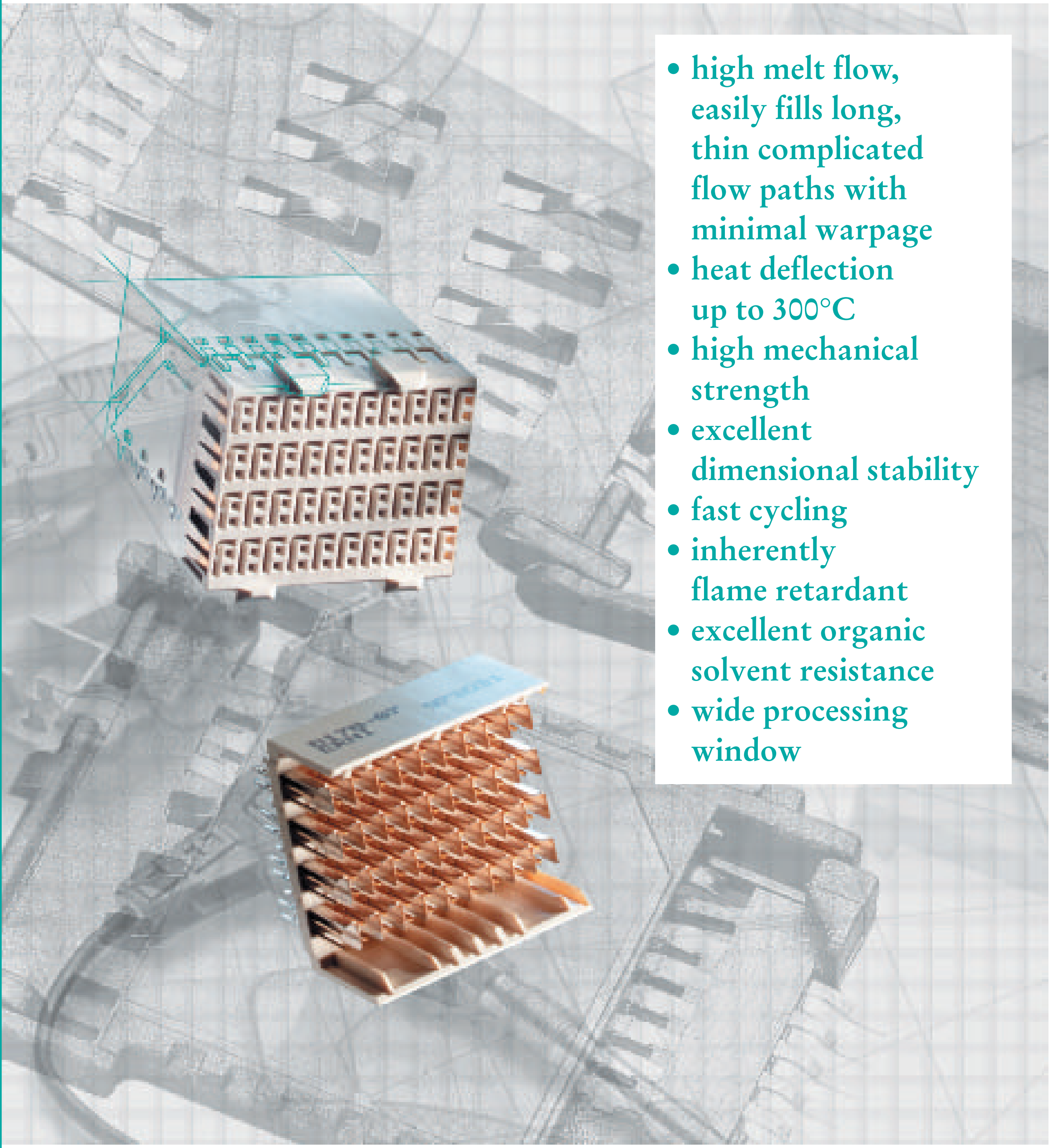
Vectra®

liquid crystal polymer (LCP)



- high melt flow, easily fills long, thin complicated flow paths with minimal warpage
- heat deflection up to 300°C
- high mechanical strength
- excellent dimensional stability
- fast cycling
- inherently flame retardant
- excellent organic solvent resistance
- wide processing window

Ticona

Table of Contents

List of Tables

List of Figures

Introduction and Overview 1
Vectra LCP Product Line 2
Physical Properties 3
Environmental Effects 4
Processing 5
Injection Molding 6
Extrusion 7
Rheology 8
Design 9
Secondary Operations 10
Conversion Tables 11
Index 12

1. Introduction and Overview

Vectra® LCPs form a family of high performance resins based on patented Ticona technology. They are distinguished from other semi-crystalline resins by their long, rigid, rod-like molecules that are ordered even in the melt phase (Fig. 1.1).

The unique melting behavior of LCPs has such a profound effect on properties and processing that we treat LCPs as a separate category of polymers (Table 1.1). Even so, they can be processed with all of the techniques common to more conventional thermoplastics including injection molding, extrusion, coextrusion, blow molding, etc.

Vectra LCPs offer a balance of properties unmatched by most other resins. They are generally selected for a specific application or market sector based on a few key characteristics such as those shown in Table 1.2 below. For instance, in molding electrical connectors, high flow in thin walls, dimensional stability at high temperatures and inherent flame retardance are the

Fig. 1.1 · Representation of Structural Differences Between Liquid Crystal Polymers and Conventional Semi-Crystalline Polymers

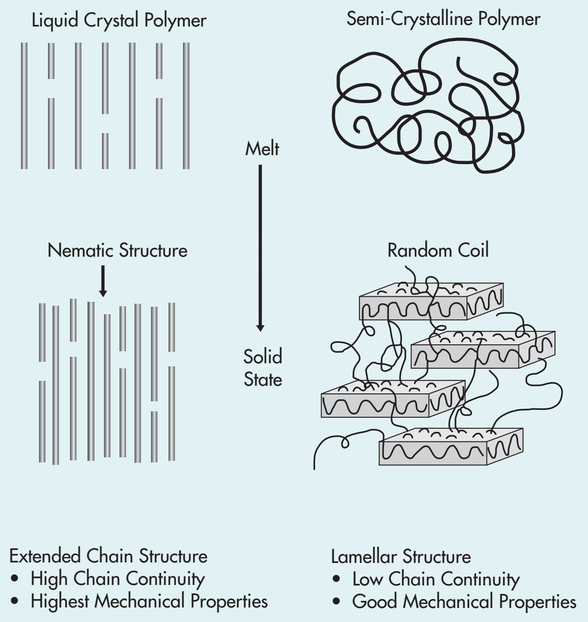


Table 1.1· Comparison of Amorphous, Semi-Crystalline, and Liquid Crystalline Polymers

Amorphous Polymers	Semi-Crystalline Polymers	Liquid Crystal Polymers
No sharp melting point/soften gradually	Relatively sharp melting point	Melt over a range of temperatures; low heat of fusion
Random chain orientation in both solid and melt phase	Ordered arrangement of chains of molecules and regular recurrence of crystalline structure only in solid phase	High chain continuity; extremely ordered molecular structure in both melt phase and solid phase
Do not flow as easily as semi-crystalline polymers in molding process	Flow easily above melting point	Flow extremely well under shear within melting range
Fiberglass and/or mineral reinforcement only slightly improves Deflection Temperature under Load (DTUL)	Reinforcement increases load bearing capabilities and DTUL considerably, particularly with highly crystalline polymers	Reinforcement reduces anisotropy and increases load bearing capability and DTUL
Can give a transparent part	Part is usually opaque due to the crystal structure of semi-crystalline resin	Part is always opaque due to the crystal structure of liquid crystal resin
Examples: cyclic olefinic copolymer, acrylonitrile-butadiene-styrene (ABS), polystyrene (PS), polycarbonate (PC), polysulfone (PSU), and polyetherimide (PEI)	Examples: polyester (Impet® and Celanex® thermoplastic polyesters, Duranex™ PBT), polyphenylene sulfide (Fortron® PPS), polyamide (Celanese® nylon), polyacetal copolymer (Celcon® POM, Hostaform® POM, Duracon™ POM)	Examples: Vectra® LCP

key reasons for choosing an LCP. Key properties, such as high flow, stiffness and resistance to sterilizing radiation and sterilizing gases may make them candidates for surgical instruments. A number of Vectra LCP grades are USP Class VI compliant and meet ISO 10993 standards (see Section 3.5).

The family of Vectra LCP resins is very easy to process in injection molding machines, which means short cycle times, high flow in thin sections and exceptional repeatability of dimensions. Molded parts exhibit very low warpage and shrinkage along with high dimensional stability, even when heated up to 200-250°C.

Vectra LCPs can be processed into thin films and multi-layer articles by conventional means, although some process development may be required. Film, sheet and laminates produced from Vectra LCPs exhibit excellent dimensional stability and exceptional barrier properties. In addition a special line of Vectran® LCPs have been developed for superior properties at much thinner barrier layers to achieve the same or better barrier performance than layers made of ethyl vinyl alcohol (EVOH) or polyvinylidene chloride (PVDC). A wide range of market segments, i.e., food, beverage, packaging, medical, industrial, and electronics utilize LCPs. Many of the applications benefit from not only the barrier properties of LCPs but also from low coefficient of linear thermal expansion (CLTE), chemical resistance, high stiffness, and strength.

New Vectra LCP compositions combine the consistency, stability, dimensional precision, and barrier properties of traditional wholly aromatic LCPs with processability at lower temperatures ranging from 220°C to 280°C. The combination of properties of these new compositions makes them good candidates for use in moldings or laminates, and in blends with polyolefins, polycarbonate, and polyesters.

The high strength-to-weight ratio of Vectra LCPs make the resins exceptional candidates for metal replacement applications. The maker of a needleless medical syringe estimated that injection molded LCP components were 75% lighter and 50% less costly than machined metal parts. Compared with less costly resins, easy-flowing Vectra LCPs cut molding cycles and many secondary operations to reduce the cost per part. In addition, many Vectra LCP compositions are listed by UL to allow the use of 50% regrind without loss of properties, enabling processors to improve cost competitiveness even further. Although and per pound or kilogram basis, they can appear expensive, on a price performance continuum, Vectra LCPs can be cost effective (Figure 1.2). For many applications exposed to high service stresses, Vectra LCPs are the preferred alternative to light metal alloys, thermosets and many other thermoplastics.

Table 1.2 · Key Performance Characteristics by Market

E/E Interconnects
Good flow in thin walls
Dimensional precision
Heat resistance
Flame retardance

Healthcare
Good flow in thin walls
Chemical resistance
Withstands sterilization
Stiffness, strength

Fiber Optics
Dimensional Precision
Excellent barrier properties

Telecommunications
Good flow in thin walls
Dimensional precision
Stiffness, strength

Automotive
Good flow in thin walls
Solvent resistance
Temperature resistance
Dimensional stability

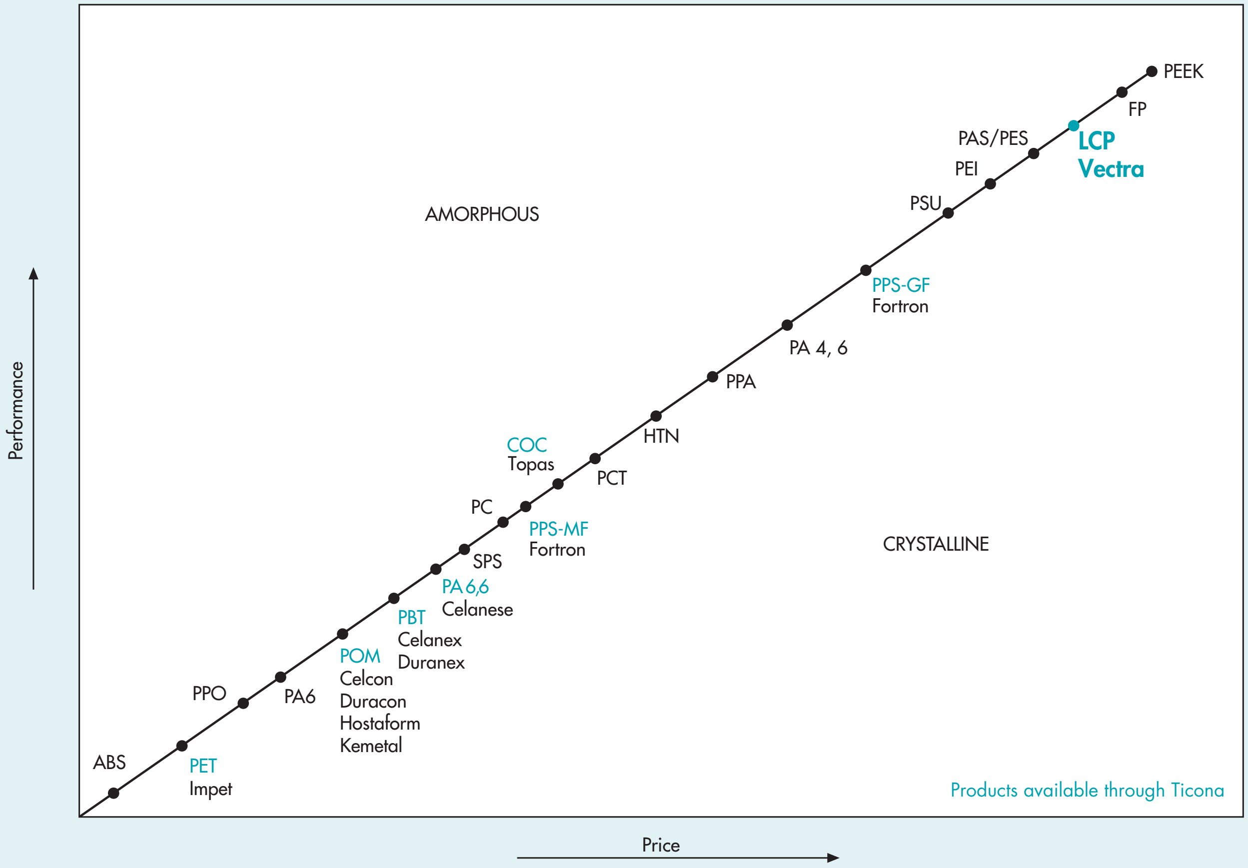
Business machines
Good flow in thin walls
Dimensional precision
Chemical resistance

Packaging
Excellent barrier properties
Stiffness, strength

Cryogenics
Excellent barrier properties
Good low temperature properties
Stiffness, strength

Audio/Video
Good flow in thin walls
Stiffness, strength
Dimensional precision
Temperature resistance

Fig. 1.2 · Price Performance Comparison of Engineering and High Performance Plastics



*** High Performance Plastics Acronyms**

ABS = acrylonitrile-butadiene-styrene
COC = cyclic olefin copolymer
FP = fluoropolymers
PA6 = polyamide 6 (nylon)
PA4,6 = polyamide 4,6 (nylon)
PBT = polybutylene terephthalate
PEEK = polyether ether ketone
PES = polyether sulfone
POM = polyoxymethylene (polyacetal)
PPS-MF = polyphenylene sulfide (mineral filled)
PPA = polyphthalamide
SPS = syndiotactic polystyrene

HTN = high temperature polyamide (nylon)
LCP = liquid crystal polymer
PA6,6 = polyamide 6,6 (nylon)
PAS = polyaryl sulfone
PCT = polycyclohexylenedimethylene terephthalate
PEI = polyether imide
PET = polyethylene terephthalate
PPO = modified polyphenylene oxide
PPS-GF = polyphenylene sulfide (glass filled)
PSU = polysulfone
PC = polycarbonate

2. Vectra® LCP Product Line

The Vectra LCP product line is built around a number of base polymers of varying compositions. The base polymers differ in their high temperature performance, rigidity, toughness and flow characteristics. Ticona is continuously developing new polymers to tailor the composition to a specific need.

Each of these compositions can be used without modification for extrusion or injection molding applications. Care should be taken when using unfilled polymers for injection molding since fibrillation of the oriented surface can occur. In addition, the base polymers can be compounded with various fillers and reinforcements to provide the necessary balance of thermal, mechanical, tribological or environmental properties for the specific application or market need.

Figure 2.1 explains the product nomenclature and surveys the Vectra LCP grades currently available.

2.1 Grade Descriptions

2.1.1 Glass fiber reinforced grades (100-series)

Reinforcement with glass fibers increases rigidity, mechanical strength and heat resistance. At the same time, the degree of anisotropy is reduced. Vectra LCPs are available with 15%, 30%, 40% or 50% glass fiber.
Examples: Vectra E130i (30% glass fiber), Vectra A130 (30% glass fiber), Vectra B130 (30% glass fiber), Vectra C150 (50% glass fiber), Vectra L140 (40% glass fiber), etc.

2.1.2 Carbon fiber reinforced grades (200-series)

Reinforcement with carbon fibers gives higher rigidity than with glass fibers. At the same time, the carbon fiber reinforced compositions have a lower density than the glass fiber grades with the same filler content. Carbon fiber reinforced polymers are used where the highest possible stiffness is required.
Note also that carbon fiber reinforced grades are conductive.
Examples: Vectra A230 (30% carbon fiber), Vectra B230 (30% carbon fiber)

2.1.3 Filler/fiber combinations (400-series)

Products with various filler and fiber combinations comprise the 400-series. The PTFE and graphite modified grades are used for bearing and wear resistant applications. The titanium dioxide modified grade has high light reflectance.
Examples: Vectra A430 (PTFE), Vectra A435 (glass fiber, PTFE)

2.1.4 Mineral filled grades (500-series)

The mineral filled grades typically have high impact strength relative to the glass fiber reinforced grades. They have good flow and a good surface finish. Selected Vectra polymers are available with 15%, 30%, 40% or 50% mineral.
Examples: Vectra A515 (15% mineral), Vectra E530i (30% mineral), Vectra C550 (50% mineral)

2.1.5 Graphite filled grades (600-series)

Graphite flake provides some added lubricity and exceptionally good hydrolytic stability and chemical resistance.
Example: Vectra A625 (25% graphite)

2.1.6 Specialty grades (700 and 800-series)

The grades in the 700 series are modified with an electrically conductive carbon black and are good candidates for electrostatic dissipation.
Examples: Vectra A700 (glass fiber, conductive carbon black), Vectra A725 (graphite, PTFE, conductive carbon black)
The 800 series grades have applications in electroless plating, EMI/RFI shielding, printed circuit boards and MID-components with integrated circuits.
Examples: Vectra C810 (glass, mineral) and Vectra E820i (mineral)

Fig. 2.1 · Vectra® LCP Product Line

Base Resin Series	**A**	**B**	**C**	**D**	**Ei**	**H**	**L**	**T**
Unreinforced Polymer	A950	B950	C950					
Glass fiber reinforced	A115 A130 A150	B130	C115 C130 C150	D130M	E130i	H130 H140	L130 L140	T130
Carbon fiber reinforced	A230	B230						
PTFE modified	A430 A435							
Mixed filler/fiber	A410							
Mineral modified	A515 A530		C550		E530i			
Graphite	A625							
Conductive (ESD) grades	A700 A725							
Metallization (e.g. MID)			C810		E820i E820iPd			

Vectra LCP

A-Polymer	- Industry Standard
B-Polymer	- Highest stiffness
C-Polymer	- Standard polymer, good flow
D-Polymer	- Encapsulated grade
E(i)-Polymer	- Easiest flow, high temperature
H-Polymer	- Highest temperature capability
L-Polymer	- High flow, balanced properties
T-Polymer	- New maximum temperature capability

2.2 Colors

The natural color of Vectra LCPs is ivory or beige. Graphite, carbon black and carbon fiber filled grades are correspondingly black or anthracite in color. Vectra LCPs can be colored in order to identify or differentiate between components. However, Vectra LCPs do not lend themselves to "color matching".

Color master batches (or concentrates) with a high pigment loading are available in a wide array of colors (Table 2.1). These master batches are supplied as pellets and are used for melt coloring of natural Vectra LCP grades during processing.

Color master batches are available in both Vectra "A" and Vectra "Ei" polymer bases and all are cadmium free. Color master batch Vectra A9500 should be used to color Vectra A, B, C, or L grades. Color master batch Vectra E9500i should be used to color Vectra Ei or H grades.

The last two digits at the end of the master batch code denote the recommended mix ratio of natural pellets to color master batch, e.g.:
VJ3040K10 = 10:1
VA3031K20 = 20:1

Lower concentrations are possible if the color effect achieved is satisfactory. Higher concentrations of master batch are not recommended because of a potential decrease in mechanical properties or flow at higher loading.

2.3 Packaging

The standard package is a 20/25 kg bag although boxes and gaylords are available under some circumstances.

Table 2.1 · Available Color Master Batches

Vectra A9500	Vectra E9500i	Vectra A9500/E9500i		
Stock number	Stock number	Color number	Standard Letdown	Color
VC0006	VC0019	VD3003K20	20:1	Black
VC0010	VC0027	VA3031K20	20:1	White
VC0004	VC0030	VG3010K20	20:1	Blue
VC0016	VC0031	VJ3040K10	10:1	Emerald green
VC0009	VC0028	VL3021K10	10:1	Yellow
VC0008	VC0032	VS3033K10	10:1	Pink
VC0011	VC0026	VS3035K10	10:1	Red

3. Physical Properties

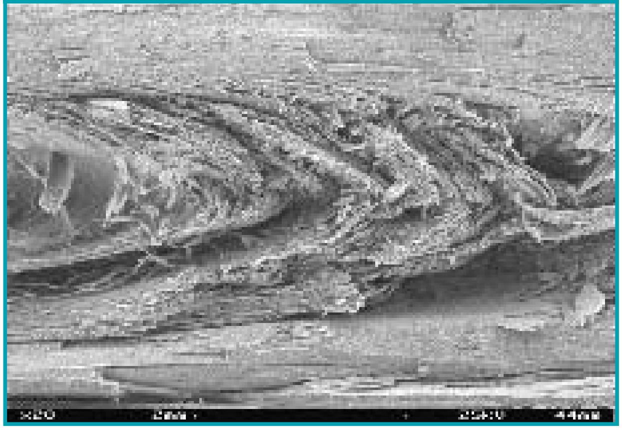
The properties of Vectra® LCPs are influenced to a high degree by its liquid crystal structure. The rod shaped molecules are oriented in the flow direction during injection molding or extrusion. Due to the highly ordered nature of LCPs, the mechanical properties, shrinkage and other part characteristics depend upon the flow pattern in the part. During mold filling, the "fountain flow" effect causes the molecules on the surface to be stretched in the flow direction. Ultimately, these molecules are located on the surface of the part, which results in a skin that is highly oriented in the flow direction (15-30% of the part's total thickness) (Figure 3.0). This molecular orientation causes a self-reinforcement effect giving exceptional flexural strength and modulus as well as good tensile performance. For example, a commonly used, 30% glass reinforced LCP, Vectra A130, has strength and stiffness about 50% higher than that of comparable 30% glass reinforced engineering resins.

Vectra LCPs belong to the Ticona family of high performance engineering resins. It is a rigid, tough material with excellent heat resistance. A summary of short-term properties for the majority of commercially available Vectra LCP grades can be found in the Short-Term Properties brochure. Please check with your local Vectra LCP representative for availability of additional grades.

All properties given in the Short-Term Properties brochure were measured on standard injection molded test specimens and can be used for grade comparison. Their applicability to finished parts is limited because the strength of a component depends to a large extent on its design.

The level of properties depends on the type of filler or reinforcement used. Glass fibers impart increased stiffness, tensile strength and heat deflection temperature. Carbon fibers give the highest stiffness. The addition of mineral fillers improves stiffness and provides increased toughness and a smoother surface compared to glass reinforced. Graphite improves elongation at break and provides added lubricity. PTFE modified grades have excellent sliding and wear properties. The impact strength of unfilled Vectra LCPs is reduced by the addition of fillers and reinforcements, but is still relatively high.

Fig. 3.0 · Fracture Surface of Unfilled Vectra LCP

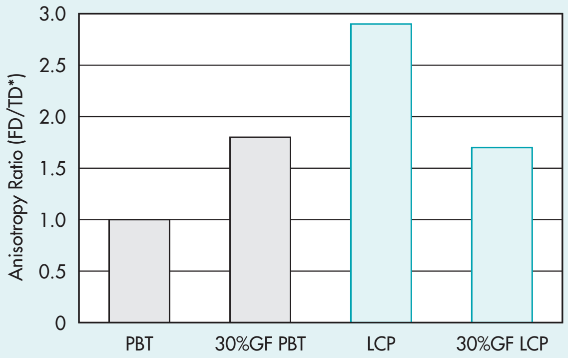


3.1 Mechanical properties

3.1.1 Effect of anisotropy and wall thickness

LCPs are well known to have anisotropic properties when molded into parts. A result of this is a tendency to fibrillate when abraded. Unlike other engineering or technical polymers, LCPs become much less anisotropic as they are formulated with glass fiber reinforcement, and to a lesser degree with mineral. An example comparing Vectra LCPs with a conventional engineering resin, PBT, both with and without glass reinforcement is shown in Figure 3.1.1. The anisotropy of 30% glass reinforced Vectra LCP and 30% glass reinforced PBT is nearly the same indicating that designing for glass reinforced Vectra and other engineering resins need not be impacted by anisotropy. Management of anisotropy can be affected by gate location and wall thickness adjustments.

Fig. 3.1.1 · Comparison of Anisotropy* of Vectra® LCP versus PBT (ISO universal test specimen)



* Tensile strength in flow direction/ tensile strength in transverse direction

Table 3.1.1 compares the anisotropy of flexural and tensile properties of various Vectra LCP grades molded in a 80 mm x 80 mm x 2 mm flat plate mold. Table 3.1.2 shows the effect of molding in a thinner part (80 mm x 80 mm x 1 mm) on the anisotropy ratio.

As the wall, film or sheet thickness decreases, the highly oriented outer layer becomes a higher percentage of the total (Figure 3.1.2) thickness. This higher percentage of highly oriented surface layer, in general, results in greater strength and modulus in thinner sections (Figures 3.1.3, 3.1.4, 3.1.5, 3.1.6). The excellent flow characteristics of Vectra LCPs enable the filling of extremely thin walls to take advantage of this stiffness and strength.

Table 3.1.1 · Anisotropy of Properties – 2 mm thick

		Unfilled	30% glass filled	30% mineral filled
Flex strength	Ratio FD/TD*	2.7	2.1	2.4
Flex modulus	Ratio FD/TD*	3.6	2.9	3.9
Tensile strength	Ratio FD/TD*	2.3	1.9	2.5
Tensile modulus	Ratio FD/TD*	3.3	2.2	2.7

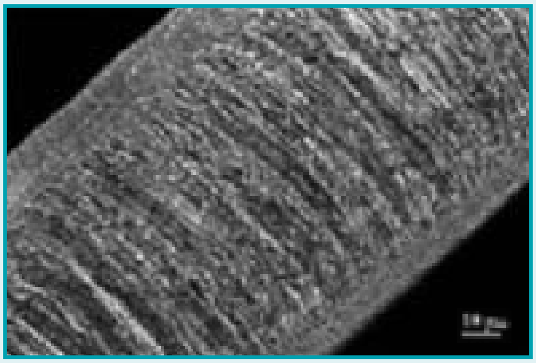
**FD/TD = anisotropy ratio – flow direction/transverse direction*

Table 3.1.2 · Anisotropy of Properties – 1 mm thick

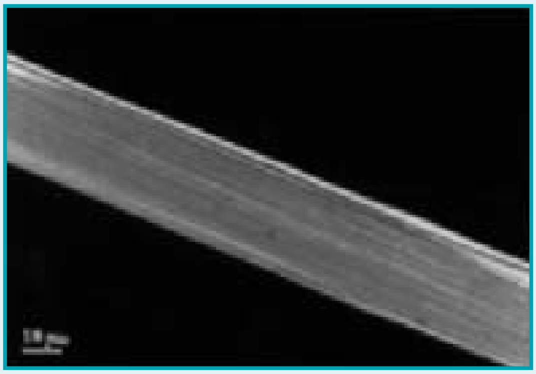
		Unfilled	30% glass filled	30% mineral filled
Flex strength	Ratio FD/TD*	3.9	3.1	2.9
Flex modulus	Ratio FD/TD*	6.7	4.4	4.8
Tensile strength	Ratio FD/TD*	3.6	2.6	3.1
Tensile modulus	Ratio FD/TD*	3.0	2.5	2.8

**FD/TD = anisotropy ratio – flow direction/transverse direction*

Fig. 3.1.2 · Micrograph of Fiber Structure showing Orientation of Outer Layers.



Strand LCP extrudate shows the higher orientation in the outer "skin" layer but not in the core;



Extruded LCP fiber is highly oriented with all "skin" observed.

Fig. 3.1.3 • Tensile Modulus versus Wall Thickness Vectra LCP

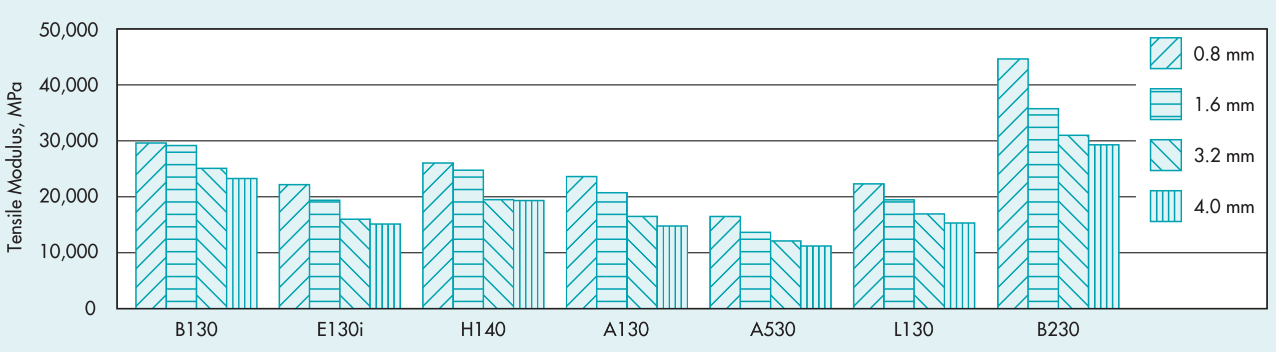


Fig. 3.1.4 • Tensile Strength versus Wall Thickness Vectra LCP

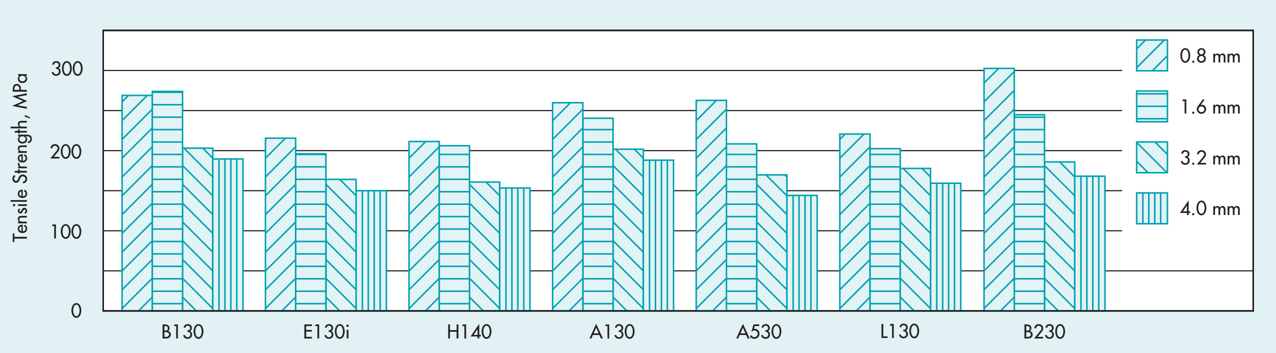


Fig. 3.1.5 • Flexural Modulus versus Wall Thickness Vectra LCP

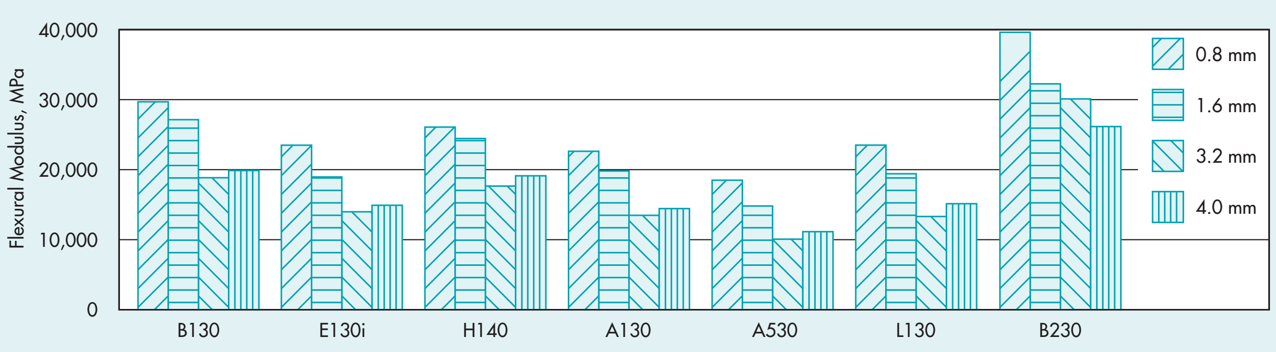
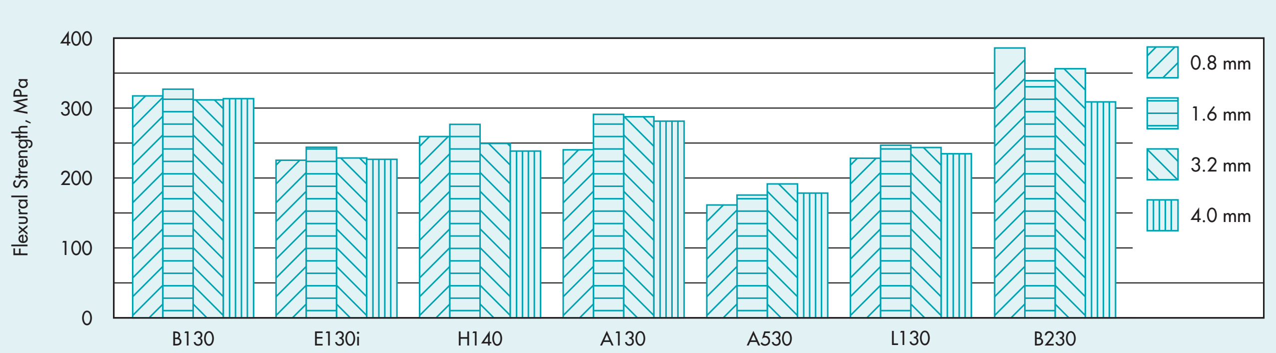


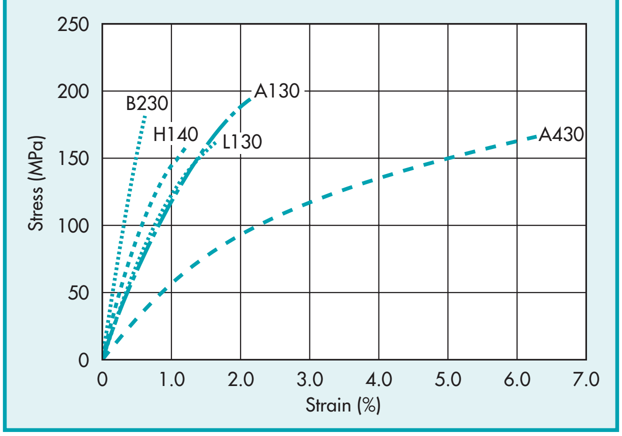
Fig. 3.1.6 • Flexural Strength versus Wall Thickness Vectra LCP



3.1.2 Short term stress

The tensile stress strain curves shown in Figure 3.1.7 are representative of the Vectra LCP product line. Vectra A130 is a 30% glass filled resin, Vectra B230 is a 30% carbon fiber reinforced resin, Vectra A430 is a 25% PTFE filled resin, Vectra L130 is a 30% glass filled resin, Vectra H140 is a 40% glass filled resin. These five products essentially cover the range of elongation (strain) for filled or reinforced Vectra LCP grades. Like most other filled or reinforced semi-crystalline plastics, Vectra LCPs have no yield point. Even unfilled LCPs have no yield point.

Fig. 3.1.7 · Stress Strain Curves at 23°C



As with any thermoplastic resin, stiffness and strength of the materials decrease with increasing temperature. Figures 3.1.8a and b show the influence of temperature on the tensile stress strain curves of Vectra B230 (carbon fiber filled, high strength and stiffness), and Vectra E130i (glass fiber filled, high temperature).

Fig. 3.1.8a · Influence of Temperature on Stress Strain Behavior, Vectra B230

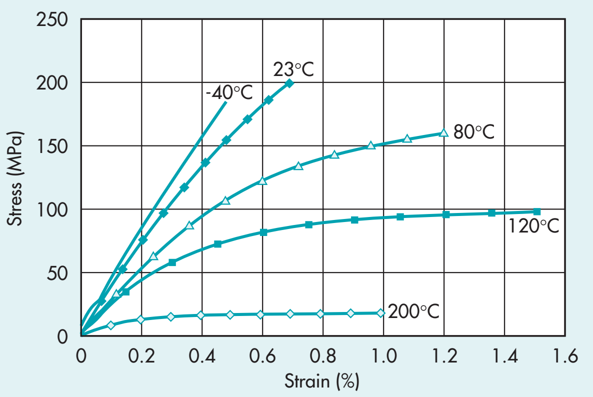
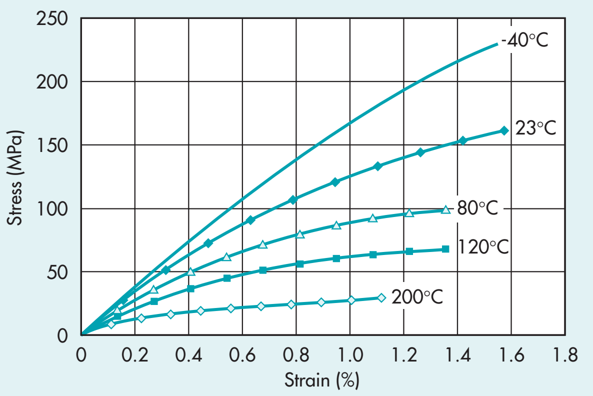


Fig. 3.1.8b · Influence of Temperature on Stress Strain Behavior, Vectra E130i



The influence of temperature on tensile properties for a number of Vectra LCP grades is given in Figures 3.1.9 and 3.1.10.

Fig. 3.1.9 · Tensile Modulus versus Temperature, Vectra LCP

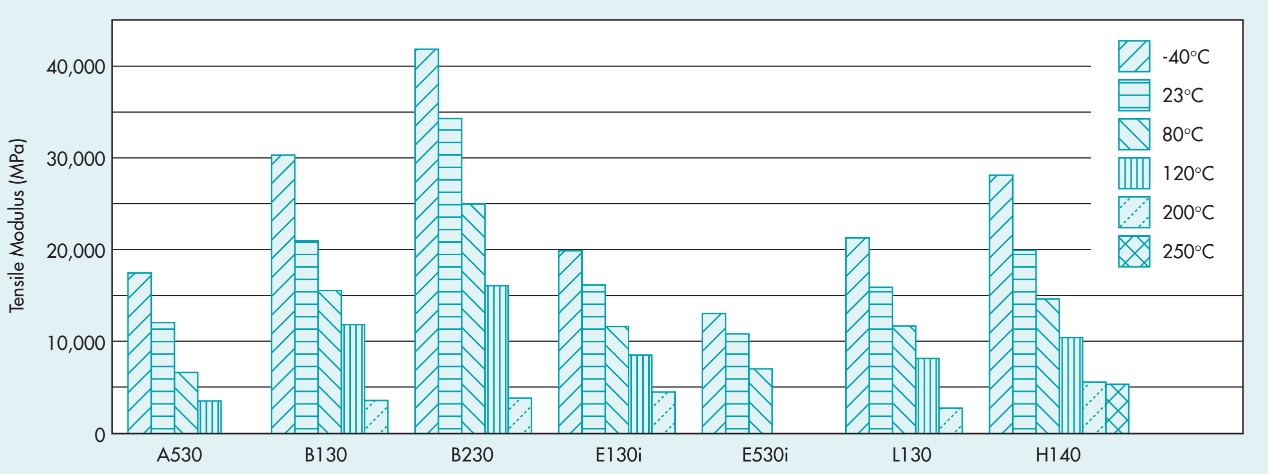
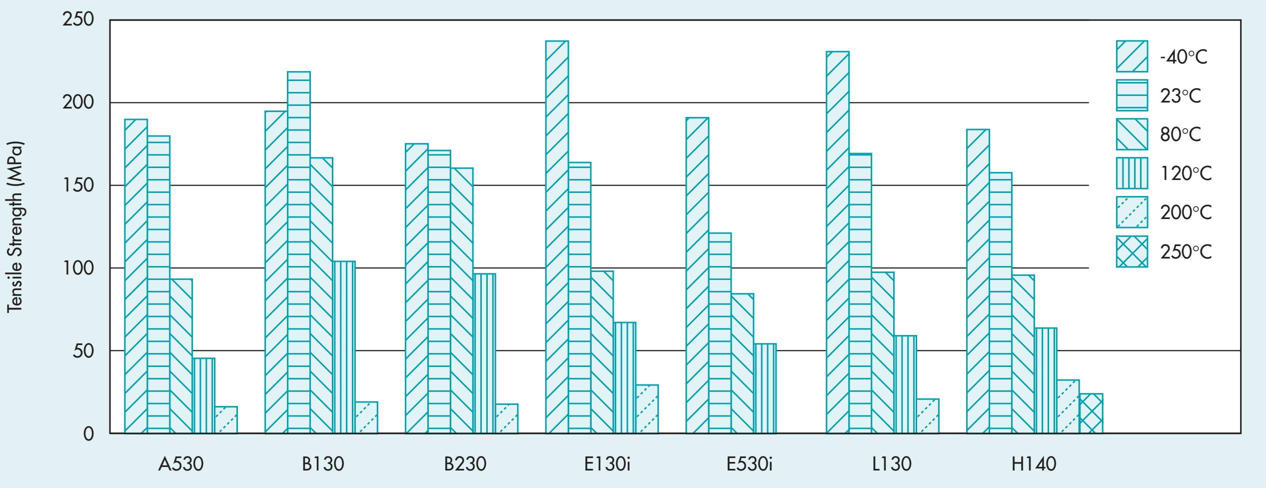


Fig. 3.1.10 · Tensile Strength versus Temperature, Vectra LCP



3.1.3 Behavior under long term stress

Vectra LCPs have good resistance to creep. Figures 3.1.11 and 3.1.12 show the tensile creep modulus of two high temperature resins, Vectra E130i and Vectra H140, for exposure at 23°C and 120°C at various stress levels. The maximum exposure time was 1,000 hours for E130i and 1,500 hours for H140. The stress levels were chosen to be 30% of the short-term failure stress and none of the samples failed in testing. No sign of creep rupture – a common form of failure – was observed at stress levels below 30%.

Figures 3.1.13, 3.1.14 and 3.1.15 show flexural creep modulus for Vectra A130, Vectra B130, and Vectra C130 – all 30% fiberglass reinforced resins.

Fig. 3.1.12 · Tensile Creep Modulus, Vectra H140

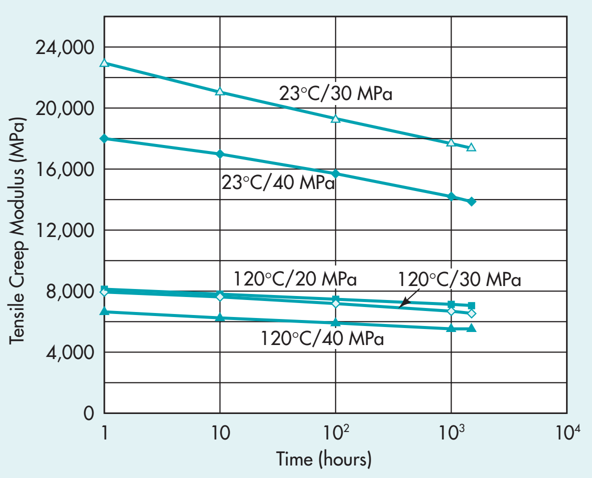


Fig. 3.1.11 · Tensile Creep Modulus , Vectra E130i

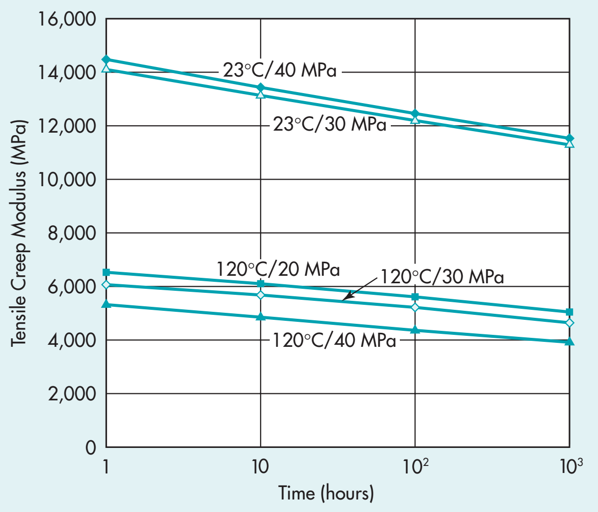


Fig. 3.1.13 · Flexural Creep Modulus, Vectra A130

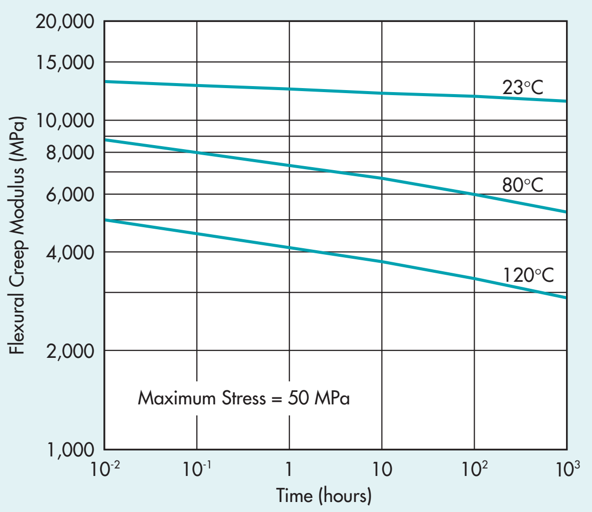


Fig. 3.1.14 · Flexural Creep Modulus, Vectra B130

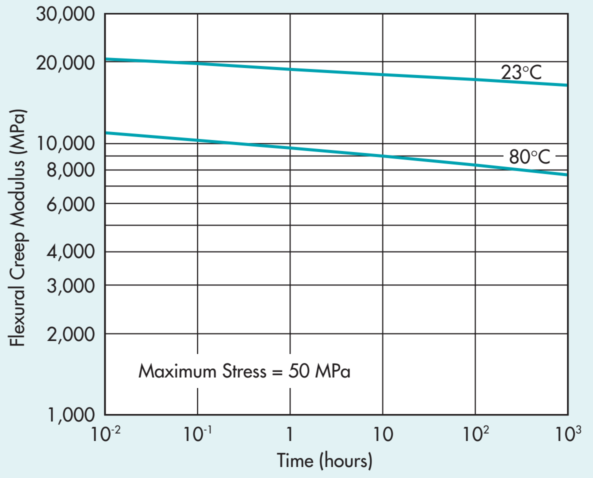
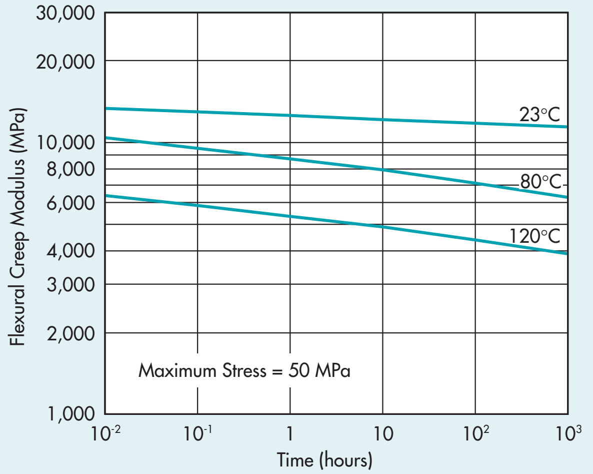


Fig. 3.1.15 · Flexural Creep Modulus, Vectra C130



3.1.4 Notch sensitivity (Impact testing)

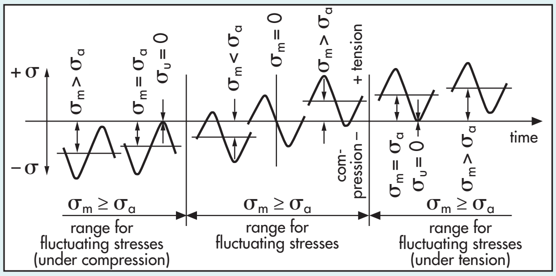
Vectra LCPs have very high notched and unnotched Charpy and Izod impact strength because of the wood like fibrous structure. If this fibrous structure is cut by notching, as in a notched Izod or Charpy specimen, the energy to break is still high compared with other glass reinforced resins.

The values for notched and unnotched impact are reported in the Short-Term Properties brochure.

3.1.5 Fatigue

Components subject to periodic stress must be designed on the basis of fatigue strength, i.e. the cyclic stress amplitude σ_a determined in the fatigue test – at a given mean stress σ_m – which a test specimen withstands without failure over a given number of stress cycles, e.g. 10^7 (Wöhler curve). The various stress ranges in which tests of this nature are conducted are shown in Figure 3.1.16

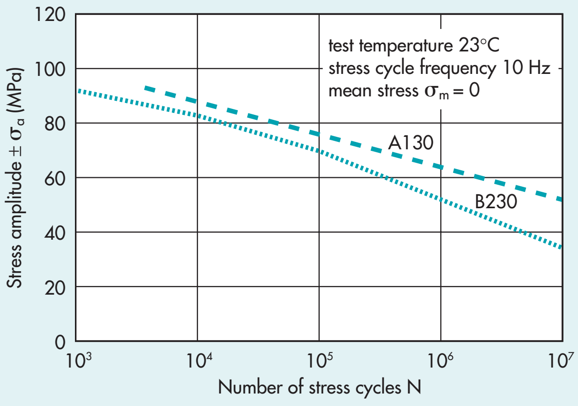
Fig. 3.1.16 · Stress Ranges in Fatigue Tests



For most plastics, the fatigue strength after 10^7 stress cycles is about 20 to 30% of the ultimate tensile strength determined in the tensile test. It decreases with increasing temperature, stress cycle frequency and the presence of stress concentration peaks in notched components.

The Wöhler flexural fatigue stress curves for three Vectra LCP grades are shown in Figure 3.1.17. The flexural fatigue strength of Vectra A130 after 10^7 stress cycles is σ_{bw} = 50 N/mm².

Fig. 3.1.17 · Wöhler Curves for Vectra, longitudinal direction determined in the alternating flexural stress range



3.1.6 Tribological properties

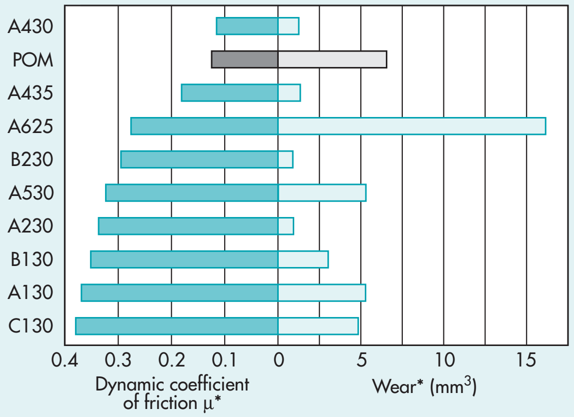
The friction and wear characteristics of Vectra LCPs are very specific to the application. In general, Vectra resins have performed satisfactorily in low load friction and wear applications. Typical wear grades of Vectra LCPs contain PTFE, carbon fibers, graphite, or a combination of these and other fillers and reinforcements. Coefficients of friction typically range from 0.1 to 0.2. More specific data are available with standardized tests (Table 3.1.3). However, we recommend that your specific bearing, friction and wear applications be reviewed with Vectra LCP technical service engineers.

Table 3.1.3 · Coefficient of Friction, μ, of Vectra® LCP (ASTM D1894)

Description	Vectra LCP Grade	Coefficient of Friction – Flow Direction	
		Static	Dynamic
Glass Fiber Reinforced	A115	0.11	0.11
	A130	0.14	0.14
	A150	0.16	0.19
Carbon Fiber Reinforced	A230	0.19	0.12
Mixed Filler/Fiber	A410	0.21	0.21
PTFE Modified	A430	0.16	0.18
	A435	0.11	0.11
Mineral Modified	A515	0.20	0.19
Graphite	A625	0.21	0.15
Carbon Fiber Reinforced	B230	0.14	0.14
Glass Fiber Reinforced	L130	0.15	0.16

Figure 3.1.18 compares the dynamic coefficient of friction, μ, of a number of Vectra LCP grades sliding against steel to that of acetal or POM. The figure also shows the wear while dry sliding on a rotating steel shaft.

Fig. 3.1.18 · Friction and Wear



**average from longitudinal and transverse to flow direction*

Friction: steel ball diameter 13 mm,
load F_N = 6 N, sliding speed v = 60 cm/min.
Wear: roughness height = 0.1 μm,
peripheral speed of the shaft v = 136 m/min,
load F_N = 3 N, duration of test 60 hr

3.1.7 Damping

The unique structural characteristics of Vectra LCPs greatly affect the damping characteristics. Generally speaking, materials with high modulus, such as metals, have low damping (internal loss) characteristics and low modulus materials, such as rubbers, have high damping characteristics. Vectra LCPs, however, exhibit high damping characteristics despite their high modulus. This is due to the rigid rod like crystalline structure of the LCP.

The relationship between internal loss, η, and damping factor, λ, is as follows:

$$\lambda T/\pi = \eta$$

where T = cycle and π = 3.14.

Figure 3.1.19 shows the damping properties of various materials. Figure 3.1.20 compares the vibration characteristics of Vectra LCP grades.

Fig. 3.1.19 · Damping Properties

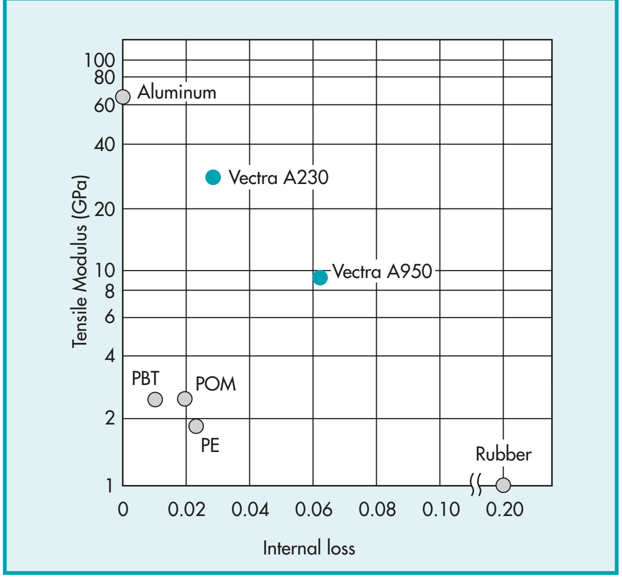
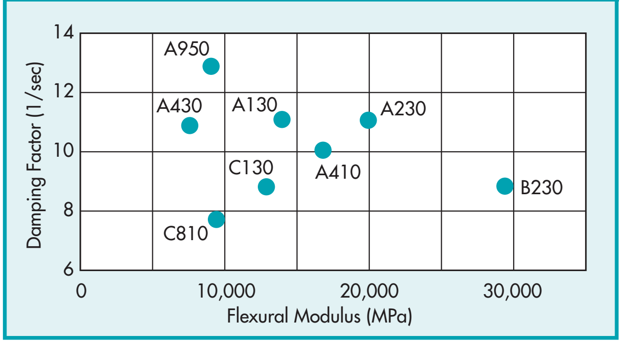


Fig. 3.1.20 · Vibration Characteristics



3.2 Thermal properties

3.2.1 Dynamic mechanical spectra

A snapshot view of the thermomechanical behavior of plastic materials is provided by Dynamic Mechanical Analysis (DMA). This technique is used to scan the storage modulus or stiffness (E′), loss modulus (E″) and damping or energy dissipation (tan δ) behavior of a material over a wide temperature range. The stiffness or modulus (E′) corresponds to, and has nearly the exact value as, the conventional tensile modulus (E) in temperature regions of low loss or damping factor. This modulus represents the recoverable elastic energy stored in a viscoelastic material during deformation. The damping factor (tan δ) represents the energy losses occurring during deformation due to internal molecular friction that occurs in a viscoelastic material.

By comparing DMA curves of two or more Vectra LCPs (Figures 3.2.1-3.2.8), retention of stiffness as temperatures are raised is easily compared. Generally the higher the stiffness at any temperature, the more creep resistant the variants will be at that temperature. In Table 3.2.1 the temperature where the modulus has fallen to 50% of the ambient temperature modulus value is tabulated for a series of Vectra LCPs. Generally, the higher this temperature, the more creep resistant the variant will be at elevated temperatures. For example, Vectra A130 ($T_{1/2E}$ = 208°C) will be more creep resistant than Vectra A530 ($T_{1/2E}$ = 126°C) in the temperature range of about 120 to 210°C. Likewise, Vectra E130i ($T_{1/2E}$ = 282°C) will be more creep resistant than Vectra A130 ($T_{1/2E}$ = 208°C) in the 210 to 280°C temperature range.

Similarly, peaks in the tan δ indicate transitions and temperature ranges where the polymer will be more energy-dissipating (note that the frequency of the measurements is very, very low, on the order of one hertz [cycle/second]. This frequency is well below the audible sound range of 20-20,000 hertz. Typically, Vectra polymers have two strong damping peaks at the glass transition, α, and at a lower temperature transition, β. These are tabulated in Table 3.2.1. Typically, the damping peaks for all Vectra LCPs fall over a wide range of temperature. Glassy transitions are usually in the 120 to 155°C range with the lower temperature secondary loss peak at 10 to 80°C. In general, the temperatures of the damping peaks at just above ambient make Vectra LCPs good sound absorbers. When struck, they do not “ring”, they “clunk” or sound “dead”.

Table 3.2.1 · Dynamic Mechanical Analysis

Sample ID	α transition (T_g) (°C)	β transition (°C)	Modulus E at 23°C (MPa)	Half Modulus Temperature $T_{1/2E}$ (°C)
Vectra A130	119	54	5100	208
Vectra A530	119	50	5000	126
Vectra B130	157	72	5700	189
Vectra B230	159	79	5900	216
Vectra E130i	135	23	4300	282
Vectra E530i	130	22	4100	204
Vectra H140	130	16	5200	290
Vectra L130	130	11	5200	238

Fig. 3.2.1 · Dynamic Mechanical Analysis Vectra A130

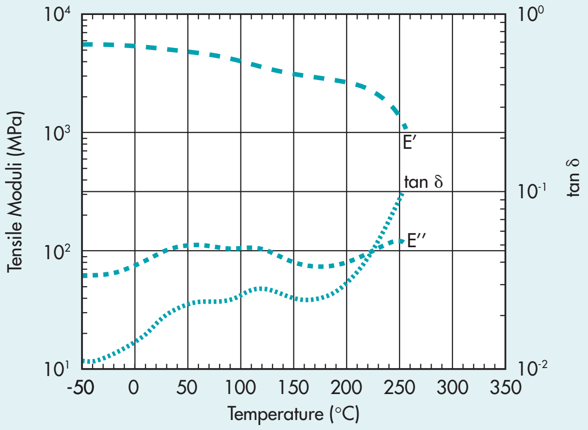


Fig. 3.2.2 · Dynamic Mechanical Analysis Vectra A530

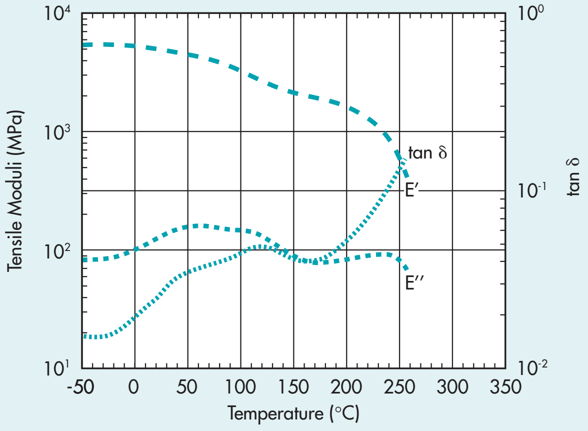


Fig. 3.2.3 · Dynamic Mechanical Analysis Vectra B130

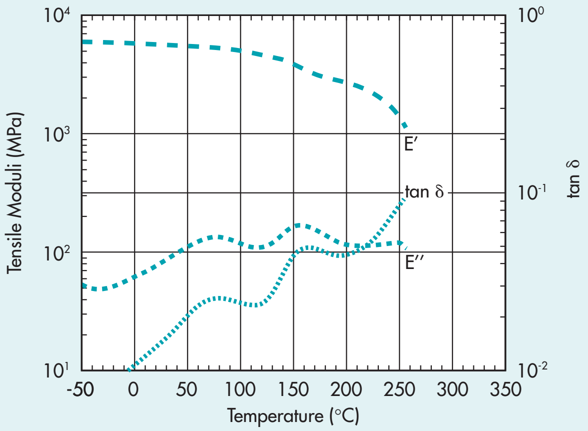


Fig. 3.2.4 · Dynamic Mechanical Analysis Vectra B230

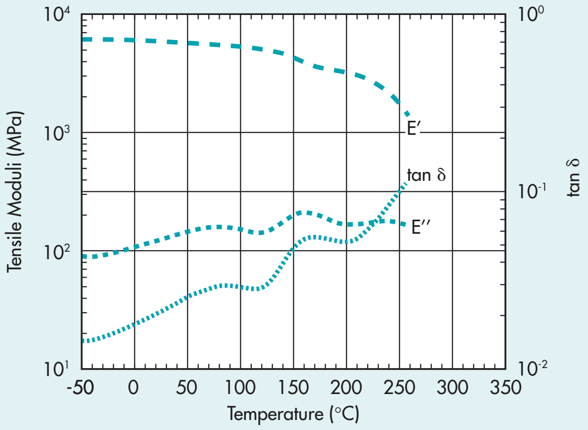


Fig. 3.2.5 · Dynamic Mechanical Analysis Vectra E130i

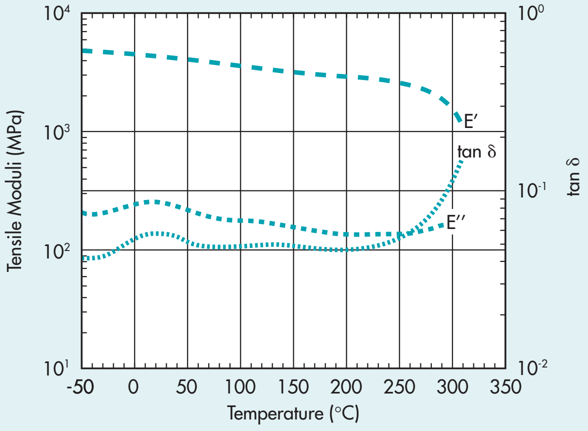


Fig. 3.2.6 · Dynamic Mechanical Analysis Vectra E530i

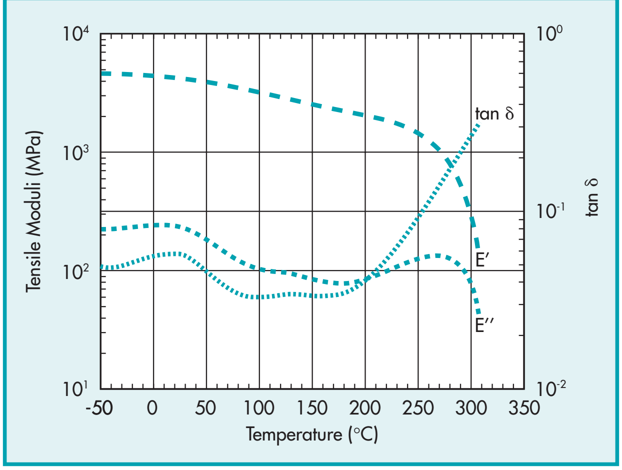


Fig. 3.2.7 · Dynamic Mechanical Analysis Vectra H140

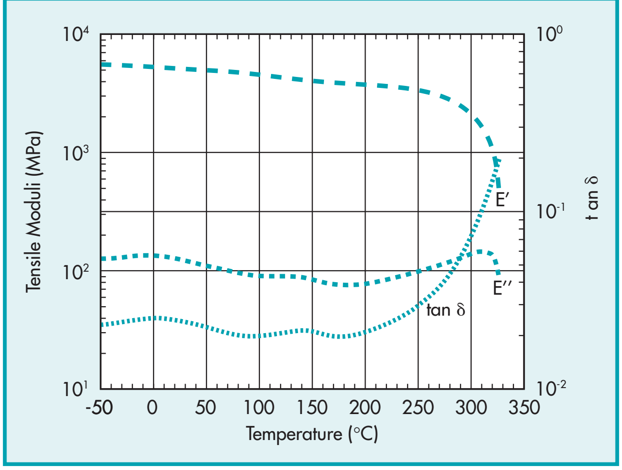
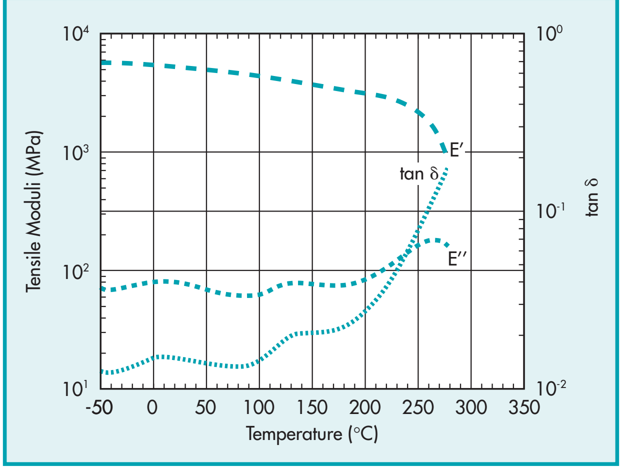


Fig. 3.2.8 · Dynamic Mechanical Analysis Vectra L130



3.2.2 Deflection temperature under load

The Deflection Temperature under Load (DTUL/ HDT) measured at 1.8 MPa for Vectra LCPs ranges from 120°C for an unreinforced, low temperature product to 300°C for the glass fiber reinforced high heat products. Although values for DTUL can be measured at loads of 8 MPa, 1.8 MPa and 0.45 MPa, values are most frequently reported for crystalline materials at 1.8 MPa. This value is provided for all Vectra LCP grades in the Short-Term Properties brochure.

3.2.3 Coefficient of linear thermal expansion

One of the advantages of Vectra LCPs are its very low coefficient of linear thermal expansion (CLTE) in comparison with other thermoplastics. The expansion coefficient displays marked anisotropy. It is much lower in the orientation direction than the cross flow direction. With very high orientation in the flow direction, the expansion coefficient may even be negative, especially for carbon fiber reinforced grades.

The expansion coefficient of Vectra LCPs can be varied within certain limits and matched to the expansion coefficient of glass, steel, ceramic, or glass fiber/epoxy substrates. Figure 3.2.9 compares the expansion coefficients of various engineering materials. When composite structures of Vectra LCPs and other materials are heated, no thermally induced stresses occur because the thermal expansion values are similar. Components for surface mounting should have expansion coefficients closely in line with those of the circuit board substrate (usually FR 4 epoxy resin/glass fiber) to avoid mechanical stresses at the soldering points as a result of thermal loading. Vectra LCPs are therefore a good material to consider for composite structures, particularly for surface mount technology (SMT) components.

The expansion coefficient is dependent on the flow-induced orientation in the part. The more balanced the flow through a given section of the part, the more balanced the expansion coefficient in the flow and the cross flow directions. Table 3.2.2 compares the expansion coefficient of select Vectra LCP grades in two geometries.

As shown in Figure 3.2.10 the orientation in the ISO universal tensile bar is higher than that in the disk because of converging flow as the bar narrows in the center. The more balanced flow and orientation in the 100 mm disk configuration results in more balanced CLTE values.

Fig. 3.2.9 · Coefficients of Linear Thermal Expansion of Selected Engineering Materials

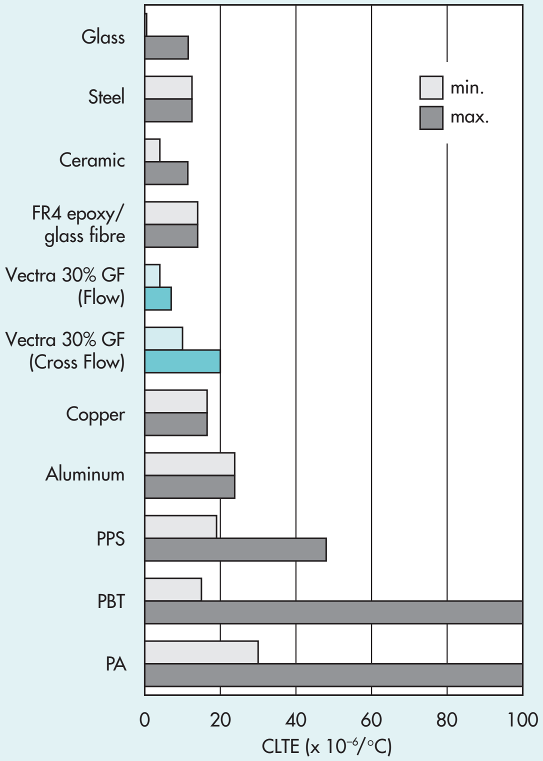


Fig. 3.2.10 · Sample Geometry for CLTE Measurements

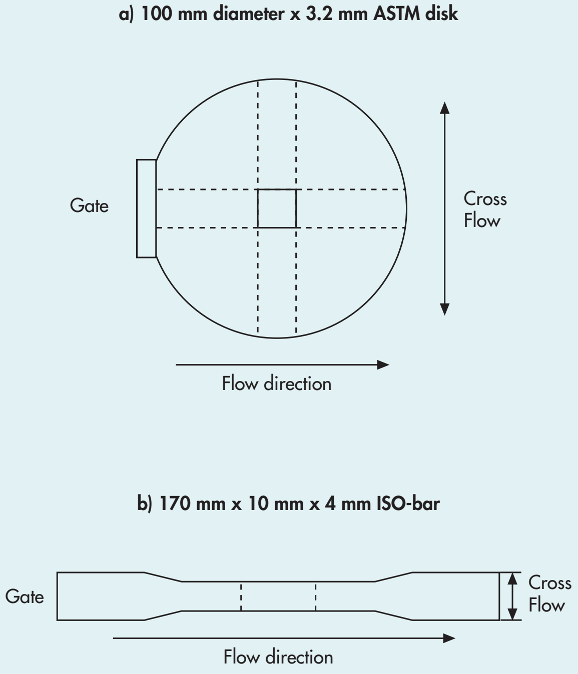


Table 3.2.2 · Coefficient of Linear Thermal Expansion (-50 to 200°C)

Vectra	Coefficient of Linear Thermal Expansion (x 10⁻⁶/°C)			
	4 mm ISO Bar		100 x 3.2 mm ASTM disk	
	Flow	Cross Flow	Flow	Cross Flow
A130	5	20	11	19
B130	3	8	9	16
E130i	5	19	9	23
E530i	4	32	13	35
H140	4	17	8	21
L130	4	16	10	11

3.2.4 Soldering compatibility

Parts molded from Vectra LCPs are commercially successful in applications requiring vapor phase, infrared and wave soldering. They have excellent dimensional stability and exhibit very low and predictable shrinkage after exposure to surface mount temperatures minimizing any tendency to bow or warp.

Table 3.2.3 shows dimensional changes on a 56 mm long connector with 40 contacts after immersion in Fluorinert® FC70, which is used in Vapor Phase Soldering.

Table 3.2.3 · Vapor Phase Soldering Stability of Vectra® LCP

		Change in Dimensions after Immersion in Fluorinert FC70 at 215°C (%)	
		45 s immersion	120 s immersion
Vectra A130 (30% GF)	ΔL	0.05	0.05
	ΔW	0.05	0.05
	ΔD	0.05	0.05
PBT (30% GF)	ΔL	0.2	0.22
	ΔW	0.3	0.5
	ΔD	0.2	0.32
PPS (40% GF)	ΔL	0.15	0.16
	ΔW	0.53	0.55
	ΔD	0.55	0.57

GF = fiber glass reinforced
ΔL = change in length dimension (%)
ΔW = change in width dimension (%)
ΔD = change in depth dimension (%)

Resistance to soldering temperatures of a number of Vectra LCP grades is given in Table 3.2.4. Experience has shown that Vectra A130 has acceptable resistance to solder temperatures up to 240°C. Above this temperature, parts can begin to soften or distort due to the proximity to the melting point (280°C). Vectra C130 can be used up to temperatures of 260°C, however, again, parts can soften or distort above this temperature as one approaches the melting point (320°C). Vectra E130i, with its much higher melting point (335°C), is able to withstand soldering temperatures of up to 300°C for a brief period of time.

Table 3.2.4 · Soldering Compatibility of Vectra® LCP

Solder Bath Temperature (°C)	Dipping Time (s)	Vectra A130	Vectra C130	Vectra LI30	Vectra E130i
240	10	O	O	O	O
	60	O	O	O	O
260	15	O	O	O	O
	20	Δ	O	O	O
	45	Δ	O	O	O
	60	Δ	O	O	O
280	10	--	O	--	O
	30	--	O	O	O
	45	--	Δ	--	O
	60	--	Δ	Δ	O
	90	--	--	--	O
290	60	--	--	Δ	O
300	30	--	--	--	O
310	10	--	--	--	O
	15	--	--	--	Δ

O = no change in appearance *-- = not tested*
Δ = change in appearance

3.2.5 Thermodynamics, phase transition

Figure 3.2.11 shows the Specific Heat, C_p, of Vectra LCPs as a function of temperature compared to PPS and PBT. Vectra LCPs have a lower Specific Heat than partially crystalline thermoplastics. The curves are more like those for amorphous thermoplastics. This is attributed to the liquid crystalline structure of LCPs. With LCPs, the transition from the solid to the melt phase is associated with a relatively small change in the state of order since the melt maintains the high orientation of the solid.

Because of the high order of the melt state and the ability to solidify with minimal change in structure, the transition energy during melting or freezing of Vectra LCPs is an order of magnitude less than that of partially crystalline thermoplastics (Figure 3.2.12).

Figure 3.2.13 shows the relative phase transition energies of Vectra A130, PBT and PPS throughout the heating or cooling cycle.

Fig. 3.2.11 · Specific Heat

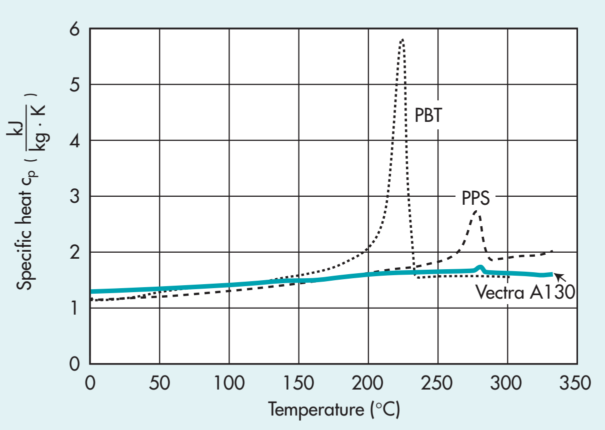


Fig. 3.2.12 · Relative Phase Transition Energy

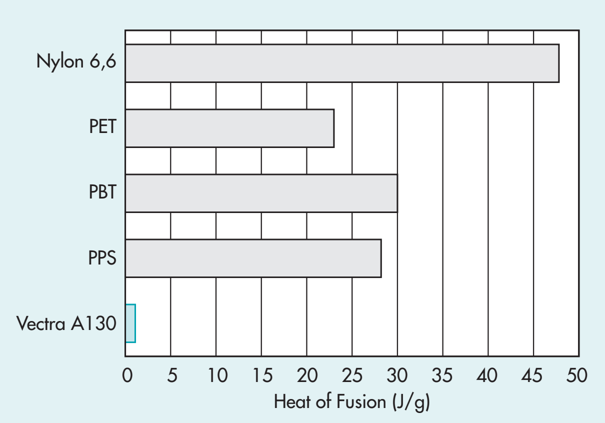


Fig. 3.2.13 · Enthalpy

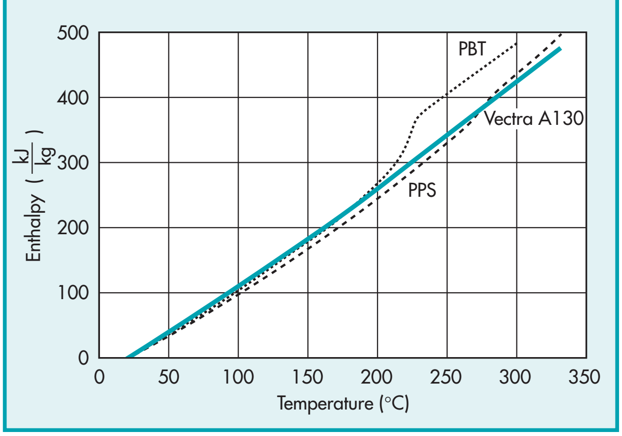
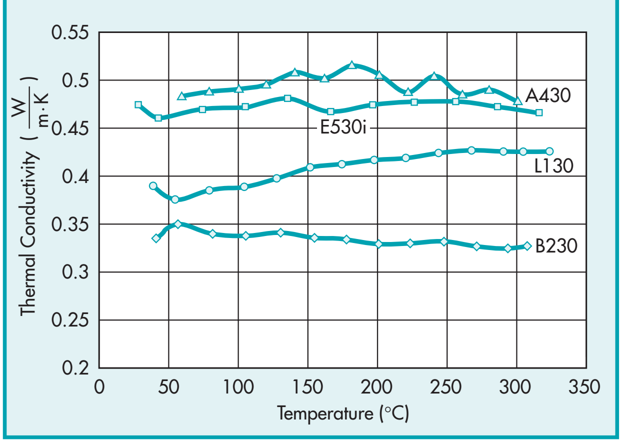


Fig. 3.2.14 · Thermal Conductivity



In designing the optimum processing machinery and parts, it is essential to know how much heat must be supplied or removed during processing. With Vectra LCPs less heat has to be removed and the melt freezes rapidly. This means that much faster cycles are possible than with partially crystalline materials, thus permitting lower-cost production of parts.

The thermal conductivity, λ, of unreinforced Vectra LCPs is in the same range as that for partially crystalline polymers. Thermal conductivity is dependent on the base polymer as well as the use of fillers and reinforcements (Figure 3.2.14).

3.3 Flammability and combustion

Vectra LCPs are inherently flame retardant (i.e. requires no additive package) and self-extinguishing. On exposure to very high flame temperatures, the fully aromatic polymers form a carbon char layer, which retards the development of flammable gases.

Vectra LCPs have a self-ignition temperature of over 540°C. The onset of thermal degradation in air is not significant until temperatures over 350°C are reached (as much as 400°C for the higher melt point polymers).

The Limiting Oxygen Index (LOI) represents the minimum amount of oxygen as a percentage in air at which the combustion of the polymer will continue after ignition without an additional source of energy. The LOI of Vectra LCPs ranges from 40% to 50% depending on the base polymer (Short-Term Properties brochure).

Smoke density measurements and products of combustion for Vectra A950 are given in Table 3.3.1 and Table 3.3.2. Combustion products are primarily carbon dioxide, carbon monoxide and water. In the Ohio State University (OSU) heat release test results meet US Federal Air Regulation (Table 3.3.3).

Vectra LCPs conform to Underwriters Laboratory UL 94 V-0 at thicknesses as low as 0.2 mm with many grades. The UL listings for several of the commercial Vectra LCP grades are given in Table 3.3.4. The listings can be found at UL under file number E83005.

Please note that Ticona is continuously developing new grades of Vectra LCP, or adding to the data already available for current grades. Please call your Vectra LCP Technical representative or logon to www.Ticona-US.com to view Product Information/ Agency Compliance for the most up to date information from UL.

Table 3.3.1 • Smoke Density of Vectra A950 (National Bureau of Standards Smoke Density Chamber, ASTM E-662)

	Thickness			
	1.6 mm		3.2 mm	
	Flaming	Smoldering	Flaming	Smoldering
Specific smoke density after 1.5 minutes	–	–	–	–
Specific smoke density after 4.0 minutes	7	–	3	–
Maximum value for specific smoke density	95	2	94	1
Time to smoke density of 90% of maximum value (minutes)	17	20	17	19

Table 3.3.2 • Products of Combustion (in ppm) of Vectra A950 (National Bureau of Standards Smoke Density Chamber, ASTM E-662, Generated on 3.2 x 76.2 x 76.2 mm plaques)

	Thickness			
	1.6 mm		3.2 mm	
	Flaming	Smoldering	Flaming	Smoldering
Chlorine	–	–	–	–
Phosgene	–	–	–	–
Hydrogen chloride	–	–	–	–
Hydrogen fluoride	–	–	–	–
Formaldehyde	–	–	–	–
Ammonia	–	–	–	–
Carbon monoxide	320	<10	300	<10
Carbon dioxide	8000	600	7000	600
Nitrogen oxides	5	–	12	–
Hydrogen cyanide	–	–	–	–
Sulfur dioxide	–	–	–	–
Hydrocarbons as n-octane	250	–	300	–

Table 3.3.3 • Heat Release of Vectra A950 (Ohio State University)

Thickness of test plaque	Accumulative heat release after 2 minutes (kW min/m²)	Maximum rate of heat release (kW/m²)
1.6 mm	16.8	57.8 (after 177 seconds)
3.2 mm	2.4	59.2 (after 293 seconds)
Specification (FAR)	<65	<65

Meets U.S. Federal Air Regulation, FAR25.853 (A-1), part IV, appendix F governing materials used in aircraft

Table 3.3.4 · Underwriters Laboratories Listings for Vectra® LCP

Material Designation	Color	Minimum Thickness mm	UL 94 Flam. Class	Hot Wire Ignition	High Amp Arc Ignition	Relative Temperature Index (RTI) Elec.	Mechanical Impact	Mechanical Strength
Thermotropic liquid crystalline polyester (TLCP) furnished in the form of pellets								
A130(+)	NC, BK	0.20	V-0	-	-	130	130	130
	ALL	0.85	V-0	-	-	240	220	220
		1.5	V-0	2	-	240	220	220
		3.0	V-0	1	4	240	220	220
	NC	1.5	V-0, 5VA	2	4	240	220	220
		CTI: 4	**HVTR:** 0	**D**495: 5				
C130(+)	ALL	0.38	V-0	4	4	130	130	130
		0.75	V-0	1	4	240	220	220
	NC	1.5	V-0, 5VA	1	4	240	220	240
		3.0	V-0, -5VA	0	4	240	220	240
		CTI: 4	**HVTR:** 0	**D**495: 5				
E130i(+1)	BK	0.43	V-0	-	-	130	130	130
	NC	0.75	V-0	2	4	240	220	240
	ALL	1.5	V-0	1	4	240	220	240
		3.0	V-0	0	4	240	220	240
		CTI: 4	**HVTR:** 0	**D**495: 5				
L130(+)	BK	0.22	V-0	-	-	130	130	130
	ALL	0.84	V-0	1	2	240	200	200
		1.5	V-0	1	2	240	200	220
		3.0	V-0	0	2	240	200	220
		CTI: 4	**HVTR:** 0	**D**495: 5				

NC = natural color, BK = black
UL-file number E83005
* Polyplastics Co. LTD Vectra Div. UL-file number E106764
(+) Virgin and Regrind from 1 to 50% by weight inclusive have the same basic material characteristics.
(+1) Virgin and Regrind from 1 to 25% by weight inclusive have the same basic material characteristics. In addition, 26 to 50% regrind by weight inclusive have the same characteristics at a minimum thickness of 1.5 mm except the RTI for the mechanical with impact property is 180°C.

Please visit our Vectra LCP web page (www.Ticona-US.com) or call your Vectra LCP Technical representative for the most up to date information from UL.

3.4 Electrical properties

Vectra LCP resins exhibit good electrical properties. The electrical characteristics combined with easy processing, dimensional stability, heat resistance and mechanical integrity make Vectra LCPs a good choice for electronic components, especially for applications involving surface mount technology. Vectra LCPs are also available with low to moderate conductivity (Table 3.4.1). These products are good candidates for dissipating (ESD) applications and limited electromagnetic interference (EMI) applications.

Table 3.4.1 · Vectra LCP Conductive Grades

	Vectra A230 Carbon fiber	**Vectra A700** Carbon black	**Vectra A725** Graphite/ carbon black	**Vectra B230** Carbon fiber
Volume Resistivity* (Ωm)	10^{-1} to 10	10^{2} to 10^{4}	10^{2} to 10^{4}	10^{-1} to 10
Surface Resisitivity (Ω)	10^{2} to 10^{3}	10^{5} to 10^{7}	10^{5} to 10^{7}	10^{2} to 10^{3}

** Measured on molded bars with ends painted with conductive silver*

Table 3.4.2 gives the Relative Permittivity, ε_r, (Dielectric Constant) and Dielectric Loss Tangent, δ, (Dissipation Factor) for different frequencies for a select number of un-plated Vectra LCP products.

Several common methods for measuring the dielectric properties of compounds were evaluated. The one with the highest reproduceability was chosen for comparison between Vectra grades (IEC250). Round platelets of 10 mm diameter were punched out of injection molded plaques of 0.4 mm thickness. These test specimens were metallized by gold vapor deposition. The plating helps eliminate surface roughness of the specimen and acts directly as a capacitor plate.

Using gold-plated specimens, the relative permittivity results (dielectric constant) determined were higher while the dielectric loss tangents (dissipation factor) were lower than on specimens that were not plated (Tables 3.4.2 and 3.4.3). This is especially true at higher frequencies. Figures 3.4.1 and 3.4.2 show the temperature dependance of the dielectric constant and dielectric loss tangents values for Vectra E820iPd, a special metallizable grade. [The tests were done by COMTECH Labor für Kunststoffe GmbH Munich via an RF-Impedance-Analyzer Hewlett-Packard HP 4291 A in the range of 1 MHz to 1.8 GHz.]

In practice, the values determined from metal plated test specimens are more realistic because antennae or parts for shielding applications usually are plated to be functional. When making a material selection based on dielectric constant and loss tangent values, the specific test method should be considered as well as the application for which the parts are designed. In addition, the orientation of filler particles as well as the LCP fibrils also has a major impact on the measured values.

Underwriters Laboratories (UL) has evaluated the majority of Vectra LCP grades. They report measurements of flammability, arc resistance, hot wire ignition, high current arc ignition, high voltage arcing rates, and comparative tracking index. The data is reported on the standard UL “Yellow Card”. Many Vectra LCP products allow the use of 50% regrind while continuing to maintain the UL rating.

In addition, UL also establishes a Relative Thermal Index (RTI). Based on thermal aging measurements, the RTI for a given formulation gives a guideline temperature for the long term retention of properties such as dielectric strength, tensile strength (mechanical strength without impact) and tensile impact strength. Vectra LCPs are assigned a generic rating of 130°C based on their chemistry and historic performance, before testing is complete.

Please note that Ticona is continuously developing new grades of Vectra LCP, or adding to the data already available for current grades. Please call your Vectra LCP Technical representative, or logon to www.Ticona-US.com to view Product Information/ Agency Compliance for the most up to date information from UL.

Table 3.4.2 · Electrical Properties of As-Molded/Un-Plated Vectra LCP

Relative Permittivity	1 MHz	10 MHz	100 MHz	1 GHz	2 GHz
A130	3.7	3.2	3.5	3.2	–
B130	3.6	3.5	3.5	3.4	–
E130i	3.3	3.2	3.2	3.1	–
H140	3.6	–	–	3.4	–
L130	3.5	3.3	3.3	3.3	3.9
E820i	3.6	–	–	–	–
Dielectric Loss Tangent					
A130	0.018	0.008	0.007	0.006	–
B130	0.008	0.006	0.006	0.002	–
E130i	0.025	0.02	0.01	0.008	–
H140	0.02	–	–	–	–
L130	0.024	0.02	0.01	0.008	0.006
E820i	0.03	–	–	–	–

Table 3.4.3 · Electrical Properties of Gold Plated Vectra LCP

Relative Permittivity	1 MHz	10 MHz	100 MHz	1 GHz	1.8 GHz
A130	5.18	5.05	5.00	5.01	5.00
A430	4.34	4.25	4.20	4.19	4.23
H130	5.56	5.31	5.18	5.34	5.38
E130i	6.77	6.49	6.33	6.26	6.29
E530i	5.30	5.11	4.97	4.93	4.98
E820i	7.19	6.92	6.79	6.74	6.79
E820iPd	6.79	6.54	6.42	6.39	6.43
Dielectric Loss Tangent					
A130	0.014	0.009	0.006	0.006	0.006
A430	0.009	0.006	0.003	0.004	0.005
H130	0.022	0.017	0.010	0.007	0.007
E130i	0.019	0.015	0.010	0.004	0.004
E530i	0.026	0.017	0.006	0.003	0.001
E820i	0.016	0.014	0.009	0.004	0.006
E820iPd	0.016	0.013	0.008	0.003	0.005

Fig. 3.4.1 · Relative Permittivity/Dielectric Loss Tangent vs Temperature, Vectra E820iPd, Gold Plated

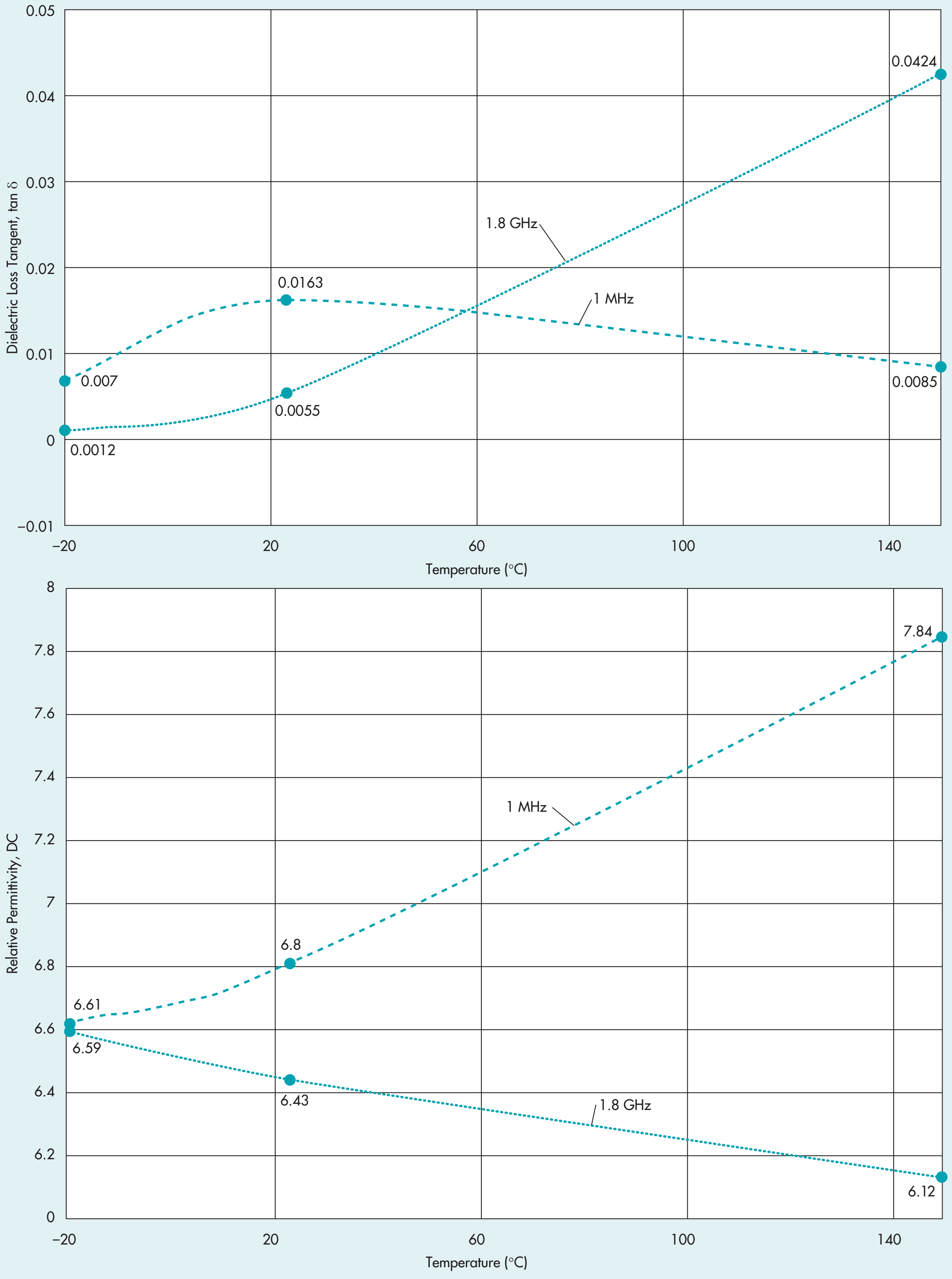
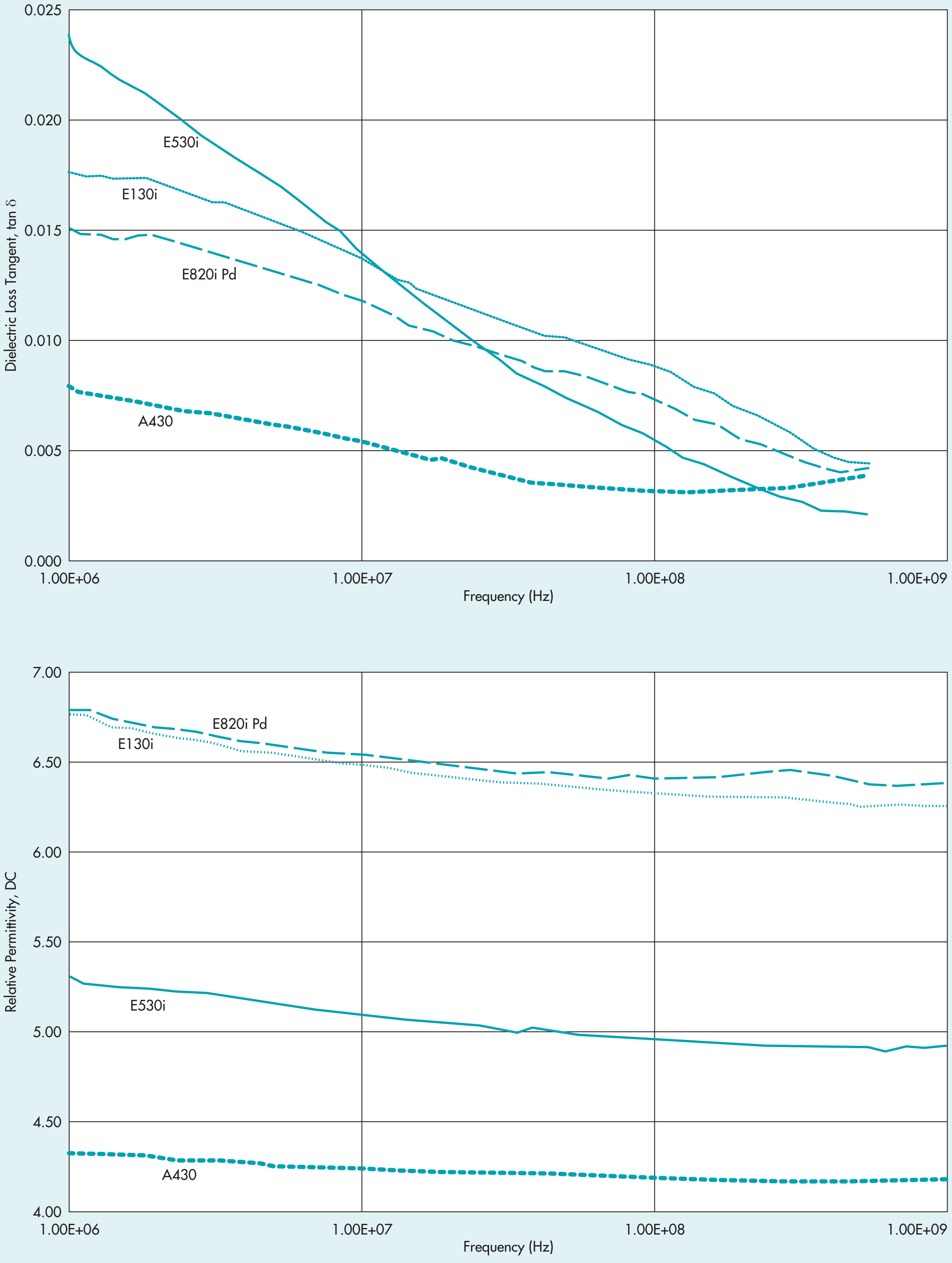


Fig. 3.4.2 • Relative Permittivity/Dielectric Loss Tangent vs Frequency for Vectra, Gold Plated



3.5 Regulatory approvals

3.5.1 Food and Drug Administration

Many Vectra grades are compliant with FDA regulations for food contact and specifically Food Contact Substance Notification (FCN #103):

Vectra A950
Vectra B950
Vectra C950

Many Vectra grades are also listed at the FDA in Drug and Device Master Files.

3.5.2 United States Pharmacopoeia

Many Vectra grades meet United States Pharmacopoeia (USP) Class VI requirements.

3.5.3 Biological evaluation of medical devices (ISO 10993)

Some grades of Vectra LCP have been found to meet the requirements of ISO 10993 biocompatibility tests.

3.5.4 Underwriters Laboratories

Most commercially available Vectra LCP products are recognized by UL. For specific listings see Table 3.3.4, contact your Vectra LCP Technical Representative, or logon to www.Ticona-US.com Product Information/Agency Compliance.

3.5.5 Canadian Standards Association

The Canadian Standards Association recognizes many of the commercially available Vectra LCP products.

3.5.6 Water approvals – Germany and Great Britain

In Germany, the following Vectra grades meet the KTW test procedure recommended by BGVV for cold (23°C) and hot (90°C) water use:

Glass reinforced	Vectra A130
Graphite modified	Vectra A625

In Great Britain, the WRc has listed the following Vectra LCP grades under BS 6920 for use in cold and hot (85°C) water:

Glass reinforced	Vectra A130
Graphite modified	Vectra A625

Updates to Regulatory Approvals are continuous. Please contact your Vectra LCP Technical Representative for the most complete listings.

4. Environmental Effects

4.1 Hydrolysis

Vectra® LCPs have exceptional resistance to hydrolysis, compared with other polyesters. Figures 4.1.1 through Figure 4.1.4 show the results of immersion tests in hot water and steam. Prolonged exposure at high temperatures leads to gradual hydrolytic degradation.

Vectra LCPs have exceptionally low equilibrium moisture content typically 0.02 to 0.04%.

Fig. 4.1.1 · Tensile Strength versus Immersion Time in Hot Water (120°C, 2 bar)

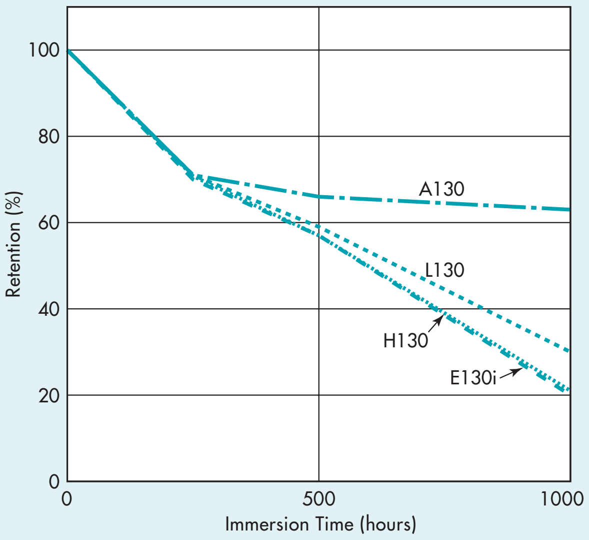


Fig. 4.1.3 · Tensile Strength versus Immersion Time in Steam

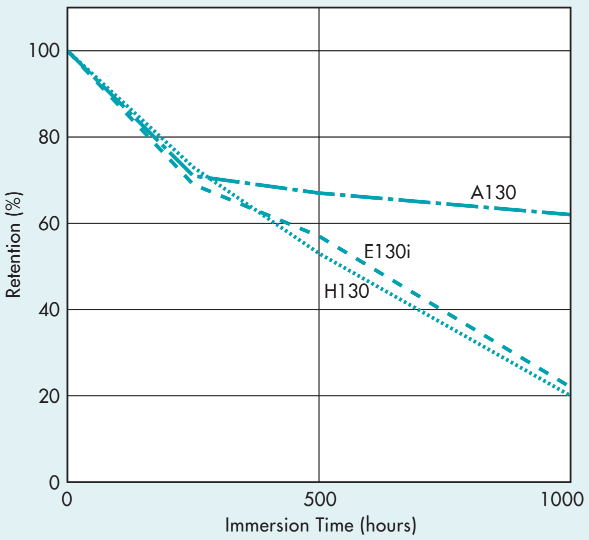


Fig. 4.1.2 · Tensile Modulus versus Immersion Time in Hot Water (120°C, 2 bar)

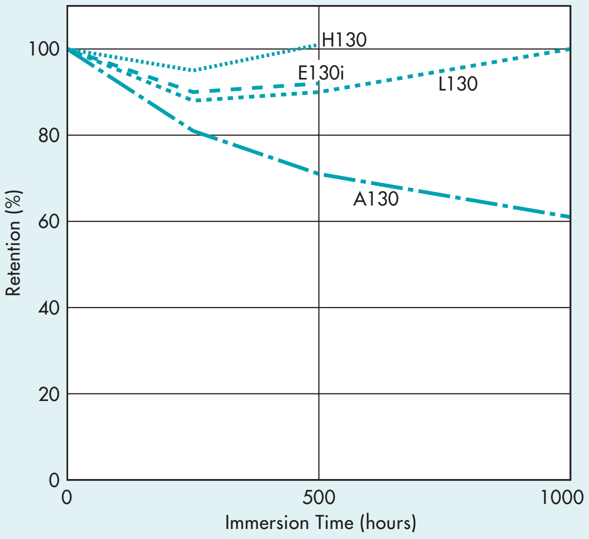
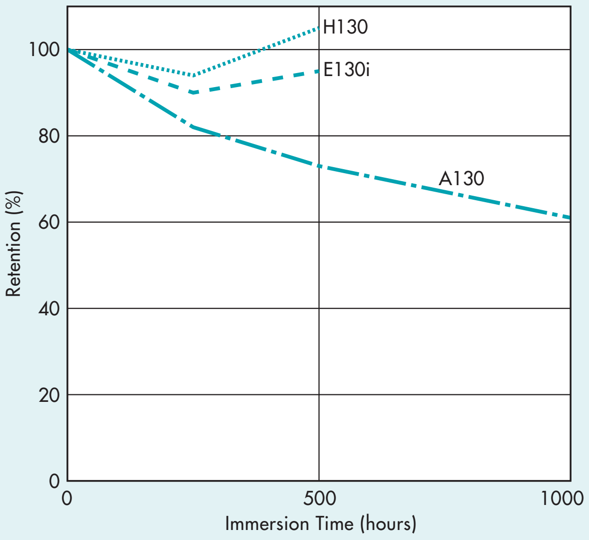


Fig. 4.1.4 · Tensile Modulus versus Immersion Time in Steam



4.2 Chemicals and solvents

Vectra LCPs have good resistance to chemicals, particularly organic solvents (even at high temperatures), cleaning agents normally used in the electronics industry and chemicals used for sterilization in the health care industry. Resistance to concentrated mineral acids and alkaline (both inorganic and organic) is highly problematic.

The resistance of Vectra LCPs to methanol and methanol containing fuels depends very much on the temperature and the degree of contact. In applications involving constant contact with methanol containing fuels, the temperature should not exceed 70°C.

The results of testing in various chemicals, solvents and fuels are given in Table 4.2.1. Five injection molded test specimens (127 mm x 12.7 mm x 3.2 mm) were immersed in the medium for a given period of time without any externally induced stress. The additional effect of mechanical stresses could alter the results. Changes in weight and dimensions, flexural strength, flexural modulus and hardness were measured. The data are for initial guidance only. Before commercial use, the material should be tested using the identical processing and exposure conditions expected in actual use.

Changes in concentration, temperature of exposure or the addition of additives can significantly affect the results.

Table 4.2.1 · Chemical Resistance

Rating: + Resistant – less than 2% change in weight and dimension, less than 5% change in mechanical properties.
o Limited resistance
– Not resistant

Medium	Conditions (time/temperature)	Vectra LCP grade	Rating
Acetic acid (glacial)	30 days/118°C	A950	+
	20 days/23°C	A625	+
Acetic acid (100%)	30 days/118°C	A950	+
Acetone	180 days/56°C	A950	+
		A130	+
		A625	+
Acetonitrile	120 days/23°C	A625	+
Brake fluid (Castrol® TLX 988C)	30 days/121°C	A130	o
		A950	+
		B950	+
		C950	+
	90 days/121°C	A130	–
Brake fluid (NAPA® brand DOT-3)	90 days/121°C	A130	o
Caustic soda solution (5%)	90 days/23°C	A130	+
		A625	+
	180 days/23°C	A950	+
		A130	o
		A625	o
		A515	+
	30 days/70°C	A950	+
	180 days/70°C	A950	o
		A130	–
		A625	–
		A515	–
Caustic soda solution (10%)	180 days/23°C	A950	+
		A130	+
		A625	o
		A515	+
	30 days/88°C	A950	o
		A130	–
		C950	+
Caustic soda solution (30%)	30 days/88°C	A950	–
		A130	–
		A625	–
		C950	–
Chlorine gas	180 days/23°C	A950	+
		A130	+
		A625	+
Chlorine/water (saturated solution)	180 days/23°C	A950	+
		A130	+
		A625	+
Chromic acid (50%)	90 days/50°C	A625	+
	180 days/50°C	A950	+
		A130	o
		A625	o
	30 days/70°C	A950	+
		A130	+
	60 days/70°C	A950	+
		A130	o
Chromic acid (70%)	30 days/88°C	A950	+
		A130	o
		A625	o

Dimethyl formamide	180 days/66°C	A950	+
		A130	+
		A625	+
Diphenylamine	180 days/66°C	A950	+
		A130	+
		A625	+
Diphenyl carbonate	10 days/250°C	A950	–
Engine oil, 10W-30	30 days/121°C	A950	+
		B950	+
		C950	+
		A130	+
		C130	+
Ethanol	30 days/52°C	A950	+
Ethyl acetate	180 days/77°C	A950	+
		A130	+
		A625	+
Ethylene diamine	30 days/100°C	A950	–
	180 days/23°C	A950	+
		A130	o
		A625	+
Ethylene glycol (50/50)	30 days/50°C	A950	+
	30 days/121°C	A950	o
		B950	o
		C950	o
		A150	–
Fluorinert® FC-70	1 day/215°C	A950	+
		A130	+
		C130	+
Formic acid (80%)	30 days/104°C	A950	+
		A625	+
	270 days/104°C	A950	o
		A625	o
	455 days/104°C	A950	–
Fuels:			
Fuel C (ASTM D471) 50/50 iso-octane/toluene	30 days/121°C	A950	+
		B950	+
		C950	+
	90 days/121°C	A130	o
Fuel C + 20% methanol	125 days/60°C	A130	+
		A230	o
Fuel C + 20% ethanol	125 days/60°C	A130	+
		A230	o
M-85 fuel	20 days/121°C	A130	–
Lead free gasoline (petrol)	30 days/121°C	A950	+
		B950	+
	90 days/121°C	A130	+
Lead free gasoline (petrol) + 10% methanol	30 days/121°C	A950	o
		B950	o
	90 days/121°C	A130	–
	90 days/93°C	A130	o
		A625	+
Gasoline (petrol) w/70/30 heptane/toluene, copper ion, t-butyl-hydroperoxide	30 days/121°C	A950	+
		B950	+
H-FCKW 123	10 days/50°C	A130	+(1)
		C130	+(1)
		A530	+(1)
		C150	+(1)
		C810	+(1)

Hexafluoro-isopropanol	10 days/25°C	A950	–
Hexane	10 days/23°C	A625	+
Hydrochloric acid (37%)	30 days/88°C	A950	+
		A130	o
		A625	o
		C950	+
	120 days/88°C	A950	o
		A130	o
		A625	o
Hydrofluoric acid (anhydrous)	30 days/23°C	A950	–
Hydrogen chloride (anhydrous)	30 days/23°C	A950	–
Iso-octane	14 days/60°C	A625	+
	120 days/23°C	A625	+
Methanol	30 days/64°C	A950	+
		B950	+
	90 days/64°C	A130	+
	45 days/110°C	A130	–
Methylene chloride	180 days/40°C	A950	+
		A130	o
		A625	+
Monochloroacetic acid	180 days/50°C	A950	+
		A130	+
		A625	+
Morpholine (200ppm/steam) (tetrahydrooxazine)	10 days/132°C	A130	+
Nitric acid (50%)	120 days/23°C	A625	+
	60 days/70°C	A950	+
		A130	+
		A625	+
	180 days/70°C	A950	+
		A130	o
		A625	+
Nitric acid (70%)	30 days/88°C	A950	o
		A130	–
		A625	o
Nitrobenzene	30 days/66°C	A950	+
Nitroglycerine	30 days/66°C	A950	+
Oil – shock absorber (Shell® GHB 15)	40 days/150°C	A130	+
Oil – silicone	30 days/200°C	A950	+
Oil – hydraulic (Skydrol®)	30 days/71°C	A950	+
		B950	+
Oil – transmission (Dexron® II)	30 days/149°C	A625	+
		C950	+
		C130	+
	90 days/149°C	A625	+
		C130	+
Pentafluorophenol	10 days/60°C	A950	–
Phenol	100 days/100°C	A950	+
		A130	o
		A625	+
Refrigerant R-22	30 days/80°C	A950	+
		A625	+
Refrigerant R-12 + 5% refrigerator oil	60 days/100°C	A625	+

Refrigerant 113	180 days/47°C	A950	+
		A130	+
		A625	+
Refrigerant 113 TR-T	30 days/23°C	C130	+
		C810	+
Refrigerant 113 TR-P (F113 + 35% isopropanol)	30 days/23°C	C130	+
		C810	+
Refrigerant 113 TR-E35 (F113 + 35% ethanol)	30 days/23°C	C130	+
		C810	+
Refrigerant R134A + 5% refrigerator oil	60 days/100°C	A625	+
Sodium hydroxide (5%)	90 days/23°C	A950	+
		A130	+
	30 days/70°C	A950	+
		A130	o
	60 days/70°C	A950	o
		A130	o
Sodium hydroxide (10%)	90 days/23°C	A950	+
		A130	+
	30 days/88°C	A950	o
		A130	–
Sodium hydroxide (30%)	30 days/88°C	A950	–
		A130	–
Sodium hypochlorite (12.5%)	28 days/23°C	A130	o
	28 days/70°C	A130	–
Sulphuric acid (50%)	180 days/88°C	A950	+
		A130	+
		A625	+
Sulphuric acid (70%)	5 days/190°C	A950	–
		A130	–
		A625	–
		C950	–
Sulphuric acid (93%)	8 days/23°C	A950	o
		A515	o
		A625	o
		B950	–
	30 days/121°C	A950	–
		A130	–
		A625	–
		A950	–
Tetrahydrofuran	120 days/23°C	A625	+
Toluene	180 days/111°C	A950	+
		A130	+
		A625	+
Trichlorethane	90 days/66°C	A950	+
Urea (46%)	60 days/88°C	A950	o
		A130	–
		A625	o
Water	10 days/121°C	A950	+
	40 days/121°C	A950	o
		A625	+
	60 days/121°C	A950	o
		A130	o
Water vapor	70 days/121°C	A950	o
		A130	o
		A625	+

[1] Weight change in 60 x 60 x 4 mm plaques only

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NAPA® is a registered trademark of National Automotive Parts Association.
SKYDROL® is a registered trademark of Monsanto Co.
DEXRON® is a registered trademark of General Motor Corp.
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4.3 Permeability

Vectra LCPs have extremely low permeability to water vapor, oxygen, hydrogen and other gases. Figure 4.3.1 and Table 4.3.1 show the superior performance of unfilled Vectra LCP polymers compared to conventional barrier materials such as ethylene vinyl alcohol copolymer (EVOH), polyvinylidene chloride (PVDC), MXD6 (a copolyamide of meta-xylenediamine and adipic acid), and PCTFE (polychlorotrifluoroethylene). Because of its greater impermeability, Vectra LCP films present the opportunity to use thinner barrier layers in coextruded structures. A new family of Vectran™ liquid crystal polymers has been specifically developed for packaging applications requiring good oxygen and moisture vapor properties (see Vectran brochure "One of the few packages Vectran LCP can't improve"). These grades may also be suitable for other applications. In the production of monolayer LCP film, the problems of fibrillation and property imbalances can be addressed through post-extrusion techniques such as biaxial orientation.

The hydrogen permeability of Vectra LCP is shown in Table 4.3.2.

4.4 Radiation resistance

Vectra LCPs have excellent resistance to gamma radiation. Table 4.4.1 shows the effect of Cobalt 60 radiation on mechanical properties of Vectra A950.

4.5 Ultraviolet and weathering resistance

Vectra LCPs, like other plastics, shows a surface change over the course of time on exposure to weathering. Typically, the exposure to ultraviolet (UV) radiation causes a white deposit of degraded material to form on the surface with consequent loss of gloss and color change. This phenomenon is commonly referred to as chalking.

Fig. 4.3.1 · Permeability of Various Polymer Films (Thickness 25µm)

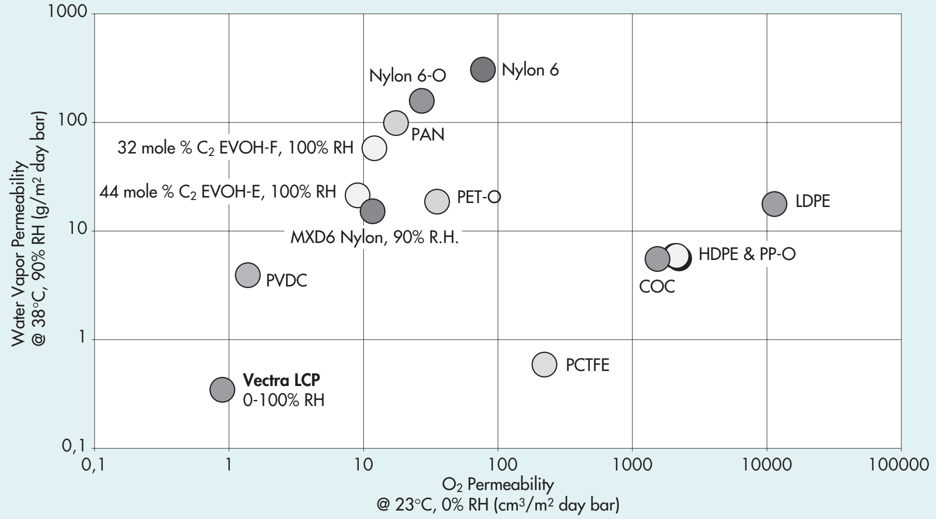


Table 4.3.1 · Permeability of Various Polymer Films (Thickness 25µm)

Material	**O_2 Permeability** 23° C, 0% RH cm³/m² day bar	**Water Vapor Permeability** 38°C, 90% RH g/m² day bar
Vectra LCP	0.9	0.3
Topas COC	1515.4	1.1
EVOH-E 100%RH	9.1	21.4
EVOH-F 100%RH	12.0	57.9
PVDC	1.4	3.9
MXD6	11.7	15.3
MXD6 + Co	0.3	15.3
PAN	17.5	98.4
Nylon 6-oriented	27.2	158.1
Nylon 6	77.3	307.1
PET-oriented	35.2	18.6
PCTFE	221.5	0.6
PP-oriented	2067.1	5.9
HDPE	2137.0	5.9

Table 4.3.2 · Hydrogen Permeability

Material	**Test Conditions**	**H_2 Permeability cm³/m²·d·bar**	**Film Thickness**
Vectra A950	40°C, 0% RH	78	50 µm
Vectra A950	150°C, 0% RH	98	2.5 mm
Vectra E130i	150°C, 0% RH	104	2.5 mm

After artificial weathering for 2,000 hours, samples molded from Vectra LCPs retained over 90% of their initial mechanical property values (Table 4.5.1). After one year of outdoor weathering a slight white deposit was detected.

Table 4.4.1 · Cobalt 60 Radiation Vectra® A950 (Percent retention of properties)

Radiation Dose	**250 Mrads**	**1,000 Mrads**	**2,500 Mrads**	**5,000 Mrads**
Tensile strength(1)	97	95	95	95
Tensile modulus(1)	100	100	106	106
Break elongation(1)	81	81	79	79
Flexural strength(2)	101	102	102	102
Flexural modulus(2)	108	108	116	125
HDT @ 1.82 MPa(3)	100	100	100	94

(1) *ASTM D638* (2) *ASTM D790* (3) *ASTM D648*

Table 4.5.1 · Results of Artificial Weathering for 2,000 hours (ASTM D2565 – xenon arc lamp, air temperature 125°C, water spray for 18 minutes every 202 minutes) (Percent retention of properties)

	Vectra A950	**Vectra A130**
Tensile strength(1)	95	95
Tensile modulus(1)	90	98
Flexural strength(2)	95	95
Flexural modulus(2)	95	95
HDT @ 1.82 MPa(3)	90	92
Notched Izod(4)	90	95

(1) *ASTM D638* (2) *ASTM D790* (3) *ASTM D648* (4) *ASTM D256*

5. Processing

Vectra® LCPs can be processed using common injection molding and extrusion techniques. Fast cycles, conventional processing and the possibility of blending with up to 50% regrind make for high cost effectiveness. Because of the material's good flow properties and low tendency to form flash, long, thin-walled parts can be produced.

5.1 Safety considerations

No particular hazards have been identified when processing Vectra LCPs provided standard industry safety practices are observed. Vectra LCP products are inherently stable materials. If heated to excessively high temperatures, however, they can decompose and give off decomposition products, as will most other thermoplastics. If insufficient ventilation is available, concentrations of these decomposition products can build up and may be harmful to health. A suitable ventilation system is therefore required.

To prevent thermal decomposition, off gassing and pressure buildup in the cylinder, melt temperatures should not exceed 330°C for lower melt point products, i.e. Vectra A-series, B-series and L-Series, or 360°C for the higher melt point products, e.g. Vectra C-series, Ei-series or H-series. These temperatures are well above the normal processing range. For more extended shutdowns (> 10 mins) run the screw dry and lower barrel temperature by 100°C. Do not process with these residence times and temperatures. See Section 6.2 for recommended processing conditions.

Other important precautions:

- Sufficient time should be allowed to heat up the machine. The cylinder should have reached the required processing temperature settings 5 minutes before feeding in the pellets and turning the screw.
- When handling hot material and molds, gloves, protective clothing and goggles should be worn.
- When switching off the machine, the injection unit should be retracted.

Material Safety Data Sheets (MSDS) are available for all Vectra LCP grades. Always consult the MSDS before working with any Vectra LCP.

5.1.1 Start up and shutdown procedures

Starting up an empty machine or one previously filled with Vectra LCP

The cylinder temperatures are set to the level required for processing. When the set values have been reached, it is advisable to wait for 5 minutes before filling the plasticizing cylinder. When the cylinder has been filled, several shots are ejected into the open (air shot). Special attention should be given to the nozzle temperature because if it is too cold the melt will freeze and block the nozzle. When the temperature of the melt ejected into the open has been checked with a needle pyrometer and the melt is flowing perfectly, processing can start.

Short and long interruptions to the molding cycle

For interruptions less than 10 minutes no special measures are required. For longer interruptions thorough evacuation of the barrel followed by a 100°C temperature reduction is recommended.

Changing from another thermoplastic to Vectra LCP

Since many other plastics are less thermally stable at the processing temperatures used for Vectra LCPs, it is advisable to purge them from the machine beforehand as thoroughly as possible. A suitable purging material is a low melt index polypropylene (glass fiber reinforced grades have a better cleaning effect). The purging material is purged into the open at about 250°C until it runs clean. Before increasing the cylinder temperatures to run Vectra LCPs be sure that the purge material is completely out of the machine. When the set temperatures are reached, run the Vectra LCP with the unit disconnected from the mold until the melt is free of all traces of the purge material.

Changing from one Vectra LCP grade to another

It is possible to process different Vectra LCP grades using one grade to remove another without purging with another polymer in between. For this purpose, the first material is completely pumped out and then displaced by the second material. In case of a color change (particularly from black to natural), no purging is necessary, but allow enough time to push all of the black out of the machine.

Shutting down the machine

If Vectra LCP is to be processed again after the machine has been shutdown, the injection unit must simply be run until empty. Then the nozzle and cylinder heaters can be switched off.

If a change to another thermoplastic is planned, the Vectra LCP must first be purged with high-density polyethylene or polypropylene. The temperatures should remain set at Vectra LCP processing temperatures because if they are reduced prematurely traces of Vectra LCP can no longer be purged out.

5.1.2 Fire precautions

Vectra LCPs are inherently flame retardant. Nevertheless, it is in the interest of the converter when storing, processing or fabricating plastics to take the necessary fire precaution measures. Particular care should be taken to observe specific regulations in individual countries.

Certain end products and fields of application may impose special requirements from the fire prevention standpoint. It is the responsibility of the raw material converter to ascertain and observe such requirements.

5.2 Drying

Vectra resins are well known for their excellent thermal and hydrolytic stability. In order to ensure these properties are optimum, the resin and any regrind should be dried correctly prior to processing. If the resin is not properly dried, residual moisture can cause voids, splay, imperfections and in extreme cases polymer degradation. These effects have the potential for poor part quality. Therefore, it is important that the material be dried using the recommended conditions and appropriate equipment.

In order to ensure the quality of molded parts, a desiccant dryer with two or more desiccant beds is strongly recommended. Multiple desiccant bed dryers allow drier air than single bed dryers to be delivered to the plastic resin, thus, reducing both moisture content and necessary drying time.

It is also recommended that the material be allowed to reach the recommended drying temperature before the drying time is started. When a resin is placed in a hopper at room temperature, it may take 2 to 6 hours for the material to reach the necessary drying temperature. This time will vary according to the thermal properties of the resin, the mass of material being dried, and the capability of the hopper.

In addition, it is important to note the location of the thermocouple that measures the temperature of the air being delivered to the hopper. Dryer systems that do not measure the air temperature at the inlet of the hopper might not accurately represent the delivery air temperature. This is because significant heat loss can occur between the exit of the dryer unit and the inlet of the hopper. Heat loss, even through insulated tubes, can result in up to a 50°C lowering in drying temperature.

Summary of Drying Recommendations

1. The resin inside the hopper should be allowed to reach the drying temperature, before the minimum drying time is started.

2. A desiccant dryer with two or more desiccant beds capable of reaching -40°C dew point or below is recommended.

3. Dry Vectra LCP resins at 150°C for a minimum of 4-6 hours in a desiccant dryer. Extended drying up to 24 hours at 150°C will not harm the resin. If necessary, Vectra Ei, H, L and T resins can be dried at 170°C in a desiccant dryer for a minimum of 4 hours. Extended drying up to 24 hours at 170°C will not harm the resin.

4. Ensure the delivery air temperature readout represents the temperature of the air being delivered to the hopper.

Drying Conditions

Vectra® LCP Series	A, C, D	B	Ei, H, L, T
Temperature (°C)	150	150	150 / 170
Time (hours)	4-24	6-24	6-24 / 4-24

Regrind should be dried an additional 2 hours over the recommended minimum time required for that grade, due to its porosity and greater surface area.

6. Injection Molding

6.1 Equipment selection

Vectra® LCP processes much like any highly crystalline thermoplastic using common injection molding equipment.

6.1.1 General

Abrasive wear by glass on injection screws occurs primarily on the lands and edges of screw flights. In time, the root diameter will wear somewhat in the transition and metering zones. The screw should be of heat-treated and stress relieved alloy steel with a hard surface.

A minimum of three zone heating control of the cylinder is necessary for precise temperature control.

Despite the thermal stability of the melt, one should aim for the shortest possible melt residence time (less than 5 minutes) in the cylinder, i.e., the capacity of the machine should be matched to the shot weight of the injection molding. The shot size ideally should be no less than 50 to 75% of the machine's rated shot capacity.

Since Vectra LCPs are a fast cycling material the machine should have a high plasticating or melting capacity to achieve fast cycle times.

6.1.2 Screw design

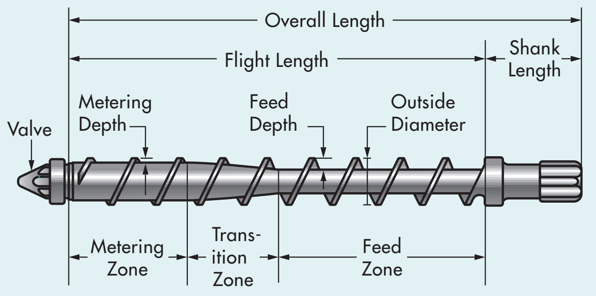
The design of the screw is not crucial for processing Vectra LCPs but some general rules should be observed:

A three-zone screw evenly divided into feed, compression and metering zones is preferred. However, a higher percentage of feed flights may be necessary for smaller machines. For these smaller machines the zone distribution would be $^{1}/_{2}$ feed, $^{1}/_{4}$ transition (compression), $^{1}/_{4}$ metering.

The screw length/diameter ratio, L/D should be from 16:1 to 24:1.

The preferred compression ratio ranges from 3:1 for larger machines to as low as 2:1 for smaller machines. See Figure 6.1.1.

Fig. 6.1.1 · Metering Type Screws Recommended for Processing Vectra® LCP

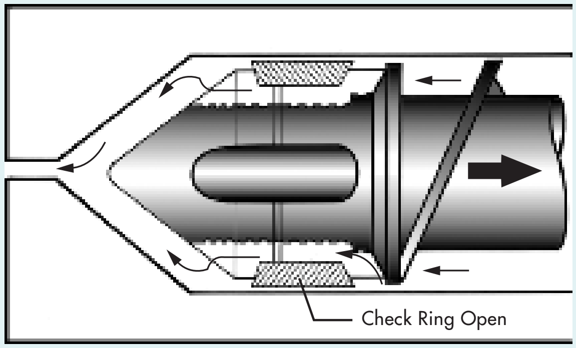


6.1.3 Check ring

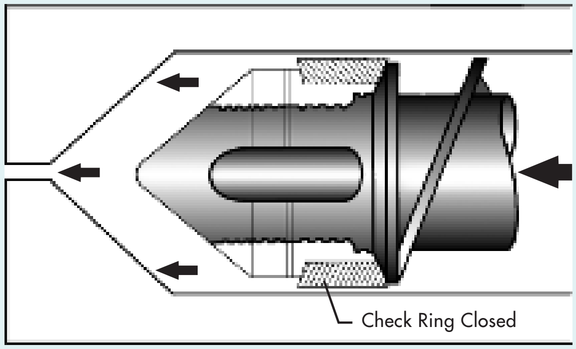
Because Vectra LCP resins have such low viscosity, it is essential that the check ring non-return valve be working correctly (Figure 6.1.2). The simplest way to ensure that the check ring seats properly is to confirm that it holds a constant 2 to 3 mm cushion. Malfunctioning check rings result in inconsistent parts, short shots and poorly formed weld lines.

Fig. 6.1.2 · Check Ring Non-Return Valve Used on Reciprocating Screw Injection Molding Machine

A. Plastication



B. Injection



6.1.4 Nozzle

Vectra LCPs can be processed with a free flow or shut off nozzle. In the case of free flow nozzles, those with a small aperture (1½ to 2½ mm) or nozzles such as a reverse taper nozzle are recommended to prevent drooling of the melt. Nozzles should be as short as possible and have a heating band with its own temperature control system. If drooling or stringing occur, the problem can normally be eliminated by reducing the nozzle temperature or reducing the nozzle diameter.

6.1.5 Hot runner systems

Vectra LCPs can be processed successfully in hot runner systems to conserve material and reduce the amount of rework generated. Externally heated hot runner systems are preferable to the internally heated systems for processing Vectra LCPs. The externally heated hot runner systems achieve an even flow of melted material with a constant melt temperature over the cross-section of the hot runner. The heat energy is evenly distributed from outside to inside; this ensures a homogeneous temperature distribution in the melt. Low voltage systems (5 or 24V) have been well proven in practice. These systems ensure accurate control and regulation of the heating power. The use of heating coils in these systems requires less space and can heat the nozzle tips.

The choice of the correct tool steel is important in the design of hot runner tools for processing Vectra LCPs.

The hot runner system designer should also consider the shearing of the material and the associated effect on viscosity. For this reason, the cross-sections of the hot runner for Vectra LCPs should be designed as small as possible. If we assume that a cross-section of 4 to 8 mm is typical for conventional plastics, then for Vectra LCPs the cross section should be 2 to 5 mm. In the same way as the hot runner, the hot runner nozzles and the gate should be given the smallest possible dimensions. Nozzle cross-sections of up to 2 mm should be used for Vectra polymer types Ei and L. Cross-sections up to 2.5 mm can be used for all other polymer types. Gates from 0.3 to 0.8 mm have been found effective in practice (Figure 6.1.3).

Care should be taken to ensure that the melted material is not retained for too long in the hot runner during processing. If possible, the total residence time in the melt should be less than 5 minutes to minimize the thermal stress on the material. It is important that, as the injection occurs, a constant flux develops from the filling start. This is achieved by correct positioning of the gate, so that it injects against a core or a wall. Jetting should be avoided. Flow to the part can be achieved either by direct hot runner or by a cold sub runner. The recommendations for Vectra distributor geometry apply to the small sub-distributor (Figure 6.1.4). All cavities should be designed in such a way that the flow resistance remains constant. Because of the low viscosity, the melt can move ahead in regions of low flow resistance, possibly leading to warpage problems.

Fig. 6.1.3 · Hot Runner System

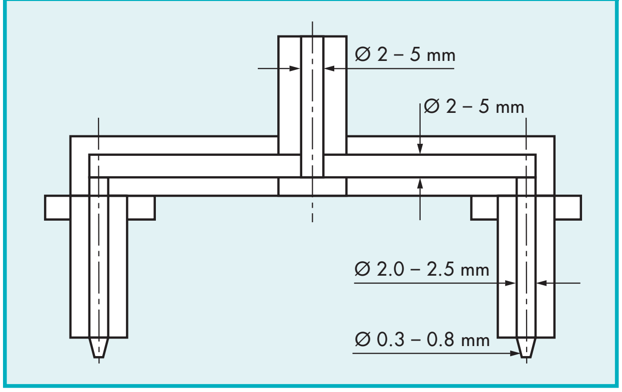
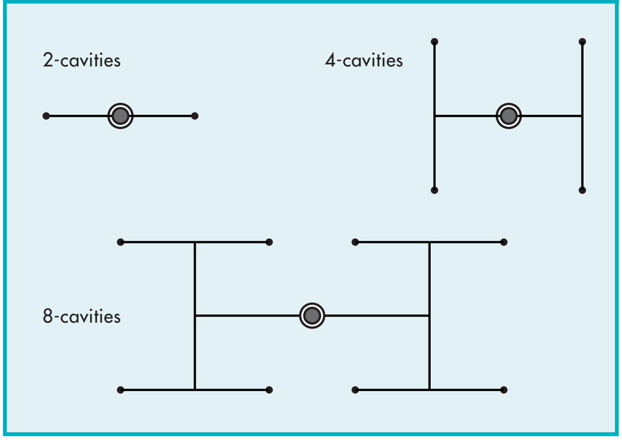


Fig. 6.1.4 · Hot Runner Distributor



Parts manufactured from Vectra LCPs with hot runner systems are typically small, thin-walled parts mainly for the electrical and electronics industries, where good temperature resistance is important for soldering processes. To maximize temperature resistance of the molded part, the processing temperature profile should be kept as low as possible within the recommended processing range. Retention times should also be minimized.

6.2 Injection molding processing conditions

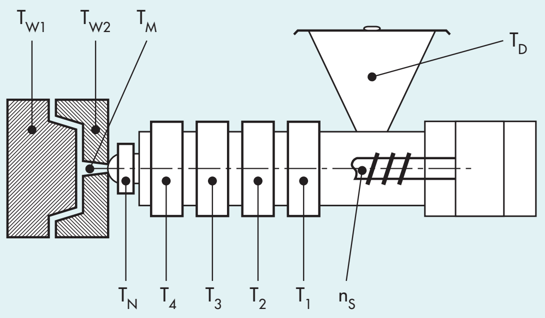
Vectra LCPs are notably easy to process. Typical processing temperatures are summarized in Figure 6.2.1. Recommendations for start up, shutdown and material changeovers are given in Section 5.1.1.

6.2.1 Melt temperature

Determine the melt temperature manually with a needle pyrometer when the machine has been cycling for several minutes. If there are any deviations from the set value, the cylinder and nozzle heater settings must be adjusted accordingly. Melt temperature should generally be checked in this way, because the melt thermocouples integrated into the injection molding machine do not usually show the true value.

If the molded parts are to be exposed to elevated temperatures above 215°C, e.g., electronic components subjected to vapor phase or infrared reflow soldering, then it is imperative that the material is not overheated during processing. The molder should maintain the melt temperature at or even below the temperatures recommended in Figure 6.2.1, and the melt residence time in the cylinder should be minimized.

Fig. 6.2.1 · Typical Injection Molding Conditions



Processing Temperatures (°C)

Series	A and B	C and D	Ei and H	L
T_1	270-280	290-300	315-325	275-285
T_2	275-285	300-310	320-330	285-295
T_3	280-290	310-320	325-335	295-305
T_4	285-295	320-330	330-340	305-315
T_N	290-300	300-330	335-345	305-315
T_M	285-295	320-340	335-345	300-320
T_{W1}	80-120	80-120	80-120	80-120
T_{W2}	80-120	80-120	80-120	80-120

n_S – see screw speed, Section 6.2.4
T_D – see drying instructions, Section 5.2

6.2.2 Injection velocity

To improve weld line strength and flow use very fast injection speeds (0.2 to 0.3 seconds fill time). For optimum mechanical performance the injection velocity should be moderate. Vectra LCP resins are shear thinning, i.e., their melt viscosity decreases quickly as shear rate increases. For parts that are difficult to fill, the molder can increase the injection velocity to improve melt flow. Increasing the injection velocity can be more effective than raising the melt temperature and is less likely to degrade the resin. If the gates are too small however, very fast injection rates can induce excessive polymer shear heating and breakage of fibrous reinforcements. An additional gate may be more appropriate in this situation to reduce shear.

6.2.3 Mold temperature

Vectra LCPs can be processed over a wide range of mold temperatures. Settings between room temperature and 180°C are possible with temperatures between 80°C to 120°C being the most common. Higher mold temperatures usually result in a smoother surface finish, improved flow and better dimensional stability under heat (i.e. surface mount technology).

6.2.4 Screw speed

The screw speed should be sufficiently high to achieve complete plastication of the melt before injection starts. Typical speeds are 100 to 200 RPM at a screw diameter of 15 to 25 mm.

6.2.5 Backpressure

Backpressure is not normally necessary during plastication and should be set to a minimum (2 to 3 bars). With fiber reinforced grades, excessive backpressure leads to fiber breakage.

6.2.6 Screw decompression

Screw decompression (suck back) is not recommended. If screw decompression is necessary to prevent drooling, it should be restricted to a minimum (2 to 4 mm). Excessive decompression can draw air or moisture into the nozzle and result in a cold slug or blistering on the surface of the molded part.

6.2.7 Injection pressure

The optimum injection pressure depends on the specific Vectra LCP grade as well on the design of the molded part, the mold and machine conditions. All Vectra LCP grades have low melt viscosity and generally require lower injection pressures than other thermoplastic materials.

6.2.8 Holding pressure

The holding pressure should be equal to or less than the injection pressure. The required holding pressure times are shorter than for partially crystalline thermoplastics since Vectra LCPs freeze very quickly. The required holding pressure time can be determined by part weight optimization.

6.2.9 Cycle time

All Vectra LCP resins have, in addition to low viscosity, a very low heat of fusion (about 5 to 10% of the heat of fusion of PET or PBT). This means that relatively little heat has to be removed from the molded part through the walls of the mold to freeze the part. Ejection can take place at high temperatures if the ejectors are designed not to make an indentation on the molding. Very low internal stresses at all mold temperatures enable the injection mold to be operated at low temperatures. These characteristics lead to exceptionally fast cycle times. As the wall thickness is changed, the cooling time varies approximately with the square of the thickness. This impacts the total cycle time.

6.3 Regrind

The regrinding procedures for Vectra LCPs are similar to those of other high modulus thermoplastics. LCPs are tough, fibrous materials that require some care in handling to produce adequate regrind chip quality. High quality regrind will improve the feeding characteristics of the regrind and virgin mix, the stability of the molding process and ultimately part performance.

Several variables will affect the regrind quality. These include the particular grade of Vectra LCP being processed, the type of filler or reinforcement, the geometry of the part (or runner), the percentage of regrind, the type of delivery system and machine.

The processor and end user must determine the upper limit of regrind by evaluating part performance and regulatory limits as well as molding process stability.

The following guidelines will produce improved regrind quality.

6.3.1 General recommendations

1. Runners, sprues and scrap parts will cut best, and shatter least, when fed to the granulator while still hot, i.e. just out of the mold. Granulating while hot will produce the smoothest chip edges and generate the least amount of tails and fines. If this is not practical, the scrap may be reheated in an oven to approximately 150°C and then cut while hot. When grinding, take care to feed the parts into the granulator slowly. This will minimize the residence time in the granulator and encourage cutting rather than smashing the scrap.
2. Select the largest hole size in the granulator screen to cut scrap into a chip size that will feed into the molding machine being used. Different size machines may require different screens. A proper screen hole size ensures a minimum amount of “shredding” and fines generation as parts are being cut.
3. Sharp blades improve regrind quality. They will tend to cut rather than shatter the scrap.
4. Minimal gaps between blade and bed knife improve regrind quality. Set to the closest gap recommended by the granulator manufacturer.

If the above procedures do not produce acceptable regrind with your existing granulators, you may have to use a low speed granulator. Machines that operate at or below 30 RPM tend to improve chip quality by shear cutting the larger oversized granules during regrinding rather than smashing or shredding them. High speed granulators tend to shatter the scrap rather than shearing it – especially when it is cold, less than 100°C. This results in Vectra LCP regrind that is rough and fibrous with a high level of fines.

The following chart indicates the approximate percentage by weight of fines generated and chip quality of parts evaluated in one test. Naturally results will vary with equipment used and parts granulated. Fines are particles that pass through a 10-mesh screen. Excessive fines and poor chip quality may cause difficulty in feeding regrind into a molding machine.

		Cut Hot	Cut Cold
Low Speed Granulator	Fines, weight %	5	13
	Chip Quality	Good	Fair
High Speed Granulator	Fines, weight %	5	17
	Chip Quality	Fair	Poor

6.3.2 Equipment

A number of users have reported success using an S-Cutter with slow RPM and low torque from Nissui Corporation for regrinding Vectra LCP runners, sprues and parts.
The equipment is available from:
Nissui Corporation
3410 West Road
East Lansing, MI 48823, USA
Tel: ++1 (517) 332-7400
Fax: ++1 (517) 332-2148
or www.nissui.com

Scholz Apparate & Anlagenbau GmbH
In der Hernau 5
D-90518 Altdorf
Germany
Tel: ++49 (0) 9187-4037
Fax: ++49 (0) 9187-42548

6.3.3 Using regrind

Four factors have the potential to cause loss of properties in regrind material: contamination, thermal decomposition, hydrolysis (reaction with water) and damage to reinforcements, especially glass fibers.

Vectra LCP resins have excellent thermal and hydrolytic stability when molded and dried at recommended conditions. Fiberglass reinforced products may exhibit some loss of notched Izod impact performance due to breakup of the glass fibers.

To maintain color uniformity and optimum mechanical properties, limit regrind to 25%. Underwriters' Laboratories accepts up to 25% regrind for UL listed applications without added testing.

Many Vectra LCP grades have also been approved by UL for use at 50% regrind. For an up to date UL listing logon to www.Ticona-US.com to view Product Information/Agency Compliance.

Whenever using regrind material, the end user must test the finished parts to ensure satisfactory performance. Best practices for using regrind include:

1. Adequately dry both the regrind and the virgin resin, preferably to less than 0.02% moisture. Refer to Section 5.2 for recommended drying procedures.
2. Regrind material must be free from contamination of any foreign material, including other plastics, metal, even other LCP resins.
3. Avoid excessive melt temperatures.
4. Maintain the melt residence time as short as possible, preferably less than five minutes.
5. Do not use screw decompression.
6. Refer to Section 6.2 for recommended injection molding conditions.

When molded using the recommended conditions, Vectra LCPs maintain about 80-100% of its strength and modulus. Glass fiber reinforced grades may exhibit a reduction in notched Izod impact due to fiber breakage during processing. After repeated moldings, a slight darkening of color has been observed.

Whenever regrind is used, and especially if a molder considers using greater than 25%, adhere to the following guidelines:

1. Run parts for qualification testing under steady state conditions. Be in continuous production with a constant feed of regrind material at the desired ratio for several hours to establish the distribution of residence time.
2. Qualify the parts by the same process used for the original qualification of virgin material.
3. Adhere to any applicable regulatory requirements.

6.4 Troubleshooting

Many processing problems are caused by easily corrected conditions such as inadequate drying, incorrect temperatures or pressures. Often solutions can be found by following the recommendations given below.

Adjustments should be moderate and made a step at a time giving the machine time to stabilize before further adjustments are made. Check that the machine is operating within the parameters recommended for the specific grade of Vectra LCP. For example, melt temperature should be confirmed on air shots collected at typical cycle times when the process is stabilized.

6.4.1 Brittleness

- Check for contamination
- Decrease amount of regrind in the feed
- Decrease melt temperature by
  - Eliminating back pressure
  - Decreasing screw speed
  - Decreasing the cylinder temperature
- Dry the resin and regrind before use

6.4.2 Burn marks

- Decrease injection rate
- Improve venting to minimize trapped gas
- Increase gate size or relocate to improve venting

6.4.3 Dimensional variability

- Confirm complete screw recovery in allotted time
- Confirm that check ring seats uniformly
- Maintain a 3 to 5 mm cushion
- Fill the mold as rapidly as possible
- Increase cooling time
- Check the machines hydraulic and electrical systems for erratic performance
- Reduce the number of cavities in the mold
- Balance the layout of runners, gates and cavity
- Improve venting

6.4.4 Discoloration

- Check for contamination of resin feed
- Purge heating cylinder
- Decrease melt temperature by
  - Eliminating back pressure
  - Decreasing the screw speed
  - Decreasing the cylinder temperature
- Minimize residence time and cycle time
- Improve venting in the mold
- Minimize residence time by moving mold to a press with a smaller shot size

6.4.5 Flashing

- Decrease injection pressure
- Decrease feed or shot size to ensure a 3 to 5 mm cushion
- Decrease injection rate
- Decrease melt temperature by
  - Eliminating back pressure
  - Decreasing the screw speed
  - Decreasing the cylinder temperature
- Check mold closure for mismatch of parting line
- Improve mold venting
- Increase gate size
- Check press platens and mold support for parallelism
- Move mold to a larger clamp tonnage press

6.4.6 Jetting

Vectra LCPs are highly oriented, exhibit little or no die swell and tend to jet into large cavities.

- Decrease injection rate
- Increase gate dimensions to 85 to 100% of wall thickness
- Improve gating so melt impinges on core, pin or wall

6.4.7 Leaking check ring

- Check ring must seat properly.
- Ensure that the check ring holds a 3 to 5 mm cushion

6.4.8 Nozzle problems

A. Nozzle drool or stringing
- Decrease nozzle temperature
- Decrease melt temperature by
  - Eliminating back pressure
  - Decreasing the screw speed
  - Decreasing the cylinder temperature
- Add minimal decompression (too much can cause blisters on reheating molded parts)
- Decrease mold open time
- Dry the material thoroughly
- Use a nozzle with a smaller orifice
- Use a nozzle with a reverse taper
- Use a nozzle with a positive shut off

B. Nozzle freeze off
- Increase nozzle temperature
- Decrease cycle time
- Increase mold temperature
- Add sprue break (carriage back) if available
- Use a nozzle with a larger orifice

6.4.9 Short shots

- Check hopper to confirm adequate feed
- Ensure check ring is seated
- Increase feed or shot size to ensure 3 to 5 mm cushion
- Increase injection pressure moderately
- Increase injection speed
- Increase mold temperature
- Check cavity vents for blockage
- Decrease size of gate (possibly runner) to increase shear

6.4.10 Sinks and voids

Vectra LCPs exhibit very low shrinkage and thus few sinks or voids. Most often, it is an indication of short shots.

- Ensure check ring is seated
- Increase feed or shot size to ensure 3 to 5 mm cushion
- Eliminate screw decompression
- Increase primary pressure time
- Check cavity vents for blockage
- Relocate gates near the heavy sections
- Core out the part

6.4.11 Sticking

A. Sticking in cavity
- Decrease primary pressure
- Decrease injection speed
- Ensure 3 to 5 mm cushion
- Eliminate secondary pressure
- Decrease primary pressure time
- Eliminate undercuts
- Increase draft
- Check part for drag marks or unbalanced ejection
- Polish tool in ejection direction
- Improve effectiveness and balance of pullers and sucker pins

B. Sticking on the core
- Measure core temperature, decrease temperature or improve cooling
- Eliminate undercuts
- Polish cores
- Increase drafts

C. Sticking in the sprue bushing
- Check the alignment and orifice size of the nozzle relative to the sprue bushing
- Eliminate secondary pressure
- Decrease primary pressure time
- Increase mold close time
- Add sprue break (carriage back) if available
- Eliminate undercuts and polish surfaces of sprue bushing
- Provide a more effective sprue puller

6.4.12 Surface marks and blisters

Vectra LCPs are highly oriented and often exhibits flow lines that are not splay marks.

- Decrease melt temperature by
  - Eliminating back pressure
  - Decreasing the screw speed
  - Decreasing the cylinder temperature
- Check for contamination
- Dry material before molding
- Eliminate screw decompression
- Decrease melt residence time by
  - Decreasing overall cycle time
  - Moving tool to a smaller capacity press
- Increase gate size

6.4.13 Warpage and part distortion

Vectra LCP products are highly oriented and shrink much less in the flow direction than in the direction transverse to flow. Most warpage is due to the flow patterns, dictated by part and gate design. Except for mold temperature, processing conditions have little effect on shrinkage differential.

- Relocate gate or adjust wall thickness to improve fill pattern
- Confirm that the part ejects uniformly
- Check for proper handling and immediate degating of parts after ejection
- Decrease mold temperature
- Increase mold close time
- Ensure that the part is properly packed by
  - Confirming that the check ring holds a 3 to 5 mm cushion
  - Increasing the primary pressure, injection rate

6.4.14 Weld lines

- Eliminate mold release
- Increase injection speed
- Increase injection pressure
- Increase mold temperature
- Increase melt temperature
- Vent cavity in weld line area
- Provide overflow well adjacent to weld line area
- Use a single gate
- Improve flow pattern by
  - Relocating gate
  - Making sure wall thickness is uniform
  - Adjusting wall thickness variations to direct the melt flow

7. Extrusion

A number of unreinforced Vectra® LCP grades can be used for extrusion of rod, profile, film and sheet, pipe, tubing, fiber and extrusion blow molding into shaped articles. A new family of Vectran™ LCPs have been specifically designed for coextrusion in multi-layer laminate film structures. These grades may also be useful for other applications.

Extruded products are historically highly anisotropic and are very strong in the machine direction. New processing techniques have been developed to improve the transverse direction properties and provide a more isotropic shaped article.

Blown film processes can be utilized to reduce the anisotropy found in cast LCP films. The process typically requires an unfilled Vectra LCP resin and is limited to a maximum film thickness in the range of 100 microns. By adjusting the machine direction draw ratio and transverse direction blow up ratio, it is possible to produce films ranging from highly anisotropic to fully isotropic in physical properties. Tensile modulus can range from 20,000 MPa/3,500 MPa (MD/TD) for an anisotropic cast film to 7,000 MPa/7,000 MPa for an isotropic blown film. This capability is especially useful in the electronics industry where precise dimensional characteristics, including low shrinkage and controllable CLTE, are required.

Mineral and fiber reinforced Vectra LCPs can be used for extrusion as long as the die cross section is large enough to accommodate the filler. Filled resins are recommended for thermoformed sheet and for an extruded shape that is to be machined. Fillers can also improve thermal and wear characteristics.

Be sure to follow the drying procedures outlined in Section 5.2 before processing Vectra LCPs.

7.1 Equipment selection

7.1.1 General

Vectra LCPs should be extruded with a relatively cool feed zone, which increases throughput. A barrel L/D ratio of at least 30:1 is recommended to ensure complete and uniform melting of the polymer. A vacuum vented extruder barrel is helpful in eliminating volatiles in the extrudate.

7.1.2 Screw design

The melt viscosity of Vectra LCPs are highly dependent on shear stress. This behavior commonly results in non-uniform melt flow, or surging. To minimize this problem, select a metering screw with deep flights in the feed zone and a uniform square pitch. A compression ratio of 4:1 to 5:1 for a single stage screw or the first stage of a two-stage screw is preferred. For the second stage of a vented screw, the compression ratio should be 2:1 to 3:1. The length of any feed or metering section should be at least five screw diameters with a gradual transition between them.

7.1.3 Screen pack

Since Vectra LCPs are often processed close to the melt temperature, efficient screen pack heaters and good insulation are essential to prevent polymer freeze up. A wide range of screen sizes (down to 100 mesh) can be used for filtering the extrudate without causing excessive pressure build up. A screen filter should not be used when extruding filled polymer.

7.1.4 Head and die

Standard dies are generally appropriate for Vectra LCP extrusion. Temperature control over the entire head and die area must be uniform. The melt pressure should be monitored and maintained as uniformly as possible, and the screen pack replaced when the pressure starts to increase significantly.

7.1.5 Melt pump

Because Vectra LCPs are a shear thinning material, they experiences a higher level of backflow over the screw flights than conventional polymers. This can result in reduced screw pumping efficiency at high extruder discharge pressure. A melt pump is recommended for high extrusion rates and whenever a filter (cartridge or screen changer) is utilized. The melt pump should be placed directly downstream of the extruder.

7.2 Processing

Safety precautions, start up, and shutdown procedures for extrusion are very similar to those outlined for injection molding in Section 5.1. Drying and storage of material is described in Section 5.2.

7.2.1 Film and sheet

Extrusion of film and sheet can be carried out with either unfilled or filled Vectra LCP polymer. Thermoforming operations generally require a glass or mineral filled grade, which can be used to extrude thicker gage sheet.

Film and sheet is often extruded close to the melt point so care should be taken against polymer freeze up in the screen pack and die, especially at start up. Thermally insulating these components is helpful. Extrusion temperatures can be carefully lowered from the recommended values for thicker sheet (greater than 0.25 mm) if necessary to maintain melt strength.

The distance from the die to the finishing roll nip should generally be kept as short as possible to avoid premature freezing of the molten extrudate. A drawdown ratio (ratio of the die gap to film thickness) of 2.0 is recommended for thin film (less than 0.25 mm), and a drawdown ratio of 1.1 to 1.2 should be used for thicker film and sheet.

Standard center feed dies can be used to extrude film and sheet. A large manifold is recommended to distribute the melt evenly across the die. The die gap setting should be adjustable to help regulate the die pressure and achieve the desired drawdown ratio.

Film up to 0.25 mm thickness can be cast on a single roll or extruded onto a three-roll stack. Thicker sheet may require a straight through string up. Finishing rolls should be heated, if possible, to provide a controlled uniform cooling rate and to produce a high quality film surface. Since Vectra LCP films neck in less at the edges that other plastics, the required width of the finishing rolls for a given die size may be greater than expected based on previous experience. Film less than 0.25 mm thick may be wound on a spool, while thicker film generally must be cut into lengths.

7.2.2 Profiles

Monofilament strands, rods and other profiles can be extruded from unfilled Vectra LCP resins, preferably Vectra A950 or Vectra B950. High molecular orientation developed during extrusion gives these products exceptional tensile strength and stiffness in the machine direction. Due to their high melt strength, both products can be extruded either horizontally or vertically. A die melt temperature of approximately 280°C to 285°C is suggested for Vectra A950, and 300°C to 305°C for Vectra B950. Keep the die pressure above 0.7 MPa to maintain a consistent densely packed product.

Unlike many engineering thermoplastics, Vectra LCP products exhibit very little die swell or distortion upon exiting the die. With the proper die design, minimal drawdown is required to achieve high mechanical strength. A drawdown ratio of 4 to 7 (ratio of die orifice area to cross sectional area of extrudate) is recommended for best results.

The entry to the die orifice should be streamlined and free of stagnation points so that polymer does not hang up and degrade. Conical entry dies with a 30 to 70° cone entry angle are recommended for extrusion of circular cross sections. A die with no land length is preferred but a short land length is acceptable. Keep the die land length to no more than 4 times the orifice diameter. A longer length will cause excessive shear deformation and reduction of tensile properties. A conical die mandrel is generally used with its tip centered upstream from the orifice entry.

Cooling and sizing of the extruded profile depends on the cross sectional area. Air-cooling is adequate for thin strands up to 0.15 mm diameter. A sizing guide should be used for any diameter greater than 3 mm.

Larger diameters and shapes should generally be water-cooled. Water baths should be temperature controlled and held at 45°C for small diameter profiles (for example, 2 mm diameter rod running at 30 m/minute line speed). A short (approximately one meter) bath length is generally sufficient. The distance between the die face and the water bath normally ranges from less than 1 meter to 3 meters and may be adjusted to achieve the most circular cross section possible for the extruded monofilament.

Due to the stiffness of the extrudate, there should be no sharp bends in the line. Roll and take up spool diameters should be no less than 200 times the diameter of the extruded rod.

7.2.3 Pipe and tubing

A wide range of pipe and tubing diameters and thicknesses can be extruded using Vectra LCPs. A melt pump between the extruder and the die provides a smoother, uniform extrudate and minimizes surging. It is recommended that extrusion melt temperatures be as low as possible to improve melt strength and increase production rates.

Small diameter tubes (up to about 2 mm) can be extruded directly into a cooling trough, while sizing is required for larger diameters. Where uniform control of diameter and roundness are critical, a vacuum water-sizing bath is preferred. If a spider die design is used, the legs should be as far from the die outlet as possible to allow a molten extrudate to rejoin and form a homogenous melt. The spider should be carefully centered to maintain a uniform wall thickness. A die land length of two or more times the tube diameter is ideal.

Sizing rings may be used to control outside diameter uniformity and smooth the outside surface of the pipe or tube. Sizing rings should be about 0.25 mm greater in diameter than the product. A protruding mandrel is required for effective sizing of the inside tube diameter.

A drawdown ratio (the ratio of the die flow annulus divided by the cross sectional area of the extruded tube) of 1.2 to 2.0 is recommended for tubing.

7.2.4 Overcoating

Vectra A950 has been used for overcoating of wire and optical glass fiber to provide extra protection and strengthening of the fiber. The coated products have very low thermal conductivity, moisture and gas permeability, water absorption and coefficient of thermal expansion.

Use a crosshead die with a converging nozzle for extrusion. A convergence ratio (ratio of the flow area cross section before and after convergence) of 10 to 20 is required to induce molecular orientation for good mechanical properties. The die land length should be about 6 mm or less to avoid excessive heat transfer to the glass fiber buffer coating.

The cooling water trough should be maintained between 25°C to 45°C to prevent too rapid cooling of the jacketed fiber. Keep a distance of 15 to 20 cm between the die face and the cooling water. Rolls need to be placed so that the jacketed fiber is never bent around a radius less than 100 times the jacketed fiber diameter.

The coated fiber can be further oriented by drawdown after exiting the die, which helps to increase tensile properties. The recommended drawdown ratio is defined as:

$$\text{Drawdown ratio} = (A^2\text{-}B^2)/(C^2\text{-}D^2)$$

A = outside diameter of the die nozzle flow annulus
B = inside diameter of the die nozzle flow annulus
C = diameter of the coated product
D = diameter of the wire or fiber

7.3 Troubleshooting

As with the injection molding troubleshooting guide (Section 6.4), many processing problems are caused by easily corrected conditions, such as inadequate resin drying, incorrect temperatures. Try the recommended solutions given below in the order in which they are listed under each problem category.

7.3.1 General extrusion

Extrudate cross section varies with time
- Check line speed uniformity
- Check for extruder surging; reduce feed zone temperature to restore even flow
- Excessive drawdown; adjust die dimensions
- Install melt pump to stabilize flow rate

Extrudate has excessive voids
- If gassing appears to be a problem, reduce melt temperature or use vacuum vented extruder
- If melt pressure is less than 0.7 MPa, increase screw RPM, adjust die size, or use finer filter in screen pack (for unfilled resins) to increase melt pressure

Poor surface appearance
- Dry resin more thoroughly
- If gassing appears to be a problem, reduce melt temperature or use vacuum vented extruder
- If striations occur, raise melt temperature in 2°C to 3°C increments

Striations on extrudate in machine direction
- Check die for nicks
- Check all equipment surfaces for contamination or degraded resin

7.3.2 Pipe and tubing

Bowing of pipe or tubing
- Uneven cooling; make sure extrudate is completely submerged in cooling water
- Check for wall thickness variation
- Check alignment of extrusion and sizing dies

Poor surface only on inner wall
- Check for material buildup on die mandrel
- Adjust length of mandrel

Wall thickness variation
- Center the die mandrel

7.3.3 Profiles

Extrudate has distorted cross section
- Adjust melt temperature either higher or lower
- Adjust die to water bath distance
- Adjust drawdown ratio
- Sizing may be required

Strand breaks in extrudate
- Dry resin more thoroughly
- Raise melt temperature incrementally
- Reduce drawdown ratio if there is a periodic variation in cross section

7.3.4 Film and sheet

Large, uniformly spaced perforations in film
- Reduce melt temperature
- Decrease die gap to reduce drawdown
- Reduce die temperature

Sagging extrudate
- Lower melt temperature

Uneven or distorted edges
- Polymer freezes up on die edges; clean die and raise melt temperature

7.3.5 Overcoating

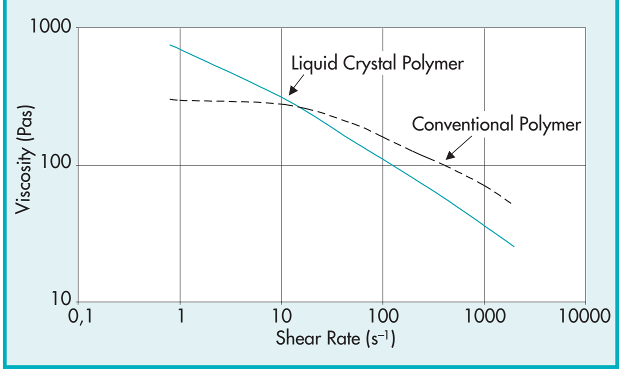
Breaks in optical fiber
- Make sure polymer and optical fiber are thoroughly dried
- Check for contamination in fiber guide
- Adjust tension at the unwind stand and die entrance

Out of round cross section
- Reduce melt temperature
- Center die tip nozzle
- Adjust die to water bath distance
- Adjust water bath temperature

8. Rheology

Vectra® LCPs have a nematic liquid crystal structure. The melt viscosity decreases continually with increasing deformation (shear) rate. At the deformation rates that normally occur during injection molding, the melt viscosity is lower than that of conventional filled or reinforced polymers (Figure 8.1).

Fig. 8.1 · Melt Viscosity Comparison
Vectra® LCP versus Semi-Crystalline Polymer



Comparisons of melt viscosity as a function of temperature for the important glass filled grades are given in Figure 8.2.

Melt viscosity of several unfilled Vectra LCPs are shown in Figure 8.3.

With Vectra LCPs, it is possible to fill very thin walls down to less than 0.2 mm. The injection pressures are lower than with amorphous or semi crystalline resins. Vectra LCPs can be used to produce thin walled miniature parts and complicated parts with long flow paths such as long, narrow connectors or small coil bobbins.

Despite good melt flow at the high shear rates, which normally occur in injection molding, Vectra LCPs do not form any flash. It is possible therefore to mold thin walled articles and parts with movable cores without any flash. In the case of connectors and relays, for example, this can sometimes bring a considerable reduction in manufacturing cost because the costly deflashing step is unnecessary.

Fig. 8.2 · Melt Viscosity versus Temperature
(Glass filled grades at shear rate = 1,000/s)

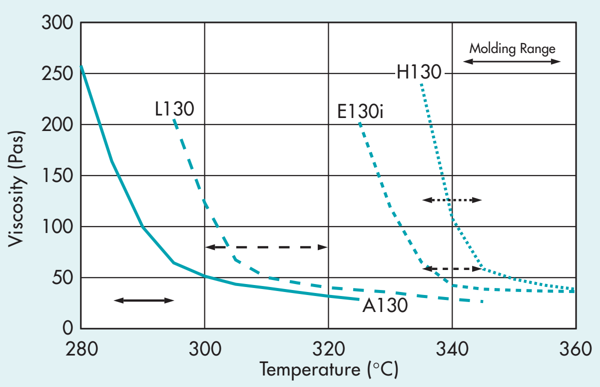
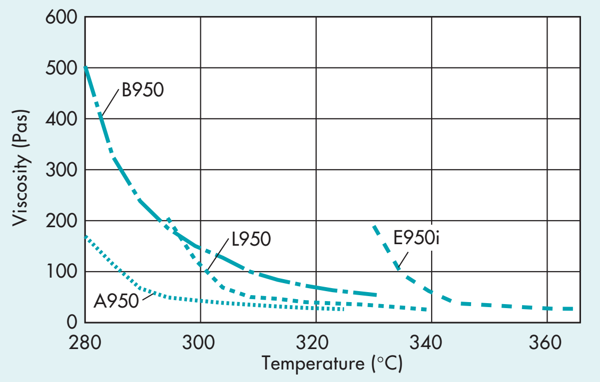


Fig. 8.3 · Melt Viscosity versus Temperature
(Unfilled grades at shear rate = 1,000/s)



9. Design

In most cases, designers and molders chose Vectra® LCPs for their excellent dimensional stability, good flow in thin walls and mechanical toughness with a broad processing window. Part design is the key consideration in optimizing both processing latitude and part performance. In general, all of the standard recommendations for good design of plastic parts are applicable when designing with Vectra LCPs. For instance, parts should be designed and molds constructed to provide smooth, uniform flow of the polymer melt. In addition, the part design must control the resins anisotropic properties – a fact that presents both opportunities and challenges. The direction of material flow in the mold influences mechanical properties of the molded parts. Thus, there is a strong link between part design, performance and end use requirements.

9.1 Part design

9.1.1 Nominal wall thickness

Of all the issues in plastic design, selecting the proper nominal wall thickness is probably the most important. Choosing the proper wall sections sometimes determines the ultimate success or failure of a product. While an inadequate wall section can lead to poor performance or structural failure, a section that is too heavy, even in just certain regions, can make the product unattractive, overweight or too expensive. Although some problems can be corrected after the mold is built, such solutions are often expensive.

The vast majority of injection-molded plastic parts have wall thicknesses in the range of 1 mm to 5 mm. Because of the low viscosity and easy flow of Vectra LCPs, typical wall thicknesses are in the range of 0.3 mm to 1 mm. Thickness within this range is generally related to the part size. This does not mean that parts cannot be molded thinner or thicker, or that a big part can not be thin or a tiny part thick. However, these norms should act as a starting point for the design.

If a part is subjected to any significant loading, the load-bearing areas should be analyzed for stress and deflection. If the stress or deflection is too high, the following alternatives should be considered:

a) use ribs or contours to increase section modulus;
b) use a higher strength, higher modulus material;
c) increase the thickness of the wall section if it is not already too thick.

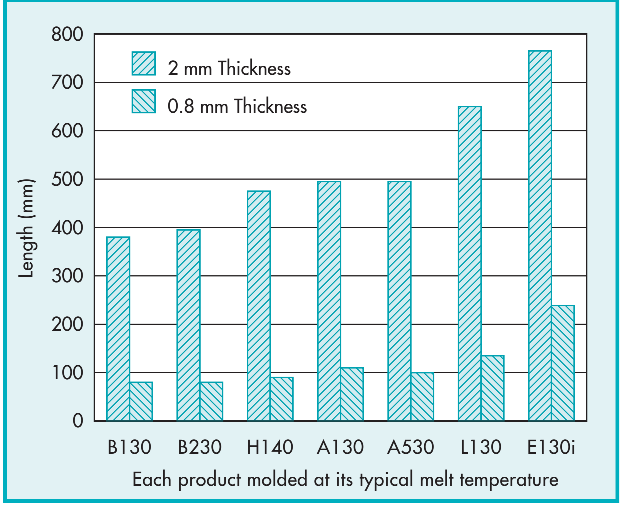
Plastic parts are good insulators for electrical and heat energy. They can also serve as filters to sound, vibrations and light. In general, insulating ability is directly related to the thickness of the plastic. In the case of sound transmission, a change in thickness may be needed to change the resonant frequency of a plastic housing.

The impact resistance of a particular part is directly related to its ability to absorb mechanical energy without fracture or plastic deformation. This in turn depends on the properties of the resin and the geometry of the part. Increasing wall thickness generally improves the impact resistance of the molded part. However, increased wall thickness could also negatively affect impact resistance by making the part overly stiff, unable to deflect and distribute the impact.

9.1.2 Flow length and wall thickness

The spiral flow lengths of select grades at two different thicknesses are shown in Figure 9.1.1. This information will give a relative measure of how far the plastic can be expected to flow from the gate. The design engineer should also refer to the data presented in Chapter 8 on rheology.

Fig. 9.1.1 · Spiral Flow Lengths (Injection pressure: 195 bar hydraulic/1000 bar specific, Mold temperature: 100°C)



9.1.3 Shrinkage

The change in volume of Vectra LCPs on solidifying from the melt is considerably less than that of other engineering thermoplastics. Shrinkage of Vectra LCPs depends mainly on orientation induced by the melt flow in the mold due to part design, wall thickness and gating. Shrinkage anisotropy is reduced by the use of fillers. Thicker sections shrink more, especially in the transverse direction. The effects of melt and mold temperature, injection pressure and injection rate are modest relative to other engineering plastics. Shrinkage data is reported in Short-Term Properties brochure.

Because of the low shrinkage, polished molds are recommended to avoid ejection problems. If necessary, a suitable draft should be provided to assist removal from the mold. The low shrinkage of Vectra LCPs coupled with their low coefficient of thermal expansion (section 3.2.3) offers the advantage of very high manufacturing precision and close tolerances. This makes it possible to achieve high reproducibility of the part dimensions which can be a crucial advantage for automatic assembly of components leading to a considerable reduction in manufacturing costs.

9.1.4 Draft angle

Vectra LCPs exhibit very low shrinkage and unusually high stiffness. Consequently, they typically eject easily from most cores. Parts have been molded with well-polished and without any draft. Even so, molding parts without a draft should be considered only when there are no alternate options. A draft angle of $\frac{1}{10}$ to $\frac{1}{4}$ degree per side is suggested. Larger draft angles provide easier ejection.

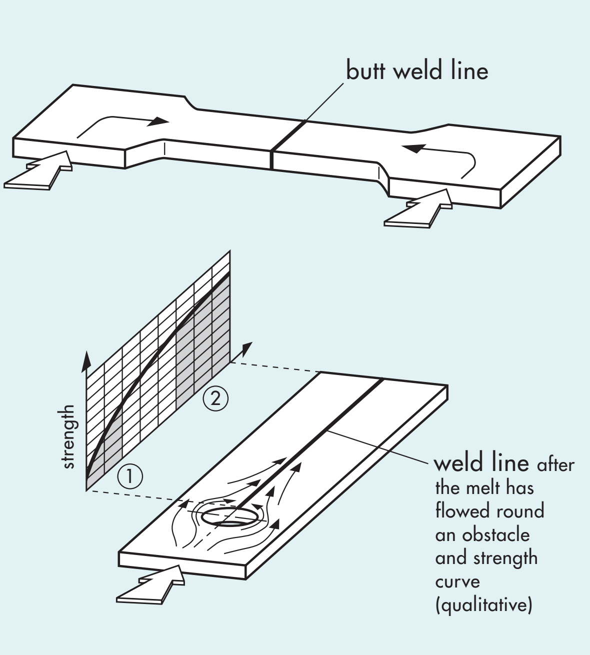
The same factors that allow molding of Vectra LCPs with minimal draft may result in parts sticking in the mold if there are slight undercuts or rough areas. With some grades of Vectra LCP, a near zero flow direction shrinkage can cause sticking in the cavity side of the mold rather than the core. Occasionally a core may need to be roughened to pull the part from the cavity.

9.1.5 Warpage

Smooth, uniform flow of the melt is crucial to controlling warpage. Wall sections should be as uniform as possible since parts are subject to warping if there is a heavy wall on one side and a thin one opposite. There is very little warpage when the parts are designed so that resin flows evenly from one end to the other in a continuous, longitudinal path without weld lines.

The difference between mold shrinkage in the flow and cross flow direction is roughly comparable to that for other 30% glass fiber reinforced semi-crystalline resins such as PBT. The differential shrinkage can be eliminated or greatly reduced by relocating the gate and by suitable design of the part. With complicated moldings, it is extremely difficult to predict shrinkage exactly since the flow behavior of the melt and subsequent orientation is difficult to foresee.

Fig. 9.1.2 · Weld Lines



9.1.6 Weld lines

Weld lines are weak points in any molding made from reinforced plastics. In liquid crystal polymers, the rigid molecular chains and reinforced fibers, if present, are oriented largely parallel to the flow front. The reinforcement is therefore interrupted in the region of the weld line. Hence, great attention must be given to the weld lines.

Butt welds in which the melt fronts meet and remain in a plane perpendicular to the flow direction are particularly critical (Fig. 9.1.2). The LCP molecules are oriented parallel to the melt front so that the strength of a test specimen can be reduced by up to 90%.

Moldings with knit lines formed after the melt has flowed around an obstacle (core) retain 50 to 60% of the transverse strength without a knit line (Figure 9.1.2). The melt stream is divided into two at the obstacle and when the two streams reunite, welding is impaired by cold melt fronts. When two melt streams meet directly behind the core at an obtuse angle, similarly low strength results as with a butt weld line (Figure 9.1.2). With growing distance from the obstacle, the two melt streams meet at an increasingly acute angle until a parallel flow front has formed. Strength increases correspondingly with increasing distance from the obstacle.

A molding without weld lines has the highest design strength. If weld lines are unavoidable, they should be sited in regions of low stress through suitable location of the gate. If possible, butt welds should be avoided. Long knit lines after an obstacle are preferable to short knit lines.

One means to improve the strength of weld lines is to create an overflow well or tab. The melt can then flow from the end of the weld line into the overflow. The overflow is then trimmed off the molded part.

9.1.7 Ribs, corners, radii

The provision of ribs on molding walls is one possible means to improve design strength and at the same time avoid material accumulation due to excessive wall thickness. However, ribs influence melt flow in the mold and can cause undesirable knit lines. If the flow direction of the melt coincides with the longitudinal axis of the ribs, the thickness of the ribs should be as near as possible to the thickness of the adjacent wall (75 to 100%). The melt then flows in the same direction through the rib and wall. If the rib is thinner, there is a tendency for the melt to first rush through the wall and then flow in the transverse direction into the rib. This would set up different directions of orientation and lead to warpage.
Any bosses should be sized the same as the ribs.

Rib connections to adjacent walls should be radiused. Radii of 0.1 to 0.2 times the thickness of the adjacent wall are recommended to reduce notch effects. Larger radii cause the melt to rush into the rib connection possibly resulting in undesirable knit lines or “back filling” of the molded part.

Transitions, corners and molding edges should have generous radii provided this does not result in disadvantages for mold filling (rushing of the melt, knit lines). For outside radii, 1.5 times the wall thickness is recommended; for inside radii 0.5 times wall thickness.

9.1.8 Holes and depressions

Holes and depressions or thinner areas are particularly critical design issues because of the need to carefully consider the impact of weld lines on the integrity of the molded Vectra LCP part. Typically, to maximize the strength of a molded-in hole the minimum distance between the edge of the hole and the edge of the part should be at least twice the hole diameter or twice the nominal part wall thickness. Use your judgement when choosing which guideline to apply, since the greater the distance the stronger the part. This is especially critical when a fastener or a press-fit pin is inserted into the hole; the stress at the hole may cause a weak weld line to fail. Similar rules hold for depressions, since they also generally cause a downstream knit line. The design situation is less critical, since there is generally no external stress imposed on a depression. If the part design is constrained to smaller than recommended dimensions between the hole and edge of the part, the knit line may be strengthened by placing an “overflow” gate and well in the vicinity of the knit line. This can dramatically strengthen a weak knit line.

9.1.9 Latches, snapfits, interference fits

Latches designed using Vectra LCPs should be tapered (typically a 2:1 taper) to provide a more uniform stress distribution along the length of the beam. This design technique will limit the stress concentration at the base of the latch. Additional deflection can also be achieved using this tapered beam approach.

Press fits depend on the interference of the components to hold the assembly together. With low elongation, high modulus materials such as Vectra LCPs, if the strain is too high, the material will fracture, losing the retention force designed to hold the components together. Except for very light press fits, this type of assembly is not recommended due to the hoop stress in the boss, which might already be weakened by a knit line. Designing an interference press fit by adding “crush ribs” to the inside diameter of the boss or hole is a technique that can lower the stress while maintaining retention. Other techniques such as the use of barbs or splines on metal pins that are inserted into the plastic can create interference and provide effective holding forces.

9.2 Mold design

The quality of a molded part is determined by the following factors:
- Properties of the molding material
- Design of the molded part
- Processing of the material

By optimizing these factors, a high quality molded part can be produced.

Modern computing methods should be used in critical cases or complex moldings to support the experience of the designer (computer aided engineering, CAE). It is often possible to assess whether a molded part will meet requirements by applying the principles of materials science. Trials under actual or simulated conditions should be carried out to confirm suitability for the application.

This guide covers the general family of Vectra LCPs. Since some grades may require additional consideration, please review your tooling requirements with a Ticona Vectra Technical Service Representative.

9.2.1 Mold material

The selection of steels for the mold can be critical to its successful performance. Just as resins are formulated to satisfy processing and performance requirements, steels are alloyed to meet the specific needs for mold fabrication, processing and its intended use. There are many different parts to the mold, e.g. cavity, gates, vents, pins, cores, slides, etc., and these may have different requirements. For example, some applications may require a mold steel with high hardness to resist wear and abrasion at the parting line while another application may require toughness to resist mechanical fatigue. Usually, steels with higher hardness and wear resistance properties tend to be more brittle and steels with higher toughness will show less wear resistance. The selection process of the tool steels should include input from the tool steel supplier, the mold designer and mold fabricator in addition to the resin supplier. Post-treatment of the mold can be used to reduce the propensity for wear. Inserts should be considered where wear may be a concern and long production runs are anticipated. Table 9.2 lists some steels that could be considered for constructing a mold.

To achieve satisfactory protection against wear, the recommended hardness should be at least Rc ≥ 56, especially for processing highly filled grades. Recommended steels for Vectra LCPs are through-hardening steels likes 5-7. As Vectra LCPs are not corrosive, special corrosion-resistant steels are generally not required. If the melt is injected against a wall or core, this area will be subject to higher abrasion. In such areas, wear resistant materials, such as hard metal alloys like D-2 or 1.2379, should be considered or suitable surface treatment carried out. The mold surface should be smooth and polished to improve surface properties and facilitate ejection. The molds can be heated with water or oil.

9.2.2 Mold finish

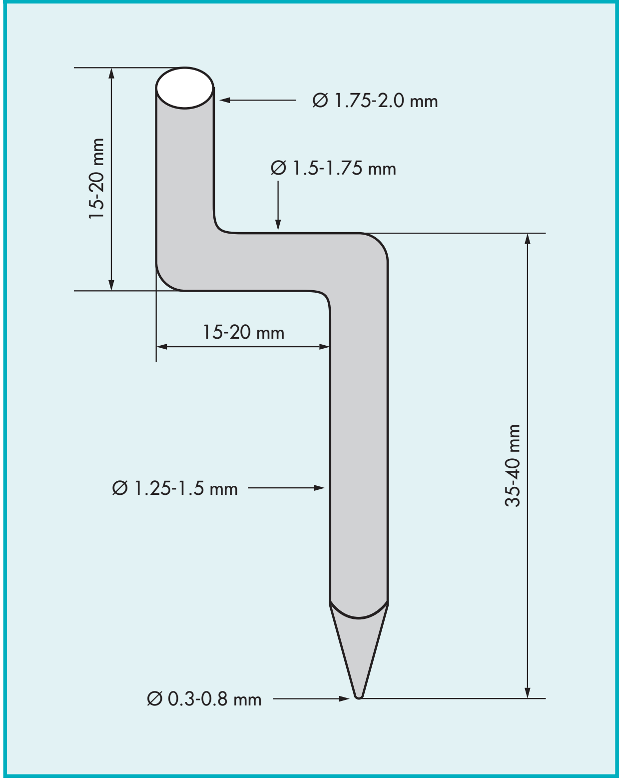
Mold finish plays an important role in determining the ease of processing as well as molded part appearance. Vectra LCPs exhibit such low shrinkage that even modest undercuts can cause poor ejection. Even EDM (Electrical Discharge Machine) or eroding marks can hold the part or imbalance the ejection stroke. Therefore, the mold should be polished to SPI #2 (U.S.) finish or better. Deep or poorly drafted pins, cores and cavities require special attention. Final polishing should occur in the axis of ejection (draw polishing).

9.2.3 Runner systems

All typical types of runner systems (hot runner, conventional cold runner or hot-runner with cold sub-runner) can be used for injection molding of Vectra LCPs. Both full round and full radius trapezoidal runners with 10° angle sides are acceptable. For multi-cavity tools, the runner system must be balanced and radiused carefully to avoid filling and ejection problems.

When designing runner systems for Vectra LCPs, the high impact shear on melt viscosity has to be taken into consideration. To enable easiest filling more shear has to be applied to Vectra LCPs versus other engineering plastics. Therefore, runners have to be generally smaller in diameter and should continuously increase shear. All extreme flow variations (diameter) are disadvantageous for consistent shear, viscosity and orientation. When designing for Ei or resins the runner should be free flowing with cold slug wells. Runner systems with a 90° angle radius should be eliminated whenever possible to aid in flow. Polishing the runner system also aids in flow. Due to the liquid crystal structure of Vectra LCPs, melt and processing history have a great influence on flow behavior and orientation. A principal runner design for a typical part made from Vectra LCPs can be seen in Figure 9.2.1.

Fig. 9.2.1 · Typical Runner Design for Vectra® LCP



9.2.4 Gate location

Selecting the gate location requires consideration of polymer orientation, warpage, jetting and knit line effects. The gate location should control the cavity flow pattern to provide optimum properties in the axis of maximum stress. In many cases, gating from the part-end is recommended.

As with mechanical properties, part shrinkage in the flow direction is smaller than in the transverse direction. The resultant shrinkage differential might cause warpage. When flatness is critical, locate the gate to minimize orientation (shrinkage) differences, i.e. balance them across the part or relocate them to non-critical areas. Due to the high flow of Vectra LCPs, single gates are generally sufficient. Avoiding multiple gates minimizes weld lines. When multiple gates are unavoidable, locate the gate so that weld lines occur in areas with lower mechanical loads and minimal strain. Note that knit weld lines are significantly stronger than butt weld lines. The gate should be located so that the knit line is made earlier during filling of the part. Continued polymer flow will improve the knit line strength.

As with all plastics, locate the gate to provide smooth and uniform filling of the part, usually from thick to thin sections. Gating directly into the thickest section can cause problems. Jetting, for example, is a form of non-uniform polymer flow due to gating directly into an open cavity section. To minimize jetting, the gate should be located so that the melt stream impinges immediately on a core or nearby wall.

Since these effects must be carefully balanced, it is important to check the filling pattern when proofing new or existing tools. Simply limit the shot size and inspect a series of short shots taken throughout cavity filling, that is from the moment the melt comes through the gate to the point of final fill. In new tools, the gate area should be part of an insert to facilitate changes or adjustments.

9.2.5 Gate size

Jetting is a phenomenon that results when plastic flows through a gate and into a cavity without sticking to the mold walls. It produces a rope-like flow or “jet” which is then compressed in the part. Ideally, the polymer should form a uniform flow front that fills the cavity smoothly. Vectra LCPs have very little die swell when exiting the gate and thus is more prone to jetting than many thermoplastics.

Techniques for controlling jetting are similar for all plastics. For three plate molds, tunnel gates and some edge gates, a smaller gate is practical and sometimes necessary for a clean break, provided that the flow is directed against a core or cavity wall to control jetting and force a uniform flow to develop. Vectra LCPs are stronger in the flow direction, therefore tunnel gates should be located in the ejector side of the mold to push rather than pull the gate and runners from the mold. On three plate molds, gate diameters should be between 20% and 50% of the wall thickness to ensure that the gate breaks easily. Usually the shear sensitivity of Vectra LCPs allows for smaller gates to fill a part more easily than larger gates.

9.2.6 Gate design

As with gate location, it is important to select the gate type appropriate to the part geometry. To minimize knit lines and differential shrinkage the gate should provide a uniform flow front. Molders usually use submarine gates for Vectra LCPs.

9.2.6.1 Submarine (tunnel) gates

Submarine gates (Figure 9.2.2) require careful sizing to balance ejection difficulties of large gates with

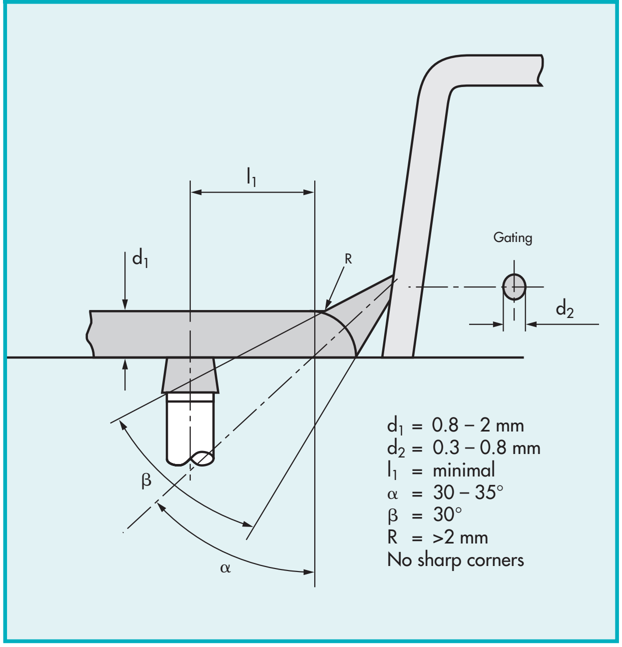
Table 9.2 · Partial Listing of Potential Mold Steels

Steel Type		Hardness	Properties	Typical Applications	Drawbacks
USA	Germany				
D-2	1.2379	60-62	Good hardness, good abrasion resistance	Gate inserts and cavity areas of high wear from glass and fillers	Brittle and somewhat difficult to grind and assemble
A-8		56-58	Good adhesive wear resistance, good toughness	Slides, lifters and cams	Fair abrasion resistance
A-6		56-58	Good heat treatment stability, high hardness and compressive strength	General purpose, air hardened steel	Moderate ductility
A-2	1.2363	56-58	Air hardened steel, high abrasion resistance and good toughness		Moderate ductility
S-7		54-56	Very good mechanical fatigue resistance and toughness		Fair adhesive and abrasive wear resistance
O-1	1.2510	56-58	General purpose oil hardening steel with moderate adhesive wear resistance	Small inserts and cores	Medium to low toughness
L-6		55-57	Very good toughness, oil hardening with good heat treatment stability		Medium hardness with medium to low wear resistance
P-5		55-57	Highly malleable	Hobbing steel	Case hardened. Low core hardness, low durability and heat treatment stability
P-6		55-57	Easily machined and welded		Low heat treatment stability with medium to low durability
P-20	1.2311	28-34	Pre-hardened steel, very tough, easy to machine	Large cavities	Subject to galling and high wear Low hardness
H-13	1.2344	46-48	Air or vacuum hardened steel with very high toughness		Low hardness
SS 420	1.2083	46-50	Very good chemical resistance		Low hardness, low mechanical fatigue strength, low thermal conductivity
Specialty Steels					
M-2		62-64	Extreme hardness, abrasive and adhesive wear resistance	Gate inserts, core pins, shut off and part lines	Difficult and costly to machine and grind
Böhler "M 340”		56	Corrosion resistant		
Böhler "K 190”		60-63	Corrosion resistant		
Böhler "M 390”		56-62	Corrosion resistant and highly dimensional stable		
Zapp CPM T420V		57	Corrosion resistant, highly dimensional stable and easily polishable		
Zapp CPM 3V		53-63	Corrosion resistant, highly dimensional stable and high toughness		
Zapp CPM 9V		55-67	Highly dimensional stable		Low corrosion resistance
WST “G25”		64-66	Corrosion resistant		
Elmax[1]		56-58	Highly wear and corrosion resistant		
Ferro-Titanit S[2]		66-70	Extremely high wear resistant and corrosion resistant		

[1] *Trademark is registered by Bohler-Uddeholm Corp.*
[2] *Trademark is registered by Thyssen Krupp Stahlunion GmbH*

jetting of small gates. Furthermore, the drop from the runner must flex enough to clear the cutting edge as the tool opens. Vectra LCPs are very stiff, so the gate design must maximize flexibility and minimize the deflection required during ejection. The runner should be small and close to the part (i.e. minimize the distance l_1). The converging angle of the cone should be relatively small (about 30°) and the drop angle from the runner relatively steep (about 30 to 35°). Most importantly, the submarine gate should extend into the ejector side of the tool so the ejection stroke can positively separate the runner from the part. The ejectors should be robust and close to the gate because Vectra LCPs have very high tensile and shear

Fig. 9.2.2 · Submarine Gate



d_1 = 0.8 – 2 mm
d_2 = 0.3 – 0.8 mm
l_1 = minimal
α = 30 – 35°
β = 30°
R = >2 mm
No sharp corners

strength in the highly oriented gate drop. If the submarine gate extends into the stationary side, the runner could split at the pullers rather than break at the gate.

9.2.6.2 Pin gates

Pin gates are used for thin sections and easy degating in most 3-plate tools. As with any small gate, direct the polymer flow onto a core, rib or cavity wall to control jetting. If this approach is impractical, enlarge the gate to minimize jetting.

9.2.6.3 Film (fan) gates

Film gates are recommended for flat, rectangular parts. A sufficiently thick transverse runner in front of the film ensures that the melt is distributed evenly across the land before entering the cavity. This way a homogeneous filling process is guaranteed, orientations are in line and warpage minimized.

9.2.6.4 Ring and diaphragm gates

For cylindrical parts, a uniform flow front is critical to maintain concentricity, dimensional stability, part performance and appearance. A diaphragm or ring gate provides the best gate designs to obtain the uniform flow front. In both types, the gate land or membrane should be significantly thinner in cross section (shallower) than the runner ring or central disk. This thickness differential forces the ring or disk to fill completely before the melt fills the membrane.

The choice of ring or diaphragm depends on part and tooling features. With an internal ring or diaphragm gate, the gate vestige is internal to the part but, depending on the tool layout, the core may not seat as solidly as with an external ring. With an external ring gate, the core can be solidly seated but the gate vestige is external.

9.2.6.5 Overflow gates

A very effective technique for strengthening the weld lines in Vectra LCP parts is to cut an overflow gate and well into the tool. Changing its internal surface contour from a flat plane to a sort of tongue and groove configuration strengthens the normally relatively weak weld line. This is done by normally forming the part during the filling stage of the molding process. Then during the packing step causing a small amount of flow at the knit plane as the overflow gate is activated by the high pressure. To create a successful overflow design, the mold must be completed, the part dimensions correct and the mold ready for final polishing, i.e., no further changes in the metal contours.

The key to a successful design is to put the overflow gate just slightly off the knit line and vent as deep as possible. Knit lines are located on the part and the overflow gate can then be located about 1½ to 2½ nominal wall thicknesses away from the knit line location. A submarine or tab gate can be used; however, it must have a small enough area that flow only occurs after the part starts to pack out. This will ensure a complete filling of the mold and proper formation of the weak knit line before the plane of the knit line is altered by the overflow. If the location is too near or too far from the knit, there will be no flow through the knit and no strengthening of the knit line. A removable insert at the approximate location of the knit line can facilitate experimenting with the overflow location to improve knit line strength.

9.2.7 Vents

The melt viscosity of Vectra LCPs decreases markedly with increased injection rate. Furthermore, fast injection rates can improve knit line strength. In many cases, the molder may need to increase injection velocity so the tool should be well vented. Short shots can be used to evaluate the proper location of the vents. Since Vectra LCPs have extremely low melt viscosity the vents should be polished when possible no deeper than 0.01 to 0.025 mm. Vents should be located in sections of the cavity where air could be trapped during filling especially at knit lines. Vents at several locations in the tool avoid forcing all of the air through one opening. The runner system should also be vented with vents that are the width of the runner.

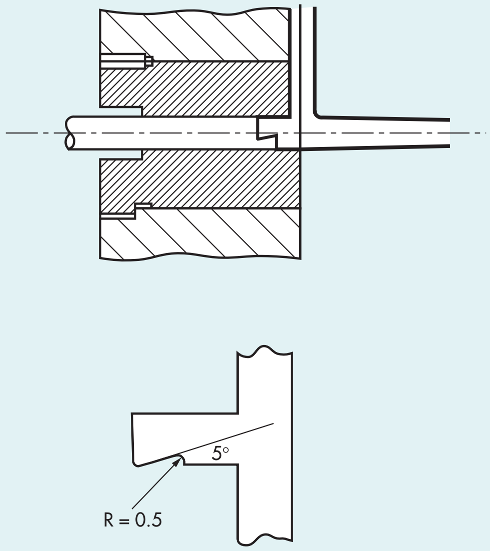
9.2.8 Ejection

The ejection of a molded part is generally by ejector pins or ejector blades. These are round or rectangular shaped pins used by the available areas for product removal. The main purpose of the blade ejector is for the ejection of very slender parts, such as ribs and other projections, which cannot satisfactorily be ejected by standard type of ejector pins. The location and number of the ejector pin/blade elements are dependent on the component's size and shape. The mold preferably should be fitted with ejectors at weld lines and at those spots around which the molding is expected to shrink (i.e., around corners or male plugs).

The ejector pins should be located so that the molded part is pushed off evenly from the core. Once the size of the ejector pins is decided, then the greater the number of ejector pins incorporated the greater will be the effective ejection force and the less the likelihood of distortion occurring. For this reason it is better to err by having too many ejector pins than by having too few. The molder and mold-maker usually are able to predict knockout problems. Often aesthetic considerations or lack of room for knockouts prevent using the number and size of pins desired. It is poor practice to build a mold under these conditions. If satisfactory ejection cannot be designed initially on paper, it will be difficult, if not impossible, to install it on the completed mold. Sometimes the parts have to be redesigned or made in two pieces and joined later. Unless a molded part can be ejected consistently, an even cycle cannot be maintained, and the part cannot be produced on a commercial basis.

Experience has shown that "Z-claws" or "Z-puller" is preferred for Vectra LCPs because of the unique material characteristics. Figure 9.2.3 gives a design recommendation for sprue puller suitable for Vectra LCPs.

Fig. 9.2.3 ·Sprue Puller



10. Secondary Operations

10.1 Annealing

The high heat deflection resistance of Vectra® LCPs can be further raised 30 to 50°C by thermal after-treatment of the molded parts. Annealing can also be used to improve the flatness of a part by fixturing the part while carrying out the thermal after-treatment. This process can be carried out in air or nitrogen in a circulating air oven under the following conditions:

Vectra A-series and Vectra B-series
- Heat oven from room temperature to 220°C over 2 hours
- Gradually increase temperature from 220 to 240°C over 1 hour
- Maintain at 240°C for 2 hours
- Gradually increase temperature from 240 to 250°C over 1 hour
- Maintain at 250°C for 2 hours
- Cool to room temperature

Vectra C-series and Vectra L-series
- Heat oven from room temperature to 220°C over 2 hours
- Gradually increase temperature from 220 to 250°C over 1 hour
- Maintain at 250°C for 2 hours
- Gradually increase temperature from 250 to 270°C over 1 hour
- Maintain at 270°C for 2 hours
- Cool to room temperature

Vectra Ei-series and Vectra H-series
- Heat oven from room temperature to 220°C over 2 hours
- Gradually increase temperature from 220 to 250°C over 1 hour
- Maintain at 250°C for 2 hours
- Gradually increase temperature from 250 to 290°C over 1 hour
- Maintain at 290°C for 2 hours
- Cool to room temperature

During annealing, some color change may occur.

10.2 Assembly

The finishing and assembly of parts made from Vectra® LCPs is quite similar to that of conventional semi-crystalline plastics like nylon and polyesters. A factor that must be considered in the design of joints and fastening techniques is the relatively weak weld line strength of liquid crystal polymer materials. Any joint formed by melting parts to fuse them together must have some shearing deformation over a large enough area to form a strong joint. When using any fastener that causes a high stress on the weld line either during assembly or service, the strength of the weld lines must be considered. Although Vectra LCPs are very chemically resistant, they can be successfully joined with adhesives, both with and without surface treatment. As with all injection-molded parts, Vectra LCP machined prototypes are poor imitations of the actual part, because most of the characteristics of Vectra LCPs are developed by flow during the injection mold.

10.2.1 Welding

With the current trend towards rationalization and economic production of plastic assemblies, joining technology is becoming increasingly important. For production and assembly reasons, it is often an advantage to join molded parts after manufacture.

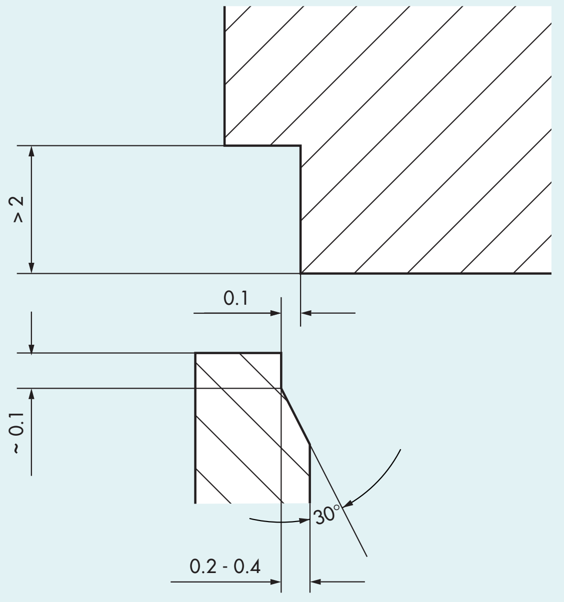
10.2.1.1 Ultrasonic welding

The most important aspect of welding Vectra LCPs is that a shear joint be used. During ultrasonic welding with Vectra LCPs, the joint strength depends largely on the shear length – a longer shear length yields higher strength. Other types of joint designs, such as energy director, scarf and butt joint, result in low strengths. The shear joint should be designed in a conventional manner for a high modulus material, that is with about a 0.2 to 0.4 mm interference and a greater than 2 mm depth (Figure 10.2.1). The strength of the weld joint will be determined more by the depth of the joint than by the interference.

All high melting point plastics require high-energy inputs to weld and Vectra LCPs are no exception. For most welding applications, a 20 kHz machine should be adequate. For very small parts, less than 13 to 19 mm diameters, a 40 kHz machine should be considered. Horn amplitudes will be large, generally between 0.05 and 0.08 mm for a 20 kHz frequency and about half that for a 40 kHz frequency machine.

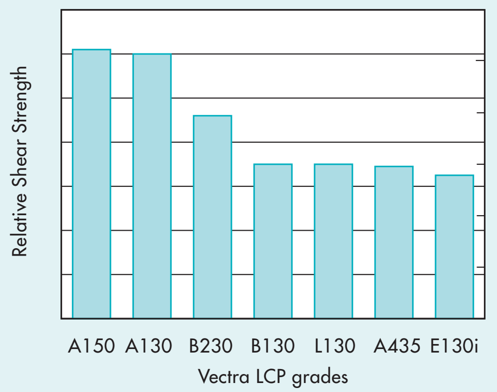
The expected weld strength will depend on both the actual welding conditions and the grade of Vectra LCP being used. Joint shear strength of about 30% to

Fig. 10.2.1 · Ultrasonic Welding Joint Design



50% of the bulk material strength should be expected when the above guidelines are followed. Figure 10.2.2 shows the relative strengths of the joint for various Vectra LCP grades.

Fig. 10.2.2 · Ultrasonic Weld Strengths



During ultrasonic welding tests, sonotrode wear was observed which could be avoided by using a hard metal material or a polyethylene layer as a buffer. Due to the stiffness of Vectra LCPs, the ultrasonic welding process can be noisy. A silicon rubber layer underneath the parts helps to diminish the noise.

10.2.1.2 Rotational (spin) welding

Joint design is critical for maximizing weld line strength. With the optimum design (Figure 10.2.3), strength of 50% of the material properties can be achieved. Due to the compressive behavior, it is difficult to evaluate the correct joint area in the part. Figure 10.2.4 gives representative values of weld strengths for comparison.

Fig. 10.2.3 · Spin Welding Joint Design

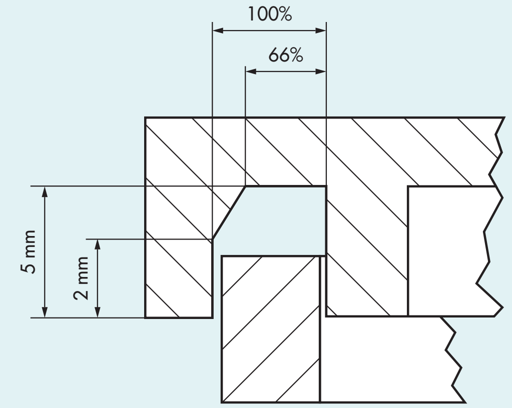
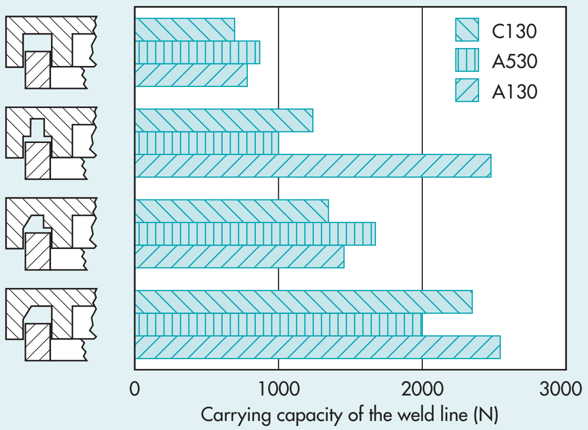


Fig. 10.2.4 · Spin Weld Strengths for Vectra® LCP



Processing Parameters: Speed = 0.84 m/s
Trigger pressure = 0.1 MPa
Weld pressure = 0.3 MPa
Weld length = 1.29 mm
Rotation impulse x 360° = 2

10.2.1.3 Hot plate welding

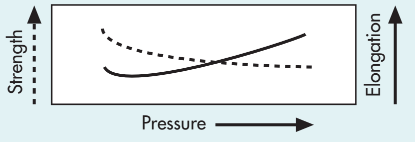
Hot plate welding is not recommended for Vectra LCPs. The strength of the weld is between 12 - 15% of the material strength. There is no significant difference between the flow and the transverse direction. The part should not have direct contact with the hot plate due to the tendency of Vectra LCPs to bond onto the plate. Radiant heat transfer alone supplies enough heat energy for the process.

10.2.1.4 Vibration welding

With vibration welding, the specific polymer structure of Vectra LCPs causes either long welding times with low pressure or short welding times with high pressure (Figure 10.2.5). Low welding pressure is recommended. With a low welding pressure, a strength of about 16% of the material properties can be achieved. It is not recommended to weld parallel to the flow direction.

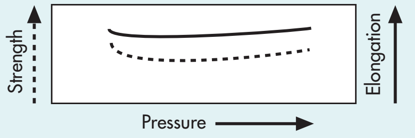
Fig. 10.2.5 · Vibration Welding

Vectra A130



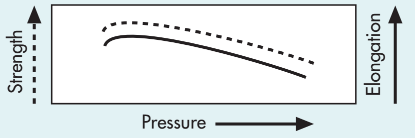
With increasing force the elongation will be better but the strength will be reduced.

Vectra C130



Vectra C130 is more insensitive to weld pressure variations.

Vectra A530



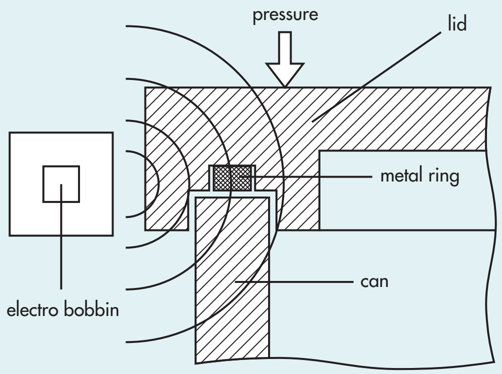
Vectra A530 has the best strength and elongation at 3 MPa.

Processing Parameters:
Frequency = 240 Hz
Amplitude = 1.4 mm
Weld pressure = <1 MPa
(for Vectra A530 Weld pressure = 3 MPa)

10.2.1.5 Electromagnetic welding

Electromagnetic welding is suitable for Vectra LCPs. The welding quality depends on process parameters, which have to be defined together with the equipment manufacturer. For efficiency reasons, the longer welding times can be compensated for by a multiple welding system. During welding trials (Figure 10.2.6) with Vectra A130 and Vectra A625 the parts withstood a break load of 1300 to 1650 Newtons (Table 10.2.1). All bonds were hermetic seals.

Fig. 10.2.6 · Electromagnetic Welding



Processing Parameters:

Testing model:	can and lid with diameter = 30 mm and thickness = 3 mm
Cross section of ring:	2.25 mm_ (Steel C45)
Welding equipment:	KVT, Type 010, generator UTG 20/3000
Welding time:	45 sec
Holding time:	20 sec
Power of generator:	2700 Watt (scale 90%)

Table 10.2.1 · Electromagnetic Welding Strengths

Variant	Pressure (bar)		Depth (mm)	Gastight 10 min./2.5 bar	Load to break (N)
	Trigger	Welding			
Vectra A130	0.5	1.0	3.2 – 3.4	Yes	1664 ± 57
	1.0	2.0	3.4 – 3.5	Yes	1542 ± 162
	1.0	3.0	3.4 – 3.5	Yes	1550 ± 119
Vectra A625	0.5	1.0	2.3 – 2.6	Yes	1302 ± 288
	1.0	2.0	2.8 – 3.2	Yes	1752 ± 445
	1.0	3.0	3.2 – 3.3	Yes	1665 ± 108

10.2.2 Hot and cold staking

Hot staking is the preferred way to form a “head” on a boss or rivet made from Vectra® LCPs. Typically, a very hard surface is recommended for the heated forming tool to reduce wear when heading bosses in parts molded from the most often used Vectra LCP glass reinforced resins. Heating rates and temperatures are similar to those used with other semi-crystalline or amorphous thermoplastics like polyesters, nylons and polycarbonates. Dwell times, temperatures relative to the nominal melting points or softening temperatures, pressures and cycle times should be established experimentally on molded prototype parts to make sure the parameters for a robust production process are known before investing in capital equipment.

Cold staking is not recommended for Vectra LCPs, since the resin is too hard and brittle to form without being heated and softened or melted.

10.2.3 Adhesive bonding

Parts made from Vectra LCPs can be effectively bonded using readily available commercial adhesives. In most cases, the bond strengths obtained with unmodified surfaces are more than adequate for product assembly. Adhesive bond strengths can be further enhanced by surface treatments which improve wetting, such as plasma treatment, corona treatment, light sanding, grit blasting, and chemical etching.

Most importantly, when bonding any molded plastic part, optimum adhesion will be obtained only when the parts are clean, the adhesive is fresh and the procedure supplied by the adhesive manufacturer is followed precisely. It is nearly impossible to completely clean mold release from a molded part and mold release will prevent good adhesion. So, do not use mold release. Surfaces to be bonded should not be touched after cleaning, because an oil film may be deposited which could interfere with adhesion.

Certain grades of Vectra LCP provide greater bond strength than others. Generally, filled or reinforced grades of Vectra LCP provide greater bond strengths than unfilled grades. Table 10.2.2 a, b and c show typical lap shear strengths (ASTM D 3163) obtained with a variety of adhesives tested at 22°C, 100°C and 150°C, respectively. Before specifying these or any other adhesives, the end user should make certain that all mechanical, thermal, electrical, chemical and other properties of the adhesive are suitable for the application in question. Please note, these data are a general screening of classes of adhesives, not a specific recommendation. Table 10.2.3 presents commercial examples of the adhesives represented in Tables 10.2.2 a, b and c. Table 10.2.4 includes examples of adhesives that comply with either FDA regulations or United States Pharmacopoeia (USP) Class VI requirements. A list of supplier information is also included.

Adhesion will be improved by proper surface preparation. Gas plasma technology has been used to improve the adhesive bond strength between Vectra LCPs and epoxy and urethane adhesives. Table 10.2.5 shows the effectiveness of plasma treating to promote adhesion.

Supplier Information

North America

Ciba Specialty Chemical
4917 Dawn Avenue
East Lansing, MI 48823
USA
Tel: ++1 (517) 351-5900
Fax: ++1 (517) 351-6255

Cole-Parmer Co.
7425 North Oak Park Avenue
Chicago, IL 60648
USA
Tel: ++1 (847) 549-7600
Fax: ++1 (847) 247-2983

Epoxy Technology, Inc.
14 Fortune Drive
Billerica, MA 01821
USA
Tel: ++1 (800) 227-2201
Fax: ++1 (800) 4446

IPN
151 Essex Street
Haverhill, MA 01832
USA
Tel: ++1 (508) 508-372-2016
Fax: ++1 (508) 6955

Emerson & Cummings
Specialty Polymers
55 Hayden Avenue
Lexington, MA 02173
USA
Tel: ++1 (800) 832-4929
Fax: ++1 (800) 861-9590

Loctite Americas
1001 Trout Brook Crossing
Rocky Hill, CT 06067
USA
Tel: ++1 (860) 571-5100
Fax: ++1 (860) 571-5465

Europe

Vantico GmbH & Co. KG
Electronic Polymers
Oflinger Straße 44
D-79664 Wehr/Baden
Germany
Tel: ++49-7762-822761
Fax: ++49-7762-4059

Novo Direct GmbH
(A Cole-Parmer Distributor)
Hafenstraße 3
D-77694 Kehl/Rhein
Germany
Tel: ++49-78-51-994571
Fax: ++49-78-51-9945799

Poly Tec GmbH
Poly-Tec-Platz 1-7
D-76337 Waldbronn
Germany
Tel: ++49-7243-6040
Fax: ++49-7243-69944

3M Company
Carl-Schulz-Straße 1
41460 Neuss
Germany
Tel: ++49-2101-140

Table 10.2.2 · Lap Shear Strength

a) Testing Performed at 22°C

Adhesive Type	Range of Values, N/mm^2		Average Values, N/mm^2	
	As Molded	Surface Treated*	As Molded	Surface Treated*
2 Part Epoxy	3.1 – 6.9	5.5 – 14.5	4.8	9.0
1 Part Epoxy	4.1 – 9.0	5.5 – 9.7	6.2	10.7
Cyanoacrylate	2.1 – 4.8	3.4 – 6.9	3.4	5.5
2 Part Acrylate	1.7 – 5.5	3.4 – 5.5	3.1	4.8

b) Testing Performed at 100°C

Adhesive Type	Range of Values, N/mm^2		Average Values, N/mm^2	
	As Molded	Surface Treated*	As Molded	Surface Treated*
2 Part Epoxy	1.0 – 2.1	1.0 – 2.8	1.4	2.1
1 Part Epoxy	1.4 – 4.8	1.7 – 5.5	3.4	4.1
Cyanoacrylate	2.1	2.1 – 3.4	2.1	2.8
2 Part Acrylic	0.7 – 1.4	1.4 – 2.1	1.0	1.7

c) Testing Performed at 150°C

Adhesive Type	Range of Values, N/mm^2		Average Values, N/mm^2	
	As Molded	Surface Treated*	As Molded	Surface Treated*
2 Part Epoxy	0.7 – 1.4	0.7 – 1.4	0.7	1.0
1 Part Epoxy	0.7 – 2.1	0.7 – 2.1	1.4	1.4
Cyanoacrylate	0.2 – 0.3	0.3 – 0.7	0.2	0.7
2 Part Acrylic	0.3	0.7	0.3	0.7

** Light sanding or grit blasting and solvent wash*

Table 10.2.3 · Typical Adhesives for Vectra® LCP

Supplier	**Grade**	**Family**	**Cure**	**Temp Range(°C)**
Lord Corporation	Fusor® 310	2 Part Epoxy	15 minutes at 105°C	-40 to 205
Ciba Specialty Chemical	REN® DA-556 [1]	2 Part Epoxy	5 minutes at 80°C	-30 to 90
3M Adhesives	Scotch-Weld® 1838 A/B	2 Part Epoxy	30 minutes at 95°C	-55 to 175
Cole-Parmer Co.	5 Minute Epoxy	2 Part Epoxy	1 hour at 20°C	-30 to 95
3M Adhesives	Scotch-Weld® 2214 Hi-Temp	1 Part Epoxy	10 minutes at 150°C	-55 to 175
3M Adhesives	Scotch-Weld® 2214 Hi-Temp, New Formula	1 Part Epoxy	15 minutes at 150°C	-55 to 230
Epoxy Technology, Inc.	EPO-TEK® H35-175MP (Electrically Conductive)	1 Part Epoxy	1.5 hours at 175°C	-50 to 160
Emerson & Cummins Specialty Polymers	ME-868-2 (Thermally Conductive)	1 Part Epoxy	1 hour at 165°C	-75 to 170
Permabond International	Permabond® 102 [2]	1 Part Cyanoacrylate	30 seconds at 23°C	-60 to 80
Permabond International	610/612 [2]	2 Part Acrylic	25 seconds at 23°C	-80 to 150

[1] *REN is the registered trademark of REN Plastics Co.*
[2] *Permabond is the registered trademark of National Starch an Chemical Corp.*

Table 10.2.4 · Adhesives Compliant with US Regulations

Supplier	Grade	Family	Cure	Temp Range (°C)	In Compliance
Tra-Con	Tra-Bond FDA-8	2 Part Epoxy	4 hours at 65°C	-51 to 150	FDA*
Epoxy Technology	Epo-Tek 301	2 Part Epoxy	1 hour at 65°C		USP Class VI
Pacer Technology	PX500 PX5	Cyanoacrylate Cyanoacrylate	30 seconds at 20°C 30 seconds at 20°C	-55 to 95 -55 to 95	USP Class VI USP Class VI
Loctite	Medical Adhesive 4013	Cyanoacrylate	30 seconds at 20°C	-40 to 105	USP Class VI

** In compliance with FDA Title 21, US Code of Federal Regulations, Food and Drug Administration (FDA) Chapter 1, Sub Part B, Sections 175.105 and 175.300.*

Table 10.2.5 · Lap Shear Strengths

	Vectra A130		Vectra A625	
	Epoxy	Urethane	Epoxy	Urethane
No treatment	7.2 MPa	0.9 MPa	6.5 MPa	1.3 MPa
Oxygen plasma	11.4 MPa	9.3 MPa	11.0 MPa	6.7 MPa
Ammonia plasma	8.8 MPa	10.5 MPa	8.6 MPa	7.2 MPa

Table 10.2.6 · Typical Boss Dimensions

Material	Screw-type (EJOT)	Hole Diameter d_b	Boss Diameter D	Screwing Depth t_e
Vectra A130	PT	0.84 x d	1.90 x d	1.80 x d
Vectra E130i	PT	0.86 x d	1.90 x d	1.80 x d
Vectra B230	PT	0.90 x d	2.00 x d	1.90 x d

10.2.4 Fasteners

10.2.4.1 Screws

Vectra LCPs can be used for producing parts that will be joined together by screw coupling. Trials were done to create the design and evaluate the ratio of screw/hole dimensions. The screw hole diameter must be designed with very narrow tolerances. Table 10.2.6 gives typical dimensions for a screw.
Figure 10.2.7 shows an example of a boss designed for an EJOT PT® K screw. Design recommendations and dimensions are shown in Table 10.2.7.

10.2.4.2 Ultrasonic inserts

Brass inserts are used to provide metal threads in thermoplastics. The inserts are installed using ultrasonic or heat equipment that develops heat between the insert and the plastic. The heat remelts the narrow zone around the insert which, once resolidified provides a high strength molded-in insert.

The Ultrasert II insert from Heli-coil has stepped inclined ribs that continually present new metal surfaces to the plastic, thus forming a continuous zone of melting and solidifying during installation.
This creates a homogenous structure around the insert. The Ultrasert II has a unique knurled flange, which provides positive downward compressive force to the molten plastic that assures complete filling of the grooves for torque resistance. Table 10.2.8 gives the performance of these inserts in Vectra LCP in three essential areas.

10.3 Decoration

10.3.1 Printing

Printing on untreated, freshly molded parts made from Vectra® LCPs has been successfully demonstrated using one and two part component inks. Pretreatment such as corona or plasma surface treatment may not be necessary. Ink suppliers are willing to assist with the selection of appropriate inks to match a customers specific application. In most cases, they have the experience to guide the customer through the complete process. If necessary, they can modify the inks and even test trial parts.

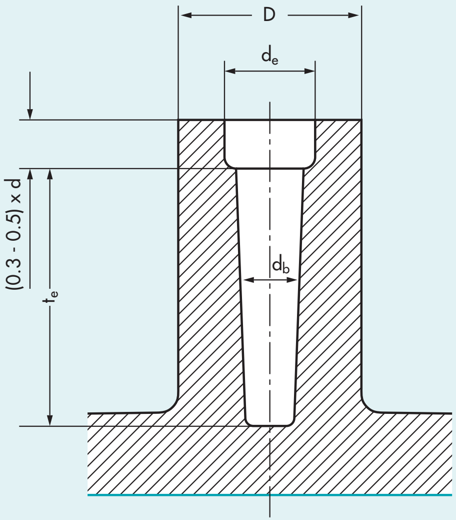
Markem Corporation
150 Congress Street
Keene, New Hampshire 03431
USA
Tel: ++1 (603) 352-1130
Fax: ++1 (603) 357-1835

Colorcon
A Division of Berwind Pharmaceutical
415 Moyer Boulevard
West Point, Pennsylvania 19486-0024
USA
Tel: ++1 (215) 699-7733
Fax: ++1 (215) 661-2605

Table 10.2.7 · EJOT PT® K Screw

	EJOT PT® K thread forming screw	nominal screw diameter, d (mm)	hole diameter, d_b (mm)	Penetration depth, t_e (mm)	driving torque (Nm)	stripping torque (Nm)	pull out strength (N)
Vectra A130	PT K 50 X 12	5	4.2	9.5	0.84	4.21	4170
	PT K 30 X 10	3	2.5	9.5	0.43	1.36	1640
Vectra E130i	PT K 50 X 12	5	4.4	9.5	0.54	2.38	2680
	PT K 30 X 10	3	2.5	6	0.37	1.09	1340
Vectra B230	PT K 50 X 12	5	4.4	9.5	0.79	2.6	3050
	PT K 30 X 10	3	2.7	6	0.4	1.09	

Fig. 10.2.7 · Boss for EJOT PT® K Screw



d = nominal screw diameter
D = boss diameter = 2 x d
d_e = d + 0.2 mm
t_e = screw depth
d_b = screw note diameter

Tampoprint International Corp.
1400, 26th Street
Vero Beach, Florida 32960
USA
Tel: ++1 (561) 778-8896
Fax: ++1 (561) 778-8289

Tampoprint GmbH
Lingwiesenstraße 1
70825 Korntal-Münchingen
Germany
Tel: ++49 (0) 7150-928-0
Fax: ++49 (0) 7150-407

Table 10.2.8 · Performance of Molded-in Inserts (Dodge Ultrasert II inserts*)

Thread Size	Part number	Tensile strength (N)	Rotational torque (Nm)	Jack-out (Nm)
#2-56	6035-02BR115	420.5	0.9	0.3
	6035-02BR188	987.9	1.1	0.4
#4-40	6035-04BR135	842.4	2.8	1.0
	6035-04BR219	1764.4	2.9	1.7
#6-32	6035-06BR150	1067.1	3.2	0.8
	6035-06BR250	2182.2	3.4	1.9
#8-32	6035-2BR185	1359.5	3.8	2.0
	6035-2BR312	2247.3	5.7	2.9
#10-32	6041-3BR225	1659.0	6.3	3.7

**Emhart Heli-Coil, Shelter Rock Lane, Danbury, CT 06810*
Phone (203) 743-7651, Fax (203) 798-2540

Ultrasonic insertion conditions
(Branson Ultrasonic welder, model 8700)

Thread size	Booster	Weld time (s)	Hold time (s)	Air pressure (MPa)
#2	Black	0.4	0.5	0.10
#4	Black	0.5	0.5	0.10
#6	Black	0.6	0.5	0.14
#8	Black	0.6	0.5	0.14
#10	Black	0.7	1.0	0.14

10.3.2 Painting

Vectra LCP resins have been successfully painted, however painting LCP resins can be difficult. Because the plastic substrate is chemically inert, Vectra LCPs can not be chemically etched to enhance adhesion. Pretreatment with a primer is recommended, as many one-coat systems do not give sufficient peel strength. Pretreatment with Ditzler Polypropylene primer, code #DPX801 has been demonstrated successfully.

Ditzler/PPG Industries
One PPG Place, 37 North
Pittsburg, Pennsylvania 15272
USA
Tel: ++1 (412) 434-3131
Customer service: ++1 (888) 774-1010

Schramm Lacke GmbH
Kettelerstraße 100
Postfach 10 17 63
D-63075 Offenbach/Main
Germany
Tel: ++49 (0) 698603-0
Fax: ++49 (0) 698603-229

Herberts Austria GmbH
Mödlinger Straße 15
A-2353 Guntramsdorf
Austria
Tel: ++43 (2236) 500-0

Berlac AG
Allmendweg 39
CH-4450 Sissach
Switzerland
Tel: ++41 (61) 976 9010
Fax: ++41 (61) 976 9620

10.3.3 Laser marking

Non-contact permanent marking of texts, patterns and serial codes by laser beam is possible with Vectra LCP surfaces. Two suitable laser-marking methods can be used:

- Laser scanning with a Nd:YAG laser
- Mask projection technique with excimer or CO_2 laser

One suggested marking condition follows:

Energy – 18 amperes
Frequency – 5,000 Hz
Minimum writing size – 1 to 2 mm

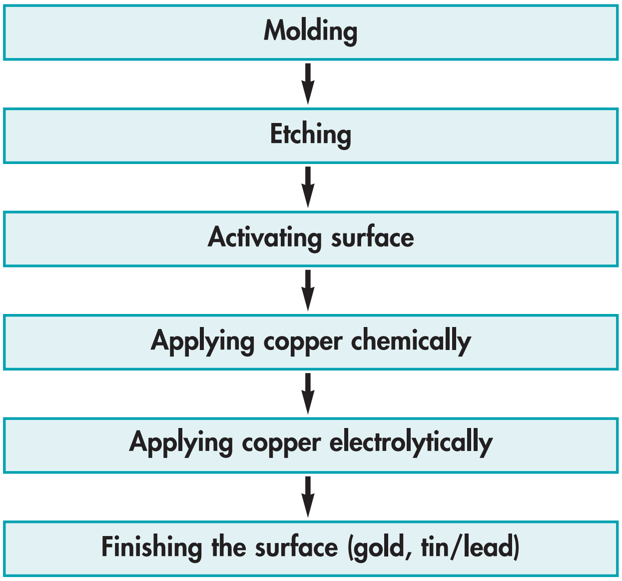
Nd/YAG lasers on natural Vectra LCP surfaces produce anthracite-colored markings; on black Vectra LCP surfaces, they produce pale gray markings.

10.4 Metallization and Molded Interconnect Devices (MID)

The Metallization of Vectra LCP

The Vectra 800 series, for example Vectra E820i, is a good candidate for metallization, and has been modified with special types of mineral. These products allow micro-roughness to be generated on the surface of the part by an alkaline etching process, so that the metal layer is provided adequate facility for adhesion. Processing chemicals can be supplied by companies such as Shipley, Omi-Enthone, or Atotech.

The adhesive strength of the metal layer depends on the injection molding parameters (drying, injection speed, cylinder temperature and mold temperature), the etching process and the test equipment. If these recommendations are followed, adhesion strengths from 0.9 to 1.5 N/mm can be reached. The metallization process is shown schematically below.



The chemically deposited layer of copper is generally 2 – 3 µm thick. The individual process parameters depend on the applications that have been developed by the various firms. After the etching and the deposition of copper over the whole surface, copper is then electrolytically applied until the desired layer thickness is achieved (approximately 20 - 30 µm). A barrier layer of nickel is then applied, and the surface is finished with tin/lead or with gold. Vectra E820i and Vectra C810 are Vectra grades that can be considered for wet chemical metallization. Vectra E820iPd is used in a special process to manufacture 3D-MIDs (see the section on MID).

In sputtering, the metal that is to be used to coat the component is subjected to ion bombardment to release ionized atoms into a surrounding vacuum. The atoms drift along the potential gradient from the metal source to the plastic part, where they accumulate in a hard, even layer. The thickness of that layer depends on the sputtering time. In practice, thicknesses of up to 5 µm are achieved with Vectra LCPs.

In aluminum vapor deposition, the components are placed in an evacuated chamber that also contains aluminum blocks as the source of metal. Very high temperatures cause the aluminum to vaporize, and the aluminum cloud precipitates on the components. This procedure is applied to Vectra LCPs for screening elements and reflectors, among other uses.

The addresses of some firms that have acquired knowledge of Vectra LCP metallization are included here:

In Europe:

VOGT Electronic FUBA GmbH
Bahnhofstraße 3
D-37534 Gittelde/Harz
Germany
Tel: ++49 (0) 5327-8 80-3 30
Fax: ++49 (0) 5327-8 80-3 12

Siegfried Schaal Metallveredlung GmbH & Co.
Laucherthaler Straße 30
D-72517 Sigmaringendorf
Germany
Tel: ++49 (0) 7571-72 09-0
Fax: ++49 (0) 7571-72 09-23

Lüberg Elektronik GmbH & Co. KG
Hans-Stiegel-Straße 3
D-92637 Weiden
Germany
Tel: ++49 (0) 961-2 70 18
Fax: ++49 (0) 961-6 21 09

Collini-Flümann AG
Ringstraße 9
CH-8600 Dübendorf
Switzerland
Tel: ++41 (01) 8 21 31 70
Fax: ++41 (01) 8 21 31 04

AHC
Boelckstraße 25–57
D-50171 Kerpen
Germany
Tel: ++49 (0) 2237-5020
Fax: ++49 (0) 2237-502100

Molded Circuits LTD
1142 Melton Road
Syston, Leicester LE7 8HA
Great Britain
Tel: ++44 (0) 116-260 9841
Fax: ++44 (0) 116-269 8392

In the USA:

Molded Interconnect Devices LLC
250 Metro Park
Rochester, NY 14623
USA
Tel: ++1 (716) 272-3100

Circuit-Wise
400 Sackett Point Road
North Haven, CT 06473
USA
Tel: ++1 (203) 281-6511

Cybershield of Texas
308 Ellen Trout
Lufkin, TX 75904
USA
Tel: 1-936-633-6387

Metal Surfaces
6060 Shull Street
Bell Gardens, CA 90201
USA
Tel: ++1 (310) 517-9285
Fax: ++1 (310) 517-9265

Crown City Platers
4350 Temple City Blvd.
El Monte, CA 91731
USA
Tel: ++1 (626) 444-9291

Providence Metallizing Company, Inc.
51 Fairlawn Avenue
Pawtucket, RI 02860-2591
USA
Tel: ++1 (401) 722-5300
Fax: ++1 (401) 724-3410

MID (Molded Interconnect Devices)

MID technology is one of the most important application areas for the metallization of Vectra LCPs. The use of planar circuit boards manufactured from glass fiber mat reinforced epoxy resins (FR4) has a long and proven history in the electronics industry. With the aid of MID technology, it is possible to manufacture 3-D structures with great freedom of design using injection molding procedures. The combination of properties specific to this material mean that Vectra LCPs are well qualified for MID applications. The platable Vectra grades can be used to fabricate precise, dimensionally stable and very finely detailed molded parts with circuitries. Because of the good flowability of Vectra LCPs, it is especially suitable for the 2-shot process. Vectra grades that have been modified with minerals are best used for the circuitries framework. Glass fiber reinforced Vectra grades are favored for the second shot, to provide the molded part with good stability and stiffness. The following variations of the procedure can be used for the 2-shot method:

The PCK procedure is:

- Injection molding of the first shot with a platable, catalytically modified Vectra grade.
- Application of the second shot, made from a non-platable type of Vectra grade.
- The surface of the component is then etched and metallized.

The SKW procedure is:

- Injection molding of the first shot with a platable Vectra grade.
- Etching and catalysation of the surface of the first shot with palladium.
- Insertion of the component into the mold and application of the second shot.
- The surface of the component is then metallized.

The 2-shot method using Vectra LCPs allows thicknesses of 0.25 mm to be realized for the track width and the track separation. Economic saving can be achieved through the miniaturization of components, higher integration density of functional parts, reduced parts count and a high level of automation.

Direct laser structuring is another MID technology used with Vectra LCPs. In this process, the component is entirely made of a platable Vectra LCPs. The whole surface of the component is then metallized and coated with etch resist. A laser is used to remove the etch to expose the copper. Subsequently the exposed copper is removed to create the desired circuitry. In a later process step the remaining etch resist is removed. The final surface is finished with gold, tin, or nickel.

10.5 Machining

Although the usual goal of designers is to produce plastic parts that can be used directly from the mold, there are times when machining is needed. Some reasons for machining are to avoid complex mold configurations, to achieve particularly tight tolerances or to avoid knit lines in critical areas. Parts molded from Vectra LCPs machine easily when the following practices are followed:

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

Compared to other thermoplastics, the stiffness, thermal conductivity and low coefficient of friction of Vectra LCPs promote good machinability. Vectra LCPs are thermoplastic and so will melt if the machining operation generates too much frictional heat.

10.5.1 Prototype machining

Properties of parts molded from Vectra LCPs depend on the molecular orientation created by gating, mold design and molding conditions. Extra care should be taken when machining prototypes for evaluation. A prototype may not have the same orientation as the final molded part and therefore mechanical, electrical and other properties may not necessarily be identical. In general, prototypes should be molded to the final geometry rather than machined from bulk stock. Surface layer properties of most polymers, including Vectra LCPs, are different from their core properties. If machining is unavoidable as little surface material as possible should be removed. If the design includes molded-in holes, drilling these holes in the prototype makes it impossible to evaluate the effect of knit lines in the production part.

10.5.2 Tooling

Dull tools tend to scrape rather than cut yielding a poor surface finish and generating excess heat in the process. The best surface finishes are obtained with sharp tools, high speeds and slow feed rates. Both machining speed and the feed rate should be uniform and uninterrupted. Cooling allows higher cutting speeds. Normally an air jet is sufficient but liquids may also be used. Vectra LCPs are not attacked, crazed, dissolved or softened by conventional cutting fluids.

In addition to having sharp cutting edges, there must be adequate clearance for chips. This eliminates problems with clogging and interference with the cutting operation. When there is a choice in tool selection, the machinist should pick one offering the greatest chip clearance, for example, drills with wide flute areas or saw blades with deep gullets. Unlike some plastics, Vectra LCPs containing abrasive fillers such as mineral, glass, or carbon fibers can be machined with standard high speed stainless steel tools, though carbide tools prolong tooling life during extended production runs.

10.5.3 Turning

Vectra LCPs are easily turned on a lathe. Tool bits must be sharp and should provide a rake angle of 5 to 15° with front and side clearance angles of 0 to 15°. A tip radius of at least 1.5 mm should be used for smooth finish cuts. Feed rates and cutting speeds for turning depend primarily on the nature of the cut and the desired finish. For most work, a peripheral part speed of 0.3 m/s is reasonable. A smooth cut finish calls for a somewhat higher turning speed and slower feed rate. As a guideline, a 12 mm diameter rod turned with a 1.5 mm tool tip radius at 100 rpm and a 0.04 mm/revolution feed advance delivers a good surface finish.

10.5.4 Milling and drilling

Standard helical-type milling cutters are satisfactory. Two-flute end mills are preferred for greater chip clearance. Using the suggested tool speeds in Table 10.5.1, Vectra LCPs can be cut without a coolant. An air jet may be desirable to keep chips from clogging the flutes. Feed rates should be adjusted to obtain the desired finish.

For drilling, standard high-speed twist drills are best. Occasionally burring may occur. This can be eliminated by clamping dummy pieces of plastic above and below the work. In any case, the work should be firmly supported and securely held. For deep holes, the drill should be raised frequently (about every 6 mm of depth) to clear the drill and hole of chips. A jet of compressed air helps to disperse chips and cool the drill.

Table 10.5.1 · Tool Speeds for Drilling or Milling

Tool diameter (mm)	Tool speed (rpm)	
	Unfilled grades	Reinforced grades
1.6	2,300	2,000
3.2	2,000	1,700
5.6	1,800	1,500
6.4	1,600	1,300
9.5	1,300	1,000
15.9	1,000	800

10.5.5 Threading and tapping

Threads may be readily cut on a lathe, using the tool and cutting conditions previously outlined. Conventional taps and dies may be used with good results. These may be threaded either by hand or by machine. A speed of about 180 rpm is suggested for screw sizes from UNC 10-24 through 3/8-16. The International metric equivalent sizes would be 6-1.00 to 10-1.50. A special tap for plastics, with two flutes, is available and offers some advantages in greater chip clearance, but it is not essential for satisfactory results.

10.5.6 Sawing

Vectra LCPs may be sawed with almost any type of saw. To prevent binding of the blade, however, the saw teeth should have some degree of offset, at least 0.125 mm offset per side. Coarse teeth and extra wide gullets for chip clearance are desirable for rapid cutting, while a finer blade gives a smoother edge. In general, the blade should have at least two teeth in contact with the part at all times. Bandsawing gives a good finish cut without cooling, using a blade speed of approximately 17 m/s, when the part is less than 6 mm thick.

11. Conversion Tables

11.1 Unit conversion factors

	⟵ Multiply by — — Divide by ⟶	
Length		
Meter (m)	0.0254	Inch (in)
Meter (m)	0.305	Foot (ft)
Area		
Square meter (m^2)	6.45×10^{-4}	Square inch (in^2)
Square meter (m^2)	0.0929	Square feet (ft^2)
Volume		
Cubic meter (m^3)	1.64×10^{-5}	Cubic inch (in^3)
Cubic meter (m^3)	0.0283	Cubic feet^3 (ft^3)
Mass		
Kilogram (kg)	0.454	Pound (lb)
Force		
Newton (N)	4.45	Pound force (lb_f)
Newton (N)	9.81	Kilogram force (kg_f)
Pressure		
Pascal (Pa)	=	Newton/meter^2 (N/m^2)
Pascal (Pa)	1.45×10^{-4}	lb_f/in^2 (psi)
Mega Pascal (MPa)	145	lb_f/in^2 (psi)
Pascal (Pa)	9.81×10^4	kg_f/cm^2
Pascal (Pa)	10^5	Bar
Viscosity		
Pascal.second (Pa.S)	0.1	Poise
Energy		
Joule (J)	4.2	Calorie (cal)
Kilojoule/kilogram (kJ/kg)	4.2	Calories/gram (cal/g)
Joule/kilogram (J/kg)	2.33×10^3	BTU/lb

11.2 Tensile or flexural property conversion

Strength		**Modulus**	
MPa	psi	MPa	psi x 10^6
75	10,900	6,000	0.87
100	14,500	8,000	1.16
125	18,000	10,000	1.45
150	21,800	12,000	1.74
175	25,400	14,000	2.03
200	29,000	16,000	2.32
225	32,700	18,000	2.61
250	36,300	20,000	2.90
275	39,900	22,000	3.19
300	43,500	24,000	3.48

11.3 Length Conversion

inches	**inches**	**mils**	**cm**	**mm**
1	1	1000	2.54	25.4
1/2	0.5	500	1.27	12.7
1/4	0.25	250	0.635	6.35
1/8	0.125	125	0.32	3.2
1/16	0.0625	62.5	0.16	1.6
1/32	0.0313	31.3	0.08	0.8
1/64	0.0156	15.6	0.04	0.4

11.4 Temperature Conversion

Degrees Centigrade (°C)	**Degrees Fahrenheit (°F)**
0	32
10	50
20	68
50	122
75	167
100	212
125	257
150	302
175	347
200	392
225	437
250	482
275	527
300	572
325	617
350	662
375	707
400	752

Conversion factor: °F = 1.8 (°C) + 32

12. Index

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