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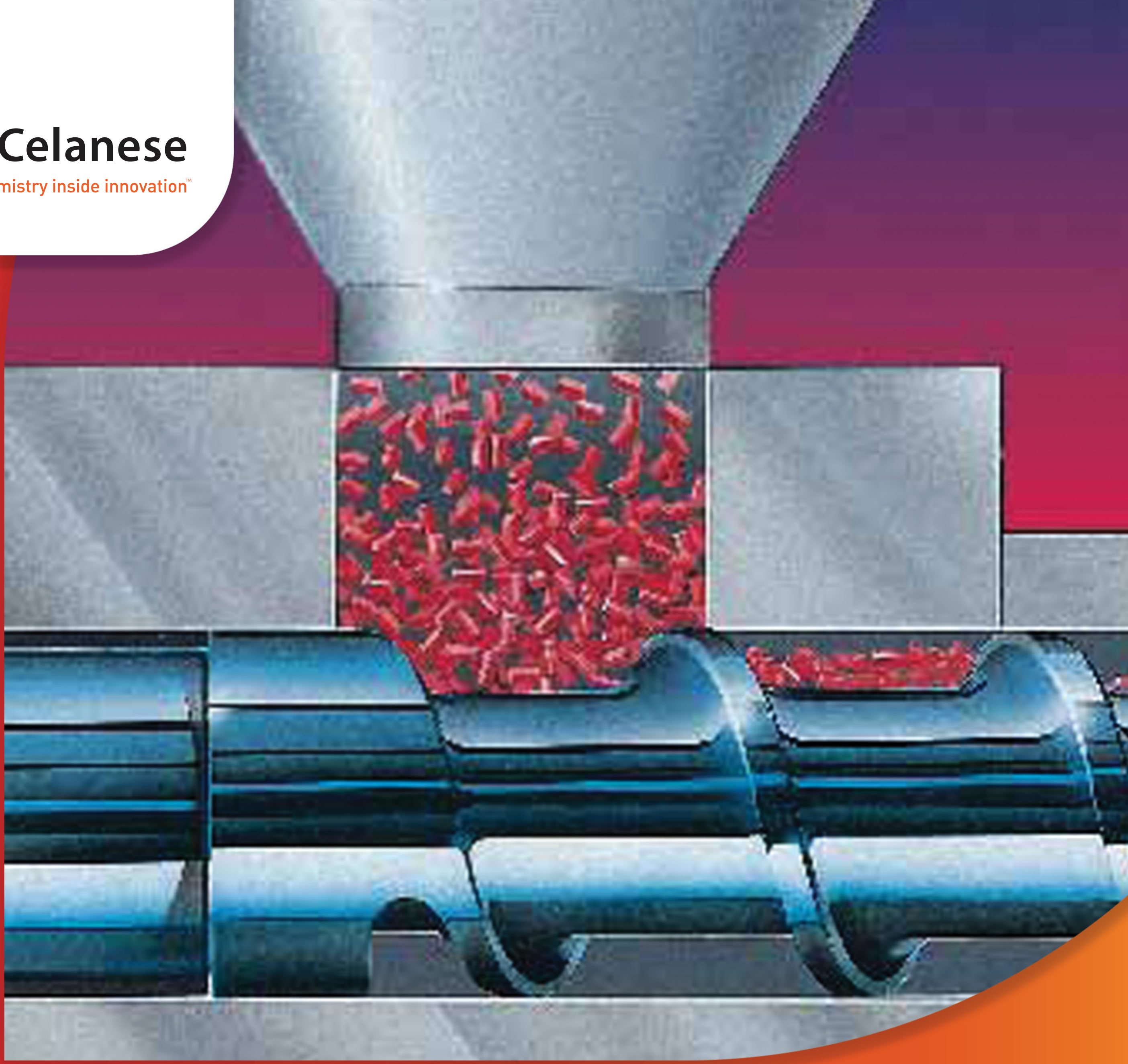

# Processing Celcon®

Acetal Copolymer

# Processing and Troubleshooting Guide

## Foreword

The Celcon® Acetal Copolymer Processing and Troubleshooting guide is written for plastics processors who require specific information on start-up, processing techniques and troubleshooting using this versatile group of products. Material handling techniques, resin drying conditions and health and safety issues are also included.

Chapters 1 and 2 cover an introduction to Celcon acetal copolymer grades and physical characteristics, regulatory and flammability listings, startup and shutdown procedures, and the safety and health aspects pertaining to handling Celcon acetal copolymer. This information is pertinent to all processing methods. **Please read these two chapters before attempting to process any grade of Celcon acetal.**

Chapter 3 is devoted to the important topic of molded part dimensional stability, including part shrinkage, annealing, dimensional tolerances and the effect of moisture absorption on part dimensions. Each of the final four chapters of the manual describes a specific processing technique: injection molding, extrusion, blow molding and rotational casting, and includes a troubleshooting section. Information on machine settings, mold design, and (where appropriate) screw design is also included.

For more information on material characteristics and part and mold design, consult the following manuals: **Celcon Acetal Copolymer Short Term Properties (CE-4), Designing with Plastic: The Fundamentals (TDM-1) and Designing with Celcon Acetal Copolymer (CE-10).** They are available by contacting your local Celanese sales representative, or by calling our Technical Information Hotline at 1-800-833-4882.

Comments and suggestions for improving this and other Celanese literature are always welcome, and may be sent to us at the above phone number, or by writing to us at the address shown on the back cover.

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# Overview

## Chemistry of Acetal Polymers

Acetal polymers are chemically known as polyoxymethylenes (POM). Two types of acetal polymers are commercially available:

Homopolymer is prepared by polymerizing anhydrous formaldehyde to form a polymer composed of oxymethylene repeating units ($-CH_2O-$). Acetal homopolymer products have somewhat better short term mechanical properties than the copolymer.

Copolymers, including Celcon® acetal copolymer, are prepared by copolymerizing trioxane (cyclic trimer of formaldehyde) with a cyclic ether (usually containing an ethoxy or other oxyalkylene group) to form a polymeric chain composed of oxymethylene ($-CH_2O-$) and oxyethylene (-CH2-CH2-O-) or similar repeating units. Copolymers have a wider processing window, better long term mechanical properties and superior chemical resistance compared to homopolymers, and are inherently more stable and resistant to thermal degradation during service life. This is because the repeating copolymer units block polymer "unzipping" under thermal stress, or exposure to hot water or hot alkaline solutions.

Both the homopolymer and copolymer are end-capped, and also contain specific additives to prevent irreversible thermo-oxidative depolymerization of the polymer backbone during processing.

## General Characteristics

Celcon acetal copolymer is a high strength, crystalline engineering thermoplastic material having an unusual and desirable balance of properties. It is an ideal candidate to replace metals and thermosets because of its predictable long-term performance over a wide range of in-service temperatures and harsh environments. Celcon acetal retains properties such as high strength, creep resistance, fatigue endurance, wear resistance and solvent resistance under very demanding service conditions.

Celcon acetal can be easily converted from pellet form into parts of different shapes using a variety of processes such as injection molding, blow molding, extrusion, rotational casting and compression molding. Rod, slab and sheet stock which can be readily machined into desired shapes are also available.

## Product Types

Both standard and special grades of Celcon acetal copolymer are designed to provide a wide range of properties to meet specific applications. Standard and custom grades of Celcon acetal copolymer can be obtained in pre-compounded color form or color concentrates which may be blended with other grades. All colorants used in Celcon resins are lead and cadmiumfree, and all Celcon acetal products conform to current environmental (OSHA) regulations for these metals. Consult our brochure: "Celcon Acetal Copolymer Short Term Properties" (CE-4) for information on specific grades. The most common categories of Celcon resins are described below.

### *Unfilled*

General pupose M-series products are identified by melt flow rate. Divide the grade number by 10 to obtain the melt flow rate. For example, Celcon® M90™ has a melt flow rate of 9.0 (grams per 10 minutes, per ASTM D 1238, @ 190°C and 2.16 Kg. load). Products designated by a higher melt flow rate fill thinner walls and complex shapes more readily, maintain the same strength and stiffness, but exhibit a slight decrease in toughness. Products with lower melt flow rates, i.e. Celcon M25 exhibit increased toughness compared to Celcon M90.

### *Glass Fiber Coupled*

Glass fiber coupled products provide higher strength, stiffness and creep resistance than the unfilled grades. These products are identified with a number indicating the percentage of short glass fiber in the product and are based on general purpose Celcon polymers. The glass fibers are chemically coupled to the polymer matrix.

### Glass Bead Filled
These grades contain glass beads for low shrinkage, better dimensional tolerances and warp resistance, especially helpful when molding large, flat and thinwalled parts.

### Low Wear
Low wear grades are chemically modified to provide low coefficient of friction and enhanced wear resistance, and are exceptional for demanding applications requiring good sliding properties, reduced gear and bearing noise and enhanced lubricity.

### Mineral Coupled
These products contain chemically coupled mineral fillers in varying percentages. The mineral filled grades are recommended whenever resistance to warpage (especially in thin sections) and dimensional stability are key application parameters. They are generally tougher than the glass bead filled polymers but are more difficult to color uniformly.

### Ultraviolet Resistant
Various melt flow rate grades are available in natural and a wide variety of colors and are lead and cadmium-free. They are specially formulated for improved resistance to color shift and mechanical degradation from ultraviolet light (both sunlight and fluorescent lighting). Consult the HTP brochure, "Celcon Ultraviolet-Resistant Grades Extend Part Life in Harsh Environments" (CE-UV) for further information about these products.

### Weather Resistant
Weather resistant products are formulated for maximum outdoor weathering resistance. Several different melt flow rate grades are offered. They are available in black color only.

### Antistatic
These products are chemically modified to decrease static build-up for applications such as conveyer belt links and audio and video cassette hubs and rollers.

### Electrically Conductive
These grades are used for applications requiring low electrical resistance and/or rapid dissipation of static build-up. Some electrically conductive grades contain carbon fibers and exhibit high strength and stiffness.

### Impact Modified
These products are formulated to provide moderate to high levels of improvement in impact strength and greater flexibility compared to the standard product.

### Laser Markable
Two new grades of Celcon acetal copolymer have been developed with enhanced capability for laser printing. These black products produce produce extremely robust white markings for applications such as bar codes, graphic or alphanumeric characters, and 2-D symbology. One of the grades has good ultraviolet light stability. Both grades have excellent toughness and dimensional stability for many applications including automotive parts.

## Regulatory Codes and Agency Listings
Many grades of Celcon® acetal are in compliance with, or approved under a variety of agency specifications and regulatory standards as shown in Table 1.1. Not all grades are covered by all regulatory listings. Call Product Information Services at 1-800-833-4882 for further information on which grades are approved under the various regulations.

## Product Support
In addition to our technical publications, experienced design and application development engineers are a vailable for assistance with part design, moldflow characterization, materials selection, specifications and molding trials. Call your local Celanese Polymers sales representative, or Product Information Services at 1-800-833-4882 for further help.

**Table 1.1 Regulatory Listings**

| Plastic | Scope |
|---|---|
| Plumbing Code Bodies:<br>International Association of Plumbing<br>Mechanical Officials (IAPMO)<br>Building Officials Conference of America (BOCA)<br>Southern Standard Building Code | Plumbing fixtures and specific plumbing and mechanical applications covered in the various codes |
| Canada Standards Association<br>"UL" ratings in Canada | Plumbing fixtures, fittings and potable water contact items, |
| Plastic Pipe Institute (PPI)<br><br>plumbing fitting | Recommended Hydrostatic Design Stress (RHDS) rating of 1,000 psi at 23°C (73°F) as an injection molded |
| Food and Drug Administration (FDA) | Repeated-use food contact applications including food machinery components conforming to 21 CFR 177.2470 |
| United States Pharmacopeia (USP) | Class VI Compliant |
| NFS International<br>Standards 14, 15, 61 | Items including plumbing components, beverage dispensers, etc., for contact with potable water |
| Underwriters Laboratories (UL) | Various UL ratings for flammability, electrical and thermal service use |
| Dairy and Food Industries Supply Association (DFISA) | Sanitary Standards 3A |
| United States Department of Agriculture (USDA) | Approved for direct contact use with meat and poultry products |
| ASTM D 4181 [Supersedes ASTM D2133,<br>Military Specification LP-392-A, Mil-P-6137A(MR)] | General Material Specification |
| SAE J2274 | Automobile Global Specifications |

# General Guidelines

## Storage and Handling

Celcon® acetal copolymer should be stored in its original container on pallets in a dry place. Open containers should be carefully resealed before returning to storage. In the winter, containers of resin should be brought into the warm processing area at least 24 hours prior to use and allowed to come to room temperature before opening. If this is not done, moisture in the air may condense on the surface of the pellets and lead to surface efects on molded or extruded plastic parts.

The use of a hopper magnet in the feedstream is highly recommended to insure aaainst any form of metallic contamination, which could occur while transporting the resin and cause equipment damage.

Every effort should be made to avoid pellet spills or loss. Spilled pellets can be very slippery and may result in employee accidents. Pellet loss to the environment could lead to fines or other penalties under Storm Water Regulations issued by the Environmental Protection Agency.

Celanese Polymers supports the Society of the Plastics Industry Operation "Clean Sweep" program.

## Safety and Health Information

The usual precautions must be observed as when processing any hot and molten thermoplastic.

**Caution: Normal processing temperatures and residence times should not be exceeded. Celcon acetal should never be heated above 238° C (460° F) nor be allowed to remain above 193° C (380° F) for more than 15 minutes without purging. Excessively high temperature or long residence time in a heated chamber can cause the resin to discolor and, in time, degrade to release formaldehyde, a colorless and irritating gas. This gas can be harmful in high concentrations, so proper ventilation is essential. If venting is inadequate, high pressures could develop in the equipment which may lead to blow back through the feed area. If no exit is available for these gases, the equipment may rupture and endanger personnel.**

Consult the current Celcon acetal Material Safety Data Sheets (MSDS) for health and safety data for specific grades of Celcon acetal prior to processing or otherwise handling these products. Copies are available by calling your local Celanese sales office or Customer Services at 1-800-526-4960.

## Flammability

When ignited, Celcon acetal copolymer burns with little or no smoke, and with a barely visible blue flame. Combustion products are carbon dioxide and water. If Celcon acetal copolymer burns with a muffled flame and combustion is incomplete, carbon monoxide and some formaldehyde may be released. Exposure to high concentrations, especially in a poorly ventilated area, can be harmful. For more detailed information on worker exposure limits for formaldehyde refer to the Material Safety Data Sheet for Celcon acetal copolymer.

### *Warning - Avoid PVC*

*Celcon® acetal copolymer and polyvinyl chloride (PVC) can chemically react and must never be allowed to mix, even in trace quant ties in the melt. When heated, PVC forms acidic decomposition products which can rapidly degrade Celcon acetal at processing temperatures. If possible, Celcon acetal and PVC should not be processed in the same equipment. If this is unavoidable, thorough purging with an acrylic or polyethylene resin is essential prior to introduction of the second material.*

*It is recommended that in cases of known or suspected contamination, the polymer processing components of the molding machine, including the barrel, screw, check ring, screw tip and nozzle, should be dismantled and thoroughly cleaned, in place of the purging process described above.*

## Drying

Celcon® acetal does not readily absorb moisture and can normally be fed to the extruder or molding machine without drying. However, if the material has adsorbed moisture due to improper handling or storage, drying may be necessary to prevent splay and odor problems during processing. It is good practice, and preferable for processing consistency, to dry the resin before processing to avoid potential production problems due to moisture.

Celcon acetal copolymer should be dried in a dehumidifying oven or a hopper dryer. For oven drying, the Celcon pellets should be spread evenly in less than one-inch deep layers on trays and placed in the oven for three to four hours at 82°C (180° F).

## Processing Start Up

To start up a machine which was shut down with Celcon acetal in the cylinder, it is most important to make sure the nozzle is not blocked. This is one of the main reasons a nozzle heater band is recommended.

- Set the nozzle temperature at 204 - 216°C (400 - 420°F).
- Set the cylinder temperature at 121 - 135°C (250 - 275°F).
- As soon as drooling at the nozzle is observed, raise the cylinder temperature to 188 - 199°C (370 - 390°F). Do not allow the cylinder temperature to exceed 160°C (320°F) until the nozzle temperature is at least 204°C (400°F) and drooling is observed.
- Clear the nozzle by making a few purge shots at reduced injection pressure and speed with no booster.
- Adjust the machine settings to production conditions.

### To start up a machine which is empty:

- Set the nozzle temperature at 204 - 216°C (400 - 420°F).
- Set the cylinder temperature at 188 - 199°C (370 - 390°F)
- Use low pressure (5,000 - 10,000 psi) and slow injection speed. Make a few air shots to to flush the barrel and nozzle and ensure there is no contamination.
- Adjust the machine settings to production conditions.

In all cases, once Celcon acetal is introduced into the cylinder it should be kept moving to prevent overheating. If a delay of over 15 minutes is anticipated, the cylinder should be retracted and the machine purged every few minutes. If a much longer delay is expected, it is recommended that the machine be shut down following the procedure outlined under "Shut Down," page 2-3 of this publication.

## Changing from Another Resin to Celcon Acetal

If the other resin in the processing equipment requires a higher melt temperature than Celcon acetal (e.g. nylon, polycarbonate, etc.) or is a resin such as PVC (see note p. 2-1) which can chemically react with Celcon and cause degradation, the cylinder must first be thoroughly purged clean of these resins.

High density polyethylene or polystyrene is suitable for purging and should be put in the machine directly behind the resin already in the cylinder and kept at the same temperature settings. After all traces of the other resin are removed, the temperature should be set at 188-199°C (370-390°F). After the temperature has stabilized, Celcon acetal can then be placed in the machine to remove the purge compound. The machine settings can be adjusted to the desired production conditions.

## Changing from Celcon® Acetal Copolymer to Another Resin

In changing from Celcon acetal to another resin, similar considerations as described earlier will apply. When the machine is started up with Celcon acetal in the cylinder, the proper procedure outlined in "Start Up" must be followed before changing over to another resin. If the new resin requires a higher or lower temperature or is one that can chemically react with Celcon acetal (such as PVC), an intermediate purging compound such as polyethylene or polystyrene must first be used to thoroughly clean the machine. The new material should be introduced to the machine only after proper cleaning and adjustment to the appropriate processing conditions.

## Processing Shut Down

To shut down a machine with Celcon® acetal, the same precautions must be taken against blockage of the nozzle as when starting up the machine. The nozzle should be the last part of the heating cylinder assembly to cool. Leave the screw in the forward position.

- Set the nozzle temperature at 204 - 21°C (400 - 420°F)
- Turn off the cylinder heaters.
- Shut off the feed to the cylinder.
- Purge and run the barrel dry.
- Shut off the power to the machine.

If the characteristics of the machine or the use of a restricted nozzle cause the resin flow to stop before the cylinder temperature drops to 177°C (350°F), the cylinder temperature should be returned to the normal processing range and the machine shut down with polyethylene or other purge material.

## Regrind

Celcon acetal can be reprocessed a number of times without significant change in physical properties or processing characteristics. Tables 2.1 and 2.2 show the effect of remolding unreinforced and fiberglass reinforced Celcon acetal copolymer. When remolding glass fiber reinforced Celcon acetal, some loss in mechanical properties may be seen, due to breakage of some of the glass fiber reinforcement.

Knife-type grinders with a 5/16 in. (8mm) screen are recommended for grinding resin sprues, runners and off-test pieces. As with other thermoplastics, regrinding may produce enough dust to cause discomfort to the operator. In addition, acetal copolymer dust can present an explosion hazard. Normal safety precautions such as the use of a dust mask and adequate ventilation are highly recommended. Dust can be minimized by keeping knife blades sharp, and using using proper clearances and screen size.

Surface adsorbtion of water on regrind tends to be slightly higher than for pellets because of the larger surface area. As a result, it is essential that regrind be properly dried before use to avoid any moisture related production problems.

To insure maximum retention of mechanical properties, regrind usage should be limited to no greater than 25% for most applications. Special care should be taken to prevent contamination by other resins, especially PVC. For any processing technique, it is particularly important to also avoid dirt and other impurities which can create surface blemishesor plug flow paths. Because of the possibility of contaminating regrind with metal (such as from the regrinder knife blade), the use of a hopper magnet in the feedstream is strongly recommended.

## Secondary Operations

### *Finishing*

Celcon acetal can be readily machined, drilled, punched, buffed, sawed, sanded and routered by methods commonly used on soft metals such as brass and aluminum. It is a good idea to direct a jet of cool, compressed air on the machined area to prevent overheating and sticking of the shavings to the molded part. High tool speed and slow feed is recommended. Avoid excessive spees and pressures. Standard metal working tools are satisfactory for machining Celcon acetal.

### *Surface Treatment*

Celcon parts can be surface treated by laser marking, printing, labeling and hot stamping.

Black, laser markable grades are available which can also possess good ultraviolet light stability if required, suchas for many automotive applications. These products produce extremely robust white markings for applications such as bar codes, graphic or alphanumeric characters, and 2-D symbology.

**Table 2.1 Effect of Remolding on the Properties of Unreinforced Celcon® Acetal**

| Property | 1st Molding | 5th Molding | 11th Molding |
|---|---|---|---|
| Tensile yield strength, MPa | | | |
| Value | 59.3 | 59.6 | 57.2 |
| Per Cent retention | — | 101 | 97 |
| Notched Izod impact strength @ 23°C (73°F), J/m | | | |
| Value | 62.5 | 66.8 | 68.3 |
| Per Cent retention | — | 107 | 109 |

**Table 2.2 Effect of Remolding on the Properties of Fiberglass Reinforced Celcon® Acetal**

| Property | 1st Molding | 3rd Molding | 5th Molding |
|---|---|---|---|
| Tensile yield strength, MPa | | | |
| Value | 110 | 92.5 | 85.6 |
| Per Cent retention | — | 81.7 | 75.6 |
| Tensile modulus, MPa | | | |
| Value | 8,280 | 7,660 | 6,970 |
| Per Cent retention | — | 92.6 | 84.2 |
| Flexural modulus, MPa | | | |
| Value | 7,250 | 6,830 | 6,350 |
| Per Cent retention | — | 94.1 | 87.6 |

Printing by conventional silk screen dry-offset, direct techniques, etc., require special inks for satisfactory adhesion. Conventional surface adherent inks are available in addition to special ones which penetrate the material and offer outstanding abrasion resistance. Printing inks usually require a high temperature bake for best adhesion.

Transfer labels exhibit moderate to good adhesion to Celcon acetal. As many as four colors can be applied using this method. Decoration with transfer labels is usually less costly than silk screening for multiple color decoration, and when a very large number (millions) of parts are involved.

Paper labels, the lowest cost decorating method, are available in many standard types including some with heat or pressure sensitive adhesives which give unusually good bonding to Celcon acetal surfaces.

Hot stamping can be used as long as recommended procedures and foil laminates are used to obtain satisfactory adhesion.

***For additional details on Secondary Operations, consult Chapter 12, "Machining and Surface Operations" of Designing with Celcon Acetal Copolymer (CE-10), or call Product Information Services at 1-800-833-4882.***

# Dimensional Stability

When manufacturing parts from Celcon® acetal, it is important to understand the factors which may cause dimensional changes. The dimensional effects of shrinkage (both in -mold and post-molding), annealing and moisture absorption are discussed in this chapter.

## Shrinkage Caused by Processing (Injection Molding)

Many factors influence mold shrinkage. They include thermal properties of the resin, filler type and level, part design (especially wall thickness), gate size, and resin flow direction. Molding conditions, including melt and mold temperature, injection speed and pressure are particularly important. Variations in mold surface temperature and mold injection pressure, for example, can cause shrinkage in test bars made from one specific grade (Celcon® M90™ ) ranging from 1.8 to 5.0%. As a result, it is difficult to predict the exact mold shrinkage of a specific part.

Typical effects of processing conditions on part shrinkage are summarized in Table 3.1:

**Table 3.1 Effect of Processing Conditions on Part Shrinkage**

| Molding | Effect on Part Shrinkage |
|---|---|
| Wall thickness increases | Increases |
| Gate size increases | Decreases |
| Pressure increases | Decreases |
| Mold Temperature increases | Increases |
| Melt Temperature increases | Decreases (for parts 3.1mm thick or less)<br>No effect (for parts 3.2 - 9.5 mm thick) |
| Resn melt viscosity increases | Increases with increasing viscosity when molded under similar processing conditions; i.e. Celcon M450 has lower shrinkage than Celcon M25 |

Shrinkage of standard unfilled Celcon acetal products measured on laboratory test specimens cover a range from 1.2 - 2.4%. Mold shrinkage for an actual part has been observed as high as 3.7%. Consult the **Celcon Short Term Properties Brochure (CE-4)** for typical values of specific Celcon grades. This information should be used only as a guide in estimating shrinkage for tool construction. Additional guidance is provided in Figure 3.1 which shows the effects of molding conditions and wall thickness on mold shrinkage, and Chapter 4 of this manual which details mold design for injection molding.

Of the process variables, injection hold (or packing) pressure and time, injection speed and mold temperature are the most significant, and about equal in importance in controlling mold shrinkage. Material temperature is also significant, but to a lesser degree.

Of the part and mold variables, wall thickness has the most significant effect on part shrinkage followed by gate size. Gate location is of lesser importance, but still significant, and is highly dependent on part geometry. Parts which are relatively long and narrow and gated at the narrow end will have material flow predominantly in one direction. This will result in anisotropic shrinkage. For unreinforced Celcon acetal, there will be less shrinkage in the width (transverse) than in the length (flow) direction. For reinforced Celcon acetal, the opposite will occur. Shrinkage will be less in the length direction than in the width direction.

The reason for this is the reinforcing glass fibers align themselves in the direction of the material flow and, when the part cools and the material solidifies, the fibers inhibit shrinkage in this direction. Anisotropic shrinkage increases with increasing wall thickness and, in thick parts, with increasing gate size.

The precise shrinkage for a given part may be obtained by initially designing the mold cavities with oversized cores and undersized cavities. Following this, parts should be molded at equilibrium molding conditions,

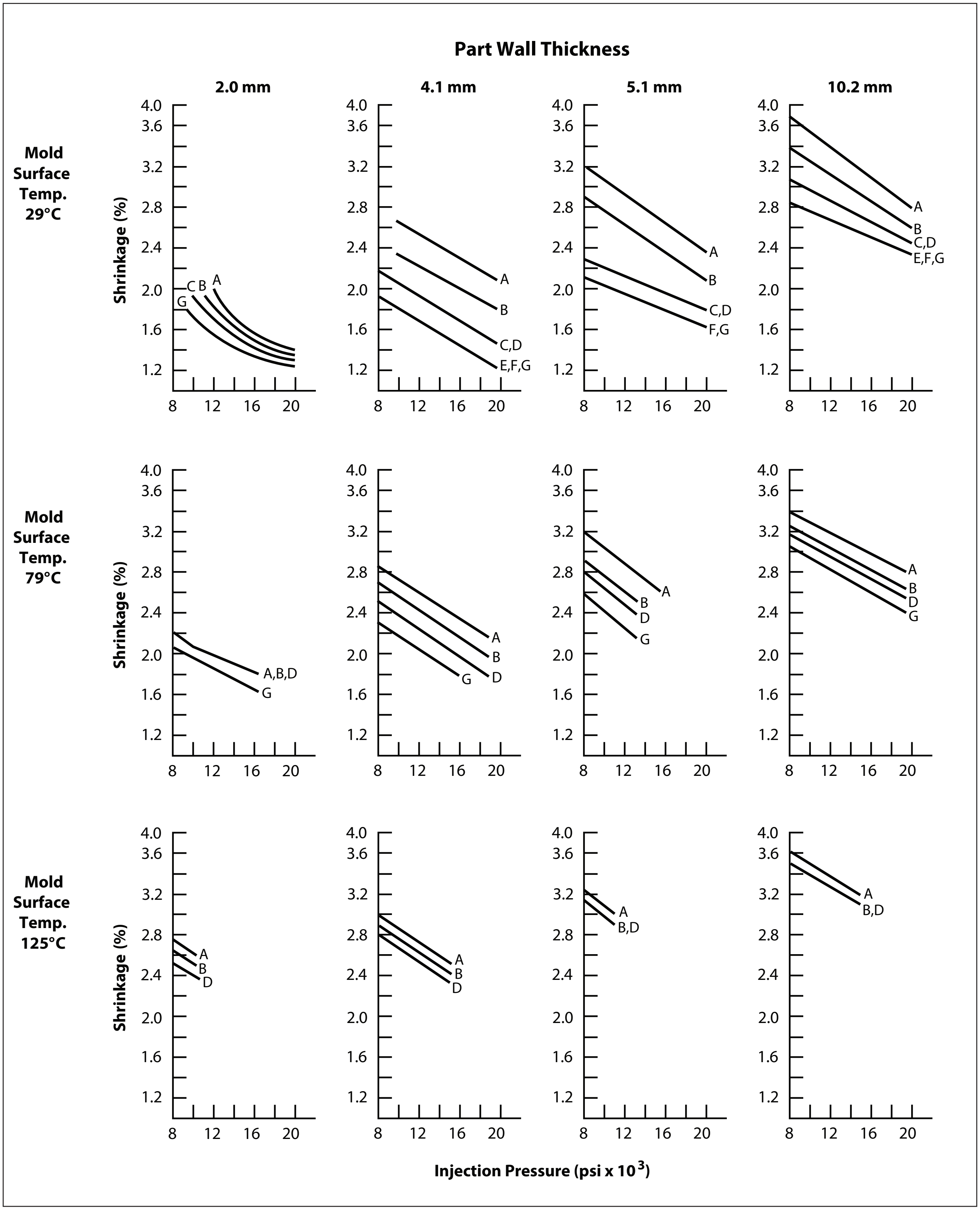


**Figure 3.1 The effect of molding conditions and wall thickness on mold shrinkage for Celcon® M90™ Acetal**

which provide the best overall results for mold cycle time and part quality for production. Parts should then be conditioned at room temperature for at least 24 (and preferably 48) hours. Dimensions of critical areas can then be measured and the cavity and core machined, if necessary, to bring the molded parts within dimensional tolerances.

## Warpage

Wall thickness should be as uniform as possible. Differences in cooling rates of thick and thin sections is a key contributor to warping. Other factors affecting warpage are:

- Gate size
- Gate location
- Mold temperature
- Filler type/level
- Orientation of fillers

## Post-Molding Shrinkage

Post-molding shrinkage is usually related to stress relaxation of the molded part, resulting in a permanent shrinkage of the part. At ambient temperatures this shrinkage is relatively small, on the order of 0.1 - 0.2% for a standard unfilled 9.0 meltflow grade of Celcon® acetal. However, continuous exposure of the molded part to high temperatures accelerates both the rate and magnitude of shrinkage due to stress relaxation. Figure 3.2 illustrates the shrinkage behavior of the standard unfilled 9.0 melt flow grade of Celcon acetal after six months exposure to various temperatures (3.2 mm thickness; flow direction).

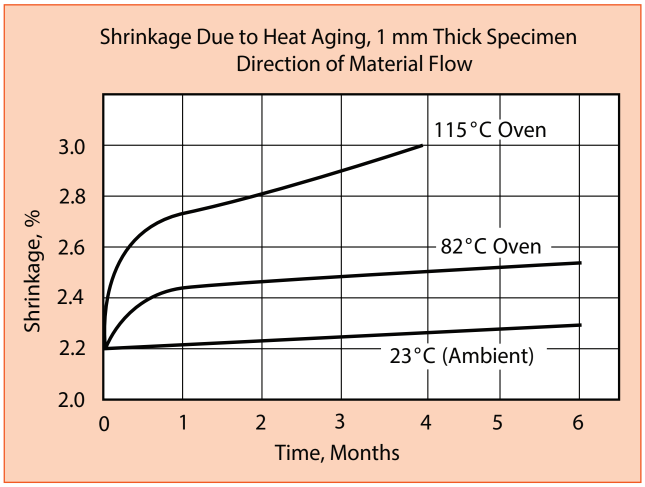


**Figure 3.2 Shrinkage due to Heat Aging for 9.0 Standard Melt Flow grade of Celcon® acetal**

## Annealing

Table 3.2 shows examples of the shrinkage resulting from annealing two different thicknesses of an unfilled Celcon acetal resin. Annealing molded parts will lead to dimensional changes so that allowances must be made for any additional shrinkage. The decision to anneal parts of Celcon acetal should therefore be made during the planning stage and definitely prior to machining the mold cavity and core to size.

**Table 3.2 Shrinkage Before and After Annealing**

| Part Thickness, mm (in.) | Annealed @ 152°C (305°F) | Flow Direction, % | Transverse Direction, % |
|---|---|---|---|
| 3.18 (0.125) | No | 2.2 | 1.8 |
| 3.18 (0.125) | Yes | 2.7 | 2.0 |
| 12.7 (0.500) | No | 2.6 | 2.0 |
| 12.7 (0.500) | Yes | 3.0 | 2.0 |

## When Annealing is Necessary

In many cases, properly molded parts will exhibit satisfactory dimensional stability, especially at continuous service temperatures of 82°C (180°F) or below. A high, typically 80 -120°C (175 - 250° F) mold temperature will optimize the dimensional stability of an as-molded part for service temperatures up to 82°C (180°F), with an occasional excursion up to 105°C (220°F).

In some cases, however, because of in-service temperatures, annealing may be required, especially where dimensional stability is of critical importance. Some general guidelines for annealing are given in Table 3.3.

Circulating air ovens and oil baths capable of providing a uniform temperature of 152 ± 2°C (305 ± 5°F) are recommended for annealing Celcon acetal. While equipment offering lower annealing temperatures may be suitable for some applications, it is not preferred because the annealing time to obtain best results can be expected to increase significantly with decreasing temperature. This situation may be impractical for production purposes.

## Tolerances

Dimensional tolerance can be defined as a variation above and below a nominal mean dimension.

**Table 3.3 Recommended Annealing Procedure**

| Required Service Temperature | Recommendation |
|---|---|
| In-service temperature of 82°C (180°F) or below | Generally, properly molded parts will not require annealing |
| In-service temperature higher than 82°C (180°F) | Annealing may be necessary to improve the dimensional stability of the molded part |
| **Annealing Parameters** | **Recommendation** |
| Time<br>thickness if using an annealing liquid; longer if annealing<br>Temperature | As a general rule, anneal for 15 minutes for each 3.1 mm (1/8 in.) of wall<br>in an air oven<br>152°C ± 2°C (305°F ± 5°F) |
| Medium | Any refined or silicone oil which is not acidic. Oil is preferred over air because it is a better conductor of heat and provides a blanket to minimize or prevent oxidation |
| Cooling | Cool annealed parts slowly (one hour for every 3.18 mm of wall thickness). |

If recommendations for part/mold design and proper molding are followed, typical tolerances expected are:

- ± 0.3% for the first inch or fraction of the first inch
- ± 0.2% for each subsequent inch

In cases where tighter tolerances are required, precision tooling as well as molding by using control feedback loops on molding equipment, and using a minimum number of tooling cavities will help to achieve this objective.

Careful consideration should be given to the need for very tight tolerance to avoid excessive mold and processing costs. Also, it may be unreasonable to expect to specify extremely close tolerances on a part which will be exposed to a wide temper-ature range.

## Moisture Absorption

Some dimensional change is seen when Celcon® acetal is exposed to moist environments. The changes are usually lower than those observed for other engineering thermoplastics. Figures 3.3 and 3.4 show that after one year of continuous exposure to high humidity arbitrary at various water temperatures, dimensional changes are minimal. See page 5.5 of the Celcon Design Manual for additional data on the effects of water on material properties.

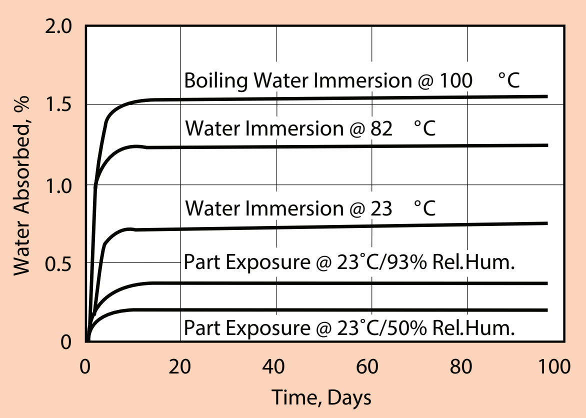


**Figure 3.3 Water absorption by unfilled Celcon acetal under various conditions**

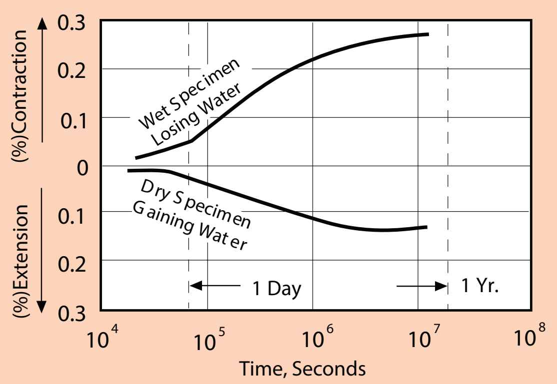


**Figure 3.4 Change in Linear Dimensions at 23°C (73°F) and 50% Relative Humidity**

# Injection Molding

## Equipment

Injection molding is the most widely used method for processing acetals. Celcon® acetal can be successfully processed in all types of commercially available injection molding machines designed for thermoplastics. These may be single or two stage, reciprocating and stationary screw injection types. Screw injection provides fast plastication and a homogeneous melt which will permit molding parts at reduced melt temperatures and pressures, as well as decreased cycle time. Ram machines may also be used for some molding jobs.

A single stage reciprocating screw injection molding machine is most commonly used with Celcon acetal.

### *Barrel and Screw*

While the standard metering screw available in commercial reciprocating-screw injection molding machines can be used, it is not totally satisfactory. Problems such as excessive oxidative deterioration, poor thermal homogeneity, unmelted resin pellets and lower productivity rates can sometimes occur.

A screw such as the one shown in Figure 4.1 having the following characteristics is reccomended for optimum results:

- The L/D (length-to-diameter) ratio should preferably be no less than 16/1 and no greater than 24/1.
- The flight clearance should be approximately 0.13 mm (0.005 in.).
- The flight width should be approximately 10% of the screw diameter.
- For unfilled Celcon resins, the screw should be hard faced or coated with a corrosion resistant material such as chrome or Stellite 6.
- For filled reinforced Celcon resins, the screw and barrel should be hard faced or coated with a corrosion and abrasion resistant material such as tungsten carbide, CPM-9V or Colmonoy 56 for screws (CPM-10V, Bimex, or Xaloy 101 or 306 for barrels).
- The screw should be fitted with a non-return valve to prevent back flow of resin in the screw channel as the resin is injected into the mold. The valve should have large clearances and well-radiused corners when open to ensure that the melt flows freely, is not "hung-up" and is not overheated.
- The channel depth ratio, i.e., the ratio of the channel depth in the feed zone to that in the metering zone, (h1 /h2), should be between 3 and 4.5. A channel depth ratio of 4:1 is recommended for optimum results.
- The feed section should occupy about 40% of the screw length, the transition zone about 30% and the metering section about 30%.

Typical screw dimensions for injection molding screws are given in Table 4.1.

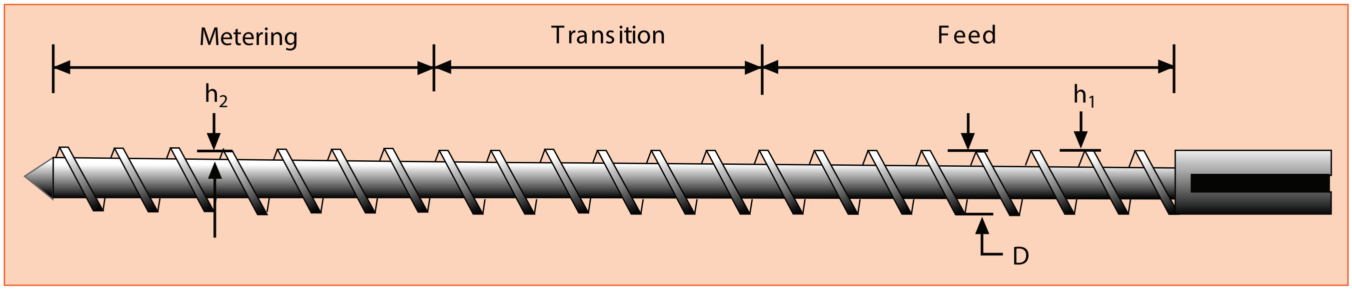


**Figure 4.1 Typical screw for injection molding Celcon® Acetal**

**Table 4.1 Typical Screw Dimensions for Plasticizing Celcon Acetal**

| Screw Diameter (in.) | Channel Depth | | | Zone Length as % of screw length | | |
|---|---|---|---|---|---|---|
| | Metering (in.) | Feed (in.) | Ratio | Feed | Transition | Metering |
| 1 1/2 | 0.083 | 0.29 | 3.5 | 40-50 | 30-20 | 30 |
| 2 | 0.089 | 0.30 | 3.4 | 40 | 30 | 30 |
| 2 1/2 | 0.097 | 0.32 | 3.3 | 40 | 30 | 30 |
| 3 1/2 | 0.108 | 0.35 | 3.2 | 40 | 30 | 30 |
| 4 1/2 | 0.119 | 0.38 | 3.2 | 40 | 30 | 30 |

A diagram of a recommended check valve is shown in Figure 4.2 and indicates the need for flats to be machined at the mating joints B and C. The flutes in the screw tip, A, and the flow path through the check ring, D, should be generously proportioned to ensure minimum flow restriction and well radiused. The mating surfaces between the screw tip and the check ring seal, E, and the check ring seal and the screw, F, should be cylindrical and machined flush to ensure no projections into the flow. All surfaces contacting the flow should have a surface finish better than 16 r.m.s. and all flow channels should be free from sharp turns.

Although standard unopened containers of Celcon® acetal usually do not have to be dried, a vented barrel machine with a two stage extraction screw may be used if the level of moisture encountered during molding is high enough to warrant removal. When improved melting is required to reduce the cycle time, a barrier flight may be introduced in the first stage. The barrier flight clearance should be 1.02 - 1.52 mm (0.040 - 0.060 in.)

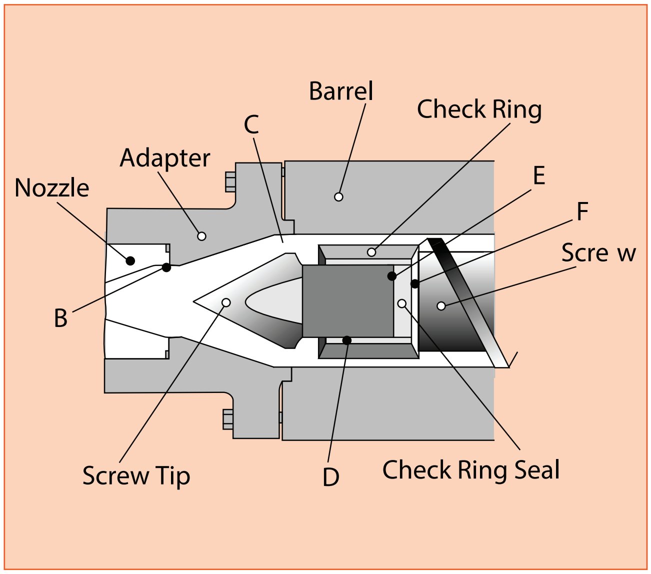


**Figure 4.2 Dimensional change due to water absorption by unfilled Celcon acetal.**

### *Nozzles*

Conventional free flow and reverse taper nylon-type nozzles fitted with a heater band for temperature control of the nozzle are recommended for Celcon acetal copolymer.

**Caution: Nozzle designs with positive shut-off devices are not recommended for safety reasons, although with proper precautions they have been successfully used. Formaldehyde gas may be released from Celcon acetal in the molding process, particularly if left at elevated temperature in the heated barrel for an extended period. This gas must be free to escape through the nozzle. If the nozzle is blocked for any reason such as by malfunction of the positive shut-off device or resin freeze-off in the nozzle, sufficient pressure could develop to cause blow-back of the resin through the feed zone and hopper or create other hazardous conditions.**

A nozzle heating band with independent temperature control is recommended for fine tuning nozzle temperature to prevent nozzle drool or freeze-off of resin in this area. While a powerstat (rheostat) can be satisfactorily used for temperature control, indicating-type temperature controllers are preferred.

### *Plasticizing Capacity*

As with other engineering plastics, Celcon acetal should not be exposed to excessive temperatures or very long residence times. The shot weight for Celcon acetal should be in the range of 50-75% of the rated machine capacity for best results.

### *Clamping Force*

Clamping force should be high enough to prevent the mold from opening during resin injection at maximum pressure and speed into the mold. Usually 3-5 tons clamping force per square inch of projected area (including molded parts, sprue and runners) is adequate for molding Celcon® acetal.

## Mold Design

### *General Criteria*

Standard industry principles for good mold design and construction apply to the design of molds for processing Celcon acetal. Conventional 2-plate, 3-plate and runnerless molds may all be used.

### *Mold Bases*

Mold bases should be fabricated in a suitable steel grade and be made sturdy enough with pillars to adequately support the cavities and the cores without buckling of the retainer plates during injection molding. They should also be large enough to accommodate water cooling channels to provide uniform mold temperature. This operation is essential to produce acceptable parts.

### *Mold Cavities and Cores*

Alloy carburizing grades or oil-hardening tool steels hardened to RC 58-60 are recommended for Celcon acetal. Beryllium-copper cavities are also satisfactory for manufacturing good parts and offer the advantage of high thermal conductivity for good heat transfer and prevention of hot spots in the mold. Hobbed cavities will work but lack the inner toughness of the alloy steels and are more susceptible to collapse under localized stress.

For prototyping or short production runs, pre-hardened steel (RC 30-35), zinc alloys or aluminum are acceptable but may not be durable enough for long or high volume production.

### *Mold Surface Finish*

A wide variety of surface finishes can be used with Celcon acetal, as the resin exhibits excellent mold definition. Various surface finishes, designs, script, etc., can be obtained by using standard techniques such as sand blasting, vapor honing, embossing and engraving the mold cavities and cores. Flash chroming is recommended to prevent  ust and preserve a highly polished surface condition. Matte finishes are also achievable with an appropriate metal surface treatment.

Several factors affect surface finish, including condition of the mold surface itself, mold temperature, cavity pressure, part configuration, wall thickness, resin melt viscosity and flow pattern. A check list of the key parameters is shown below:

## Mold Surface Condition and Surface Temperature

- Check mold surfaces for nicks, blemishes, etc.
- Check for worn surfaces from glass-reinforced resins. To minimize this problem, mold steel should be hardened to RC 50-55.
- Make sure melt temperature is not on the low side; this can lead to abrasion from reinforced and filled resin grades.
- Mold surface temperatures should be high enough to prolong freezing of the melt in the cavity and gate, allowing better pressure transmission to the part extremities.
- Minimum mold surface temperatures of 82°C (180°F) are recommended for thin-walled parts (> 1.5 mm or 0.06 in. or less). Lower surface temperatures may be satisfactory for thicker-walled parts.

## Cavity Pressure

- Packing pressure must be adequate to force the melt against the mold surface and keep it there until a cooled surface film has formed to insure adequate reproduction of the surface. If the pressure drop from the gate to the furthest point of fill is too high, the frozen skin may pull away from the mold surface as the resin shrinks, leading to a shiny area in an otherwise matte surface.
- A large enough gate should be present to increase cavity pressure. If necessary, relocate the gate or put in an additional gate.
- Ensure that injection hold time is adequate to prevent loss of cavity pressure before resin freeze-off in the gate.

## Part Configuration

- Ensure that the resin melt flow path is not too long or too complex. Pit marks in the surface is a clear indication of low cavity pressure.
- Check the fill rate to ensure adequate cavity pressure.

## Wall Thickness

- Injection fill pressure should be adequate, especially where a part has a thick wall-thin wall configuration. Otherwise too low cavity pressure may result.
- Wall thickness should not be too thick in relation to gate size; otherwise jetting or tumbling of the melt may occur, creating "fold-over lines" and inadequate surface definition.
- Gate size should not be too small for the wall thickness; otherwise sink marks may occur. Use a relatively coarse grain on the mold surface and a rib thickness 50% of the adjoining wall surface in highshrink resins to assure sink-free parts.

## Resin Melt Viscosity

- Melt viscosity may in some cases be too high to allow adequate packing of the cavity; runners and gates may have to be enlarged to assure adequate fill. Increasing melt temperature and using a faster fill rate may marginally increase packing pressure and eliminate the problem. Be careful not to exceed the critical melt shear rate, which may lead to resin flow lines, splay and pit marks. Refer to the discussion on excessive melt shear during runnerless molding (page 4-5) for further comments.

## Sprue Bushings

Standard sprue bushings with a taper of 2 1/2° per side perform satisfactorily with Celcon® acetal. The sprue diameter should be larger than the mating end of the molding machine nozzle to prevent an undercut and facilitate ejection of the sprue.

The end of the sprue bushing which mates with the runner should be equal to the diameter of the runner and be radiused at the junction. Opposite the junction of the sprue bushing and the runner, provision should be made for a cold slug well and a standard "Z" (or other design) sprue puller. The sprue puller pin should be kept below the runner system to prevent interference with resin flow.

Secondary sprues used for gating in 3-plate molds should have a taper of 2° - 3° included angle and should also be radiused where they join the runner. The sprue size must be larger than the maximum wall thickness of the molded part.

## Runners

In designing a runner system, it is preferable to restrict the length and diameter to minimize the amount of material that has to be recycled. Runners should be as short as possible and adequate in cross-sectional diameter to allow fill of the mold cavities while preventing freeze-off. Full round, half round and trapezoidal crosssection runners are all acceptable, but full round runners are preferred. Suggested dimensions for full round runners are shown in Table 4.2, page 4-5. Runners should be made thicker than the maximum wall thickness of the molded part.

When a multi-cavity mold is used, the runner system should be balanced, i.e., the flow paths from the sprue to the far end of each cavity should be equivalent.

## Runnerless Molding

In comparison with cold-runner molding, runnerless molding can reduce the amount of resin per molding cycle, shorten production cycle time, enhance productivity and improve part quality. It is estimated that approximately 25% of all Celcon acetal molding jobs are currently being performed using runnerless molds.

Celcon acetal copolymer is well suited to the demands of hot runner molding, and, in fact, is superior to other acetal resins. Celcon acetal has better thermal stability, important because of the longer heat history during runnerless molding, as well as excellent lot-to-lot and in-lot consistency, ensuring stable processing parameters. Celcon acetal processes 10°C (18°F) lower than some other acetals, reducing heating requirements and producing faster molding cycles.

Some applications are natural fits with runnerless tooling; i.e. applications such as medical parts, where regrind cannot be used. Here hot runners can be justified because they eliminate scrap and the need for auxiliary equipment such as sprue pickers and granulators. Another suitable application is in high-volume jobs, where the same material is run for a long time without switching grades or colors. Finally, where parts with very precise surface appearance are required, zero vestige gates can be used to virtually eliminate gate marks.

**Table 4.2 Runner Size Recommendations for Celcon® Acetal Copolymer**

| Part thickness diameter mm (in.) | Runner length mm (in.) | Minimum runner diameter mm (in.) |
|---|---|---|
| Less than 0.51 (0.020) | Up to 50.8 (2) | 3.18 (0.125) |
| 0.51 - 1.52 (0.020 - 0.060) | Greater than 50.8 (2) | 4.78 (0.188) |
| 1.52 - 3.81 (0.060 - 0.150) | Up to 101.6 (4) | 4.78 (0.188) |
| 1.52 - 3.81 (0.060 - 0.150) | Greater than 101.6 (4) | 6.35 (0.250) |
| 3.81 - 6.35 (0.150 - 0.250) | Up to 101.6 (Up to 4) | 6.35 (0.250) |
| 3.81 - 6.35 (0.150 - 0.250) | Greater than 101.6 (Up to 4) | 7.92 (0.312) |

Practically all commercial hot runner systems work well with Celcon® acetal, with the exception of insulated runner systems. In general, melt flow channels should be large and streamlined, with generous radii and no sharp corners. This will prevent resin hangup, facilitate resin melt flow and reduce pressure loss.

A full range of drops are available for runnerless molding. Either bushings or hot runner nozzles can be used successfully, as can partial systems such as hot sprues. A wide variety of drop designs are acceptable, including hot tip, hot edge, angle gate, torpedo, angle tip, multitip and E-type nozzles. Machine system suppliers can provide extensive design services to determine the best drops for a specific application.

A variety of gate configurations can be used for processing Celcon acetal in hot runners, including systems which provide thermal freeze-off. Valve gates, especially hydraulic designs, work well with parts requiring zero vestiges. Generally, gates should be relatively unrestricted and should not subject the melt to shear rates higher than 1,500 - 2,000 sec-1 at polymer melt temperatures. Excessive shear may result in melt fracture. Gate design and location influence mold filling patterns and affect mechanical properties, dimensions and surface finish. The gate land should be 1 mm (0.040 in.).

In addition, tips should be hardened to reduce wear, especially with reinforced or filled systems, and should be designed to be easily replaced when excessively worn.

Temperatures need to be accurately controlled in all melt channels. Thermocouple placement is critical. It is recommended that control systems based on proportional-integral-derivative (PID) algorithms be used. These systems anticipate temperature fluctuations and account for thermal inertia when regulating heaters. The result is much finer control over melt temperature.

## Molded-in Inserts

A wide variety of molded-in inserts have been successfully mated with various grades of Celcon acetal. Because of the resin's high strength and excellent creep resistance characteristics, retention of the inserts is good, even after exposure to severe temperature and moisture cycling tests. Recom-mended designs for molded-in inserts are shown below in Figure 4.3.

In addition to standard insert molding, inserts can be assembled in pilot holes of molded Celcon® acetal

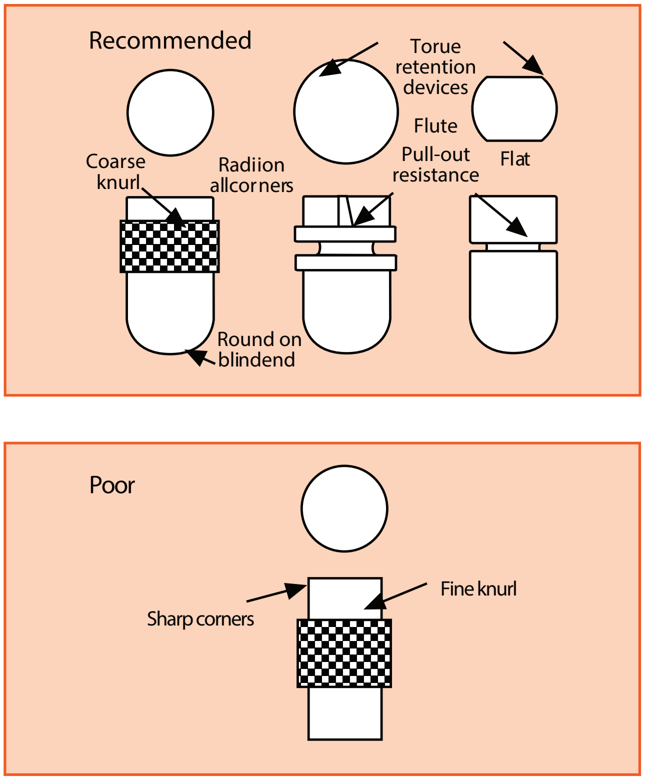


**Figure 4.3 Recommended Molded-in Insert Designs for Celcon Acetal**

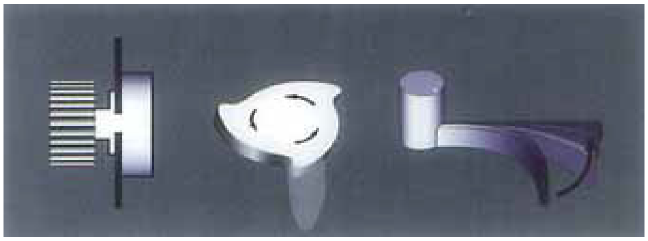

**Figure 4.4 Outset Molded Moving Parts: Gear (left), cam (center), and spring (right)**

parts, using press fits, spin welding or ultrasonic welding in a post-molding operation.

## Outsert Molding

Insert molding is a well established process for mating plastics and metals, but outsert molding extends its advantages to produce entire subassemblies with multifunctional acetal copolymer parts. The process is claimed to eliminate assembly steps and improve quality and productivity. One company, for example, molds over 100 acetal components onto a specially designed galvanized steel baseplate for a video recorder. All of the parts are formed from a single shot of an acetal copolymer, sent to four levels via a mold with 25 pinpoint gates per level.

Celcon acetal is ideal for injection molding both fixed and movable parts onto a metal plate clamped into the mold. Parts can include gears, pins, bushings, wall sections, springs, cams and other shapes. The plates themselves are usually 0.040 - 0.080 in. thick with tolerances of ± 0.002 in. In addition to holes used for mounting parts, two holes secure the plate in the mold. The distance between them must be controlled to a tolerance of ± 0.001 in. per 4.0 in. length to ensure precise molding locations.

Either three-plate or hot runner molds with multiple pin gates can be used. Unlike conventional parts, shrinkage allowance in outsert molding is determined from the center of each individual molding on the plate.

For more information on this technique, call us at 1-800-833-4882.

## Gating - Standard Injection Molding

### Gate Type

Parts made from Celcon acetal have been successfully made with a variety of gate types. Figure 4.5 gives examples of common gate types suitable fo molding Celcon acetal parts.

### Gate Size

Gate size should be selected so that the molten plastic in the gate freezes before the second stage pressure is released, thereby preventing backflow of the plastic. Recommended gate sizes for rectangular edge gates are given in Table 4.3 for various ranges of thickness. The smaller gate dimension should be one-half to two-thirds of the maximum part wall thickness.

The minimum diameter recommended for a round gate is 0.76 mm (0.030 in.), preferably greater than 1.52 mm (0.060 in.), although parts have been successfully produced with gates as small as 0.5 mm (0.020 in.).

### Gate Location

Gating in areas of the molded parts which will be subjected to high stress, bending or impact during use should be avoided. Gates should generally be located in the thickest cross-section of the part and be in a position so that the initial flow of plastic into the mold impinges on a wall. This will prevent jetting and blush marks.

For round or cylindrical parts which must be concentric, a center sprue gate, a diaphragm gate, disk gate or a set of three gates spaced at 120° intervals around the part is recommended.

### Vents

With all plastics, cavities should be well vented to allow the escape of trapped gases and air. Inadequate venting can cause burn marks, short shots, dimensional problems, surface defects and blushing. Proper venting, on the other hand, will help to lower injection and clamp pressures, reduce cycle times, eliminate or reduce molded-in stress, and minimize shrinkage and warpage.

**Table 4.3 Recommended Gate Dimensions for Rectangular Edge Gates, mm (in.)**

| Part thickness mm (in.) | Gate width mm (in.) | Gate depth (in.) | Land length mm (in.) |
|---|---|---|---|
| 0.76 - 2.29 (0.030 - 0.090) | 0.51 - 2.29 (0.020 - 0.090) | 0.51 - 1.52 (0.020 - 0.060) | 1.02 (0.04) |
| 2.29 - 3.18 (0.090 - 0.125) | 2.29 -3.30 (0.090 - 0.130) | 1.51 - 2.16 (0.060 - 0.085) | 1.02 (0.04) |
| 3.18 - 6.35 (0.125 - 0.250) | 3.30 -6.35 (0.130 - 0.250) | 2.16 - 4.19 (0.085 - 0.165) | 1.02 (0.04) |

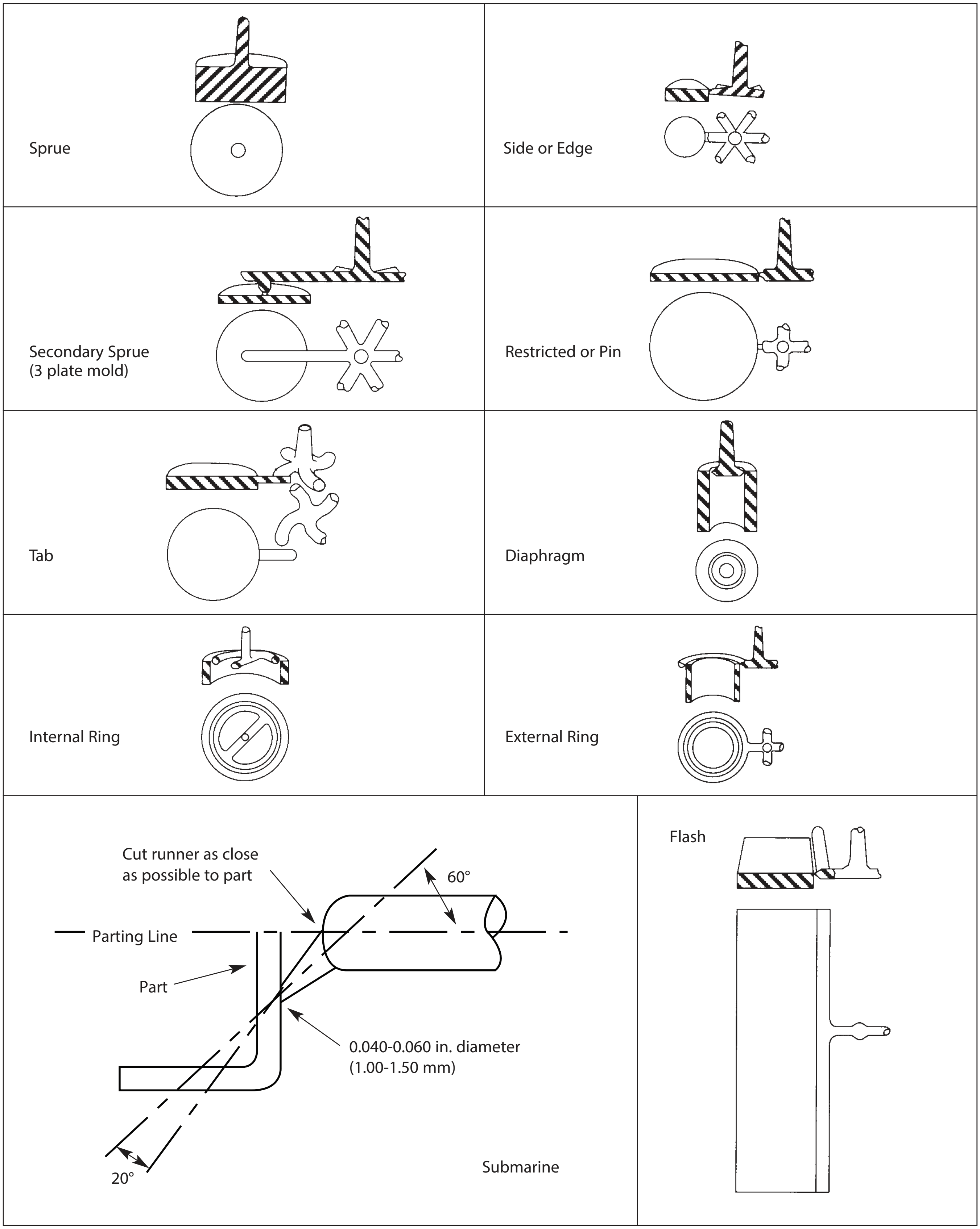


**Figure 4.5 Some Basic Gate Designs Suitable for Celcon Acetal**

It is advisable to have as much venting as possible without allowing the resin to flow out of the mold.

#### *Size*

Vents should be 0.0254 mm (0.001 in.) maximum deep by 3.175 - 6.35 mm (0.125-0.250 in.) wide. To prevent blockage of the vents, they should be deepened to 1.59 mm (1/16 in.) at a distance of 3.175-4.76 mm (1/8-3/16 in.) from the cavity to the outside. Peripheral venting is preferred whenever possible.

#### *Location*

Vents should preferably be located at the farthest point of the mold cavity opposite the gate. Vents should be placed in other locations as well including the runner system, weld line regions, and other areas of possible gas entrapment.

Natural vents can be built into the parting line of the tool and at the interface of the pieces of metal used to build up the cavities. Ejector pins can also provide some venting.

Ejector and core pins used for venting should be flattened 0.0254 mm (0.001 in.) on one side. Blind holes where gases may become trapped, can be vented by drilling a small (3.175 - 6.35 mm; 1/8 -1/4 in.) hole at the bottom of the cavity and inserting a small diameter pin flattened to 0.0254 mm (0.001 in.) on one side. When using these techniques, we recommend that mold temperatures be kept in excess of 180°F to avoid gas condensation on the pins and prevent corrosion.

### Cooling Channels

The actual mold temperature as well as temperature uniformity is extremely important in ensuring good quality molded parts. Each mold must contain cooling channels to help maintain uniform heat distribution throughout the tool. The cooling channels should be as large in diameter as is practical (at least 14.3 mm or 9/16 in.) and located in areas directly behind the cavities and the cores. Channels should be uniformly spaced to prevent localized hot spots. Non-uniform cooling can lead to surface blemishes, sink marks, excessive molded-in stresses, warpage and poor dimensional control with a possibility of excessively long cycle times.

### Draft

Plastic parts are almost always designed with a taper in the direction of mold movement to ease ejection from the mold. This is commonly referred to as draft in the line of draw. The deeper the draw, the more draft will be required.

Some Celcon® acetal parts have been successfully designed with no draft and have exhibited little problem with part ejection. However we suggest a minimum draft of 1/2 - 1° per side for best results.

### Parting Line

Parting lines should be located away from aesthetically important areas but should not complicate mold construction. Where appearance is important, the parting line should be placed in an area where the line will be concealed, such as an inconspicuous edge of the part, an area of changing geometry or on a shoulder.

### Auxiliary Equipment

#### *Mold Temperature Control Units*

Three types of mold temperature control units are commercially available and suitable for molding parts of Celcon acetal:

1. Non-pressurized water circulating units in which the reservoirs are open to the atmosphere.
2. Pressurized water-circulating units.
3. Pressurized oil-circulating units.

To maintain a mold surface temperature of 93°C (200°F), the mold temperature control unit must usually be operated in the range of 104 - 110°C (220 - 230°F) to compensate for heat loss in water lines, platens, etc. In a non-pressurized unit using water only, these temperatures cannot be attained because the water will boil off. If the heaters, gaskets, etc. in such a unit are operable at these high temperatures, the boiling point of the water may be safely raised by the addition of ethylene glycol. A solution of 60% ethylene glycol/water (by volume) will boil at 113°C (235°F); an 80% ethylene glycol solution boils at 138°C (280°F).

With a pressurized water-circulating unit, maximum temperatures of 93-99°C (200-210°F) are attainable in most molds when the unit is operated at the extreme high limit of its temperature range.

For those moldings where mold temperatures higher than 99°C (210°F) are needed, a pressurized oilcirculating unit is normally required. For flexible temperature control, the oil reservoir in the unit should be equipped with a suitable heat exchanger for lowering the oil temperature.

An alternate system for mold temperature control is to install cartridge heaters of an appropriate size in the cooling channels of the mold and control temperature via a powerstat (rheostat). The cartridge heaters should tightly fit the diameter of the cooling channel to prevent premature burn-out of the heaters and prolong their life. While this is a relatively simple and inexpensive system for mold temperature control, it could cause localized hot spots in the mold resulting in various molding problems and is therefore not preferred.

It is prudent to check the mold temperature after the machine has been operating for about 30 minutes. If necessary, readjust the mold heater temperature settings to maintain the desired temperature.

### *Process Control*

Where it is important to maintain tight dimensional tolerances, a closed-loop system should be considered. This will automatically adjust molding conditions to provide consistently satisfactory parts. Open-loop systems which are less costly can be set up to stop the molding cycle or sound an alarm to indicate that molding conditions to provide satisfactory parts have changed and should be readjusted to prevent rejects. Both types of systems are suitable for molding Celcon® acetal.

Local ventilation should be provided in either case to remove off-gases.

## Processing

Before placing Celcon acetal in a molding machine, it is highly recommended that you refer to Chapter 2 of this publication,"General Guidelines" for safe handling and processing information. The Material Safety Data Sheets for specific grades of Celcon acetal will also provide additional information related to safety, handling and use, and may be obtained by calling 1-800-526-4960.

### *Typical Molding Conditions*

Typical processing conditions for injection molding Celcon acetal are shown in Table 4.4, below. The recommendations should be used as an initial guide, and "fine-tuned" as necessary for each specific application.

### *Melt Temperature*

Most moldings are made using a melt temperature in the range 182 - 199°C (360 - 390°F) to facilitate processing and provide good quality parts at minimum cycle. Melt temperatures substantially above 199°C (390°F) should be accompanied by a corresponding decrease in residence time to avoid overheating and possible degradation of the resin. This can be achieved by using a smaller capacity machine relative to the shot size, decreasing the overall cycle time, or, if practical, increase the number of cavities in the mold.

**Celcon® acetal should never be processed above 238°C (460°F). If overheating is observed or suspected, lower the cylinder temperature and purge the overheated material, dropping the purgings into water. Stay away from the nozzle and the machine hopper as much as possible to avoid inhaling any fumes. Provide local exhaust to remove off-gases.**

**Table 4.4 Typical Molding Conditions**

| | |
|---|---|
| Cylinder temperature, °C (°F) | 182 (360) Rear<br>1882 (370) Center<br>193 (380) Front<br>204 (400) Nozzle |
| Melt temperature, °C (°F) | 188 - 199 (370 - 390) |
| Mold surface temperature, °C (°F) | 82 - 121 (180 - 250) |
| 1st stage injection pressure, MPa (103 psi) | 100 - 138 (14.5 - 20.0) |
| 2nd (Hold) injection pressure, MPa (103 psi) | 55 - 103 (8.0 - 15.0) |
| 1st stage injection speed, secs | 2 - 5 (Medium - fast) |
| Back pressure, MPa (psi) | 0 - 0.3 (0 - 50). Use higher end of range if running color concentrates |
| Screw rotational speed, rpm | 20 - 40 |
| Overall cycle, secs | 15 - 60 (Depending on wall thickness) |
| Drying | Dehumidifier 82°C (180°F) for 3 hrs. |

### *Mold Surface Temperature*

Mold surface temperature required for Celcon acetal ranges from 38 - 127°C (100 - 260°F) with 93°C (200°F) being the most common. Typically, a mold temperature in the range of 77 - 93°C (170 - 200°F) is used to provide a good balance of properties, reduce molded-in stress, provide a high surface gloss and assure good part dimensional stability. For fiberglass reinforced Celcon acetal, a slightly higher mold temperature of 93 - 127°C (200 - 260°F) is recommended to provide a resin-rich, high gloss surface. Molding with this higher mold temperature will also facilitate resin flow into the cavities, reduce molded-in stress and provide parts with improved dimensional stability in end-use.

Uniform mold temperature control is extremely important, especially for molding parts consistently within precision tolerances.

### *Injection Pressure*

Injection pressure will vary with several factors including geometry of the molded part, length of flow, design of the runner and gates, melt temperature, clamp capacity of the molding machine, condition of the mold with regard to flash, etc. While most moldings of Celcon acetal are successfully produced in the range of 104 - 138 MPa (15 - 20 Kpsi), generally adjustments must be made to adequately fill the mold without flash. To avoid back flow before the gate seals, first and second stage injection pressures should be the same for most moldings. In some cases, it may be advantageous to reduce second stage injection pressure, e.g., to reduce molded- in stress in the gate area.

### *Cushion*

A 3.2 - 6.4 mm (1/8 - 1/4 in.) cushion is recommended. The check ring non-return valve must function properly and ensure that the recommended cushion is held constantly throughout the molding cycle. Malfunctioning check rings may not seat tightly and will usually result in inconsistent parts, short shots, poor control of dimensional tolerances and weak weld lines.

### *Injection Speed*

Rapid fill of the mold cavities is preferred for most moldings and can be accomplished by opening the flow control valve to the maximum and adjusting the first stage so that it stays on for the full injection stroke. If flash occurs, injection speed should be reduced (preferably by turning down the flow control valve) as little as is necessary to eliminate flash. Injection hold time should be adequate to fill the mold cavities, have the screw come to a complete stop in the fully forward position and allow the gate to seal under pressure before the pressure is released. This is particularly important to prevent suck-back of resin through the gate when the screw is withdrawn.

If surface imperfections such as splay or flow marks are encountered, reduce the injection speed in small increments.

### *Solidification Time*

Solidification time should be adequate for the resin to properly set up in the mold and maintain dimensional tolerance and geometry without distortion, warpage or ejector pin penetration of the molded parts on ejection.

### *Decompression Settings*

Most commercially available injection molding machines are equipped with a decompression (suck-back) feature. This is used to relieve pressure on the resin after plastication in the heating cylinder and prevent nozzle drool during the mold open time prior to injection of resin in the mold. Usually about 0.2 - 0.6 seconds decompression time is satisfactory for Celcon acetal.

### *Screw Speed*

Screw rotational speed and back pressure should be kept to a minimum, preferably 20-30 rpm and zero back pressure, respectively. Excessive screw speed and back pressure can cause severe overheating of the resin and, in the case of fiberglass reinforced products, increase glass fiber breakage leading to a significant reduction in mechanical properties.

### *Cycle Time*

Cycle time depends primarily on wall thickness which governs the rate of cooling, and to some extent on part design, dimensional tolerance, molding equipment, mold design, etc. Some approximate cycle times versus wall thickness are shown in Table 4.5, below, for unfilled Celcon resins. Faster cycles than indicated may be obtained with grades of resins that are reinforced, filled and those with higher melt flow rates.

## Effect of Molding Conditions on Mechanical Properties

Celcon acetal can be satisfactorily molded over a broad range of conditions. However, since molding conditions influence aesthetics, structural integrity, mold shrinkage and physical properties of the molded part, it is important to identify the major requirements for a given application in order to select the appropriate molding conditions.

Among the important molding conditions that can influence physical properties are melt and mold temperature, injection pressure, hold time, injection speed and screw rotational speed. Slightly different molding conditions are required to optimize individual key properties. Because every application is unique and new in some way, the molding conditions discussed below should be used as a guide only. Some adjustments will generally be necessary to ensure that the optimum cycle time and part performance are obtained.

**Table 4.5 Approximate Cycle Times as a Function of Wall Thickness - Unreinforced Grades**

| Wall thickness, mm (in.) | Approximate total cycle time (secs.) |
|---|---|
| 1.6 (1/16) | 20 |
| 3.2 (1/8) | 30 |
| 6.4 (1/4) | 60 |
| 12.7 (1/2) | 75 |

The data shown below in Table 4.6 were measured in carefully controlled experiments using standard ASTM test specimens 3.2 mm thick. Molds had generous gates, runners and vents. Restrictive gates, runners of varying wall thickness and weld lines in parts or molds may significantly affect these results.

Occasionally, part design criteria or processing equipment parameters may require deviation from the above guidelines. Moreover, actual parts are usually more complex in shape than laboratory test specimens. To maximize engineering performance, the processor should work closely with the part designer to specify molding parameters based on actual part performance.

### *Unreinforced Celcon Acetal Grades*

**Tensile strength** Increases with increasing injection pressure and is optimum with a melt temperature in the range of 188 - 199°C (370 - 390°F ) and mold emperature of 77 - 104°C (170 - 220°F). Screw rotational speed and injection speed have little effect on tensile strength.

**Tensile impact strength** is highest with low injection pressure and medium injection speed. It increases with decreasing mold temperature, melt temperature and screw rotational speed.

**Flexural modulus** is most significantly affected by both mold temperature and melt temperature and increases with an increase in both temperature conditions. Maximum flexural modulus is obtained with a melt temperature of 188 - 199°C (370 - 390°F) and mold temperature of 104°C (220°F). Decreasing injection speed tends to increase flexural modulus but to a lesser degree than both melt and mold temperatures. Injection pressure and screw rotational speed have little effect on flexural modulus.

**Table 4.6 Effects of Molding Conditions on Mechanical Properties - Unreinforced Grades**

| | Injection Pressure | Melt Temperature | Mold Temperature | Screw Speed | Injection Speed |
|---|---|---|---|---|---|
| To optimize tensile strength | ↑ | 188 - 199 °C (370 - 390 °F) | 77 - 104 °C (170 - 200 °F) | — | — |
| To optimize flexural modulus | — | 188 - 199 °C (370 - 390 °F) | > 104 °C (> 200 °F) | — | ↓ |
| To optimize tensile impact | ↓ | ↓ | ↓ | ↓ | — |
| To decrease mold shrinkage | ↑ | ↓ | ↓ | — | ↑ |
| 4 1/20.119 | ↓ | ↑ | ↑ | — | ↓ |

↑Increase ↓Decrease — No significant effect

**Mold shrinkage,** in both the flow and transverse directions, decreases with increasing injection pressure, increasing injection speed, decreasing mold temperature and a melt temperature in the lower range of 171 - 182°C (340 - 360°F). Conversely mold shrinkage increases with decreasing injection pressure, decreasing injection speed, increasing mold temperature and a melt temperature in the range of 182 - 210°C (360 - 410°F). Typical molding conditions for providing minimum and maximum mold shrinkage are shown in Table 4.7.

### *Glass-Mineral Coupled and Filled Celcon® Acetal Grades*

The effect of molding conditions on physical properties as discussed below should be used only as a guide. Some variation in conditions will most likely be required to achieve optimum properties for each part.

While screw rotational speed, back pressure and injection speed have little or no effect on the properties of unreinforced Celcon acetal except where they cause severe overheating of the resin, these conditions can have a significant effect on the mechanical properties of fiberglass reinforced grades due to glass breakage. Increased glass breakage can be expected to occur mostly with increasing screw rotational speed and to a lesser extent with increasing injection speed and back pressure.

**Tensile strength, flexural strength and modulus** will decrease with increasing screw rotational speed due to breakage of glass fibers.

**Mold shrinkage** will increase with increasing screw rotational speed for the same reason. When molding fiberglass reinforced Celcon acetal, screw speed and back pressure should be kept to a minimum, 20-30 rpm and 0 psi respectively. Injection speed should be medium to maximum consistent with adequate fill of the mold cavities and with no flash occurring.

### *Deposits on Molds*

In those rare instances when deposits may build up on mold cavity and runner surfaces, the most likely causes are inadequate venting, mold surfaces that are colder than recommended, or excessive shear heating by injecting at high rates through small diameter runners and tiny gates. To prevent deposit build-up, assure adequate venting of the cavities and runners, use surface temperatures of 82°C (180°F) or higher, make sure runners have thicker cross sections than the maximum wall thickness of the molded part, and gates larger than 1 mm (0.040 in.).

To remove the deposits, we would recommend heating in a hot 82°C (180°F) detergent solution for several hours followed by rigorous scrubbing. An alternate approach for small cavity blocks would be to immerse inverted in a hot 82°C (180°F) detergent solution within an ultrasonic bath for several hours. After deposit removal, the cavities should be dried and treated with a rust preventative.

**Table 4.7 Typical Molding Conditions for Minimum/Maximum Shrinkage of Unreinforced Celcon Acetal Copolymer**

| For mimimum mold shrinkage | | For maximum mold shrinkage |
|---|---|---|
| Melt temperature, °F (°C) | 171 - 182 (340 - 360) | 182 - 210 (360 - 410) |
| Mold temperature, °F (°C) | 71 - 110 (160 - 230) | 121 (250) |
| Injection pressure, psi (MPa) | 104 - 138 (15,000 - 20,000) | 35 (5,000) |
| Injection speed | Maximum | Minimum |
| Screw rotational speed has little effect on mold shrinkage of unreinforced Celcon grades. | | |

## Table 4.7 Typical Molding Conditions for Minimum/Maximum Shrinkage of Unreinforced Celcon Acetal Copolymer

| SYMPTOMS | POSSIBLE SOLUTIONS |
| --- | --- |
| Brittleness | - Check and eliminate resin contamination in both virgin/regrind feed<br>- Decrease melt temperature to avoid degradation or increase to avoid unmelted pellets<br>- Decrease regrind level<br>- Modify part design |
| Burn mark | - Decrease injection speed<br>- Improve venting<br>- Increase gate size<br>- Decrease melt temperature |
| Delamination | - Check and eliminate resin contamination in both virgin/regrind feed<br>- Increase gate size<br>- Provide adequate cold slug well |
| Discoloration | - Purge machine<br>- Decrease cylinder temperature by:<br>1. Lowering temperature<br>2. Decreasing back pressure<br>3. Lowering screw speed<br>- Lower nozzle temperature<br>- Reduce injection speed<br>- Inspect for feed contamination<br>- Examine nozzle and cylinder for hold-up points<br>- Use smaller capacity machine |
| Nozzle drool | - Lower nozzle temperature<br>- Lower melt temperature<br>- Minimize cushion<br>- Use decompression<br>- Delay sprue break time<br>- Decrease mold open time<br>- Use smaller diameter orifice |
| Part distortion | See Warpage |
| Pit Marks | - Increase feed<br>- Increase injection pressure<br>- Increase mold temperature<br>- Decrease cushion<br>- Increase injection speed<br>- Increase injection time<br>- Add vents<br>- Increase gate size or the size of the runner system<br>- Use larger machine |
| Short shots | - Eliminate any material bridging at hopper throat<br>- Increase feed<br>- Increase injection pressure<br>- Increase mold temperature<br>- Decrease cushion<br>- Increase injection speed<br>- Increase injection time<br>- Add vents<br>- Increase gate size or the size of the runner system<br>- Use larger machine |
| Sink marks | - Increase injection pressure<br>- Increase screw forward time<br>- Decrease cushion<br>- Decrease tool temperature<br>- Increase injection speed<br>- Increase feed-gate runner sprue<br>- Relocate gate to heavy section<br>- Modify part design |

| SYMPTOMS | POSSIBLE SOLUTIONS |
|---|---|
| Splay Marks | - Reduce cylinder temperature<br>- Increase mold temperature<br>- Decrease injection speed<br>- Provide proper mold venting<br>- Dry material |
| Sticking in cavity | - Decrease injection pressure<br>- Decrease screw forward time<br>- Minimize cushion<br>- Increase mold close time<br>- Lower cavity tool temperature<br>- Eliminate undercuts and insufficient draft<br>- Radius all sharp corners |
| Sticking on core | - Decrease or increase injection pressure (machine dependent)<br>- Decrease injection hold time<br>- Minimize cushion<br>- Decrease mold close time<br>- Decrease core temperature<br>- Eliminate all undercuts and draft<br>- Radius all sharp corners<br>- Relocate gate to heavy section<br>- Use larger machine |
| Unmelted pellets | - Ensure coorrect srew design is used<br>- Increase screw speed<br>- Increase back pressure<br>- Increase temperature, especially at hopper end |
| Voids | - Increase injection pressure<br>- Increase screw forward time<br>- Decrease cushion<br>- Increase mold temperature<br>- Increase gate, runner and/or sprue thickness<br>- Check mold/cavity venting |
| Warpage | - Confirm temperature on both halves of mold is uniform<br>- Ensure uniformity of ejection<br>- Reduce mold temperature<br>- Increase injection time<br>- Increase injection pressure<br>- Reduce melt temperature<br>- Increase mold close time<br>- Jig the part and cool uniformly<br>- Reduce variations in wall thickness<br>- Radius all sharp corners |
| Weld lines | - Increase injection pressure<br>- Increase screw forward time<br>- Increase mold temperature<br>- Provide adequate venting at area of weld<br>- Increase stock temperature<br>- Increase injection speed<br>- Relocate gate to alter flow pattern<br>- Provide overflow well at weld area |

# Blow Molding

## Blow Molding Methods

Blow molding Celcon® acetal allows the production of hollow and irregular shapes through either extrusion or injection techniques. While most commercial applications are for relatively small components such as cosmetic bottles, dishwasher spray arms and automotive hydraulic fuel reservoirs, blow molders have produced plenums measuring 50 in. long and 16 in. wide in developmental runs.

The two general methods for blow molding plastics articles are extrusion blow molding and injection blow molding. Both methods may be used to produce items made from Celcon acetal. The two methods differ primarily in the method of preparation of the "parison," i.e., the tube of molten resin from which the molded article is formed. Both techniques have much in common, and information on recommended grades of Celcon acetal for both blow molding processes can be obtained by calling Product Information Services at 1- 800-833-4882.

### *Extrusion Blow Molding*

Extrusion blow molding is more extensively used than injection blow-molding and parts are made either by a continuous or discontinuous (intermittent) extrusion method.

In the continuous method there is no interruption in parison extrusion. When the parison reaches the appropriate length, a mold closes around it, and the parison is cut. Air is introduced and pressurized to create the blow-molded part.The mold moves and a new mold closes around the continuously moving parison. More than half of all Celcon acetal blow-molded parts are made using the continuous method, due to its lower cost and shorter processing cycle.

The discontinuous method is suitable only for processing resins which are not heat sensitive, and is not recommended for Celcon acetal.

### *Injection Blow Molding*

Injection blow-molding is a two-stage process for manufacturing completely finished thermoplastic containers.

Advantages of injection over extrusion blow molding are the ability to mold a finished neck on a container with good dimensional control and better dimensional control of wall thickness. This results in better product quality, less material usage, and a minimum of waste material to be reworked.

The major advantages and disadvantages of each method are summarized in Table 5.1.

## Equipment

### *Extruder*

Any conventional commercially available extruder can be used to plasticize/melt Celcon acetal with little difficulty for use in blow molding. It is highly recommended that the selected machine have a screw with an L/D (lengthto-to-diameter) ratio of at least 16:1, and preferably higher (20:1 or 24:1). The use of a machine with a higher L/D ratio allows more uniform mixing of the molten resin, eliminates resin memory and provides a more uniform melt temperature.

In selecting an extruder, it is recommended that particular attention be given to the quality of the temperature controls on the machine. Parison temperature control is critical for troublefree blow molding.

### *Screws*

Screws for the extrusion of Celcon acetal parisons should be of the general purpose type, having a few flights of uniform depth in the feed zone, a tapered compression zone, and several flights of uniform depth in the metering zone. Screw pitch should be uniform and equal to the screw diameter. Comp-ression ratio should be in the range of 3:1 - 4:1.

A typical 2 1/2 in. diameter, 20:1 L/D screw for extruding Celcon acetal should have:

- 3 to 5 flights of uniform depth in the feed zone,
- 30 - 12 flights of increasing root diameter in the compression (transition) zone, and
- 5 flights of uniform depth in the metering zone.

**Table 5.1 Comparison of Injection and Extrusion Blow Molding**

| **Equipment Costs** | **Extrusion** | **Injection** |
|---|---|---|
| Total equipment cost | Lower | Higher |
| Parison die cost | Lower | Higher |
| Blow mold cost | Approx. equal | Approx. equal |
| **Processing** | **Extrusion** | **Injection** |
| Production rates | Lower | Higher |
| Finishing required | Considerable | Little or none |
| Waste and regrind | Some | Little or none |
| **Product** | **Extrusion** | **Injection** |
| Overall quality achievable | Good | Excellent |
| Sizes obtainable | Small, medium, large | Small to medium |
| Wall thickness control | Good | Excellent |
| Tolerance on neck finish | Fair | Excellent |

Flight depth in the feed zone would be 0.44 in., and 0.11 in. in the metering zone. Recommended screw characteristics to plasticize Celcon acetal for extrusion blow molding are summarized in Table 5.1.

### *Screen Pack*

A screen pack of assorted screen sizes (e.g 20-60-80- 20 mesh) should be placed immediately in front of the screw to filter out any unmelted particulates which could lead to defective products or abrasion of the inner head and die surfaces. The screen pack also serves to maintain back pressure which prevents uneven parison flow due to surging. The screen pack should be replaced at regular intervals.

### *Breaker Plate*

A breaker plate should be used to hold the screen pack firmly in place while interfering as little as possible with a smooth flow of the melt stream. A breaker plate is a steel plate usually about 6.4 mm (1/4 in.) thick and perforated with closely-spaced 6.4 (1/4 in.) holes. The holes in the breaker plate are frequently chamfered on the side facing the screw to improve melt flow.

### *Die Head*

A die head and adaptor is generally placed between the breaker plate and the parison die to guide the melt stream to the die entrance. Many assemblies require that the melt stream turn 90° as it approaches the die. To encourage smooth flow and avoid undesirable weld lines, flow "pin spiders" with helical deflectors machined to a knife edge at the point of convergence are often used. The melt stream can flow freely around such a die pin without dead spots where material could hang up. A flow divider of this type is shown in Figure 5.1.

To further weld the material passing the die pin and discourage streaks, an annular restriction ("choke") should be placed downstream from the flow divider. The choke serves to increase back pressure in the melt stream by reducing the cross-sectional area between the flow divider and the die. The higher pressure which is achieved tends to smooth out the weld and reduce the chance of streaking.

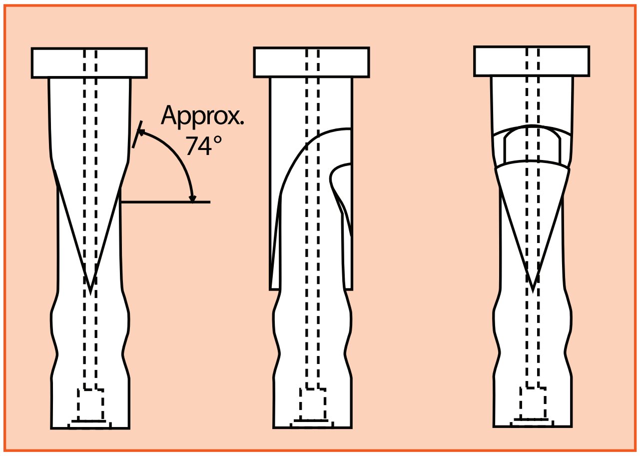


**Figure 5.1 Flow Pin Divider to Promote Smooth Flow and Avoid Weld Lines**

**Table 5.2 Typical Screw Characteristics to Plasticize Celcon Acetal for Blow Molding**

| Screw Diameter (in.) | Channel Depth | | | Zone Length as % of screw length | | |
|---|---|---|---|---|---|---|
| | Metering (in.) | Feed (in.) | Ratio | Feed | Transition | Metering |
| 38.1 (1.5) | 2.11 (0.083) | 7.37 (0.29) | 3.5 | 40 - 50 | 30 - 20 | 30 |
| 50.8 (2.0) | 2.26 (0.089) | 7.62 (0.30) | 3.4 | 40 | 30 | 30 |
| 63.5 (2.5) | 2.46 (0.097) | 8.13 (0.32) | 3.3 | 40 | 30 | 30 |
| 88.9 (3.5) | 2.74 (0.108) | 8.89 (0.35) | 3.2 | 40 | 30 | 30 |
| 114.3 (4.5) | 3.02 (0.119) | 9.65 (0.38) | 3.2 | 40 | 30 | 30 |

Type - Metering general purpose type; constant pitch    L/D - 20:1 to 24:1 preferred; 16.1 mimimum    Compression ratio - 3:1 to 4:1

The die should be kept hot to avoid freeze-off of the molten resin after it has passed through the "spider".

### *Die*

The parison die is a key element in blow molding because it controls material distribution in the finished item, and, in turn, influences the economics of the final product. Figure 5.2 shows a parison die with an adjustable core pin which allows control of the thickness of the parison.

### *Hopper*

The hopper on the extruder should be large enough to hold Celcon pellets for about a half hour's production. If the hopper is manually loaded, it should be equipped with a hinged or tightly fitted lid to avoid contamination. While Celcon resins normally can be used directly from their original shipping container without drying, a hopper drier can be beneficial where pick-up of excess moisture has inadvertently occurred. The use of a magnetic screen or metal detector placed in the hopper is advised to minimize the risk of contamination or equipment damage due to foreign metal.

### *Molds*

A choice of materials for molds depends on the anticipated volume of production, complexity of the mold piece, technique used and number of molds required. Aluminum and zinc are commonly used to make the low cost molds for short runs. Beryllium-copper, a harder material, is sometimes used despite its higher cost because it has excellent heat transfer characteristics. Steel dies are relatively expensive and are mostly used for long production runs.

If a mold cavity is not properly vented, trapped air can hold the plastic material away from the cavity surface,

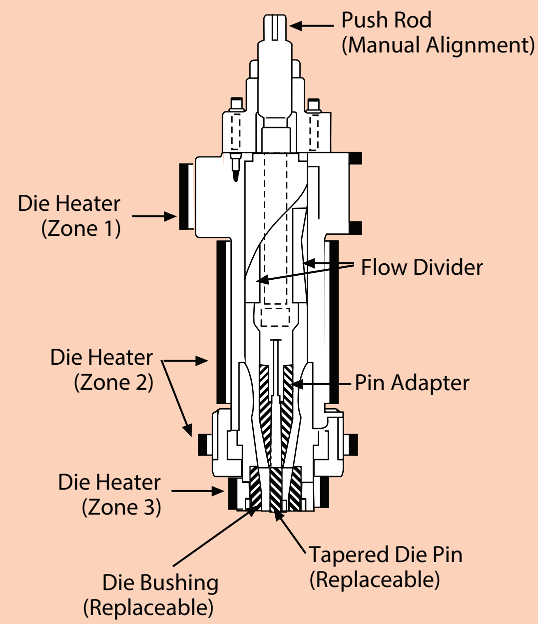


**Figure 5.2 Parison Die with Adjustable Core Pin for Control of Parison Thickness**

interfere with heat transfer in the cavity and result in a poor finish on the molded part. Vents 0.051-102 mm (0.002-0.004 in.) deep should be provided at the mold parting line in areas where air entrapment is likely. Molds can be vapor honed or sand blasted to provide a matte surface which prevents sticking and facilitates part ejection.

## Processing

The extruder should be started up by the procedures outlined in Chapter 6 of this publication. As the extrudate issues from the die, the cold parison will appear rough and translucent. Raising the temperature produces a well converted, clear transparent parison. If parison temperature is too high, bubbles and slight discoloration will appear.

Each different blow molding job will require some variation in operating conditions to optimize the production process. Usually the lowest material melt temperature should be used consistent with obtaining a fully plasticized melt (no unmelted pellets), but providing a satisfactory parison with maximum melt strength.

### *Barrel Temperature*

Initially, barrel temperature profiles should be relatively flat but after operation is well underway, some benefit will be derived from raising the temperature in the feed section and lowering the temperature of the succeeding zones to establish a descending profile. The highest temperature should be at the feed zone. If extrusion rates are relatively low and there is danger of bridging in the feed zone, the temperature in the feed zone should be kept low and the second zone made the high point for the decreasing temperature profile.

Barrel temperatures can range from 165°C (329°F) to as high as 216°C (420°F) depending on the blown part geometry, dimensions, blowing cycle, and many other factors. Typical operating conditions used in preparing various blown parts are shown in Table 5.3.

**Table 5.3 Typical Blow Molding Conditions**

| **Item** | **Aerosol Container<br>3.5 oz. Bullet shape** | **Aerosol Container<br>5 oz. Barrel shape** | **Float** |
|---|---|---|---|
| Approx. size diam x ht., mm x mm (in. x in.) | 40.6 x 132.1 (1.6 x 5.2) | 55.9 x 83.8 (2.2 x 3.3) | 63.5 x 25.4 (2.5 x 1) |
| Weight, grams | 29 | 44 | 27 |
| Blow molding method | Extrusion Multi-station rotary | Extrusion Multi-station rotary | Extrusion, Fixed Moldaccu-mulator |
| Extruder size, in. | 2 1/2 | 2 1/2 | 2 1/2 |
| L/D | 24:1 | 24:1 | 20:1 |
| Compression ratio | 3.5:1 | 3.5:1 | 2.5:1 |
| Die busing i.d., mm (in.) | 14.9 (0.588) | 17.8 (0.700) | — |
| Die mandrel o.d., mm (in.) | 8.0 (0.313) | 5.6 (0.220) | — |
| Land length., mm (in.) | 12.7 (0.500) | 25.4 (1.00) | — |
| **Temperature, °C (°F)** | | | |
| Mold | 93 (200) | 93 (200) | 88 (190) |
| Barrel Zone 1<br>Zone 2<br>Zone 3<br>Zone 4 | 149 (300)<br>171 (340)<br>182 (360)<br>166 (330) | 171 (340)<br>166 (330)<br>171 (340)<br>171 (340) | 216 (420)<br>210 (410)<br>204 (400)<br>204 (400) |
| Adapter | 188 (370) | 166 (330) | 204 (400) |
| Die Zone 1<br>Zone 2<br>Zone 3 | 188 (370)<br>204 (400)<br>210 (410) | 166 (330)<br>166 (330)<br>191 (375) | 204 (400)<br>210 (410)<br>— |
| Melt | 210 (410) | 196 (385) | 199 (390) |
| Screw, rpm | 30 | 45 | 70 |
| Current, Amps | 100 | 95 | 12 |
| Back pressure, MPa (psi) | 8.3 (1,200) | 11.0 (1,600) | — |
| Blow pressure, MPa (psi) | 0.83 (120) | 0.83 (120) | 0.45 (65) |

### *Mold Temperature*

A mold temperature of as high as 138°C (280°F) is often used to achieve the optimum in part quality. A mold temperature below 93°C (200°F) is not recommended.

### *Blowing Pressure*

Typical blowing pressure for Celcon® acetal is in the range of 0.69 - 0.90 Mpa (100 - 130 psi). Pressures below 0.55 Mpa (80 psi) can be used but are not recommended. Blow pressures for Celcon acetal are higher than required for polyethylene and, consequently, require higher clamping forces on the mold.

## Effects of Process Variables on Part Dimension and Quality

### *Mold Shrinkage*

Mold shrinkage for blow molded Celcon acetal generally ranges from 2-5%. Mold shrinkage is dependent on such factors as mold temperature, cooling time, blow pressure and wall thickness.

The effect of these variables on shrinkage are shown in Figures 5.3 through 5.6. Average shrinkage values obtained in a round 3.4 ounce container with a nominal 1.27mm (0.050 in.) wall thickness are shown in Figures 5.3, 5.4 and 5.5 while the effect of wall thickness on shrinkage in a relatively hot (127°C/260°F) mold is seen in Figure 5.6.

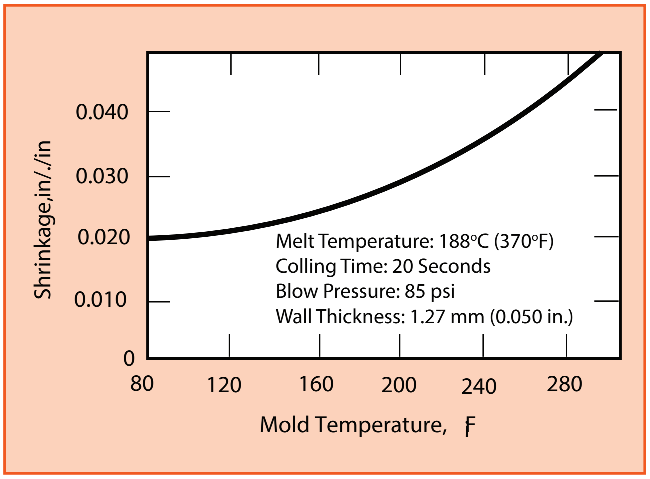


**Figure 5.3 Effect of mold temperature on shrinkage**

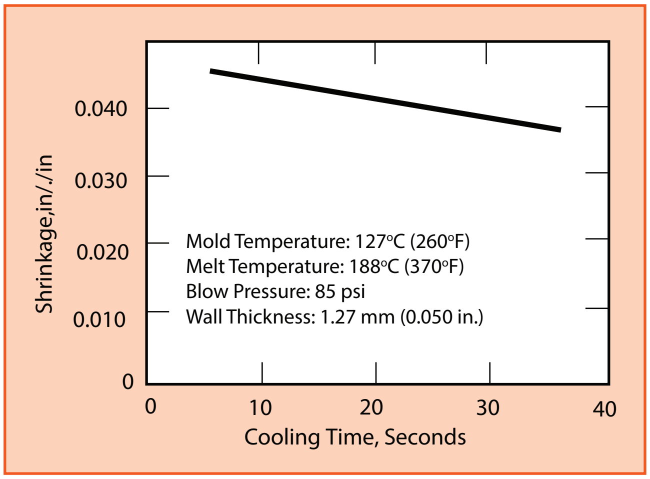


**Figure 5.4 Effect of cooling time on shrinkage**

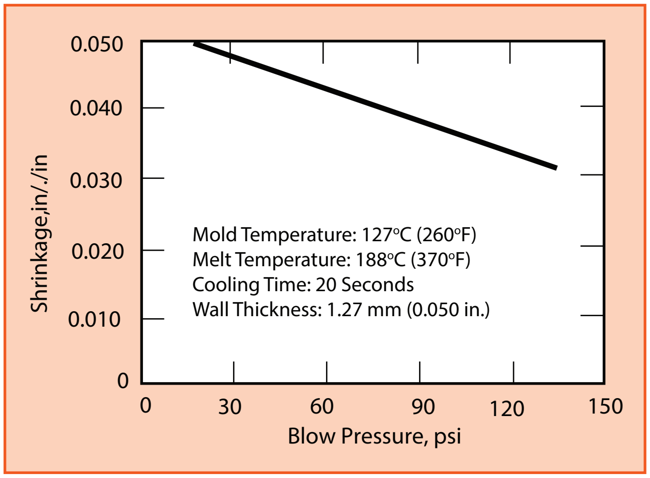


**Figure 5.5 Effect of blow pressure on shrinkage**

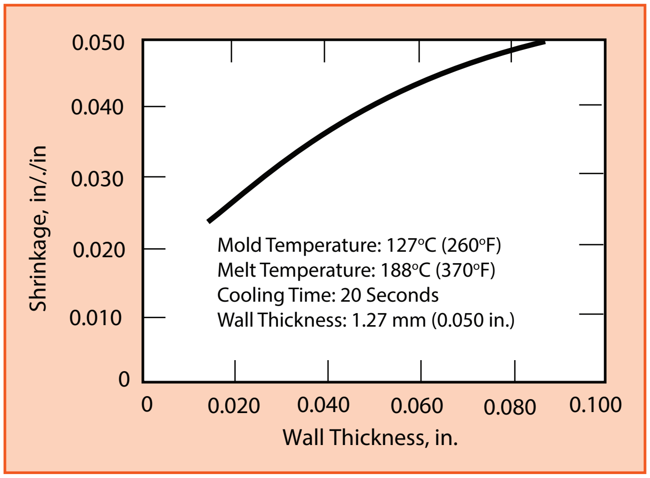


**Figure 5.6 Effect of wall thickness on shrinkage**

In general, a blown container will shrink slightly more in its length than in its diameter, and slightly more in the neck area than in other sections.

### *Surface Appearance*

The surface appearance of blown Celcon® acetal containers depends primarily on mold finish and mold temperature, and partly on the ability to prevent air entrapment in the cavity. Air entrapment can be prevented by proper venting. Where air entrapment is a problem and a high glossy surface is not required, a textured finish on the cavity is recommended.

### *Impact Strength*

Impact strength in a blown container is dependent primarily upon the general design and wall thickness of the part, but mold temperature can have a significant effect. Optimum impact strength is often achieved by maintaining the mold at 93°C (200°F ) or higher. In some items where impact failures have occurred in the pinch-off area because of poor welding, a landed pinch-off, i.e., the use of a flat rather than a knife-edge pinch-off as shown in Figure 5.7 will yield significant improvement in impact strength.

### Table 5.4 Blow Molding Troubleshooting Guide

| SYMPTOMS | POSSIBLE SOLUTIONS |
|---|---|
| Die Lines | - Polish die lip<br>- Increase mold temperature<br>- Increase air volume<br>- Eliminate hang-up area in die<br>- Modify die to eliminate weld lines |
| Internal Roughness | - Increase material temperature<br>- Dry air supply<br>- Increase length of land |
| Low Gloss | - Increase mold temperature<br>- Increase stock temperature<br>- Increase parison thickness<br>- Improve mold surface finish |
| Poor Definition | - Increase mold temperature<br>- Increase air volume<br>- Increase air pressure<br>- Increase stock pressure<br>- Increase parison wall thickness |
| Poor Pinch-Off Weld | - Reduce blowing pressures<br>- Use wider pinch-off blades |
| Walls too thick | - Decrease screw speed<br>- Change die dimensions as required |
| Walls too Thin | - Increase screw speed<br>- Change die dimensions as required |

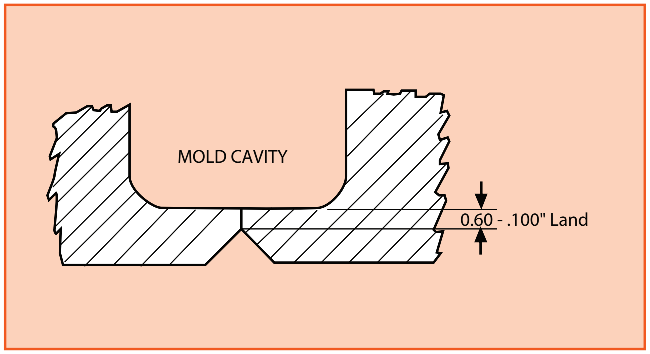


**Figure 5.7 Landed pinch-off for improved impact strength**

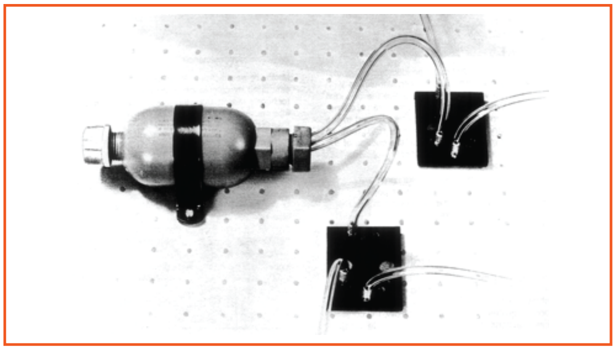

**Figure 5.8 Blow molded fluidic capacitor**

# Extrusion

Higher molecular weight grades of Celcon® acetal copolymers (higher viscosity than for injection molding, such as Celcon M25) are recomended for extrusion. Sheets up to about 6.4 mm (0.25 in.) thick and tubes with wall thicknesses 0.38 to 1.0 mm (0.015 to 0.040 in.) can be extruded.

Call Product Information Services at 1-800-833-4822 for recommendations on specific grades of Celcon acetal for each type of job requirement.

The information on equipment given below applies generally to all types of extrusion. Additional specific details for high speed tubing, film and sheet, and profile extrusion are also covered in this Chapter.

## Equipment

### *Materials of Construction*

At extrusion temperatures, Celcon acetal copolymer is not affected by contact with copper, zinc, iron, nickel, brass or bronze. The designer therefore has greater freedom in selecting the most cost effective material for a specific application for dies, sizing sleeves, etc.

### *Extruder Barrel*

A barrel with an L/D (length-to-diameter) ratio of 16:1 (and preferably up to 24:1) is recommended to allow sufficient residence time for proper melting. In conjunction with a properly designed screw, longer barrels tend to improve melt homogeneity and reduce melt temperature and pressure fluctuations.

If a shorter barrel (L/D less than 16:1) must be used, the use of a high resistance die with either long lands or a small die opening is recommended to generate the necessary back pressure to "work" the material. With low resistance dies, the use of a valve in the extruder head is suggested to increase the back pressure level in the barrel.

### *Screw Design*

A metering screw as shown in Figure 6.1 is recommended for extruding Celcon acetal.

Characteristics of this screw are:

- An L/D ratio of 16:1 (minimum); up to 24:1 preferred.
- The flight clearance should be approximately 0.13mm.(0.005 in).
- The flight width, (w), should be approximately 10% of the screw diameter.
- For unfilled Celcon acetal, the screw should be hard faced or coated with a corrosion reistant material such as chrome or Stellite 6.
- For filled Celcon acetal, the screw and barrel should be hard faced or coated with a corrosion and abrasion resistant material such as tungsten carbide, CPM-9V or Colmonoy 56 for screws, and CPM-10V, Bimex or Xaloy for barrels.

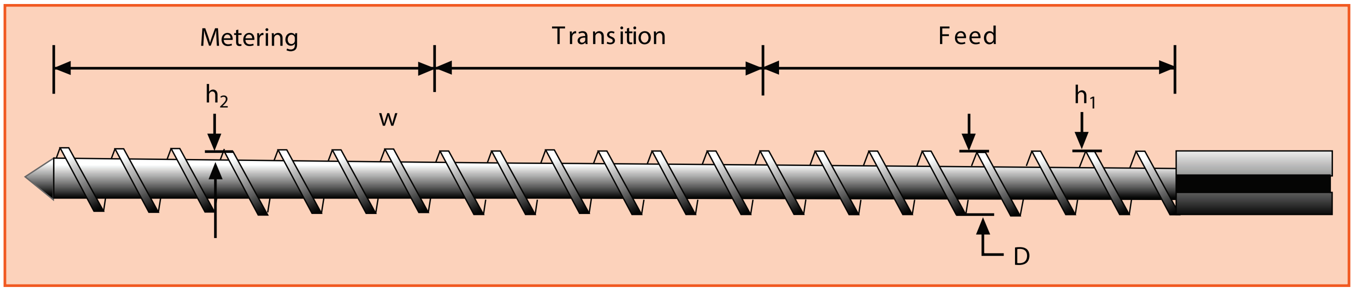


**Figure 6.1 Recommended Metering Screw for Extrusion**

- The channel depth ratio, i.e., the ratio of the channel depth in the feed zone to that in the metering zone, (h1/h2), should be between 3 and 4.5. A channel depth ratio of 4 is recommended for optimum results.
- The feed section should occupy about 35% of the screw length, the transition zone about 30% and the metering zone about 35%.

Recommended dimensions for extrusion screws are given in Table 6.1.

### *Screen Pack*

A 20-60-100-60-20 mesh screen pack is generally recommended preceding the breaker plate when extruding unfilled resins. This will remove most unmelted contaminants. It is especially important to use a screen pack when regrind is used. The screen pack also helps to increase back pressure and minimize surging while improving mixing. If the resin contains a filler or reinforcement, a screen pack is not used.

### *Head and Die Design*

Straight-through, crosshead or offset dies may be used to extrude Celcon® acetal copolymer. All inside surfaces should be highly polished and streamlined. If there are any areas of stagnation or hold-up, resin in such areas could degrade and result in discolored streaks in the extrudate.

Low resistance dies may not provide sufficient back pressure. In such cases, relatively long lands are recommended. As a rule-of-thumb, land length for circular cross sections should be at least equal to the diameter of the die, or the lands should be 10 to 20 times the thickness of the extruded section. An approach angle of 20-30° to the die lands is recommended for most types of dies.

Accurate heat control at all points on the die and die head, as well as the ability to determine the stock temperature in the head via a melt thermocouple are essential. A pressure gauge should be mounted on the die head to help establish and maintain proper operating conditions. The gauge is also a safety feature to alert the operator if excessive pressure build-up should develop.

### *Hopper*

The hopper on the extruder should be large enough to hold pellets for about a half hour's production. If the hopper is manually loaded, it should be equipped with a hinged or tight-fitting lid to avoid resin contamination. While Celcon acetal grades normally can be used directly from their original shipping containers without drying, a hopper drier can be beneficial where pick-up of excess moisture has inadvertently occurred.

The use of a magnetic screen or metal detector is advised to minimize the risk of contamination or equipment damage due to foreign material.

## High Speed Tubing Extrusion

## Equipment

### *Extruder Size*

There is no strict requirement for size, but the extruder must be able to deliver the required resin output at a constant temperature, properly plasticated and without surging. For example, to make brake cable tubing with o.d. 5.8mm. (0.230 in) and wall thickness 0.64mm (0.025 in.) at a rate of 91 m/min (300 ft/min), a machine must deliver 82 kg/hr (180 lb/hr) of molten resin. Since this is the upper limit for a 2 1/2 in. or 60mm extruder, a 3 1/2 in. or 90 mm extruder is necessary.

### *Water Bath*

A three axis positioning water bath is needed to properly align the bath to the die and extrusion path. This alignment is critical in high speed extrusion for good

**Table 6.1 Recommended Metering Screw Dimensions for Extrusion**

| Screw Diameter (in.) | Channel Depth | | Zone Length as % of screw length | | |
|---|---|---|---|---|---|
| | Metering (in.) | Feed (in.) | Feed | Transition | Metering |
| 38.1 (1.5) | 1.78 (0.070) | 7.11 (0.28) | 35 | 30 | 35 |
| 63.5 (2.5) | 2.79 (0.110) | 11.18 (0.44) | 35 | 30 | 35 |
| 88.9 (3.5) | 3.18 (0.125) | 12.70 (0.50) | 35 | 30 | 35 |
| 114.3 (4.5) | 3.56 (0.140) | 14.72 (0.56) | 35 | 30 | 35 |

surface finish. Bath length may vary from 1.8 - 3.7 meters (6 - 12 ft.) with temperature maintained typically between 16°C (60°F) and 38°C (100°F).

## Processing

### *Die and Head Temperature*

The die and head temperatures should be in the range of 190 - 230°C (370 - 450°F) for Celcon® acetal copolymer. A temperature profile with a die temperature of 10 - 38°C (50 - 100°F) greater than the head temperature gives the best results.

In practice, for every 6°C (10°F) increase in melt temperature, surface roughness is reduced by about 10 microinches R.M.S. Although surface roughness decreases with increasing die temperature, a die temperature of 230°C (450°F) usually yields the best balance of minimum surface roughness and good appearance. Typical processing conditions are shown in Table 6.2.

### *Sizing Techniques*

An external sizing sleeve submerged in a water bath will provide good results. A series of platesor rollers should follow the sleeve to keep the tube below the water level in line with the external sleeve. This will prevent "chatter marks" on the tube.

In conjunction with the air pressure injected through the mandrel, tube diameter is controlled by the film of water trapped between the tube and the external sizing sleeve. Tubing with diameter 2.5 - 5.8 mm (0.100 - 0.230 in.) can be made using a 6.2mm (0.245 in.) diameter sleeve. Increasing the inside diameter of the tube is accomplished using air pressure of 0.07 - 0.35 kg/cm2 (1 - 5 psig) transmitted into the tube via the die mandrel.

Vacuum sizing is generally conducted at higher line speeds and may also be used for tubing extrusion of Celcon acetal. A draw down ratio of 1.5 to 2.1 is recommended. The sizing plates should gradually decrease in diameter in the direction of extrusion. The last plate should be 1 to 5% oversize, depending on the line speed, to allow recrystallization and shrink down to the desired final diameter.

### *Orientation*

When producing tubing, biaxial orientation of the extrudate is the best way to reduce brittleness. Heavy walled tubing can be biaxially oriented by drawing down the outside surface by a factor of 1.7:1 and blowing up the inside surface by a factor of approximately 1.6:1. For example, to make brake cable with an o.d. of 5.84 mm (0.230 in.) and wall of 0.64 mm (0.025 in.), use a die with an opening of 10.2 mm (0.400 in.) and a 2.8 mm (0.110 in.) mandrel.

| | | |
|---|---|---|
| o.d. | 10.2mm/5.84mm<br>(0.400 in./0.230 in.) | = 1.74 drawdown ratio |
| i.d. | 4.57mm/2.79mm<br>(0.180 in./0.110 in.) | = 1.6 blow-up ratio |

The tubing produced in this manner will be less brittle than that extruded without biaxial orientation.

**Table 6.2 Typical Conditions for Tubing Extrusion**

| | |
|---|---|
| Machine | 3 1/2 in. |
| L/D Ratio | 24:1 |
| Size of Motor | 75 Hp (56 kW) |
| Amp Rating | 192 |
| Screw type<br>Compression ratio 3:1<br>Metering zone depth 3.6 mm (0.14 in.) | Metering |
| Screw speed | 33 RPM |
| Screen pack | 20-40-80-40-20 mesh |
| Sizing | Four plates, 6.4 mm (2 1/2 in.) apart:<br>#1. 7.1 mm (0.281 in.) diameter<br>#2. 6.2 mm (0.242 in) diameter<br>#3. 5.6 mm (0.220 in) diameter<br>#4. 5.2 mm (0.204 in) diameter |
| Die dimensions<br>Mandrel<br>Bushing<br>Die temperature | <br>4.3 mm (0.170 in.) diameter<br>7.2 mm (0.285 in.) diameter<br>230°C (450°F) |
| Barrel temperature °C (°F)<br>Zone 1<br>Zone 2<br>Zone 3<br>Zone 4<br>Zone 5 | <br>180 (360)<br>190 (370)<br>195 (380)<br>200 (390)<br>205 (400) |
| Line Conditions<br>Motor<br>Line speed<br>Air pressure | 24 Amps<br>128 m/min (420 ft/min)<br>0.1 kg/cm$^2$ (1 1/4 psig) |
| Head pressure | 210 kg/cm$^2$ (3,000 psig) |

The above settings produce tubing with an i.d. of 4.1 - 4.2 mm (0.161 - 0.165 in.); an o.d. of 5.1 - 5.2 mm (0.200 - 0.205 in.) and a wall thickness of 0.46 - 0.56 mm (0.018 - 0.022 in.)

## Film and Sheet Extrusion

### *Equipment*

For highest efficiency, a long barrel extruder (L/D 24:1) is recommended. This should have a metering screw with at least a five - turn metering section to ensure melt homogeneity.

Standard center feed dies may be used. The die manifold can be in a straight line or bent to form a "Y", but the latter is preferred because it provides a more uniform flow from the die.

An adjustable choker bar, which acts as a valve, can be used to regulate the thickness across the sheet. The choker bar combines with the die lip to give enough back pressure to force the plastic out to the ends of the manifold. Thick or wide sheets require longer lands and more choking to ensure die fill out. Die lands should be 38-51 mm (1 1/2 in.) long, depending on the thickness of the die opening.

Either a two or three rolled stack system may be used. The three roll system is preferred because it provides greater precision and control and provides a glossy finish on both sides of the product. Rolls may also be textured to produce a variety of patterns on the finished sheet.

### *Processing*

Extrusion conditions depend on the gauge and width of the film or sheet being produced. A careful balance between material temperature and roll temperature is necessary for good surface finish, and to prevent sticking to the roll. Typical conditions for film and sheet of various gauges are shown in Table 6.4 on the following page.

Die lip to roll take-up distance must be kept as small as possible for heavy sheets, but can be greater for thinner films. Slabs of up to 3.2 mm (1/8 in.) may be prepared by extrusion. Thicker slabs (up to 25.4 mm or 1 in.) have been prepared by stock shape manufacturers using compression molding.

## Profile Extrusion - Equipment

### *Extruder*

Extruders with barrel diameter of 35 - 60 mm. (1 1/2- 2 1/2 in. ) and 5 -15 HP drives are typical. The extruders used for the profile extrusion of Celcon® acetal are generally small because most profile cross sections are small and output rates are low.

### *Screw*

Metering screws as described in Figure 6.1 and Table 6.1 are recommended for profile extrusion of Celcon acetal. Best results are obtained for screws with:

| | |
|---|---|
| L/D ratio | 20:1 to 24:1 |
| Pitch/diameter ratio | 1:1 |
| Compression ratio | 3:1 to 4:1 |
| Length of metering section | 25% length of screw (5 to 6 diameters) |
| Tip shape | Conical (150° included angle) |

### *Die*

Steel is commonly used for die construction. Chrome plating of all internal surfaces is recommended for long production runs. Brass and beryllium copper are sometimes used for short runs because they are easy to machine and are good heat conductors.

Both straight through and cross-head dies may be used, with straight through dies preferred in most cases. Because of the melt elasticity and strength of Celcon acetal, the die should be 15-20% oversize in width and 10% in thickness. It is recommended that land length to thickness ratio should be 8:1 - 15:1 to provide the correct level of exit velocity, back pressure and mixing to give a smooth, lustrous surface to the extruded part.

### *Sizing and cooling*

Air from an air ring or "profiled" copper tubing should be blown on the surface of the part. Water is generally not recommended for cooling Celcon profiles.

For sizing of simple thin shapes, the extrudate should be passed through a set of brass or aluminum sizing plates with the first plate 5-8% oversize and the otherspprogressively smaller. Complex shapes can be sized by passing through a number of adjustable brass fingers which are appropriately positioned to produce the desired cross section.

## Processing

Profile extrusion processing conditions can vary significantly depending on the geometry of the part, thickness, equipment, resin grade and numerous other variables. It is advisable to begin processing using the general start up conditions outlined earlier this chapter and ensure that the selected Celcon resin will provide adequate melt strength, which is critical for this technique.

### *Special Sizing Techniques*

Some complex contours can be more easily made by extruding a simple shape - tube or sleeve - and continuously post-forming after the die with specially designed sizing plates, sleeves or simple brass fingers. An example of post-forming is shown in Figure 6.2. This procedure, though versatile and uses cheaper dies, requires more care and design to achieve dimensional control and may eventually be more costly.

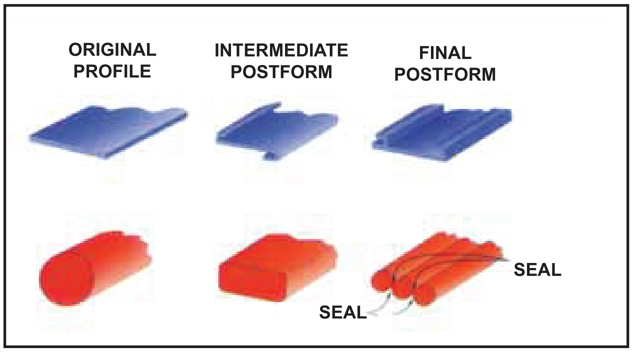


**Figure 6.2 Miscellaneous Post-Formed Profiles Shapes such as these can be made by extruding a simpler shape and forming it into a more complex contour while the extrudate is still pliable.**

**Table 6.3 High Speed Tubing Extrusion Troubleshooting Guide**

| SYMPTOMS | POSSIBLE SOLUTIONS |
|---|---|
| Brittleness | - Increase land length<br>- Decrease head temperature<br>- Decrease screw speed<br>- Biaxially orient tubing |
| Concentricity (poor) | - Increase take-off speed<br>- Increase die temperature<br>- Decrease cooling water temperature |
| Surface roughness (inside) | - Increase land length<br>- Increase take-off speed<br>- Decrease screw speed<br>- Dry resin<br>- Heat mandrel |
| Surface roughness (outside) | - Increase die temperature<br>- Decrease screw speed<br>- Control volume in the head |
| Wall thickness variation | - Maintain minimum volume in the head<br>- Increase land length<br>- Use a lower melt index material<br>- Decrease screw temperature |

### Table 6.4 Typical Conditions for Film and Sheet Extrusion

| Parameter | Film | Sheet |
|---|---|---|
| Gauge, mm (mils) | <0.25 (<10) | 0.25 - 2.5 (10 -100) |
| Materials | Celcon® M25. M90™, Special grades | |
| Extruder | 90 mm (3 1/2 in.) | |
| Screen pack, mesh size | 20-40-60-80-100 | |
| Barrel temperature, °C (°F)* | | |
| Zone 1 - rear | 185 (365) | |
| Zone 2 - rear | 195 (380) | |
| Zone 3 - rear | 195 (380) | |
| Zone 4 - rear | 200 (395) | |
| Zone 5 - Front | 200 (395) | |
| Gate temperature, °C (°F) | 195 (380) | |
| Die temperature, °C (°F) | 190 (170) | |
| Casting roll temperature, °C (°F) | | |
| Roll 1 | 115 (235) | |
| Roll 2 | 115 (235) | |
| Screw speed, rpm | 56 | 80 |
| Back pressure, MPa (psi) | 3.4 (500) | |
| Compression ratio | 3.25:1 | |
| Die | | |
| Type | "Coat hangar" or "Y" | |
| Dimensions, cm (in.) | 40 (16) | |
| Land length, cm (in.) | 3.8 (1.5) | 5.1 (2.0) |
| Production rate, mpm (fpm) | 6 - 12 (20 - 40) | 0.6 - 6 (2 - 20) |

* Using a reverse temperature profile for the extruder barrel may be helpful when maximum melt strength is required, especially for large diameter and /or heavy wall profile extrusion. Call us at 1-800-833-4882 for further information.

### Table 6.5 Film and Sheet Troubleshooting Guide

| SYMPTOMS | POSSIBLE SOLUTIONS |
|---|---|
| Dull surface | - Increase melt temperature<br>- Increase roll temperature<br>- If cloudy, dry resin<br>- If problem persists, use vented barrel |
| Lines - Across direction of extrusion | - Decrease roll temperature<br>- Eliminate chatter due to take-off<br>- Blow air between rolls and sheet/film |
| Lines - Curved | - Improve mixing by:<br>• increasing back pressure, and/or<br>• increasing screw speed, or<br>• using higher compression screw |
| Lines - in direction of extrusion | - Eliminate die nicks<br>- Eliminate lip build-up<br>- Dry resin<br>- Increase roll temperature |
| Pockmarks/spots | - Improve mixing as for curved lines<br>- Decrease roll temperature, if sticking<br>- Dry resin<br>- Use vented barrel |
| Warping | - Increase roll temperature<br>- Increase tension at take-off |

**Table 6.6 Profile Extrusion Troubleshooting Guide**

| SYMPTOMS | POSSIBLE SOLUTIONS |
|---|---|
| Distortion | - Ensure uniform temperature at all points on the die<br>- Change location of sizing plates and fingers<br>- Modify design |
| Gloss - Low in strips | - Eliminate cold or rough spots in die or sizing devices |
| Gloss - low all over | - Increase die temperature<br>- Increase melt temperature<br>- Decrease cooling rate |
| Lines | - Clean die to remove any hard particles<br>- Remove any nicks or burrs on take-off system |
| Pits - Bottom surface only | - Cool the part more throughly before placing on conveyor belt |
| Pits - All over surface | - Dry resin<br>- Check for contamination and eliminate |
| Surface roughness | - Increase die temperature<br>- Dry resin<br>- Decrease exit speed at die<br>- Use die with larger openings or longer lands<br>- Use a smaller machine |
| Surging | - Check for broken gear tooth, worn belts, controller and repair<br>- Remove likely causes for any variation in temperature, pressure, screw speed or motor load<br>- Increase pressure/lower rate<br>- Decrease temperature<br>- Use a die with longer lands<br>- Use better mixing screw |
| Warpage | - Ensure uniform cooling<br>- Support warping section until cool enough to hold shape<br>- Provide more gradual cooling<br>- Lower line speed |
| Wrong shape - Too large | - Increase pull on the contour<br>- Change take-off speed or material temperature (either way may help)<br>- Use longer lands |
| Wrong shape - Too small | - Decrease pull on the contour<br>- Change take-off speed or material temperature (either way may help)<br>- Use shorter lands |

# Rotational Casting

Rotational casting is also referred to as rotational molding or rotomolding and is a process for manufacturing hollow and seamless products of all sizes and shapes. It offers significant advantages compared to other molding techniques for the following reasons:

- Low equipment and mold costs
- Little or no scrap
- Easy adaptibility for short production runs
- Multiple products and multiple colors can be molded simultaneously

Celcon® acetal copolymer has been rotomolded into parts up to 20 feet long and weighing hundreds of pounds. For information on specific grades and processing parameters, please call Product Information Services at 1-800-833-4882.

One disadvantage of rotational casting is the potential for weak points in the rotomolded part since no pressure is applied to promote complete melding of all part sections. For applications where parts will be exposed to repeated impact, rigorous testing is recommended to ensure adequate strength over the total part surface.

## Equipment

Celcon acetal can be readily rotomolded using any type of commercially available machine, including a "carousel", "clamshell", "rock-and-roll", or "shuttle". The "shuttle" and "rock-and-roll" type machines are used most often to produce longer and heavier parts.

## Molds

For small and medium-sized parts, cast aluminum is commonly used because of its good heat transfer characteristics and cost-effectiveness. One major drawback of using cast aluminum is that its surface is easily damaged.

Sheet metal molds are normally used for prototyping and for extremely large parts. Electro- or vapor-formed nickel molds give excellent surface quality but are much more expensive.

## Particle size

Plastic powders must be used for rotational casting to ensure rapid and adequate melting. Resin particles greater than 30 mesh size will significantly increase cycle time.

## Drying

Powders used for rotational casting will have a higher surface area than the pellets normally used for other processing methods. As a result, a higher content of adsorbed water is expected. To avoid poor finished part surface due to moisture, proper drying is necessary. Six hours in an air circulating oven at 82°C (180°F) is recommended. Using a dehumidifying hopper dryer adds extra insurance against adsorbed moisture.

## Oven Conditions

Oven temperature and time must be balanced to yield a satisfactory part while avoiding thermal degradation of the polymer. Time is a key parameter in obtaining a smooth surface finish.

Too little oven time will cause inadequate melting of the plastic powder; too long oven time may lead to resin degradation.

**Figure 7.1 Rotomolded acetal copolymer parts production.**

The optimum temperature for each situation will vary and will be influenced by processing parameters such as air circulation rate, mold material of construction, and mold wall thickness, all of which affect heat transfer. In no case should melt temperature be allowed to exceed 238°C (460°F) nor should the resin be allowed to remain above 193°C (380°F) for more than 30 minutes. For thick walled parts (greater than 6.4 mm or 1/4 in.), a melt temperature of 216°C (420°F) is recommended.

## Cooling Rate

Air cooling at a moderate rate is recommended for best finished part properties. Rapid cooling will induce brittleness. For that reason, water cooling should be avoided.

**Table 7.1 Rotational Casting Troubleshooting Guide**

| SYMPTOMS | POSSIBLE SOLUTIONS |
|---|---|
| Bubbles on outer wall | - Dry resin |
| Discolored part | - Reduce time/temperature to prevent degradation |
| Flash excessive | - Ensure proper venting<br>- Confirm good parting line seal |
| Long oven cycle | - Improve air circulation<br>- Increase temperature or check temperature calibration<br>- Reduce mass of rotation arms for better heat transfer |
| Low density (less than 1.37 g/cm3) | - Optimize temperature/time to prevent degradation<br>- Dry resin |
| Poor mold filling | - Increase rotation speed<br>- Increase radii or width of mold recesses |
| Poor properties | - Increase cooling time<br>- Check part density and reduce temperature/time as needed |
| Rough inner surface | - Increase temperature and/or time for adequate melting of powder |
| Surface pitting | - Use less or no mold release<br>- Clean mold surfaces |
| Uneven wall thickness | - Remove excess metal which may be acting as heat sinks from flanges and arms<br>- Balance speed of each axis for uniform polymer flow<br>- Improve air flow path around mold |
| Warpage | - Ensure continuous mold rotation from heating through cooling cycle<br>- Clear vents to prevent vacuum formation<br>- Use slower rate of cooling |

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ENGINEERED MATERIALS

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## Engineered Materials

- Celanex® thermoplastic polyester (PBT)
- Hostaform® and Celcon® acetal copolymer (POM)
- Celstran,® Compel® and Factor® long fiber reinforced thermoplastic (LFRT)
- Celstran® continuous fiber reinforced thermoplastic (CFR-TP)
- Fortron® polyphenylene sulfide (PPS)
- GUR® ultra-high molecular weight polyethylene (UHMW-PE)
- Impet® thermoplastic polyester (PET)
- Riteflex® thermoplastic polyester elastomer (TPC-ET)
- Thermx® polycyclohexylene-dimethylene terephthalate (PCT)
- Vandar® thermoplastic polyester alloy (PBT)
- Vectra® and Zenite® liquid crystal polymer (LCP)

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