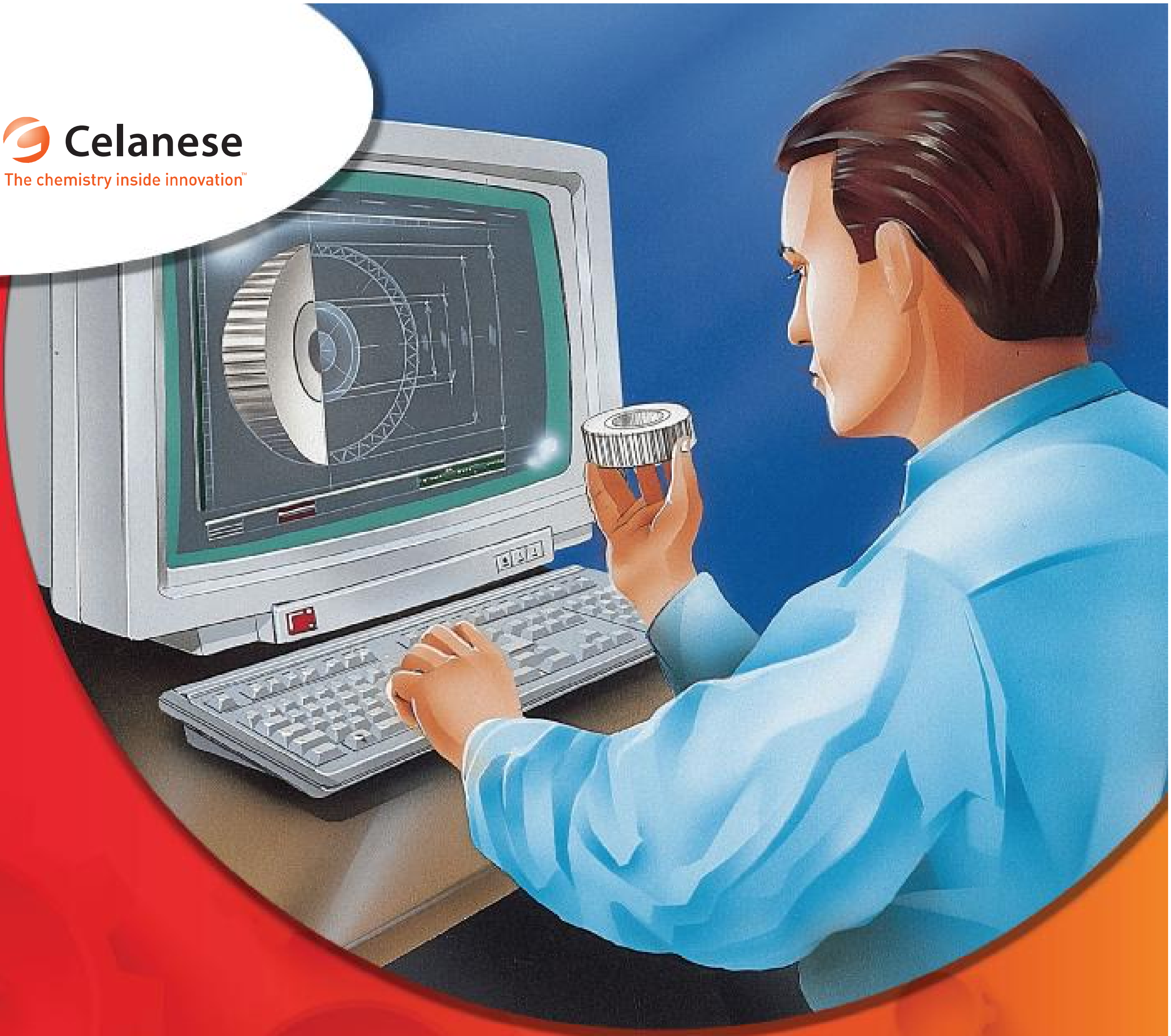
Celanese

The chemistry inside innovation™



Celcon® POM

Acetal Copolymer (POM)

Designing with Celcon®

Foreword

The Celcon® Acetal Copolymer Design Manual (CE-10) is written for parts designers, materials engineers, mold designers and others wishing to take advantage of the unique and desirable features of this versatile line of thermoplastic materials.

This manual covers the basic structure and product characteristics of the broad classes of the Celcon acetal copolymer product line and its physical, thermal, mechanical, and electrical properties. Dimensional stability, creep and other long term properties, and resistance to the environment (including chemical resistance) are also discussed. An introduction to gear and bearing design is included. Mold design criteria, methods of assembly, and secondary operations including machining, part bonding and surface decoration complete the brochure.

Throughout the manual, the design information is presented primarily for product classes rather than for individual grades, using a descriptive rather than a detailed mathematical treatment. Some simple calculation examples are included to illustrate a specific property (such as creep deflection) where appropriate.

Celanese provides additional technical literature to compliment this brochure. Readers will find information on general design principles of engineering thermoplastics in Designing with Plastics: The Fundamentals (TDM-1). Additional specific information on Celcon acetal copolymer can be found in Celcon acetal copolymer Short-term Properties Brochure (CE-4), Celcon acetal copolymer Processing and Troubleshooting Guide (CE-6) and Celcon acetal copolymer Ultraviolet Resistant Grades Extend Part Life in Harsh Environment (CE-UV). These brochures are available from our Internet site, www.celanese.com, or can be requested through Technical Information at 1-800-833-4882.

Comments and suggestions for improvement of this and other Celanese technical literature are always welcome, and should be sent to us by phone at 1-800-833-4882, or by writing to us at the address shown on the back cover.

Table of Contents

Introduction

Overview **1**
Physical and Thermal Properties **2**
Mechanical Properties **3**
Dimensional Stability **4**
Environmental Resistance **5**
Electrical Properties **6**
Part Design Criteria **7**
Gear Design **8**
Bearing Design **9**
Mold Design **10**
Assembly **11**
Machining and Surface Operations **12**

List of Figures

Overview 1
Physical and Thermal Properties 2
Mechanical Properties 3
Dimensional Stability 4
Environmental Resistance 5
Electrical Properties 6
Part Design Criteria 7
Gear Design 8
Bearing Design 9
Mold Design 10
Assembly 11
Machining and Surface Operations 12

List of Figures (continued)

List of Tables

Overview 1
Physical and Thermal Properties 2
Mechanical Properties 3
Dimensional Stability 4
Environmental Resistance 5
Electrical Properties 6
Part Design Criteria 7
Gear Design 8
Bearing Design 9
Mold Design 10
Assembly 11
Machining and Surface Operations 12

List of Tables (continued)

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 (-CH2O). Acetal homopolymer products have somewhat better short-term mechanical properties than copolymer.
- **Copolymers,** including Celcon® acetal copolymer, are prepared by copolymerizing trioxane (cyclic trimer of formaldehyde) with a cyclic ether (usually containing an ethoxy group) to form a polymeric chain composed of oxymethylene (-CH2O) and oxyethylene (-CH2-CH2-O-) repeating units. Copolymers have a wider processing window than homopolymers, and are inherently more stable and resistant to thermal degradation during service life. This is because the repeating copolymer units block polymer "unzipping" under thermal stress.

Both the homopolymer and copolymer are endcapped, and also contain specific additives to prevent irreversible thermal depolymerization of the polymer backbone during processing.

1.2 General Characteristics

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

Celcon acetal copolymer can be converted easily 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 and slab stock, which can be machined readily into desired shapes, is also available.

1.3 Product Types

Both standard and specialty 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 form and in color concentrates, which may be blended with other grades. All colorants used in Celcon resins are lead and cadmium- free. The most common categories of Celcon resins are described below.

Unfilled

General purpose M-series products are identified by melt flow rate. Divide the grade number by 10 to obtain the melt flow rate [e.g., Celcon acetal copolymer M90™ has a melt flow rate of 9.0 (grams per 10 minutes, per ASTM D 1238)]. Products designated by a higher melt flow rate (i.e. Celcon acetal copolymer M450) fill thinner walls and complex shapes more readily and maintain the same strength and stiffness, but exhibit a slight decrease in toughness. Products with lower melt flow rates, i.e. Celcon acetal copolymer M25 exhibit, increased toughness. Celcon acetal copolymer CFX-0288 is an unfilled acetal polymer used for blow molding and extrusion where high melt strength is required.

Glass Fiber Coupled

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

Glass Bead Filled

These grades contain glass beads for low shrinkage and warp resistance, especially in large, flat and thin-walled parts.

Low Wear

Low wear grades are chemically modified to provide low coefficient of friction and enhanced wear resistance, and are exceptional for demanding applications requiring low surface wear and enhanced lubricity.

Mineral Coupled

These products contain chemically coupled mineral fillers in varying percentages. The mineral filled grades are recommended whenever resistance to warpage (especially in thin sections) and dimensional stability are key application parameters.

Ultraviolet Resistant

These grades are available in a wide variety of colors and are lead- and cadmium-free. They are specially formulated for improved resistance to color shift and mechanical degradation from ultraviolet light and are available in various melt flow rates. Consult the Celanese brochure, Celcon® Acetal Ultraviolet- Resistant Grades Extend Part Life in Harsh Environments (CE-UV) for further information about these products.

Weather Resistant

Weather resistant products are formulated for maximum outdoor weathering resistance. Several different melt flow rate grades are offered. Black is the only color available.

Antistatic

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

Electrically Conductive

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

Impact Modified

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

Table 1.1 · Regulatory listings

Agency	Scope
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
Canadian Standards Association	Plumbing fixtures, fittings and potable water contact items
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)	Food contact applications including food machinery components conforming to 21 CFR 177.2470, Drug and Device Master Files
United States Pharmacopoeia (USP)	Class VI Compliant
NSF International Standards 14, 51, 61	Items including plumbing components for contact with potable water
Underwriters Laboratories (UL)	Various UL ratings for flammability, electrical, mechanical and thermal service use
Dairy and Food Industries Supply Association (DFISA)	Sanitary Standards 3A compliant
United States Department of Agriculture (USDA)	Approved for direct contact use with meat and poultry products
ASTM 6778 [Replaces ASTM 4181, Military Specification LP-392-A, Mil-P-6137A(MR)]	General Material Specification

1.4 Regulatory Codes and Agency Listings

Many grades of Celcon® acetal copolymer are in compliance with 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 or go to www.celanese.com for further information.

1.5 Product Support

In addition to our technical publications, experienced design and application development engineers are available for assistance with part design, mold flow characterization, materials selection, specifications and molding trials. Call Product Information Services at 1-800-833-4882 for further help.

1.6 Safety and Health Information

The usual precautions must be observed 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 Material Safety Data Sheets (MSDS) for health and safety data for specific grades of Celcon acetal copolymer prior to processing or otherwise handling of these products. Copies are available by calling your local Celanese sales representative or Customer Services at 1-800-526-4960 or www.celanese.com.

Warning – Avoid PVC and partially cross-linked thermoplastic elastomer vulcanizates

Celcon acetal copolymer and polyvinyl chloride (PVC) (or other chlorinated polymers) are mutually incompatible and must never be allowed to mix in the molten polymer during processing, even in trace amounts.

When heated, PVC forms acidic decomposition products which can rapidly degrade Celcon acetal copolymer at processing temperatures, releasing large quantities of irritating formaldehyde gas. Celcon acetal copolymer and PVC should not be processed in the same equipment. If this is unavoidable, thorough purging with acrylic or polyethylene or disassembling and thoroughly cleaning the machine's components is essential prior to the introduction of the second material.

Some partially cross-linked thermoplastic elastomer vulcanizates contain catalysts that are detrimental to Celcon acetal copolymer and potentially can cause the release of large quantities of irritating formaldehyde gas. Celcon acetal copolymer and the partially crosslinked thermoplastic elastomer vulcanizates should not be processed in the same equipment. If this is unavoidable, thorough purging with acrylic or polyethylene or disassembly and thorough cleaning of the machine's components is essential prior to the introduction of the second material.

It is strongly recommended that in cases of known or suspected contamination, the molding machine including the barrel, screw, check ring, screw tip and nozzle, be disassembled and thoroughly cleaned.

2. Physical and Thermal Properties

2.1 Crystallinity

Celcon® acetal copolymer is a semicrystalline polymer consisting of amorphous and crystalline regions. Molding conditions have a significant effect on the degree of crystallization of a molded part which, in turn, affects performance. For parts with walls less than 1.5 mm thick, use a mold temperature of at least 82°C (180°F) to fully crystallize the part and obtain the optimum performance properties.

2.2 Thermal Conductivity

Celcon acetal copolymer, like other thermoplastics, is a thermal insulator and is slow to conduct heat. The addition of inorganic materials such as glass fibers and minerals, may cause a slight increase in thermal conductivity. Some typical values are shown in Table 2.1.

2.3 Specific Heat

Specific heat is a parameter used in mold flow calculations for processing and also for part design. It measures the amount of heat energy necessary to increase the temperature of a given mass of material by one degree. Typical values for Celcon acetal copolymer in the solid and in the molten state are shown in Table 2.1.

2.4 Coefficient of Linear Thermal Expansion

The coefficient of linear thermal expansion (CLTE) is a measure of the linear change in dimensions with temperature, and for plastics the CLTE is generally much higher than for metals. This is an important design consideration and will be covered in detail in Chapter 4 (Dimensional Stability).

2.5 Thermal Stability

Heating Celcon acetal copolymer above 238°C (460°F) should be avoided. At these temperatures, formaldehyde, a colorless and irritating gas that can be harmful in high concentrations, is generated. Proper ventilation should always be provided when processing Celcon acetal copolymer at elevated temperatures.

Table 2.1 · Thermal and physical properties of Celcon acetal copolymer grades

Property	Units	Unfilled Grades	25% Glass Fiber Grades	Toughened Grades
Specific Gravity 23°C (73°F)	—	1.41	1.58	1.37 – 1.39
Specific Heat				
Solid	cals/g/°C	0.35	0.27	—
	BTU/lb/°F	0.35	0.27	—
Melt	cals/g/°C	0.56	0.41	0.49
	BTU/lb/°F	0.56	0.41	0.49
Coefficient of Linear Thermal Expansion Range: 23°C to 80°C Flow Direction	°C-	1.2 x 10-4	0.3 x 10-4	1.2 - 1.4 x 10-4
Thermal Conductivity	BTU/hr/ft2/°F/in.	0.00552	—	—
	cal/sec/cm2/°C/cm	1.6	—	—
Melting Point	°C (°F)	165 (329)	165 (329)	165 (329)

2.6 Flammability

Based on the ASTM D635 flammability test, Celcon® acetal copolymer is classified as a slow burning material. Typical burning rates for the unfilled and glassfilled products are shown in Table 2.2.

The burning rate of Celcon acetal copolymer decreases rapidly as thickness increases, according to Federal Motor Vehicle Safety Standard (FMVSS) 302. At a thickness of 1.5 mm, which is generally the minimum for Celcon acetal copolymer molded parts, the rate is 28 mm/min which is well below the maximum allowable rate of 100 mm/min.

In areas where life support in an occupied environment can be affected by burning materials, factors such as smoke generation, oxygen depletion and toxic vapors must be considered when selecting the proper plastic. Once ignited, Celcon acetal copolymer burns in air with a barely visible blue flame and little or no smoke. Combustion products are carbon dioxide and water. If air supply is limited, incomplete combustion will lead to the formation of carbon monoxide and, possibly, small amounts of formaldehyde.

Table 2.2 · Flammability and burning rate of Celcon acetal copolymer

Flammability Test	Product	Sample Thickness	Burn Rate
ASTM D 635	Unfilled 25% Glass	3.2 mm 3.2 mm	28 mm/min. 25 mm/min.
Federal Motor Vehicle Safety Standard 302	Unfilled Unfilled	1.5 mm 1.0 mm	28 mm/min. 51 mm/min.
UL 94	Unfilled	≥ 0.71 mm	Flame Class HB

3. Mechanical Properties

Celanese

3.1 Introduction

Properly designed parts made of Celcon® acetal copolymer have been used in a wide variety of industrial and consumer applications for many years because of its advantages over metals, other thermoplastics and acetal homopolymers. To take full advantage of the superior characteristics of Celcon acetal copolymer, a knowledge of its mechanical characteristics is essential. This chapter will cover both the short-term mechanical properties and the long-term time and temperature dependent characteristics that must be considered for proper part design.

For designers who would like a general overview of the principles and concepts of plastic part design, we recommend the Celanese publication, Designing with Plastic: The Fundamentals (TDM-1). It may be obtained by contacting your local Celanese representative, Product Information Services at 1-800-833-4882 or by going to www.celanese.com.

3.2 ISO Test Standards

Celanese performs its plastic testing and reporting of data according to ISO (International Organization for Standardization) test methods, where available. The ISO standards provide reproducible and consistent test data for Celcon acetal copolymer products and support the global quality standards for all of our plastic products. This brochure contains both ISO and ASTM data as indicated.

As an illustration, Table 3.1 presents a partial listing of the ISO and ASTM short term property data for three representative grades of Celcon acetal copolymer. A more complete listing of ASTM data can be found in the brochure Celcon acetal copolymer Short Term Properties (CE-4).*

*Note. Since ISO testing uses samples having different specimen geometry and different test conditions than ASTM, ISO and ASTM test results may not be equivalent for the same plastic material, even when both results are expressed in metric units. For example, from Table 3.1 the ASTM tensile strength value for the standard 9.0 melt flow grade is 60.7 MPa (8,800 psi): the corresponding ISO value is 66 MPa.

Table 3.1 · ISO/ASTM typical properties comparison

ISO Data*			**Grade/Type**		
Property	**Method**	**Units**	**Grade M90™ Unfilled; 9.0 melt flow**	**Grade TX90 Plus Unfilled; very high impact strength**	**Grade GC25T 25% Glass-coupled**
Tensile Strength (Yield)	ISO 527	MPa	66	46	131 (Break)
Tensile Modulus	ISO 527	MPa	2,780	1,700	8,520
Elongation @ Yield	ISO 527	%	9	14	3 (Break)
Flexural Modulus	ISO 178	MPa	2,640	1,560	8,470
Charpy Notched Impact	ISO 179/1eA	KJ/m2	5.8	11	8.7
Izod Notched Impact	ISO 180/1eA	KJ/m2	5.5	9.8	7.9
DTUL@ 1.80 MPa	ISO 75/Af	°C	100	80	150
ASTM Data*			**Grade/Type**		
Property	**Method**	**Units**	**Grade M90™ Unfilled; 9.0 melt flow**	**Grade TX90 Plus Unfilled; very high impact strength**	**Grade GC25T 25% Glass-coupled**
Tensile Strength	D 638	psi	8,800	6,000	20,000
Elongation (Yield)	D 738	%	8	11	3.5 (Break)
Flexural Modulus	D 790	psi x 104	37.5	22.0	120
Izod Impact (Notched)	D 256	ft-lb/in.	1.3	2.5	1.8
HDT@ 264 psi	D 648	°F	230	176	325

3.3 Short Term Mechanical Properties

3.3.1 Tensile and Elongation

A typical Celcon® acetal copolymer stress-strain curve per ISO 527 test conditions is shown in Figure 3.1 for glass-coupled, unfilled, and impact modified grades.

For the unfilled material, the stress/strain response is effectively linear to approximately 1% strain. This corresponds to a stress of about 28 MPa indicatingan effective modulus of about 2,800 MPa. All of the standard unreinforced grades of Celcon acetal copolymer exhibit a strength at yield (which is also the ultimate strength) of approximately 66 MPa.

Fig 3.1 · Celcon acetal copolymer stress-strain properties (ISO 527)

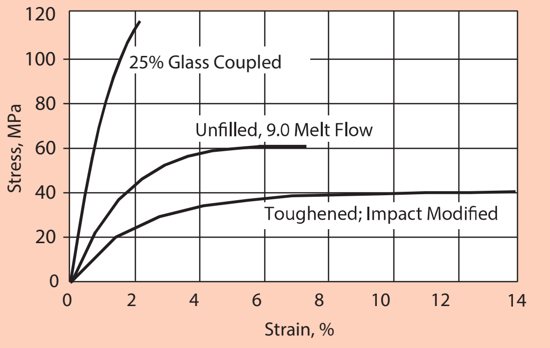
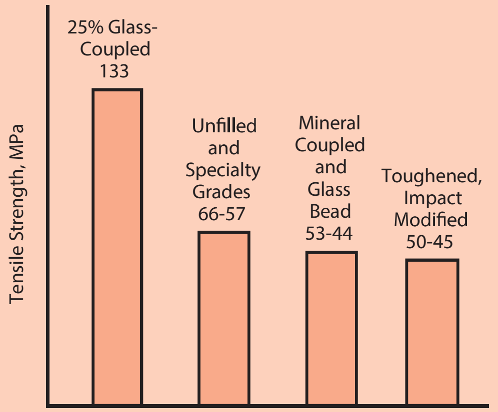


Fig 3.2 · Celcon acetal copolymer tensile strength range (ISO 527)



The range of tensile strength of the various Celcon acetal copolymer grades is shown in Figure 3.2. Ultimate tensile strength values range from 133 MPa for the 25% glass-reinforced grade to approximately 45 MPa for an unreinforced, impact modified grade.Glass reinforcement up to 25% increases tensile strength approximately 85% over the unfilled base polymer.

Fig 3.3 · Celcon acetal copolymer tensile modulus range (ISO 527)

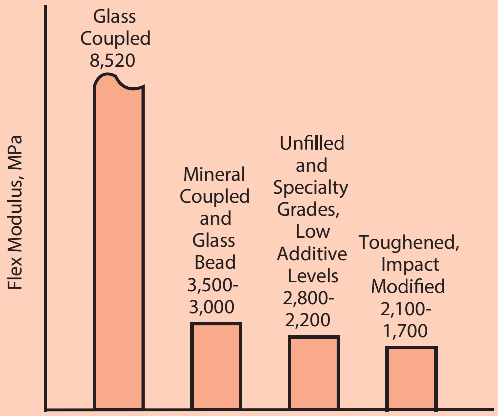
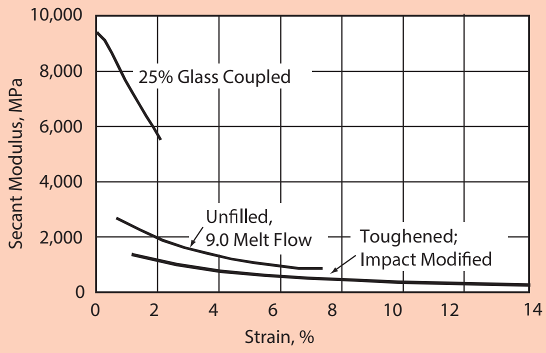


Fig 3.4 · Celcon acetal copolymer secant modulus range (ISO 527)



3.3.2 Elastic Modulus

The elastic modulus generally reported for plastic materials is either the tensile modulus or the flexural modulus according to ISO 178. Either tensile or flexural modulus may be used in design calculations calling

for the elastic modulus (or Young's modulus). Figure 3.3 depicts typical values of the tensile modulus for various grades of Celcon® acetal copolymer. As expected, the fiber reinforced grades show the highest modulus of up to approximately 8,500 MPa. The modulus of the standard grades and those grades with low levels of various additives are typically around 2,600-2,800 MPa. Mineral and glass bead modified grades are generally higher while impact modified grades become progressively lower as impact modifier concentration increases.

3.3.3 Secant Modulus

The initial modulus is useful for a first approximation of polymer stress-strain values. Either the tensile or flexural modulus value can be used according to ISO or ASTM test methods. However, at strain values greater than 1.0% (at room temperature), a better approximation of stress can be obtained by using the secant modulus.The secant modulus is calculated by dividing the stress by the strain, so that Figure 3.4 (Celcon acetal copolymer secant modulus range) is derived from Figure 3.1.

Example 3-1. Predicted Stress from Secant Modulus

A part made from a standard unfilled grade of Celcon acetal copolymer is subjected in use to a momentary 3% strain. From the initial modulus of 2,800 MPa, the predicted stress would be 84 MPa, well beyond the yield strength of approximately 66 MPa shown in Figure 3.1. However, using the secant modulus of approximately 1,800 MPa (at 3% strain) from Figure 3.4, the predicted stress would be 54 MPa, which is less than the 66 MPa yield strength value.

3.3.4 Charpy and Izod Impact

While not directly used in design calculations, the Charpy and Izod Notched Impact Test (ISO 179 and ISO 180) and similar impact tests are used as indications of the sensitivity of the material to sharp corners and notches in the molded parts. Table 3.1 shows the range of notched Charpy and Izod notched impact test results for the various Celcon acetal copolymer grades. The highest notched impact value of 11 kJ/m2 is reported for the grade with a maximum level of impact modifier, while the lowest value of 2.5 kJ/m2 is obtained for glass bead modified grade. Most standard grades of Celcon acetal copolymer have notched Charpy impact values of approximately 5-6 kJ/m2.

3.3.5 Poisson's Ratio

Poisson's ratio for most plastics falls between 0.3 and 0.4. Celcon acetal copolymer is no exception. Using a Poisson's ratio of 0.37 is generally adequate for most stress and deflection calculations requiring this value. At elevated temperatures, a Poisson's ratio of 0.38 may be more appropriate.

3.3.6 Shear Modulus

For general design calculations, the shear modulus can be obtained from the relationship between tensile modulus and Poisson's ratio as given by the following equation:

$$G = \frac{E}{2\,(1 + \nu)}$$

where G is the shear modulus, E is the tensile modulus, and ν is Poisson's ratio. At ambient conditions a good working value for shear modulus for standard unmodified Celcon acetal copolymer grades is 1,000 MPa.

3.3.7 Shear Strength

The shear strength for standard grades of Celcon acetal copolymer is typically given as 53 MPa (7,700 psi) using the conditions specified in ASTM D 732. (There is no comparable ISO method). The test involves measuring the load as a round hole is punched in the specimen. As a result the shear strength as measured includes contributions by bending and compressive forces. Therefore, when the shear strength is required, it is recommended that either the published strength or 1/2 of the tensile strength be used, whichever is smaller. This is usually adequate for most design calculations and applies to all grades of Celcon acetal copolymer.

3.3.8 Weld Line Strength

Weld line strength of Celcon® acetal copolymer approaches the strength of the base resin in well molded parts. To compensate for difficult mold flow conditions and complex design requirements, it is recommended that the weld line strength be conservatively estimated as 80-90% of the published tensile strength for the specific Celcon grade. Thus, the weld line strength of most grades of Celcon acetal copolymer with strengths of 66 MPa and above can be estimated at 53-59 MPa.

This value is particularly critical for glass reinforced resins, because the weld line strength is considerably below the tensile strength of the material in the flow direction, which is typically reported. This is due to the glass reinforcement not crossing the weld line. The designer should contact Product Information Services at 1-800-833-4882 for information on weld line characteristics for specific grades.

3.3.9 Molding Effects

The data shown in this manual was generated for test samples molded at the recommended processing conditions for the various grades of Celcon acetal copolymer. Consult Bulletin Celcon acetal copolymer Processing and Troubleshooting Guide (CE-6) for typical molding conditions. Occasionally, part design criteria or processing equipment parameters such as gate size, melt temperature and mold temperature may require the molder to deviate from recommended conditions. Moreover, actual parts are usually more complex than laboratory tensile or flex bars. To maximize engineering performance, the designer, molder and raw materials supplier should work closely together to specify molding parameters based on actual part performance.

3.3.10 Anisotropy

Most crystalline thermoplastic resins, including unfilled and fiber-reinforced grades of Celcon acetal copolymer, are anisotropic; i.e. they exhibit different properties in the flow and transverse directions after molding (such as different shrinkage values). Another effect of anisotropy is seen in differences in mechanical properties. In some cases the strength in the transverse direction can be as little as 50% of that reported in the machine direction. The effect is minimal in unfilled grades of Celcon acetal copolymer and literature values for mechanical properties may be used "as is" for design purposes.

However, when designing parts using glass fiber-reinforced grades of Celcon acetal copolymer we recommend that the literature values for strength and modulus of these grades be reduced by approximately 20%-25% to compensate for the effects of anisotropy. For round or cylindrical parts, less of a reduction needs be taken.

Since our results are based primarily on tests of laboratory samples, it is recommended that the designer consult with his local Celanese representative, or call Product Information Services at 1-800-833-4882 for further information before finalizing part geometry.

3.3.11 Abrasion/Wear Resistance

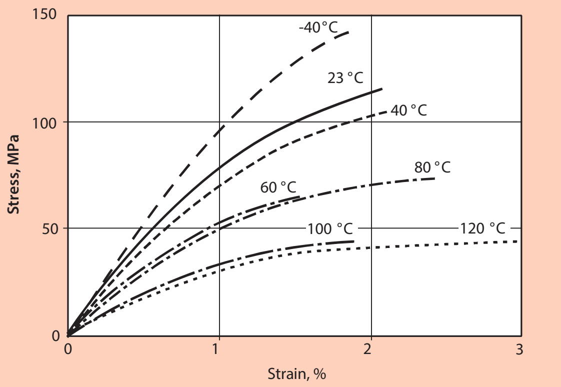
Abrasion resistance is commonly measured by the Taber Abrasion Test, in which a weighted wheel abrades a Celcon acetal copolymer molded disc at a constant rate. Per ASTM D 1044, using a 1,000 g load and a CS-17F wheel, the abrasion resistance for both unfilled and glass-reinforced Celcon acetal copolymer grades was 6 mg at 1,000 cycles. Other polymers including nylon and polyester have significantly higher abrasion rates.

Many end-use applications for Celcon acetal copolymer take advantage of the inherent lubricity, smooth surface and excellent wear resistance exhibited by the base polymer. Applications such as conveyer links, gears and bearings (see Chapters 8 and 9) depend on these properties for successful operation. Celcon acetal copolymer low wear grade, such as LW90, LW90F2 and LW90S2, can be used to further enhance wear resistance and reduce noise generation.

3.3.12 Temperature Effects

Short term property data sheets generally provide information only at room temperature. Other tests are needed to expand the thermal range of mechanical properties. The most useful data for design is tressstrain measurements at various temperatures. Other tests including Dynamic Mechanical Analysis (DMA), eflection Temperature Under Load (DTUL) and Underwriters Laboratories (UL) Thermal Index Ratings are used to compare or specify materials. As a general rule, copolymers, as typified by Celcon® acetal copolymer, retain their mechanical properties under thermal stress to a greater extent than acetal homopolymers (See Chapter 1).

Fig 3.5 · Stress-strain plot for 25% glass-reinforced grade of Celcon acetal copolymer (ISO 527)



3.3.13 Stress-Strain Measurements

Stress-strain plots measured at different temperatures are useful tools for describing the thermal-mechanical behavior of a plastic. Figures 3.5, 3.6 and 3.7 present the stress-strain plots at various temperatures for three basic grades of Celcon acetal copolymer: 25% glass fiber reinforced, unfilled 9.0 melt flow and a toughened grade respectively.

Fig 3.6 · Stress-strain plot for unfilled 9.0 melt flow grade of Celcon acetal copolymer (ISO 527)

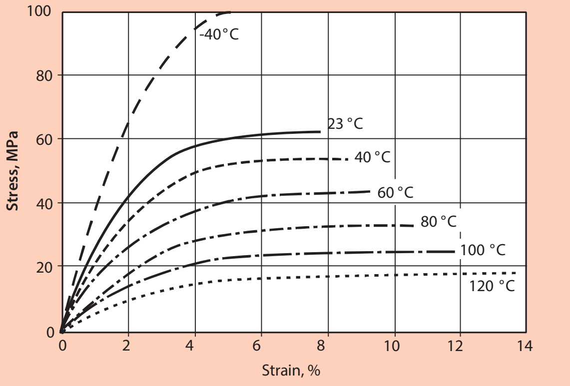
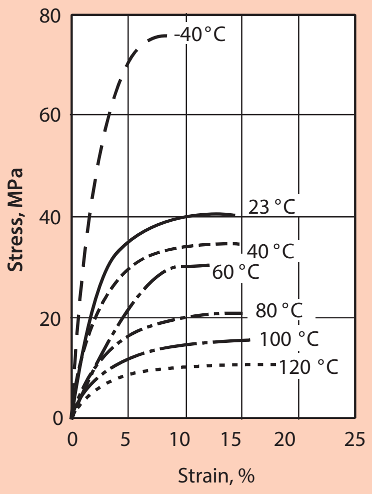


Fig 3.7 · Stress-strain plot for toughened grade of Celcon acetal copolymer (ISO 527)



Figures 3.8, 3.9 and 3.10 respectively show the secant modulus-strain curves generated from the stress-strain curves for the same three Celcon® acetal copolymer grades, again plotted versus temperature. These plots provide insight into mechanical performance for typical grades at elevated temperatures and may be used in part design.

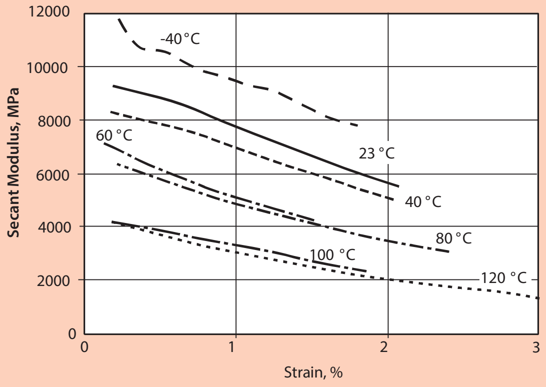


Fig 3.8 · Secant modulus-strain plot for 25% glass-reinforced grade of Celcon acetal copolymer

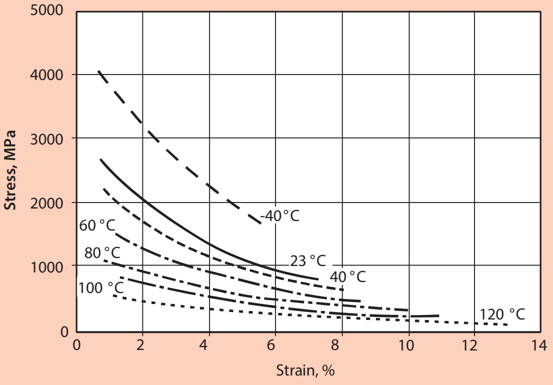


Fig 3.9 · Secant modulus-strain for unfilled 9.0 melt flow grade of Celcon acetal copolymer

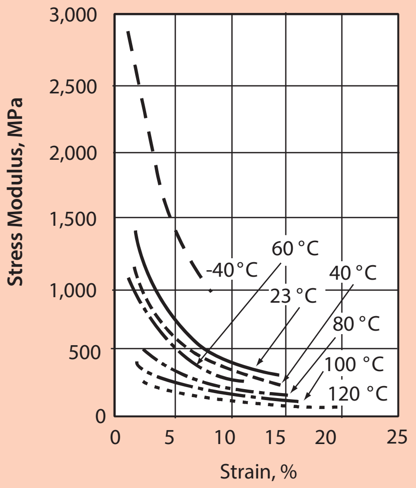


Fig 3.10 · Secant modulus-strain plot for toughened grade of Celcon acetal copolymer

3.3.14 Dynamic Mechanical Analysis

Dynamic Mechanical Analysis (DMA) was developed primarily to investigate the morphology of materials together with their energy absorption characteristics. Parts designers have begun to use this technique to investigate elastic modulus behavior within their useful temperature range. The test is most useful when stress-strain curves are lacking or incomplete over the operating temperature range of the material.

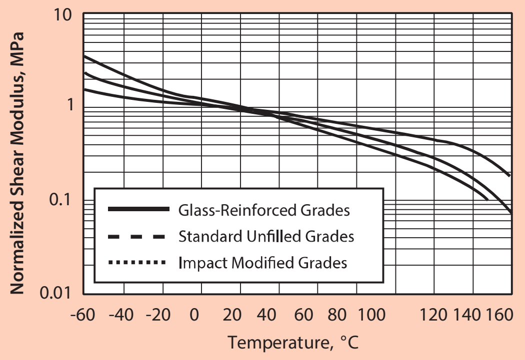
Test samples can be loaded in tension, bending or shear. The test imposes very small oscillating deflections while measuring the resulting force on the test specimen over the temperature range of -40°C to almost the melting point of the material. A continuous plot is generated of modulus (or other characteristic) versus temperature.

The temperature-modulus plot is often normalized by dividing all of the modulus data per individual curve by the room temperature modulus value to more readily compare different DMA tests obtained on the same material but run under different test conditions.

A semi-log plot of temperature-modulus provides additional insight into modulus values at elevated temperatures. The beginning of the final downward curvature at elevated temperatures is often considered the maximum useful temperature of the material. The designer should exercise extreme care and evaluate prototype parts whenever the operating specifications call for thermal exposure close to the material's DMA downward point of curvature.

Figure 3.11 illustrates the normalized DMA plot of shear modulus versus temperature of typical grades of Celcon® acetal copolymer (measured by the torsional pendulum method). Most grades of Celcon acetal copolymer will fall within the range of these plots. The data indicate that all three grades show the start of downward curvature at approximately 120°C.

Fig 3.11 · Typical normalized Celcon acetal copolymer DMA plot



The designer can use the DMA plot to determine a shift factor to be applied to the room temperature modulus value to obtain a modulus at any operating temperature. For example, the modulus of a standard unfilled 9.0 melt flow grade of Celcon acetal copolymer is 50% of its room temperature value at approximately 80°C.

3.3.15 Deflection Temperature Under Load (DTUL)

DTUL Values are given in Table 3.1 using ISO Test Method 75/Af (flatwise test) for three typical grades of Celcon acetal copolymer: Celcon acetal copolymer GC-25T [25% glass-fiber reinforced] (150°C); Celcon acetal copolymer M90™ [standard unfilled 9.0 melt flow] (100°C); and Celcon acetal copolymer TX90 PLUS, [a toughened grade] (80°C). DTUL is useful for comparing different materials for their relative resistance to mechanical stress (three-point bending) at elevated temperature.

The designer can, however, obtain much more information than just the relative material resistance information referred to above by properly interpreting the DTUL test results.

Under DTUL, a test specimen is loaded in threepoint bending at a specified stress. The deflection is then continuously measured as the temperature of the test bar is increased at a rate of 2°C per minute using a heating medium such as an oil bath. The temperature is recorded when a specific deflection is reached. Since both the stress and strain (deflection) are specified, if it is assumed that the material is linearly elastic and follows Hooke's Law; then the test temperature can be measured when the flexural modulus drops to a specific value.

Table 3.2 illustrates the corresponding flexural modulus at the DTUL temperature for any material tested under the three test methods specified in ISO 75:

Table 3.2 · DTUL stress-modulus values per ISO 75 test method

Test Method	**A**	**B**	**C**
Applied Stress, MPa	1.8	0.45	8.0
Flexural Modulus @ DTUL Temperature, MPa	930	230	4,100
Flexural Modulus @ Room Temperature, MPa		**Value**	
Standard Unfilled Grade		2,600	
Toughened Grade		1,600	
Glass-Reinforced Grade		8,500	

Using Method A as an example, if the designer requires a material with a flexural modulus of 1,520 MPa, then the temperature where the modulus has dropped to only 930 MPa may well be of interest; as is the case with the standard unfilled grade. In this case Method A or B would be appropriate to use. However Method A (or B) would not be of much interest to designers requiring high modulus values (such as with the glass-reinforced grade) which has an initial room temperature modulus of 7,600 MPa, because by the time the temperature has reached a modulus of 930 MPa one is very close to the crystalline melting point of the material and well beyond its useful temperature range. In this case one would choose Method C, which provides much more useful DTUL information than either Methods A or B for all glass reinforced grades.

Table 3.3 provides DTUL values for typical grades of Celcon® acetal copolymer together with recommendations as to which values to use by grade type:

Table 3.3 · Expanded DTUL table for Celcon acetal per ISO 75 test method

Grade Type	**Recommended ISO Test Method**	**DTUL Temperature °C**
Standard Unfilled	A	100
	B	155
Toughened	A	80
	B	135
Glass-Reinforced	A	150
	C	130

3.3.16 Underwriters Laboratories (UL) Thermal Index Ratings

The UL Relative Thermal Index (RTI), often referred to as the Continuous Use Temperature, has been obtained for most grades of Celcon acetal copolymer and can be found on the UL "Yellow Card" or on-line at http://database.ul-.com. This card lists values for electrical properties (dielectric strength), mechanical properties with impact (i.e. impact strength) and mechanical properties without impact (i.e. tensile strength). These values are an estimate of the temperature at which grades of Celcon acetal copolymer can be continuously exposed, before losing 50% of its original property value over the estimated life of the molded part. Note that a mechanical load is not imposed on the test specimen. This test is most useful when comparing the performance of different plastics. Under these conditions, typical values for most grades of Celcon acetal copolymer range from 95°C to above 110°C.

Table 3.4 summarizes the Relative Thermal Index ratings for grades of Celcon acetal copolymer.

The designer needs to estimate the actual temperature

Table 3.4 · Summary of UL relative thermal index ratings for Celcon® acetal copolymer

Celcon acetal copolymer Grade -3.0 mm (1/8”)	Electrical	Relative Thermal Index °C Mechanical	Mechanical with Impact
Standard Unfilled	110	100	90
Glass fiber Reinforced	105	105	95
Unfilled Toughened	50	50	50

that the part will encounter during service, as well as the critical mechanical and other properties for the specific application before selecting Celcon acetal copolymer. Call Product Information Services at 1-800-833-4882 for UL information for specific grades and approvals.

3.4 Long Term Mechanical Properties

3.4.1 Introduction

Adequate consideration of long term loads, especially based on creep and stress relaxation, is critical to the design of parts made from Celcon acetal copolymer. This can avoid issues such as incorrect estimates of inuse performance capability, part warranty and loss of customer satisfaction.

Fatigue effects are usually considered by parts designers, but must be approached with care to properly model the realities of the end-use environment. Improperly designed tests can produce erroneous results, which may be artifacts and may not reflect real end-use performance.

3.4.2 Creep

The instant any material, including metals, is loaded it begins to creep. The viscoelastic properties of plastics require that creep behavior be considered, even for room temperature plastic parts design.

Several points need to be considered when dealing with creep. Often, parts are subjected to relatively low loads in which deflection is a factor but stress is not. In other cases, the primary concern is mechanical failure of the part under long term loads with minimal consideration of deflection. Deflection recovery after removal of long term loads is important in some applications.

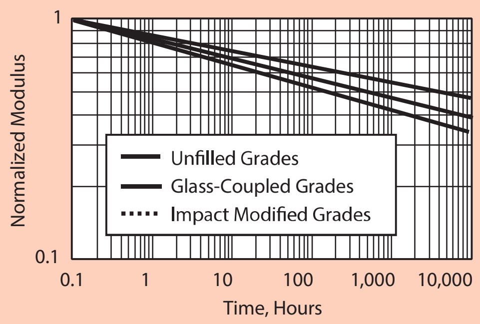
In general, Celcon acetal copolymer, because of its high crystallinity, withstands creep stress better than most other plastics.

3.4.3 Creep Deflection

The creep modulus may be used in place of the flexural or tensile modulus in the standard equations of linear elasticity used in engineering design. The range of creep moduli for the standard Celcon acetal grades, the impact modified grades and the reinforced grades are shown in Figure 3.12.

The graph was prepared by measuring the flexural creep of various Celcon grades at loads up to 1/3 of the published tensile strength of the low elongation grades over the temperature range of 23-80°C. Very little influence from stress was seen on the creep modulus reduction with time. Each regression curve was normalized by dividing by the modulus value at 0.1 hour.

Fig 3.12 · Normalized creep modulus plots for Celcon acetal copolymer grades



To calculate actual values when using Figure 3.12, refer to Table 3.5 which gives the initial values for creep (flexural) modulus for the various grades of Celcon® acetal copolymer.

Table 3.5 · Initial creep (flexural) modulus values for grades of Celcon acetal

Celcon acetal copolymer Grade	Flexural Modulus, MPa
Standard Unfilled	2,600
Glass fiber Reinforced	8,590
Unfilled Toughened	1,700

There is a considerable variation in creep deflection of plastic assemblies in actual end-use. This is due to variations in wall thicknesses and dimensional variations in the molded parts. To compensate for these factors, it is strongly suggested that the designer use a safety factor of 2 whenever creep deflection is important in the end use application.

Example 3-2. Calculation of Long Term Deflection for a Part

Consider a molded part involving a U-beam 200 mm long in cross section as illustrated in Figure 3.13. The beam will carry a uniform load across its length and the ends will be designed to snap into sockets, making the beam simply supported. The channel supports slide-in components weighing 200 grams. The operating temperature of the part is 70°C and the service life is ten years. Due to alignment requirements for the components, the maximum allowable deflection for the beam is 1.0 mm. Would the channel be satisfactory if fabricated from a standard grade of Celcon acetal copolymer?

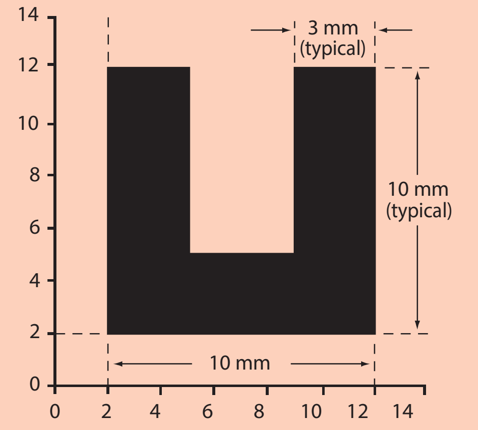
Solution: The equations of a U-beam cross section and a simply supported beam with a uniform load may be found in Chapter 7 of **Designing With Plastic: The Fundamentals (TDM-1).** (Call Product Information Services at 1-800-833-4882 for your copy or see internet site at www.celanese.com). Initial analysis of the part at room temperature assuming a modulus of 2,600 MPa shows that the stress in the component is very low, (0.43 MPa) and the deflection is 0.12 mm. Many designers on seeing these low stress and relatively low deflection values may consider further analysis unnecessary.

However, using the secant modulus plot (Figure 3.9), we see that the modulus is reduced by half at 70°C to approximately 1,300 MPa. While the stresses are unchanged the deflection is now 0.25 mm.

Finally, estimating the creep modulus at 10 years (approximately 80,000 hours) requires projecting one decade beyond the creep curve in Figure 3.12. By doing this, it is estimated that the creep modulus is 30% of the initial value after 10 years. Thus we estimate a new modulus of 30% of 1,300 MPa or approximately 390 MPa. Using this modulus we now calculate the deflection in 10 years to be 0.83 mm.

If our maximum allowable deflection is 1.0 mm, the largest deflection permitted for design is 0.5 mm to maintain a safety factor of 2; the minimum safety factor recommended for creep calculations as previously defined under Creep Deflection. Therefore, some alteration of the design concept is needed. One alternative among many is to extend the legs of the channel. If they are extended to 12 mm the calculated deflection at 70°C after 10 years is 0.48 mm, which satisfies the design requirements.

Fig 3.13 · U-beam cross section



3.4.4 Creep Rupture

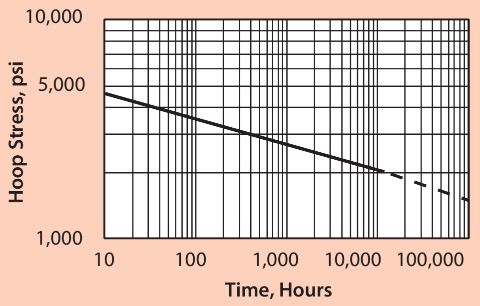
The second creep issue is creep rupture, in which a high continuous load is imposed. In this case uncontrolled part deformation or part breakage can occur. It is typically characterized by much higher stresses than the deflection-limited creep discussed above.

Unfortunately, rupture considerations are not as simple as the analysis of deflection limited creep using the modulus. Rupture is highly dependent on design geometry, processing conditions, temperature and environmental exposure. As the starting point for designing for creep rupture, use a minimum safety factor of 10 applied to the short term data to determine the design strength at the operating temperature of the plastic part, depending on the above factors.

The above general rule of thumb applies to any Celcon® acetal copolymer grade required to carry a continuous load for an extended period of time. Figure 3.14 shows a creep rupture curve for a laboratory test specimen. The curve is for the hoop stress for a standard Celcon acetal copolymer unfilled 9.0 melt flow grade molded into tubes and subjected to hydrostatic pressure for an extended time at ambient temperature. At 100,000 hours, (about 12.5 years), rupture strength under this test condition is approximately 1,800 psi. This is approximately 1/5 of the initial short term tensile strength of the material. Thus, a safety factor of 2 at 100,000 hours suggests a design strength of approximately 1/10 of the initial tensile strength.

This result is based on a laboratory test specimen under controlled conditions and falls within our suggested guidelines of a minimum safety factor of 10. This holds whenever creep rupture is an important consideration in part design.

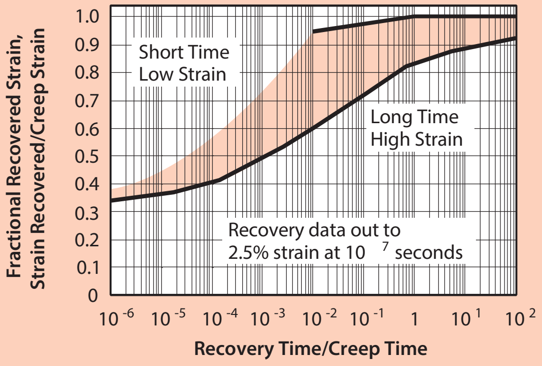
Fig 3.14 · Creep rupture, Celcon acetal copolymer unfilled 9.0 melt flow grade



3.4.5 Creep Recovery

When plastics are loaded for any length of time, they do not instantaneously recover to their original shape when the load is removed. In many applications the recovery time or the amount of deformation recovered must be considered. Figure 3.15 shows the ratio of strain recovered to creep strain versus the ratio of recovery time to creep time. At low strains, on the order of 1/4% to 1/2%, complete recovery occurs only when the recovery time is equal to the time at load.

Fig 3.15 · Creep recovery for Celcon acetal copolymer



Example 3-3. Snap Finger Strain Recovery

A simple snap finger is designed for a peak strain of 2.5% during engagement. The finger is subjected to a definite tensile load after insertion. Thus, once it is inserted and released, it is held in position against its retainer and can no longer recover in strain. If it is inserted quickly, creep strain is brief and the recovery time is equally brief. What will be the strain recovery?

Solution: The ratio of recovery time to creep time is about 1. The snap finger may be expected to recover about 80% of the 2.5% strain; therefore, approximately 0.5% strain will remain. Alternatively, if the insertion time is slow with a quick release after engagement, the recovery to creep time may be 1:100. In this case, only 60% of the strain is recovered, so the snap finger will be locked at a permanent 1% strain.

3.4.6 Relaxation

Stress relaxation is similar to creep. In creep, a constant stress is imposed and the strain gradually increases. When a constant strain is imposed, there is an initial stress that gradually decays or relaxes with time. Relaxation data is not as common as creep data. Fortunately, creep data give a good approximation of the relaxation phenomenon.

Example 3-4. Press Fit Strain Recovery

A 10 mm diameter pin is pressed into a hole in a part made of a standard grade of Celcon® acetal copolymer with an interference of 0.1 mm. The hoop strain is 0.1/10 = 0.01 or 1%. The resulting stress at a material modulus of 2,800 MPa is 28 MPa. However, after 1,000 hours the effective modulus is reduced by half. Therefore, the stress would be 14 MPa even though the strain is still 1%.

Now consider the recovery if the pin is suddenly removed. The initial recovery typically follows the initial modulus rather then the creep modulus. Thus, as the stress drops from 14 MPa to zero when the pin is removed, the initial strain recovery is 14 MPa/2800 MPa, or 0.005 (0.5%). From Figure 3.15, note that 6 minutes is 1/10,000 of the stress relaxation time of 1,000 hours. Examining the creep recovery curve at this recovery time to creep time ratio, we see that the middle of the colored region indicates that half (0.5%) of the strain is recovered.

Example 3-5. Clock Gear Design

In many electric alarm clocks, Celcon acetal copolymer gears are insert molded or pressed onto steel shafts. If insert molded, the gears grip the shafts with a strain equivalent to the mold shrinkage. Therefore, the strain on the gears holding them to the shafts is 0.5-2%. The strain with press fits is much more variable. This system works well in driving the clock hands as there is little load required between the gears and the shaft.

However, the final gear (the hour hand), often trips the alarm mechanism. This is the highest torque gear in the system requiring the tightest grip on the shaft. Over time, the gear may relax its grip on the shaft and slip rather than trip the alarm. This would be accompanied by increased gear noise. In this case, a spline, knurled or flattened shaft ultrasonically inserted in the hole will eliminate the slippage.

At low load levels, a splined or knurled shaft may be press fit. This requires careful control of tolerances to prevent over-stressing the plastic. A refinement of this procedure is to use a single or double "D" shaft and hole in the plastic and press fit the assembly together.

These changes will eliminate the problem of gear relaxation/slippage as a cause of premature failure, and provide the normal lifetime of service for the clock assembly.

Parts subjected to a continuous high strain may also fail at some future time in a manner similar to creep rupture. Again, this failure mechanism is highly dependent on temperature, environmental exposure, design and processing conditions. In general, a continuous strain in excess of 2.5% is to be avoided in standard, unfilled Celcon acetal copolymer parts. The strain should be less than 2.5% to avoid cracking at weld lines or under specific environmental exposure conditions.

Lower continuous strain exposure must be used with glass reinforced grades. It is recommended that no more than 33% of the elongation at break be considered. Also, at part weld lines for glass-coupled grades, the neat plastic alone must carry the load. Therefore, small strains in the molded part can be large stresses for the base plastic. For example, a 0.5% strain on a part having a modulus of 1,000,000 psi is 5,000 psi. This stress must cross the weld line. As previously discussed, a long term stress of this magnitude would be excessive for most unreinforced plastics.

Example 3-6. Hoop Stress Calculation

Consider the 10 mm diameter pin with a 0.1 mm interference fit discussed in Example 3-4. The material is a glass reinforced Celcon® acetal copolymer grade with 7,000 MPa modulus. The hoop stress induced from 1% strain is 70 MPa. While the glass reinforced Celcon acetal copolymer might tolerate this stress if well molded, weld lines are probably present at the hole in the part. Since the fiber reinforcement does not cross the weld, only the unreinforced base resin is present at this stress point. The part will probably break in a relatively short period of time, since the hoop stress exceeds the strength of the base resin.

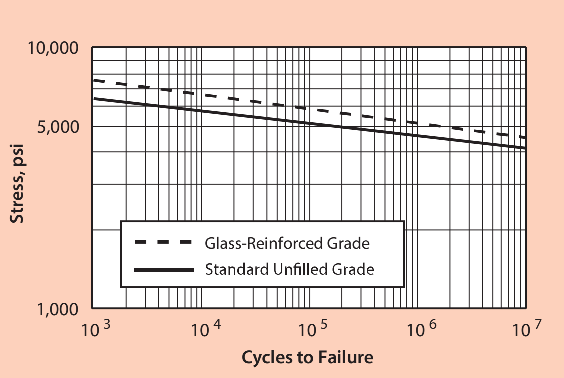
Drilling or heat punching the hole, or moving the weld line by redesign of the mold have all been used in various actual end-use applications to overcome the problem and provide normal part service life. Clearly, with reinforced grades of Celcon acetal copolymer, the interference strains should be kept quite low; on the order of 0.25-0.5%.

3.4.7 Fatigue

Fatigue strength, like creep rupture strength, is highly dependent on design, processing, temperature and end-use environment. In addition, the nature of the load influences the fatigue performance. Harmonic, square wave, saw tooth or pulse loading can have very different effects on plastic fatigue.

Plastics can also fail in fatigue due to hysteresis heating and deformation rather than the fatigue cracking typically expected. Due to its highly crystalline nature, Celcon acetal copolymer resists hysteresis heating and has superior fatigue performance compared to other plastics.

Fig 3.16 · Flex fatigue plot for Celcon acetal copolymer (ASTM D 671)



However, each application requires careful testing under conditions that model accurately the enduse environment.

Figure 3.16 illustrates fatigue curves for glass reinforced and standard grades of Celcon acetal copolymer tested according to ASTM D 671. This test involves a beam with a uniform taper (constant stress beam) under harmonic excitation. Note that the unreinforced grade retains approximately 1/2 of its original flexural fatigue strength over 107 cycles. The glass reinforced grade is only slightly better then the unreinforced grade. This is probably due to the interaction of the many glass ends and the notch sensitivity of the material. These curves should be used as starting points since the actual end-use conditions may deviate considerably from the laboratory test conditions.

Laboratory fatigue testing should be used only as a guide. For example, harmonic excitation is typically used in laboratory testing. The end-use environment may be a saw tooth or pulse loading. These loadings could produce a very different response resulting in either a shorter or longer life than that predicted by the laboratory test.

End-use tests run continuously to achieve the required life cycles often overheat the test part, resulting in lower fatigue life than the part might have in the intermittent and, therefore, lower temperature end use. Alternatively, an accelerated fatigue test run at a controlled, elevated temperature to model the enduse environment, may overestimate the fatigue performance of the part by failing to consider aging effects at elevated temperature.

4. Dimensional Stability

4.1 Coefficient of Linear Thermal Expansion

The coefficient of linear thermal expansion (CLTE) is a measure of the change in dimension with changes in temperature. Table 4.1 gives CLTE values for various grades of Celcon® acetal copolymer.

4.2 Shrinkage Caused by Processing (Injection Molding)

Mold shrinkage can vary with several factors. The most important factor is molding conditions. Variations in mold surface temperature and mold injection pressure, for example, can cause shrinkage in test bars made from one specific grade (Celcon acetal copolymer M90™) ranging from 0.018 to 0.050 mm/mm. Figure 4.1 provides a graphical illustration of the shrinkage for this grade for the above parameters. Other factors such as mold design, wall thickness, gate size, flow length and flow direction, filler type and level and polymer melt viscosity can also affect shrinkage. As a result it is difficult to predict the exact mold shrinkage of a specific part.

Shrinkage of standard Celcon acetal copolymer products measured on laboratory test specimens generally range from 0.004 mm/mm for glass-reinforced products to 0.022 mm/mm for unreinforced grades. Mold shrinkage as high as 0.037 mm/mm has been observed on an actual part. Consult the **Celcon Short Term Properties Data Brochure (CE-4)** for typical values of laboratory-tested specific Celcon grades. This information is useful for preliminary estimates of shrinkage, but should be used only as an initial guide in tool construction.

It is highly recommended to begin with oversized cores and undersized cavities to minimize retooling costs. Following this, parts should be molded at steady-state molding conditions (see **Celcon acetal copolymer Processing and Troubleshooting Guide (CE-6)** for recommended molding conditions) and then exposed to ambient temperature for about 48 hours. Dimensions of critical areas can then be measured to determine any additional machining that may be required. Computer Aided Design (CAD) Flow Shrinkage Analysis can greatly improve the accuracy of mold dimension deformation. Contact Product Information Services
at 1-800-833-4882 for further information.

4.3 Warpage

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

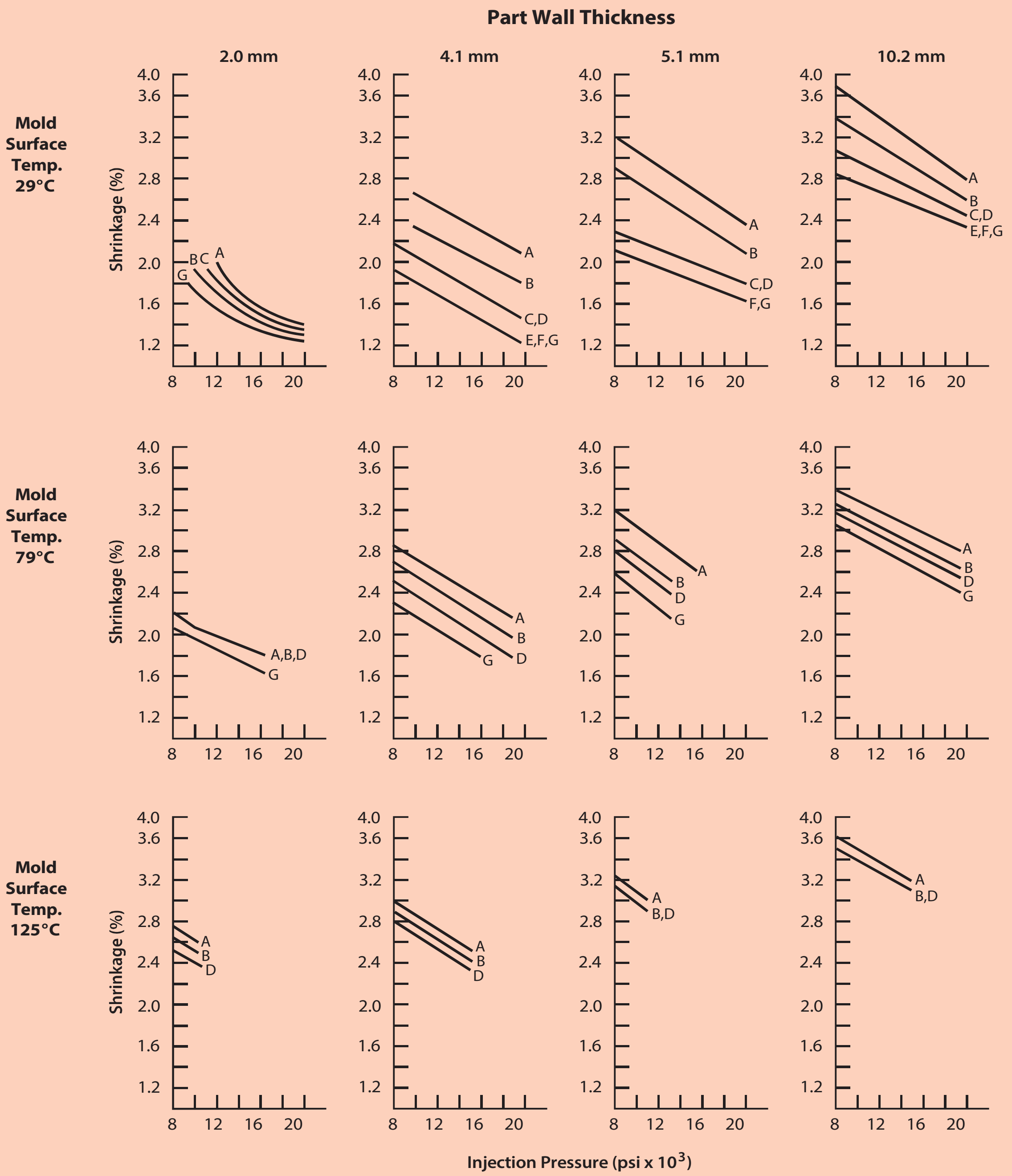
- Gate size
- Gate location
- Mold temperature
- Filler type/level
- Orientation of fillers
- Molded-in stresses

Consult the **Celcon acetal copolymer Processing and Troubleshooting Guide (CE-6)**
for further information on these parameters.

Table 4.1 • Coefficient of linear thermal expansion (CLTE) for various grades of Celcon acetal copolymer, 23-80°C*

Celcon acetal copolymer Grade	Description	Units: 10-4/°C
M270™	Unfilled 27.0 Melt Flow	1.2
M90™	Standard Unfilled 9.0 Melt Flow	1.2
M25	Unfilled 2.5 Melt Flow	1.2
GC25A™	25% Glass Fiber Coupled	0.3
GB25	Glass-Bead Reinforced	0.9
TX90PLUS	Toughened; High Impact	1.4
LW90GCS2	Low Wear; Lubricated	0.3

Fig 4.1 · Effect of molding conditions and wall thickness on mold shrinkage for Celcon® acetal copolymer M90™



Gate	Area mm²	Gate	Area mm²
A	1.9	E	18.1
B	3.9	F	23.9
C	7.7	G	31.3
D	12.2		

Note. Melt Temperature: 190°C-204°C.
Shrinkage measured in direction of material

Table 4.2 • Effect of processing conditions on part shrinkage

Parameter	**Effect on Part Shrinkage**
Wall thickness increases	Increases
Gate size increases	Decreases
Injection pressure increases	Decreases
Mold temperature increases	Increases
Melt temperature increases	Decreases (for parts 3.1 mm thick or less) No effect (for parts 3.2-9.5 mm thick)
Resin Melt Viscosity	Increases with increasing viscosity (when molded under similar processing conditions; i.e., Celcon acetal copolymer M450 has lower shrinkage than Celcon acetal copolymer M25)

Some general observations on part shrinkage in the mold are shown in Table 4.2.

4.4 Post-Molding Shrinkage

Post-molding shrinkage is usually related to stress relaxation of the molded part, resulting in a permanent shrinkage of the part. At ambient temperatures this shrinkage is relatively small, on the order of 0.1- 0.2% for a standard unfilled 9.0 melt flow grade of Celcon® acetal copolymer. However, continuous exposure of the molded part to high temperatures accelerates both the rate and magnitude of shrinkage due to stress relaxation. Figure 4.2 illustrates the shrinkage behavior of the standard unfilled 9.0 melt flow grade of Celcon acetal copolymer after six months of exposure to various temperatures (3.2 mm thickness, flow direction).

4.5 When Annealing is Necessary

In many cases, properly molded parts will exhibit satisfactory dimensional stability. A high mold temperature (95-120°C) will optimize the dimensional stability of an as-molded part. In some cases, prolonged and elevated in-service temperatures may necessitate annealing.

Some general guidelines are given below:

- In-service temperatures of 82°C or below – Generally, properly molded parts will not require annealing.
- Temperatures greater than 82°C – Annealing may be necessary to improve the dimensional stability of the molded part.

Recommended annealing procedure:

- Time: As a general rule, use 15 minutes for each 3.1 mm of wall thickness.
- Temperature: 152 ± 2°C
- Medium: Any refined or silicone oil which is not acidic. Oil is preferred over air because it is a better conductor of heat and provides a blanket to minimize or prevent oxidation.
- Cooling: Cool annealed parts slowly (one hour per 3.1 mm of wall thickness).

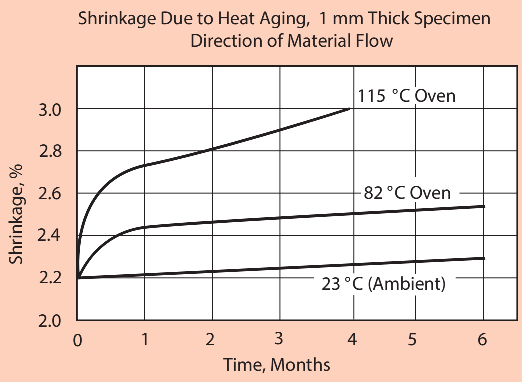
4.6 Tolerances

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, the typical tolerances expected are:

± 0.002 mm/mm for the first 25 millimeters or fraction of the first 25 millimeters of wall thickness.

± 0.001 mm/mm for each subsequent 25 millimeters of wall thickness.

Fig 4.2 • Shrinkage due to heat aging for 9.0 standard melt flow grade of Celcon acetal copolymer



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

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

Table 4.3 shows examples of the shrinkage resulting from annealing two different thicknesses of a typical unfilled Celcon® acetal copolymer grade. Annealing molded parts will lead to dimensional changes so that allowances must be made for any additional shrinkage. The decision to anneal Celcon acetal copolymer parts should therefore, be made during the planning stage and definitely prior to machining the mold cavity and core to size.

Note that the unannealed thicker part shrank approximately 15% more than the unannealed thinner part, and the annealed thicker part shrank 9% more than the annealed thinner part (flow direction data). Part shrinkage in the transverse direction was about the same for all laboratory test samples, whether annealed or unannealed.

4.7 Moisture Absorption

Some dimensional change is observed when Celcon acetal copolymer is exposed to moist environments. The changes are usually lower than those observed for other engineering thermoplastics. Figures 4.3 and 4.4 may be used to estimate the changes that may occur when Celcon acetal copolymer is exposed to various conditions of heat and humidity. Also consult Figure 5.5 for additional long-term continuous exposure data in hot (82°C) water.

Table 4.3 • Shrinkage before and after annealing different part thicknesses

		Part Shrinkage	
Part Thickness cm	**Annealed 152°C**	**Flow Direction cm/cm**	**Transverse Direction cm/cm**
0.318	No	0.040	0.032
0.318	Yes	0.049	0.036
1.27	No	0.047	0.036
1.27	Yes	0.054	0.036

Fig 4.3 • Water absorption of unfilled Celcon acetal copolymer under various conditions

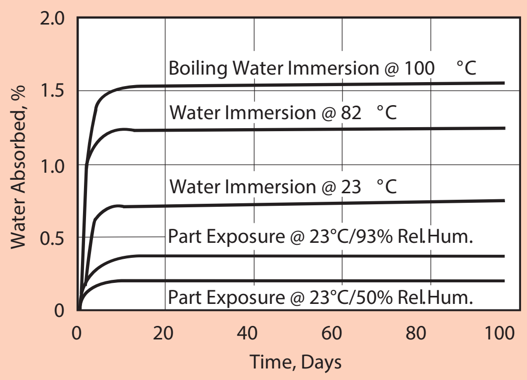
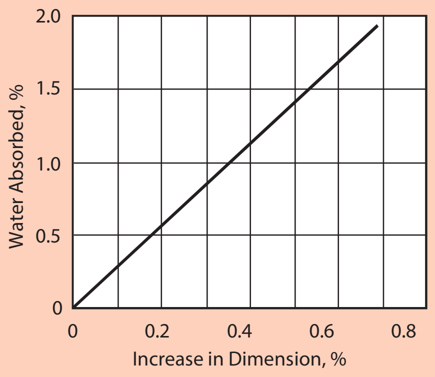


Fig 4.4 • Dimensional change due to water absorption of unfilled Celcon acetal copolymer



5. Environmental Resistance

5.1 Chemical Resistance

The part design engineer will appreciate the need to consider the chemical environment to which the part will be exposed during its service life. Celcon® acetal copolymers have excellent resistance to many chemicals and solvents when molded parts are exposed in an unstressed state. In some cases, slight discoloration is observed with little change in the mechanical properties measured. Table 5.1 summarizes the performance of Celcon acetal copolymer after exposure to a variety of chemicals over a range of temperature and exposure times.

In general, Celcon acetal copolymer is minimally affected by a wide variety of solvents and chemicals, except by strong mineral acids (sulfuric, nitric, hydrochloric, etc.) and strong oxidizing agents such as aqueous solutions containing high concentrations of hypochlorite or permanganate ions. A summary of the performance of test specimens of Celcon acetal copolymer in various environments is given below:

Fuels: Celcon acetal copolymer shows small changes in dimensions, weight and strength when exposed to oxygenated and non-oxygenated fuels at 65°C.1

Oils: Almost no effect is seen following exposure to various hydrocarbon and ester oils such as mineral oil, motor oil and brake fluids, even at elevated temperatures.

Organic Reagents: Most of the organic reagents tested did not affect Celcon acetal copolymer. Only a slight change was seen for common degreasing solvents such as carbon tetrachloride, trichloroethylene and acetone at room temperature. Prolonged exposure at elevated temperature to more aggressive solvents such as ethylene dichloride, phenolic solutions and aniline should be avoided, unless the application is designed around the potential change in properties.

Aqueous Bases (Alkalies): Celcon acetal copolymer is especially resistant to strong bases (alkalies) showing superior resistance in this medium when compared to acetal homopolymer. Molded Celcon acetal copolymer specimens immersed in almost boiling 60% sodium hydroxide solution and other strong bases for several months, showed little change.

Aqueous Acids: Celcon acetal copolymer is not recommended for use in the presence of mineral acids or strong Lewis acids such as zinc chloride or boron trifluoride. Celcon acetal copolymer should only be exposed to aqueous solutions that have a pH above 4.0.

Detergents: Immersion for up to six months at 82°C (180°F) in several commercial dishwashing detergent solutions produced virtually no change in the tensile strength of molded parts of Celcon acetal copolymer.

Potable Water: Prolonged or continuous exposure of Celcon acetal copolymer in aqueous solutions containing hypochlorite ions should be limited to hypochlorite concentrations typically found in U.S. domestic potable water supplies.

Table 5.1 summarizes the exposure tests of three unfilled Celcon acetal copolymer grades to a wide spectrum of inorganic and organic chemicals, as well as commercial products including automotive fluids and detergents. The results illustrate the resistance shown by Celcon acetal copolymer to most common solvents and chemicals.

[1] Reference "Plastics and Aggressive Auto Fuels – a 5,000 Hour Study of Seven Plastics and Nine Fuel Blends," 01-300, March, 2001.

Fig 5.1 · Chemical resistance of Celcon® acetal copolymer standard unfilled grades

Chemical	Exposure Time (Months)	Temp. °C	Yield Strength % Change	Tensile Modulus % Change	Length* % Change	Weight % Change	Visible Effect**
Control (Air)	2	23	0	0	0	0.22	N.C.
Inorganic Chemicals							
10% Aluminum Hydroxide	6	23	0	0	0.3	0.88	Disc.
	12	23	0.7	-16	0.3	1.03	Disc.
	6	82	-0.3	-12	0.4	0.74	Disc.
3% Hydrogen Peroxide	6	23	2	-15	0.3	0.97	N.C.
	12	23	3	-12	0.3	0.88	N.C.
10% Hydrochloric Acid	6	23	x	x	x	x	x
10% Nitric Acid	6	23	x	x	x	x	x
10% Sodium Chloride	6	23	2	-12	0.2	0.59	N.C.
	12	23	3	-15	0.2	0.71	SL.Disc.
	6	82	4	-10	0.2	0.77	SL.Disc.
2% Sodium Carbonate	6	23	0	-9	0.2	0.77	N.C.
	12	23	6	-9	0.2	0.78	N.C.
	6	82	3	-2	0.4	0.96	N.C.
20% Sodium Carbonate	6	82	3	-2	0.2	0.61	N.C.
1% Sodium Hydroxide	6	23	1	2	0.2	0.80	N.C.
	12	23	2	2	0.2	0.84	N.C.
10% Sodium Hydroxide	6	23	1	-8	0.2	0.49	N.C.
	12	23	-2	-6	0.2	0.73	N.C.
	6	82	-3	-8	0.2	0.83	SL.Disc.
60% Sodium Hydroxide	6	82	-3	-6	-0.1	-0.18	SL.Disc.
4-6% Sodium Hypochlorite	6	23	x	x	x	x	x
26% Sodium Thiosulfate	6	82	3	-12	0.2	0.61	N.C.
3% Sulfuric Acid	6	23	0	-8	0.4	0.81	N.C.
	12	23	2	-14	0.2	0.82	N.C.
30% Sulfuric Acid	6	23	x	x	x	x	x
Buffer, pH 7.0	6	82	2	-15	0.3	0.94	SL.Disc.
Buffer, pH 10.0	6	82	4	-12	0.3	0.89	SL.Disc.
Buffer, pH 4.0	4	82	x	x	x	x	x
Water (Distilled)	6	23	0	-12	0.2	0.83	N.C.
	12	23	4	-12	0.2	0.84	N.C.
	12	82	0	-18	-0.1	-3.32	Disc.
Organic Chemicals							
5% Acetic Acid	12	23	0.6	-16	0.2	1.13	N.C.
Acetone	6	23	-4	-20	0.7	3.60	N.C.
	12	23	-17	-48	1.6	3.68	N.C.
Aniline	6	82	-26	-73	4.8	12.10	Reddish Tint
Benzene	6	49	-17	-43	1.8	3.93	N.C.
Carbon Tetrachloride	6	23	-1	-4	0.2	0.86	N.C.
	12	23	2	-6	0.1	1.39	N.C.
	6	49	-11	-32	1.2	5.23	N.C.
10% Citric Acid	6	23	0	-12	0.3	0.74	N.C.
	12	23	3	-10	0.2	1.93	N.C.
Dimethyl Ether	6	23	-15	-26	1.1	2.09	N.C.
Dimethyl Formamide	6	82	-19	-63	3.1	7.70	N.C.
Ethyl Acetate	6	23	-5	-20	0.6	3.62	N.C.
	12	23	-17	-46	1.6	4.25	N.C.
	6	49	-22	-50	2.1	5.23	N.C.
Ethylene Dichloride	6	49	-23	-68	3.2	10.05	N.C.
50% Ethylene Glycol	6	82	x	x	x	x	x
95% Ethanol	6	23	-4	-19	0.6	1.43	N.C.
	12	23	-6	-35	0.7	2.19	N.C.
	6	49	-17	-31	1.3	2.54	N.C.

(See notes page 37 bottom)

Fig 5.1 · Chemical resistance of Celcon® acetal copolymer standard unfilled grades

Chemical	Exposure Time (Months)	Temp. °C	Yield Strength % Change	Tensile Modulus % Change	Length* % Change	Weight % Change	Visible Effect**
Organic Materials Continued							
50% Ethanol	6	23	-4	-24	0.6	1.62	N.C.
	12	23	-5	-32	0.7	1.98	N.C.
	6	49	-13	-34	1.0	2.27	N.C.
Heptane	12	23	3	4	-0.07	0.09	N.C.
	6	82	-6	-9	0.02	0.35	N.C.
Oleic Acid	12	23	3	31	-0.04	1.26	N.C.
	6	82	0	-9	0.5	1.04	N.C.
5% Phenol	6	23	-15	-45	2.1	9.34	N.C.
	12	23	-10	-46	1.4	4.70	Disc.
Toluene	6	23	-7	-17	0.4	1.12	N.C.
	12	23	-7	-19	0.7	1.87	N.C.
	6	82	-14	-43	1.6	3.80	N.C.
Other Materials							
Automatic Transmission Fluid	6	82	5	5	-0.07	-0.15	N.C.
Anti-Freeze (Telar®)	6	82	x	x	x	x	x
Brake Fluid, "Super 9®"	6	23	0	-12	0.3	0.34	N.C.
	12	23	3	-1	0.2	0.53	N.C.
Brake Fluid, "Lockheed 21®"	7	23	-3	-13	0.3	0.70	N.C.
	12	23	0.5	-9	0.2	1.05	N.C.
	6	82	-11	-41	1.4	3.60	N.C.
Brake Fluid, "Delco 222®"	6	82	-5	-33	1.3	3.18	N.C.
Detergents							
"Acclaim®"	6	82	2	-11	0.2	0.85	SL.Disc.
"Calgonite®"	6	82	3	-15	0.3	1.00	SL.Disc.
"Electro-Sol®"	6	82	3	-10	0.3	1.04	N.C.
50% Igepal®	6	23	18	-14	0.4	0.75	N.C.
	12	23	3	-15	0.4	0.84	N.C.
	6	82	0	-18	0.7	1.64	N.C.
Detergent Solution***	6	82	-3	-20	0.4	1.04	SL.Disc.
1% Soap Solution	6	82	-2	-15	0.5	1.32	N.C.
Fuels							
Mobil® Reg. (93.5 Octane)	6	49	-11	-12	0.7	1.30	N.C.
Mobil® "Hi-Test" (99.0 Octane)	6	49	-12	-12	0.7	1.50	N.C.
Sunoco® "280" (103 Octane)	6	49	-6	-10	0.7	1.43	N.C.
Gasohol	8	23	-8	—	0.6	1.42	N.C.
10% Ethanol/90% Gasoline	8	40	-6	—	0.5	1.26	N.C.
Kerosene	6	82	0	-7	0.3	0.34	N.C.
Linseed Oil	6	82	8	11	0.2	-0.13	N.C.
Lubricating Grease	6	82	4	3	0.2	-0.03	N.C.
Mineral Oil ("Nujol®")	12	23	3	-1	-0.06	0.05	N.C.
	6	82	8	7	0.0	-0.18	N.C.
Motor Oil (10W30)	12	23	5	7	-0.06	-0.14	N.C.
	6	82	5	0	-0.06	-0.14	N.C.
Diesel Fuel C	6	71	-8	-32	0.99	2.44	N.C.
	12	71	-10	-33	1.04	2.39	N.C.

*** Type 1 Tensile bars used in these tests measure 21.3 x 12.6 x 3.2 mm; initial yield strength is 61 MPa; tensile modulus 2800 MPa; weight 13 grams.
*** x = Not recommended; N.C. = No Change; Disc. = Discoloration; SL.Disc. = Slight Discoloration.
*** Consists of 0.5 grams of an alkyl sulfonate + 0.20 grams of trisodium phosphate per liter of water.

Delco® is the registered trademark of General Motors Corporation.
Acclaim® is the registered trademark of Ecolab Inc.
Calgonite® is the registered trademark of Reckitt Beneckiser NV Corporation.
Igepal® is the registered trademark of Rhone-Poulenc Surfactants and Specialties.
Mobil® is the registered trademark of Mobil Oil Corporation.
Sunoco® is the registered trademark of Sunmarks Inc.

5.2 Fuel Resistance

Celcon® acetal copolymer shows excellent stability in various types of fuels; even aggressive fuel systems containing high levels of water and methanol as described in Table 5.2. Figures 5.1 through 5.4 show the effect on tensile strength after fuel exposure at 65°C for up to about 5,000 hours. After an initial decrease of about 15% which occurs in less than 1,000 hours, the tensile strength remained essentially unchanged through the remainder of the exposure test.

Dimensional changes were also minimal. A 50 mm disk of a standard unmodified grade of Celcon acetal copolymer immersed in gasoline at room temperature (23°C) increased in size only 0.5% after 12 months' exposure. More aggressive fuel solutions caused dimensional changes of between 1-2% after 12 months' exposure both at room temperature and 66°C.

Additional information is available in Plastics and Aggressive Auto Fuels – a 5,000-Hours Study of Seven Plastics and Nine Fuel Blends.

In a separate test, the fuel permeation rate for a Celcon acetal copolymer standard unfilled grade was less than 0.07 gm-mm/hr-m2 over the temperature range of 45-80°C.

Table 5.1 • STest fuels composition

CMO	Fuel C (50% isooctane and toluene)
CAP	Fuel C + aggressive water + peroxide (sour gas)
CM15A	85% Fuel C + 15% methanol + aggressive water
CM25A	75% Fuel C + 25% methanol + aggressive water
CM85A	15% Fuel C + 85% methanol + aggressive water
CE22A	78% Fuel C + 22% ethanol + aggressive water
CE85A	15% Fuel C + 85% ethanol + aggressive water
TF1	GM TF1 (equivalent to 1E10)
TF2	GM TF2 (equivalent to IM5E2)

Fig 5.1 • Tensile strength at yield for Celcon acetal copolymer M90™ after exposure to various fuels at 65°C

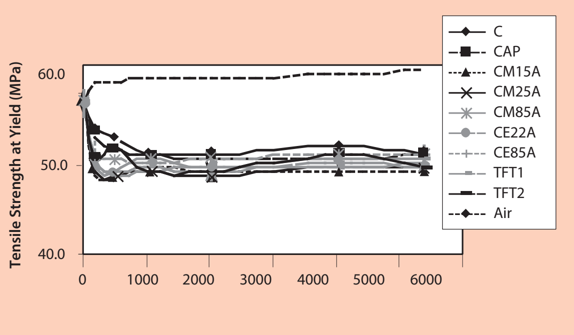


Fig 5.2 • Tensile strength at yield for Celcon acetal copolymer TX90Plus after exposure to various fuels at 65°C

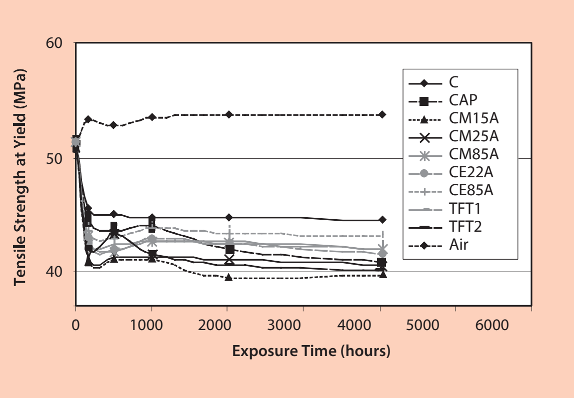


Fig 5.3 • Tensile strength at yield for Celcon acetal copolymer EC90Plus after exposure to various fuels at 65°C

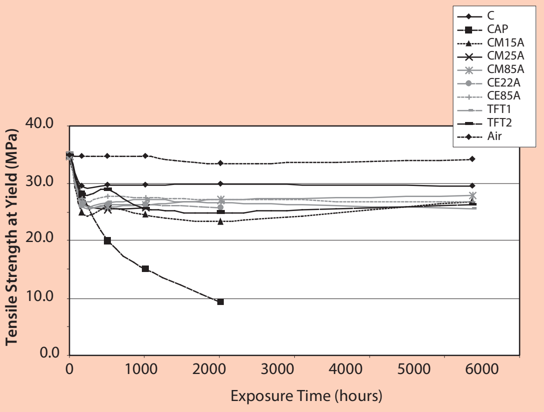
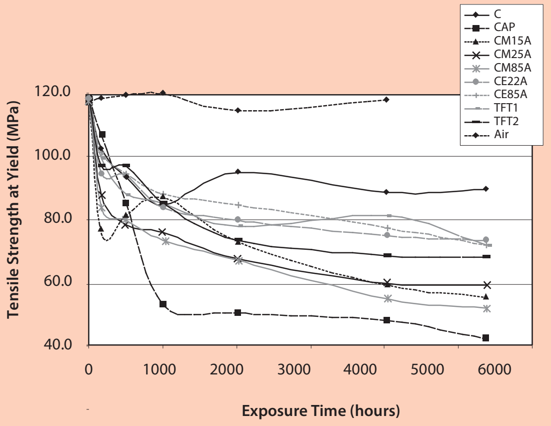


Fig 5.4 • Tensile strength at break for Celcon acetal copolymer GC25TF after exposure to various fuels at 65°C



5.3 Hydrolytic Stability

Exceptional resistance to long-term exposure to high humidity and hot water is a primary reason why Celcon® acetal copolymer is so widely used for many plumbing related applications. Certain grades of Celcon acetal copolymer are in compliance with various standards and codes of the regulatory agencies shown in Chapter 1, Table 1.1.

Figures 5.5 and 5.6 show that after one year of continuous exposure to moderate humidity conditions 23°C/50% Relative Humidity), laboratory tests demonstrate that most properties of unfilled standard 9.0 melt flow grade Celcon acetal copolymer are virtually unchanged and after two years only a moderate change is seen. Molded Celcon acetal copolymer parts show retention of nearly all their original mechanical properties following continuous exposure for up to nine months in boiling water and up to two years in 82°C water. All samples were tested for property retention at room temperature before and after the specified water immersion time.

Fig 5.5 • Change in linear dimensions at 23°C (73,F) and 50% relative humidity

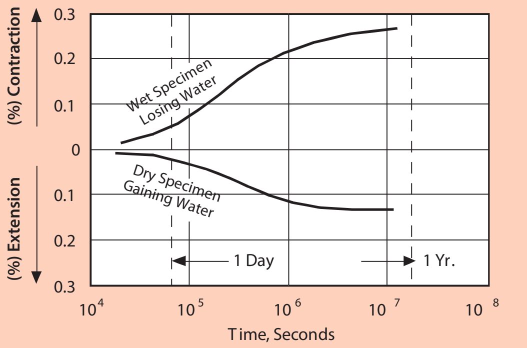
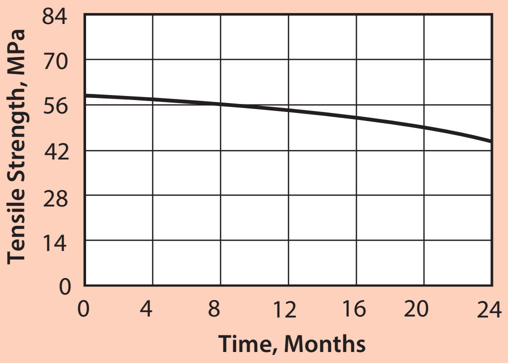


Fig 5.6 • Change in tensile strength after exposure to 82°C water and tested at 23°C and 50% relative humidity



Note: all samples were tested at room temperature (23°C) after the specified immersion period in water.

Fig 5.7 • Change in tensile modulus after hot water exposure at 82°C and 100°C

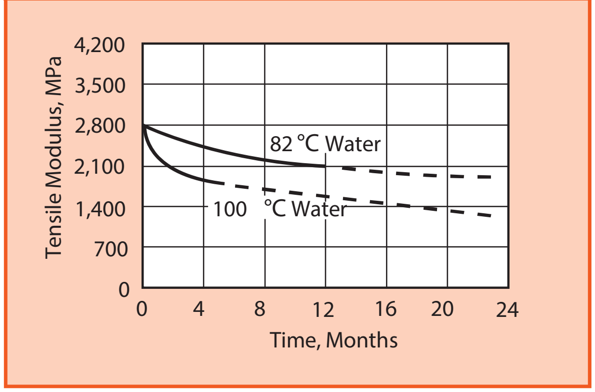


Fig 5.8 • Change in notched izod impact after hot water exposure at 82°C

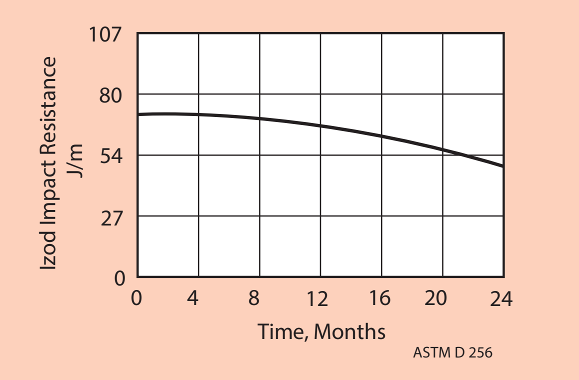


Fig 5.9 • Change in melt flow rate after hot water exposure at 82°C

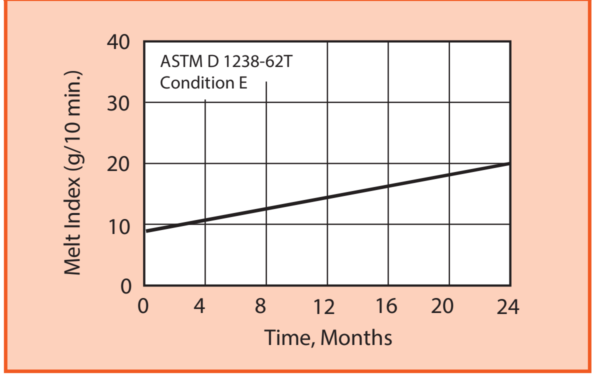
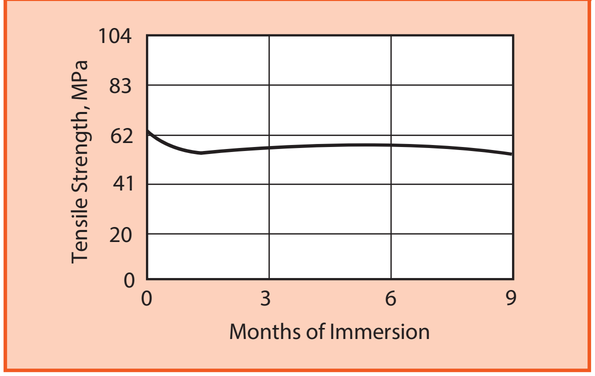


Fig 5.10 • Change in tensile strength after boiling water exposure at 100°C



Note: all samples were tested at room temperature (23°C) after the specified immersion period in water.

The hot water tests were performed in a system that allowed a gradual changeover in the water supply. Seven to ten days were required for a complete change in water. Celcon® acetal copolymer is not recommended for use in closed loop systems where water may become stagnant or is not replenished.

5.4 Recommended Use Temperatures

The maximum recommended continuous use temperature for Celcon acetal copolymer in water is 82°C (180°F), although intermittent use at 100°C is allowable. Short periods at 120°C (pressurized systems) can be tolerated, but are not recommended since these higher temperatures will accelerate aging effects and reduce load-bearing capacity.

5.5 Weathering Resistance

Many end-use environments such as automotive interiors, home window treatments and outdoor devices such as lawn sprinklers involve prolonged exposure to ultraviolet (UV) light. Natural (unpigmented) and colored standard grades of Celcon acetal copolymer are not recommended for these applications due to some loss of mechanical properties, surface gloss and color shift. UV-resistant Celcon acetal copolymer grades have been developed and are available in natural, black and a variety of cadmium-free and lead-free colors to meet these demanding applications.

Various Celcon acetal copolymer grades recommended for ultraviolet applications are summarized in Table 5.3.

Figure 5.9 illustrates the outdoor weathering resis-

Table 5.3 • Celcon acetal copolymer grades for weathering resistance

Grade	Melt Flow	Type	Typical Application
UV25Z	2.5	Precolored	All interior applications including automotive, general industrial and home use that are exposed to filtered sunlight.
UV90Z	9.0		
UV140LG	14.0		
UV270Z	27.0		
WR25Z	2.5	Black	Applications where maximum outdoor UV stability is needed. Only available in black color.
WR90Z	9.0		
M25UV	2.5	Natural	All interior applications where a natural translucent color is required such as drapery hardware that are exposed to filtered sunlight.
M90UV™	9.0		
M270UV™	27.0		

tance over 12 months of a typical black unfilled and glass-filled Celcon acetal copolymer grade. Tensile strength retention ranged between 80-89% of its original value for both grades. In another test, a laboratory simulated UV source (Xenon Arc Weatherometer) was used to compare colored grades of Celcon acetal copolymer containing a special

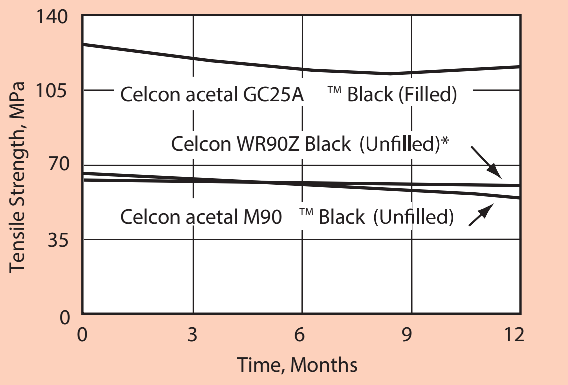
light stabilized formulation to the pigmented, but non-UV stabilized, grade. Figure 5.10 illustrates the excellent protection against color drift provided by the UV-stabilized pigmented grades of Celcon acetal copolymer.

Consult the publication, **Celcon Acetal Copolymer – Ultraviolet Resistant Grades Extend Part Life in Harsh Environments (CE-UV)** for further information and typical test data. A copy is available from www.celanese.com or call Product Information Services at 1-800-833-4882.

5.6 Gas Permeability

The rate of vapor permeation of plastics is dependent on the type of plastic, thickness and temperature. Permeability characteristics for various Celcon acetal copolymer grades appear in Table 5.4. Test results show that above 0.25 mm (0.010 in.) film thickness the permeability of both Celcon acetal copolymer unfilled and glass-reinforced

Fig 5.11 • Outdoor weathering resistance for Celcon acetal copolymer (black)



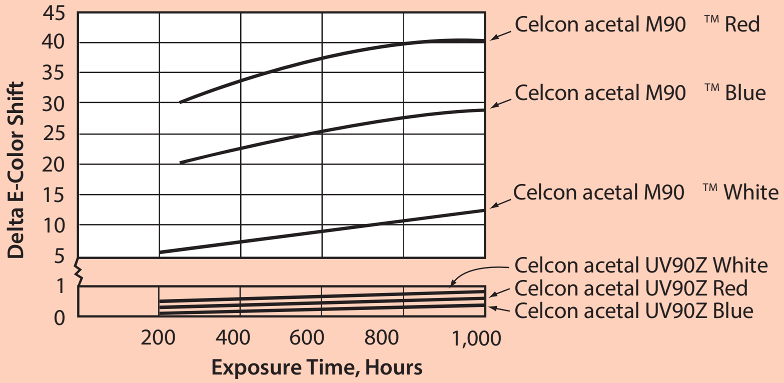
*Note: Data for Celcon WR90Z generated using SAE test method J 1960; 2,000 hours exposure.

Table 5.4 • Gas permeability of Celcon M25™, M90™ and M270™

Material Environment	Gas Transmission Rate (P-Factor) at 23°C (73°F) cm^3-mil/100 in^2-day-atm*
Air	2.2-3.2
Nitrogen	2.2-3.2
Oxygen	5.0-7.4

*Note. Data measured on film 0.15 mm thick

Fig 5.12 • Simulated weathering resistance for Celcon acetal copolymer (colored grades)



6. Electrical Properties

Celcon® acetal copolymer exhibits good dielectric strength and volume resistivity in conjunction with a low dielectric constant and dissipation factor, particularly at frequencies between 102 and 105 Hz. More importantly, Celcon acetal copolymer offers a combination of these superior electrical properties with excellent mechanical properties and long-term stability. As a result, Celcon acetal copolymer has been used successfully in electrical applications involving low voltages and currents. **Celcon acetal copolymer should not be used in electrical applications involving arc resistance, since the material can ignite from arcing.**

Typical electrical properties are similar for both the standard unfilled grades and the glass-reinforced grades of Celcon acetal copolymer and are shown in Table 6.1.

The dielectric constant and the dissipation factor in air were measured on samples of unfilled Celcon acetal copolymer over a wide range of frequency and humidity at room temperature. Figure 6.1 shows that the dielectric strength decreases from 106,000 V/mm for 0.125 mm (0.005 in.) thick film and then levels off to a minimum of 20,000 V/mm for film thicknesses of 1.5 mm (0.060 in.) and greater. The dielectric constant (Figure 6.2) remains unchanged from 102 Hz to 105 Hz, with a very slight increase at higher humidities. The dissipation factor (Figure 6.3) reaches a minimum at 104 Hz and is also sensitive to relative humidity.

6.1 Effects of Aging

No change was detected in the electrical properties shown in Table 6.1 after heat aging at 140°C for up to 6 months.

6.2 Effects of Thickness

Most electrical properties do not vary with thickness, except for the dielectric strength as noted in Figure 6.1.

Table 6.1 • Electrical properties of Celcon acetal copolymer (at 23°C and 50% relative humidity)

Property	Range	Units	Unfilled Grades and Glass-Reinforced Grades
Dielectric Constant (1 mm thick sheet)	102 to 106 Hz	—	3.7
Dissipation Factor (1 mm thick sheet)	102 to 103 Hz 104 Hz 106 Hz	—	0.005 0.0015 0.006
Surface Resistivity (3.2 mm thick sheet)		ohm	1.3 x 1016
Volume Resistivity (3.2 mm thick sheet)		ohm-cm	1.0 x 1014
Arc Resistance (3.2 mm thick sheet)		sec	240 (burns)
Dielectric Strength 0.125 mm film 2.5 mm sheet		volts/mm	 106 20

Fig 6.1 • Dielectric strength of unfilled Celcon® acetal copolymer vs. thickness @ 23°C

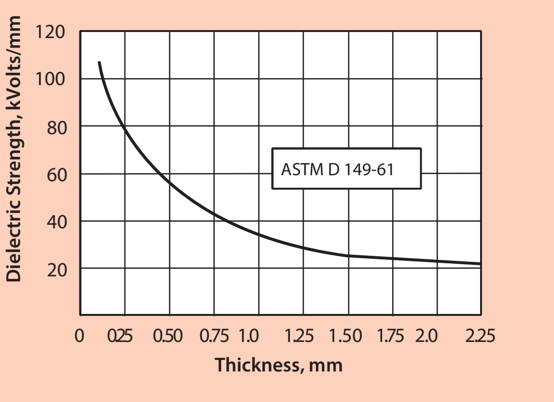


Fig 6.2 • Dielectric constant of unfilled Celcon acetal copolymer vs. frequency @ 23°C

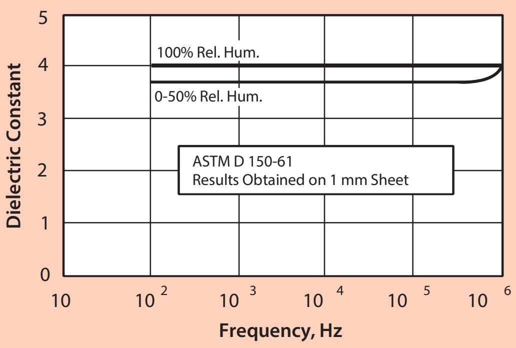
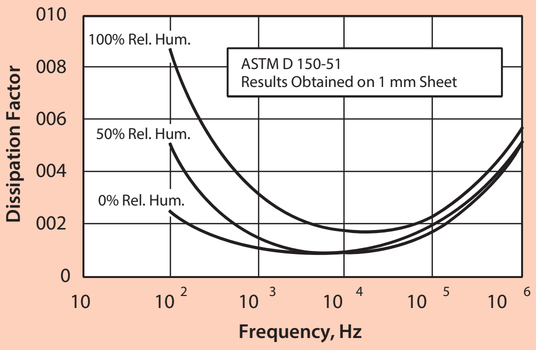


Fig 6.3 • Dissipation factor of unfilled Celcon acetal copolymer vs. frequency @ 23°C



7. Part Design Criteria

7.1 Basic Principles

For an in-depth discussion on the fundamentals of plastic part design, read Chapter 8 of **Designing with Plastic: The Fundamentals (TDM-1),** which can be obtained by contacting Product Information Services at 1-800-833-4882 or from web at www.celanese.com.

7.2 Wall Thickness

Proper wall thickness is a key component of any design project involving plastics, and will significantly affect the following parameters:

Part strength

Part performance

Processing time

Mold Shrinkage

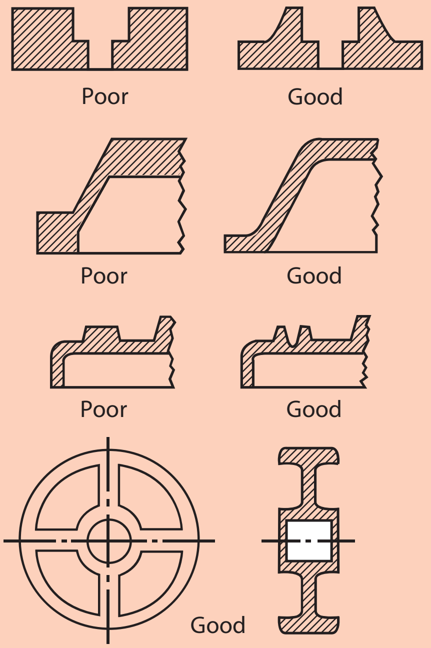
Material consumption

Part cost

When designing injection molded parts, nominal wall thickness should be as uniform as possible. However, when changing from a relatively thick cross-section to a thinner section, the change should be gradual and not abrupt. Sharp internal corners in the part design should be avoided. The internal corners should be rounded with a radius of 50-75% of the adjacent wall thickness. Some examples of good and poor (non-uniform) wall thickness are shown in Figure 7.1. Non-uniform walls within the same part will experience differential cooling rates, which can lead to voids, sinks and warpage. When non-uniform walls cannot be avoided, there should be a gradual transition between thick and thin sections.

For best results with Celcon® acetal copolymer parts, use a wall thickness in the range of 0.76-3.2 mm (0.030-0.125 in.). For thinner wall sections and especially if the flow from the gate is long, the restriction to flow created may make it difficult to fill the entire mold cavity. For very thick parts, differential cooling can lead to the formation of voids or sink marks. Walls of up to 12.7 mm (0.5 in.) thickness have been molded with a minimum of voids, but a combination of proper sprue, runner and gate design, and molding conditions are essential. In a few cases, parts containing wall thicknesses up to 19 mm (0.75 in.) have been successfully molded. Preferably, thick walls should be cored out and consideration should be given to using ribs to strengthen the part while maintaining wall thicknesses in the recommended range. This more economical approach will prevent the occurrence of voids, sinks and long processing times, while keeping material usage to a minimum. Ribs are discussed in greater detail in the next section of this chapter. Cores, fillets and radii will also be discussed later as alternate means of designing parts with relatively uniform wall thicknesses and adequate strength without using excessively heavy walls.

Fig 7.1 • Examples of uniform and non-uniform (poor) wall thickness



7.3 Ribs

Ribs are often used to accomplish the following:

- Reduce wall thickness
- Increase part strength and stiffness
- Reduce part weight
- Reduce part cost
- Improve flow paths
- Prevent warping (if not designed properly, ribs may lead to sink marks and can induce warpage)

The thickness of ribs should be no more than 50% of the adjacent wall thickness to prevent voids, sink marks or other distortion. To further minimize sink marks, the ribbing contour should conform to the exterior contour of the part, and the rib height should not exceed 19 mm (0.75 inch). Make certain all corners and all rib intersections with a wall are properly radiused.

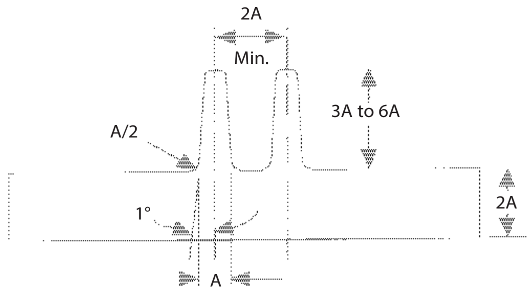
Recommendations for proper rib proportion appear in Figure 7.2. A minimum one degree draft (per side) is recommended for all ribs to facilitate ejection from the mold. An example illustrating good and poor rib design is shown in Figure 7.3.

7.4 Bosses and Studs

Bosses and studs are frequently used around holes for reinforcement, or as mounting or fastening points. The following guidelines should be used when designing a boss or stud:

- The height of the boss or stud should not be more than twice the diameter.
- Draft should be sufficient to ensure easy part ejection as in Figure 7.4a.
- When using solid bosses, the boss diameter should be less than the thickness of the wall from which it protrudes, preferably less than 1/2 of the wall thickness.
- A rib may be used to strengthen a boss (see Figure 7.4b) if required for end-use performance.
- Bosses and studs should be located at the apex of angles where the surface contour of the part changes abruptly as shown in Figure 7.4c.
- Full travel ejector sleeves should be provided for ejecting mounting bosses to prevent hang-up in the cavity. To effectively prevent hang-up, the stroke of the ejector sleeve should be at least 3/4 of the full length of the boss as in Figure 7.4d.

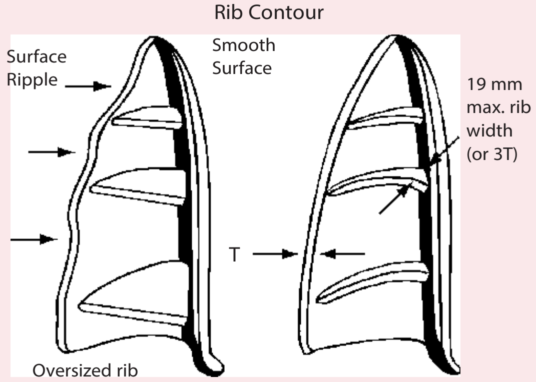
Fig 7.2 • Proper rib proportions



A = Rib Thickness at the Base

These proportions for reinforcing ribs will minimize shrinkage and sink marks.

Fig 7.3 • Poor and good rib design



Poor rib design

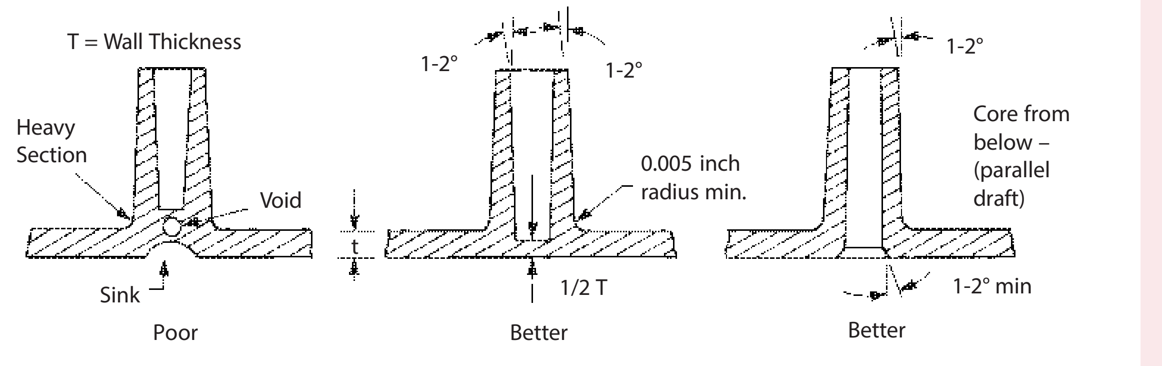
Good rib design

T= Part Wall Thickness

7.5 Cores

Cores can be used to create an opening in the part, or simply to reduce excessively thick walls. Both through holes and blind holes may be readily produced in various shapes.

Fig 7.4a • Proper draft angle for bosses



A through hole is easier to produce because the core pin can be telescoped for support on both ends making it less susceptible to distortion by the forces exerted during molding. A core pin for a blind hole is only supported on one end and is more easily bent. The depth of a blind hole should never exceed three times its diameter or minimum cross-sectional dimension.

When used, cores should be parallel to the line of draw of the mold. Radius the base of the core inside and out. If holes are at an angle, the core pin which forms the hole must be moved manually, mechanically or hydraulically as the mold opens and closes. This adds cost to the mold and can significantly lengthen cycle times.

There should be a minimum distance of one hole diameter between successive holes, or between the holes and the side wall. For threaded holes, or holes for thread-forming or thread-cutting screws, the distance should be increased to three times the diameter. Threading will be covered in further detail in Chapter 11.

7.6 Fillets and Radii

Sharp internal corners in injection-molded plastic parts should always be avoided since they cause poor flow patterns and localized areas of high stress concentration, which cause premature failure of the molded part. Fillets or radii are recommended for all corners to minimize stress concentration as well as permit easier part ejection. Inside and outside corners should be rounded with a radius of 50%-75% of the adjacent wall thickness.

Fig 7.4b • Use of ribs with bosses

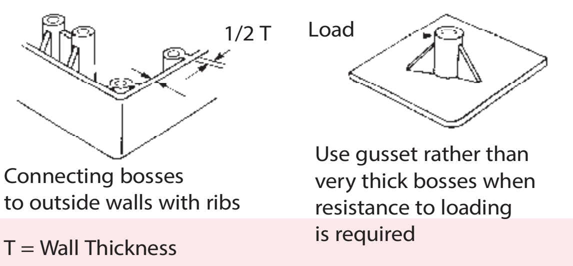


Fig 7.4c • Poor (left) and good (right) bosses

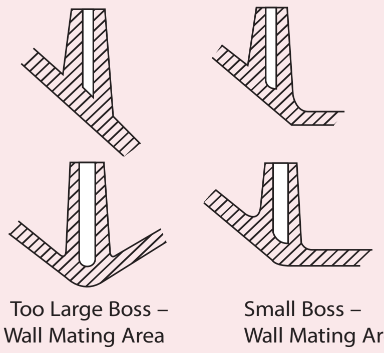
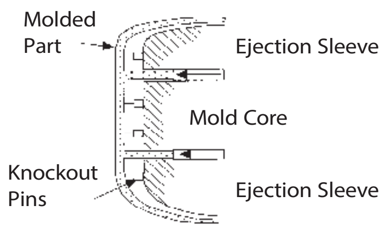


Fig 7.4d • Recommended ejector system for bosses



Pre-colored Celcon acetal copolymer reduces the cost of speaker grilles as much as 25% over painted metal and other plastics by eliminating painting. General Motors, Ford and Volkswagen produce similar speaker grilles from Celcon acetal copolymer.

Celcon acetal copolymer gives the Water Pik® Shower Massage™ its modern look. The material maintains its excellent appearance because it resists chemicals, abrasion, and mineral build-up. Water Pik® Shower Massage is the registered trademark of Water Pik Technologies.

Delco Chassis significantly reduced costs for its washer pump housings by using snap-fit joints molded from Celcon acetal copolymer resins to eliminate three assembly steps.

Celcon acetal copolymer replaced a complex assembly of metal parts in fuel sender unit. The retention of chemical resistance and dimensional stability in the presence of virtually any fuel made it the excellent choice.

Celcon acetal copolymer M90™ provided the heat stability, dimensional stability, and material consistency which Sabin Corporation required for these precision medical fittings.

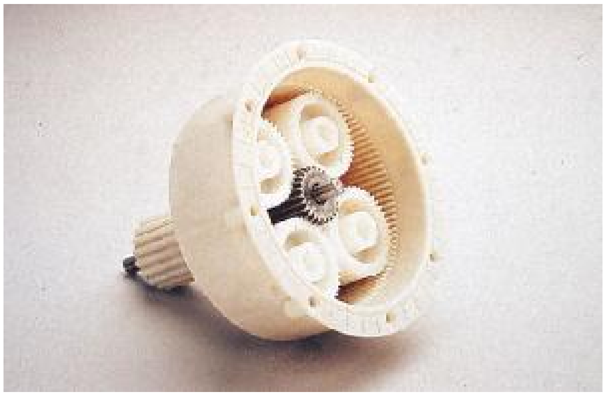
By switching from aluminum to Celcon® acetal copolymer, Senco Products, Inc. was able to produce longer lasting drive cylinders at a lower cost.

The wear resistance and dimensional accuracy of Celcon acetal copolymer make it the ideal material for the snap-fit connectors in the Rodon Group K'Nex® brand toys. K'Nex® is the registered trademark of K'Nex Industries.

The supply mechanism of the powder inhaler for asthmatic patients mainly consists of spring elements and gears and is made of acetal copolymer.

The sideflexing chain shown above features a unique ribbed surface for easy product transfers. It complies with FDA and USDA requirements for direct food contact. Celcon acetal copolymer was selected because of its low sliding friction and high strength.

Automotive seat belt components produced from Celcon acetal copolymer UV90Z show less color change during service than competitive UV-stabilized polyacetals.



Celcon acetal copolymer M50 and GC25A™ helped Whirlpool's splutch gear last over four times the normal machine life while reducing moving parts by 20 percent in its World Washer.

8. Gear Design

Nonmetallic thermoplastic gears are gaining increased acceptance for a wide variety of industrial applications, due to the advantages of lighter weight, quieter operation and reduced production costs. Thermoplastic gears can be produced in a wider range of configurations than is practical with machined metal gears. Cams, lugs, ribs, webs and shaft holes can all be molded in one integral design and in a single operation. These features must be added carefully to maintain effective tolerance control on the gear. Surface finishing and machining steps common in metallic gear manufacture can be eliminated.

Various Celcon® acetal copolymer grades, both natural and glass-reinforced, are used for many types of gears, ranging from miniature clock and timing gears to large, heavy duty washing machine gear transmissions, worm gears for conveyer belts and other power transmission applications. Celcon acetal copolymer offers a combination of high strength and stiffness, excellent fatigue strength, wear and chemical resistance, light weight and a low coefficient of friction.

Although many of the techniques involved in thermoplastic gear design are derived from metal gear technology, some basic and significant differences exist. It is the purpose of this chapter to provide an introduction to acetal gear design, so as to contribute to the successful design of gears tailored to meet specific requirements.

8.1 Spur Gear Dimensions and Terminology

The primary purpose of gears is the transmittal of uniform motion. Most commonly, plastic gears are composed of involute gear teeth (the involute of a circle is a mathematical curve that may be graphically described by a point at the end of a line that is unwound from the circumference of a fixed diameter cylinder referred to as the base circle. Refer to Figure 8.1.

Figure 8.2 illustrates the basic terminology associated with a gear tooth, and Table 8.1 further defines these and other terms.

Fig 8.1 • Involute curve generation

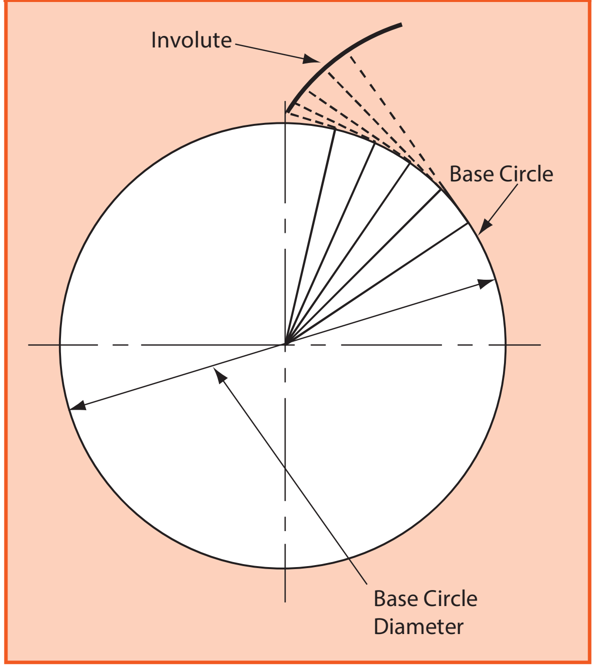


Fig 8.2 • Basic gear nomenclature

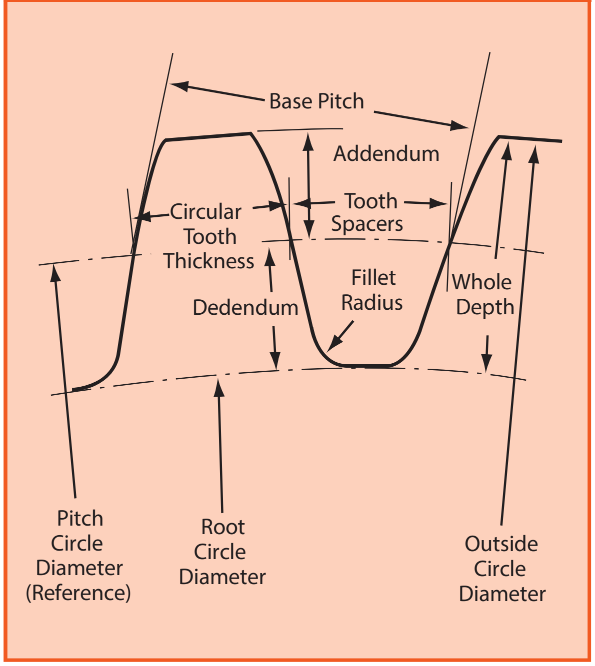


Fig 8.1 · Gear tooth nomenclature and definitions

Active Profile - The part of the gear tooth profile that actually comes in contact with the profile of its mating tooth along the line of action.

Addendum - The height of the gear tooth outside the reference pitch circle.

AGMA Quality Number - The relative quality of a gear as specified by the American Gear Manufacturer's Association. The higher the number, the more accurate the gear in terms of tooth geometry errors and gear runout. For values, refer to the current AGMA Quality Tables, obtainable from AGMA. Their address is: 1500 King Street, Suite 201, Alexandria, VA 22314-2730. Phone 703-684-0211.

Angle of Action - The angle through which one tooth travels from the time it first makes contact with its mating tooth on the line of action until it ceases to be in contact. It is divided into:

1. **Angle of Approach -** Angle through which the tooth moves from the time it first comes into contact with the mating tooth until contact is made at the pitch point.
2. **Angle of Recess -** Angle through which the tooth moves from time of contact at pitch point until end of contact.

Angular Velocity - Time rate of angular motion about an axis.

Backlash - The amount by which a tooth space exceeds the thickness of the engaging tooth in order to prevent tooth binding under operating conditions.

Base Circle - The involute of the base circle defines the gear tooth geometry. See Figure 8.1.

Base Circle Diameter - The diameter of the base circle is a fundamental dimension of involute gearing. See Figure 8.1.

Base Pitch - The perpendicular distance between two successive parallel involutes that forms the profiles of two adjacent teeth. It is equal to the circumference of the base circle divided by the number of teeth in the gear. This is a fundamental dimension of involute gearing. The base pitch of mating gears must be equal. See Figure 8.1.

Center Distance - Distance between the centers of a pair of mating gears.

Circular Pitch - The length of an arc of the reference pitch circle that corresponds to one tooth interval. It equals the circumference of the pitch circle divided by the number of teeth in the gear.

Circular Tooth Thickness - Thickness of a single tooth measured along the reference pitch circle. For an unmodified tooth it is equal to one-half the circular pitch.

Dedendum - Depth of the tooth space below the reference pitch circle.

Diametral Pitch - The ratio of the number of teeth to the reference pitch diameter of a gear. It represents the number of teeth per unit length of pitch diameter.

Face Width - The width of the tooth measured parallel to the gear shaft.

Fillet Radius - The radius of curvature of the corner where the tooth joins the root circle. A full root radius should always be used with plastic gears.

Form Dedendum - The distance below the reference pitch circle to the start of the involute form on the tooth flank.

Gear - Defined as the larger of a pair of mating gears.

Gear Rack - A spur or helical gear with an infinite base circle diameter. Its pitch "circle" is a plane that has translational motion while rolling with the operating pitch cylinder of the mating pinion.

Gear Ratio - The ratio of the number of teeth in the gear to the number of teeth in the pinion.

Interference - A condition that permits contact between mating teeth away from the line of action. It is a deterrent to the transmission of uniform motion and can cause the transmission to seize or fail.

Involute of a Circle - The fundamental profile of the operating surface of the gear tooth in involute gearing. Visually, the involute of a circle is the curve described by a point on the end of a string as it is unwound from the circumference of a cylinder. See Figure 8.1.

Line of Action - The line along which correct contact between mating teeth is made, resulting in the transmission of uniform conjugate motion from one gear to the other. It is the line tangent to the base circle of two mating gears.

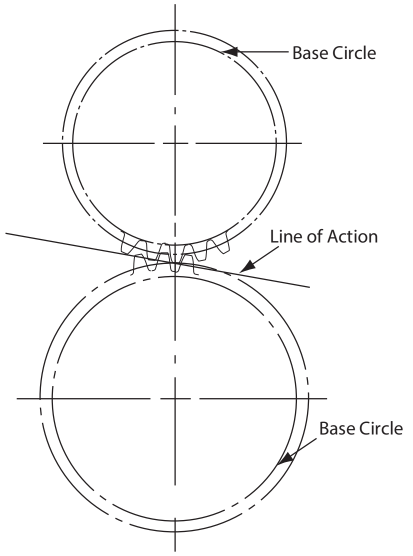


Fig 8.1 · Gear tooth nomenclature and definitions (continued)

Module - The ratio of the pitch diameter of a gear to its number of teeth. It is the reciprocal of the diametral pitch. It is typically used to describe metric gears.

Number of Teeth - The number of teeth contained in the whole circumference of the pitch circle.

Operating Pitch Circle - The circle that represents a smooth disc that would transmit the desired relative motion by friction. It passes through the pitch point. It is not necessarily the same as the standard pitch circle.

Operating Pitch Diameter - Twice the radial distance from the center of the gear to the pitch point.

Pinion - The smaller of a pair of mating gears.

Pitch - Diameter of the pitch circle.

Pitch Diameter - The diameter of the standard pitch circle. It is defined by the number of teeth and the specified diametral pitch or module.

Pitch Point - The intersection of the line between centers with the line of action of two mating gears.

Power - The time rate at which work is done.

Pressure Angle - For involute gears, the angle between the line of action and a line perpendicular to the common center line of the two mating gears. It is also the angle between the radius cutting the tooth face at the pitch point and the tooth face. Usual pressure angles are 14.5°, 20° and 25°; 20° is most commonly used by far.

Root Circle - The circle tangent to the bottoms of the spaces between the gear teeth.

Root Diameter - Diameter of the root circle.

Standard Pitch Circle - A circle whose diameter is defined by multiplying the number of gear teeth by the specified module; or dividing the number of gear teeth by the specified diametral pitch.

Torque - The product of the force and the perpendicular distance from the line of action of the force to the axis of rotation that tends to produce bending or rotation.

Whole Depth - The total depth of the space on a gear measured radially between circles containing the outside diameter of the teeth and the root diameter.

Working Depth - The depth that the teeth of one gear extend into the spaces of its mating gear. It is equal to the sum of the addenda of the mating gears. It is also equal tothe whole depth minus the clearance.

Table 8.2 lists the symbols used for these terms in this manual. Table 8.3 describes the tooth proportions of a gear rack designed according to an AGMA (American Gear Manufacturer's Association) standard, an ISO standard and one of the more common profiles used by the manufacturers of plastic gearing. Additional tooth profile standard systems are available from standards organizations and gear manufacturers.

Most common tooth forms have a working depth of 2.0/Pd or 2.0 m. However, it is often necessary to use working depths up to 35% greater. Increasing the working depth allows for changes in the effective operating center distances of plastic gears caused by the environment (thermal, chemical and moisture expansion) and/or the manufacturing tolerances required of plastic gearing.

The plastic gear designer needs to carefully consider that the standard tooth profiles only provide a convenient starting point, and should not be used solely as the basis of gear design; otherwise substandard or inadequate gear performance may result. Optimizing the gear set profile can improve operating performance to highly acceptable levels. Further discussion on this topic is beyond the scope of this manual.

Table 8.2 • Gear symbol technology

a	addendum	m	module	D_r	root diameter
d	dedendum	d_F	form dedendum	D_o	outside diameter
h	whole depth	r	fillet radius	N	number of teeth
h_w	working depth	V	pitch line velocity	f	face width
t_c	circular tooth thickness	c	center distance	n	angular velocity
Pd	diametral pitch	P	circular pitch	T	torque
Dp	pitch diameter	P_b	base pitch	W	power
φ	pressure angle	D_b	base diameter	F_T	tangential force

Table 8.3 • Standard gear dimensions*

Gear Feature	**AGMA Fine Pitch Pd > 20**	**ISO 53** Coarse Pitch Pd < 20**	**Common Plastic Form*****
Pressure angle, φ	20°	20°	20°
Circular pitch, P	π/Pd	π/Pd	π/Pd
Tooth thickness, T_c	π/2Pd	π/2Pd	π/2Pd
Addendum, a	1/Pd	1/Pd	1/Pd
Working depth, h_w	2/Pd	2/Pd	2/Pd
Dedendum, d	1.2/Pd + 0.002	1.25/Pd	1.33/Pd
Whole depth, h	2.2/Pd + 0.002	2.25/Pd	2.33/Pd
Form dedendum, d_F	1.2/Pd	1.0526/Pd	1.0469/Pd
Fillet radius, r	0	0.3/Pd	0.4303/Pd

* Note 1. For metric gearing, substitute 0.0508 mm for 0.002 in. in the AGMA Fine Pitch column and the module, m, for 1/Pd throughout Table 8.3.

** Note 2. Formerly known as AGMA Coarse Pitch (withdrawn).

*** Note 3. The common plastic form described is designated "PGT-1" and is available from Plastic Gearing Technology, Manchester, CT.

Table 8.4 illustrates the fundamental relationships between the various terms that define the geometry of a single spur gear. Table 8.5 lists some conversion factors used in single gear geometry. Table 8.6 shows the basic relationships between two mating gears.

Table 8.4 · Terms used in defining single spur gear geometry

Terms	Equations
Pitch Diameter	$D_p = N/P_d = Nm$
Circular Pitch	$P = \pi/P_d = \pi m$
Outside Diameter	$D_o = D_p + 2a$
Root Diameter	$D_r = D_o - 2h = D_p - 2d$
Base Circle Diameter	$D_b = D_p \cos \varphi$
Base Pitch	$P_b = P \cos \varphi$ $P_b = \pi D_b/N = \pi D_p \cos \varphi/N$
Pitch Line Velocity	$V = n D_p/2$
Torque	$T = F_T D_p/2$
Power	$W = F_T V = nT$

Table 8.5 · Conversion factors for terms used in defining single gear geometry

Conversions	Equations
RPM to Angular Velocity (min^{-1})	$n = 2\pi$ RPM
RPM to Angular Velocity (sec^{-1})	$n = \pi/30$ RPM
Pitch Line Velocity (ft/min)	$V = \pi D_p$ RPM/12 (D_p expressed in inches)
Pitch Line Velocity (m/sec)	$V = \pi D_p/60{,}000$ (D_p expressed in millimeters)
Power (Horsepower)	$W = F_T V/33{,}000$ (F_T in lbs; (V in ft/min)
Power (Watts)	$W = F_T V$ (F_T in Newtons, (V in m/sec)

Table 8.6 · Fundamental relationships between a spur gear and pinion*

(1) Gear ratio $r = N_G / N_P$

To transmit uniform motion, the pinion and gear must have the same base pitch and pressure angle. It follows that the gear and pinion must have the same diametral pitch or module. Therefore:

(2) $N_G / N_P = D_{bG} / D_{bP} = r$

At the pitch point, the tangential velocities and the tangential force on the gear and the pinion must be equal. Therefore:

(3) $F_T = F_{TG} = F_{TP}$

$V = V_G = V_P$

From equations 1,2,3 above, and the equations in Table 8.4, the following relationships can be derived:

(4) $r = D_{PG} / D_{PP} = n_G / n_P = T_G / T_P$

And the nominal center distance for the gear set is given by:

(5) $C = (D_{PG} + D_{PP}) / 2 = (N_G N_P) / 2P_d = (1 + r) D_{PP} / 2$

* Note 1. At nominal conditions. The $_P$ and $_G$ subscripts represent pinion and gear, respectively.

8.2 Comparison of Metal and Plastic Gear Design

The basic metal gear design equations can be used with plastic gears, including those made from Celcon® acetal copolymer, to obtain theoretical stress values useful for first approximations. However, the significant material property differences between metals and plastics make plastic gear design much more challenging. Generally, four major differences exist between plastic and metal gear behavior:

- Plastics have lower elastic moduli and strengths.
- Plastics are more temperature-sensitive. Properties such as strength and modulus vary more rapidly with temperature compared to metals.
- Plastic part dimensions vary greatly compared to metals due to greater thermal expansions than metals together with dimensional shifts caused by moisture or chemical exposure.
- Plastics have different surface effects (i.e., coefficient of friction and wear).

The most obvious effect of lower modulus is reduced dynamic loading of plastic gears during operation resulting in lower noise. Misalignment and tooth error subject gears to non-productive loads during rotation. Gear teeth must deform to compensate for these inaccuracies. Since less force is required to deform plastic than metal, these loads are much lower. As a result, plastic gears are generally much quieter than metal gears, even when produced at AGMA quality levels one to two lower than the metal gears. However, since the plastic teeth have lower mesh stiffness than metal teeth, somewhat greater backlash is typically needed with plastic gears. Also, particularly in lubricated plastic gears, tip relief is often necessary where it might not be needed in metal gearing.

The lower modulus for plastics also slightly decreases the susceptibility of plastic gears to stress oncentration, due to load redistribution. However, the notch sensitivity of plastics varies greatly. If an adequate fillet radius is used with the plastic gear tooth (radius greater than 25% of module or 0.25 divided by the diametral pitch), stress concentration effects can be

ignored. Generally, a full fillet radius is preferred. Since a full fillet radius is also needed for dimensional stability and processing reasons, it should not be ignored even in lightly loaded plastic gears.

The lower modulus of plastic gears also results in a greatly increased contact area which lowers the contact stress on the tooth flanks. This also helps to redistribute the load and compensates for misalignment and tooth errors. Due to the lower modulus, plastic gears need not be limited to the 1:1 aspect ratio (face width to diameter) typically accepted for metal gears. The lower contact stress and generally superior lubricity also give plastics an advantage over metals when running without lubrication.

Due to the lower strength of plastic, the tooth design of each gear of a set should usually be adjusted to balance the tooth strengths or, in the case of two different plastics, balance the safety factors. This will greatly increase the capacity of the set. For a plastic gear mated with a metal pinion, it is usually desirable to increase the plastic gear tooth to the maximum thickness possible while thinning the pinion, since the load capacity of the set is usually dependent on the plastic.

Temperature effects are important when designing plastic gears. Large modulus changes also occur with temperature. Increased temperature greatly reduces the mesh stiffness leading to increased tooth deflections. As a result, it may be necessary to further increase the backlash and tip relief if significant loads are to be carried. The decrease in tensile strength with temperature reduces the bending strength of the gear teeth. Therefore, in plastic gearing, it is usually necessary to examine the tooth stresses not only at ambient conditions but also at the highest and lowest tooth temperatures expected in the end-use. This is not usually necessary with metal gearing.

In unlubricated gears, the wear rate of the tooth flank increases with increasing temperature. The temperature of meshing gear teeth is affected by pitch line velocity, torque, lubrication and other factors. In unlubricated gears, the temperature increases markedly with increasing pitch line velocity. Therefore, it is necessary to understand not only the environmental temperature in which the gears operate but also the frictional heating of the gear teeth themselves.

Often a gear set is made of two different materials and the housing of a third. Thermal expansion or dimensional changes due to moisture or chemical absorption differences between the gears and housing can reduce the clearance and backlash to the point that the teeth jam. Conversely, dimensional shifts can result in increases in clearance to the point where the gear set cannot operate properly. A plastic gear set at nominal conditions is typically designed with a contact ratio of 1.3 to 1.5. However the worst tolerance and environmental conditions must be examined for both the open mesh and the tight mesh condition. In the first case, the contact ratio may drop below one. In the second, the clearance or backlash may be unacceptable.

In view of the above, it is good practice to work out the preliminary design at nominal conditions. The system tolerances, quality class and environmental conditions can then be used to determine the worst case for both open and tight mesh conditions. The system is then redesigned at the tight mesh condition to ensure maximum contact ratio along with adequate backlash and tip relief. The system is then evaluated at the open mesh condition to ensure that the contact ratio is above one and that there is sufficient load capacity.

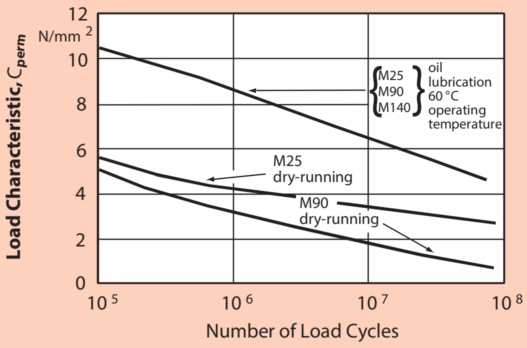
Finally, surface effects such as coefficient of friction can have both positive and negative effects. Lower plastic thermal conductivity can increase temperatures at the mating surfaces, causing wear and deformation. Conversely, the self-lubricating properties of Celcon® acetal copolymer, as compared to other plastics, can reduce friction and increase gear tooth life.

8.3 Design Calculations for Celcon Acetal Copolymer Spur Gears

Accelerated tests of grease-lubricated Celcon acetal copolymer spur gears usually result in tooth fracture as the primary mode of failure, so that design calculations should be based on stress at the tooth root. Dryrunning gears show greater wear on the intermeshing teeth, requiring that design calculations should be based on flank stress. For preliminary and approximate design calculations in both the dry and lubricated cases, the load-bearing capacity (as calculated using the load characteristic c) is a useful guide as to whether or not to consider Celcon acetal copolymer as the gear material of choice. Figure 8.3 shows the load characteristic c_{perm} for some of the typical gear grades of Celcon acetal copolymer as a function of load cycles.

Generally, if c is less than $c_{perm,}$ this indicates that gears of Celcon acetal copolymer will be satisfactory. However, this calculation should be used primarily for initial design concepts. Often, minor design changes or lubrication can provide satisfactory results even when c is greater than c_{perm}.

Fig 8.3 • Load bearing characteristics for grades of Celcon acetal copolymer vs. load cycles



The load characteristic c is dependent on the different materials of gear construction, loading conditions and tooth geometry, lubrication, temperature and peripheral gear speed. The load characteristic is determined experimentally and is only valid for gearwheel pairs operating under similar conditions. It is defined as shown in Table 8.7.

Table 8.7 • Definition of load characteristic *c*

$c = F_T / (F \cdot P) \leq c_{perm}$	[MPa]
$F_T = 2T / D_p$	Tangential force [N]
$P = m \cdot \pi$	Circular Pitch
m	Module [mm]
f	Smallest face width [mm]

8.4 Gear Accuracy

Plastic gears need to maintain gear accuracy in intermeshing as do metal gears. While plastic gears are more compliant than metal, inaccurately dimensioned plastic gears can still result in premature tooth failure, excessive wear, or noise and vibration.

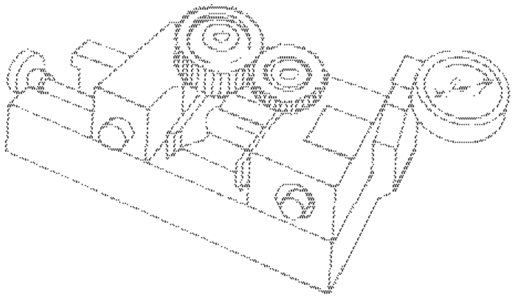
Four types of gear inaccuracy exist:

- Runout (eccentricity)
- Lateral Runout (wobble due to imbalance)
- Pitch Error (non-uniform tooth spacing)
- Profile Error (non-uniform tooth profile)

Pitch and profile errors combine to give tooth-totooth error (TTE). Similarly, total runout is a combination of runout and lateral runout. Runout and tooth error combined are labeled total composite error (TCE).

Tooth-to-tooth and total composite error can be measured using a device that plots radial displacement when a test gear is run in close mesh with a master gear of known accuracy. Figures 8.4 and 8.5 show one type of variable center measuring device and a chart of the radial displacements measured. This method is simple to use and gives a good measure of overall gear dimensions. Both mechanical (hand-operated) and electrical/electronic measuring devices are available. Such devices are useful for production and quality control. However, they cannot pinpoint the source of error and are of limited help when setting up a new tool.

Fig 8.4 • Variable center distance measuring device



Element checking and optical comparators are necessary to develop new or modified parts, or solve molding problems.

The American Gear Manufacturer's Association (AGMA) uses a system in which a numerical gear rating is related to gear accuracy. This AGMA Quality Number denotes the maximum errors permitted in a gear. Higher numbers denote greater accuracy. Contact AGMA for their current standard. The International Organization for Standardization (ISO) has similar quality classes, as do other organizations concerned with writing standards. See Table 8.8 for typical AGMA quality ranges for gear applications.

The AGMA quality system (or a similar system) is strongly recommended for specifying the accuracy of injection molded plastic gears. Once the desired accuracy is machined into the molding tool, the accuracy of plastic gears is consistent throughout the production run. This is generally less expensive than the alternate process of machining individual metal gears to the desired accuracy, and is another reason to specify plastic gears for all applicable jobs.

Tooth-to-tooth errors in plastic gears can often be reduced even one to two AGMA quality classes better than specified. Runout is much more difficult to control in plastics and usually defines the quality rating of the gear. This is because the total composite tolerance increases slightly with gear diameter for any given quality class. However, plastic gear runout variation increases almost linearly with diameter. Therefore, large diameter plastic gears are usually made to a lower quality class than smaller gears.

Fig 8.5 • Idealized chart of measuring device radial displacements

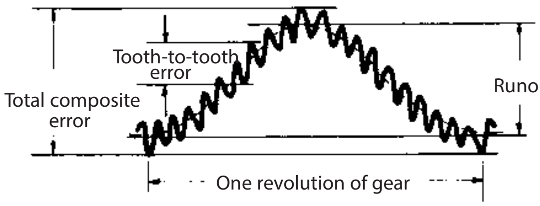


Table 8.8 • Typical quality number ranges for gear applications

Application	AGMA Quality Number
Aircraft instruments	10-14
Clocks	5
Commercial meters (Gas, water, parking)	7-9
Computer/Fax Printers and Copiers	7-10
Data processing	7-9
Farm equipment	4-8
Fishing reels	7-10
Gauges	8-10
Home appliances	5-8
Metering pumps	6-8
Motion picture equipment	8
Photographic equipment	10-12
Radar equipment	10-12
Small power tools	6-9
Vending machines	5-7
Washing machines	5-8

However, modern computer-controlled reciprocatingscrew injection molding machines and improved tooling have greatly improved the capability to produce larger diameter gears at high quality levels.

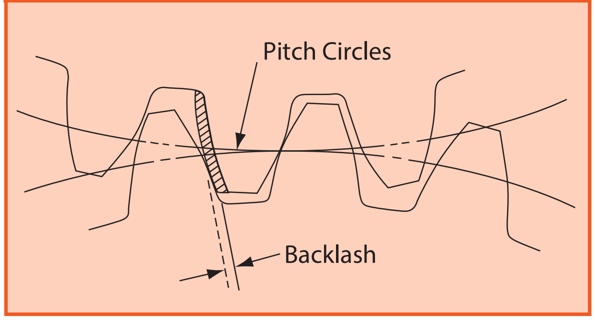
8.5 Gear Tooth Modification

For optimum performance when designing and using plastic gears, additional factors need to be considered. These are:

- Tooth thickness modification
- Long-short addendum system
- Full fillet radius at the tooth root
- Tip modification

The discussion that follows will describe these operations, but it should be emphasized that construction of gear prototypes is recommended before the mold is cut to final dimensions. Since this manual is primarily an overview on plastic gear design, complicated or unusual situations should be discussed with your local Celanese technical representative, or contact Product Information Services at 1-800-833-4882.

Fig 8.6 • Backlash in a gear pair



8.6 Tooth Thickness

The standard tooth thickness of a gear is the circular tooth thickness at the reference pitch diameter. Standard thickness is a theoretical concept in the sense that it only applies to dimensionally exact gears operating at the theoretically correct center distance.

Actual gears must always be designed taking into account additional factors including thermal expansion, dimensional shifts of gears and housing due to moisture and lubricant absorption, bearing runout, gear accuracy and others. These factors tend to either force a pair of gears into closer mesh (gear binding), or pull them apart (loss of smooth action and inefficient power transmission).

Various ways exist to compensate for these factors:

- Addition of backlash, i.e., trimming the entire tooth profile to make it thinner than standard to allow more "play" during gear intermeshing (see Figure 8.6). Equations exist for calculating the operating gear pressure angle and the allowable sum of tooth thicknesses for two mating gears, but which require knowledge of proposed gear dimensions, maximum bearing runout, thermal expansion center distance tolerance, and the AGMA Quality Number Tolerance.
- Increasing the effective center distance by an amount equal to the total distance the gears are forced further into mesh. Since the effective center distance then equals the theoretical center difference, there is no change in the pressure angle and the standard tooth thickness can be used. This technique has the advantage of not weakening the gear teeth but may not be feasible because of space limitations. The design calculations referred to on page 57 can be used to approximate the effective center distance.

- Using plastic housings to eliminate differential thermal expansion. Whenever possible plastic housings should be used with plastic gears, preferably of the same material. This has the effect of essentially cancelling the gear intermeshing expansion by the gear shaft separation, and reducing movement into and out of mesh.

8.7 The Long-Short Addendum System

A gear with too few teeth may result in an undercut gear. Undercuts weaken gear teeth and can remove a portion of the material lying on the involute curve adjacent to the base circle. This can reduce contact ratio and cause excessive wear.

A number of techniques have been developed for preventing undercutting, including increasing the number of gear teeth and/or increasing the operating pressure angle. Undercutting may also be prevented by slightly lengthening the pinion addendum and shortening the gear addendum by a proportional amount. The pressure angle during gear intermeshing may be unchanged. The outside radius of the pinion is increased, and since the tooth profile penetrates less deeply into the gear blank, undercutting is reduced or eliminated.

When a long-short addendum system is used to avoid undercut on a pinion, backlash should be applied by reducing the gear tooth thickness.

Table 8.9 · Approximate values of addendum for balanced strength

M_G (gear Ratio) N_G / N_p		Number of pinion teeth, N_p					
		17		25		35	
From	To	Pinion a_p	Gear a_G	Pinion a_p	Gear a_G	Pinion a_p	Gear a_G
1.00	1.08	1.058	0.942	1.012	0.988	1.010	0.990
1.08	1.16	1.058	0.942	1.024	0.976	1.020	0.980
1.16	1.26	1.058	0.942	1.038	0.962	1.032	0.968
1.26	1.37	1.061	0.939	1.053	0.947	1.044	0.956
1.37	1.48	1.080	0.920	1.067	0.933	1.056	0.944
1.48	1.60	1.098	0.902	1.080	0.920	1.065	0.935
1.60	1.75	1.116	0.884	1.093	0.907	1.076	0.924
1.75	1.90	1.130	0.870	1.105	0.895	1.085	0.915
1.90	2.05	1.145	0.855	1.117	0.883	1.094	0.906
2.05	2.22	1.158	0.842	1.127	0.873	1.102	0.898
2.22	2.42	1.172	0.828	1.137	0.863	1.110	0.890
2.42	2.62	1.186	0.814	1.147	0.853	1.118	0.882
2.62	2.84	1.198	0.802	1.156	0.844	1.124	0.876
2.84	3.09	1.210	0.790	1.163	0.837	1.130	0.870
3.09	3.35	1.221	0.779	1.170	0.830	1.135	0.865
3.35	3.65	1.232	0.768	1.177	0.823	1.140	0.860
3.65	3.96	1.241	0.759	1.183	0.817	1.145	0.855
3.96	4.29	1.250	0.750	1.189	0.811	1.150	0.850
4.29	4.64	1.260	0.740	1.193	0.807	1.153	0.847
4.64	5.00	1.267	0.733	1.198	0.802	1.158	0.842
5.00	5.40	1.274	0.726	1.201	0.799	1.160	0.840
5.40	5.88	1.280	0.720	1.203	0.797	1.162	0.838
5.88	6.42	1.288	0.712	1.204	0.796	1.163	0.837
6.42	7.00	1.292	0.708	1.205	0.795	1.164	0.836

Note. Straight line interpolation may be used for intermediate numbers of teeth.

Long-short addendums may also be used to balance the strength of teeth when the pinion and gear are made of the same material. Table 8.9 shows the approximate values of the gear and pinion addendums to obtain balanced strength in pairs of
intermeshing gears.

8.8 Full Fillet Radius

Gears are very susceptible to stress build up at the roots of the teeth due to shock loading. In plastic gears (including those made from Celcon® acetal copolymer) a full fillet radius should be used in the root region between adjacent teeth. The lower stiffness of Celcon acetal copolymer coupled with the use of a full fillet radius allows bending stresses to be calculated without adding a stress concentration factor.

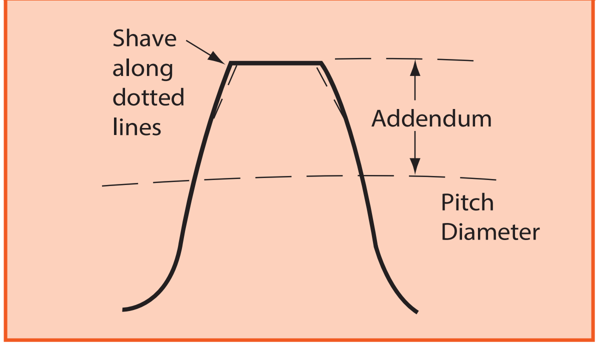
A full fillet radius also improves the polymer flow into the tooth portion of the mold cavity. There is less tendency for the polymer to "hang up" as it enters the tooth cavity, which could lead to flaws at the tooth root. Flow around a larger radius also improves the molecular orientation of the polymer due to less disruption of the flow path. This is especially true with glass-reinforced plastics in which poor glass orientationand glass breakage can occur at a sharp radius. Moreover, plastic shrinkage in the area between two teeth with a sharp radius at the tooth root can lead to high molded-in stresses, significantly reducing the bending capacity of the teeth.

A full fillet radius will also improve the heat transfer from the molten plastic to the mold. Plastic material near a sharp inside corner stays hotter longer, leading to uneven shrinkage, reduced dimensional control and increased molded-in stresses.

8.9 Tip Modification

Tooth deflection during gear rotation can cause interference, noise, dynamic loads and excessive wear. The most common remedy is called "tip relief", and involves trimming the tips of the teeth. This is accomplished by shaving the tips starting approximately halfway up the addendum (see Figure 8.7). The amount of trim depends on tooth deflection under load, the amount of backlash and the AGMA gear quality number. Plastic gears tend to deflect considerably more than metal gears and for this reason are more likely to require tip modification.

Fig 8.7 • Tip relief



8.10 Gear Noise

Noise can be a problem in any gear system, but plastic gears are inherently quieter than metal gears. This is primarily due to their relatively low modulus which compensates for quality errors, thus reducing shock loading. The resiliency and self-lubricating quality of Celcon acetal copolymer plastic gears reduces noise even further.

When additional noise reduction is required, several of the methods mentioned previously may be used, including the long-short addendum system, tip modification and an increase in gear accuracy. It has been found that increasing the gear accuracy by at least two numbers can significantly reduce residual noise. Also, as with metals, changing from spur to helical gears greatly reduces noise and can also enhance power transmission. Special low noise generation Celcon acetal copolymer formulations are available for the ultimate in quiet gears.

8.11 Attaching a Plastic Gear to a Shaft

Several techniques are used to attach a plastic gear to a shaft:

- Molded-in metal shaft. No finishing operation is required with this technique, but molding cycle time may be increased slightly because the inserts (shafts) must be placed in the mold. It is recommended that the insert be heated to 90-150°C before molding to reduce stresses caused by differential shrinkage. For the same reason, the mold should be heated to 105°C, the melt temperature should be 195-200°C and a slow injection speed should be used. If significant torque is to be transferred from the shaft to the gear, the shaft should be knurled or upset, then wire brushed or sandblasted to eliminate sharp points.

- **Splined shaft.** This method is preferred because it offers very high torque capacity and the splined teeth can easily be molded into the gear hub. Manufacturing costs are higher because the shaft must be machined, milled or rolled.
- **Press-fitted shaft.** This method can lead to residual stresses in the plastic gear. However, if the torque requirements are low, an interference fit may be acceptable. A splined or knurled shaft may be press-fit ultrasonically to create a layer of molten plastic. This technique minimizes residual stresses and considerably improves gear-shaft torque.
- **Integrally molded plastic shaft.** This method is economical, but can lead to shaft bending under load, because of plastic's lower flex modulus compared to metal. Small variations in molding conditions can also cause shaft warpage. A hollow shaft can be used to maintain uniform wall thickness, which can improve shaft torsional strength.
- **Keyed shaft.** This method of shaft attachment is relatively low cost, has fairly high torque capacity and is easy to disassemble. Only rounded keys should be used with gears made from Celcon® acetal copolymer to reduce the possibility of stress concentration. Multiple keys are recommended whenever high torque loads may occur. The keyway corners in the plastic should be radiused for stress relief.
- **Shaft attached by set screw.** This technique can only be used where torque loads are low. Manufacturing costs are likewise low. Self-tapping screws can be used with gears of Celcon acetal copolymer to further reduce costs.

8.12 Stress Concentration

Plastic gears, like metal, exhibit stress concentration effects and, like metals, vary widely in their notch sensitivity. Therefore, all sharp corners should be radiused 50-75% of the adjacent wall thickness (except the tooth roots, which should have a full fillet radius as previously discussed). These operations should reduce stress concentration effects to acceptable levels.

8.13 Gear Types Summary

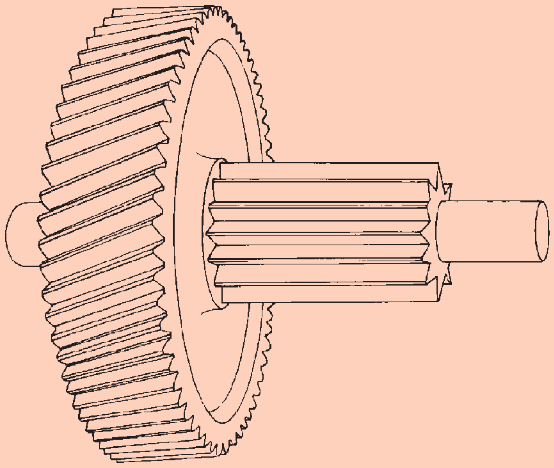
There are several gear types (see Figure 8.8) that are typically used in various applications. They are:

- **Spur.** Simple to design, usually preferred for most applications and can be used at any rotation speed that can be handled by the other gear types. It is somewhat noisier than the other gear types.
- **Helical.** Generally used when high speed, high horsepower and noise reduction are required. Helical gears are highly efficient (up to 99% efficiency).
- **Bevel.** Ordinarily used on right angle drives when high efficiency (up to 98%) is needed, but require considerable positional and dimensional accuracy.
- **Worm.** Also used on right angle drives when lower efficiency (up to 90%) is acceptable. Most worm drives designed in plastic are actually crossed helical gears.
- **Hypoid.** Less efficient than bevel gears, but can transmit greater power in the same amount of space. However, these are not involute gears and require considerable gear tooth and position accuracy. The inability to meet accuracy requirements can greatly reduce capacity.
- **Face.** A face gear coupled with a spur gear is an excellent choice for a right angle drive. It has good power capacity and less sensitivity to position errors and dimension shifts than other right angle drives for plastic gearing.
- **Internal.** Internal gears may be either spur or helical. The shorter center distance of an internal gear pair is advantageous where space is limited. The internal gear also forms a protective cover over its mate. Internal gears are easily produced in plastic. When used in epicyclic gear sets, they provide relatively high power densities in a small space.

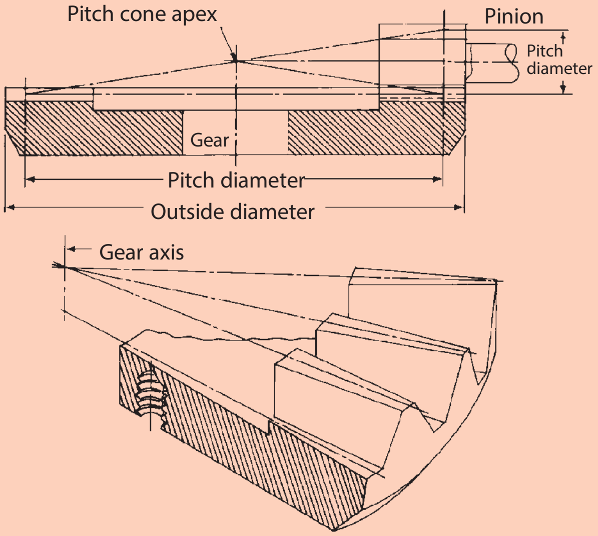
Figure 8.8 illustrates some of the typical gear types and arrangements that have been successfully fabricated from various grades of Celcon acetal copolymer.

Independent of the gear type chosen, power-splitting transmissions are recommended when large torque values are expected during service life. While more gears may be required, the overall transmission size is significantly reduced. Epicyclic transmissions are generally considered the best choice for power-splitting transmissions.

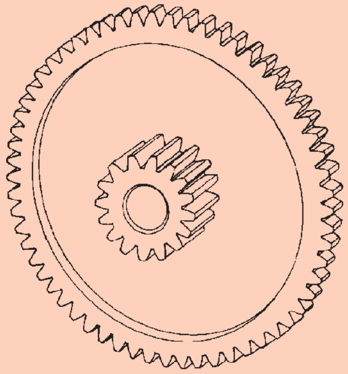
Fig 8.8 • Some typical gear types and arrangements



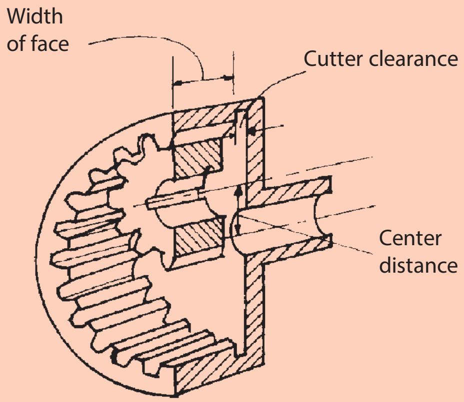
32 Diametral pitch helical gear and 32 diametral pitch spur pinion



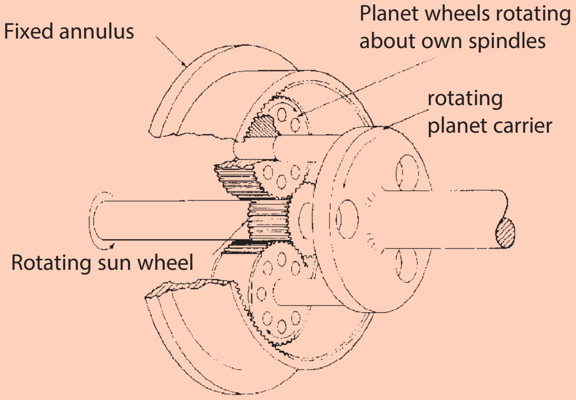
Face Gear



Cluster spur gear



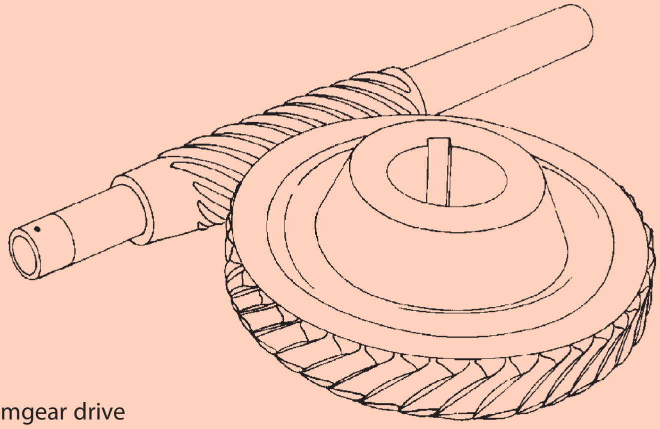
Internal gear and pinion



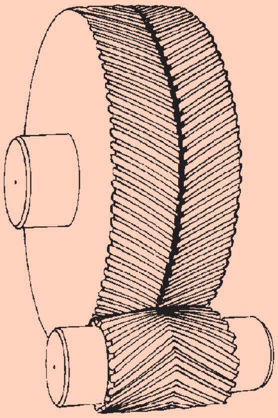
Epicyclic planetary gear arrangement

Line drawings of face gear, planetary gear, internal gear (page 63), and wormgear, helical gear, bevel and hypoid gears (page 64) adapted from Gear Handbook, First Edition, B. W. Dudley (Editor) (1962) McGraw – Hill Publishers. Used with permission of the McGraw – Hill Companies.

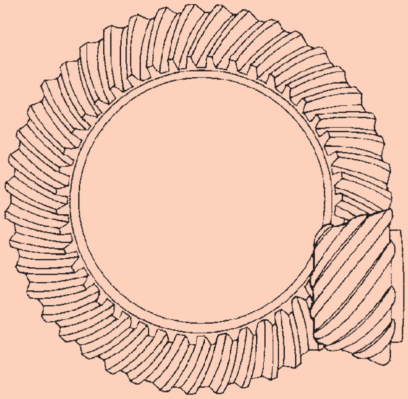
Fig 8.8 • Some typical gear types and arrangements (continued)



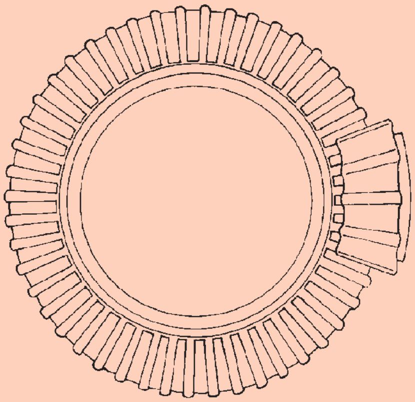
Single-enveloping wormgear drive



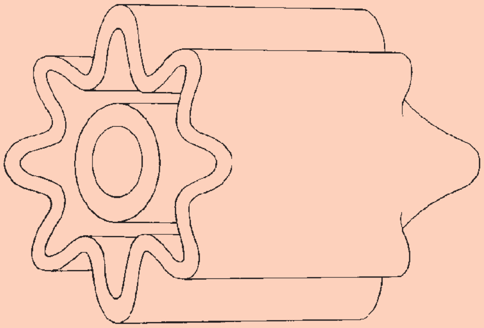
Double-helical or “herringbone” gear



Hypoid-gear drive



Straight bevel gear



Cored 10 diametrical pitch pinion

8.14 Gear Application Quality Number

Based on the many gear applications of Celcon® acetal copolymer already in place, approximate criteria have been developed for relating gear accuracy to a specific application. A partial list is shown in Table 8.6.

Most injection molded gears are in the Q6 to Q9 range. Some molders have produced Q10 to Q12 in small diameter, fine pitch gears. Many larger gears required to have a quality of Q10 and above are machined rather than molded. However, machine, product and process improvements are steadily increasing the quality level obtainable in a given size plastic gear.

9. Bearing Design

9.1 Introduction

The function of a bearing is to support rotating, oscillating or sliding movement by means of surface contact, and to accomplish this with a minimum of power-dissipating friction and deterioration at the interface. As with the design of gears discussed in Chapter 8, the use of Celcon® acetal copolymer for bearings has increased design flexibility, as a replacement for the traditional metal-oil film bearing. The desirable features of metal bearings such as strength, hardness, stiffness, dimensional stability and creep resistance have been augmented with lubricity, wear resistance, thermal and electrical insulating qualities and lower cost.

9.2 Properties of Celcon acetal copolymer Bearings

Celcon acetal copolymer is widely used as a bearing material because of its unique combination of properties, especially its relatively low and temperatureconstant frictional values. Friction generates heat and increases bearing wear. Even unlubricated Celcon acetal copolymer grades have low coefficients of friction, especially against dissimilar materials. Special low wear grades containing lubricant additives can reduce frictional values even further. Table 9.1 shows typical coefficient of friction values.

Table 9.1 • Dynamic coefficient of friction for unlubricated standard Celcon acetal copolymer against other materials

Other Material	**Coefficient of Friction (ASTM D 1894 - 61T)**
Steel	0.15
Brass	0.15
Aluminum	0.15
Nylon 66	0.17
Celcon acetal copolymer (Standard Unfilled Grade)*	0.35

* Note. The coefficient of friction of Celcon acetal copolymer against steel is essentially constant over the temperature range 21-93°C (70-200°F). Lubricated Celcon acetal copolymer bearings show coefficient of friction values as low as 0.05 against metals.

For all plastics, frictional values are not necessarily constant, but can vary with load, sliding rate, surface finish and smoothness, temperature and humidity. Celcon acetal copolymer shows lower initial frictional values than many other plastic materials, and more constant values over wide temperature and humidity ranges. Figures 9.1 and 9.2 illustrate the dynamic coefficient of friction of bearings of Celcon acetal copolymer as a function of speed and pressure versus a steel shaft.

Fig 9.1 • Dynamic coefficient of friction vs. speed

The dynamic coefficient of friction of Celcon acetal copolymer as a function of the sliding rate at a constant bearing pressure of 0.26 MPa (37.5 psi) against a hardened and polished steel shaft

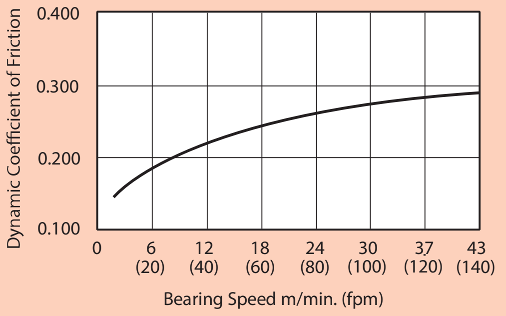
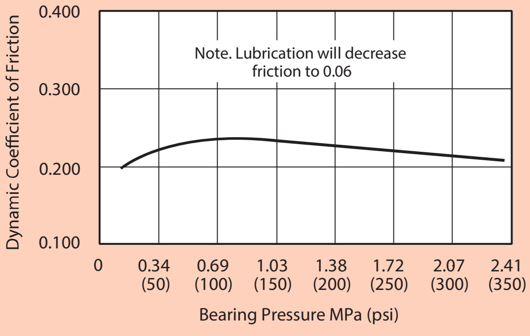


Fig 9.2 • Dynamic coefficient of friction vs. pressure

The dynamic coefficient of friction of Celcon acetal copolymer as a function of the mean surface pressure at constant sliding speed of 10 m/min. (33 fpm) against a hardened and polished steel shaft


Note. Lubrication will decrease friction to 0.06

Other properties of Celcon® acetal copolymer useful for bearing applications are:

- **High fatigue resistance.** Fatigue resistance is important in both continuous and start-and-stop motion. Some plastics show premature failure due to fatigue. Celcon acetal copolymer exhibits high and sustained fatigue resistance. Also, startstop operation can actually lead to lower heat build-up, allowing higher bearing loads. Static and dynamic frictional values are similar, which should minimize stick-slip problems.
- **Good creep resistance.** Excessive creep or cold flow under load can lead to bearings with "flat spots", and loss of smoothness in operation. Celcon acetal copolymer is highly resistant to creep over a wide temperature range. See Chapter 3 for further information.
- **Good dimensional stability.** Celcon acetal copolymer is relatively unaffected by humidity variations. Other plastics such as nylon 6/6 can shrink markedly with lower humidity. Summer to winter humidity change has caused press-fit nylon bearings to fall out of their housings. Additional dimensional stability data can be found in Chapter 4.
- **Excellent environmental resistance.** Bearings may be subject to attack from aggressive environments such as salt, hot water, chlorinated solvents and other chemical agents. Celcon acetal copolymer, as shown in Chapter 5, Table 5.1, is resistant to many common chemicals and solvents.
- **Good electrical properties.** Bearings and sliding surfaces may be subjected to electrical stress, such as in small motor main shaft bearings, switches and circuit breakers. Celcon acetal copolymer, as described in Chapter 6, has good electrical insulating properties including dielectric strength, volume resistivity, and low dielectric constant and loss factor. Properties are retained even after long service in either dry or humid environments.
- **Good compatibility with shaft materials.** Bearings of Celcon acetal copolymer can be used with most shaft materials including aluminum, unhardened steel and plastic. Some materials used for bearings are abrasive or contain abrasive fillers such as glass; these require specially hardened shafts to reduce scoring. Celcon acetal copolymer is soft enough so that shaft wear is minimal. If a plastic shaft is required for a specific application, Celcon acetal copolymer can be used for both the shaft and bearing if lubrication is provided. Both pre-lubrication and a low wear grade of Celcon acetal copolymer is recommended. The most effective all-plastic system uses a Celcon acetal copolymer bearing coupled with a nylon 6/6 or polyester shaft. This combination has low friction and long service life, even if unlubricated.
- **Low noise.** Celcon acetal copolymer has a high internal damping capacity compared to metals, which tends to produce low noise levels during operation. Relatively tight clearances that would be unsatisfactory with metal bearings because of high noise levels produce acceptable noise when made from Celcon acetal copolymer. Celcon acetal copolymer sliding against itself can sometimes produce noise because of a slip-stick behavior against itself. Light initial lubrication usually cures this problem. Special low-noise Celcon acetal copolymer formulations are available for unusually difficult noise-generating applications.

9.3 Celcon acetal copolymer Bearing Grades

Standard unfilled and glass-reinforced grades of Celcon acetal copolymer are most often considered for bearings. These include:

Celcon acetal M25	Melt flow 2.5, Tough extrusion and injection molding grade.
Celcon acetal M90™	Melt flow 9.0, Injection molding grade; excellent processability.
Celcon acetal M270™	Melt flow 27, High flow, excellent for thin-wall parts or complex shapes.
Celcon acetal GC25A™	A 25% glass-coupled grade for enhanced stiffness.

Four low-wear grades and one low-noise grade based on the above products are available. They contain various lubricant systems as indicated:

Celcon acetal LW90	A low-wear grade for high speed, low load service against metal surfaces.
Celcon acetal LW90S2	A 2% silicone fluid modified M90™ for wear resistance against glass, metal or plastic.

Celcon® acetal LW90F2	A PTFE modified M90™ for use where silicone lubricants are incompatible or ineffective.
Celcon acetal LWGCS2	A 2% silicone fluid modified GC25A for enhanced wear resistance and stiffness.
Celcon acetal M140L1	A special low noise formulation.

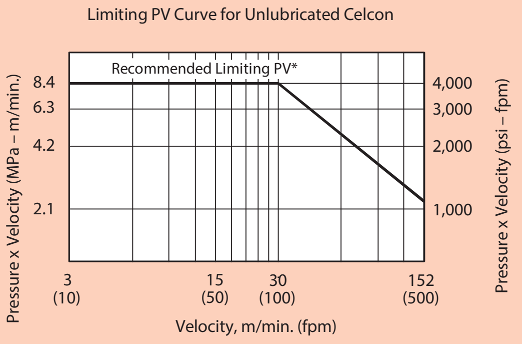
9.4 Pressure-Velocity Relationship

The Pressure-Velocity (PV) factor has been used for many years to predict the journal bearing performance of sintered metal bearings. This approach has been found empirically useful in predicting performance of plastic resins, including Celcon acetal copolymer. It can be used as an initial predictor of a specific bearing application.

The usefulness of a plastic bearing is particularly dependent on the heat build-up at the rotating member. Two factors affecting the heat generation rate are the load (or pressure P) on the bearing and the surface velocity (V). The product of these factors (PV) reflects the rate of heat generation at the bearing and its mating surface, and gives an indication of the severity of the application. Each bearing material has a "PV" at each velocity, which is dependent on the bearing dimensions. Figure 9.3 illustrates the empirically derived PV values vs. surface rotation for standard unlubricated Celcon acetal copolymer grades as journal bearings.

Self-lubricated bearings made from Celcon acetal copolymer can have PV values up to five times as great as the values shown in Figure 9.3, but it is strongly recommended that a prototype bearing be designed and tested before actual production begins. This is because the effects of both internal and external lubricant systems are complex and often unpredictable.

Fig 9.3 • PV values for unlubricated grades of Celcon acetal copolymer



*This Limiting PV Curve has been found suitable for ambient temperatures of up to 93 °C (200 °F)

Table 9.2 summarizes the recommended PV ranges for both unlubricated and self-lubricated Celcon acetal copolymer systems. PV values may be calculated using standard engineering equations. Pressure is equal to load divided by area. Area depends on bearing configuration: bushings, journal bearings, thrust washers, or flat sliding surfaces. **As a general precaution, Celcon acetal copolymer should not be used for bearings if the pressure exceeds 6.9 MPa (1,000 psi).**

Similarly, velocity is the average sliding speed between the two moving parts and is calculated from the shape and configuration of the bearing. **As a general precaution, Celcon acetal copolymer should not be used for bearings if the velocity exceeds 305 m/min. (1,000 ft./min.).**

Table 9.2 • PV ranges for Celcon acetal copolymer systems

Grade Type	PV Value	Remarks
M25, M90, GC25A	See Figure 9.3	Standard grades (with and without reinforcement) are acceptable
LW grades	45 MPa – m/min. (20,000 psi – fpm)	Lubricated grades are acceptable from 3-150 mpm (10-500 fpm) velocity
—	Greater than 45 MPa – m/min.	PV exceeds the recommended limit for Celcon acetal copolymer. Redesign bearing to reduce pressure and/or velocity.

Example 9-1.

A plastic sleeve bearing for a hot water pump assembly is designed to carry a load stress of 34 Kg at a maximum surface velocity of 200 rpm. Bearing dimensions are 25.4 mm I.D. x 30 mm length, maximum ambient temperature is 82°C. The assembly may run unlubricated. Calculate the PV value to determine whether Celcon® acetal copolymer M90™ will be suitable for this application.

Solution:

$$P = \frac{\text{Load Stress}}{\text{Surface Area}}$$

(Load stress = 34 Kg = 332 Newtons)

(Surface area = 25.4 mm x 30 mm = 762 mm ^{2})

$$P = \frac{332}{25.4 \times 30} = 0.436 \text{ N/mm}^2 = 0.436 \text{ MPa}$$

$$V = \frac{\Pi \times 200 \text{ rpm} \times 25.4 \text{ mm}}{1000 \text{ mm/meter}} = 15.96 \text{ m/min.}$$

PV = 0.436 MPa x 15.96 m/min. = 6.95 MPa – m/min.

From Figure 9.3 the allowable PV value at a velocity of 16 m/min. is 8.4 MPa – m/min. The calculated PV value of 6.95 is well below the allowable PV limit. In addition the given operating temperature of 82°C is within the temperature limit for the allowable PV curve of 93°C.

Therefore Celcon acetal copolymer M90™ is a satisfactory material for this bearing assembly.

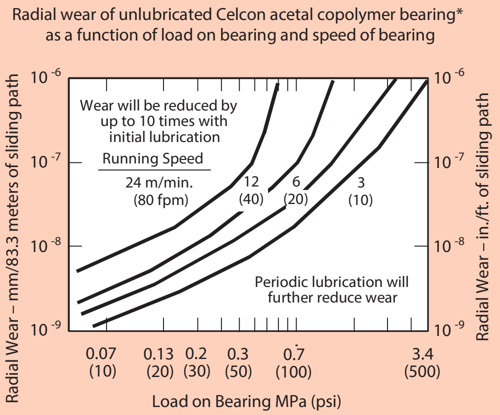
Moreover, because of the continual hot water immersion, Celcon acetal copolymer is superior in dimensional stability to nylon 6/6 and superior in creep resistance to polyesters under these conditions.

Celcon acetal copolymer M90 was selected not only for the bearing but also for the cage assembly supporting the bearing and has performed satisfactorily over the service life of the part.

9.5 Bearing Wear Factors

A second factor in plastic bearing design is wear at the moving surfaces. Wear rate is usually derived empirically since it is a function of both the inherent lubricity of the moving surfaces and the thermal effects. Figure 9.4 gives the experimental values of radial wear for an unlubricated Celcon acetal copolymer journal bearing. It can be used as an initial check of wear properties. If the results obtained from the design prototype are significantly poorer than Figure 9.4, the design should be rechecked for possible inconsistencies.

Fig 9.4 · Radial wear of unlubricated Celcon acetal journal bearing



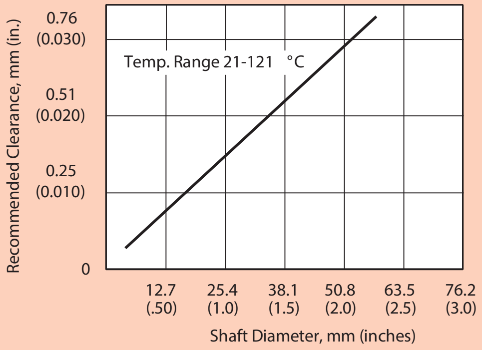
* Data developed for 10 mm (I.D.) x 10 mm length journal bearing made of Celcon acetal copolymer. Shaft was polished steel, ambient temperature 23 °C (78 °F); clearance was 0.015 mm (0.0006").

9.6 Clearance

Another important consideration in plastic bearing design is bearing-to-shaft clearance. If excessive wear is observed under allowable bearing loads and speeds, it is almost always due to insufficient clearance. Empirically, running clearances of about 0.013 in/in (0.013 mm/mm) bearing diameter provide optimum running life. Figure 9.5 illustrates recommended clearances for various shaft diameters over an operating temperature range of 21-121°C. These clearances take into account dimensional changes in a plastic bearing's inside diameter as the operating temperature increases.

Fig 9.5 • Recommended bearing clearances

Recommended Bearing Clearances for different shaft diameters
(Celcon acetal copolymer bushing in metal housing)



9.7 Bearing Wall Thickness

Wall thickness should be held to a minimum to facilitate heat transfer from the bearing to the metal housing and surrounding areas. The following empirical equation can be used to calculate the average wall thickness, which should be adequate for most applications:

(Metric units)	(English units)
$T = 0.06\,d + 0.25$	$T = 0.06\,d + 0.010$

T = wall thickness, mm or in.
d = shaft diameter, mm or in.

Bearings subjected to impact or other forces may require somewhat greater thicknesses.

9.8 Bearing Length

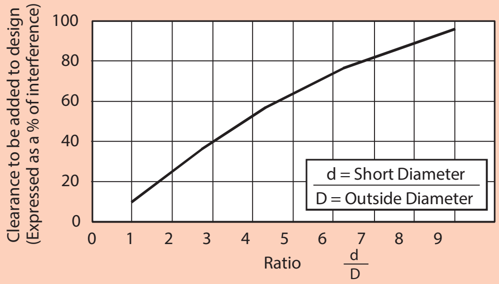
Bearing lengths are recommended to be no greater than 1.5 times bearing shaft diameter. Greater lengths may cause out-of-round bearing dimensions, leading to local overheating and reduced service life. In some cases, bearing lengths may need to be increased slightly to reduce excessive shaft vibration or increase stability at the moving surfaces.

9.9 Bearing Attachments

Bearings of Celcon® acetal copolymer can be anchored by using snap-fits, press-fits, interference-fits, threads, keys, flanges, etc., or by being molded as an integral part of the housing. The resilience, creep resistance and thread strength of Celcon acetal copolymer allow easy and positive attachment not possible with some other plastic materials.

Attachments made using an interference fit require a dimensional adjustment, because it causes a decrease in the inside diameter of the bearing and reduces clearance. Figure 9.6 illustrates the compensation required when interference fits are used. The value shown should be added to the calculated clearance to determine the design bore dimension.

Fig 9.6 • Clearance for interference fit bearings



Celcon acetal copolymer can also be successfully press fitted because of its creep resistance and resistance to dimensional change caused by humidity variations.

9.10 Other Design Tips

- Surface finish (smoothness) of bearings is less critical than the surface finish of the shaft. Bearing surface finish need only be 197 micron (50 microinches) RMS (Root Mean Square) as measured on a suitable instrument; however, the shaft surface finish should be targeted for no less than 60 microns (16 microinches) RMS.

- Avoid sharp corners in bearing design to reduce stress concentration effects. It is recommended that all corners be radiused 50-75% of the adjacent wall thickness.

- Do not anchor the ends of a bearing. This restricts thermal expansion and may cause bearing distortion and reduced clearance.

- It is recommended that all plastic bearings be pre-lubricated, even those made with the lowwear grades of Celcon® acetal copolymer. This procedure should extend bearing service life by up to ten-fold over unlubricated bearings. Constant or even occasional in-service lubrication, if feasible, will improve bearing life even further. Many different types of lubricants can be used with bearings of Celcon acetal copolymer, including mineral oil, silicone oil, ordinary motor oil (10W-30), graphite and PTFE lubricants.

- However, if lubrication is impractical, unlubricated bearings of Celcon acetal copolymer can function effectively in many bearing applications if properly designed.

- Depending on its complexity, a new bearing design can, in some cases, be prototyped by machining available Celcon acetal copolymer rod stock, rather than cutting a new injection mold. Machining the prototype is usually faster and less costly than machining a mold. It has been determined that as a first approximation, machined and molded parts of Celcon acetal copolymer have similar bearing characteristics including friction and wear.

- Service life of a molded bearing should, moreover, exceed that of a bearing machined from rod stock of Celcon acetal copolymer because of its better surface finish.

10. Mold Design

10.1 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.

10.2 Mold Bases

Mold bases should be fabricated in a suitable steel grade and be made sturdy enough with pillars to dequately 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.

10.3 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. cavities, 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 used successfully for unfilled Celcon acetal copolymer 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 (Rc 30-35), zinc alloys or aluminum are acceptable but may not be durable enough for long or high volume production.

10.4 Mold Surface Finish

A wide variety of surface finishes can be used with Celcon acetal copolymer, 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, embossingand 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 thickerwalled parts, but precautions should be aken 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 freezeoff 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 adequate 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) for further comments.

10.5 Sprue Bushings

Standard sprue bushings with a taper of 2 1/2°-3 per side perform satisfactorily with Celcon® acetal copolymer. 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.

10.6 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 crosssectional 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 10-1. 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.

10.7 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 copolymer molding jobs are currently being performed using runnerless molds.

Table 10.1 • 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	7.92 (0.312)

Celcon® acetal copolymer is well suited to the demands of hot runner molding. Celcon acetal copolymer has good thermal stability which is 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 good use of runnerless tooling 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 copolymer in hot runners, including systems that 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.

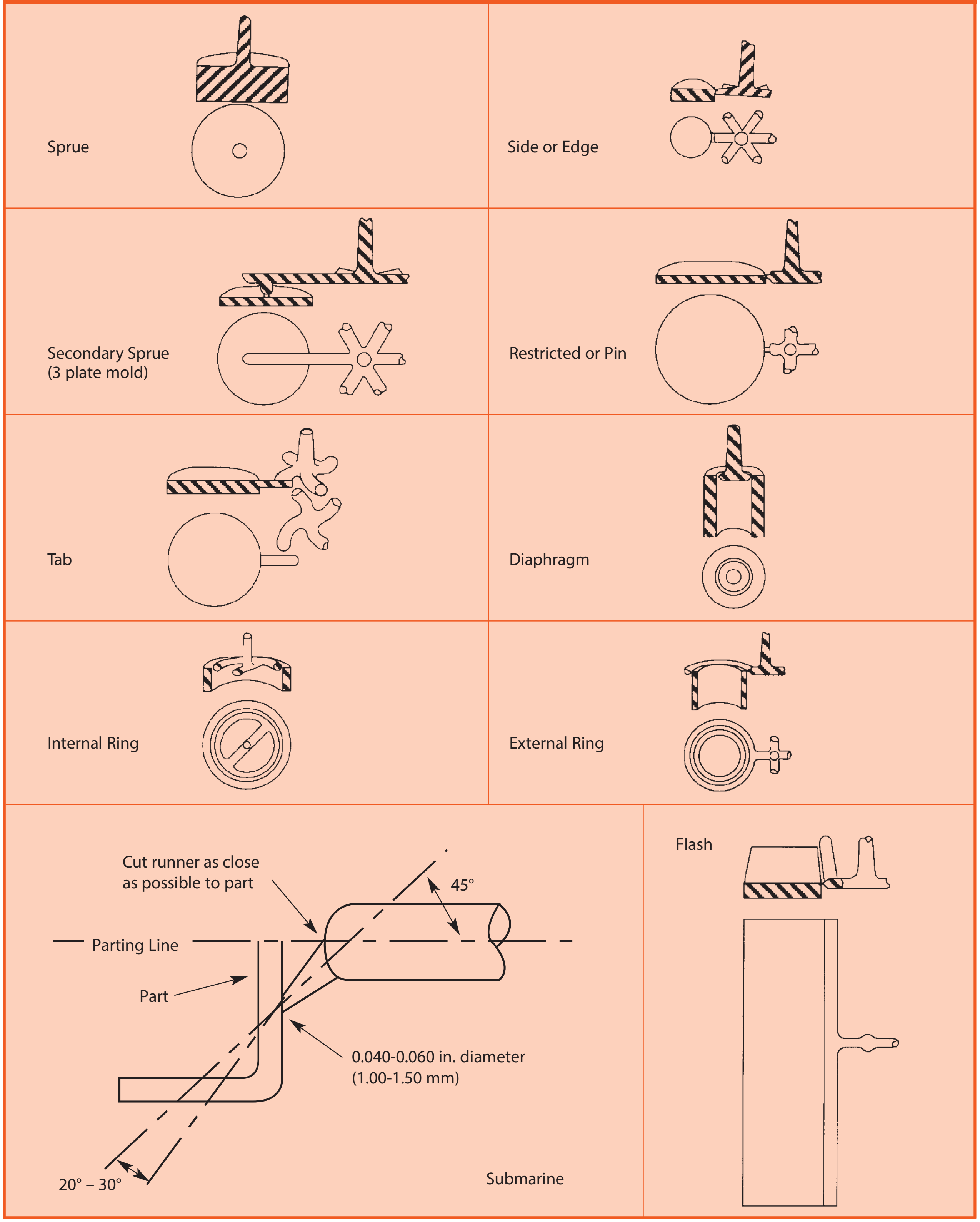
10.8 Gates - Standard Injection Molding

Gate Type: Parts made from Celcon acetal copolymer have been successfully made with a variety of gate types. Figure 10.1 gives examples of common gate types suitable for molding Celcon acetal copolymer parts.

Table 10.2 • 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 10.1 • Some basic gate designs suitable for Celcon® acetal copolymer



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 10.2 for various ranges of thickness. The smaller gate dimension should be about 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 with 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 that 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.

10.9 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 plastic to flow out of the mold.

Size: Vents should be 0.0254 mm (0.001 in.) maximum depth by 3.175 - 6.35 mm (0.125-0.250 in.) width. 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 s 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 ondensation on the pins and prevent corrosion.

10.10 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.

10.11 Draft

Plastic parts are almost always designed with a taperin 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 copolymer 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.

10.12 Parting Lines

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.

10.13 Molding Machine Barrels and Screws

This topic is covered in detail in the Celanese brochure CE-6: Celcon® acetal copolymer Processing and Troubleshooting Guide. It is available by calling 1-800-833-4882 or on the web site at www.celanese.com. A brief discussion is presented here.

The design of the screw in the majority of modern reciprocating screw injection molding machines should be specified with a compression ratio suitable for processing Celcon acetal copolymer. The most important design characteristics are:

- Metering zone of five complete flights; compression zone of four flights.
- L/D of 20:1-24:1 for adequate residence time and complete plasticization.
- Compression ratio of 3.0-4.0 is preferred to ensure a homogenous melt.
- Back-flow check valve is required to obtain adequate pressure. Flow passages should be large and sharp corners must be avoided.
- The flight depth in the metering zone should not be too deep; otherwise unmelted pellets may result. As an example, a screw of 38 mm diameter should have a flight depth of 1.6 to 2.2 mm in the metering zone, and 4.8 to 8.8 mm in the feed zone.

Xaloy® 101 or Xaloy® 306 are suggested for barrel liners especially where glass or mineral filled Celcon acetal copolymer will be molded. For unfilled resins, the screw should be coated or hard faced with a corrosion resistant material such as chrome or Stellite® 6. For filled resins, a more abrasion resistant material such as tungsten carbide, CPM® 9V, CPM® 10V, or Colmonoy® 56 is required.

10.14 Suppliers

Xaloy®
Xaloy Corporation
101 Xaloy Way,
Pulaski VA 24301

CPM®
Crucible Service Centers
111 Hollender Parkway
Rochester, NY 14615

Colmonoy®
Wall Colmonoy Corp.
30261 Stephenson Highway
Madison Heights, MI 48071

Ramax S®
Uddeholm Corp.
4902 Tollview Drive
Rolling Meadows, IL 60008

Stellite®
Stellite Coatings
1201 Eisenhower Drive North
Goshen, IN 46527

11. Assembly

Molded parts of Celcon® acetal copolymer are readily joined by a variety of techniques. The crystalline polymer permits a high degree of long term structural loading on the joined assembly up to maximum service temperatures of 104°C (220°F) in air and 82°C (180°F) in water. Conversely, care must be taken that assembly designs do not damage the surfaces of the male or female molded part, which could reduce mechanical properties such as impact strength.

Some of the more common techniques for joining molded parts of Celcon acetal copolymer are discussed below.

11.1 Molded-In Assemblies

These include snap-fits, press-fits and molded-in threads. Advantages include no special assembly equipment required and fast, inexpensive assembly.

11.2 Snap-Fit Joints

A common method of assembling two plastic parts is the snap-fit, a form-fitting joint that permits great design flexibility. All of the various types basically involve a projection (such as a barb) molded on one part, which engages a corresponding hole or undercut on the other. During assembly, the parts are elastically deformed and tend to return to their original shape, which provides the holding force for the two parts. Snap-fits are often designed to be non-detachable and this type of joint can withstand a high degree of permanent loading. Designing a snap-fit for repeated assembly-disassembly is also feasible.

The three common types of snap-fit joints are:

- Barbed leg
- Cylindrical
- Ball and socket

Barbed legs are spring elements supported on one or both sides, and are sometimes pressed through holes in the mating part. The hole can be rectangular, circular or slotted. The cross section of the barbed leg is usually rectangular, but shapes based on round cross sections are also used. Here, the originally cylindrical snap-fit is divided by one or several slots to reduce assembly force.

In designing a barbed leg, care should be taken to prevent overstressing at the most vulnerable point of support. The radius r should be as large as possible, as shown in Figure 11.1 and at least 50% of the leg wall thickness.

Cylindrical snap-fits (Figure 11.2) have a molded cylindrical part with a lip or thick section, which engages a corresponding hole or groove in the mating part. The difference between the largest diameter of the shaft, DG, and the smallest diameter of the hub, DK, is the interference depth, H:

$$H = D_G - D_K$$

The parts are deformed by the amount of this interference depth during assembly.

Fig 11.1 • Barbed leg snap-fit

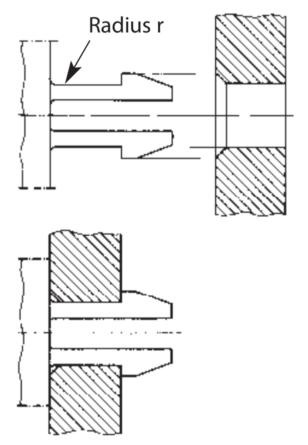
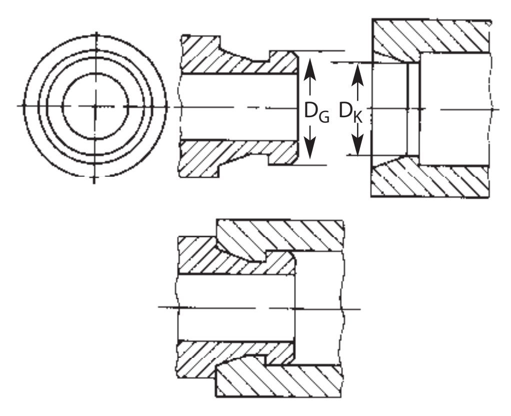


Fig 11.2 • Cylindrical snap-fit



Ball and socket snap-fits (Figure 11.3) are mainly used as motion transmitting joints. A ball section engages in a corresponding socket; the interference depth H is the difference between the ball diameter DG and the socket opening diameter DK.

With cylindrical and ball and socket snap-fits, the maximum permissible interference depth Hmax is obtained from the maximum permissible elongation using the relationship:

$$H_{max} = (E_{max}/100) \times D_G$$

where Emax is the maximum elongation (%).

Independent of the type of snap-fit, there is a linear relation between the undercut depth and the hub elongation; i.e. the maximum permissible undercut depth is limited by the maximum specified allowable elongation. The load-carrying capacity of snap-fits depends on the elastic modulus and coefficient of friction. It can be matched to the requirements of the joint by adjusting the undercut depth and the assembly or retaining angle.

The maximum permissible elongation for most Celcon® acetal copolymer grades used for barbed leg snap-fits is 6%, and for cylindrical or ball and socket snap-fits it is 4%.

Another type of snap-fit assembly is called a snap-on or snap-in fit. It can sometimes be molded into the part, and is most often used with rounded parts. Its advantage is that in operation, some or all of the entire part flexes, but the total deflection is very small and is well below the yield strain value. Figure 11.4 illustrates this type of snap-fit configuration.

Snap-ons are also amenable to release of the assembled part by using a tool to provide a releasing force. This is required when it may be necessary to have repeated servicing of the operating equipment within the plastic assembly.

Fig 11.3 • Ball and socket snap-fit

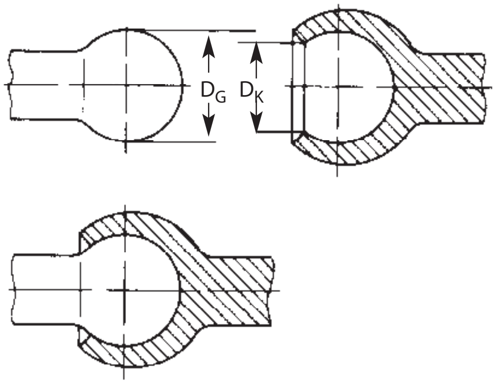
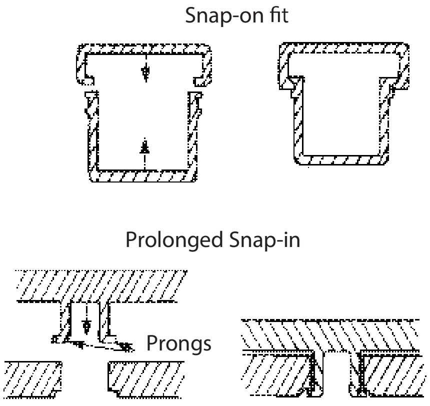


Fig 11.4 • Snap-on/snap-in fits



11.3 Molded-In Threads

Mating male and female threads molded into the parts to be assembled characterize this type of assembly. It is not widely used for parts of Celcon acetal copolymer because its chief applications are containers, caps, and molded plastic hardware. Molding female internal threads usually requires some type of unscrewing or collapsing mechanism which complicates the tooling and is expensive. Male threads are easier to mold by splitting the mold across the parting line, as in Figure 11.5. Molding very fine threads (greater than 28 pitch) is usually not practical with most plastics. Bosses/ inserts in the region of moldedin threads must be well radiused.

The roots and crests of all threads should be rounded with a 0.13 - 0.25 mm (0.005-0.010 inch) radius to reduce stress concentration and provide increased strength. Threads of Celcon® acetal copolymer, unlike those of metal, should not be terminated with a feather edge. The thread form should be ended as a complete thread in order to reduce the possibility of cross-threading. Similarly, a thread should not be ended abruptly at the base of the part so as to form a sharp notch, as this may contribute to increased stress concentration. Instead, it should be blended into the diameter with a generous radius starting from approximately 1/32 inch or more from the shoulder.

11.4 Press-Fits

This technique has already been referred to in Chapter 8, Gear Assembly. A plastic part is mated to another part such as a metal shaft or hub using an interference fit. The main advantage of press-fits is the relatively simple tooling required; the chief disadvantage is the relatively high stresses created in the plastic part. Figure 11.6 illustrates some alternative designs to reduce stress concentration.

Fig 11.5 · Molded plastic internal and external threads

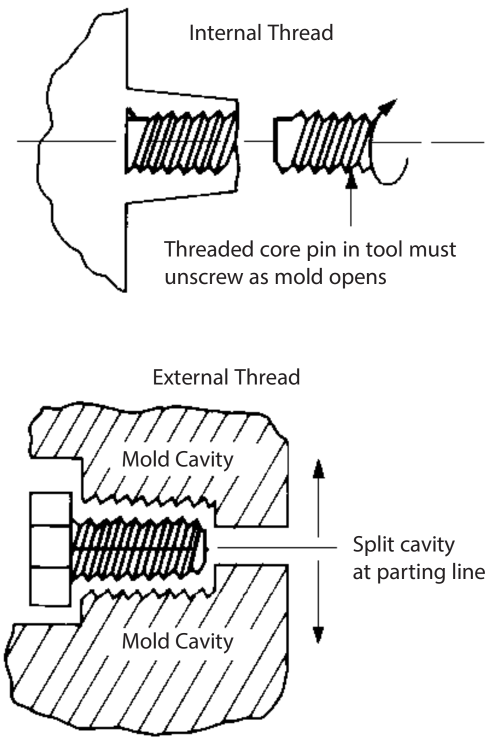
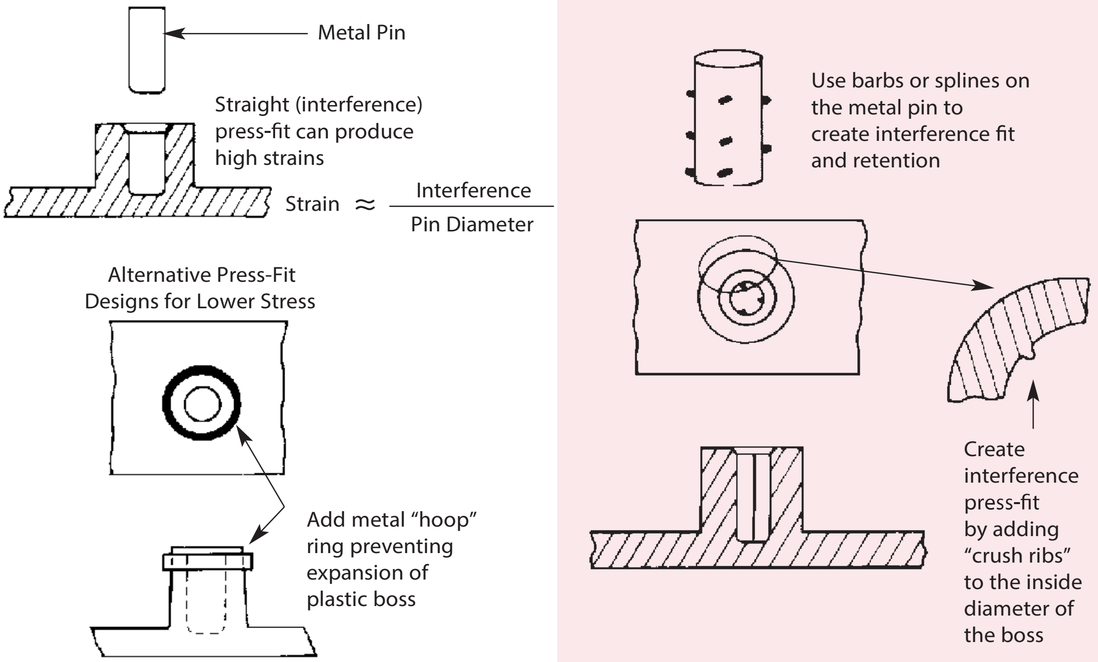


Fig 11.6 · Alternative press-fit designs for a metal pin in a plastic hub



11.5 Thermal Welding

This technique is rapid, economical, and produces adequate bond strengths for many applications, but requires expensive and complex equipment. Most commonly used is ultrasonic welding; others include hot plate, spin, linear orbital, vibrational and RF heating. They all rely on an interface or bond line melting sufficiently to create a weld between the two parts.

In ultrasonic welding, electrical energy is converted into vibrational energy of approximately 20 kHz (most widely used) or 40 kHz (used for small, delicate parts). The energy is then amplified and transmitted to the mating part in contact with the machine. The vibrating part rubs against the stationary second part and quickly melts the surface by frictional heat. Bonding is virtually instantaneous, and the bond strength is close to 100% of the tensile strength of Celcon® acetal copolymer, especially when a shear joint is used.

With this type of joint, welding is accomplished by melting the small initial contact area and then continuing the melting process with a controlled interface along the vertical walls as the parts telescope together. This process creates a strong, structural seal as the molten interface completely fills the empty spaces between the two mating parts. Figure 11.7 illustrates the equipment. Figure 11.8 shows joint configurations for semi-crystalline plastics such as Celcon acetal copolymer. The shear joint is the preferred joint configuration.

Once the proper operating conditions have been established, virtually any grade of Celcon acetal copolymer can be welded ultrasonically. Glass-reinforced grades, however, will only possess the bonding strength of the unreinforced grades since the glass does not extend through the mating surface of the two parts.

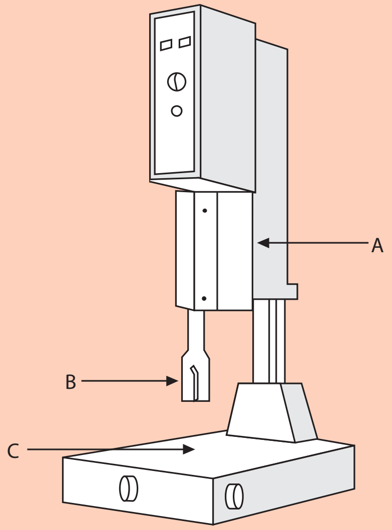
To obtain acceptable, high quality welded joints, three design factors must be considered:

- Initial contact area between the mating surfaces should be small to concentrate and decrease total time and energy required.
- Mating surfaces surrounding the entire joint interface should be uniform and in intimate contact with each other. If possible, the joint area should be on a single plane.
- Mating parts must be perfectly aligned by using support fixtures and/or pins and sockets, tongues and grooves, etc. Do not depend on the vibrating horn of the ultrasonic machine to hold parts in place.

As with other joining and machining techniques, molded parts with sharp corners should be generously radiused to avoid fracturing or causing any other damage during ultrasonic welding. Holes and voids, such as ports or other openings in the mating areas, should be avoided because they can create an interruption in the transmission of ultrasonic energy and compromise the integrity of the weld. Similarly, bosses, tabs, or other projecting surfaces on the interior or exterior of the part should be well radiused to avoid fracturing due to mechanical vibration.

"Bowing" (distortion) of flat, circular parts sometimes occurs during ultrasonic welding. This can usually be eliminated by increasing wall thickness and/or adding internal support ribs. Minimizing ultrasonic weld time is also helpful.

Fig 11.7 • Typical ultrasonic welding equipment



(A) Ultrasonic assembly stand
(B) Horn
(C) Work piece area

Design and quality control of the parts, proper placement of the welding amplifier ("horn") and maintenance of equipment settings are all critical to obtaining consistent and reproducible adhesion.

It should also be pointed out that the method is most successful for joining parts with similar or equivalent melting characteristics and chemical compatibility, i.e., Celcon® acetal copolymer to itself.

Adequate ventilation should be provided at each workstation to remove all fumes during the welding operation.

Table 11.1 gives the interference guidelines for shear joints using Celcon acetal copolymer.

Other techniques illustrated in Figure 11.9 are ultrasonic staking, swaging and spot welding. These are useful for various special operations in part assembly. Ultrasonic staking uses the controlled melting and reforming of a plastic stud to lock two components of an assembly in place. The stud in the first component protrudes through a hole in the mating part. Ultrasonic energy melts the stud, which then fills the hole volume to produce a molten head, which upon cooling locks the two components into place. Some of the advantages include: very short cycle times, tight assemblies, ability to perform multiple staking with one machine horn and the elimination of mechanical assembly such as with screws and rivets. Metal inserts used for subsequent mechanical assembly can also be ultrasonically driven into the plastic part.

Ultrasonic spot welding can be used where large, complex parts need to be joined in specific locations, and a continuous joint or weld is not feasible or necessary.

11.6 Assembly with Fasteners

Many applications require mechanical assembly of a part of Celcon acetal copolymer to another component, such as in a pump housing, or where servicing of the interior mechanism may be necessary. Standard fasteners, screws, bolts, lock nuts and washers, etc. can all be used to fasten sub-assemblies of Celcon acetal copolymer. Precautions should be taken in part design to prevent overstress of the plastic part when using metal fasteners. Further information can be found in the Celanese brochure **TDM-1, Designing with Plastic: The Fundamentals,** available by calling 1-800-833-4882 or from the web site at www.celanese.com. Figure 11.10 gives some examples of poor and good bolt assembly designs.

11.7 Self-Tapping Screws

Fig 11.8 · Joint design for ultrasonic welding

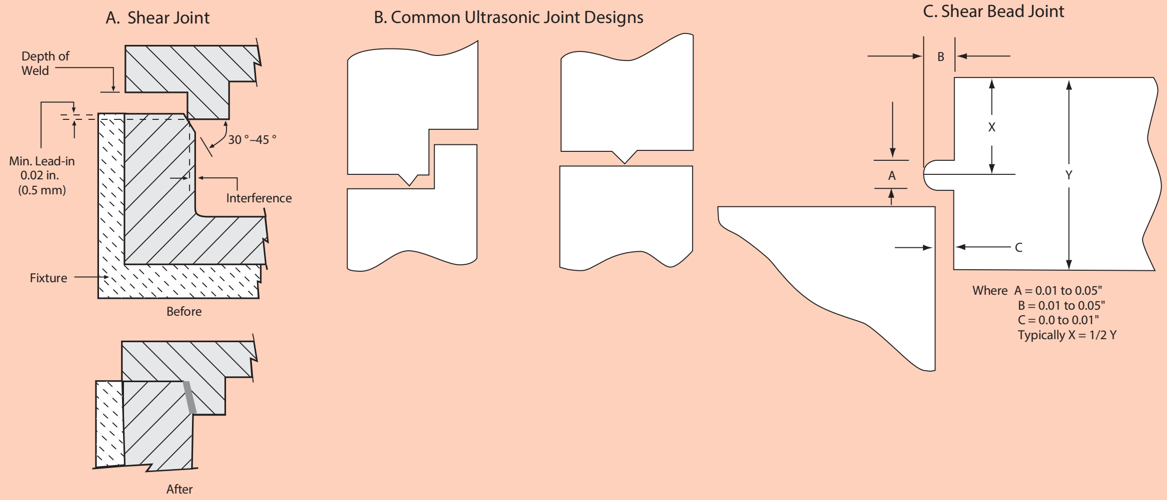


Table 11.1 • Interference guidelines for shear joints with Celcon® acetal copolymer

Maximum Part Dimension mm (in.)	Interference per Side mm (in.)	Part Dimension Tolerance mm (in.)
< 18 (0.75)	0.2-0.3 (0.008-0.012)	± 0.025 (0.001)
18-35 (0.75-1.5)	0.3-0.4 (0.012-0.016)	± 0.050 (0.002)
> 35 (1.5)	0.4-0.5 (0.016-0.020)	± 0.075 (0.003)

Fig 11.9 • Ultrasonic staking, swaging and spot welding

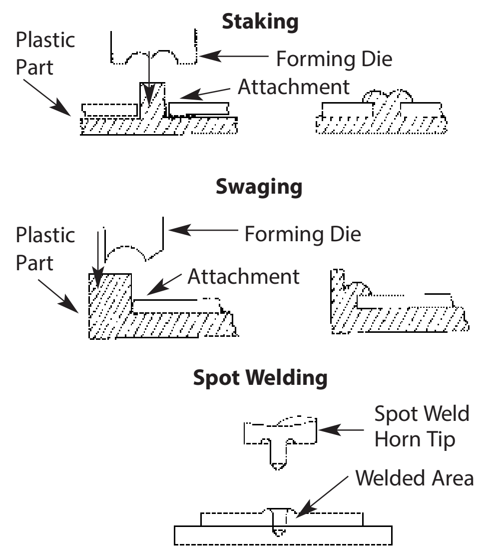
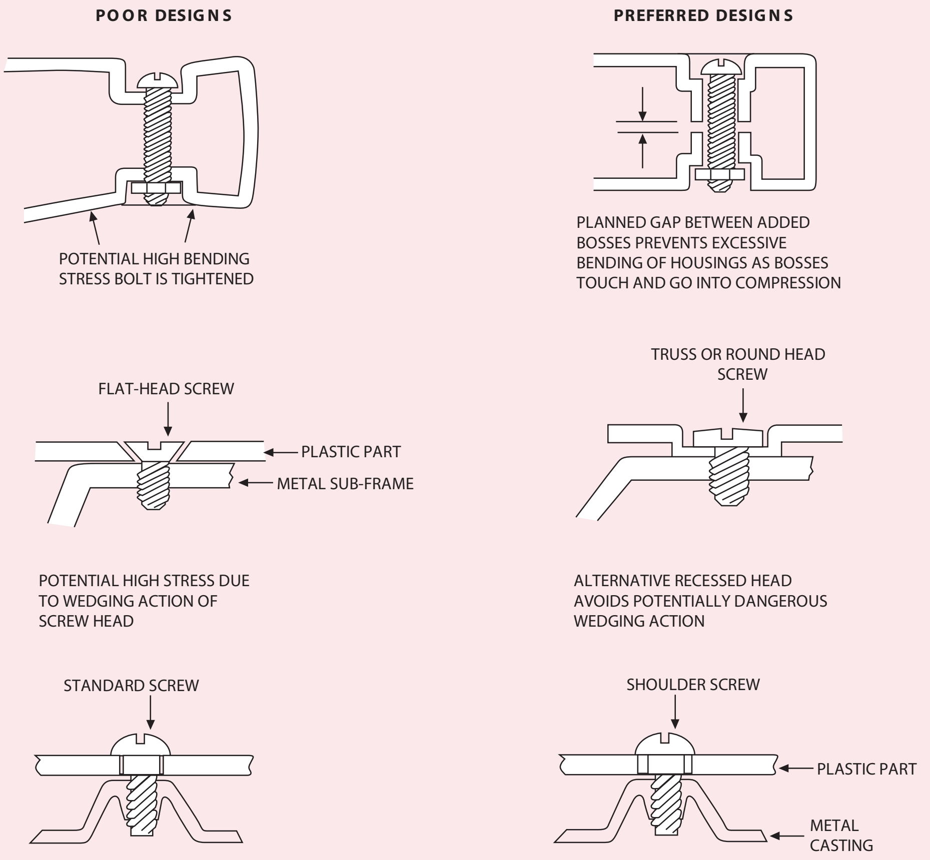


Fig 11.10 • Bolt assembly, stress problems and solutions



An effective and relatively inexpensive method of assembly is to use self-tapping screws. Only a pilot hole need be drilled or molded into the components to be joined.

Both thread-cutting and thread-forming screw designs are widely used. Combinations of both designs are very popular because they have excellent holding power and minimize stresses produced during thread forming. The design of thread-forming and thread-cutting screw is evolving rapidly. Consult screw manufacturers for for the most recent developments. Some guidelines for self-tapping screws are:

- Size the diameter of the pilot hole properly to minimize hoop stress from undersized holes. Pilot hole tolerances of ± 0.025 mm (0.001 in.) give optimum fastening strengths. Table 11.2 shows some typical values for anchoring Celcon® acetal copolymer (standard unfilled grade) with self-tapping screws.
- Control depth of the molded or drilled hole to prevent bottoming of the leading edge of the screw.
- If a boss is used to anchor the screw, the outside diameter of the boss should be at least twice the major diameter of the screw.
- Do not use thread-forming screw designs on glass-reinforced plastics such as Grade GC25A.
- Use torque-controlled drivers on production lines to avoid stripping or high-stress assemblies.

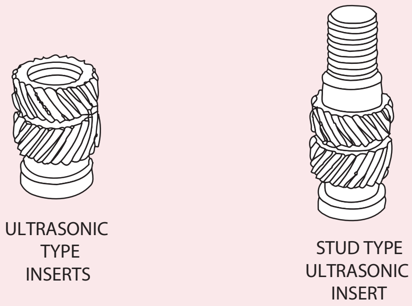
11.8 Threaded Metal Inserts

Threaded metal inserts are also commonly used to anchor sub-assemblies of Celcon acetal copolymer. They provide metallic machine threads, which are permanently installed in the plastic. Inserts are typically installed in molded bosses whose internal diameter is sized for the specific insert used. A very popular and preferred type of insert for Celcon acetal copolymer and other plastics is the ultrasonically installed type shown in Figure 11.11. The resulting installation is strong and relatively free of stress, because the plastic melts around the insert as it is installed. Installation is fast and can often be performed by the molding machine operator.

11.9 Sheet Metal Nuts

A wide variety of stamped sheet metal fasteners are available to provide light to medium duty assembly of Celcon acetal copolymer and other plastic parts. Figure 11.12 illustrates a typical push-on style nut, which is simply pushed onto a simple molded plastic stud or boss. They are easy to use, inexpensive and vibration-resistant. They are used for attaching exter-

Fig 11.11 • Ultrasonic type thread inserts



ADVANTAGES — EXCELLENT PERFORMANCE
VERY FAST (OFTEN DONE AT MOLDING MACHINE)
VERY LITTLE INDUCED STRESS

DISADVANTAGES— REQUIRES EXPENSIVE EQUIPMENT
SOMETIMES NOISY

Table 11.2 • Driving and stripping torques on self-tapping screws in Celcon M90™ acetal copolymer

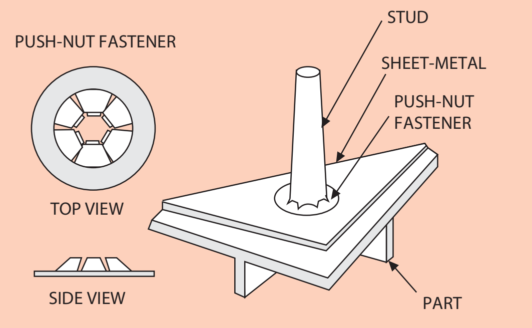
Screw Size	Penetration Depth mm (in.)	Pilot Hole mm (in.)	Drive Torque m-kg (in-lb)	Strip Torque m-kg (in-lb)
# 4-40	9.5 (0.38)	2.4 (0.9)	0.4-0.6 (3-4)	1.4-1.7 (10-12)
# 6-32	9.5 (0.38)	2.9 (0.12)	1.0-1.2 (7-9)	2.9-3.2 (21-23)
# 8-32	9.5 (0.38)	3.7 (0.14)	1.1-1.2 (8-9)	2.9-3.3 (21-24)
# 10-32	9.5 (0.38)	4.2 (0.17)	1.7-1.9 (12-14)	4.0-4.6 (29-33)
# 1/4-20	9.5 (0.38)	0.228 (5.8)	3.0-3.9 (22-28)	14.7-15.2 (106-110)

nal decorative parts such as trim, escutcheons and faceplates, where metal fasteners would be unsatisfactory. Table 11.3 shows the performance of this type of fastener using a Celcon® acetal copolymer standard unfilled grade.

11.10 Chemical Bonding

Because of its excellent chemical resistance, chemical bonding of parts made of Celcon acetal copolymer is less widely used than other joining methods, such as mechanical assembly or thermal bonding. Solvent welding, for example, is difficult because the limited number of solvents for Celcon acetal copolymer are toxic and/or corrosive. Similarly, adhesive bonding with either structural or non-structural adhesives is possible, but because of the high surface lubricity of Celcon acetal copolymer. The bond strength is only about 10% of the strength of unreinforced Celcon acetal copolymer. Bonding is improved by a commercial chemical surface etch or mechanical roughening of the surface with sandpaper or plasma surface treatment.

Fig 11.12 • "Push-on" style fasteners



Call your Celanese sales representative or Product Information Services at 1-800-833-4882 for more information on various surface bonding techniques. Table 11.4 gives some typical laboratory test values obtained by adhesive bonding of Celcon acetal copolymer parts. The self-curing adhesives are used where maximum bond strengths and service use temperature conditions are required.

Table 11.3 • Performance of "push-on" style fasteners using Celcon acetal copolymer M90™ studs

Fastener size, mm (in)	**3.2 (0.13)**		**6.4 (0.25)**	**9.5 (0.38)**	
	"Light Duty"	**"Heavy Duty"**	**"Heavy Duty"**	**"Light Duty"**	**"Heavy Duty"**
Celcon Stud Size*, mm (in.)	3.2 (0.13)	3.2 (0.13)	6.4 (0.25)	9.5 (0.38)	9.5 (0.38)
Push-on Force, Kg (Lb.)	4.5 (10)	15.9 (35)	22.7 (50)	18.1 (40)	47.6 (105)
Removal Force, Kg (Lb.)	57 (125)	98 (215)	159 (350)	170 (375)	281 (620)

* Tolerance ± 0.025 mm (0.001 in.)

Table 11.4 • Adhesive bonding of Celcon acetal copolymer to itself and other substrates

Adhesive Type	Curing Method	Lap Shear Strength (Celcon to itself) MPa (psi)	Max. Use Temp. °C (°F)	Bonding of Celcon acetal copolymer to other substrates
Cyanoacrylate	Moisture	4.8 (700)	82 (180)	Other plastics, rubber, metals
Epoxy	Catalyst	3.4-4.3 (500-625)	121 (250)	Paper, wood, metal, thermoset plastics
Polyester/ isocyanate	Heat/ catalyst	3.4-4.0 (500-575)	93 (200)	Polyesters, vinyl, steel, wood

* Note. Shear strength values shown were obtained by chemically etching both surfaces.

Values will be 25% lower for mechanical roughening of the mating surfaces.

Values will be essentially nil if no surface preparation is used.

12. Machining and Surface Operations

12.1 Machining – General Criteria

Celcon® acetal copolymer can be readily machined using conventional tools, but care must be taken to minimize cutting tool marks that can act as stress concentration points. This can lead to as much as 20% (or higher for glass-filled products) reduction in mechanical properties compared to injection molded parts. Machine removal of the "skin" of a molded part will expose the interior to any mechanical or chemical abuse involved in the application. Surface properties as well as wear and bearing characteristics may also be adversely affected.

Shapes of Celcon acetal copolymer such as rod or bar stock should be annealed before machining, and again after the initial coarse machining, operation has been carried out. This will prevent build-up of stress concentration points. Refer to the discussion on annealing in Chapter 4 for further information.

It is strongly recommended that definitive estimates of mechanical properties for the finished part be deferred until an actual molded prototype is produced. Conclusions based solely on the performance of a machined part may be erroneous, normally unrealistically low.

To ensure the best results when machining Celcon acetal copolymer :

- Use sharp tools.
- Provide adequate chip clearance.
- Support the work properly.
- Provide adequate cooling.

12.1.1 Drilling

Standard twist drills and special "plastic" twist drills are suitable for use with Celcon acetal copolymer. Although a drill point angle of 118° can be used with a standard twist drill, for best results reduce the drill point angle to 90°. The lip clearance angle should be maintained within 10° to 15°.

During drilling, the work should be firmly supported. For deep holes, the drill should be raised frequently during drilling — about every 1/4 inch of depth — to clear the drill and hole of chips. A jet of compressed air should be directed into the hole to disperse chips and cool the drill. Typical feeds and speeds recommended for drilling Celcon acetal copolymer with 900 point drills are listed in Table 12.1.

12.1.2 Sawing

High speeds and sharp teeth are best for sawing. The saw teeth should have some degree of "set" to prevent binding of the blade. A special bandsaw known as a "skiptooth" saw, which has coarse teeth and extra width gullets for chip clearance, is most suitable.

12.1.3 Turning

Parts of Celcon acetal copolymer may be readily turned on a lathe. Tool bits should be ground to provide a positive rake angle of about 5°, with front and side clearance angles of 15-20°. No side rake is required. Sketches of typical tool bits suitable for turning Celcon acetal copolymer are shown in Figure 12.1.

Feeds and turning speeds depend mostly on the nature of the cut and finish desired. Roughing cuts may be made at the highest speed and feed feasible without excessive heat build-up. A fine finish cut requires a high speed and a slow feed.

Table 12.1 • Recommended drilling speeds for Celcon acetal copolymer

Drill Size	Work Thickness	Approximate Drill Speed		Approximate Drill Feed
mm (in.)	mm (in.)	R.P.M.	Surface mpm* (f/min.)	cm per rev. (in./ rev.)
3.2 (0.125)	3.2 (0.125)	4,500	46 (150)	0.025 (0.010)
3.2 (0.125)	32 (1.25)	3,000	30 (100)	0.038 (0.015)
12.7 (0.5)	3.2 (0.125)	1,200	49 (160)	0.020 (0.008)
12.7 (0.5)	32 (1.25)	900	37 (120)	0.051 (0.020)

12.1.4 Milling

Standard helical type milling cutters are satisfactory for use on Celcon® acetal copolymer. Speeds of approximately 150 surface feet per minute are recommended. Feed rates should be adjusted to obtain the desired quality of surface finish.

12.1.5 Threading and Tapping

Threads may be cut in Celcon acetal copolymer with a tool bit having a rake angle of 5° and a clearance angle of 15-20°, as described under "Turning." Conventional taps and dies may also be used. A thread with a rounded root (rather than a sharp V root) is recommended to avoid notch sensitivity. A special tap designed for plastics, which has two flutes instead of four, offers some advantage in terms of greater chip clearance.

12.1.6 Reaming

Straight-fluted or spiral reamers with polished flutes and narrow margins are suitable for Celcon acetal opolymer. Speeds of 80-150 surface feet per minute give the best results. A jet of air should be used as a coolant.

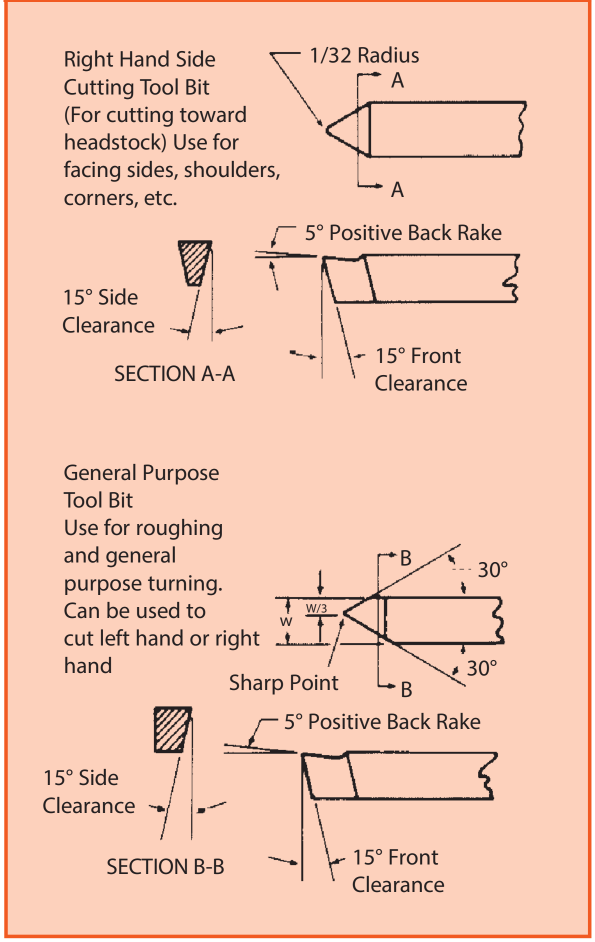
12.1.7 Blanking and Punching

Sheets of Celcon acetal copolymer in thicknesses as heavy as 1.8 mm (0.070 in.) can be cleanly blanked and punched if sharp dies are used. Either hand- or power-operated punch presses are satisfactory. High rates of blanking and punching are attainable if dies are used that provide maximum shearing during the operation. If cracking should occur during blanking or punching, the sheet should be annealed or heated to 65-80°C (150-175°F) before blanking.

12.1.8 Shaping

Standard shapers and cutting tools for metals can be used without modification for cutting Celcon acetal copolymer.

Fig 12.1 • Typical lathe tool bits for turning Celcon acetal copolymer



12.2 Automatic Screw Machines

Rod stock of Celcon® acetal copolymer can be processed on automatic screw machines with excellent results. Both simple and complex parts have been produced; in all cases surface finish and dimensional tolerance are acceptable. Higher production rates can be achieved with Celcon acetal copolymer than when working with brass or other metals because of higher screw speeds and feeds. In one test of machining 25.4 mm (1.0 in.) diameter rod stock, the Celcon acetal copolymer M90™ overall cycle time was 25% faster than a corresponding brass rod; (45 sec. vs. 60 sec.).

12.3 Finishing Operations

12.3.1 Sanding

Celcon acetal copolymer can be wet-sanded using conventional belt and disc sanding equipment. Moderate speeds should be used in sanding to prevent overheating of the plastic part. After sanding to smooth finish, Celcon acetal copolymer can be buffed to a high surface luster using a buffing wheel impregnated with jewelers rouge. Then use a dry buffing wheel to remove the polishing compound from the finished part.

12.3.2 Rotary Power Filing

Standard medium-cut, high speed steel burrs operated at 80-100 surface feet per minute are very effective in removing unwanted material rapidly. Ground burrs are preferred over hand-cut rotary files because they provide better chip clearance. Carbide burrs may cause excessive frictional heat build-up and are not recommended.

12.3.3 Barrel Deburring and Polishing

When deburring and polishing many Celcon acetal copolymer parts at one time, barrel deburring and polishing is recommended. The polishing medium can be an aqueous slurry of mildly abrasive stone or dry tumbling using graded sizes of crushed nut shells. A preferred wet tumbling medium consists of aluminum oxide chips with a high-sudsing burnishing compound. The most effective grit-slurry polishing medium and optimum tumbling cycle must be determined on a case-by-case basis.

12.3.4 Surface Operations

The surface of Celcon acetal copolymer parts may be treated in various ways for purposes that are decorative, functional, or a combination of both. For more detailed information on decorative or functional surface operations, contact Product Information Services at 1-800-833-4882.

12.3.5 Painting

Because of the chemical inertness of Celcon acetal copolymer, adhesion cannot be obtained by direct application of paint to its surface. To develop the desired adhesion, the parts must be either primed or acid etched and primed prior to painting. Other surface treatment techniques, such as plasma or corona stimulation, also work well. For more information on these techniques, as well as applicable grades of Celcon acetal copolymer, contact Product Information Services at 1-800-833-4882.

Acrylic- or alkyd-based topcoats give excellent adhesion with no visible chalking, fading, blistering, cracking or loss of adhesion after over one year's outdoor exposure. Celcon acetal copolymer can tolerate the high temperatures (120-150°C) for the time periods typically developed in topcoat bake ovens without part distortion or deterioration.

12.3.6 Printing

Parts of Celcon acetal copolymer may be printed by a wide variety of methods including silk screen, offset, wipe-on, and with lasers. These enable manufacturers to mark graphics, serial numbers, bar/lot codes, etc. on finished parts.

Thermodiffusing dyes, when directly applied to items of Celcon acetal copolymer by silk creening, spraying, brushing or pad printing, produce surfaces that exhibit excellent wear resistance, retention of print sharpness and are unaffected by normal solvents.

Printed paper and foil labels can also be applied to properly primed or surface-treated parts of Celcon acetal copolymer.

Celanese has done considerable work in laser printing techniques. Through the use of specialized pigments with improved absorption at laser wavelengths, characters are imprinted into the polymer matrix resulting in a clean, crisp appearance that resist rubbing or scratching. Printing of various colors on a contrasting background is feasible. For more information on laser printing, other techniques and applicable grades of Celcon® acetal copolymer contact Product Information Services at 1-800-833-4882.

12.3.7 Hot Stamping and Decorating

The best results for hot stamping Celcon acetal copolymer with foil laminates can be obtained by adhering to the following guidelines:

- Die Temperature - Set between 160-205°C (325-400°F). This is the key variable and will need to be determined experimentally with each kind of foil.
- Dwell Time - Set at 0.5 second to start and vary in ± 0.1 second units.
- Pressure - This is best determined experimentally after die temperature and dwell time have been fixed.
- Stripping Time - Stripping at slow speeds usually gives the best results.

12.3.8 Colorability

Natural Celcon acetal copolymer is white, somewhat translucent in appearance and may be quite suitable "as is" for a final part. In some applications a special type of color or surface decoration may be required.

The simplest method for obtaining colored parts of Celcon acetal copolymer is to use grades with pigments already incorporated into the resin. The color will be uniformly distributed throughout the molded part and will not be removed by abrasion or chipping. A wide range of standard colors of Celcon acetal copolymer are available that have been pre-compounded with pigments that contain no cadmium or lead. Custom colors may be obtained by special order. A color chip chart that illustrates the range of colors may be obtained by requesting CE-9, Celcon acetal copolymer Color Chips from Technical Information at 1-800-838-4882.

A less desirable option is to mix a pigment concentrate with the base resin prior to processing ("salt and pepper technique"). The color will not be as homogeneous as with the pre-compounded colored resin. Also, a reduction in properties may be seen in localized areas where pigments exist at extremely high levels due to inadequate dispersion. This is especially true in the case of pigmented, UV-resistant Celcon grades, where precompounded grades are recommended to obtain maximum weathering resistance.

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. The information contained in this publication should not be construed as a promise or guarantee of specific properties of our products.

Further, the analysis techniques included in this publication are often simplifications and, therefore, approximate in nature. More vigorous analysis techniques and prototype testing are strongly recommended to verify satisfactory part performance. Anyone intending to rely on any recommendation or to use any equipment, processing technique or material mentioned in this publication should satisfy themselves that they can meet all applicable safety and health standards.

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.

Properties of molded parts can be influenced by a wide variety of factors including, but not limited to, material selection, additives, part design, processing conditions and environmental exposure. Any determination of the suitability of a particular material and part design for any use contemplated by the user is the sole responsibility of the user. The user must verify that the material, as subsequently processed, meets the requirements of the particular product or use. The user is encouraged to test prototypes or samples of the product under the harshest conditions to be encountered to determine the suitability of the materials.

Material data and values included in this publication are either based on testing of laboratory test specimens and represent data that fall within the normal range of properties for natural material or were extracted from various published sources. All are believed to be representative. These values alone do not represent a sufficient basis for any part design and are not intended for use in establishing maximum, minimum, or ranges of values for specification purposes. Colorants or other additives may cause significant variations in data values.

We strongly recommend that users seek and adhere to the manufacturer's current instructions for handling each material they use, and to entrust the handling of such material to adequately trained personnel only. Please call the numbers listed on the back cover for additional technical information. Call Customer Services at the number listed on the back cover for the appropriate Material Safety Data Sheets (MSDS) before attempting to process our products. Moreover, there is a need to reduce human exposure to many materials to the lowest practical limits in view of possible adverse effects. To the extent that any hazards may have been mentioned in this publication, we neither suggest nor guarantee that such hazards are the only ones that exist.

The products mentioned herein are not intended for use in medical or dental implants.

Celanese

The chemistry inside innovation™

ENGINEERED MATERIALS

celanese.com/engineered-materials

Engineered Materials

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

Contact Information

Americas
8040 Dixie Highway, Florence, KY 41042 USA

Product Information Service
t: +1-800-833-4882 t: +1-859-372-3244

Customer Service
t: +1-800-526-4960 t: +1-859-372-3214
e: info-engineeredmaterials-am@celanese.com

Europe
Am Unisys-Park 1, 65843 Sulzbach, Germany

Product Information Service
t: +(00)-800-86427-531 t: +49-(0)-69-45009-1011
e: info-engineeredmaterials-eu@celanese.com

Asia
4560 Jinke Road, Zhang Jiang Hi Tech Park
Shanghai 201203 PRC

Customer Service
t: +86 21 3861 9266 f: +86 21 3861 9599
e: info-engineeredmaterials-asia@celanese.com

CE-10R3_Celcon_POMdesignGuideBro_AM_1112