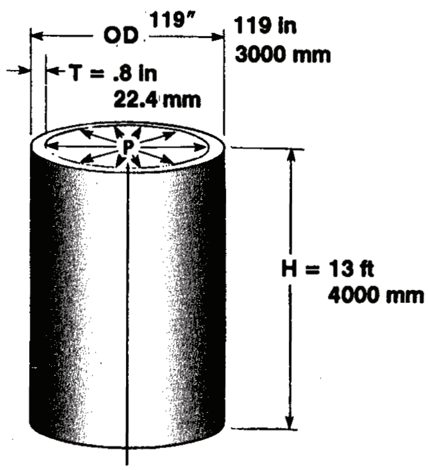
$$= \frac{1.5\ \text{kg/l} \times 0.0098 \times 4000\ \text{mm}}{0.987\ \text{kg/l}}$$

$$= 59.6\ \text{kPa}$$

$$T = \frac{P \times OD}{2\,Sd} = \frac{59.6\ \text{kPa} \times 3000\ \text{mm}}{2 \times 4000\ \text{kPa}}$$

$$T = 22.4\ \text{mm}$$

*Obtain Sd value from resin supplier for specific resin



Hoop Stress in Cylindrical Tank Wall

Applicable in determining hoop stress after pressure and wall thickness are known.

Only applicable for the following conditions:

(a) Atmospheric pressure
(b) Ambient Temperature 60-85° F (16-28° C)
(c) Vertical cylindrical tanks

This formula should be used in conjunction with design wall thickness to verify hoop stress for selected resins.

Formula $S = \frac{P \times OD}{2T}$

Where S = Hoop stress in tank wall
*P = Pressure
OD = Tank outside diameter
**T = Tank wall thickness

American Standard

Sample Calculation

Tank diameter = 9 ft 11 in (119 in)

Fluid head = 13 ft

Fluid density = 12 lb/gal (US)

Tank wall thickness = 0.80 in
*Pressure = 8.1 psi

$$S = \frac{P \times OD}{2T} = \frac{8.1 \text{ psi} \times 119 \text{ in}}{2\text{x } (0.8 \text{ in})} = 600 \text{ psi}$$

** See design wall thickness for calculation of T (thickness) pg. 19.
* See design wall thickness for calculation of P (pressure) pg. 19.

Metric Standard

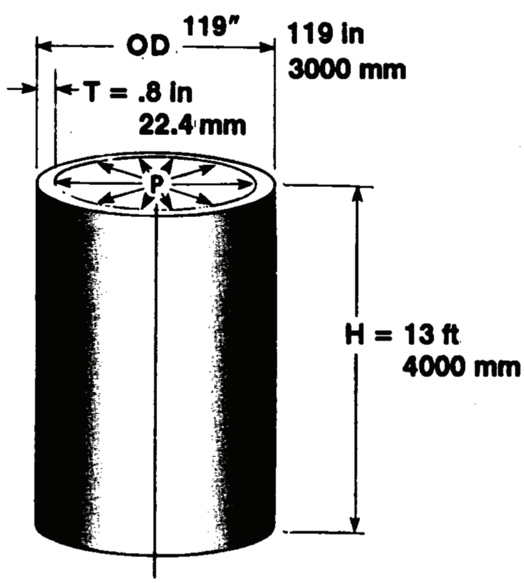
Tank diameter = 3000 mm

Fluid Head = 4000 mm

Fluid density = 1.5 kg/l

Tank wall thickness = 22.4 mm
*Pressure = 59.6 kPa

$$S = \frac{P \times OD}{2T} = \frac{59.6 \text{ psi} \times 3000 \text{ mm}}{2\text{x } (22.35 \text{ mm})} = 4000 \text{ kPa} = 4 \text{ mPa}$$



Calculating Part Weight Assuming a Given Wall Thickness

Applicable in determining resin weight for molding any type of plastic part

American Standard

Formula

Part weight (lb) =

$$\frac{\text{Area (in}^2\text{) x Thickness (in) x Density (g)}}{(\text{cm}^3)} \times \frac{1\text{ (lb)}}{454\text{(g)}} \times \frac{2.54^3(\text{cm}^3)}{(\text{in}^3)}$$

wt (lb) =

Area (in^2) x Thickness(in) x Density (g/cc) x 0.036

Where

Area = surface area of part

Thickness = estimated or desired wall thickness

Density = resin density express in g/cm^3

Sample Calculation

Area = 592 in^2

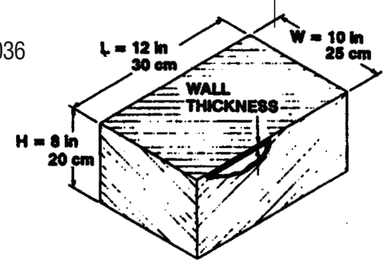
Desired thickness = 0.125 in

Resin density = 0.939 g/cm^3

wt = 592 x 0.125 x 0.939 x 0.036

wt = 2.50 lb

L x W x 2 Sides	= 240 in^2
L x H x 2 Sides	= 192 in^2
H x W x 2 Sides	= 160 in^2
Total Surface Area	= 592 in^2



Metric Standard

Park weight (g) =

Area (cm^2) x Thickness (cm) x Density (g/cm^3)

Area = surface area of part (cm^2)

Thickness = estimated or desired wall thickness (cm)

Density = resin density (g/cm^3)

Area = 3750 cm^2

Desired thickness = 0.3 cm

Resin density = 0.939 g/cm^3

wt = 3750 x 0.3 x 0.939

wt = 1056 g

L x W x 2 Sides	=	1550 in^2
L x H x 2 Sides	=	1200 in^2
H x W x 2 Sides	=	1000 in^2
Total Surface Area	=	3750 in^2

Estimating Part Weight in Polyethylene

Applicable in rough estimating resin weight in polyethylene.

American Standard

Formula

$$\text{Part Weight} = \frac{\text{Surface Area (in}^2)}{232}$$

= Weight @ 0.125 in wall thickness

Sample Calculation

$= \frac{***600\text{ in}^2}{232}$ = 2.59 lb @ 0.125 in wall thickness

*5.18 lb @ 0.25 in wall thickness

**7.77 lb @ 0.375 in wall thickness

* For 0.25 in wall thickness, double the weight of 0.125 in wall thickness

** For 0.375 in wall thickness, triple the weight of 0.125 in wall thickness

*** See page 20 for calculation

Metric Standard

$$\text{Part Weight} = \frac{\text{Surface Area (mm}^2)}{348.71}$$

= Weight @ 3 mm wall thickness

= ***375000 mm^2

= 1075 g @ 3 mm wall thickness

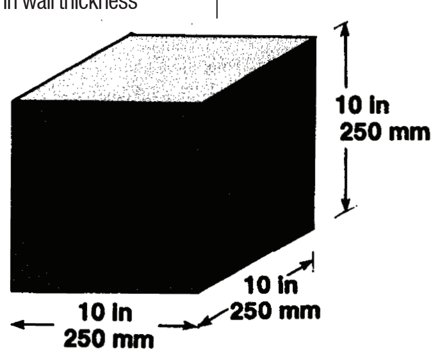
* 2150 g @ 6 mm wall thickness

** 3225 g @ 9 mm wall thickness

* For 6 mm wall thickness, double the weight of 3 mm wall thickness

** For 9 mm wall thickness, triple the weight of 3 mm wall thickness

*** See page 20 for calculation



Estimating Part Wall Thickness

Applicable in comparing various material weights and resultant wall thickness.
Based on the support data in the formula for determining part weight we use the following format:

American Standard

Formula

$$\text{Part Thickness} = \frac{\text{wt}}{\text{area x density x 0.036}}$$

Sample Calculation

wt = 5 lb

Area = 592 in^2

Density = 0.939 g/cc^3

$$\text{Thickness} = \frac{5}{592 \text{ x } 0.939 \text{ x } 0.036}$$

Thickness = 0.249 in

Metric Standard

$$\text{Park Thickness} = \frac{\text{wt}}{\text{area x density}}$$

wt = 2300 g

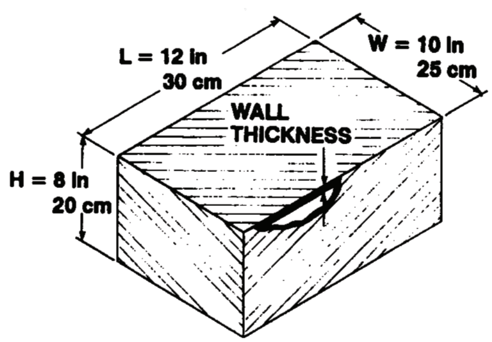
Area = 3700 cm^2

Density = 0.939 g/cc

$$\text{Thickness} = \frac{2300}{3700 \text{ x } 0.939}$$

Thickness = 0.66 cm

L x W x 2 Side	= 240 in^2
L x H x 2 Sides	= 192 in^2
H x W x 2 Sides	= 160 in^2
Surface Area	= 592 in^2



L x W x 2 Side	= 1550 in^2
L x H x 2 Sides	= 1200 in^2
H x W x 2 Sides	= 1000 in^2
Surface Area	= 3700 in^2

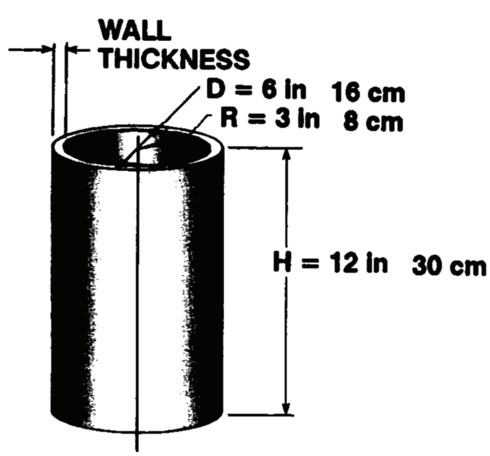
Closed Cylinder

For a closed cylinder, the surface area may be calculated as follows:

American Standard

Total surface area of closed cylinder

Side: 3.142 x D x H	= 226 in^2
Ends: 3.142 x R^2 x 2	= 57 in^2
Total Surface Area	283 in^2



Metric Standard

Total surface area of closed cylinder

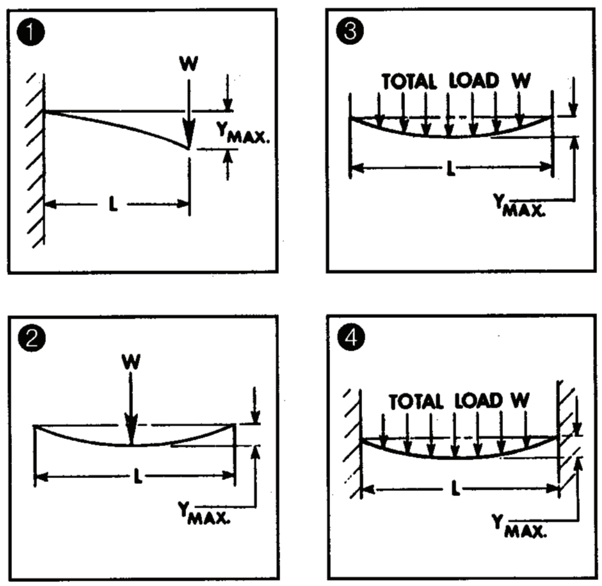
Side: 3.142 x D x H	= 1518 in^2
Ends: 3.142 x R^2 x 2	= 402 in^2
Total Surface Area	1910 in^2

Calculating Deflection

Applicable to determine deflection of simple beams due to specific loading.
Note: This calculation is for theoretical purposes only to provide an indication of potential suitability. It does not take into account the viscoelastic nature of the polymer being used.

Formula

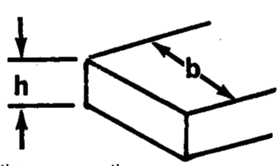
1	End loaded cantilever beam	$Y_{max} = \frac{WL^3}{3EI}$
2	Center loaded beam with simple supports	$Y_{max} = \frac{WL^3}{48\,EI}$
3	Uniform load - simple supports	$Y_{max} = \frac{WL^3}{EI}$ (Metric $= \frac{1\,WL^3}{77\,EI}$)
4	Uniform load - fixed ends	$Y_{max} = \frac{WL^3}{384\,EI}$



American Standard

Where

Ymax = Maximum deflection
W = Load in lbs
L = Length (in)
E = Flexural modulus (lb/in^2)
I = Second moment of area of the cross section



Sample Calculation

HDPE with cross-section 0.5 in x 5 in (Refer to illus. 1)
W = 10 lb
L = 12 in
E = 80,000 psi

$$I = \frac{bh^3}{12} = \frac{5(0.5)^3}{12} = 0.052\ in^4$$

$$Y_{max} = \frac{WL^3}{3\,EI} = \frac{10(12)^3}{3\,(80000)\,(0.052)} = 1.385\ in$$

Metric Standard

Ymax = Maximum deflection
W = Load in kg
L = Length (mm)
E = Flexural modulus (kg/mm^2)
I = Second moment of area of the cross section

HDPE with cross-section 10 mm x 120 mm (Refer to Illus. 1)
W = 4.5 kg
L = 300 mm
E = 54 kg/mm^2

$$I = \frac{bh^3}{12} = \frac{120\,(12)^3}{12} = 17280\ mm^4$$

$$Y_{max} = \frac{WL^3}{3EI} = \frac{4.5\,(300)^3}{3\,(54)\,(17280)} = 43.4\ mm$$

Conversion Formulas/Useful Information

Useful Information

To find circumference of a circle, multiply diameter by 3.1416.
To find diameter of a circle, multiply circumference by .31831
To find area of a circle, multiply square of diameter by .7854.
Area of a rectangle = length multiplied by breadth.
Doubling the diameter of a circle increases its area four times.
To find area of a triangle, multiply base by ½ perpendicular height.
Area of ellipse = product of both diameters x .7854.
Area of a parallelogram = base x altitude.
To find side of an inscribed square, multiply diameter by 0.7071 or multiply circumference by 0.2251 or divide circumference by 4.4428.
Side of inscribed cube = radius of sphere x 1.1547.
To find side of an equal square, multiply diameter by .8862.
Square. A side multiplied by 1.4142 equals diameter of its circumscribing circle.
A side multiplied by 4.443 equals circumference of its circumscribing circle.
A side multiplied by 1.128 equals diameter of an equal circle.
A side multiplied by 3.547 equals circumference of an equal circle.
To find cubic inches in a ball, multiply cube of diameter by .5236.
To find cubic contents of a cone, multiply area of base by 1/3 the altitude.
Surface of frustrum of cone or pyramid = sum of circumference of both ends x ½ slant height plus area of both ends.
Contents of frustrum of cone or pyramid = multiply area of two ends and get square root. Add the 2 areas and multiply 1/3 altitude.
Doubling the diameter of a pipe increases its capacity four times.
A gallon of water (US standard) weighs 8-1/3 lbs. and contains 231 cubic inches.
A cubic foot of water contains 7 ½ gallons, 1728 cubic inches, and weighs 62 ½ lbs.
To find the pressure in pounds per square inch of a column of water, multiply the height of the column in feet by .434.
Steam rising from water at its boiling point (212°F) has a pressure equal to the atmosphere (14.7 lbs. to the square inch).
A standard horse power: the evaporation of 30 lbs. of water per hour from a feed water temperature of 100°F into steam at 70lbs. gauge pressure.
To find capacity of tanks any size, given dimensions of a cylinder in inches, to find its capacity in US gallons: square the diameter, multiply by the length and by .0034.

Avoirdupois Weight

Grains	Drams	Ounces	Pounds	Hundred-Weight	Gross Tons
1.	.03657	.002286	.000143	.00000128	.000000064
27.34375	1.	.0625	.003906	.00003488	.000001744
437.5	16.	1.	.0625	.00055803	.00002790
7000.	256.	16.	1.	.0089286	.0004464
784000.	28672.	1792.	112.	1.	.05
15680000.	573440.	35840.	2240.	20.	1.

1 pound avoirdupois = 1.215278 pounds troy.
1 net ton = 2000 pounds = 0.892857 gross ton

Linear Measure

Inches	Feet	Yards	Rods	Furlongs	Miles
1	.08333	.02778	.0050505	.00012625	.00001577
12	1.	.33333	.0606061	.00151515	.00018939
36	3.	1.	.1818182	.00454545	.00056818
198	16.5	5.5	1.	.025	.003125
7920	660.	220.	40.	1.	.125
63360	5280.	1760.	320.	8.	1.

Cubic or solid Measure

1 cubic inch = .0005787 cubic foot = .0000214333 cubic yard.
1 cubic foot = 1728 cubic inches = .03703704 cubic yard.
1 cubic yard = 27 cubic feet = 46656 cubic inches
1 cord of wood = 128 cubic feet = 4 feet by 4 feet by 8 feet

Liquid Measure

Gills	Pints	Quarts	Gallons	Barrels	Cubic Inches
1	.25	.125	.03125	.000992	7.21875
4	1.	.5	.125	.003968	28.875
8	2.	1.	.25	.007937	57.75
32	8.	4.	1.	.031746	231.
1008	252.	126.	31.5	1.	7276.5

The British imperial gallon = 277.410 cubic inches or 10 pounds avoirdupois of pure water at 62 degrees Fahrenheit and barometer at 30 inches.
The British imperial gallon = 1.20091 United States gallons.
1 fluid ounce = 4.80 minims = 8 drachmas = .0625 pint.

Metric System

Length - Basic unit is meter (m)

Metric Unit	Meters	Inches	Feet	Yards	Miles
Millimeter (mm)	.001	--	--	--	--
Centimeter (cm)	.01	.3937	--	--	--
Decimeter (dm)	.1	3.937	.3281	.1094	--
Meter (m)	1	39.37	3.281	1.094	--
Decameter (dkm)	10	393.7	32.81	10.94	--
Hectometer (hm)	100	3937	328.1	109.4	--
Kilometer (km)	1000	--	3281	1094	.6214

To convert

In. to Millimeters - multiply by 25.4
Yards to Meters - multiply by .9144
Millimeters to in. - multiply by .03937
Meters to Yards - multiply by 1.094
Feet to Meters - multiply by .3048
Miles to Kilometers - multiply by 1.609
Meters to Feet - multiply by 3.281
Kilometers to Miles - multiply by .6214

Area - Basic unit is centare (ca) which is 1 square meter

Metric Unit	Centares	Square Inches	Square Feet	Square Yards	Acres
Sq. Millimeter (sq. mm)	.000001	--	--	--	--
Sq. Centimeter (sq. cm)	.0001	.1550	--	--	--
Sq. Decimeter (sq. dm)	.01	15.50	.1076	--	--
Centare/Sq. Meter (ca/sq. m)	1	1550	10.76	1.196	--
Are (a)	100	--	1076	119.6	--
Hectare (ha)	10,000	--	--	--	2.471
Sq. Kilometer (sq. km)	1,000,000	--	--	--	247.1

To convert

Sq. In. to Sq. cm - multiply by 6.452
Sq. cm to Sq. In. - multiply by .1550
Sq. Ft. to Sq. m - multiply by .0929
Sq. m. to Sq. Ft. - multiply by 10.76
Sq. Yds. to Sq. m. - multiply by .8361
Sq. m. to Sq. Yds. - multiply by 1.196
Acres to Hectares - multiply by .4047
Hectares to Acres - multiply by 2.471
Acres to Sq. km. - multiply by .004047
Sq. km. to Acres - multiply by 247.1
Sq. Miles to Sq. km. - multiply by 2.590
Sq. km. to Sq. Miles - multiply by .3861

Volume - Basic unit is stere (s) which is 1 cubic meter

Metric Unit	Steres	Square Inches	Square Feet	Square Yards
Cu. Millimeter (cu. mm)	.000000001	--	--	--
Cu. Centimeter (cu. cm)	.000001	.06102	--	--
Cu. Decimeter (cu. dm)	.001	61.023	--	--
Desistere (ds)	.1	6102.3	3.531	.1308
Stere Cu Meter (s/cu m)	1	61023	35.31	1.308
Decastere (dks)	10	--	353.1	13.08

To convert

Cu. In. to Cu. mm - multiply by 1639
Cu. mm to Cu. In. - multiply by .000061
Cu. In. to Cu. cm. - multiply by 16.39
Cu. cm to Cu. In. - multiply by .06102
Cu. Ft. to Cu. m - multiply by .0283
Cu. m to Cu. Ft. - multiply by 35.31
Cu. Yds. to Cu. m - multiply by .7646
Cu. m to Cu. Yds - multiply by 1.308

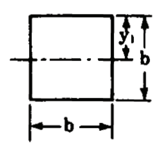
Weight - Basic unit is gram (g)

Metric Unit	Grams	Grains	Ounces	Pounds
Milligram (mg)	.001	.01543	--	--
Centigram (cg)	.01	.1543	--	--
Decigram (dg)	.1	1.543	--	--
Gram (g)	1	15.43	.03527	--
Decagram (dkg)	10	154.3	.3527	--
Hectogram (hg)	100	1543	3.527	.22046
Kilogram (kg)	1000	--	35.27	2.2046
Quintal (q)	100,000	--	3527	220.46
Metric Ton (MT)	1,000,000	--	--	2204.6

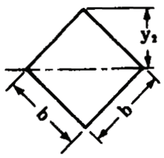
To convert

Grains to Centigrams - multiply by 6.48
Centigrams to Grains - multiply by .1543
Ounces to Grams - multiply by 31.103
Tons (2000#) to Metric Tons - multiply by .9078
Metric Tons to Tons (2000#) - multiply by 1.1023
Grams to Ounces - multiply by .03527
Pounds to Kilograms - multiply by .4536
Kilograms to Pounds - multiply by 2.2046

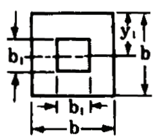
Equatoins for Area of Plane Shapes



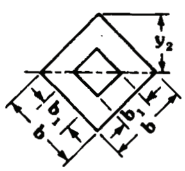
$A = b^2$



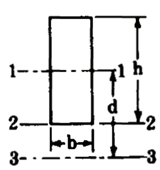
$A = b^2$



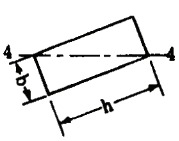
$A = b^2 - b_1^2$



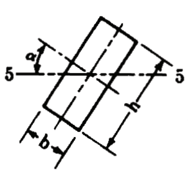
$A = b^2 - b_1^2$



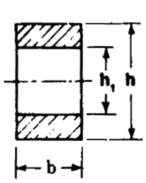
$A = bh$



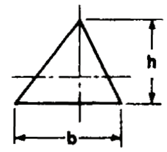
$A = bh$



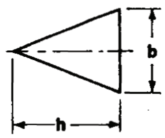
$A = bh$



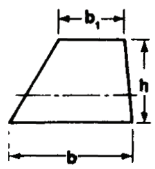
$A = b(h - h_1)$



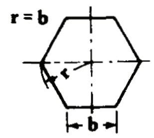
$A = .5bh$



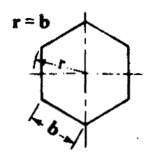
$A = .5bh$



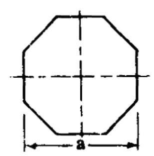
$A = .5h(b + b_1)$



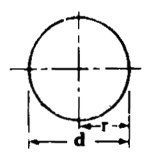
$A = 2.598b^2$



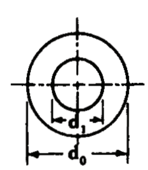
$A = 2.598b^2$



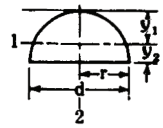
$A = .8284a^2$



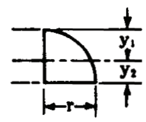
$A = 3.1416r^2$



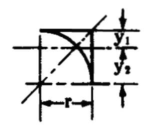
$A = .7854(d_0^2 - d_1^2)$



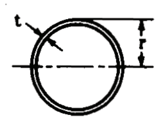
$A = 1.5708r^2$



$A = .7854r^2$



$A = .2146r^2$

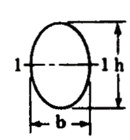


$A = 6.283rt$

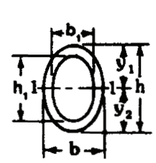
$A = 3.1416rt$

$A = 1.5708(r^2 - r_1^2)$

$A = .7854(r^2 - r_1^2)$



$A = .7854bh$

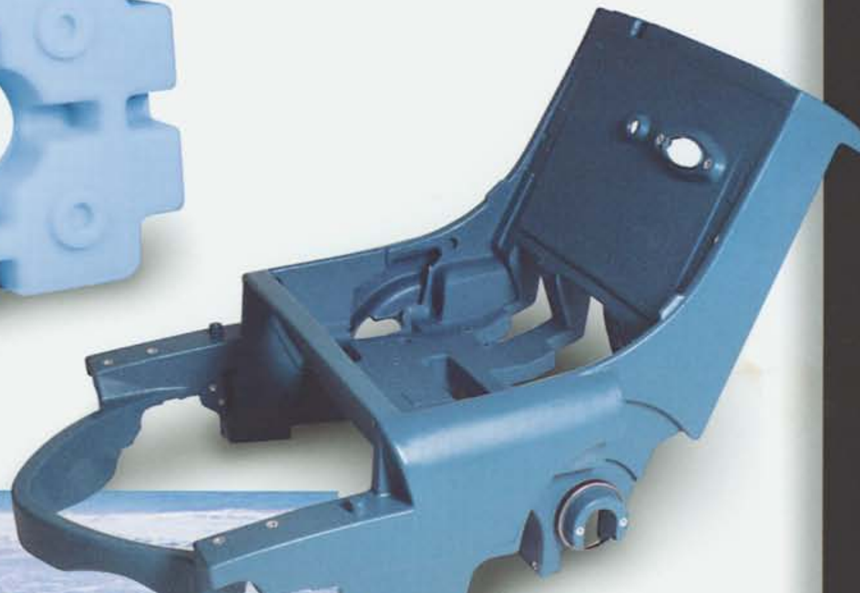


$A = .7854(bh - b_1h_1)$

Surface Area of a Sphere = $4 \pi r^2$

Volume of a Sphere = $^4/_3 \pi r^3$

Automotive fluid recycling tank



Floor sweeper frame

Vehicle crash bars

Water filtration unit

Inflatable oxygen mask seal

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