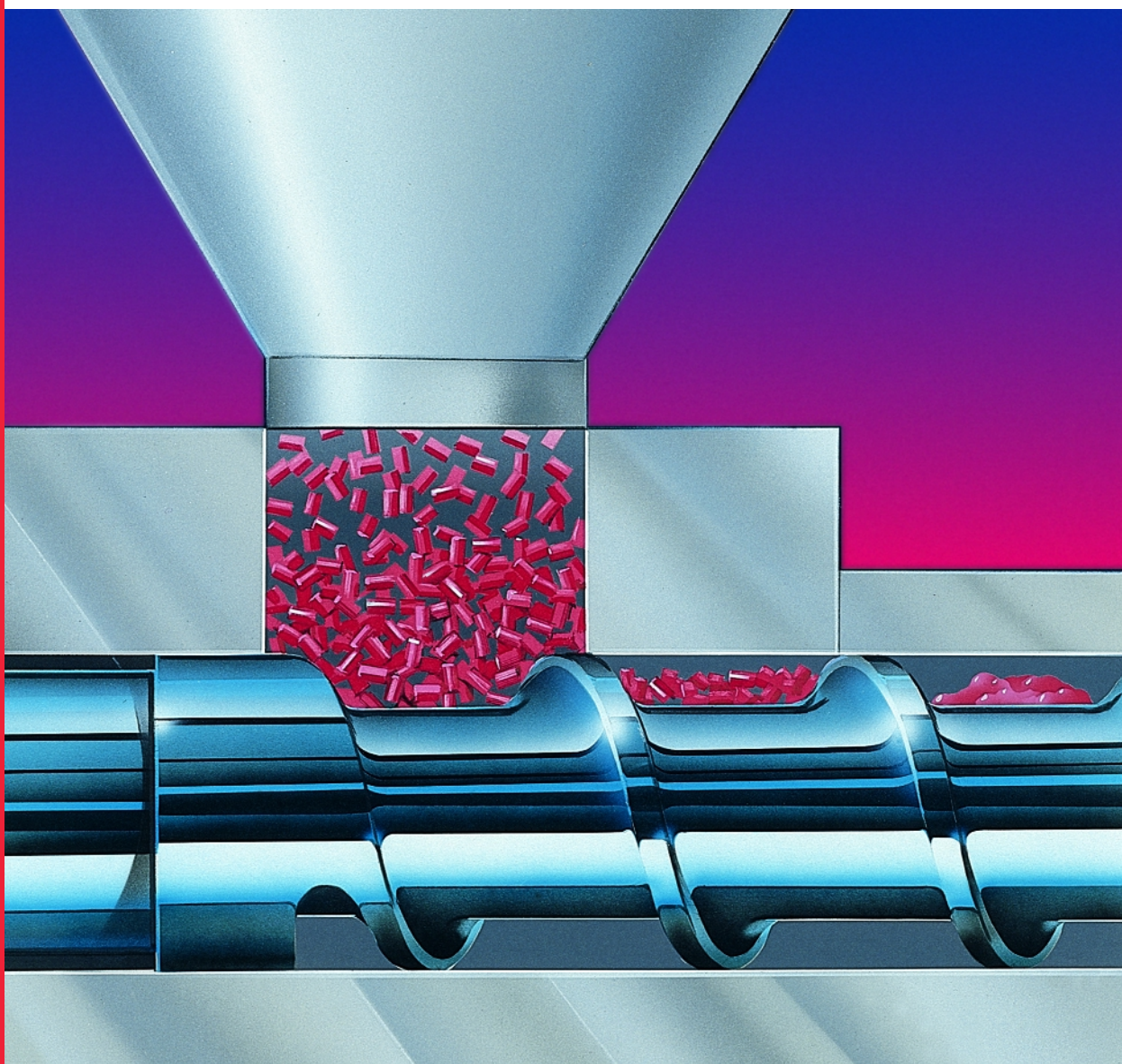


Processing Celcon®

acetal copolymer

CE-6

Processing Celcon® *acetal copolymer*



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, start-up and shutdown procedures, and the safety and health aspects pertaining to handling Celcon acetal copolymer. This information is pertinent to all processing methods. These two chapters should be read before attempting to process any grade of Celcon acetal copolymer.

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 Ticona sales representative, by calling our Technical Information Hotline at 1-800-833-4882, or on our web site, www.ticona.com.

Comments and suggestions for improving this and other Ticona literature are always welcome, and may be sent to us at the above phone number, by writing to us at the address shown on the back cover or by e-mailing the webmaster on our internet site.

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1. Overview

1.1 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 ($-\text{CH}_2\text{O}-$). Acetal homopolymer products have somewhat better short term mechanical properties than the copolymer.

Copolymers, including Celcon® acetal copolymer, are prepared by copolymerizing trioxane (a cyclic trimer of formaldehyde) with a cyclic ether (usually containing an ethoxy or other oxyalkylene group) to form a polymeric chain composed of oxymethylene ($-\text{CH}_2\text{O}-$) and oxyethylene ($-\text{CH}_2-\text{CH}_2-\text{O}-$) 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 randomly dispersed comonomer 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.

1.2 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.

1.3 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, mercury, and cadmium-free, 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.

General Purpose: General purpose 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 or ISO 1133, @ 190°C and 2.16 Kg. load). In comparison to M90, products designated by a higher melt flow rate, i.e. M270, 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 but may be more difficult to mold into parts with thin walls or long flow paths.

Glass Fiber Coupled: Glass fiber coupled (GC) 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 glass bead (GB) filled grades contain glass beads for lower shrinkage, better dimensional tolerances and warp resistance, and are especially helpful when molding large, flat and thin-walled parts.

Low Wear: Low wear (LW) 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 mineral coupled (MC) 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: The ultraviolet resistant (UV) products are available with various melt flow rates in natural and a wide variety of colors and are lead, mercury 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 Ticona brochure, “Celcon® Ultraviolet-Resistant Grades Extend Part Life in Harsh Environments” (CE-UV) for further information about these products.

Weather Resistant: Weather resistant (WR) 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 antistatic (AS) products are chemically modified to decrease static build-up for applications such as conveyor belt links and audio and video cassette hubs and rollers.

Electrically Conductive: These electrically conductive (EC) 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: The impact modified (TX) products are formulated to provide moderate to high levels of improvement in impact strength and greater flexibility compared to the standard product.

Laser Markable: The laser markable (LM) grades of Celcon acetal copolymer have been developed with enhanced capability for laser printing. These black products 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.

Colors: Most grades are available in natural, black and custom colors. There are standard color concentrates available for use in all natural grades. Custom color concentrates can also be made.

1.4 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.

1.5 Product Support

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

Table 1.1 • Regulatory Listings

Plumbing Code Bodies: International Association of Plumbing Mechanical Officials (IAPMO) Building Officials Conference of America (BOCA) Southern Standard Building Code	Plumbing fixtures and specific plumbing and mechanical applications covered in the various codes
Canada Standards Association (CSA)	Plumbing fixtures, fittings and potable water contact items, "UL" ratings in Canada
Plastic Pipe Institute (PPI)	Recommended Hydrostatic Design Stress (RHDS) rating of 1,000 psi at 23°C (73°F) as an injection molded plumbing fitting
Food and Drug Administration (FDA)	Repeated-use food contact applications including food machinery components conforming to 21 CFR 177.2470
United States Pharmacopoeia (USP)	Class VI Compliant
NSF International Standards 14, 51, 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
International Association of Food Industry Suppliers (IAFIS)	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, Military Specification LP-392-A, Mil-P-6137A(MR)]	General Material Specification
SAE J2274	Society of Automotive Engineers Global Specifications
ISO 9988-1, -2	Designation system processing conditions and testing protocols for comparative properties.

Power Seat Belt Transmission Gear Set

1



Celcon® M90™ Acetal Copolymer

Provides:

- Lubricity
- Low Coefficient of Friction
- Resistance to Lubricants
- Mechanical Strength
- Fatigue Endurance
- Surface Hardness
- Dimensional Stability
- Ease of Molding

2. General Guidelines

2.1 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 defects on molded or extruded plastic parts. This is especially critical with impact modified grades which can be moisture sensitive and deteriorate during processing.

The use of a hopper magnet in the feedstream is highly recommended to insure against 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.

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

2.2 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 copolymer 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 copolymer Material Safety Data Sheets (MSDS) for health and safety data for specific grades of Celcon acetal copolymer prior to processing or otherwise handling these products. Copies are available by calling your local Ticona sales office or Customer Services at 1-800-526-4960 or from the internet site, www.ticona.com.

2.3 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 flame. Do not allow mixing of this material with PVC, other halogen-containing materials, and partially and/or fully crosslinkable thermoplastic elastomers. Do not heat above 460°F (238°C). Avoid prolonged heating at or above the recommended processing temperature. Recommended melt temperatures 360 - 390°F (182 - 199°C).*

Avoid strong acids and oxidizing agents. Do not allow the end use application to come in contact with acidic solutions of pH = 4 or less, especially mineral acid solutions like hydrochloric, sulfuric, hydrofluoric, perchloric, nitric or phosphoric. Do not use with strongly acid salts such as zinc chloride or other Lewis acids. Do not use with chlorinated water solutions which are not typical of domestic potable water.

2.4 Drying

Celcon® acetal copolymer 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). For a hopper dryer, a three hour residence time at 82°C (180°F) is sufficient.

Caution: Formaldehyde fumes may be released; good ventilation is required in the area.

2.5 Processing Start-Up

To start up a machine which was shut down with Celcon acetal copolymer in the cylinder, the nozzle must not be blocked. This is one of the main reasons a nozzle heater band is recommended. See Table 2.1 for the typical start-up conditions.

The procedure for starting a machine with Celcon acetal copolymer already in the cylinder is as follows:

Table 2.1 · Typical Start-Up Conditions

Cylinder Temperature:		
Rear	360°F	182°C
Center	370°F	188°C
Front	380°F	193°C
Nozzle	390°F	198°C
Melt Temperature (measured by "air shot")	360 - 390°F	182 - 199°C
Mold Temperature	180 - 250°F	82 - 121°C
1st Stage Injection Pressure	11,000 - 20,000 psi (75-138 MPa)	
2nd Stage (Hold) Pressure	11,000 - 20,000 psi (75 - 138 MPa)	
1st Stage Injection Fill Time	2 - 5 seconds	
1st Stage Injection Speed	moderate	
Screw Speed	20 - 40 rpm	
Back Pressure	0 - 50 psi (Higher end if using concentrates)	
Cushion	1/8 - 1/4 in.	
Drying	180°F (82°C) for 3 hrs. (Usually not necessary)	

Set the nozzle temperature at 400-420°F (204-216°C) and cylinder temperatures to 250-275°F (121-135°C). As the nozzle and cylinder come up to temperature, the nozzle orifice should be watched for signs of drooling. When drooling occurs (indicating that the material in the nozzle is fully molten), cylinder temperatures may be raised to 370-380°F (188-193°C). A few purge shots should then be taken at reduced injection pressure and speed with no booster. If there is no blockage, cylinder and nozzle temperatures as well as other conditions may be adjusted as desired, the heating cylinder closed to the mold, and molding started on cycle.

When Celcon acetal copolymer is started in an empty cylinder, nozzle temperature should be set at 400-420°F (204-216°C) and cylinder temperature at 370-390°F (188-199°C). Using low pressure (approximately 5,000 psi) and slow injector speed, pack Celcon resin into the cylinder with several short, deliberate strokes of the screw (plunger). After a few minutes, commence another series of strokes and repeat this procedure.

As the material melts, successive packing strokes will work the material farther into the cylinder until it is full. A few air shots should then be taken to clear the cylinder of any air bubbles which may have been entrapped during the packing process. Cylinder and nozzle temperatures, cycle time and other conditions may then be adjusted as required and molding may proceed.

In all cases, once Celcon acetal copolymer is introduced into the cylinder, it should be kept moving to prevent overheating. If a delay of more than 15 minutes is anticipated, the cylinder should be backed away from the mold and the machine purged (on cycle or manually) every few minutes. If a longer delay is expected, it is recommended that the machine be shut down entirely, following the procedure outlined under "Shutting Down a Machine with Celcon."

2.6 Changing from Another Resin to Celcon Acetal

If the other resin in the processing equipment requires a higher melt temperature than Celcon acetal copolymer (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 acrylic 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 copolymer can then be placed in the machine to remove the purge compound. The machine settings can be adjusted to the desired production conditions.

2.7 Changing from Celcon Acetal Copolymer to Another Resin

In changing from Celcon acetal copolymer to another resin, similar considerations as described earlier will apply. When the machine is started up with Celcon acetal copolymer 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 copolymer (such as PVC), an intermediate purging compound such as polyethylene or acrylic 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.

2.8 Processing Shutdown

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 - 221°C (400 - 420°F)
- Turn off the cylinder heaters.
- Shut off the feed to the cylinder.
- Purge and run the barrel dry.
- Leave the screw in the forward position.
- Shut off the power to the machine.

2.9 Use of 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 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 proper clearances and screen size.

Surface absorption 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, other halogenated polymers and partially and/or fully crosslinkable thermoplastic elastomers. For any processing technique, it is particularly important to also avoid dirt and other impurities which can create surface blemishes or 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.

Table 2.2 • 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
percent retention	—	101	97
Notched Izod impact strength @ 23°C (73°F), J/m			
Value	62.5	66.8	68.3
percent retention	—	107	109

Table 2.3 • 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
percent retention	—	81.7	75.6
Tensile modulus, MPa			
Value	8,280	7,660	6,970
percent retention	—	92.6	84.2
Flexural modulus, MPa			
Value	7,250	6,830	6,350
percent retention	—	94.1	87.6

2.10 Secondary Operations

2.10.1 Finishing

Celcon® acetal can be readily machined, drilled, punched, buffed, sawed, sanded and routed 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 speeds and pressures. Standard metal working tools are satisfactory for machining Celcon acetal.

2.10.2 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, such as 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.

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 information on machining, 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.

3. 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.

3.1 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 1.2 to 3.7%. 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.

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.

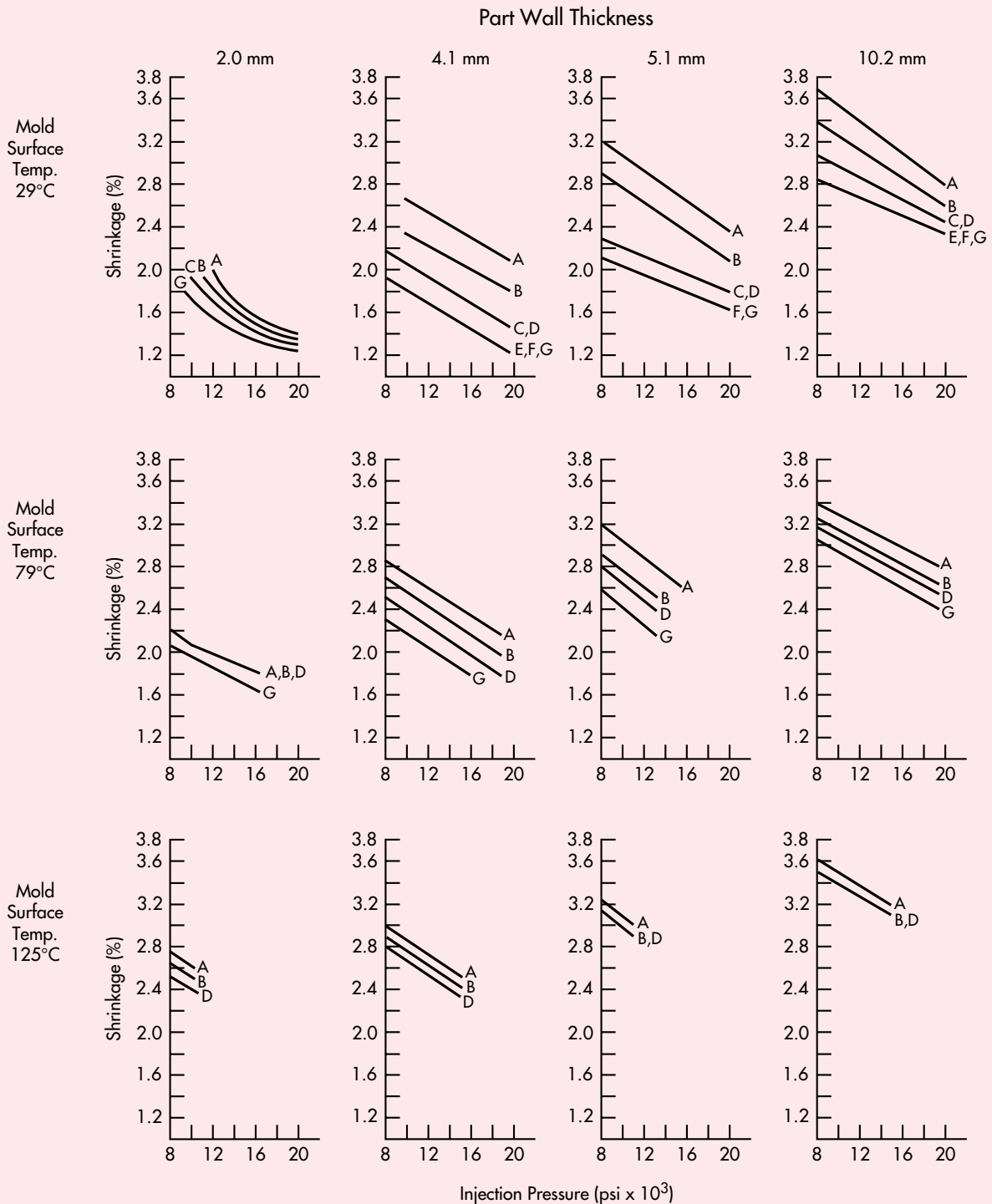
The reason for this is that reinforcing glass fibers align themselves in the direction of the material flow and, when the part cools and the material solidifies, the fibers inhibit shrinkage in this direction. Anisotropic shrinkage increases with increasing wall thickness and, in thick parts, with increasing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

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	Decreases (for parts up to 3.2 mm) No effect (for parts 3.2 - 9.5 mm thick)
Resin melt viscosity increases	Increases with increasing viscosity when molded under similar processing conditions; i.e., Celcon M270 has lower shrinkage than Celcon M25

Fig 3.1 • The Effect of Molding Conditions and Wall Thickness on Mold Shrinkage for Celcon® M90™ Acetal



NOTE: Melt temperature: 190-204°C.
Shrinkage measured in the direction of material flow.

Gate	Area (mm ²)
A	1.9
B	3.9
C	7.7
D	12.2
E	18.1
F	23.9
G	31.3

3.2 Part 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
- Mold cooling

3.3 Post-Molding Shrinkage

After mold shrinkage has occurred and the part reaches ambient temperature, further mold shrinkage may occur as time passes. This post-molding shrinkage is usually related to stress relaxation and additional crystallization within the molded part resulting in a permanent shrinkage of the part and it is affected by cooling rate, i.e. mold temperature and part thickness. Hot mold temperatures of 82 - 120°C (180 - 250°F) reduce post-mold shrinkage to nearly negligible values. At ambient temperatures, this shrinkage is relatively small, on the order of 0.1 – 0.2% for the standard unfilled 9.0 melt flow grade of Celcon® acetal copolymer.

Continuous exposure of the molded parts to high temperatures accelerates both the rate and magnitude of the post-molding shrinkage. Figure 3.2 illustrates the shrinkage behavior of the standard unfilled 9.0 melt flow grade of Celcon acetal copolymer after a six month exposure at several temperatures in the flow direction for a part 3.2 mm thick.

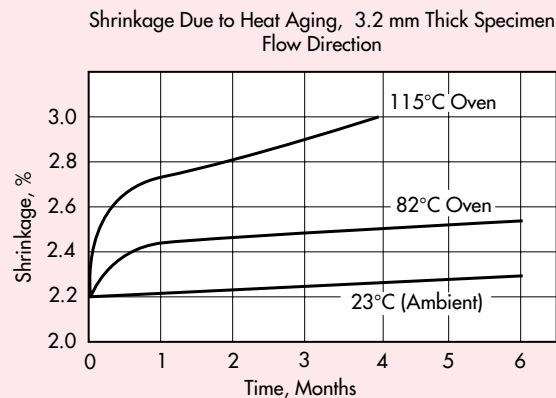
It is extremely important to utilize mold surface temperature in excess of the anticipated maximum temperature that the part may see in end use since stress is frozen into the part at the mold temperature. The frozen-in stresses will be relieved by annealing causing additional deformation.

3.4 Annealing

Annealing of Celcon acetal copolymer is sometimes useful to relax molded-in stresses and stabilize dimensions. The amount of shrinkage that may occur primarily depends on cooling rate that is affected by part thickness and mold temperature.

Table 3.2 shows examples of the shrinkage resulting from annealing two different thicknesses of an

Fig 3.2 • Shrinkage Due to Heat Aging for 9.0 Standard Melt Flow Grade of Celcon® Acetal



unfilled Celcon acetal test specimen. Annealing molded parts will lead to dimensional changes so that allowances must be made for any additional shrinkage. The decision on whether to anneal parts of Celcon acetal copolymer in a post molding operation should be made while the part and mold design are in the initial planning stage and certainly prior to machining the mold cavities and cores to size. As parts of Celcon acetal copolymer will shrink in annealing, allowance must be made for the additional shrinkage in determining the mold shrinkage which should be used for the mold cavities and cores.

As a guide, the typical values of mold shrinkage and total shrinkage after annealing obtained on 1/8 inch (3.12 mm) and 1/2 inch (12.7 mm) thick test bars, 1/2 inch (12.7 mm) wide by 5 inches (127 mm) long are shown in Table 3.2. The specimens were end-gated, molded using a mold temperature of 200°F (93°C) and annealed in oil at 305°F (152°C).

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, 82 -120°C (180 - 250° F) mold temperature will optimize the dimensional stability of an as-molded part for service temperatures up to 82°C (180°F).

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

Table 3.3 • Recommended Annealing Procedure

Required Service Temperature In-service temperature of 82°C (180°F) or below In-service temperature higher than 82°C (180°F)	Recommendation Generally, properly molded parts will not require annealing Annealing may be necessary to improve the dimensional stability of the molded part
Annealing Parameters Time Temperature Medium Cooling	Recommendation As a general rule, anneal for 15 minutes for each 3.2 mm (1/8 in.) of wall thickness if using an annealing liquid; longer if annealing in an air oven 152°C ± 2°C (305°F ± 5°F) 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 Cool annealed parts slowly (one hour for every 3.2 mm of wall thickness).

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.

3.5 Tolerances

Dimensional tolerance can be defined as a variation above and below a nominal mean dimension. If recommendations for part/mold design and proper molding are followed, typical tolerances expected are:

- ± 0.2% up to the first 25 mm (1 inch or less)
- ± 0.1% for additional length over 25 mm (1 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 tolerances to avoid excessive mold and processing costs. Also, it may be unreasonable to specify extremely close tolerances on a part which will be exposed to a wide temperature range.

3.6 Moisture Absorption

Some dimensional change is seen when Celcon acetal copolymer 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 or immersion 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.

Fig 3.3 • Water Absorption by Unfilled Celcon® Acetal Under Various Conditions

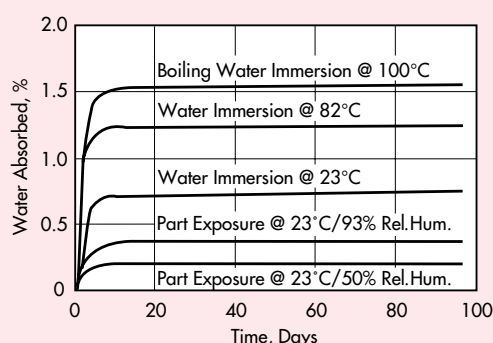
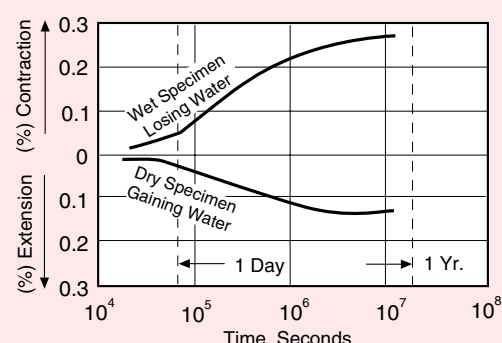


Fig 3.4 • Change in Linear Dimensions at 23°C (73°F) and 50% Relative Humidity



4. Injection Molding

4.1 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.

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

4.1.1 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/or lower productivity rates can sometimes occur.

A screw such as the one shown in Figure 4.1 having the following characteristics is recommended 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 (w) 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, (h_1 / h_2), 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.

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

Fig 4.1 • Typical Injection Molding Screw for Plasticizing Celcon® Acetal Copolymer

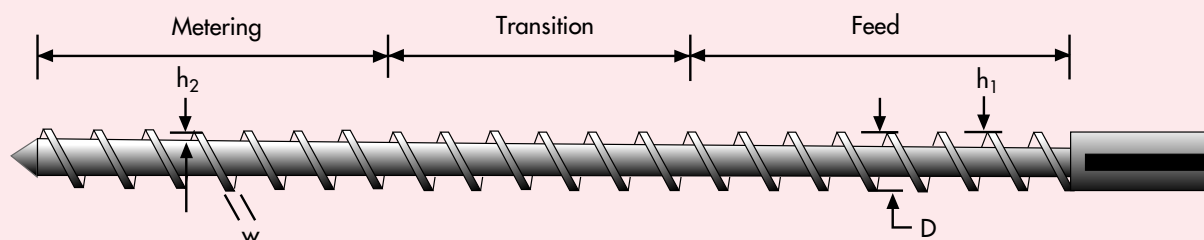


Table 4.1 • Typical Screw Dimensions for Plasticizing Celcon® Acetal Copolymer for Injection Molding

Screw Diameter (in.)	Metering (in.)	Channel Depth Feed (in.)	Ratio	Zone Length as % of screw length		
				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

ring, D, should be generously proportioned and well radiused to ensure minimum flow restriction. The mating surfaces between the screw tip, A, 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.)

4.1.2 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 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.

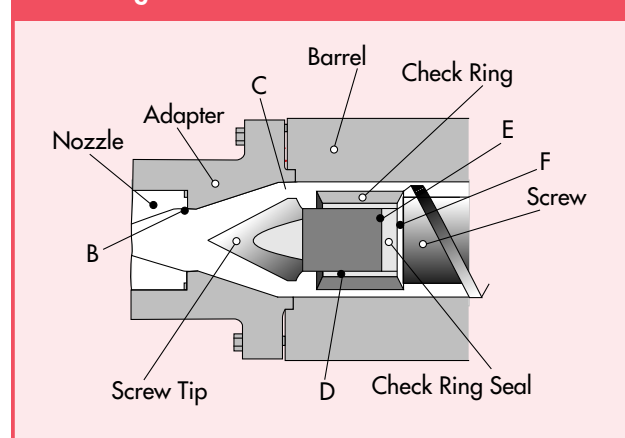
A nozzle heating band with independent temperature control is recommended for fine tuning nozzle temperature to prevent nozzle drool or freeze-off of resin in this area. While a powerstat (rheostat) can be satisfactorily used for temperature control, indicating-type temperature controllers are preferred.

4.1.3 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.

4.1.4 Clamping Force

Clamping force should be high enough to prevent the mold from opening during resin injection at maximum pressure and speed. Usually 5-10 tons clamping force per square inch of projected area (including molded parts, sprue and runners) is adequate for molding Celcon acetal copolymer. The clamping force must exceed the projected area times the second stage pressure.

Fig 4.2 • Recommended Check Valve

4.2 Mold Design

4.2.1 General Criteria

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

4.2.2 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.

4.2.3 Mold Cavities and Cores

The selection of steels for the mold can be critical to its successful performance. Just as resins are formulated to satisfy processing and performance requirements, steels are alloyed to meet the specific needs for mold fabrication, processing and its intended use. There are many different parts to the mold, e.g. cavity, gates, vents, pins, cores, slides, etc., and these may have different requirements. For example, some applications may require a mold steel with high hardness to resist wear and abrasion at the parting line while another application may require toughness to resist mechanical fatigue. Usually, steels with higher hardness and wear resistance properties tend to be more brittle and steels with higher toughness will show less wear resistance. The selection process of the tool steels should include input from the tool steel supplier, the mold designer and mold fabricator in addition to the resin supplier. Post-treatment of the mold can be used to reduce the propensity for wear. Inserts should be considered where wear may be a concern and long production runs are anticipated. For example, P-20 tool steel can be successfully used for unfilled Celcon acetal copolymer grades where a limited production run is anticipated and Rc 58 -60 tool steel may be required for molding a highly glass filled grade where an extensive production campaign is anticipated. 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 (R_C 30-35), zinc alloys or aluminum are acceptable but may not be durable enough for long or high volume production.

4.2.4 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 rust 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:

For mold surface condition and surface temperature,

- Check mold surfaces for nicks, blemishes, etc.
- Check for worn surfaces from glass-reinforced resins.
- Make sure the 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. Surface pit marks and visible flow lines are indications of low mold surface temperature.
- A minimum mold surface temperature of 82°C (180°F) is recommended for thin-walled parts (< 1.5 mm or 0.06 in. or less). Lower surface temperatures may be satisfactory for thicker-walled parts, but precautions should be taken against increased post-molding shrinkage.

For 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.
- The gates should be large enough that the cavity pressure is adequate to completely fill the part. If necessary increase the gate size, relocate the gate or add additional gates.
- Ensure that the injection hold time is adequate to prevent loss of cavity pressure before resin freeze-off in the gate.
- Pit marks in the surface are a clear indication of low cavity pressure.

For part configuration,

- Ensure that the resin melt flow path is not too long or too complex.
- Check the fill rate to ensure adequate cavity pressure.

For wall thickness,

- Injection fill pressure should be adequate, especially where a part has a thick wall-thin wall configuration. Otherwise a 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 high-shrink resins to assure sink-free parts.

For 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 ade-

quate fill. Increasing the 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.

4.2.5 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 larger than 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.

4.2.6 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. Avoid the use of sharp corners; turns should be curved to promote streamline flow and minimize stagnant areas. Full round, half round and trapezoidal cross-section 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.

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)

4.2.7 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. Celcon acetal copolymer has better thermal stability, important because of the longer heat history during runnerless molding. Celcon acetal copolymer processes at least 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. Hot runners can also 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.

Practically all commercial hot runner systems work well with Celcon acetal copolymer, with the possible 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, multi-tip 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 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 a minimum 1 mm (0.040 in.).

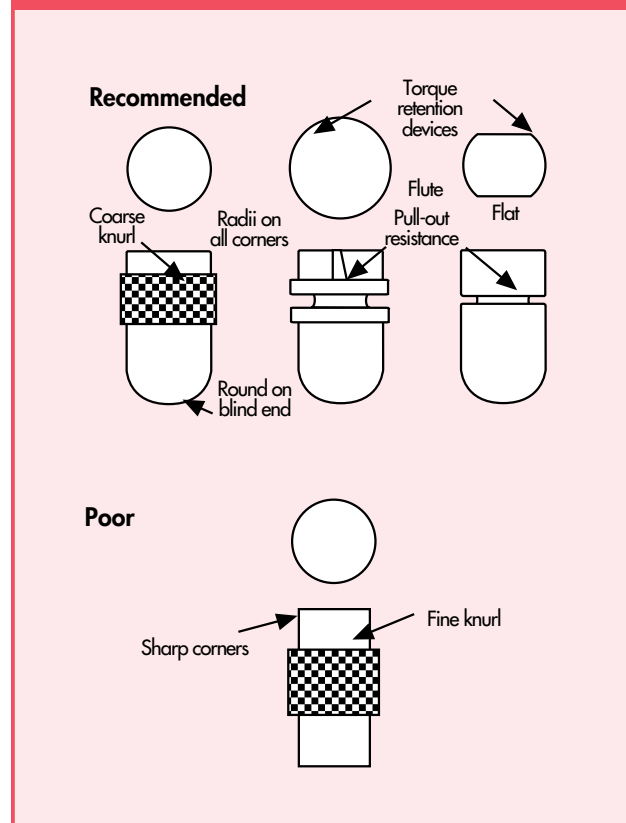
Tips should be hardened to reduce wear, especially with reinforced or filled systems, and should be designed to be easily replaced when excessively worn.

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.

4.2.8 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. Recommended designs for molded-in inserts are shown in Figure 4.3.

Fig 4.3 • Recommended Molded-In Insert Designs for Celcon® Acetal



In addition to standard insert molding, inserts can be assembled in pilot holes of molded Celcon® acetal parts, using press fits, spin welding or ultrasonic welding in a post-molding operation.

4.2.9 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.

4.2.10 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 for molding Celcon acetal parts.

Fig 4.4 • Outsert Molded Moving Parts: Gear (left), cam (center), and spring (right)

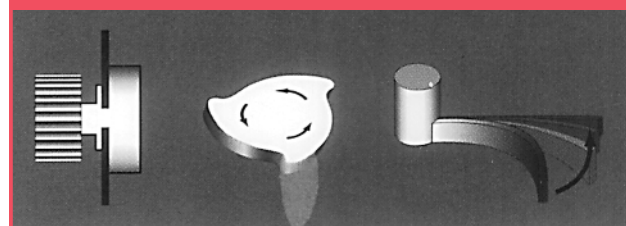
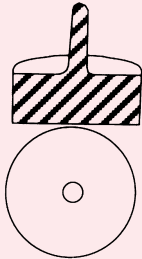
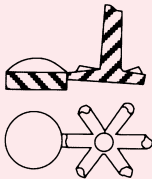
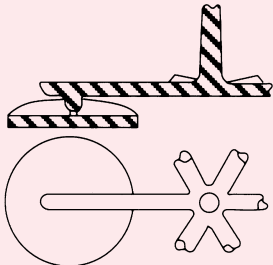
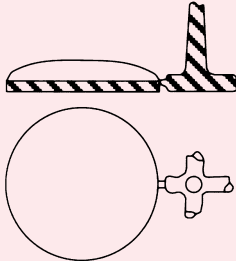
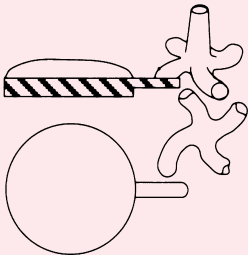
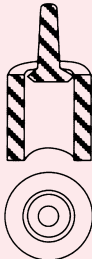
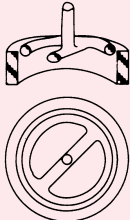
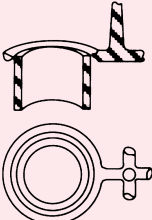
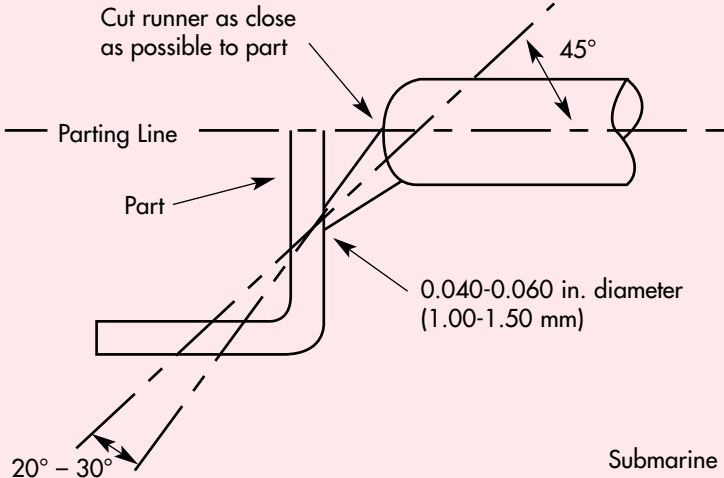
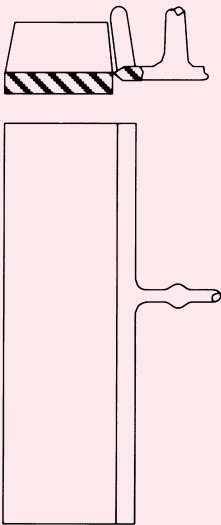


Table 4.3 • Recommended Gate Dimensions for Rectangular Edge Gates, mm (in.)

Part thickness mm (in.)	Gate width mm (in.)	Gate depth mm (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)

Fig 4.5 • Some Basic Gate Designs Suitable for Celcon® Acetal

Sprue 	Side or Edge 
Secondary Sprue (3 plate mold) 	Restricted or Pin 
Tab 	Diaphragm 
Internal Ring 	External Ring 
Cut runner as close as possible to part Parting Line Part 45° 0.040-0.060 in. diameter (1.00-1.50 mm) 20° - 30° Submarine  Flash 	

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 1.0 mm (0.040 in.), preferably greater than 1.5 mm (0.060 in.). Although parts have been successfully produced with gates as small as 0.5 mm (0.020 in.). These gate sizes should be restricted to very small parts weighing less than 1 gram wall thicknesses of less than 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.

4.2.11 Vents

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. 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 last point to fill. 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 but should not be used as the primary means of 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.

4.2.12 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.

4.2.13 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.

4.2.14 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.

4.3 Auxiliary Equipment

4.3.1 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 oil-circulating 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 when required.

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 is not recommended as it could cause localized hot spots and lead to various molding problems.

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.

4.3.2 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.

4.4 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.

4.4.1 Typical Molding Conditions

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

4.4.2 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

Table 4.4 • Typical Start-Up Conditions

Cylinder temperature, °C (°F)	182 (360) Rear 188 (370) Center 193 (380) Front 198 (390) Nozzle
Melt temperature, °C (°F)	182 - 199 (360 - 390)
Mold surface temperature, °C (°F)	82 - 121 (180 - 250)
1st stage injection pressure, MPa (10 ³ psi)	76 - 138 (11.0 - 20.0)
2nd (Hold) injection pressure, MPa (10 ³ psi)	76 - 138 (11.0 - 15.0)
1st stage injection fill time, sec.	2 - 5
1st stage injection speed	moderate
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	82°C (180°F) for 3 hrs.

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.

4.4.3 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 82 - 93°C (180 - 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.

4.4.4 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 76 - 138 MPa (11 - 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.

4.4.5 Cavity Pressure Measurement (CPM) Technology

CPM technology has been eminently successful in making it possible to produce high quality parts “shot after shot” for months (and even years!). In the basic process, pressure sensing instruments (called transducers) are placed in the mold (usually in the cavity, or at the gate) to track pressures during every cavity-filling incident. Since the cavity pressure is normally proportional to the amount of molten polymer present in the cavity (before solidification), you thus have a convenient means to determine shot-to-shot reproducibility of the process. Should one cavity-filling incident not agree with the “norm”, the parts that are produced in that specific cycle are usually segregated into a “reject” parts bin, or the like. These systems use a computer to analyze the data and make it rather easy to do diagnostic studies on a molding problem. Then, you can make any corrections that may be required to optimize the whole molding process.

The net result is that it allows one to produce parts that fall within very tight tolerances on weight, dimensions, etc. Since “out of spec” parts are not

produced or are caught when they are made, the amount of post molding QC can be reduced. Because process “fine tuning” can usually be done through the judicious use of the data generated at the time of operation, it is often possible to reduce the variability of molded part product quality.

4.5 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.

4.5.1 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, the injection speed should be reduced (preferably by reducing the injection velocity set point) as little as is necessary to eliminate flash. The injection hold time should be adequate to completely fill the mold cavities, with the screw coming to a complete stop in the fully forward position and then 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.

4.5.2 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.

4.5.3 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 beginning the next cycle. Usually about 0.2 - 0.6 seconds decompression time is satisfactory for Celcon acetal copolymer.

4.5.4 Screw Speed

Screw rotational speed and back pressure should be kept to a minimum, preferably 20-40 rpm and zero back pressure, respectively. The screw speed should be set such that the screw fully retracts just prior to the expiration of the mold close time. 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.

4.5.5 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 for unfilled Celcon acetal copolymer. Faster cycles than indicated may be obtained with grades of resins that are reinforced, filled and those with higher melt flow rates.

4.5.6 Process Optimization: Conducting a Design of Experiments (DOE)¹

Process optimization can be handled in a number of ways, but the technique that is recognized as the preferred one by injection molding experts is called the DOE, an abbreviation for Design of Experiments. Before the DOE made its entry into the field of process optimization, the most widely used technique was to conduct a long series of experiments where one process variable was changed at a time (e.g., the temperature, or the pressure, or the speed) and the effect noted. So, for example, mold temperature might be raised from an initial value of 80°F to 200°F in steps while keeping all the other molding parameters fixed. Samples would be collected at each step for testing. Then, after setting mold temperature at “the best” value, the next variable (e.g. injection pressure) would then be studied in a similar way.

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)	50
12.7 (1/2)	75

The steps repeated until all variables were studied. Thus, the process optimization would be studied one variable at a time. Obviously, the whole process was a long and involved one, and in most cases its use never really led to the “best” conditions. The big shortcoming was that the interactions among injection molding parameters would not be studied directly.

In conducting a DOE, you reduce the number of experiments substantially while still being able to measure the effects that each variable has on the process and parts. Additionally, you are able to see clearly the influence of interactions among variables. For example, what effects do the interaction of injection pressure and melt temperature (a two-factor interaction) have on the part properties? Similarly, what effects does the interaction of injection pressure, melt temperature and mold temperature (a three-factor interaction) have on part properties? Thus, the information that you obtain from the DOE provides a very detailed map of the whole process for optimizing the molding parameters.

¹ Box, G.E.P., Hunter, W.G. and Hunter, J.S., Statistics for Experimenters, John Wiley & Sons, Inc., New York (1978).

4.6 Quality Control of Molded Parts

4.6.1 Part Weight

Molded parts most often have to meet very exacting specifications, such as dimensions, color/appearance, or some measurement of performance capabilities (mechanical strength, an end-use tests, etc.). Such QC tests are usually done many hours (24 or 48) after the parts are molded. Over the years, we have found that one of the best and most timely Quality Control (QC) test that a molder can perform to predict just how a part will measure up against the established release specifications or end-use performance criteria for the part is part weight. A major feature of part weight is that it can be done almost contemporaneous with the part's molding, i.e., the weight can be determined just seconds after the part is ejected from the mold. Thus, the molder can obtain almost immediate feedback, thus allowing very timely corrective actions to be taken.

The procedure that is normally followed is to determine the average weight of known “good” parts, along with the range of deviations (+/-) from the average (e.g., 10.6 +/- 0.03 grams). Then, a systematic

weight check would be made on all production parts as they are produced. Any part over or under the range (10.57 to 10.63g) would be set aside, while those within the range would be kept for the usual subsequent QC. Causes could be identified and corrective actions taken to improve production efficiencies.

4.6.2 Part Dimensions

In the same way that part weight was determined *directly after molding*, part dimensions can be used as a QC check just as soon as the part is ejected from the mold. While we know that dimensions change with time after molding, this could be factored into the analysis. What one would do is to measure the particular dimension(s) as a function of time after molding, e.g., 0.50, 1, 4, 8, 12, 18 and 24 hours. Next, plot these data, and extrapolate the plotted line back to “zero” time. This would then give you a dimension for parts “right off the mold”, and indicate what the dimension would be 24 hours later.

4.7 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 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.

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

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 modulus	—	188 - 199 °C (370 - 390 °F)	> 104 °C (> 200 °F)	—	↓
To optimize notched bar impact	↓	↓	↓	↓	—
To decrease mold shrinkage	↑	↓	↓	—	↑
To increase mold shrinkage	↓	↑	↑	—	↓

↑ Increase

↓ Decrease

— No significant effect

Occasionally, part design criteria or processing equipment parameters may require deviation from the 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.

4.7.1 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 temperature of 77 - 104°C (170 - 220°F). Screw rotational speed and injection speed have little effect on tensile strength.

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

Modulus is most significantly affected by both mold temperature and melt temperature and increases with an increase in both temperatures. Maximum 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 modulus but to a lesser degree than both melt and mold temperatures. Injection pressure and screw rotational speed have little effect on modulus.

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). By minimizing shrinkage during molding, you will maximize the potential level of post-molding shrinkage. Thus, during use, the part could shrink out of dimensional tolerance. It is recommended to adjust initially the mold cavity dimensions for maximum shrinkage and mold at conditions of maximum shrinkage. Typical molding conditions for providing maximum mold shrinkage are shown in Table 4.7.

4.7.2 Glass-Mineral Coupled and Filled Celcon Acetal Grades

The effect of molding conditions on physical properties should be used only as a guide. Some variation in conditions will most likely be required to achieve optimum performance 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 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 consistent with adequate fill of the mold cavities with flash.

Table 4.7 • Typical Molding Conditions for Maximum Shrinkage of Unreinforced Celcon® Acetal Copolymer

Melt temperature, °C (°F)	180 - 210 (360 – 410)
Mold temperature, °C (°F)	121 (250)
Injection pressure, MPa (psi)	35 (5,000)
Injection speed	Minimum

Screw rotational speed has little effect on mold shrinkage of unreinforced Celcon grades.

4.8 Molding Problems

4.8.1 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 mold 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 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.

4.8.2 Troubleshooting Injection Molding

Table 4.8 lists common injection molding problems with possible corrective actions in the preferred order of implementation.

Table 4.8 • Troubleshooting Guide for Injection Molding Celcon® Acetal Copolymer

SYMPTOMS	POSSIBLE SOLUTIONS
Brittleness	- Lower material temperature - Check for contamination - Decrease regrind level
Burn marks	- Decrease injection speed - Decrease injection pressure - Improve venting - Increase gate size
Discoloration	- Purge machine - Lower cylinder temperature - Decrease back pressure - Lower screw speed - Decrease nozzle temperature - Reduce injection speed - Eliminate contamination from feed - Examine nozzle and cylinder for hold up points - Ensure molding machine has free flowing check ring - Move mold to machine where shot size is 50 - 75% of capacity
Nozzle drool	- Lower nozzle temperature - Lower material temperature - Minimize cushion - Delay sprue break time - Decrease mold open time - Use nozzle with smaller diameter orifice - Use decompression
Poor Weld Lines	- Increase injection pressure - Increase screw forward time - Raise mold temperature - Vent cavity at area of weld line - Raise melt temperature - Increase injection speed - Relocate gate to alter flow pattern - Provide overflow well at weld area - Check for leaking check ring

Table 4.8 • Troubleshooting Guide for Injection Molding Celcon® Acetal Copolymer (continued)

SYMPTOMS	POSSIBLE SOLUTIONS
Short Shots, Pit Marks, and Surface Ripples	- Increase feed - Increase injection pressure - Increase mold temperature - Decrease cushion - Increase injection speed - Increase injection time - Add vents - Use larger machine - Check for leaking check ring
Sink marks	- Increase injection pressure - Increase screw forward time - Maintain proper cushion - Reduce tool temperature - Increase injection speed - Increase feed - Enlarge gate or runner
Splay Marks/Delamination	- Decrease injection speed - Reduce injection rate - Enlarge gate size - Reduce cylinder temperature - Increase mold temperature - Dry material
Sticking in Cavities	- Decrease injection pressure - Decrease screw forward time - Minimize cushion - Increase mold close time - Lower mold temperature - Check for undercuts or insufficient draft
Sticking in Core	- Decrease injection pressure - Decrease hold pressure - Minimize cushion - Decrease mold close time - Decrease core temperature - Check for undercuts or insufficient draft
Unmelted Pellets	- Machine plasticizing capacity too small for shot and cycle speed required - Temperatures too low, particularly at rear zone - Increase screw speed - Increase back pressure - Check for proper compression screw - Check for wear of the screw or barrel - Check for proper screw flight depth
Voids	- Increase injection pressure - Increase screw forward time - Decrease cushion - Increase mold temperature - Increase feed, gate, runner, sprue - Check for leaking check ring
Warpage/part distortion	- Equalize temperature in both halves of mold - Check uniformity of ejection - Check handling of parts after ejection from mold - Increase hold time - Alter injection pressure - Increase cooling time - Reduce material temperature - Try differential mold temperatures to counteract warp - Fixture parts in a cooling jig

5. Blow Molding

5.1 Blow Molding Methods

Blow molding Celcon® acetal copolymer allows for 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 fluid 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.

5.1.1 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.

5.1.2 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.

5.2 Equipment

5.2.1 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 (length-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 trouble-free blow molding.

5.2.2 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. Compression 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,
- 10 - 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		
Production rates	Lower	Higher
Finishing required	Considerable	Little or none
Waste and regrind	Some	Little or none
Product		
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 5.2.

5.2.3 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.

5.2.4 Breaker Plate

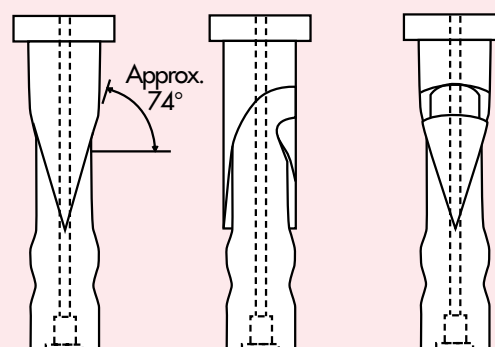
A breaker plate should be used to hold the screen pack firmly in place while interfering as little as possible with a smooth flow of the melt stream. A breaker plate is a steel plate usually about 6.4 mm (1/4 in.) thick and perforated with closely-spaced 6.4 (1/4 in.) holes. The holes in the breaker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

5.2.5 Die Head

A die head and adapter 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.

Fig 5.1 • Flow Pin Divider to Promote Smooth Flow and Avoid Weld Lines



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.

Table 5.2 • Typical Screw Characteristics to Plasticize Celcon® Acetal Copolymer for Blow Molding

Screw Diameter mm (in.)	Channel Depth			Zone Length as % of screw length		
	Metering mm (in.)	Feed mm (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 minimum 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”.

5.2.6 Die

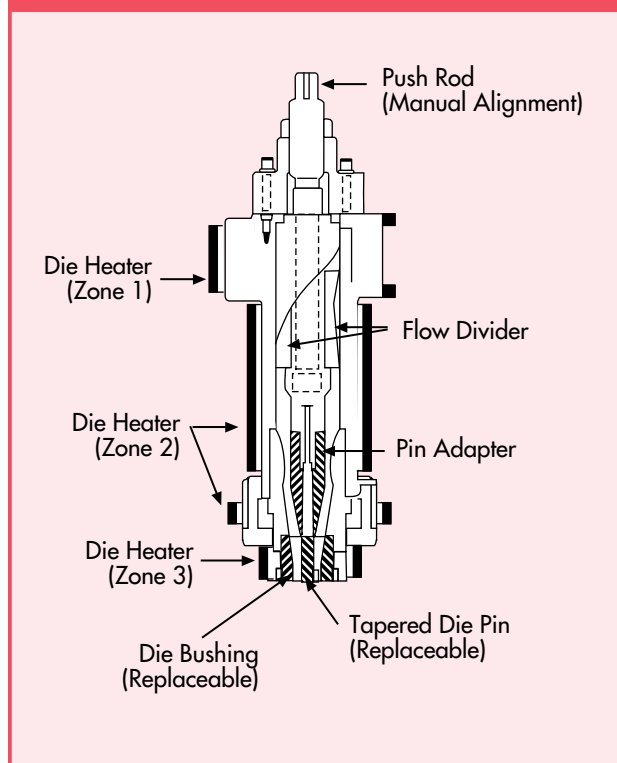
The parison die is a key element in blow molding because it controls material distribution in the finished item, and, in turn, influences the economics of the final product. Figure 5.2 shows a parison die with an adjustable core pin which allows control of the thickness of the parison.

5.2.7 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 with a three hour capacity 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.

5.2.8 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.

Fig 5.2 • Parison Die with Adjustable Core Pin for Control of Parison Thickness

If a mold cavity is not properly vented, trapped air can hold the plastic material away from the cavity surface, interfere with heat transfer in the cavity and result in a poor finish on the molded part. Vents 0.051-0.102 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.

5.3 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) to provide a satisfactory parison with maximum melt strength.

5.3.1 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 3.5 oz. Bullet shape	Aerosol Container 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 Mold- accumulator
Extruder size, mm (in)	64 (2.5)	64 (2.5)	64 (2.5)
L/D	24:1	24:1	20:1
Compression ratio	3.5:1	3.5:1	2.5:1
Die busing ID, mm (in.)	14.9 (0.588)	17.8 (0.700)	—
Die mandrel OD, 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	149 (300)	171 (340)	216 (420)
Zone 2		171 (340)	166 (330) 210 (410)
Zone 3		182 (360)	171 (340) 204 (400)
Zone 4		166 (330)	171 (340) 204 (400)
Adapter	188 (370)	166 (330)	204 (400)
Die Zone 1	188 (370)	166 (330)	204 (400)
Zone 2		204 (400)	166 (330) 210 (410)
Zone 3		210 (410)	191 (375) —
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)

5.3.2 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.

5.3.3 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.

5.4 Effects of Process Variables on Part Dimension and Quality

5.4.1 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.

Fig 5.3 • Effect of Mold Temperature on Shrinkage

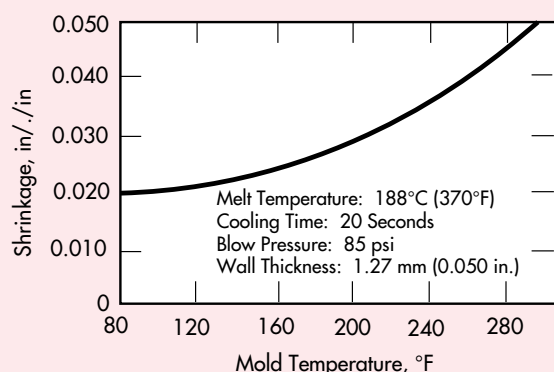


Fig 5.4 • Effect of Cooling Time on Shrinkage

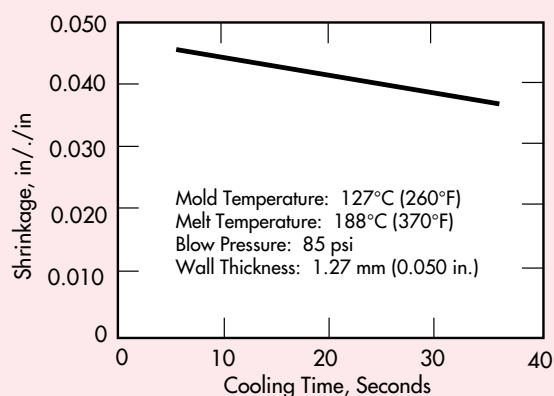


Fig 5.5 • Effect of Blow Pressure on Shrinkage

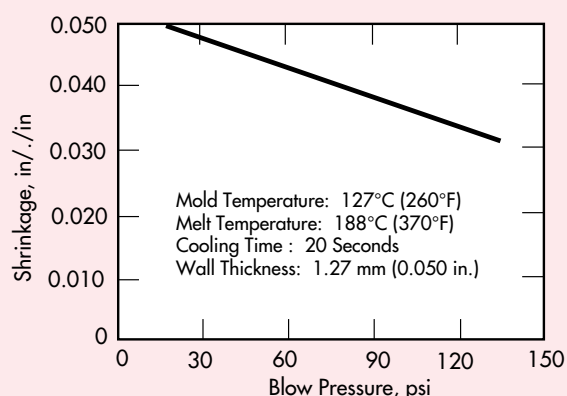
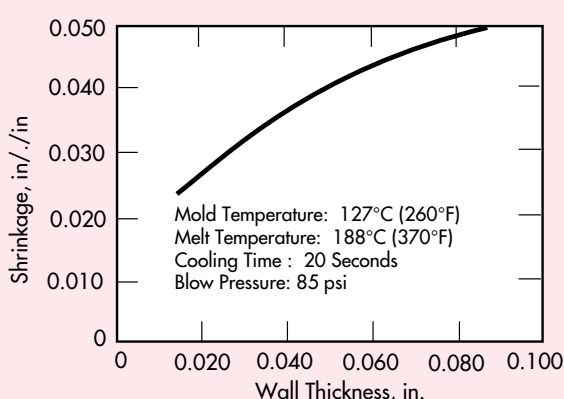


Fig 5.6 • Effect of Wall Thickness on Shrinkage



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.

5.4.2 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.

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

Fig 5.7 • Landed Pinch-off For Improved Impact Strength

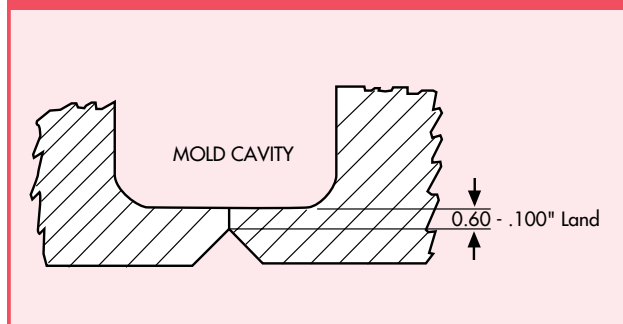
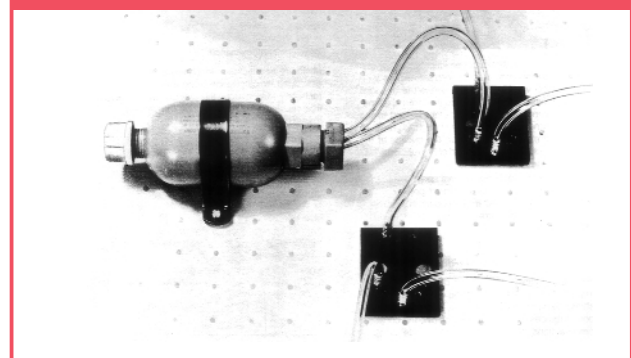


Fig 5.8 • Blow Molded Fluidic Capacitor



6. Extrusion

Higher molecular weight grades of Celcon® acetal copolymers (higher viscosity than for injection molding, such as Celcon M25) are recommended 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.

6.1 Equipment

6.1.1 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 freedom in selecting the most cost effective material for a specific application for dies, sizing sleeves, etc.

6.1.2 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.

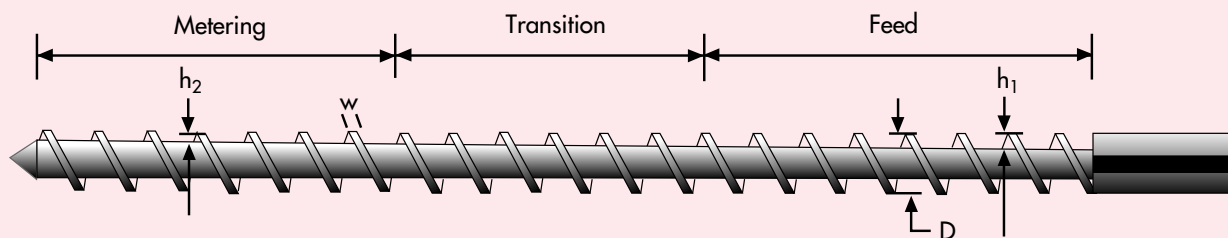
6.1.3 Screw Design

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 resistant 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.

Fig 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, (h_1/h_2), 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.

6.1.4 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.

6.1.5 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.

6.1.6 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 with a three hour capacity 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.

6.2 High Speed Tubing Extrusion

6.2.1 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 OD 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.

Table 6.1 • Recommended Metering Screw Dimensions for Extrusion

Screw Diameter mm (in.)	Channel Depth		Zone Length as % of screw length		
	Metering mm (in.)	Feed mm (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

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 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).

6.2.2 Processing

Die and Head Temperature: The die and head temperatures should be in the range of 190 - 230°C (374 - 446°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 micro-inches R.M.S. Although surface roughness decreases with increasing die temperature, a die temperature of 230°C (446°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 plates or 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

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	Metering
Compression ratio 3:1	
Metering zone depth 3.6 mm (0.14 in.)	
Screw speed	33 RPM
Screen pack	20-40-80-40-20 mesh
Sizing	Four plates, 6.4 mm (2 1/2 in.) apart: #1. 7.1 mm (0.281 in.) diameter #2. 6.2 mm (0.242 in.) diameter #3. 5.6 mm (0.220 in.) diameter #4. 5.2 mm (0.204 in.) diameter
Die dimensions	
Mandrel	4.3 mm (0.170 in.) diameter
Bushing	7.2 mm (0.285 in.) diameter
Die temperature	230°C (450°F)
Barrel temperature °C (°F)	
Zone 1	180 (360)
Zone 2	190 (370)
Zone 3	195 (380)
Zone 4	200 (390)
Zone 5	205 (400)
Line Conditions	
Motor	24 Amps
Line speed	128 m/min (420 ft/min)
Air pressure	0.1 MPa (1 1/4 psig)
Head pressure	210 MPa (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.)

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 = 1.74 drawdown ratio
(0.400 in./0.230 in.)

i.d. 4.57mm/2.79mm = 1.6 blow-up ratio
(0.180 in./0.110 in.)

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

Troubleshooting: Table 6.3 lists some typical problems for high speed tubing extrusion and suggested solutions.

6.3 Film and Sheet Extrusion

6.3.1 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 (1.5 - 2.0) 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.

6.3.2 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.

6.3.3 Troubleshooting

Table 6.5 lists potential problems during film and sheet extrusion and possible corrective actions.

6.4 Profile Extrusion

6.4.1 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 screw	25% length of (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 others progressively 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.

6.4.2 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 in this chapter and ensure that the selected Celcon® resin will provide adequate melt strength, which is critical for this technique.

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. Examples of post-forming parts are shown in Figure 6.2. This procedure, though versatile and using less expensive dies, requires more care and design to achieve dimensional control and may eventually be more costly.

Fig 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.

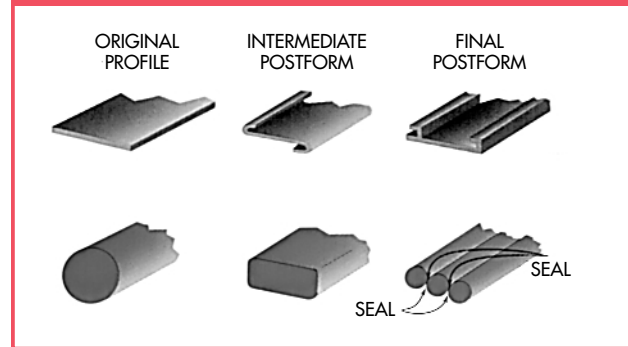


Table 6.3 • High Speed Tubing Extrusion Troubleshooting Guide

SYMPTOMS	POSSIBLE SOLUTIONS
Brittleness	- Increase land length - Decrease head temperature - Decrease screw speed - Biaxially orient tubing
Concentricity (poor)	- Increase take-off speed - Increase die temperature - Decrease cooling water temperature
Surface roughness (inside)	- Increase land length - Increase take-off speed - Decrease screw speed - Dry resin - Heat mandrel
Surface roughness (outside)	- Increase die temperature - Decrease screw speed - Control volume in the head
Wall thickness variation	- Maintain minimum volume in the head - Increase land length - Use a lower melt flow rate material - 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	Celcon® M25, M90, Special grades
Extruder	90 mm (3 1/2 in.)	90 mm (3 1/2 in.)
Screen pack, mesh size	20/40/60/80/100	20/40/60/80/100
Barrel temperature, °C (°F)*		
Zone 1 - rear	185 (365)	185 (365)
Zone 2 - rear	195 (383)	195 (383)
Zone 3 - rear	195 (383)	195 (383)
Zone 4 - rear	200 (392)	200 (392)
Zone 5 - Front	200 (392)	200 (392)
Gate temperature, °C (°F)	195 (383)	195 (383)
Die temperature, °C (°F)	190 (374)	190 (374)
Casting roll temperature, °C (°F)		
Roll 1	115 (239)	115 (239)
Roll 2	115 (239)	115 (239)
Screw speed, rpm	56	80
Back pressure, MPa (psi)	3.4 (500)	3.4 (500)
Compression ratio	3.25/1	3.25/1
Die		
Type "Coat hangar" or "Y"	"Coat hangar" or "Y"	
Dimensions, cm (in.)	40 (16)	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 - Increase roll temperature - If cloudy, dry resin - If problem persists, use vented barrel
Lines - Across direction of extrusion	- Decrease roll temperature - Eliminate chatter due to take-off - Blow air between rolls and sheet/film
Lines - Curved	- Improve mixing by: • increasing back pressure, and/or • increasing screw speed, or • using higher compression screw
Lines - in direction of extrusion	- Eliminate die nicks - Eliminate lip build-up - Dry resin - Increase roll temperature
Pock marks/spots	- Improve mixing as for curved lines - Decrease roll temperature, if sticking - Dry resin - Use vented barrel
Warping	- Increase roll temperature - 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 - Change location of sizing plates and fingers - Modify design
Gloss - Low in strips	- Eliminate cold or rough spots in die or sizing devices
Gloss - low all over	- Increase die temperature - Increase melt temperature - Decrease cooling rate
Lines	- Clean die to remove any hard particles - Remove any nicks or burrs on take-off system
Pits - Bottom surface only	- Cool the part more thoroughly before placing on conveyor belt
Pits - All over surface	- Dry resin - Check for contamination and eliminate
Surface roughness	- Increase die temperature - Dry resin - Decrease exit speed at die - Use die with larger openings or longer lands - Use a smaller machine
Surging	- Check for broken gear tooth, worn belts, controller and repair - Remove likely causes for any variation in temperature, pressure, screw speed or motor load - Increase pressure/lower rate - Decrease temperature - Use a die with longer lands - Use better mixing screw
Warpage	- Ensure uniform cooling - Support warping section until cool enough to hold shape - Provide more gradual cooling - Lower line speed
Wrong shape - Too large	- Increase pull on the contour - Change take-off speed or material temperature (either way may help) - Use longer lands
Wrong shape - Too small	- Decrease pull on the contour - Change take-off speed or material temperature (either way may help) - Use shorter lands

7. 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 adaptability 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 one or more impact, rigorous testing is recommended to ensure adequate strength over the total part surface.

7.1 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.

7.2 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.

7.2.1 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.

7.3 Processing Parameters

7.3.1 Resin Drying Conditions

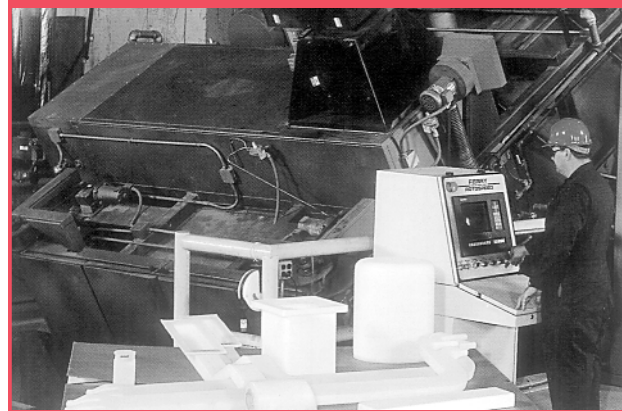
Powders used for rotational casting will have a higher surface area than the pellets normally used for other processing methods. As a result, a higher content of adsorbed water is expected. To avoid poor finished part surface due to moisture, proper drying is necessary. Six hours in an air circulating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

7.3.2 Part Heating Oven Parameters

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.

Fig 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.

7.3.3 Part Cooling Rates

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.

7.4 Troubleshooting

Table 7.1 lists some potential problems that may be encountered during rotational casting and possible solutions.

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 - Confirm good parting line seal
Long oven cycle	- Improve air circulation - Increase temperature or check temperature calibration - Reduce mass of rotation arms for better heat transfer
Low density (less than 1.37 g/cm ³)	- Optimize temperature/time to prevent degradation - Dry resin
Poor mold filling	- Increase rotation speed - Increase radii or width of mold recesses
Poor properties	- Increase cooling time - 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 - Clean mold surfaces
Uneven wall thickness	- Remove excess metal which may be acting as heat sinks from flanges and arms - Balance speed of each axis for uniform polymer flow - Improve air flow path around mold
Warping	- Ensure continuous mold rotation from heating through cooling cycle - Clear vents to prevent vacuum formation - Use slower rate of cooling

NOTICE TO USERS: To the best of our knowledge, the information contained in this publication is accurate; however, we do not assume any liability whatsoever for the accuracy and completeness of such information.

Any values shown are based on testing of laboratory test specimens and represent data that fall within the standard range of properties for natural material. Colorants or other additives may cause significant variations in data values.

Any determination of the suitability of this material for any use contemplated by the users and the manner of such use is the sole responsibility of the users, who must assure themselves that the material as subsequently processed meets the needs of their particular product or use.

It is the sole responsibility of the users to investigate whether any existing patents are infringed by the use of the materials mentioned in this publication.

Please consult the nearest Ticona Sales Office, or call the numbers listed above for additional technical information. Call Customer Services for the appropriate Materials Safety Data Sheets (MSDS) before attempting to process these products.

Celcon® acetal copolymer is not intended for use in medical or dental implants.

Products offered by Ticona

Celcon® and Hostaform® *acetal copolymer (POM)*

GUR® *ultra-high molecular weight polyethylene (UHMWPE)*

Celanex® *thermoplastic polyester*

Impet® *thermoplastic polyester*

Vandar® *thermoplastic polyester alloy*

Riteflex® *thermoplastic polyester elastomer*

Vectra® *liquid crystal polymer (LCP)*

Celstran® *long fiber reinforced thermoplastics*

Fortron® *polyphenylene sulfide (PPS)*

Celanese® *Nylon 6/6 (PA 6/6)*

Topas® *cyclic-olefin copolymer (COC)*

Encore® *recycled thermoplastic molding resins*

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