Module III

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acetal resin

Design information

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DELRIN® acetal resins: design information

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1. General

Introduction to DELRIN® acetal resins

DELRIN® acetal resins have a combination of physical properties not available with either metals or most other plastics. DELRIN® is a thermoplastic engineering polymer manufactured by the polymerization of formaldehyde. It has gained widespread recognition for reliability of performance in many thousands of engineering components all over the world. Since its commercial introduction in 1960, it has been used in the automotive, appliance, construction, hardware, electronics and consumer goods industries.

The chemical composition, regular molecular structure and high degree of crystallinity are the basis of these outstanding attributes of DELRIN®:

- Toughness at low temperature (down to –40°C).
- High mechanical strength and rigidity.
- Fatigue endurance unmatched by other plastics.
- High resistance to repeated impacts.
- Excellent resistance to moisture, gasolines, solvents and many other neutral chemicals.
- Excellent dimensional stability.
- Natural lubricity.
- Resilience.
- Good electrical insulating characteristics.
- Ease of fabrication.
- Wide useful temperature range.

Service life is reduced by lengthy use in steam, hot water, strong acids, or strong bases. DELRIN® resins are classified as slow burning.

Design in DELRIN®

DELRIN® acetal resins, because of their singular attributes as materials of construction, offer many opportunities to the designer. These range from direct cost reduction of assemblies, longer life and improved component performance, to greater freedom in styling and appearance.

Imaginative design can make it possible to injection mould DELRIN® into finished parts which combine a variety of functions in one unit. For example, mechanical parts which combine gear, cam, bearing and shaft functions in one piece are common. The properties of DELRIN® also make possible such rapid assembly techniques as snap- and press-fitting, cold-heading, riveting, self-threading screws, as well as spin, vibration and ultrasonic welding.

Injection moulding of DELRIN® permits production of appealing geometric shapes not feasible in metals and some plastic materials. Colour and surface texture can be moulded into the part or alternatively, the surface can be painted, metallized or printed after moulding.

The elimination of parts, assembly and post-finishing operations, through the use of DELRIN®, can permit significant cost-savings on overall assemblies. Therefore, DELRIN® acetal resins frequently can replace die-cast alloys, brass and sheet metal on both cost and performance basis.

The final success of any plastic component in the field depends to a large extent on the design, quality and cost of the component. This dictates optimization of not only material selection but also of part design, mould design, processing technique and production control. This manual provides data for optimum design in DELRIN®.

Design principles are described in the Design Handbook: "General Design principles for DuPont Engineering Polymers", Module I.

Fabrication

DELRIN® acetal resins can be fabricated by the following techniques: injection moulding, extrusion, blow moulding, roto-moulding, stamping, and machining. The resins are particularly suited to injection moulding. The surface finish of correctly moulded parts in DELRIN® replicates the surface finish and shape of the mould; proper mould shrinkages can be estimated.

Standard extrusion equipment can be used to extrude the resins into rods, slabs, sheeting and small diameter tubing.

Semi-finished extruded shapes of DELRIN® such as rod and slab stock are used extensively in the machining of small components, linear cams and other large parts because of excellent machinability and mechanical properties. Stock of DELRIN® can be more easily machined than brass with standard brass-cutting tools.

Compositions

DELRIN® is available in four viscosities, in order to meet the flow requirements of a wide range of end-use applications.

Special grades are available to meet specific customer needs:

- toughened and supertough resins;
- UV resistant grades;
- low-friction and low-wear resins;
- extrusion resins.

An overview on all available resins, including their mechanical and physical properties, is shown in the "DELRIN® product guide and properties".

Properties of most DELRIN® grades are also available on CAMPUS diskettes.

Standard grades

Grade	Process	Characteristics	Typical applications
DELRIN® 100	Injection moulding	DELRIN® 100 is an unreinforced, high viscosity acetal resin for injection moulding.	High performance engineering parts, e.g. gears, seatbelt restraint systems, fasteners.
DELRIN® 100P	Injection moulding	DELRIN® 100P is an unreinforced, high viscosity acetal resin for injection moulding. It has improved processing thermal stability.	Same as DELRIN® 100.
DELRIN® 111P	Injection moulding	DELRIN® 111P is an unreinforced, high viscosity, nucleated acetal resin for injection moulding. It has improved thermal stability, more isotropic properties, low warpage and fewer voids.	Fuel systems, wheels, gears.
DELRIN® 107	Injection moulding	DELRIN® 107 is an unreinforced, high viscosity, UV stabilised acetal resin for injection moulding.	Ski bindings, seat belt restraint systems.
DELRIN® 127UV	Injection moulding	DELRIN® 127UV is an unreinforced, high viscosity, UV stabilised acetal resin for injection moulding. It has excellent UV resistance and thermal stability. Well suited for automotive interior applications.	Automotive parts with maximum UV performance requirements.
DELRIN® 311DP	Injection moulding	Medium viscosity, fast moulding resin.	Automotive and industrial parts, snap-fits.
DELRIN® 500	Injection moulding	DELRIN® 500 is an unreinforced, medium viscosity general purpose acetal resin for injection moulding.	General mechanical parts, automotive fuel systems, snap-fits, fasteners, gears.
DELRIN® 500P	Injection moulding	DELRIN® 500P is an unreinforced, medium viscosity acetal resin for injection moulding. It has excellent flow characteristics and improved processing thermal stability.	Same as DELRIN® 500.
DELRIN® 507	Injection moulding	DELRIN® 507 is an unreinforced, medium viscosity, UV stabilised acetal resin for injection moulding.	Automotive and industrial parts.
DELRIN® 511P	Injection moulding	DELRIN® 511P is an unreinforced, medium viscosity, nucleated acetal resin for injection moulding. It has improved thermal stability, more isotropic properties, low warpage and fewer voids.	Fuel systems, springs, conveyor belts.
DELRIN® 527UV	Injection moulding	DELRIN® 527UV is an unreinforced, medium viscosity, UV stabilised acetal resin for injection moulding. It has excellent UV resistance and thermal stability. Well suited for automotive interior applications.	Automotive parts with maximum UV performance requirements.
DELRIN® 900P	Injection moulding	DELRIN® 900 is an unreinforced, low viscosity acetal resin for injection moulding. It has excellent flow characteristics and improved processing thermal stability.	Multicavity moulds and parts with thin sections, e.g. consumer electronics parts, zippers.
DELRIN® 911P	Injection moulding	DELRIN® 911P is an unreinforced, low viscosity, nucleated acetal resin for injection moulding. It has improved thermal stability, more isotropic properties, low warpage and fewer voids.	Aerosol valves, filters, micro components.
DELRIN® 927UV	Injection moulding	DELRIN® 927UV is an unreinforced, low viscosity, UV stabilised acetal resin for injection moulding. It has excellent UV resistance and thermal stability. Well suited for automotive interior applications.	Loudspeaker grills.

Extrusion grade (separate data sheet available)

Grade	Process	Characteristics	Typical applications
DELRIN® DE7031	Extrusion	DELRIN® DE7031 is an unreinforced, high viscosity acetal resin for extrusion. It has improved processing thermal stability.	Extruded rods and slabs for machining, tubes and sheets.

Speciality grades

Toughened grades

Grade	Process	Characteristics	Typical applications
DELRIN® 100ST	Injection moulding	DELRIN® 100ST is an unreinforced, high viscosity, super tough acetal resin for injection moulding. It has excellent break resistance.	Fasteners, lock systems.
DELRIN® 100T	Injection moulding	DELRIN® 100T is an unreinforced, high viscosity, toughened acetal resin for injection moulding. It has improved break resistance.	Fasteners, seat belt restraint systems, gears.
DELRIN® 500T	Injection moulding	DELRIN® 500T is an unreinforced, medium viscosity, toughened acetal resin for injection moulding. It has improved break resistance.	Fasteners, gears.

Low friction and wear grades (separate data sheets available)

Grade	Process	Characteristics	Typical applications
DELRIN® 100AL	Injection moulding	Advanced lubricated 100 grade. General purpose low wear/low friction grade.	Applications requiring low wear and / or coefficient of friction against steel, DELRIN® or other plastics (low noise).
Delrin® 100KM	Injection moulding	DELRIN® 100KM is a 20 % KEVLAR® fibre filled, high viscosity, lubricated acetal resin for injection moulding. It is well suited for low wear applications.	Applications which require high wear resistance in abrasive environment.
DELRIN® 500AL	Injection moulding	DELRIN® 500AL is an unreinforced, medium viscosity, lubricated acetal resin for injection moulding. It is well suited for low wear, low friction applications.	Applications requiring low wear and / or coefficient of friction against steel, DELRIN® or other plastics (low noise).
DELRIN® 500CL	Injection moulding	DELRIN® 500CL is an unreinforced, medium viscosity, lubricated acetal resin for injection moulding. It is well suited for low wear, low friction against metals.	Gears, drive trains, sliding devices.
DELRIN® 500SC	Injection moulding	Masterbatch DELRIN® 500 grade with 20 % of silicone fluid. DELRIN® 500SC is a medium viscosity silicone fluid masterbatch.	Intended for low wear – low friction applications.
DELRIN® 520MP	Injection moulding	DELRIN® 520MP is a 20 % TEFLON® powder filled, medium viscosity acetal resin for injection moulding. It is well suited for low wear, low friction applications.	Applications which require low wear and / or low coefficient of friction against steel, DELRIN® or other plastics.
DELRIN® 500AF	Injection moulding	DELRIN® 500AF is a 20 % TEFLON® fibre filled, medium viscosity acetal resin for injection moulding. It is well suited for low wear, low friction applications.	Speciality friction and wear applications, conveyor systems.
DELRIN® 900SP	Injection moulding	DELRIN® 900SP is an unreinforced, low viscosity, lubricated acetal resin for injection moulding. It is well suited for low wear, low friction against metals.	Consumer electronics. Applications requiring low wear and/or low friction against DELRIN® and other plastics (low noise).

Speciality grades

Higher stiffness grades (separate data sheets available)

Grade	Process	Characteristics	Typical applications
DELRIN® 510GR	Injection moulding	DELRIN® 510GR is a 10% glass fibre reinforced, medium viscosity acetal resin for injection moulding.	Parts requiring very high strength and stiffness.
DELRIN® 525GR	Injection moulding	DELRIN® 525GR is a 25% glass fibre reinforced, medium viscosity acetal resin for injection moulding.	Parts requiring very high strength and stiffness.
DELRIN® 570	Injection moulding	DELRIN® 570 is a 20% glass fibre reinforced, medium viscosity acetal resin for injection moulding.	General engineering parts.
DELRIN® 577	Injection moulding	DELRIN® 577 BK000 is a 20% glass fibre reinforced, UV stabilised medium viscosity acetal resin for injection moulding in black colour.	General engineering parts.

2. Value engineering

Design benefits

The economic incentive for using Delrin® in any application is the difference in value-in-use of the present assembly and that of a proposed design in Delrin®. This incentive will be greatest when multi-functional parts of Delrin®, moulded in one geometric piece and produced in large volume, replace assemblies of die-cast alloys, sheet metal or other plastic materials.

In many cases, design alternatives in Delrin® may appear equally feasible from the mechanical point of view. In such situations, it is good practice to select the alternative which offers the lowest final cost in terms of the development, tooling, manufacturing, assembly and finishing costs.

A review of commercial applications suggests the following design possibilities:

- *Multifunctional parts:* The elimination of parts associated with assemblies of traditional design is possible.
  Components in Delrin® frequently can be designed using specific properties to incorporate bearings, cams, gears, and integral springs moulded in one self-lubricating piece. Direct benefits of eliminated parts are reduced part inspection, handling, inventory, assembly and associated costs.
- *Use as moulded:* The elimination of finishing operations often results. Parts of Delrin® can be produced fully finished with integral colours and ready for use as ejected from the mould.
- *Moulded-in detail:* Very accurate threads and fine detail can be moulded in. When the volume of production is large, the amortized cost for special mould actions to produce threaded parts can be less than machining the threads.
- *Built-in assembly:* Assembly operations can be eliminated or accelerated. Where assembly operations cannot be eliminated by moulding one-piece parts in Delrin®, the resilience, ductility and strength of Delrin® make it possible to use rapid assembly techniques such as snap-fitting, press-fitting, cold-heading, and welding by ultrasonics, spin or vibration.
- *Self-lubricated:* Maintenance and service costs can be reduced. The inherent lubricity of Delrin® acetal resins can eliminate the lubrication required with metals or other plastic materials, and the need for lubrication during use. Increased part life results because of the good wear life of Delrin®. Reduced driving power requirements result from low friction characteristics. Contamination by lubricants can be eliminated. Self-lubricating bearings of Delrin® can be especially useful where cross-contamination of products must be eliminated (food, conveyors, pharmaceutical, and textile equipment).
- *Solvent and chemical resistance:* Where occasional cleaning or accidental contact occurs with solvents, the excellent solvent resistance of Delrin®, compared to other plastics (polycarbonate, modified PPO, ABS), will ensure that parts in Delrin® neither crack nor soften.
- *Reduced weight:* Weight savings are possible over metal designs. The high strength/weight ratio of Delrin® enables producing strong, lightweight parts, which reduce the weight of the overall assembly. Finished parts will be easier to handle and shipping costs will be reduced.
- *Reduced noise:* Mechanical noise associated with metallic components can be reduced significantly by making them in Delrin®.
- *Integral colours:* Avoid the need for painting parts of metal by using pre-coloured moulding resins. Produce colour-coded parts in Delrin® by using coloured moulding resins to mould easily distinguished components.
- *Metal replacement:* Avoid corrosion problems associated with metals such as rusting and dezincification by design in Delrin®. Mould maintenance costs are significantly lower with Delrin® than for die-cast alloys.
- *Food contact:* Many applications are in direct contact with food and potable water, requiring a material that is in compliance with international food contact regulations. A wide variety of colours are available using food contact acceptable pigments.

Caution: Do not use Delrin® in medical applications involving permanent implantation in the human body. For other medical applications see “DuPont Medical Caution Statement” H- 50102.

Cost analysis – Injection moulding and assembly

Careful study of end-use requirements in a given application will establish whether or not a composition of Delrin® is suitable. If Delrin® is suitable, preliminary designs should be drawn up and their commercial feasibility determined.

The cost to the end-user of injection moulded parts of Delrin® is the sum of the costs for the mould, material, moulding and post moulding operations. Thus, the part design selected for production should be that which minimizes the total cost of producing and assembling the required number of parts. This approach helps avoid waste of design and development effort on designs whose inherent nature makes them commercially unattractive.

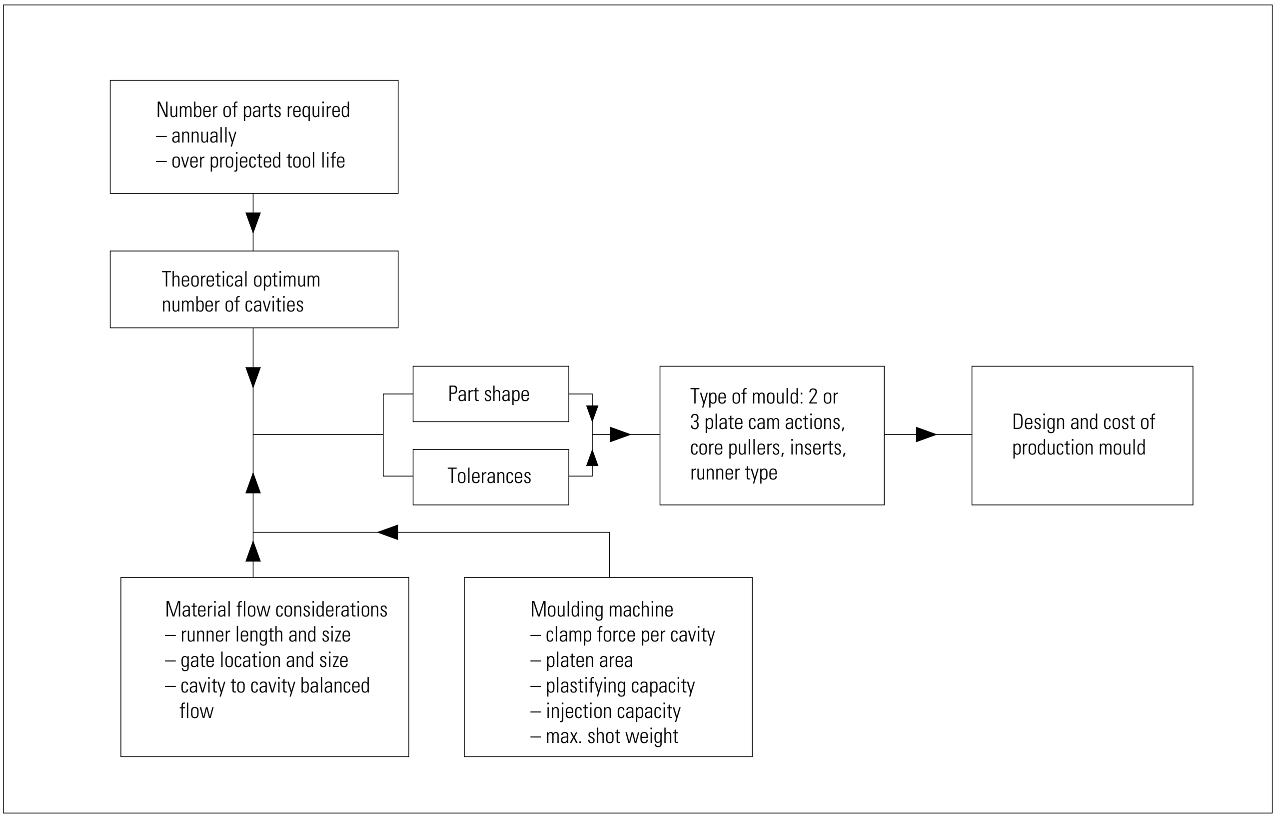

Figure 2.1 **Guide to factors important in mould design**

As a general guideline, the designer can contribute towards reducing the cost of moulding by designing components with thin uniform walls and selecting materials that can be moulded with short cycles with high productivity.

Effect of mould cost

The influence of mould cost on the costs of parts is largely dependent on the volume of production and the time interval over which the moulded part will become obsolete. Normally moulds are amortized over 1 – 3 years, involving several million parts.

Because mould costs contribute significantly to user's costs, the design of injection moulds for production should be left to an experienced mould designer. It is advisable to consult the mould designer before part design is finalized, since even seemingly insignificant changes in part geometry may greatly influence the cost of producing the part. The accompanying flow diagram (Figure 2.1) is a guide to the factors which must be taken into account in designing economical injection moulds. Part shape, tolerances, and wall dimensions are all important factors. These are discussed more fully in Chapter 5. Unnecessarily tight tolerances for example, can greatly increase cost.

Effect of material cost

The contribution of material cost to the purchased cost of parts moulded in DELRIN® acetal resin usually is between 40 and 60% of total cost*. As with most other plastic materials, the unit price of DELRIN® is a function of purchased quantity and grade.

The size of sprues and runners should be kept to a practical minimum by proper mould design, to avoid unnecessary production of rework. Sprues, runners and reject parts which have not been degraded or contaminated may be reground and blended with virgin resin depending on specifications. In most cases up to 30% regrind can be used.

In some cases runnerless moulds may be considered, since they eliminate the production of rework derived from sprues and runners.

Adequate quality control should be carried out on parts as they are produced to improve the overall efficiency of moulding and to minimize the production of rework.

Effect of the moulding operation

The value added to material cost in the moulding operation usually constitutes 40-60% of moulded part cost*. The specific value depends on the machine size, machine capacity used, the production yield and the number of parts produced per hour. The size of the moulding machine depends on the size and weight of the part, the annual part requirements, the size of the mould and the moulding cycle.

The various aspects of design which will give economical moulding cycles are considered in the "Design Handbook – Module I".

* Excludes mould costs

Post-moulding or finishing operations

Most parts moulded of Delrin® are produced as fully finished parts. However, sometimes it is desirable or necessary to perform assembly, machining or finishing operations.

Assembly techniques, decorating and machining are discussed in Chapter 12 and in the "Design Handbook – Module I".

Although no cost figures are suggested, the costs for these various operations will depend on auxiliary material and labour costs and the rate of production.

Other costs

Special packaging and handling of moulded parts or short moulding runs may incur supplementary charges. If decorating requires the use of special fixtures or masks as in silk-screening, it can be expected that these equipment items will be charged for separately. The purchaser of the parts would amortize them just as he would the production mould.

3. Summary of properties

Table 3.01 – Typical properties of DELRIN® resins

	Property	Test conditions	Test method ISO	Units	High viscosity 100	100P	Medium viscosity 311DP	500	500P	Low viscosity 900P	Toughened 100ST	500T
MECHANICAL	Melt flow rate (= MFI)	23°C	1133	g/10 min	2,3	2,3	7	14	15	24	1,9	12
	Yield stress[1]	23°C	527-1/-2	MPa	72	71	74	72	70	71	43	59
		60°C			56	56	59	56	55	55	32	44
		90°C			38	38	38	37	37	35	18	27
		120°C			22	22	27	23	23	22	11	18
	Yield strain[1]	23°C	527-1/-2	%	25	23	15	15	14	12	30	16
		60°C			19	19	15	14	14	13	24	14
		90°C			11	11	10	9	9	10	20	13
		120°C			9	9	9	8	9	8	20	11
	Strain at break[1]	23°C	527-1/-2	%	50	65		45	40	25	>100	55
	Nominal strain at break[1]	23°C	527-1/-2	%	45	45	35	30	30	25	>50	40
	Tensile modulus[2]	23°C	527-1/-2	GPa	3,1	3,0	3,3	3,2	3,2	3,2	1,5	2,5
		60°C			1,7	1,6	2,0	1,9	1,9	1,5	0,5	1,2
		90°C			1,0	1,0	1,3	1,1	1,1	1,0	0,2	0,6
		120°C			0,6	0,8	0,8	0,6	0,6	0,6	0,1	0,4
	Tensile creep modulus	1 h	899-1	GPa	2,9	2,7		2,9	2,8	2,8	1,35	2,3
		1000 h			1,6	1,5		1,7	1,6	1,5	0,55	1,15
	Flexural modulus	23°C	178	GPa	2,8	2,6	3,2	3,0	3,0	3,0	1,35	2,3
		70°C			1,5	1,4	1,6	1,5	1,3	1,4		
		100°C			0,9	0,8	1,1	0,9	0,8	0,8		
		120°C			0,7	0,6	0,8	0,7	0,6	0,6		
	Izod impact strength (notched)	23°C	180/1A	kJ/m^2	14	14	10	9	9	7	90	14
		−40°C	(1993)		13	12	9	9	9	7	20	8
	Charpy impact strength (notched)	23°C	179/1eA	kJ/m^2	15	15	10	9	9	7	100	15
		−30°C	(1993)		11	11	9	8	8	6	20	12
THERMAL	Temperature of deflection under load[3]	1,8 MPa	75	°C	115	110	115	115	110	110	70	90
	Melting temperature, by DSC	10°C/min	11357-1/-3	°C	178	178	178	178	178	178	178	178
	Vicat softening temperature	10 N	306 A50	°C	174	174	174	174	174	174	168	171
		50 N	306 B50		160	160	160	160	160	160	115	140
	Coefficient of linear thermal expansion	23°C-55°C	11359	10^{-4}/°C	1,2	1,2	1,1	1,2	1,2	1,2	1,2	1,2

1) Testing speed 50 mm/min 2) Testing speed 1 mm/min 3) Annealed specimen

To be continued on page 10

Table 3.01 – Typical properties of DELRIN® resins (continued)

	Property	Test conditions	Test method ISO	Units	High viscosity 100	100P	Medium viscosity 311DP	500	500P	Low viscosity 900P	Toughened 100ST	500T
ELECTRICAL	Volume resistivity		IEC 93	Ω m	10^{13}	10^{12}	10^{13}	10^{13}	10^{12}	10^{12}	10^{12}	$>10^{13}$
	Surface resistivity		IEC 93	Ω	10^{15}	$>10^{15}$	10^{15}	10^{15}	10^{15}		10^{14}	10^{15}
	Relative permittivity	100 Hz	IEC 250		3,8	3,8	3,8	3,8	3,9	3,7	4,7	3,6
		1 MHz	IEC 250		3,6	3,8	3,7	3,7			4,5	
	Electric strength, short time		IEC 243	MV/m	32	32	32	32	21	32	39	
	Dissipation factor	100 Hz	IEC 250	10^{-4}	180	200		100	200	180	60	
		1 MHz	IEC 250	10^{-4}	50	40	50	60	60	50	70	160
	Arc resistance		ASTM D 495	s	200 no tracking	200 no tracking	200 no tracking	200 no tracking	200 no tracking	200 no tracking	120 no tracking	120 no tracking
MISCELLANEOUS	Density		1183	g/cm^3	1,42	1,42	1,42	1,42	1,42	1,42	1,34	1,39
	Flammability		UL 94		HB	HB	HB	HB	HB	HB	HB	HB
	Water absorption		62	%								
	– 24 hours immersion				0,25	0,32	0,25	0,25	0,32	0,32	0,40	0,31
	– 50 % R.H., equilibrium				0,22	0,30	0,25	0,22	0,30	0,30	0,35	0,20
	– Equilibrium immersion				0,90	1,30	0,90	0,90	1,40	1,40	0,90	0,80
	Rockwell hardness		2039 (R + M)		M92 R120	M92 R120	M92 M120	M92 R120	M92 R120	M92 R120	M58 R105	M79 R117
	Mould shrinkage, ISO test specimen[1]		294-4	%								
		Parallel (in flow direction)			2,1	2,1	2,0	2,1	2,1	2,1	1,3	1,8
		Normal (perpendicular to flow)			1,9	1,9	1,9	2,0	2,0	2,0	1,4	1,7

Chemical resistance	All resins have outstanding resistance to neutral chemicals and a wide variety of solvents

[1] In moulded parts, the typical shrinkage is higher (see Chapter 5).

4. Material data for flow analysis

Table 4.01 contains information about thermal properties, wich are required for flow analysis simulation of different grades of Delrin®.

Additional data, like viscosity curves, are available through your local DuPont representative.

Table 4.01 – Material data for flow analysis

	100 100P	100ST	500 500P	500T	570	900P
Solid density (kg/m^3)	1420	1340	1420	1390	1560	1420
Liquid density (kg/m^3)	1160	1140	1160	1140	1300	1160
Specific heat of the melt (J/kg °C)	3100	2200	3000	2200	2900	3100
Latent heat of fusion (kJ/kg)	120	80	140	120	115	140
Lower transition temperature (°C) (No-flow temperature)	141	141	142	141	144	141
Higher transition temperature (°C)	153	151	153	153	153	153
Freezing temperature (°C)	140	140	140	140	140	140
Conductivity of the melt (W/m °C)	0,15	0,13	0,15	0,14	0,15	0,15
Recommended melt temperature (°C)	215	205	215	205	215	215
Recommended mould temperature (°C)	90	40	90	40	90	90

5. Dimensional considerations

Introduction

Delrin® acetal engineering resins have good dimensional stability compared to other polymers over a wide range of temperatures in the presence of moisture, lubricants or solvents. They find extensive use in industry for the fabrication of precision gears, bearings, housings and similar devices, because of their unique combination of dimensional stability with other properties, such as fatigue resistance and tensile strength. However, as with all materials of construction, there are factors affecting the dimensional stability of Delrin® which must be considered when close tolerances are essential.

Moulding shrinkage and post-moulding shrinkage occur as natural consequences of the moulding process. They influence the tolerances that can be obtained for moulded parts. Data on these effects are presented in this chapter.

Further dimensional variations in moulded parts of Delrin® can arise from changes in the temperature or nature of the surroundings. The effects of moisture and temperature are presented here, while the immersion in chemicals and fuels is discussed in Chapter 7.

Moulding shrinkage

The moulding shrinkage is the shrinkage which occurs within 24 hours of moulding; it is defined as the difference between cavity and actual part dimension, both measured at room temperature. It is due to the difference in specific volume of Delrin® at crystallisation temperature and its specific volume at room temperature.

The typical moulding shrinkage of Delrin® resins is between 1,8 and 2,2%, except for the glass-filled and supertough grades (Delrin® 570, 577 and 100ST) which have a lower shrinkage.

The moulding shrinkage is dependent on factors which affect the crystallinity of Delrin®; these include:

- mould temperature;
- part thickness;
- hold (pressure) time;
- injection hold pressure.

Furthermore, the shrinkage is also dependent on the geometry of the part and the flow pattern of the resin.

Studies of shrinkage were made using 180 by 27 mm plaques with thicknesses from 1,5 to 6 mm. Four values of shrinkage were measured: close to and far from the gate, parallel and perpendicular to the flow. For most Delrin® grades, it is observed that the shrinkage is higher far from the gate than close to the gate (typically by 0,1 to 0,3%), and that the shrinkage in the flow direction is about 0,1% higher than perpendicular to the flow.

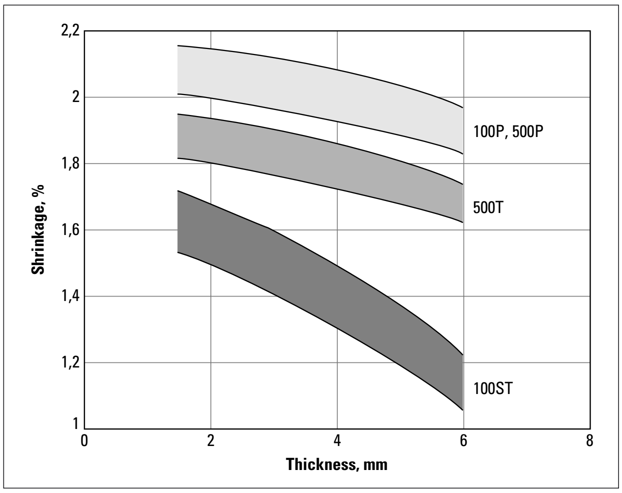

Figure 5.01 **Average shrinkage for various grades of Delrin®; besides thickness, the shrinkage depends on overall part design and on processing conditions**

Figure 5.01 shows the average shrinkage as a function of thickness, for different grades of Delrin®. The DuPont expert system CAMDO allows more detailed predictions of shrinkage, including the effects of processing parameters like mould temperature and hold pressure; such calculations can be obtained through your DuPont representative.

Post-moulding shrinkage

The post-moulding shrinkage is defined as the shrinkage which takes place more than 24 hours after moulding. It is a consequence of continued crystallisation and relaxation of moulded-in stresses, where the resin moves towards a more stable state; this happens because the glass transition temperature of Delrin® is below room temperature.

The post-moulding shrinkage of parts moulded in Delrin® can be estimated from Figure 5.02.

Parts moulded with the recommended mould temperature (90°C) or higher will have a low post-moulding shrinkage, which ensures good dimensional stability over the lifetime of the part.

However, parts moulded with a cold mould (<80°C) will have a higher post-moulding shrinkage, because fast cooling leaves the Delrin® in an unstable crystalline state and results in more significant recrystallisation; if such Delrin® parts are then exposed to high temperatures, the recrystallisation causes a high post-moulding shrinkage.

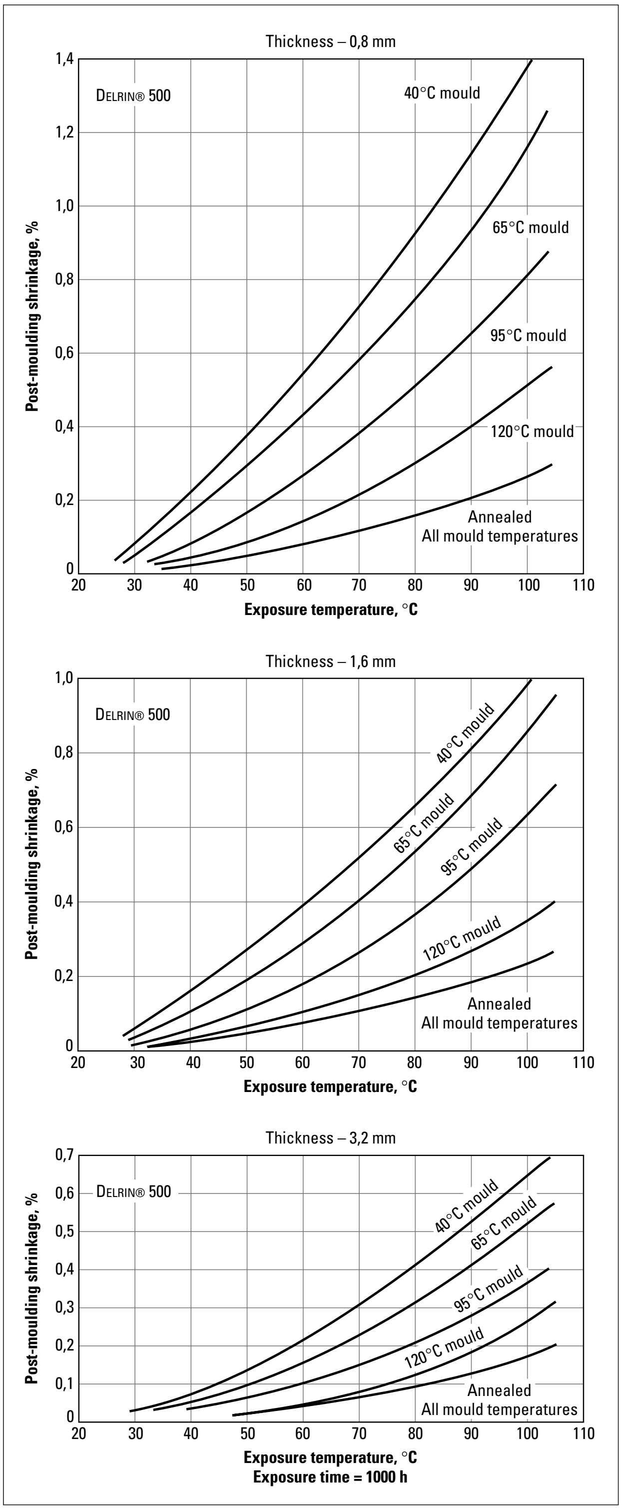

Figure 5.02 **Post-moulding shrinkage in air**

The significant influence of part thickness on post-moulding shrinkage is also shown in Figure 5.02. This influence must certainly be considered when specifying tolerances and the degree of dimensional stability required for a part.

Annealing

Annealing is occasionally used to accelerate stress relaxation and dimensional stabilisation of parts. It is an additional process and should only be used when moulded parts require very tight tolerances and exposure to high temperatures for prolonged periods.

Annealing is also suggested as a test procedure in setting-up moulding conditions on a new mould, to evaluate post-moulding shrinkage and moulded-in stresses; the changes in dimensions during annealing will closely represent the ultimate change in part size in use.

When dimensional precision is a prime requirement, the use of a high mould temperature (90-120°C) is strongly recommended. Attempts to reach good dimensional stability by annealing parts moulded in a cold mould (<80°C) will lead to high post-moulding shrinkage and may introduce stresses during the recrystallisation process, resulting in uncontrolled deformation.

Annealing procedure

Annealing should be performed in air or in inert mineral oils at 160 ± 3°C, for 30 minutes + 5 minutes per mm of wall thickness; overheating and hot spots should be avoided, and parts should neither contact each other nor the walls of the oven/bath. Parts should be left in the oven to cool slowly until 80°C is reached; stacking or piling, which may deform the parts while they are hot, should be delayed until the parts are cool to the touch. This procedure was used to obtain the results shown in Figure 5.02, which allows the ultimate dimensional changes that a part is likely to experience in normal use to be estimated.

To simply stabilise parts for continuous high temperature use (<90°C), parts may be heated to 90°C for up to 24 hours. Post-moulding shrinkage of around 0,1 to 0,2% will then be seen if the parts were moulded in a mould at 90°C ± 10°C.

Dimensional tolerances

General

Taking into account mould dimensions and processing variability, experience suggests that the following dimensional tolerances are achievable with good moulding practice:

- dimensions up to 150 mm:
  ±0,15% for precision moulding
  ±0,3% for technical moulding
- dimensions above 150 mm:
  ±0,25% for precision moulding
  ±0,4% for technical moulding

Moulds

For multicavity moulds, the toolmaking tolerances are important. They have a direct effect on the dimensional tolerance of the part. As an example, for a mould dimension of 30 mm manufactured to within ±0,01 mm, experience has shown that dimensional consistency better than ±0,03 to 0,04 mm cannot be expected for parts from different cavities in a single shot.

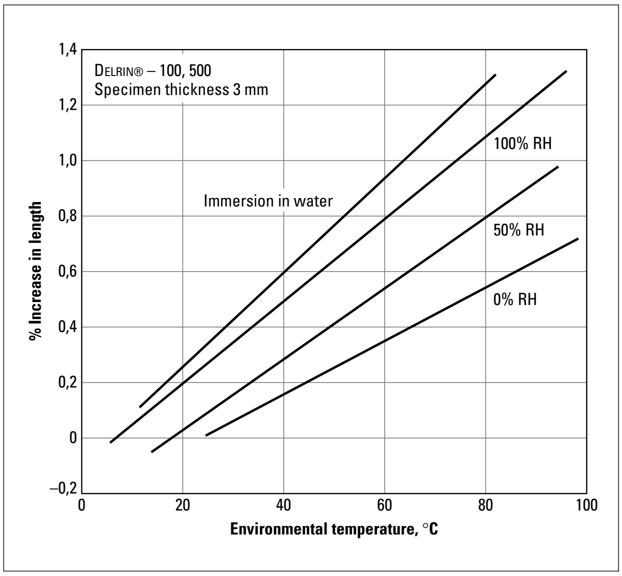

Figure 5.03 **Dimensional changes of Delrin® with variations of temperature and moisture content**

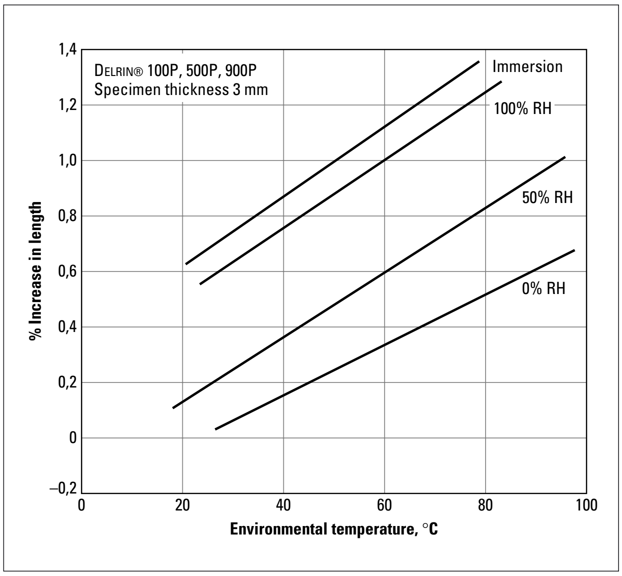

Figure 5.04 **Dimensional changes of Delrin® with variations of temperature and moisture content**

Moulding conditions

Parts moulded under recommended conditions (gate, runner, nozzle, screw, machine parameters) as defined in the moulding guide are subject to small shot to shot variations in dimensions. Any change in machine parameters or conditions will effect dimensional tolerance; for example, a colder mould leads to higher post-moulding shrinkage, too short Hold (Pressure) Time leads to inconsistent shrinkage, deformation and larger variability in part dimensions.

Effect of moisture

Delrin® absorbs a small amount of water which affects the dimension of moulded parts. Figures 5.03 and 5.04 present the relationship between dimensional changes and variations in moisture content at various temperatures. The rate at which water will be absorbed by a part of Delrin® under various conditions in shown in Figure 5.05.

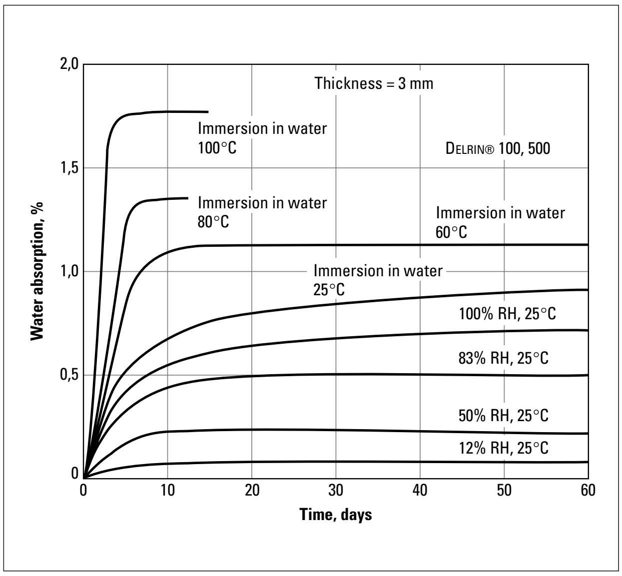

Figure 5.05 **Rate of water absorption of Delrin® under various conditions**

6. Mechanical properties

The DuPont Handbook entitled "General Design Principles – Module I", shows how to use the properties discussed in this chapter for the design of parts.

Definitions

Some engineering definitions are particularly relevant to a basic understanding of the mechanical behaviour of thermoplastics.

- *Elasticity:* The property of being able to recover its original shape and size after removal of the load causing its deformation.
- *Plasticity:* The tendency of a material to remain deformed after reduction of the deforming stress.
- *Proportional limit:* Proportional limit (or elastic limit) is the greatest stress which a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law).
- *Modulus of elasticity:* The modulus of elasticity (E) in tension, compression or flexure of a material is the ratio of stress to corresponding strain below the proportional limit in the particular type of stress involved.
- *Yield stress:* The first stress in a material at which an increase in strain occurs without an increase in stress.
- *Tensile strength:* The maximum tensile stress sustained by the specimen during a tensile test. For Delrin®, the tensile strength is generally equal to the yield stress.

The mechanical behaviour of thermoplastics ranges from elastic to plastic depending on: the nature of the material, magnitude of the stress, duration of the stress, temperature, chemical nature of the environment and time allowed for recovery.

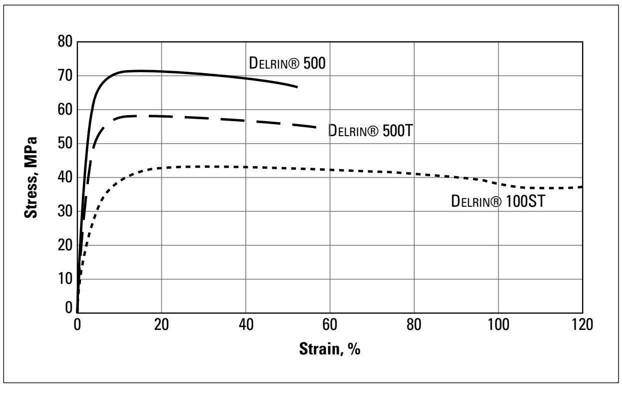

Figure 6.01 **Typical stress-strain curves for 3 Delrin® acetal resins (strain rate 50 mm/min)**

Elastic behaviour dominates when at a specific temperature the stress applied is small in relation to the tensile strength and when short-term loads are involved. The mechanical response of Delrin® to short-term loads is shown in Figures 6.01 to 6.08.

Plastic behaviour becomes important when stresses are high in relation to tensile strength and when long-term loads are involved. It becomes increasingly important as temperature approaches the flow point of the material. Data for the behaviour of Delrin® in air under long-term loads at various temperatures are presented in Figures 6.09 to 6.12. Complementary data for long-term unstressed exposure in air at various temperatures is in Figure 7.02.

The effect of moulding conditions

As with other thermoplastics, the properties of moulded parts of Delrin® can be influenced by moulding conditions. Recommended moulding conditions are described in the DuPont bulletin TRD 30 entitled "Precision moulding with Delrin®".

Toughness and fatigue resistance can be impaired seriously by unsound choice of moulding conditions. For this reason, the evaluation of moulded prototypes should be carried out on samples made in test cavities under moulding conditions representative of production conditions.

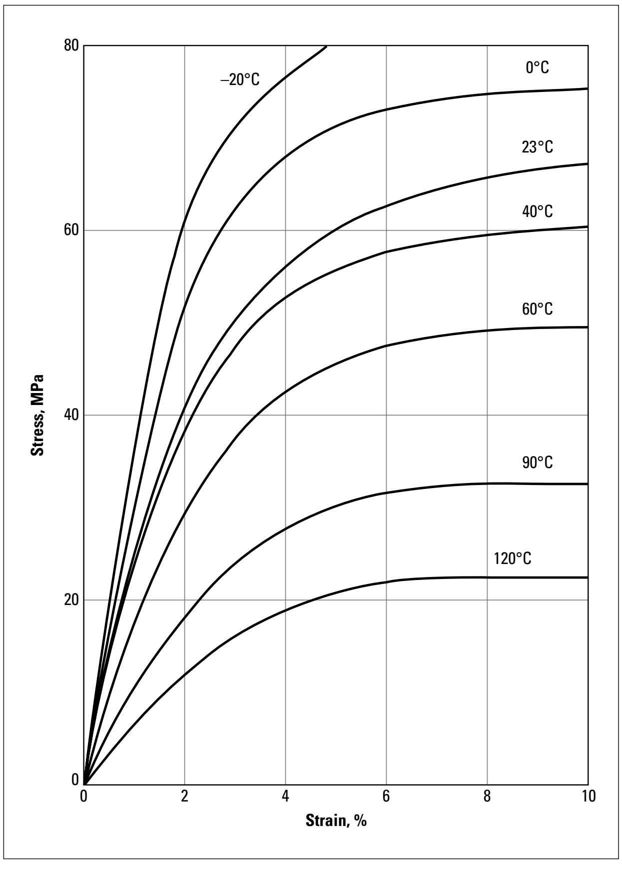

Figure 6.02 **Stress vs. strain for Delrin® 500 at various temperatures (strain rate 5 mm/min)**

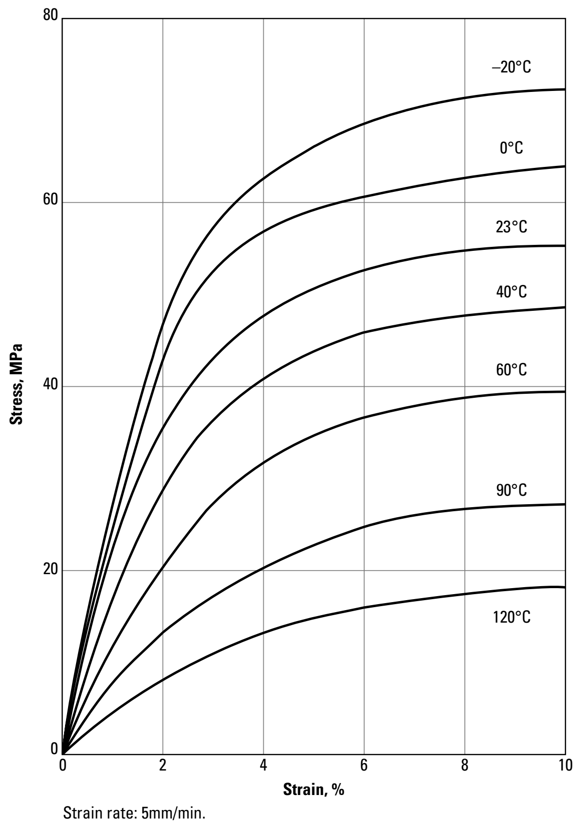

Figure 6.03 **Stress vs. strain for Delrin® 500T at various temperatures (strain rate 5 mm/min)**

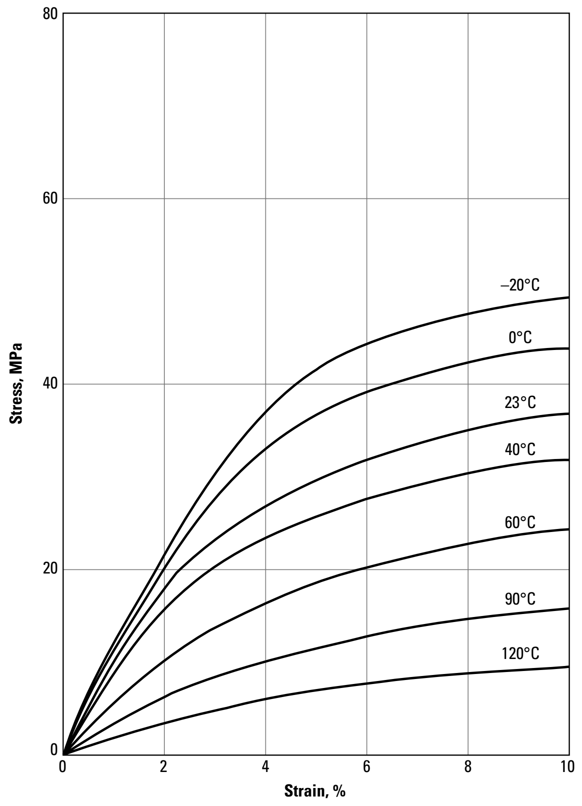

Figure 6.04 **Stress-strain curves for Delrin® 100ST at various temperatures (strain rate 5 mm/min)**

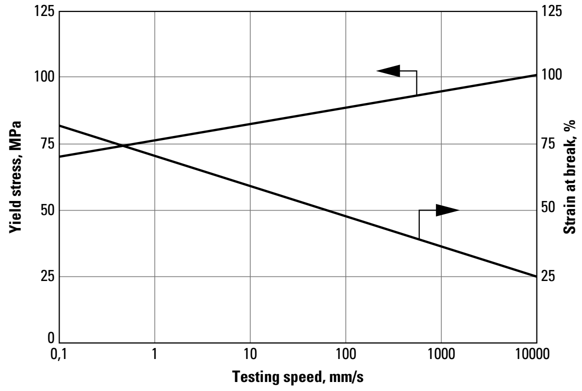

Figure 6.05 **High speed tensile test at room temperature for Delrin® 500. Adapted from C.J.G. Plummer et al., in *Impact and dynamic Fracture of Polymers and Composites,* 1995, Mechanical Engineering Publications, London, pp. 265-280.**

Short-term loads

The stress-strain curve

Typical stress-strain behaviour of the three main Delrin® product families is shown in Figure 6.01. The unmodified Delrin® resins show higher strength and stiffness, while the toughened and supertough resins show increasing ductility. This also appears in Figures 6.02 to 6.04 which give the temperature dependence of the stress-strain curves up to 10% strain.

The influence of strain rate on the tensile behaviour of Delrin® 500 can be seen in Figure 6.05.

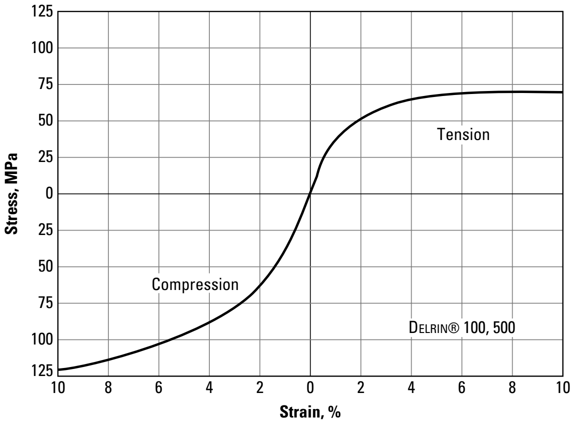

Figure 6.06 **Stress-strain curves for Delrin® in tension and compression at 23°C. The measurements were done according to ISO 527 and ISO 604 using injection-moulded samples.**

Tension and compression

Figure 6.06 is a stress-strain curve for Delrin® in both compression and tension. The tests were carried out at 23 °C and at 1 mm/min. This graph indicates that the strength in compression is greater than that in tension, whereas the elastic moduli are equal.

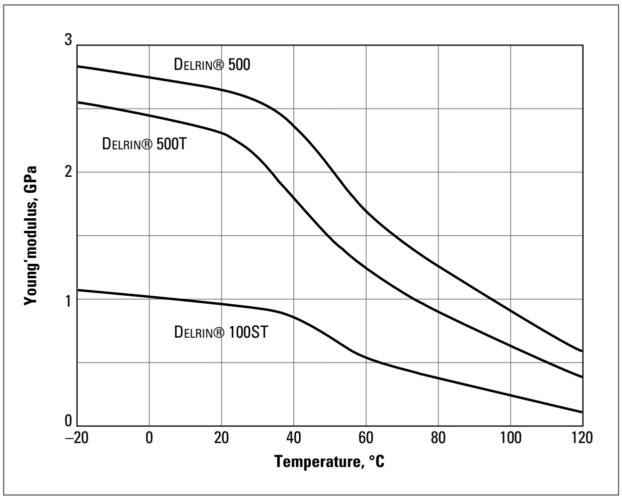

Figure 6.07 **Young's modulus of DELRIN® as a function of temperature (measured at 5 mm / min)**

Modulus of elasticity

The modulus of DELRIN® is affected significantly by changes in the ambient temperature. Figure 6.07 shows the variation of the tensile modulus (Young's modulus) with temperature. At room temperature the tensile modulus remains constant over a broad range of strain rate (0,1–10^5 mm/s).

The value of the flexural modulus is marginally lower (about 5%).

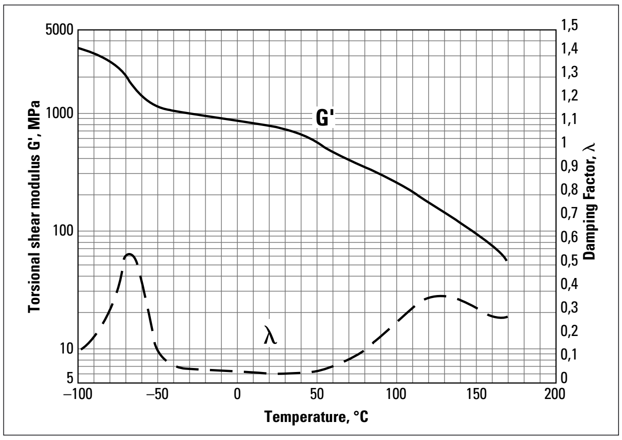

Figure 6.08 **Torsion pendulum diagram of DELRIN® 100 NC010**

Shear modulus, Poisson's ratio

Like the strength and modulus in tension, the shear strength and shear modulus vary with temperature. Figure 6.08 shows the torsional shear modulus from –100°C up to the melting temperature. The associated curve of the damping factor shows no transition in the typical operating range of temperature (–50 to 60°C).

In isotropic materials the shear modulus G′ is theoretically related to the elastic modulus E and the Poisson's ratio ν:

$$G' = E/\{2\ (1 + \nu)\}$$

For DELRIN® $\nu = 0{,}35$ and the above equation is only an approximation.

Long-term stressed exposure

Except for approximate linearity under conditions of low load and initial loading, there is no linear section in the stress-strain curves for DELRIN®. "Creep" and "Relaxation" phenomenae are consequences of this non-linearity.

Creep is defined as a time dependent strain, resulting from stress. It can occur in tension, compression, flexure or shear.

Relaxation is defined as decrease of the stress required to maintain constant strain over a given time period.

Stressed in air

The results of experiments in flexural creep at various air temperatures and levels of stress have been plotted in Figures 6.09 to 6.12. Data from these figures may be used to predict creep or relaxation phenomena in parts of DELRIN® acetal resins under similar loads, by substitution of the stress-temperature-time dependent (creep or relaxation) modulus in the appropriate engineering formulae.

It is suggested that the above data be used in conjunction with data for unstressed exposure of DELRIN® in air (see text and Figure 7.02) to formulate designs and prototypes in DELRIN® for intermediate stress-temperature-time conditions. The design should be thoroughly evaluated by realistic testing.

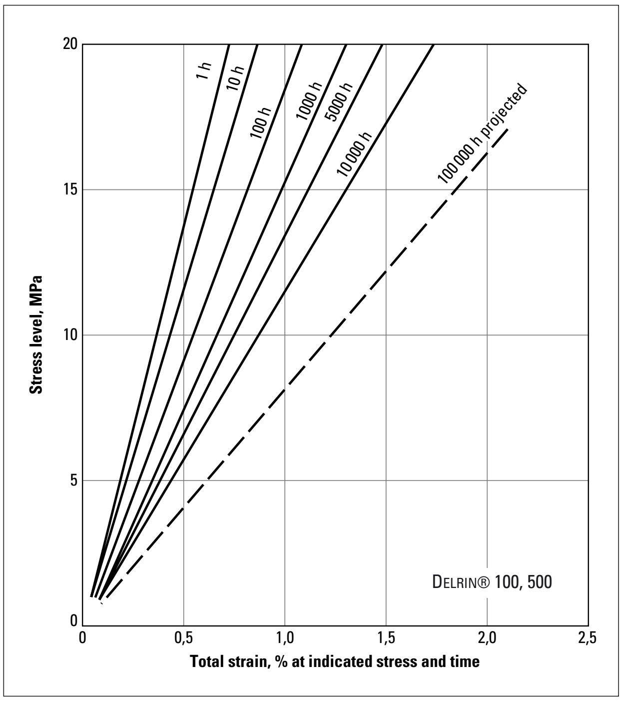

Figure 6.09 **Isochronous stress-strain curves of DELRIN® under flexural load at 23°C, air**

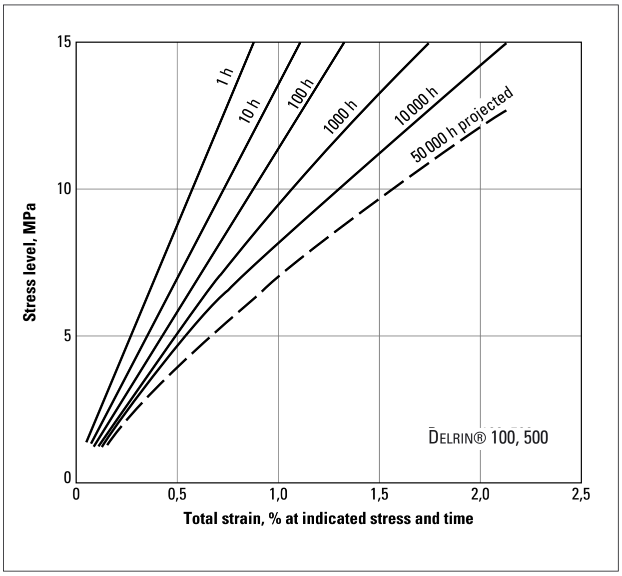

Figure 6.10 **Isochronous stress-strain curves of DELRIN® under flexural load at 45°C, air**

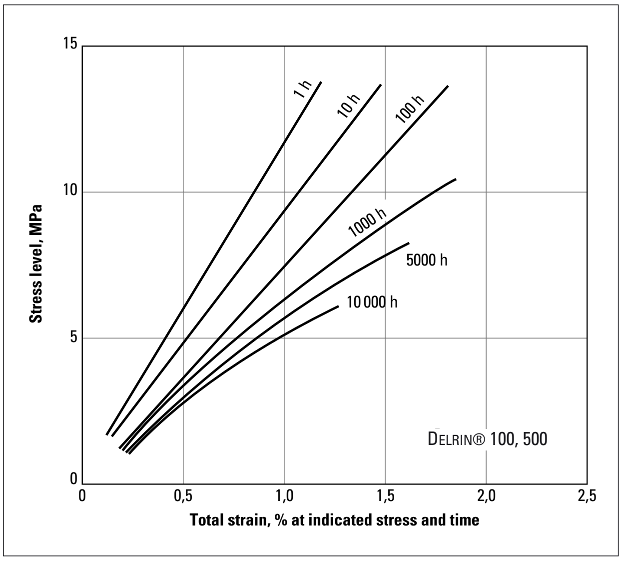

Figure 6.11 **Isochronous stress-strain curves of DELRIN® under flexural load at 85°C, air**

Notes on figures 6.09 to 6.12

1. Parts designed by use of the appropriate creep or relaxation moduli and engineering formulae will be over-designed below the chosen time "t" and under-designed beyond time "t" in terms of their creep or relaxation behaviour. However, their response to rapidly applied and removed loads will not be affected greatly, provided "stress time" limits at the temperature are not exceeded.
2. The rate of creep and relaxation increases with increasing level of stress.
3. Extrapolations of data in Figures 6.09 to 6.12 to higher stresses and temperature or longer times than shown should not be made unless the design of parts thus arrived at can be verified by rigorous testing.
4. For greatest accuracy, prototypes of production parts should be fabricated by the same methods and under the same conditions as parts intended for production.

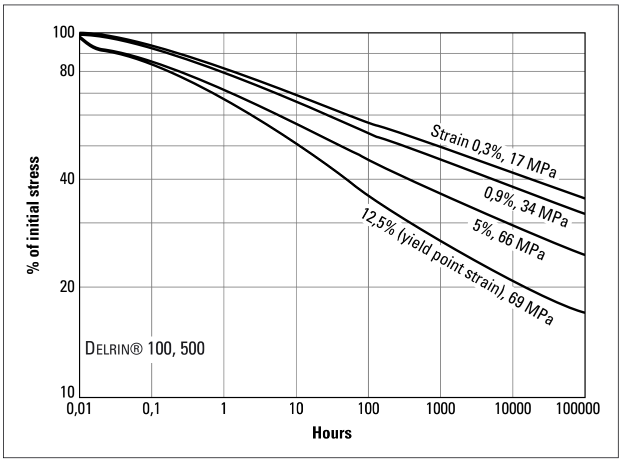

Figure 6.12 **Tensile stress relaxation of DELRIN® under constant strain at 23°C**

Recovery from cyclic, long-term loading

In general, the amount of recovery after static loads are removed will depend on: the duration of the loads, the level of stress under load, temperature and time allowed for recovery as well as on the nature of the environment. Upon removal of a 14 MPa deforming stress there is an immediate recovery of about 40%, followed by a time-dependent recovery.

Fatigue resistance

When materials are stressed cyclically at high levels of stress in relation to their tensile strength, they tend to fail at levels of stress below their ultimate tensile strength. The phenomenon is termed "fatigue failure".

DELRIN® acetal resins have extremely high resistance to fatigue failure from –40° to 80°C.

Furthermore, their resistance to fatigue is not greatly affected by the presence of water, solvents, neutral oils and greases. This has been demonstrated by both industrial and laboratory experience that has accrued since the resins were introduced commercially in 1960.

Fatigue resistance data (in air) for injection moulded samples of DELRIN® are shown in Figures 6.13 and 6.14. These "Sonntag" data were obtained by stressing the samples at a constant level and 1800 cpm (30 Hz) and observing the number of cycles to failure at each testing load on a Sonntag-Universal testing machine.

Impact resistance

Impact resistance is the ability to withstand a sudden blow rather than a slowly applied load. No single test has been designed that can evaluate the impact resistance under all the different conditions met by plastic parts.

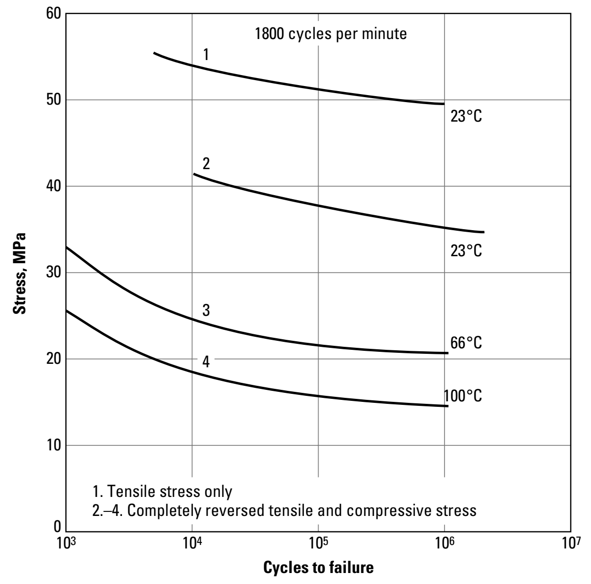

Figure 6.13 **Fatigue resistance of Delrin® 500 at 1800 cpm vs. temperature (air)**

Some pratical tests have been developed to measure in a comparative way the toughness of different polymers. Among them the notched Charpy and notched Izod fit well to Delrin® in the way that they allow to measure the breakage energy, even if the notch is a very artificial feature not representative of an actual part.

In contrast to many other engineering polymers, Delrin® has the unusual advantage of maintaining its high toughness down to very low temperatures, as is shown in Figure 6.15. This is due both to its high crystallinity and to its low glass transition temperature.

In common with other polymers, the toughness of Delrin® increases with its molecular weight, and hence with its (melt) viscosity. Figure 6.16 shows the variation of notched impact performance of the standard grades, from the lowest to the highest viscosity range. Delrin® 100 grade has the best impact performance.

When a higher toughness is required, impact modified grades exist (Delrin® T and ST) which have an impact strength similar to the best toughened engineering polymers grades. Obviously this modification will reduce slightly the modulus.

Figure 6.17 shows the notched impact performance of the various toughened Delrin® grades compared to the standard ones.

As the other similar polymers, standard Delrin® grades are sensitive to sharp angles. Figure 6.18 shows the influence of the radius of curvature at the “sharp angle” on the impact performance of a moulded test specimen; it appears that rounding the sharp angles to radii of the order of 0,2 to 0,5 mm can double the impact strength.

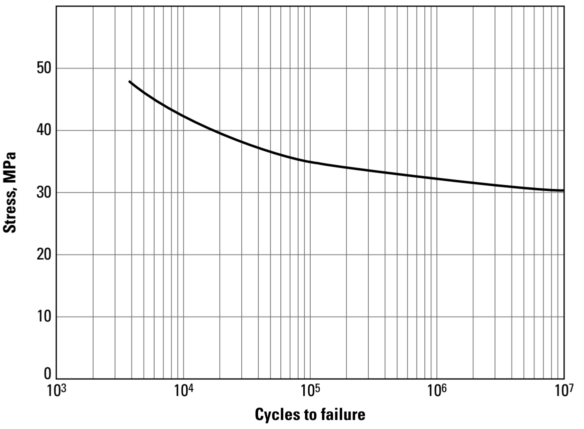

Figure 6.14 **Flexural fatigue of Delrin® 100 (ASTM D671) at 23°C; 50% RH**

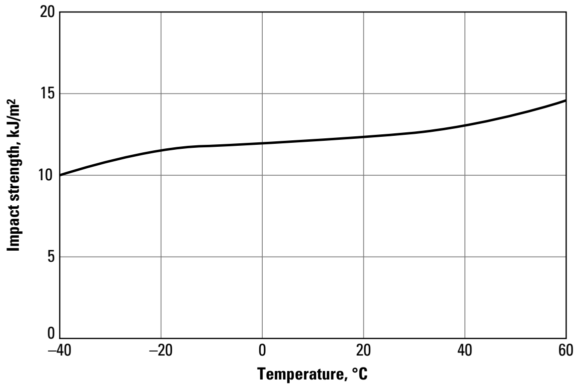

Figure 6.15 **Izod notched impact strength vs. temperature for Delrin® 100**

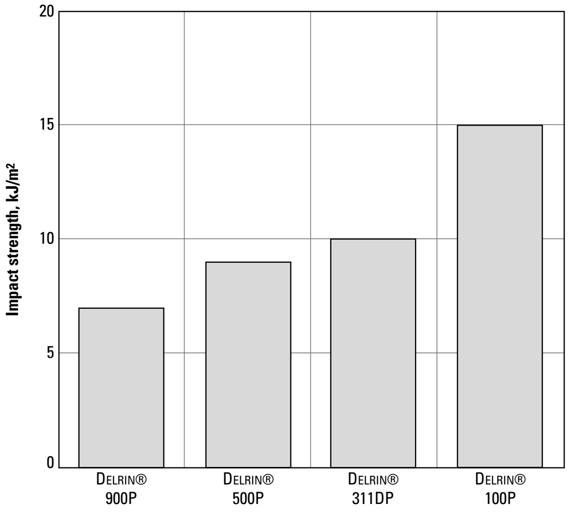

Figure 6.16 **Charpy notched impact strength at room temperature for standard grades of Delrin®. The highest viscosity gives the highest impact strength**

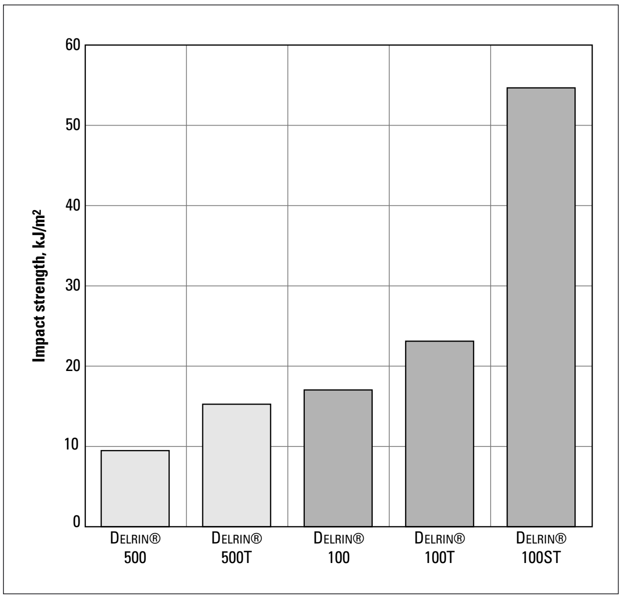

Figure 6.17 **Charpy notched impact strength for standard and toughened resins, at 23°C**

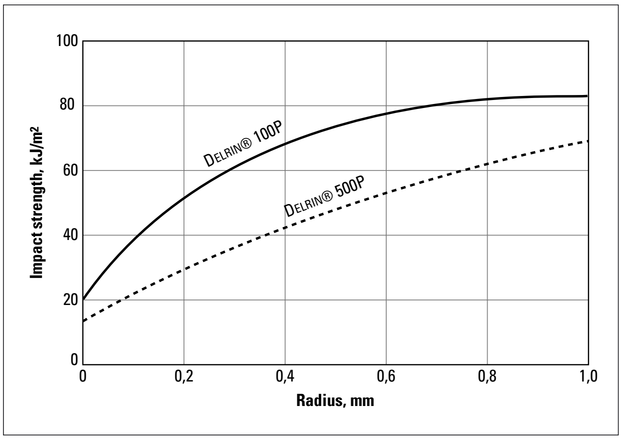

Figure 6.18 **Impact strength as a function of the radius of curvature of a moulded notch. Rounding sharp angles gives a large improvement of impact resistance**

Fracture toughness

Materials may fail in service due to various mechanisms, including yield, creep and (catastrophic) fracture.

Conventional impact testing (Izod, Charpy, falling-dart) is an attempt to model the most severe conditions to which a material can be subjected, and derives energy measurements that represent the impact strength of the material tested.

The resulting values of the impact strength are strongly dependent upon the geometry of the specimen used, and the loading conditions; so this impact strength does not represent a material property.

Designers search for such a material property (that is, a parameter that is independent of the test method) for the resistance to fracture, or fracture toughness, of a material.

The engineering discipline of fracture mechanics starts from the assumption that all materials have inherent cracks (defects, flaws) in them, and has developed two approaches to defining fracture resistance as a material property.

The first approach considers the energy balance in a stressed material, in which stored strain-energy is released in the form of stable crack growth. Increasing the stress on the material eventually releases the stored energy at such a rate that the crack grows catastrophically. This critical strain-energy release rate G_c describes the resistance to crack propagation in a material.

A second approach analyses the stress concentration around a crack. At a critical level of stress, for a given inherent flaw size in the material, catastrophic fracture occurs due to crack propagation. This critical stress intensity factor K_c describes the fracture toughness of the material.

Table 6.1 lists the values of fracture mechanics parameters for three grades of Delrin®. The truly outstanding toughness of Delrin® 100 is clearly shown.

It is anticipated that the fracture toughness derived in these fundamental ways will have utility in materials characterization and design.

Table 6.1 – Fracture mechanics parameters for Delrin®

Grade of Delrin®	K_{Ic} (MPa m$^{1/2}$)	G_{Ic} (kJ/m^2)
100	3,4	4,7
500	2,4	2,1
900	2,4	2,2

Note: The subscript **I** in the fracture mechanics parameters describes the most common (tensile) crack opening mode, MODE **I**.

7. Effects of the environment

Introduction

This chapter presents information on the behaviour of Delrin® in various conditions of use, including exposure to chemicals at ambient temperature, to air over a range of temperatures, and to weathering. Evaluation of the chemical resistance and weatherability of Delrin® was accomplished in a series of laboratory tests where unstressed specimen were exposed in the selected environment for periods up to one year; the final appreciation was based on visual observation, the changes of weight and dimension, and measurement of mechanical properties. The chemical composition of the environment, exposure time, and temperature were confirmed as the main factors influencing the behaviour.

These results can be used to estimate the suitability of Delrin® under comparable exposure conditions. It must be recognized however that there are always limitations to the prediction of actual performance from laboratory data obtained using unstressed specimen in continuous exposure to a certain environment. Intermittent exposure and service stresses can strongly modify the behaviour of the part. Therefore the information in this chapter should be considered as a starting point. It is not meant to substitute for any testing that may be required to determine the suitability of Delrin® under expected service conditions.

Table 7.1 – Behaviour of Delrin® exposed to various chemicals. Unless a concentration is specified, samples were immersed in the pure liquids at room temperature for periods up to one year. The final appreciation is based on the visual appearance, the changes of weight and dimension, and the retention of mechanical properties. The ratings range from "resistant" (no visible chemical attack, tensile strength changed by less than 20%) to "unsatisfactory" (severe chemical attack and/or changes of mechanical properties).

Chemical	Behaviour	Chemical	Behaviour
Acetic acid (5%)	resistant	Hydrofluoric acid (10%)	unsatisfactory
Acetic acid (20%)	limited resistance	Hydrogen peroxide (1%)	resistant
Acetic acid (50%)	unsatisfactory	Hydrogen peroxide (30%)	unsatisfactory
Acetone	resistant	Hydrogen sulphide	unsatisfactory
Air (all pressures)	resistant	Insecticides	resistant
Alcohol (all types)	resistant	Iso-octane	resistant
Ammonia (10%)	unsatisfactory	Jet Fuel / kerosene	resistant
Aniline	limited resistance	Lubricating oil	resistant
Benzene	resistant	Methyl chloride	limited resistance
Bleaching fluid (10% chlorine)	unsatisfactory	Methylene chloride	limited resistance
Brake fluid	resistant	Methyl ethyl ketone	limited resistance
Butane	resistant	Mineral oil	resistant
Calcium chloride (10%)	resistant	Motor oil	resistant
Carbon dioxide	resistant	Nitric acid (10%)	unsatisfactory
Carbon monoxide	resistant	Nitrous acid	unsatisfactory
Chloracetic acid (10%)	unsatisfactory	Nitrous oxide (dry)	unsatisfactory
Chlorine gas	unsatisfactory	Oils (food)	resistant
Chlorinated water	limited resistance	Oils (mineral)	resistant
Chloroform	limited resistance	Oleic acid	resistant
Chromic acid (10%)	unsatisfactory	Palmitic acid	resistant
Citric acid	limited resistance	Paraffins	resistant
Cyclohexane	resistant	Perchloric acid (10%)	unsatisfactory
Detergents	resistant	Phosphoric acid (30%)	unsatisfactory
Diesel fuel	resistant	Potassium hydroxide (10%)	unsatisfactory
Ethanol	resistant	Propane (liquified gas)	resistant
Ethyl acetate	resistant	Sodium chloride (10%)	resistant
Ethyl ether	resistant	Sodium hydroxide (10%)	unsatisfactory
Ethylene glycol	resistant	Sodium hypochlorite (5%)	unsatisfactory
Formaldehyde (37%)	resistant	Sulfur dioxide	unsatisfactory
Formic acid	unsatisfactory	Sulphuric acid (30%)	unsatisfactory
Fuel oil	resistant	Tetrahydrofuran	resistant
Fruit juice	resistant	Toluene	resistant
Gasoline	resistant	Trichloroacetic acid	unsatisfactory
Glucose (sat. sol.)	resistant	Trichloroethane (1,1,1-)	resistant
Heptane	resistant	Turpentine / white spirit	resistant
Hexane	resistant	Urea (5%)	resistant
Hydrochloric acid (10%)	unsatisfactory	Vinegar	resistant

Resistance to chemicals

One of the outstanding properties of Delrin® acetal homopolymer is high resistance to a variety of organic compounds that cause rapid failure of other plastic materials. Delrin® resins have good load-carrying ability in many neutral organic and inorganic materials, even at elevated temperatures. Typical chemicals to which they are resistant include alcohols, aldehydes, esters, ethers, hydrocarbons, agricultural chemicals, and many weak acids and bases; Delrin® has a good dimensional stability in most of these substances.

The Table 7.1 presents the results of tests for representative groups of chemicals. Injection-moulded bars were immersed in the chemical and maintained at room temperature. After exposure, the bars were examined for evidence of chemical attack, and measured to determine the changes in length, weight, and tensile properties; such changes may be reversible (absorption) or permanent (chemical attack, mechanical failure).

A change in length of the bar can result from stress relief due to exposure conditions, swelling, and/or chemical decomposition. In the majority of the tests, there was a length increase due to absorption. For this reason, dimensional variations in parts with close tolerance need to be verified under the proposed service conditions.

The Table 7.1 also shows cases where Delrin® was unsatisfactory under the given test conditions. A change in service (intermittent contact, different concentration) may permit the use of Delrin® with satisfactory performance and service life.

Zinc chloride and chlorine

Delrin® acetal resin is not recommended for use in zinc chloride solutions or environments that may generate zinc chloride. Zinc chloride acts to depolymerise (corrode) Delrin® acetal resin. The extent of attack will depend on stress, temperature, concentration, and time of exposure. This should not be construed to imply that Delrin® acetal resin cannot be used in contact with zinc or zinc plated metals. Delrin® acetal resin has been used successfully in many such applications since its commercialisation in 1960. However, where continuous exposure to salt water and contact with zinc plated steel is encountered, extensive testing is recommended. Sacrificial corrosion can produce zinc ions. These, together with chlorine ions, present in the salt water, can produce an effect similar to, but slower than, that produced by zinc chloride. Delrin® acetal resin is not affected by exposure to salt water alone.

Delrin® acetal resin is attacked by chlorine at concentrations of 3 to 5 ppm and higher. It is not recommended for long term, continuous exposure at these concentrations.

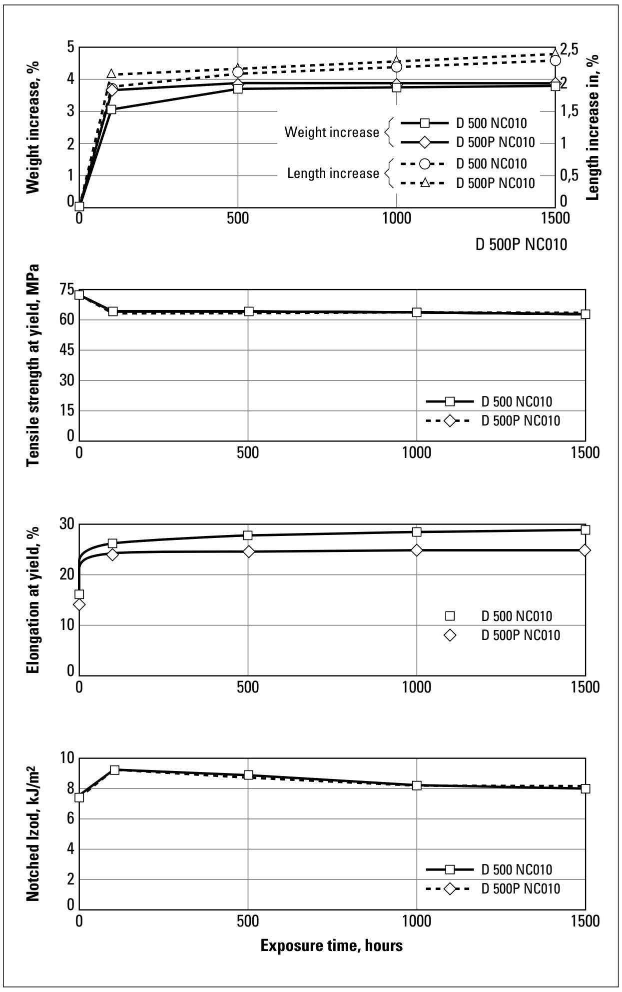

Figure 7.01 **Changes of weight, dimension and mechanical properties of Delrin® 500 and 500P immersed in fuel M-15 at 60°C**

Fuel resistance

Gasolines and blends with alcohols

Standard Delrin® grades have an excellent behaviour in the various gasolines or gasoline-alcohol blends available today. Blends with methanol are increasingly common and are known to cause more swell compared to regular gasolines and ethanol blends.

Standard specimen of Delrin® 500 NC010 and Delrin® 500P NC010 were aged up to 1500 hours at 60°C in a M-15 blend (regular gasoline +15% methanol). The Figure 7.01 illustrates the change in dimensions and properties as a function of exposure time. Only small changes can be noticed, explained by a slight plastification effect due to the fuel absorption.

Diesel, bio-Diesel, kerosene

Standard Delrin® grades have an outstanding performance in these fuels. Almost no effect on dimensional and mechanical properties can be noticed after exposure at 60°C up to 2000 hours.

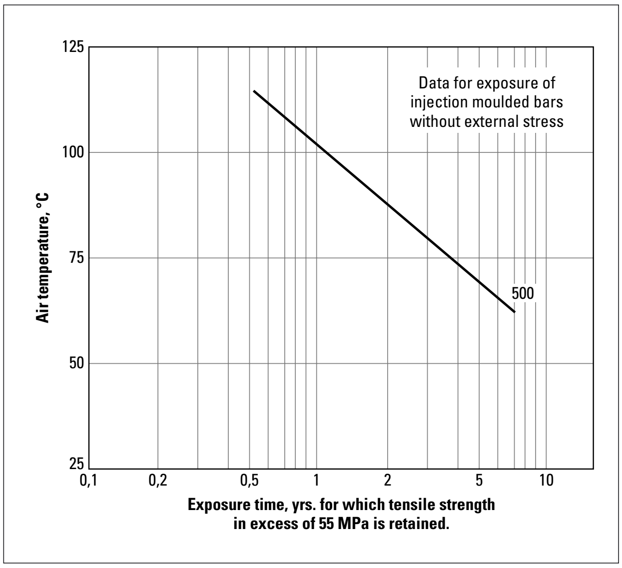

Figure 7.02 **Long-term unstressed exposure in air**

Permeability

Due to its high crystallinity, DELRIN® is permeated only slowly by many substances including aliphatic, aromatic and halogenated hydrocarbons, alcohols and esters. Its permeability to small polar molecules such as water, methanol and acetone is higher, and these products induce changes of dimensions and/or mechanical properties (see the sections on effect of moisture, in Chapter 5, and on resistance to fuels, above).

Permeability characteristics and strength properties of DELRIN® make it a suitable material for containers, particularly of the aerosol type, and for parts in fuel reservoirs.

Exposure in air at elevated temperature

Figure 7.02 shows the results of tensile tests on injection-moulded tensile bars of DELRIN® exposed in air at various temperatures. The abscissa is the exposure time for which a tensile strength in excess of 55 MPa is retained, and the ordinate is the exposure temperature. On this basis, DELRIN® 500 would keep a tensile strength in excess of 55 MPa for approximately 5 years at 60°C.

Test bars moulded of DELRIN® 500 have been stored for about 20 years in absence of light at room temperature. After that time tensile strength, elongation at break, molecular weight and notched Izod impact strength were unchanged, and the bars still retained their lustre.

The high crystallinity of DELRIN® provides good structural rigidity close to its melting point, as evidenced by the heat distortion temperature of 172°C at 0,5 MPa. This implies suitability in conditions where brief exposure to high peak temperatures is encountered, as in annealing (see Chapter 5) and in paint ovens.

Weathering

Acetal resins, like most polymers, are affected by light; particularly sunlight, which includes damaging ultra-violet radiation of wavelength 290-400 nm. At the shortest wavelengths in the ultra-violet region, the photon *energy* is of the same order of magnitude as the energies of the bonds in common polymers. The *intensity* of this short-wavelength radiation is strongly dependent on season and location.

Weathering is a complex mode of exposure – although the degradation initiated by UV is a significant component of the weathering process, the combined effects of humidity, oxygen, and temperature (including temperature rise due to absorbed infra-red) have to be considered as well.

For outdoor applications involving intermittent exposure, or a service of 1 to 2 years, coloured DELRIN® resins are generally suitable, based on mechanical property retention, as the colourant generally offers some UV-screening protection.

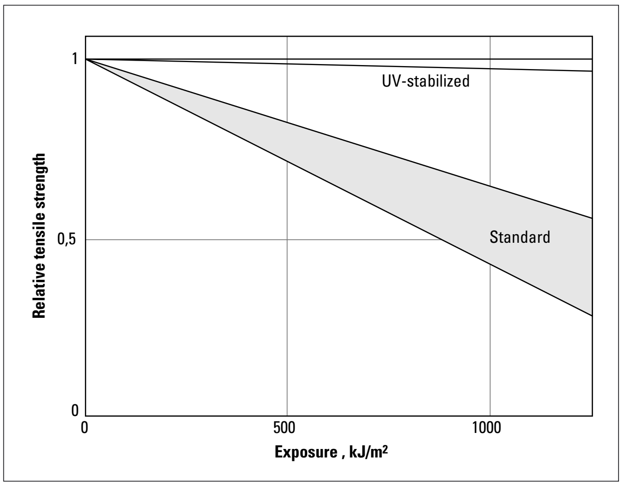

Figure 7.03 **Accelerated Interior Weathering according to SAE J-1885**

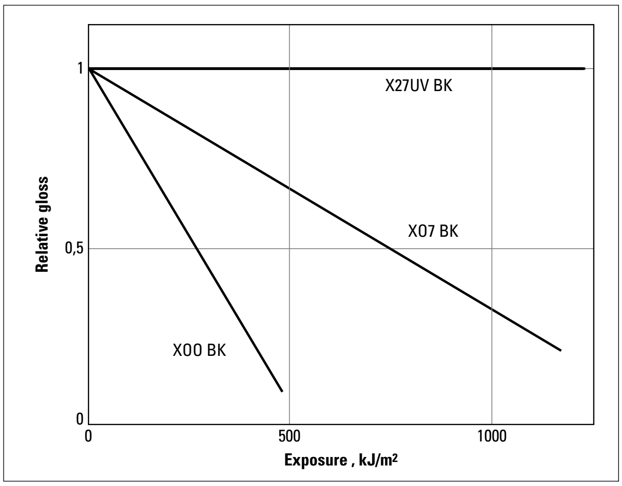

Figure 7.04 **Accelerated Interior Weathering according to SAE J-1885**

Improved weathering performance (retention of surface appearance as well as mechanical properties) is achieved in the DELRIN® x07 Series by the use of a selected UV stabilizer package, as Figure 7.03 illustrates.

The DELRIN® x27 UV Series

This DELRIN® x27 UV family of resins combines outstanding UV stability with the excellent processability of DELRIN® P, and the superior mechanical properties of acetal resin.

Specially-formulated colours, together with an optimized UV stabilizer system, provide even better performance than the DELRIN® x07 Series.

DELRIN® x27 UV is intended for applications where parts are exposed to sunlight through glass, which includes automotive interior components and window hardware.

Figure 7.04 illustrates schematically how outstanding improvements in weatherability have been achieved through the selection and optimization of UV stabilizer systems for DELRIN®.

Exterior weathering

The DELRIN® x27 UV family of resins are also well suited for sporting goods and other items used outdoors, but stored indoors.

High levels of carbon black act as an effective UV-screen, and are recommended for non-critical outdoor applications.

Exposure to high energy radiation

Particulate radiation, such as the protons and electrons of the Van Allen radiation belts, is damaging to acetal resins and will cause loss of engineering properties. For example, DELRIN should not be used in a radiation environment where the total electron dose is likely to exceed 1 Mrad. When irradiated with 2 MeV electrons, a 1 Mrad dose causes only slight discoloration while 2,3 Mrads causes considerable embrittlement.

The effect of gamma rays on DELRIN® is essentially the same as that observed with high energy electrons. Exposure to the gamma radiation of a ground test reactor caused rapid decrease in tensile strength with increasing dose. The predominant mode of degradation resulting from excessive gamma ray dosage appears to be depolymerization.

Bacteria, fungi and underground applications

In many applications, the materials of construction used must not support growth of bacteria and fungi and in addition, should be easy to clean. Where these requirements are demanded, DELRIN® acetal resin is comparable to other materials of construction currently employed.

Basic tests of bacteria and fungus resistance of DELRIN® were made to determine:

a. mildew resistance properties;
b. bacterial resistance properties;
c. if absorption or adsorption of nutrients from pasteurized milk, which could lead to an increase in bacterial population following standard washing and disinfecting procedures of the food industries, would occur.

It was concluded that DELRIN® is comparable to other materials in the rate of bacterial growth in foods in contact with it, and that DELRIN® causes no significant decrease or increase in bacterial population. In this respect it is similar to stainless steel or rubber.

Samples of DELRIN® buried underground for a long period of time showed no signs of deterioration of physical properties as a result of possible effects from fungi, bacteria, or insects exposure.

8. Thermal properties

Melting and freezing behaviour

The temperatures and heat flows associated with melting and freezing of Delrin® are illustrated in Figure 8.01, as measured by Differential Scanning Calorimetry (DSC).

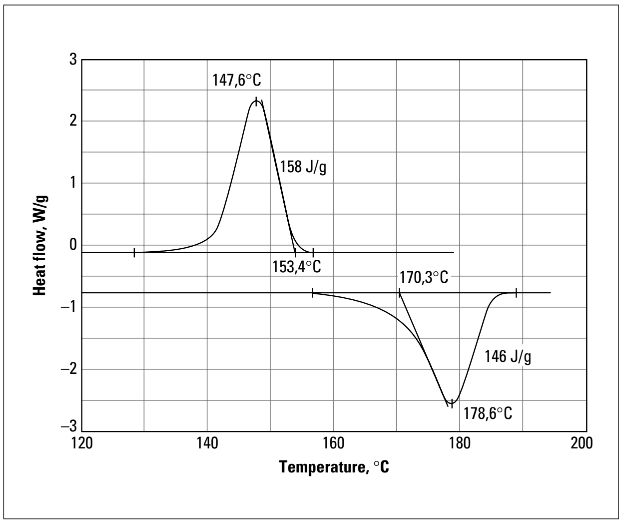

Figure 8.01 **Typical DSC of Delrin® 100 NC010. The heating and cooling rates are 10° C/min, and the sample mass is 5,4 mg**

Between –50 and 200° C, the only peaks visible by DSC are the melting and freezing; no other transition appears. This contributes to Delrin® being suitable for short-term exposure to temperatures close to the melting temperature.

The enthalpy of fusion is higher for Delrin® than for all other engineering polymers, which is a consequence of the high crystallinity of this material.

In such DSC measurements, the details of the shape of the endotherm (exotherm) depend on the heating (cooling) rate, the sample mass, the previous thermal history of the sample and the grade of Delrin® (standard versus toughened); the temperatures at onset and at peak typically vary by ± 2° C, while the energies of fusion/solidification can vary by up to ± 15%.

Glass transition temperature

The glass transition is defined by the onset of molecular movement of the non-crystalline units in the solid material. The temperature (T_g) at which this transition takes place can be measured by different means, i.e. DMA, torsion pendulum, DSC, ans is characterised by a 2-3 orders of magnitude drop in elastic modulus.

Observation of Fig. 6.08 (p. 19) leads to the value $T_g = -60$° C* for Delrin®. Together with $T_m = 175$° C and the high degree of crystallinity, this results in a wide useful temperature range, which is a characteristic feature of Delrin®.

Thermal expansion

Thermal expansion is an important design consideration when the end-use temperature will vary significantly, and especially when plastic and metal parts are used in the same assembly. The coefficient of thermal expansion for most Delrin® grades ranges from $(10 \text{ to } 14) \cdot 10^{-5}\ K^{-1}$ over the temperature range –40 to 100° C. Delrin® 570, containing glass fibres, is substantially lower. Actual data for each resin can be found in Table 3.01.

Thermal conductivity

Thermal conductivity is a measure of the rate of heat transfer through a material. The values for Delrin® resins in the solid state range from 0,30 to 0,37 W/m·K. This places Delrin®, like the other plastics, in the class of good insulators – poor conductors (when compared to metals), and results in heat retention and damping of rapid temperature changes.

The thermal conductivity in the molten state is 0,14 W/m·K.

Specific heat

The specific heat is the ratio of the amount of heat required to warm 1 g of substance through 1°C to the amount of heat similarly required for water. Specific heat is dimensionless. Many laboratories are using the Differential Scanning Calorimeter for this measurement.

The specific heat has been determined for some Delrin® acetal resins as an average over the range from –18 to 100° C. The value is constant at 0,35.

Deflection under load

The Temperature of Deflection under Flexural Load (TDFL) is the temperature at which a standard sample has reached a specified deflection as the temperature is increased; details depend on the standard considered, the specimen shape and its mode of loading.

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* Some authors attribute the onset of molecular movement at –60° C in Delrin® to a “crankshaft” rotation in the crystalline domains (involving 2-3 repeat units), and they reserve the term “glass transistion” to the onset of collective movements of 20-80 repeat units in amorphous zones, which is claimed to occur at –13° C. In typical injection-moulded parts of Delrin® the crystallinity is so high that there are few such long segments in amorphous zones, and the transition at –13° C is hardly observed. However the transition at –60° C always appears, and the behaviour of parts at –30° C corresponds well to molecular mobility. So for practical purposes it can be said that Delrin® has a T_g at –60° C.

Also named Heat Deflection Temperature (HDT), this quantity is sometimes used in specifications, although it should neither be used to judge the maximum use temperature nor for design purposes; such information should be derived from strength, stiffness, creep and ageing data.

Temperatures of Deflection under Flexural Load obtained according to the standard ISO-75 can be found in Table 3.01.

Ball pressure test

The ball pressure test (IEC 309) is a measure of the indentation resistance of the material as function of temperature.

At the selected test temperature, a ball of 5 mm diameter is pressed at 20 N for 1 hour against the sample. After the ball is removed, the sample is cooled within 10 s. The material passes the test at this temperature if the diameter of the impression caused by the ball does not exceed 2 mm.

DELRIN® passes this test at 165°C.

9. Electrical properties and flammability

Electrical characteristics

Delrin® acetal resins have characteristics that make them attractive for electrical applications.

As a result of the low moisture absorption of Delrin®, its electrical properties are essentially not sensitive to humidity.

Due to the degradation mechanism of Delrin®, sparks or continuous arcs do not form a conductive path (carbon track), hence the insulating properties of natural colour resins are conserved. High levels of carbon black, as used in some black grades, may induce carbon tracking.

Dielectric strength

The dielectric strength is the minimum voltage which, when applied to a material, results in the destruction of its insulating properties. The practical unit is kV per mm of insulation thickness. The dielectric strength changes with the material thickness, as illustrated in Figure 9.01: the thinner the sample, the higher the value.

Values measured according to IEC 243 can be found in Table 3.01.

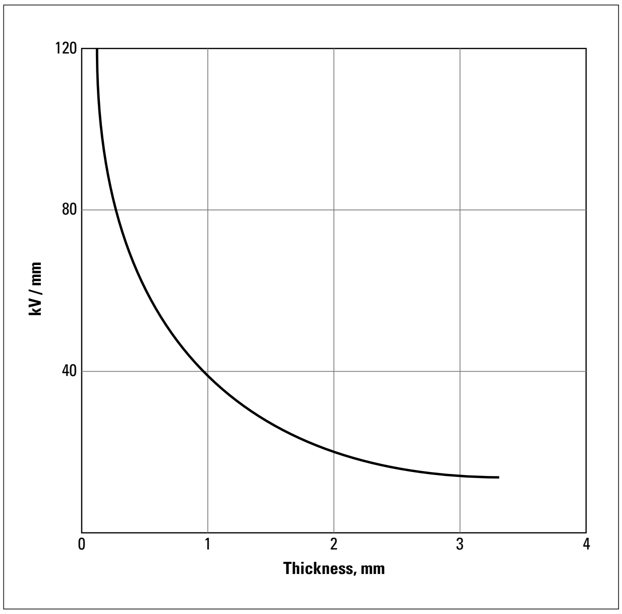

Figure 9.01 **Dielectric strength (ASTM D149) Delrin® 500 NC010 at 23°C**

Relative permittivity

The relative permittivity, or dielectric constant, is the ratio of the permittivity of the material to the permittivity of vacuum. In more practical terms, when air is replaced by another insulating material in a capacitor, then the capacitance is multiplied by the relative permittivity of the material.

The value of relative permittivity changes with temperature, frequency and humidity, as illustrated in Figures 9.02 to 9.04.

Values measured according to IEC 250 can be found in Table 3.01.

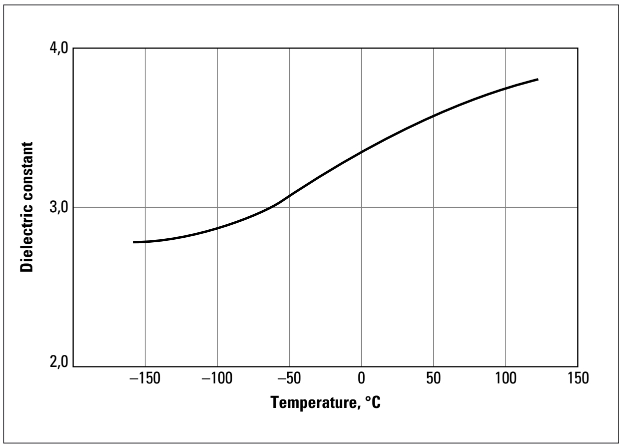

Figure 9.02 **Dielectric constant (ASTM D150) vs. temperature for Delrin® 100, 500 NC010 at 50% RH and 10^3 to 10^6 Hz**

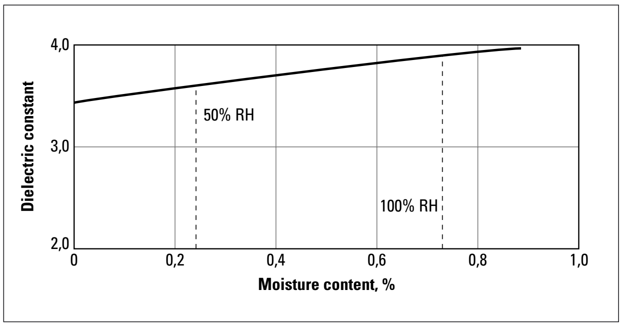

Figure 9.03 **Dielectric constant (ASTM D150) vs. moisture content for Delrin® 500 NC010 at 23°C, 10^3 to 10^6 Hz**

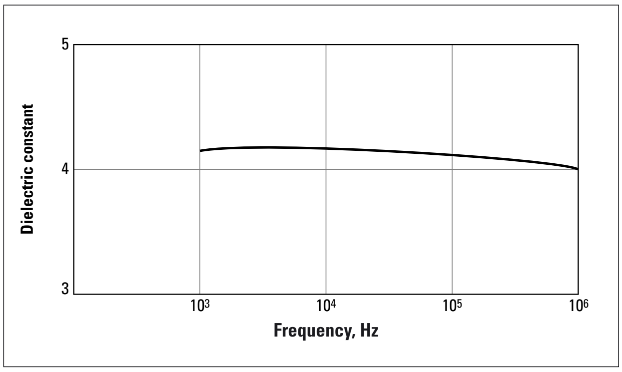

Figure 9.04 **Dielectric constant (ASTM D150) vs. frequency for Delrin® 500 at 50% RH or after immersion in water at 23°C**

Dissipation factor

The dissipation factor is the fraction of electrical energy absorbed by an insulating material and dissipated as heat. As for dielectric strength and relative permittivity, values may change with frequency, temperature and humidity, as illustrated in Figures 9.05 to 9.07.

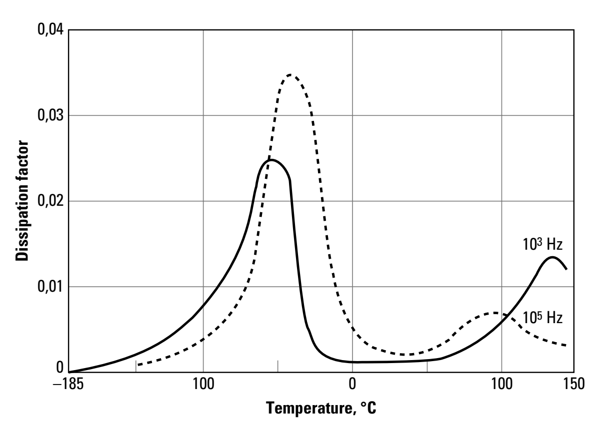

Figure 9.05 **Dissipation factor (ASTM D150), Delrin® 500 NC010 vs. temperature at 10^3 and 10^6 Hz**

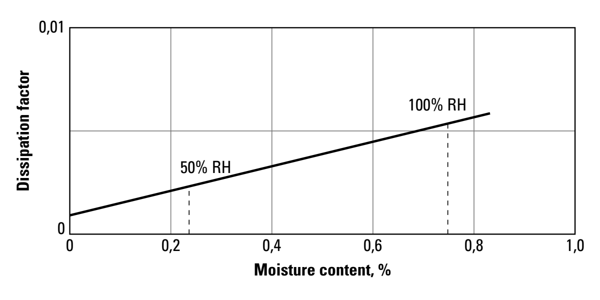

Figure 9.06 **Dissipation factor (ASTM D150) vs. moisture content. Delrin® 500 NC010 at 23° C**

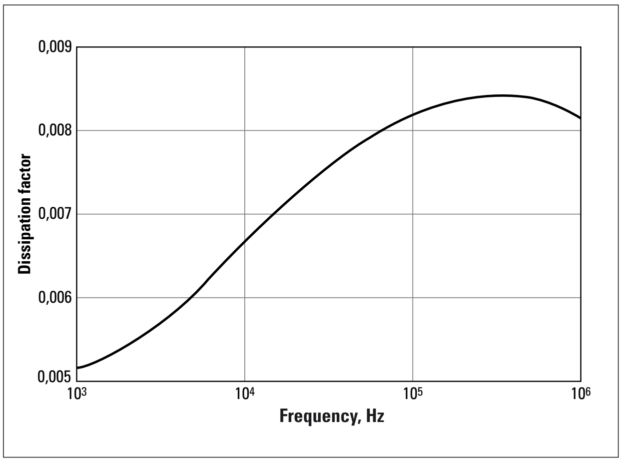

Figure 9.07 **Dissipation factor (ASTM D150) vs. frequency for Delrin® 500 at 50% RH or after immersion in water at 23° C**

Volume and surface resistivities

Volume resistivity is the internal resistance of material to current flow; it is expressed in Ω·cm. Materials with volume resistivities above 100 MΩ·cm are considered insulators, while below 1000 Ω·cm they are conductors.

Surface resistivity is the resistance to leakage of a charge across a square area of surface; it is expressed in Ω.

Values measured according to IEC-93 can be found in Table 3.01.

Arc resistance

This method is intended to differentiate in a preliminary fashion among similar materials with respect to the resistance to form a conducting path under the action of a high-voltage / low-current arc close to the surface of insulation. It is expressed in seconds to failure. Data according to ASTM D 495 is reported in Table 3.01.

Flammability classification

The flammability classification of Delrin® acetal resins under UL standard 94 is HB (horizontal burning) for all compositions.

Ignition temperature

Flash ignition temperature is the lowest temperature at which the material supplies enough vapour to be ingnited by an external flame. For Delrin®, flash ignition is at 320° C, and self-ignition is at 375° C.

Rate of burning

Delrin® burns slowly at rates around 50 mm/min for a 1 mm thick horizontal sample (measured according to FMVSS 302).

Glow wire test

The glow wire test (IEC 695-1) simulates the thermal conditions that may be produced by incandescent sources of heat and ignition, in order to evaluate the fire hazard. Values vary with the thickness of the specimen, and are expressed in °C. Delrin® passes the test at 550° C, at a thickness of 1 mm.

10. Tribological properties

Tribology is that field of science and technology concerned with "interacting surfaces in relative motion". The tribological properties are among the outstanding features of DELRIN® acetal resin.

Hardness

DELRIN® is unusually hard for a material with such good toughness. This combination has a distinct advantage in many applications, and contributes to the excellent wear and friction properties of DELRIN®.

Wear and abrasion

Wear is the progressive loss of material due to interacting surfaces in relative motion. Numerous distinct and independent mechanisms are involved in the wear of a polymer.

These include:

- abrasive wear ("abrasion") – caused by hard irregularities on the countersurface;
- fatigue wear – failure of the polymer due to repeated stressing from hard irregularities on the countersurface;
- adhesive wear – the basis of a process normally involving transfer of polymer to the countersurface.

In reality, polymer wear is a complex, combined function of these mechanisms. For practical purposes, we are often interested only in the *rate* at which wear occurs, independent of its mechanism.

A fundamental point of understanding of the wear of polymers is that:

> "wear resistance is not a material property, but the property of a tribological system".

This means that the wear rate in practice is typically influenced by the:

- contact pressure and contact force (load) at the surfaces;
- relative velocity of the surfaces;
- (ambient) temperature of operation;
- geometry of motion (sliding, fretting, rolling);
- nature of the motion (continuous, intermittent, reciprocating);
- nature and surface finish (roughness) of the countersurface;
- lubrication (initial, continuous, dry-running, moisture…).

Two important implications of this are that:

- selection of an engineering polymer for an application involving wear requires a detailed understanding of the tribological system;
- although standardized tests can give indications of the relative wear rates of polymers, prototype testing is an essential stage in application development.

Frictional properties

Friction is a measure of the resistance to motion of two interacting surfaces. As with wear, friction is a system property, not a material property, and is influenced by many of the factors previously highlighted.

The excellent frictional characteristics of DELRIN® make it suitable for many applications where lubricants are not permitted or desirable.

This elimination of lubrication reduces the total system cost. Continuous or initial lubrication of course extends the application range and life of many applications for DELRIN® resins.

Wear and friction – Grades

Several technologies are used, or under development, to further enhance the friction and wear properties of DELRIN®, including the incorporation of various forms of TEFLON® (as in 500AF and 520MP), silicone (as in 500SC), KEVLAR® (as in 100KM) or other lubricants (as in 500CL, 500AL and 900SP).

These different families of resins exhibit specific properties which make them particularly suitable for certain types of applications.

Tribological properties are a function of many parameters and variables. In view of this complexity, specific details are required to assess the preferred grade of DELRIN® for any particular application.

Wear and friction – Data

As a typical example of the behaviour of a family of DELRIN® resins designed for friction and wear applications, Fig. 10.01 shows the specific wear rate W_s and the dynamic coefficient of friction μ_k for resins containing different amounts of TEFLON® micro-powder, in contact with themselves. From 0 to 20% TEFLON®, the wear rate decreases by three orders of magnitude and the coefficient of friction is divided by two.

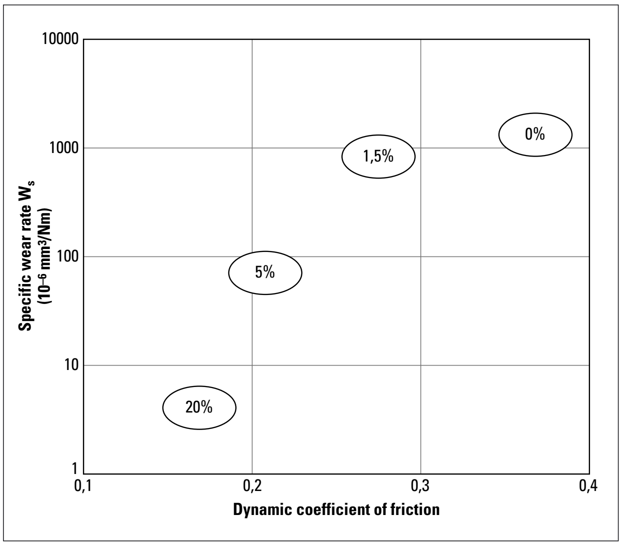

Figure 10.01 **The effect of TEFLON® PTFE micropowder addition level on the wear and friction of DELRIN®**

The single-point data in Table 10.1 show the typical values of wear and friction for various standard and modified grades of DELRIN® in contact with themselves and hard steel countersurfaces, measured in reciprocating motion at low speed under moderate load. They are grouped by Melt Flow Index and listed in order of decreasing wear rate. The relative ranking of these resins can change markedly with the applied conditions. Note that the wear rate of almost all grades of DELRIN® against many types of steel is very low.

Further information on this subject can be provided upon request.

Table 10.1 – Characteristics, specific wear rate and dynamic coefficient of friction of various grades of DELRIN® designed for friction and wear applications

Grade of DELRIN®	Characteristics	Specific wear rate $[10^{-6}$ mm^3/N·m]		Dynamic coefficient of friction	
		against itself1)	against 100 Cr_6 steel2)	against itself1)	against 100 Cr_6 steel2)
100P		**1150**	**12**	**0,38**	**0,27**
500SC @ 5% in DELRIN® 100	silicone masterbatch let down in DELRIN® 100	160		0,13	
100AL	"Advanced Lubricant"-system	60	6	0,22	0,19
500SC @ 10% in DELRIN® 100	silicone masterbatch let down in DELRIN® 100	11		0,10	
100KM	modified with KEVLAR® aramid resin		2		0,41
500P		**1500**	**12**	**0,35**	**0,33**
500CL	"Chemically lubricated"	1200	4	0,36	0,27
500SC @ 5% in DELRIN® 500	silicone masterbatch let down in DELRIN® 500	214		0,15	
500AF	modified with TEFLON® PTFE fibers	40	2	0,22	0,20
500AL	"Advanced Lubricant"-system	22	6	0,16	0,18
500SC @ 10% in DELRIN® 500	silicone masterbatch let down in DELRIN® 500	11		0,13	
520MP	modified with TEFLON® PTFE micropowder	5	3	0,19	0,18
900P		**1400**	**12**	**0,33**	**0,33**
900SP	"Special Polymer" (proprietary lubricant system)	20		0,10	

1) Surface and countersurface are consisting of the same grade of DELRIN®. The specific wear rate was measured at low speed (0,084 m/s) with a pressure of 0,624 MPa in a reciprocating motion (total sliding distance: 1,52 km), and the coefficient of friction was measured at a similar speed (0,08 m/s) with a pressure of 0,196 MPa, also in reciprocating motion.

2) Surface roughness Ra [μm]: 0,10; hardness HRB: 93. The specific wear rate was measured at low speed (0,084 m/s) with a pressure of 0,624 MPa in a reciprocating motion (total sliding distance: 4,25 km); the coefficient of friction was measured at a high speed (0,5 m/s) with a load of 10 N in a sliding motion (Block-on-Ring).

11. Regulatory compliance

For use in many applications, a material has either to be approved by or must meet the requirements of various governmental or private agencies. This is mainly to protect the user, the general public or the environment.

Besides meeting such regulations, all products and / or their constituents have to be listed in various chemical inventories. Specific regulations exist for certain application areas like electrical applications or applications in contact with food.

DuPont makes sure that all materials supplied to its customer are in compliance with applicable regulations for the material itself.

As a subscriber to the RESPONSIBLE CARE* initiative, DuPont has also accepted to share information and help the product users to handle, process, use, recycle and dispose of its materials safely and in an environmentally sound manner.

For selected specific application areas, DuPont has developed information which will enable the product user to obtain approvals from authorities or to certify compliance with regulations.

These areas are:

Material classifications by Underwriters' Laboratories, Inc.

For most of DuPont DELRIN® resins UL 'yellow cards' are available showing flammability ratings and upper temperature limits for continuous use.

Compliance statements with European and non-European food contact regulations

Europe:

The EU (European Union) Directive 90/128 and its subsequent amendments plus country specific regulations where applicable.

USA:

FDA 21 CFR 177.2480 (Food and Drug Administration of the United States Department of Health, Education and Welfare).

Canada:

HPB (Health Protection Branch of Health and Welfare).

Other countries:

Compliance statements can be established on request.

Compliance statements with European and non-Euopean drinking water regulations

Germany:

The KTW (Kunststoff-Trinkwasser-Empfehlungen) recommendation.

Italy:

The circular on plastics materials for pipes and auxiliaries intended to be used in contact with potable water.

The Netherlands:

The Guideline: Quality of materials and chemicals for drinking water supply and KIWA (Keuringsinstituut voor Waterleidingartikelen) cerfication.

UK:

The WRC (Water Research Council).

USA:

The NSF (National Sanitary Foundation).

Other countries:

Please consult with your DuPont representative on availability of special grades or alternative materials.

Support information for approval of applications for food processing equipment in the USA

by NSF (National Sanitary Foundation) or USDA (United States Department of Agriculture).

Support information for approval of application under European and non-European pharmaceutical regulations

Statements on the content of certain regulated chemicals as required e.g. by the 'Deutsche Dioxinverbotsverordnung' or the 'Clean Air Act' in the USA.

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* Regulations are constantly adapted to new information available, new test methods and also issues of concern developing in the public arena.

DuPont will adapt its products to the changing market needs or develop new products to satisfy new requirements. The same is true for information needed to support customers for regulatory compliance of their applications.

It is impossible in the frame of this Design Manual to provide up-to-date information on all grades of DELRIN® meeting the various specifications. Our recommendation is therefore to consult with your DuPont representative on the best material selection for a given application in an early stage of a development.

12. Post-moulding operations

Machining

For some low volume productions, it may be more suitable to machine threads or other fine details than to invest in the additional complexity of including them in the moulding process.

Another application of machining is the production of prototype parts from commercially available stock-shapes of DELRIN® (rods, cylinders, plates).

DELRIN® can be machined using standard machine-shop equipment by sawing, drilling, milling, turning, threading and tapping. It is easier to perform these operations on DELRIN® than on most machinable brass or aluminium alloys.

The main differences compared to metal machining are the following:

- the stiffness is lower, so that thin walls must be supported to avoid deflection;
- the thermal conductivity and the melting point are much lower, so it is necessary to keep the heat generated to a minimum; overheating leads to inaccurate dimensions, and in extreme cases to melting of the material.

Additional details on various machining operations are given in the Design Handbook “General Design Principles for DuPont Engineering Polymers”, Module I.

Surface decoration

The surface of injection-moulded parts of DELRIN® can be decorated with various methods, including hot stamping, silk screen printing, pad printing, painting, metallising and laser marking.

Hot stamping

Excellent markings can be obtained on DELRIN® by hot stamping, although crystalline thermoplastics, such as DELRIN®, are not as easily hot-stamped as the amorphous thermoplastics.

Because of the hard surface, solvent resistance and sharp melting point of DELRIN®, process variables (pressure, die temperature, dwell time) must be optimised for each application. The best combination depends on factors like the tape characteristics and the geometry of the part. As a starting point for testing, the following parameters are suggested: a die temperature of 190°C, a dwell time from 0,2 to 2 s, and a contact pressure in the range 0,35 to 0,55 MPa.

Silk screen printing and offset pad printing

Silk screen printing and offset pad printing produce prints of high quality. They can be used on flat and curved surfaces in a two-step process: the application of the ink is followed by a cure (baking in an oven, infrared lamps, flame treatment). The effect of curing on part dimension should be evaluated when close tolerances are essential (in particular when baking in an oven).

Painting

Good paint adhesion is possible on pre-treated parts of DELRIN® with the following types of paints: nitrocellulose lacquer, acrylic lacquer, polyurethanes, epoxy enamel, phenolic enamel.

Since DELRIN® has good structural properties for short-term exposure at high temperature, painted articles can be baked up to 160°C to harden the paint. The effect on part dimension should be evaluated when close tolerances are essential.

Metallisation

Besides aesthetic considerations, metallic layers may be desirable for electrical conductivity, or for some improvement of stiffness, flame resistance and weatherability.

The surface must be chemically etched prior to metallisation. Vacuum evaporation and electroplating process were used to produce coatings of chrome, aluminium, copper and gold with good appearance and durability. For electroplating, the same process can be used as for ABS (except for the etching step).

Laser marking

Laser marking of certain types of plastic parts is protected by patents (for example EP 27532 and EP 53256), and it is the responsibility of the end-user to secure licence to operate from the patent owner.

Laser marking offers a combination of features not available with other decorating techniques:

- high rate contactless process;
- flexibility, easy change of layout and character type;
- no surface pre-treatment, no solvent, no ink;
- high durability of the marking.

This method is particularly suited when the batch sizes are small and marking variability is required (e.g. serial numbers or different languages). There are many ways to mark surfaces using lasers. Depending on the type of laser and the absoption behaviour of the plastic, contrast formation can result from thermal effects (carbonisation, foaming, etching by evapouration of material, bleaching of dyes) or from photochemical reactions (with light-sensitive pigments). Tests wered already conducted in the 1980’s with plaques of DELRIN® exposed to various types of lasers. Markings were achieved in many cases; particularly favourable combinations are dark colours with pulsed Nd:YAG or excimer lasers, which can result in very contrasted light markings with almost no engraving.

Surface pre-treatment

The chemical structure and solvent resistance of Delrin® lead to a relatively poor adhesion of solvent-based paints and cements. This is largely overcome by surface treatment prior to application of the coating.

DuPont developed a chemical etching process, named "satinisation", where a mildly acidic solution produces uniformly distributed anchor points on the surface. A more recent 3-step etching procedure, using chemicals that are better compatible with today's environmental requirements, has also been successfully tested.

Other surface treatment methods for acetal were reported in literature or patented. In addition to several variants of etching baths, they include mechanical roughening, treatment with ozone, laser etching and plasma treatment. It is not possible to give a single recommendation, and the final choice of a method should consider efficiency, investment and operating cost.

Assembly techniques

Parts made of Delrin® can be joined using a variety of assembly techniques.

Self-tapping screws, snap-fits, and press-fits allow disassembly. Welding, riveting and adhesives create a permanent joint.

Detailed guidelines about these assembly techniques, including design equations and examples, can be found in the Design Handbook "General Design Principles for DuPont Engineering Polymers", Module I.

Additional information specific to adhesive joining of Delrin® is given here.

Large complicated shapes or assemblies of dissimilar materials are sometimes easiest obtained by adhesive joining. This is particularly true at the prototyping stage, or for small production series.

The design of bonded joints is critical for the performance of the final assembly. Adhesives are strongest in compression and shear modes, but they perform comparatively weakly in tension, cleavage and peel modes.

Adhesion depends on the surface preparation of the parts. Cleaning and degreasing is an absolute minimum. Surface roughening, mechanically with sand-paper or chemically with an etching bath, strongly improves the results.

Several types of adhesives are to be considered, including two-component epoxy, two-component polyurethane or cyano-acrylate.

An additional method is possible for joining Delrin® parts together: solvent cementing with hexafluoroisopropanol. No surface roughening is needed and the bonded joint is stronger than with standard adhesives, but this solvent is expensive and presents some toxicity (check the MSDS before use).

Table 12.1 – 3-step etching procedure

	Step 1	Alternative Step 1 A	Step 2	Step 3
Solution	71 % o-H_3PO_4 (orthophosphoric acid). Mix 5 vol. parts of commercial concentrated (85 %) o-H_3PO_4 with 1 vol. part of DI water (deionized water).	Preparation: Mix 5 vol. parts of (85 %) o-H_3PO_4 with 1 vol. part glycerin DAB7[1] and 0,5-1,0 g/liter sodium alkylarylsulfonate[2] (phenylsulfonate).	12 % NaOH (sodium-hydroxide). Preparation: Dissolve 120 g NaOH in 1 liter of DI water.	1 % acetic acid. Preparation: Add 20 ml of glacial acetic acid to 1 liter of DI water.
Bath temperature	70°C	85°C	100°C	80°C
Dipping time	5 minutes	5 minutes	6 minutes	10 minutes
Rinse	Thoroughly 1 min./23°C with water.	As for Step 1.	As for Step 1.	As for Step 1, followed by a supplementary rinse in DI water.
Heating elements	Quartz or heating elements coated with Teflon®.	As for Step 1.	Stainless steel, titanium, heating elements coated with Teflon® or quartz.	As for Step 2.
Material for dipping tanks recommended	PVC, polypropylene (PP), high density polyethylene (HDPE) or glass.	PVC, PP, HDPE or glass.	Stainless steel, mild steel or glass.	PVC, PP, HDPE or glass.
Remarks	If the surface of the parts is significantly contaminated (mould release agent, finger prints, traces of oils, etc.) the parts should be degreased prior to the dipping.	The solution of Step 1 A has some degreasing character but may give less good adhesion.		

[1] Heat stabilized type used for explosive manufacture.

[2] Common detergent.

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