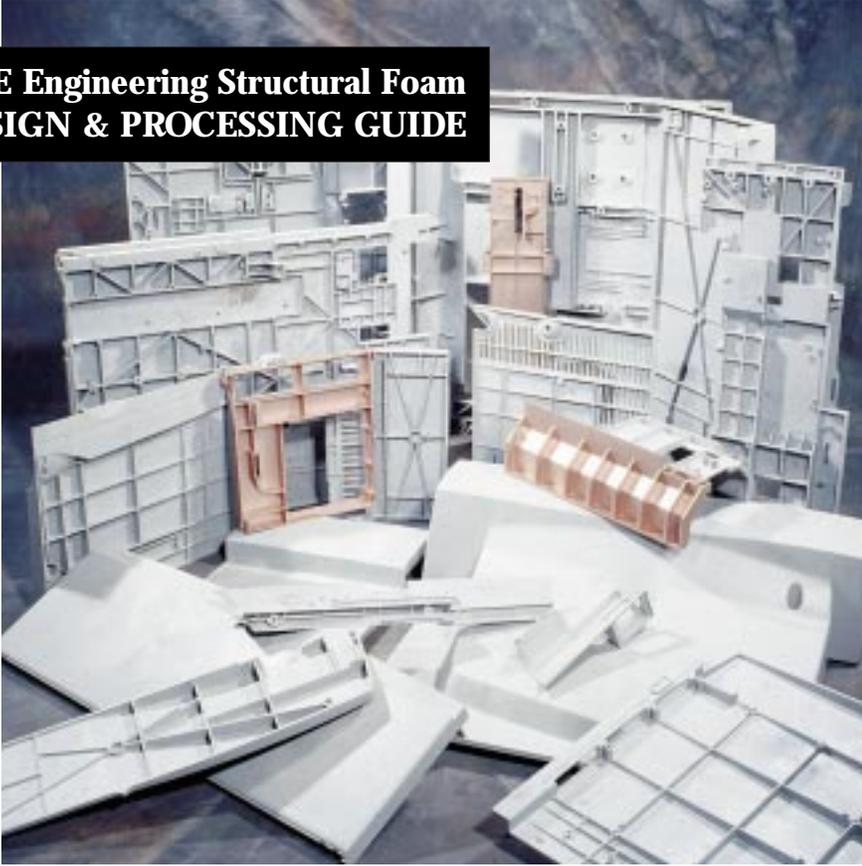




GE Plastics

**GE Engineering Structural Foam
DESIGN & PROCESSING GUIDE**



Engineering Structural Foam Design & Processing Guide

Contents

Introduction

About GE	iii
About GE Plastics	iii
What is Engineering Structural Foam	iv
GE Resins/Foam Molding Process	v

Material Selection

Foamable LEXAN® Resin	1-2
Foamable NORYL® Resin	1-6
Foamable VALOX® Resin	1-8
Blowing Agents Concentrates	1-10

Properties

Mechanical	
Stiffness-to-Weight	2-2
Tensile Strength	2-3
Flexural Properties	2-5
Impact Strength	2-7
Thermal	
Heat Deflection Temperature	2-8
Thermal Conductivity	2-9
UL Relative Thermal Index Ratings	2-9
Flame Resistance	2-10
Environmental	
Environmental Stability	2-11
Acoustical	2-12

Design Considerations

Load Considerations	3-2
Stress-Strain	3-2
Apparent Modulus and Creep	3-5
Fatigue	3-7
Working Stress	3-7
Thermal Stress/CTE	3-8
Structural Design	3-8
Bending	3-10
Tension	3-11
Compression	3-11
Torsion	3-12
Flat Plates and Ribs	3-12
Sample Rib Calculation	3-13
Wall Thickness	3-13
Material Flow Lengths	3-14
Transition Sections	3-15
Fillet and Radii	3-15
Tolerances/Warpage Control	3-16
Draft Angles	3-17
Snap Fits	3-18
Hinges	3-20
Full Pin Hinge	3-20
Partial Pin Hinge	3-21
Projected Pin Hinge	3-22
Simulated Hole Hinge	3-22
Bosses	3-23
Ribs	3-24
Guides	3-25
Louvers	3-26

Assembly

Assembly and Fastening	4-2
Self-Tapping Fasteners	4-2
Ultrasonic Inserts	4-3
Performance Definitions	4-4
Expansion Inserts	4-5
Assembly System Suppliers	4-5
Molded-In Inserts	4-6
Press Fits	4-6
Ultrasonic Bonding	4-7
Vibration Welding	4-8
Solvent Bonding	4-9
General Techniques	4-9
Adhesive Bonding	4-9
Joint Design	4-10
Types of Adhesives	4-11

Prototyping

Fabrication	5-2
Molds	5-2
Converted Tools	5-3

Processing

Material Preparation	
Moisture Control	6-2
Blowing Agent Concentrates Amounts	6-3
Blending of Concentrates	6-4
Blowing Agent Compatibility	6-4
Recycling Materials	6-4
Processing Methods	
Physical or Nitrogen Process	6-5
Chemical Blowing Agent Process	6-5
Nozzle Design	6-6
Gas Counterpressure Process	6-6
Molding	
Machine Settings	6-8
Clamping Force	6-8
Melt Temperature	6-9
Flow	6-9
Temperature Setting	6-10
Cylinder Purging	6-12
Mold Temperature	6-13
Warp Control	6-13
Shrinkage/Release	6-13
Pressure Settings	6-14
Cooling Time	6-15
Shot Size	6-15
Balancing Flow	6-16
Troubleshooting	6-17
Tooling	
Mold Design	6-17
Materials of Construction	6-18
Cooling Lines	6-18
Vents	6-18
Gates	6-20
Runners	6-20

Glossary	7-2
----------	-----

Literature	7-5
------------	-----

Sales Offices	7-6
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About GE

The General Electric Company has its roots in the *age of invention* when, in 1882, it was incorporated as the successor to Edison Electric founded by pioneering inventor Thomas Edison. Closely following its founder's philosophy of innovation and the creative application of technology, GE has grown to become one of the largest and most diversified companies in the world.

Today, GE products and services make a positive contribution to virtually every sector of commerce and industry. From jet engines to financial services, from lighting and medical systems to factory automation, power generation, transportation and construction.

About GE Plastics

Of all GE businesses, one of the fastest growing is GE Plastics. In 40 years, GE Plastics has emerged as one of the world's leading producers of engineering thermoplastics. Through application development centers around the world, customers can access data from GE designers, engineers, and tooling, processing and finishing experts, utilizing some of the most sophisticated equipment and systems available.

Working closely with customers is at the core of the GE Plastics' business culture. Today's customers need to get the job done better, more cost-effectively and within tighter schedules. Having a concentration of molding equipment, testing laboratories and product specialists close to the action permits a cross flow of information that can lead to important breakthroughs and exciting new product developments.

At the nucleus of this unmatched global technical network are the world-class facilities at GE Plastics' headquarters in Pittsfield, Massachusetts. Realizing that speed is the key to profitability today, these services are backed up by production plants in several locations in the U.S., Europe, Australia, Japan and Mexico.

Cover Photo:

FM Corp., a contract manufacturer with core competencies in high and low pressure injection molding, assembly, machining, metal fabrication and finishing, molded over 30 structural foam parts for the structure and skins of the Abbott Laboratories i2000 diagnostic analyzer.

Engineering Structural Foam

What is Engineering Structural Foam?

A form of injection molding, the engineering structural foam process offers an efficient and economical way to gain high strength and rigidity required for structural parts. Structural foam parts have a foam core between two dense skins. The foam core is achieved by introducing an inert gas producing foaming agent with the molten resin. When the resin/gas mixture is injected into the mold cavity as a short shot, the gas expands within the plasticized material as it fills the mold. The skin is created by compressing the foam against the mold cavity surfaces. Since the cavity is not completely filled upon the injection of the mixture, low cavity pressures occur. This low pressure process features the ability to provide a quality low stress part molded with an internal cellular structure and a tough external skin while enjoying the economics of reduced clamp tonnage.

Typical wall thickness for structural foam applications range from about 0.150 to 0.500 in (3.81 to 12.7 mm), nominal being 0.250 in (6.35 mm). Parts are referred to as having weight or density reduction. This describes how much the part weight has been reduced when compared to a solid injection molded part. A part having a 15% weight reduction is produced by filling the mold cavity 85% full. The other 15% is filled by the expansion of the resin. Thick wall parts achieve higher weight reductions than thin walls.

An alternative to metal, the combination of performance properties and process features deliver high strength and rigidity per unit weight. In addition to the increased stiffness to weight ratio, structural foam parts enjoy better heat insulation, improved electrical and acoustical characteristics, and increased chemical resistance when compared to conventional injection molded parts.

GE Resins and the Foam Molding Process

With foamable resins from GE Plastics formulated specifically for the structural foam molding process, large load-bearing parts and assemblies can be produced with the optimum balance of functionality, performance, aesthetics and costs. Today's innovative design engineers are capitalizing on the unique property profiles of foamable NORYL[®], VALOX[®] and LEXAN[®] resins to design parts. By incorporating molded-in features such as snap-fits, card guides, bosses, ribs and hinges, one part can do the job of many, in some cases eliminating costly assembly operations.

In addition to providing exceptional design freedom, foamable GE resins have inherently wide processing parameters, assuring consistent high-volume reproducibility of top-quality parts.

Overall part costs can also be reduced by utilizing optimal wall thickness to minimize both cycle times and material usage. With the ability of foamable GE resins to maintain physical properties over a wide range of wall thicknesses. Parts have been successfully designed with wall thicknesses as low as 0.156 in (4 mm) and as high as 0.500 in (12.7 mm), depending on product requirements. New materials and process refinements further expand the application of the foam process to even broader dimensional limits. Developed specifically for structural foam molding, foamable grades of LEXAN, NORYL or VALOX resins suitable for a given application will depend on the specific design, process and performance requirements.

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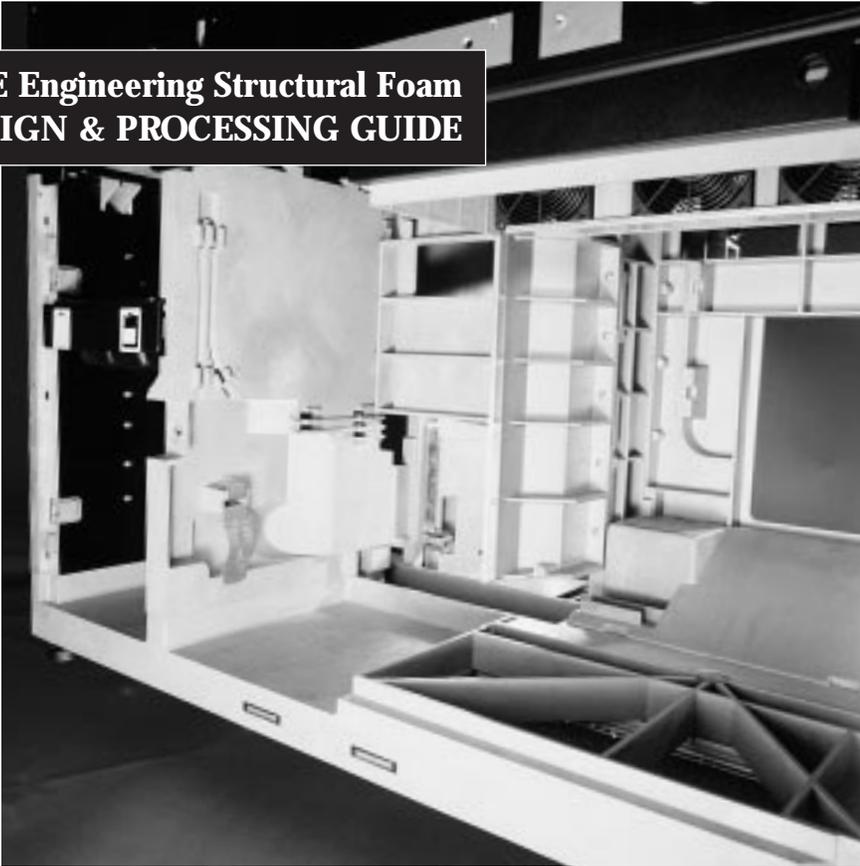


Photo Courtesy of:

FM Corp., Rogers AR – Molder
MSI, Cedar Rapids, IA – Moldmaker
Robert Luoma, Irving, TX – Designer
Abbott Laboratories, Irving, TX – OEM

Engineering Structural Foam
Material Selection

Product Selection

Foamable LEXAN® PC Resin Grades

With outstanding impact strength, high heat resistance, creep resistance and processability, LEXAN foamable polycarbonate resin can be an ideal choice for structural components where load-bearing capability at elevated temperatures is a key requirement. Thus, it can be an excellent alternative to metal and other plastics in automotive, appliance, computer and telecommunications applications.

FL900

- high heat/creep resistance
- excellent impact
- excellent flexural strength/rigidity

FL903

- UV stabilized
- high heat/creep resistance
- excellent impact
- excellent flexural strength/rigidity

FL910

- high flexural strength
- high modulus impact/heat resistant

FL913

- UV stabilized
- high flexural strength
- high modulus impact/heat resistant

FL920

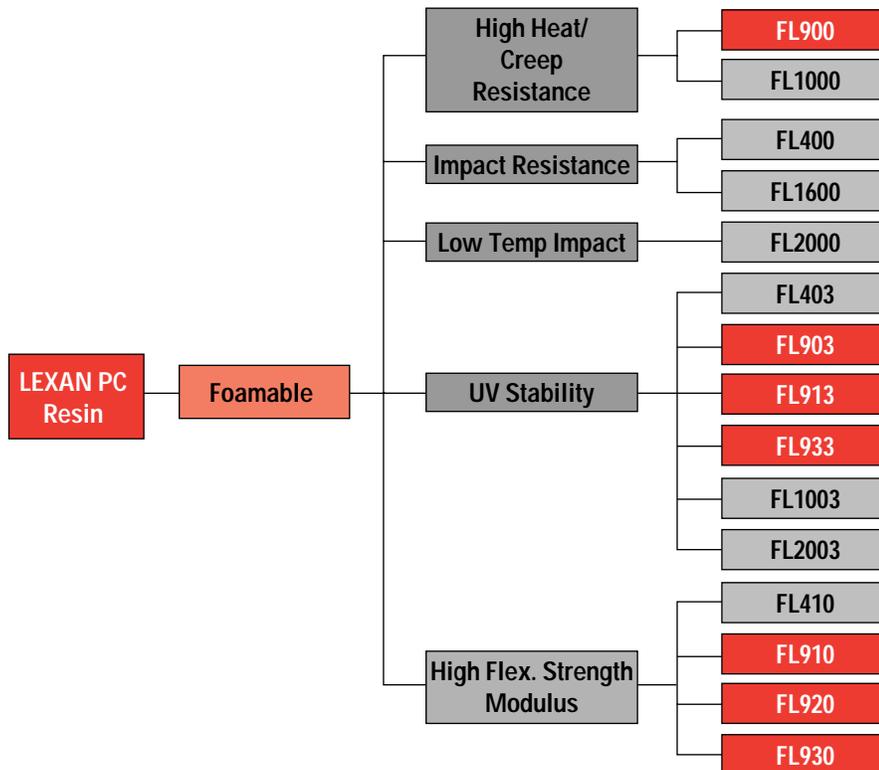
- very good modulus
- high tensile strength
- high heat resistance

FL930

- very good flexural strength
- very good modulus
- good tensile strength

FL933

- UV stabilized
- very good flexural modulus
- very good modulus
- good tensile strength



Material Properties

Typical Property Values - LEXAN Foamable Resin Grades									
PROPERTY	ENGLISH UNITS (SI UNITS)	TEST METHOD	LEXAN FL900 resin	LEXAN FL903 resin	LEXAN FL910 resin	LEXAN FL913 resin	LEXAN FL920 resin	LEXAN FL930 resin	LEXAN FL933 resin
MECHANICAL									
FOAM - MECHANICAL	%	—	10	10	10	10	10	10	10
.250" Wt Reduction									
Tensile Strength, yield, 0.250" (6.4mm)	psi(MPa)	ASTM D 638	7,300(50)	7,300(50)	7,600(52)	7,600(52)	8,500(59)	10,500(72)	10,500(72)
Tensile Elongation, break, 0.250" (6.4mm)	%	ASTM D 638	6.2	6.2	4.8	4.8	3.6	3.0	3.0
Tensile Modulus, 0.250" (6.4mm)	%	ASTM D 638	355,000(2,450)	355,000(2,450)	460,000(3,170)	460,000(3,170)	620,000(4,275)	1,005,000(6,925)	1,005,000(6,925)
Flexural Strength, yield, 0.250" (6.4mm)	psi(MPa)	ASTM D 790	13,000(90)	13,000(90)	13,000(90)	13,000(90)	15,500(107)	18,500(59)	18,500(59)
Flexural Modulus, 0.250" (6.4mm)	psi(MPa)	ASTM D 790	405,000(2,790)	405,000(2,790)	510,000(3,514)	510,000(3,514)	745,000(5,135)	1,000,000(6,890)	1,000,000(6,890)
Compressive Strength, 10% deformation	psi(MPa)	ASTM D 695	—	—	—	—	—	16,000(41)	16,000(41)
IMPACT									
FOAM - IMPACT - .250" Wt Reduction	%	—	10	10	10	10	10	10	10
Izod impact, unnotched, 73°F (23°C)	ft-lb/in(J/m)	ASTM D 256	14.0(748)	14.0(748)	16.0(854)	16.0(854)	8.0(427)	9.0(481)	9.0(481)
THERMAL									
FOAM - THERMAL	%	—	10	10	10	10	10	10	10
.250" Wt Reduction									
HDT, 66 psi (0.45 MPa), 0.250" (6.4mm) unannealed	°F (°C)	ASTM D 648	280(138)	280(138)	285(141)	285(141)	290(143)	290(143)	290(143)
HDT, 264 psi (1.82 MPa), 0.250" (6.4mm) unannealed	°F (°C)	ASTM D 648	260(127)	260(127)	272(133)	272(133)	278(137)	282(139)	282(139)
CTE, flow, -40°F to 200°F	in/in-°F(m/m-°C)	ASTM E 831	2.8 (5.0) E-5	2.8 (5.0) E-5	1.8 (3.2) E-5	1.8 (3.2) E-5	1.5 (2.7) E-5	1.2 (2.2) E-5	1.2 (2.2) E-5
Specific Heat	BTU/lb-°F	ASTM C 351	0.28	0.28	0.28	0.28	0.28	0.25	0.25
Relative Thermal Index, Elec Prop	°C	UL 746B	110	80	110	80	110	110	—
Mech Prop with impact	°C	UL 746B	110	80	110	80	110	110	—
Mech Prop without impact	°C	UL 746B	110	80	110	80	110	110	—
PHYSICAL									
FOAM - PHYSICAL	%	—	10	10	10	10	10	10	10
.250" Wt Reduction									
Specific Gravity, solid	—	ASTM D 792	1.25	1.25	1.25	1.25	1.32	1.43	1.43
Specific Gravity, foam molded	—	ASTM D 792	1.18	1.13	1.12	1.12	1.19	1.29	1.29
Water Absorption, 24 hours @ 73°F (23°C)	%	ASTM D 570	0.160	0.160	0.160	0.160	0.140	0.120	0.120
Water Absorption, equilibrium, 73°F (23°C)	%	ASTM D 570	0.35	0.35	0.32	0.32	0.30	0.26	0.26
Mold Shrinkage, flow, 0.250" (6.4mm)	in/in E-3	ASTM D 955	5-7	5-7	4-6	4-6	3-5	2-4	2-4
ELECTRICAL									
FOAM - PHYSICAL	%	—	20	20	20	—	20	20	20
.250" Wt Reduction									
Volume Resistivity	ohm-cm(Ohm-m)	ASTM D 257	2.5 E17(2.5 E15)	2.5 E17(2.5 E15)	2.4 E17(2.4 E15)	—	2.5 E17(2.5 E15)	2.4 E17(2.4 E15)	2.4 E17(2.4 E15)
Surface Resistivity	ohm/sq	ASTM D 257	<1.1E17	<1.1E17	<1.1E17	—	<1.1E17	<1.1E17	<1.1E17
Dielectric Strength, in air, 250 mil (6.4 mm)	V/mil(kV/mm)	ASTM D 149	204(8.0)	204(8.0)	265(10.4)	—	296(11.7)	279(11.0)	279(11.0)
Dielectric Constant, 100 Hz	—	ASTM D 150	2.22	2.22	2.45	—	2.52	2.70	2.70
Dielectric Constant, 1 Mhz	—	ASTM D 150	2.12	2.12	2.40	—	2.50	2.61	2.61
Dissipation Factor, 100 Hz	—	ASTM D 150	0.0012	0.0012	0.0013	—	0.0008	0.0034	0.0034
Dissipation Factor, 1 Mhz	—	ASTM D 150	0.0061	0.0061	0.0065	—	0.0052	0.0075	0.0075
FLAME CHARACTERISTICS*									
FOAM - Flame Class	g/cm ³	—	0.75	0.71	0.85	0.97	0.85	0.90	—
Minimum Density									
UL 94 V-1 Flame Class Rating	in(mm)	UL 94	0.157(4.0)	—	—	—	—	—	—
UL 94 V-O Flame Class Rating	in(mm)	UL 94	0.240(6.10)	0.247(6.3)	0.248(6.3)	0.152(3.9)	0.248(6.3)	0.248(6.3)	—
UL 94 5VA Flame Class Rating	in(mm)	UL 94	0.240(6.10)	—	0.248(6.3)	0.152(3.9)	0.248(6.3)	0.248(6.3)	—
Oxygen Index (LOI)	%	ASTM D 2863	40.4	—	—	—	—	40.4	40.4

*These ratings are not intended to reflect hazards presented by any material under actual fire conditions.

Product Selection

Foamable LEXAN® PC Resin Grades (Continued)

FL400

- unreinforced
- Thinwall capability
- outstanding impact strength
- UL 94 V-0/5V rating*

FL403

- UV stabilized
- unreinforced
- Thinwall capability
- outstanding impact strength
- UL 94 V-0/5V rating*

FL410

- 10% glass reinforced
- Thinwall capability
- very good impact strength
- very good flexural strength/rigidity
- UL 94 V-0 rating* (in wall thickness .153")

FL1000

- 5% glass reinforced
- very good physical properties
- outstanding processability
- UL 94 V-0/5V rating*

FL1003

- UV stabilized
- 5% glass reinforced
- very good physical properties
- outstanding processability
- UL 94 V-0/5V rating*

FL1600

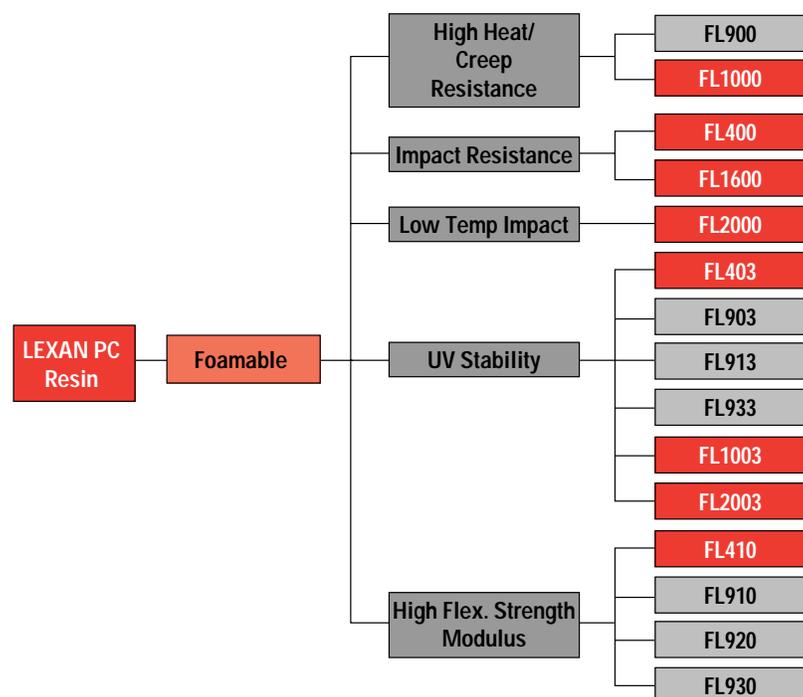
- 5% glass reinforced
- very good flow characteristics for smooth surfaces and lighter weight parts

FL2000

- unreinforced
- outstanding impact strength even at low temperatures
- good surface finish and flow characteristics
- inherent flame resistance

FL2003

- UV stabilized
- unreinforced
- outstanding impact strength even at low temperatures
- good surface finish and flow characteristics
- inherent flame resistance



*These ratings are not intended to reflect hazards presented by any material under actual fire conditions.

LEXAN PC Resin

Typical Property Values - Foamable LEXAN Resin Grades										
PROPERTY	ENGLISH UNITS (SI UNITS)	TEST METHOD	LEXAN FL400 resin	LEXAN FL403 resin	LEXAN FL410 resin	LEXAN FL1000 resin	LEXAN FL1003 resin	LEXAN FL1600 resin	LEXAN FL2000 resin	LEXAN FL2003 resin
MECHANICAL										
FOAM - MECHANICAL	%	—	10	10	10	10	10	10	10	10
0.250" Wt Reduction										
Tensile Strength, yield, 0.250" (6.4mm)	psi(MPa)	ASTM D 638	7,900(54)	7,900(54)	7,300(50)	7,000(48)	7,000(48)	7,000(48)	7,800(54)	7,800(54)
Tensile Elongation, break, 0.250" (6.4mm)	%	ASTM D 638	7.2	7.2	4.8	5.2	5.2	5.2	7.8	7.8
Tensile Modulus, 0.250" (6.4mm)	%	ASTM D 638	305,000(2,100)	305,000(2,100)	460,000(3,170)	355,000(2,450)	355,000(2,450)	355,000(2,450)	335,000(2,310)	335,000(2,310)
Flexural Strength, yield, 0.250" (6.4mm)	psi(MPa)	ASTM D 790	12,500(86)	12,500(86)	13,500(93)	13,000(90)	13,000(90)	13,000(90)	11,000(76)	11,000(76)
Flexural Modulus, 0.250" (6.4mm)	psi(MPa)	ASTM D 790	360,000(2,480)	360,000(2,480)	555,000(3,825)	400,000(2,760)	400,000(2,760)	400,000(2,760)	280,000(1,930)	280,000(1,930)
Compressive Strength, 10% deformation	psi(MPa)	ASTM D 695	—	—	—	8,600(59)	8,600(59)	8,600(59)	8,700(60)	8,700(60)
IMPACT										
FOAM - IMPACT	%	—	10	10	10	10	10	10	10	10
0.250" Wt Reduction										
Izod Impact, unnotched, 73 F (23 C)	ft-lb/in(J/m)	ASTM D 256	50.0(2,670)	50.0(2,670)	16.0(854)	13.0(694)	13.0(694)	14.0(748)	50.0(2,670)	50.0(2,670)
THERMAL										
FOAM - THERMAL	%	—	10	10	10	10	10	10	10	10
0.250" Wt Reduction										
HDT, 66 psi (0.45 MPa), 0.250" (6.4mm) unannealed	°F (°C)	ASTM D 648	280(138)	280(138)	280(138)	280(138)	280(138)	280(138)	280(138)	280(138)
HDT, 264 psi (1.82 MPa), 0.250" (6.4mm) unannealed	°F (°C)	ASTM D 648	260(127)	260(127)	270(132)	260(127)	260(127)	260(127)	260(127)	260(127)
CTE, flow, -40°F to 200°F (-40°C to 95°C)	in/in-°F(m/m-°C)	ASTM E 831	3.7 (6.7) E-5	3.7 (6.7) E-5	1.8 (3.2) E-5	2.8 (5.0) E-5	2.8 (5.0) E-5	2.8 (5.0) E-5	3.1 (5.6) E-5	3.1 (5.6) E-5
Specific Heat	BTU/lb-°F	ASTM C 351	0.32	0.32	0.27	0.29	0.29	0.27	0.28	0.28
Relative Thermal Index	°C	UL 746B	80	80	80	110	80	—	80	80
Elec Prop										
Mech Prop with impact	°C	UL 746B	80	80	80	110	80	—	80	80
Mech Prop without impact	°C	UL 746B	80	80	80	110	80	—	80	80
PHYSICAL										
FOAM - PHYSICAL	%	—	10	10	10	10	10	10	10	10
0.250" Wt Reduction										
Specific Gravity, solid	—	ASTM D 792	1.20	1.20	1.25	1.20	1.20	1.25	1.21	1.21
Specific Gravity, foam molded	—	ASTM D 792	1.08	1.08	1.13	1.08	1.08	1.13	1.09	1.09
Water Absorption, 24 hours @ 73 F (23 C)	%	ASTM D 570	0.140	0.140	0.140	0.200	0.200	0.140	0.130	0.130
Water Absorption, equilibrium, 73 F (23 C)	%	ASTM D 570	0.31	0.31	0.31	0.40	0.40	0.33	0.34	0.34
Mold Shrinkage, flow, 0.250" (6.4mm)	in/in E-3	ASTM D 955	6-8	6-8	4-6	5-7	5-7	5-7	6-8	6-8
ELECTRICAL										
FOAM - PHYSICAL	%	—	20	20	20	20	20	20	20	20
0.250" Wt Reduction										
Volume Resistivity	ohm-cm(ohm-m)	ASTM D 257	3.5 E17(3.5 E15)	3.5 E17(3.5 E15)	2.4 E17(2.4 E15)	2.9 E17(2.9 E15)	2.9 E17(2.9 E15)	2.8 E17(2.8 E15)	3.6 E16(3.6 E14)	3.6 E16(3.6 E14)
Surface Resistivity	ohm/sq	ASTM D 257	<1.1E17	<1.1E17	<1.1E17	<1.1E17	<1.1E17	<1.1E17	<1.1E17	<1.1E17
Dielectric Strength, in air, 250 mil (6.4mm)	V/mil(kV/mm)	ASTM D 149	304(11.9)	304(11.9)	245(9.6)	322(12.6)	322(12.6)	280(11.0)	307(12.0)	307(12.0)
Dielectric Constant, 100 Hz	—	ASTM D 150	2.42	2.42	2.40	2.48	2.48	2.45	2.47	2.47
Dielectric Constant, 1 Mhz	—	ASTM D 150	2.43	2.43	2.32	2.48	2.48	2.44	2.68	2.68
Dissipation Factor, 100 Hz	—	ASTM D 150	0.0011	0.0011	0.0028	0.0010	0.0010	0.0070	0.0037	0.0037
Dissipation Factor, 1 Mhz	—	ASTM D 150	0.0044	0.0044	0.0081	0.0042	0.0042	0.0042	0.0039	0.0039
FLAME CHARACTERISTICS*										
FOAM - Flame Class	g/cm ³	—	1.06	1.05	1.00	1.15	1.05	—	0.94	1.12
Minimum Density										
UL 94 HB Flame Class Rating	in(mm)	UL 94	—	—	—	—	—	—	—	0.236(6.0)
UL 94 V-1 Flame Class Rating	in(mm)	UL 94	—	—	—	—	—	—	—	—
UL 94 V-0 Flame Class Rating	in(mm)	UL94	0.125(3.2)	0.125(3.2)	0.150(3.8)	0.125(3.2)	0.120(3.04)	—	0.246(6.2)	—
UL 94 5VA Flame Class Rating	in(mm)	UL94	0.125(3.2)	—	0.150(3.8)	0.247(6.3)	—	—	—	—
Oxygen Index (LOI)	%	ASTM D 2863	39.0	39.0	—	—	—	—	28.2	28.2

*These ratings are not intended to reflect hazards presented by any material under actual fire conditions.

Product Selection

Foamable NORYL® Modified PPO® Resin Grades

Although these materials have lower deflection temperatures than the other foamable GE resins, they exhibit an outstanding combination of strength plus heat and impact resistance, together with UL 94 V-0, V-1, and 5V ratings*. Excellent dimensional stability, including low creep and water absorption, makes NORYL foamable resin ideal for applications such as business machine housings and their structural bases, electrical components offering weather resistance, and lightweight structural interior components for transportation.

FN150X

- unreinforced
- Thinwall capability
- improved reliability/productivity
- UL 94 V-0/5V rating*

FN170X

- unreinforced
- general purpose
- UL 94 V-1/5V rating*

FN215X

- unreinforced
- improved reliability/productivity
- UL 94 V-1, V-0/5V ratings*

FM3020

- 30% glass/mineral reinforced
- UL 94 V-1/5V ratings*

FM4025

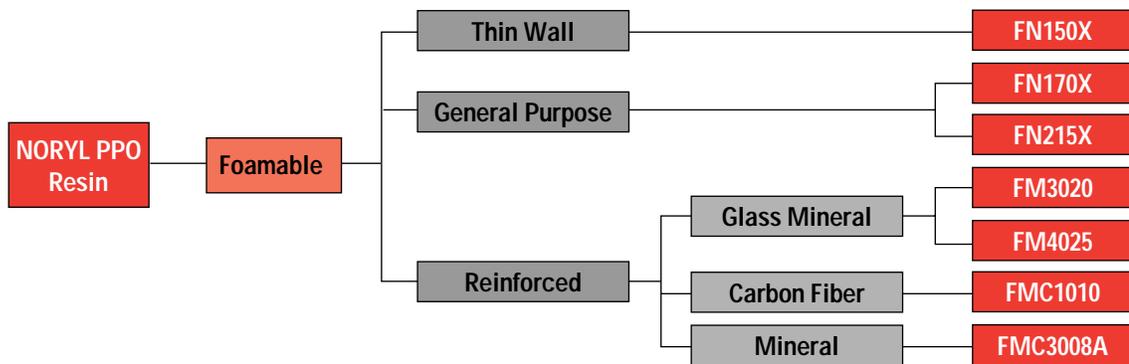
- 40% glass/mineral reinforced
- UL 94 V-1, V-0/5V ratings*

FMC1010

- 10% carbon fiber reinforced
- static dissipative
- non-brominated, non-chlorinated flame retardant system

FMC3008A

- 30% glass/mineral/carbon fiber reinforced
- static dissipative
- tight tolerance molding applications



*These ratings are not intended to reflect hazards presented by any material under actual fire conditions.

NORYL Modified PPO Resin

Typical Property Values - NORYL Foamable Grades									
PROPERTY	ENGLISH UNITS (SI UNITS)	TEST METHOD	NORYL FN150X resin	NORYL FN170X resin	NORYL FN215X resin	NORYL FM3020 resin	NORYL FM4025 resin	NORYL FMC1010 resin	NORYL FMC3008A resin
MECHANICAL									
FOAM -MECHANICAL	%	—	20	10	20	10	10	20	20
.250" Wt Reduction									
Tensile Strength, yield, 0.250" (6.4mm)	psi(MPa)	ASTM D 638	4,100(28)	4,230(29)	4,200(29)	10,500(72)	12,000(82.7)	6,600(45)	7,100(49)
Tensile Strength, break, 0.250" (6.4mm)	psi(MPa)	ASTM D 638	4,100(28)	4,140(29)	—	—	—	—	—
Tensile Elongation, yield, 0.250" (6.4mm)	%	ASTM D 638	7.3	5.7	—	2.0	1.5	—	—
Tensile Elongation, break, 0.250" (6.4mm)	%	ASTM D 638	14.0	13.1	12.0	—	—	41	3.5
Flexural Strength, yield, 0.250" (6.4mm)	psi(MPa)	ASTM D 790	7,600(52)	9,650(66)	8,900(61)	15,200(105)	17,600(121)	13,800(95)	14,800(102)
Flexural Modulus, 0.250" (6.4mm)	psi(MPa)	ASTM D 790	253,000(1,745)	309,000(2,130)	276,000(1,900)	950,000(6,550)	1,150,000(7,925)	870,000(6,000)	1,130,000(7,785)
Hardness, Rockwell R	—	ASTM D 785	121	—	—	83	85	—	—
Taber Abrasion, CS-17, 1 kg	mg/1000 cy	ASTM D 1044	152	—	—	100	100	—	—
IMPACT									
FOAM -IMPACT -	%	—	20	10	20	10	10	20	20
.250" Wt Reduction									
Izod impact, unnotched, 73°F (23°C), 0.250"	ft-lb/in(J/m)	ASTM D 256	6.4(342)	5.2(278)	3.8(203)	1.8(96)	1.3(69)	2.9(155)	1.9(102)
THERMAL									
FOAM -THERMAL	%	—	20	10	20	10	10	20	20
.250" Wt Reduction									
HDT, 66 psi (0.45MPa), 0.250" (56.4mm) unannealed	°F (°C)	ASTM D 648	193(89)	193(89)	192(89)	245(118)	245(118)	219(104)	241(116)
HDT, 264psi (1.82MPa), 0.250" (6.4mm) unannealed	°F (°C)	ASTM D 648	165(74)	173(78)	170(76)	230(110)	230(110)	207(97)	228(109)
Relative Thermal Index, Elec Prop	°C	UL 746B	50	85	85	50	50	50	50
Mech Prop with impact	°C	UL 746B	50	85	85	50	50	50	50
Mech Prop without impact	°C	UL 746B	50	85	85	50	50	50	50
PHYSICAL									
FOAM -PHYSICAL	%	—	20	10	20	10	10	20	20
.250" Wt Reduction									
Specific Gravity, solid	—	ASTM D 792	—	1.11	1.10	1.32	1.43	1.15	1.28
Specific Gravity, foam molded	—	ASTM D 792	1.12	1.00	0.88	1.19	1.29	0.92	1.02
Water Absorption, 24 hours @ 73°F (23°C)	%	ASTM D 570	0.060	0.060	0.070	0.080	0.080	—	—
Mold Shrinkage, flow, 0.250" (6.4mm)	in/inE-3	ASTM D 955	6-8	6-8	6-8	2.5	1.5	1.5-2.5	1.5-2.5
Mold Shrinkage, xflow, 0.250" (6.4mm)	in/inE-3	ASTM D 955	6-8	—	—	3.0	2.5	2.0-4.0	1.5-3.5
ELECTRICAL									
FOAM -PHYSICAL	%	—	—	—	—	20	20	20	20
.250" Wt Reduction									
Volume Resistivity	ohm/cm(ohm-m)	ASTM D 257	—	—	—	10E17(10E15)	10E17(10E15)	8.0E3(8.0E1)	1.0E4(1.0E2)
Surface Resistivity	ohm/sq	ASTM D 257	—	—	1.0E17	10E17	10E17	1.3E4	1.0E5
Dielectric Strength, in air, 250 mil	V/mil(kV/mm)	ASTM D 149	—	—	—	330(13)	381(15)	—	—
Dielectric Constant, 1 Mhz	—	ASTM D 150	—	—	2.20	—	—	—	—
Dissipation Factor, 1 Mhz	—	ASTM D 150	—	—	0.0044	—	—	—	—
FLAME CHARACTERISTICS*									
FOAM - Flame Class	g/cm ³	—	0.90	1.00	0.85	1.12	1.26	0.96	0.96
Minimum Density									
UL 94 V-1 Flame Class Rating	in(mm)	UL 94	—	0.121(3.07)	0.154(3.91)	0.113(2.87)	0.113(2.87)	0.156(3.96)	0.156(3.96)
UL 94 V-0 Flame Class Rating	in(mm)	UL 94	0.156(3.96)	—	0.240(6.09)	—	0.195(4.95)	—	—
UL 94 5VA Flame Class Rating	in(mm)	UL 94	0.156(3.96)	0.186(4.72)	0.154(3.91)	0.113(2.87)	0.113(2.87)	—	—

*These tests are not intended to reflect hazards presented by any material under actual fire conditions

Product Selection

Foamable VALOX® PBT Resin Grades

The foamable VALOX resin grades offer the desirable properties of thermoplastic polyesters, including high deflection temperature under load, chemical solvent resistance, good fatigue endurance and high flexural strength and modulus. The good flow properties of VALOX resin simplify the molding of parts requiring high heat endurance, moderate creep resistance and good chemical resistance.

FV608

- 30% glass reinforced
- heat and chemical resistance
- toughness
- flex fatigue resistance

FV649

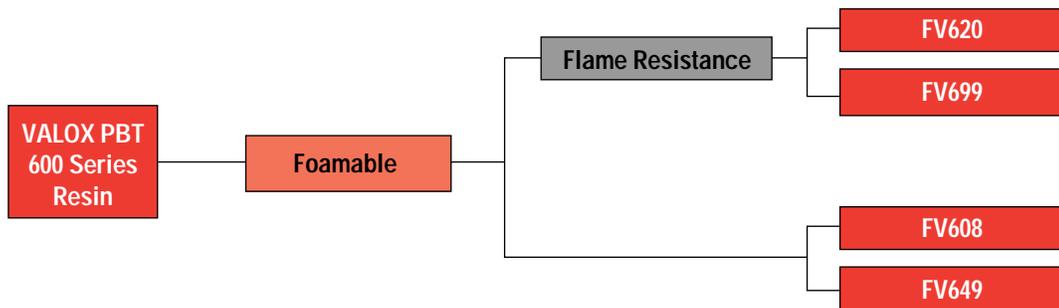
- 10% glass reinforced
- improved toughness, chemical resistance
- low warpage

FV699

- 10% glass reinforced
- very good chemical and heat resistance
- Thinwall/greater weight reduction possible
- flame resistant

FV620

- 30% glass reinforced
- very good heat and chemical resistance
- high flexural modulus
- flame resistant



VALOX PBT Resin

Typical Property Values - Foamable VALOX Resin Grades						
PROPERTY	ENGLISH UNITS (SI UNITS)	TEST METHOD	VALOX FV608 resin	VALOX FV620 resin	VALOX FV649 resin	VALOX FV699 resin
MECHANICAL						
FOAM -MECHANICAL .250" Wt Reduction	%	—	10	10	10	10
Tensile Strength, yield, 0.250" (6.4mm)	psi(MPa)	ASTM D 638	15,700(180)	11,200(77)	6,800(47)	7,200(50)
Tensile Elongation, break, 0.250" (6.4mm)	%	ASTM D 638	4.3	4.8	5.4	6.0
Tensile Modulus, 0.250" (6.4mm)	psi(MPa)	ASTM D 638	1,195,000(8,235)	1,215,000(8,370)	435,000(3,000)	355,000(2,450)
Flexural Strength, yield, 0.250" (6.4mm)	psi(MPa)	ASTM D 790	23,100(159)	21,300(148)	11,700(81)	11,900(82)
Flexural Modulus, 0.250" (6.4mm)	psi(MPa)	ASTM D 790	1,000,000(6,890)	1,110,000(7,650)	465,000(3,205)	430,000(2,965)
Compressive Strength, 10% deformation	psi(MPa)	ASTM D 695	17,000(117)	17,000(117)	8,500(59)	8,600(59)
IMPACT						
FOAM -IMPACT - .250" Wt Reduction	%	—	10	10	10	10
Izod impact, unnotched, 73°F (23°C)	ft-lb/in(J/m)	ASTM D 4812	13.0(694)	10.0(534)	20.0(1068)	19.0(1015)
THERMAL						
FOAM -THERMAL .250" Wt Reduction	%	—	10	10	10	10
HDT, 66 psi (0.45MPa), 0.250" (6.4mm) unannealed	°F(°C)	ASTM D 648	405(207)	395(202)	240(116)	240(116)
HDT, 264 psi (1.82MPa), 0.250" (6.4mm) unannealed	°F(°C)	ASTM D 648	295(146)	285(141)	226(108)	226(108)
CTE, flow, -40 to 200°F (-40 to 95°C)	in/in-°F(m/m-°C)	ASTM E 831	1.3 E-5(2.3E-5)	1.3 E-5(2.3E-5)	1.8 E-5(3.2E-5)	1.8 E-5(3.2E-5)
Relative Thermal Index	°C	UL 746C	—	105	75	75
Elec Prop	—	—	—	—	—	—
Mech Prop with impact	°C	UL 746C	—	90	75	75
Mech Prop without impact	°C	UL 746C	—	100	75	75
PHYSICAL						
FOAM -PHYSICAL .250" Wt Reduction	%	—	10	10	10	10
Specific Gravity, solid	—	ASTM D 792	1.50	1.62	1.26	1.27
Specific Gravity, foam molded	—	ASTM D 792	1.35	1.46	1.13	1.14
Water Absorption, 24 hours @ 73°F (23°C)	%	ASTM D 570	0.060	0.040	0.150	0.120
Water Absorption, equilibrium, 73°F (23°C)	%	ASTM D 570	0.13	0.090	0.33	0.28
Mold Shrinkage, flow, 0.250" (6.4mm)	in/in E-3	ASTM D 955	2.5-4.5	3-5	3.5-5.5	3.5-5.5
ELECTRICAL						
FOAM -PHYSICAL .250" Wt Reduction	%	—	20	20	20	20
Volume Resistivity	ohm/cm(ohm-m)	ASTM D 257	3.0E17(3.0E15)	2.5E17(2.5E15)	1.4E17(1.4E15)	1.6E16(1.6E14)
Surface Resistivity	ohm/sq	ASTM D 257	<1.1E17	<1.1E17	<1.1E17	<1.1E17
Dielectric Strength, in air, 250 mil (6.4 mm)	v/mil(kV/mm)	ASTM D 150	335(13)	—	326(13)	328(13)
Dielectric Constant, 100 Hz	—	ASTM D 150	2.82	3.09	2.71	2.58
Dielectric Constant, 1 Mhz	—	ASTM D 150	2.81	2.94	2.80	2.73
Dissipation Factor, 100 Hz	—	ASTM D 150	0.0012	0.0040	0.0028	0.0024
Dissipation Factor, 1 Mhz	—	ASTM D 150	0.0080	0.0110	0.0347	0.0414
FLAME CHARACTERISTICS*						
FOAM - Flame Class Minimum Density	%	—	—	1.20	1.00	0.99
UL 94 HB Flame Class Rating	in(mm)	UL 94	—	—	0.122(310)	—
UL 94 V-0 Flame Class Rating	in(mm)	UL 94	—	0.191(4.85)	—	0.195(4.95)
UL 94 5VA Flame Class Rating	in(mm)	UL 94	—	0.191(4.85)	—	0.195(4.95)

*These ratings are not intended to reflect hazards presented by any material under actual fire conditions.

Product Selection

Blowing Agent Concentrates for Foamable GE Resins

Chemical blowing agent concentrates (CBAs) are used in the structural foam process. They are blended with the base resin prior to being plasticized. After being exposed to a certain temperature, the blowing agent decomposes, releasing an inert gas that mixes with the molten resin. The gas/resin mixture remains under pressure in the injection machine.

Two types of CBAs used in structural foam processing are Endothermic – products that absorb heat, and Exothermic, products that generate heat. Advantages and disadvantages exist for both types. Exothermic CBAs are higher gas pressure generators, generally resulting in better sink mark control, larger cells and longer cool time requirements. Endothermic CBAs are lower gas pressure generators, and typically produce finer cell structures, exhibit enhanced surface finishes and shorter cool time requirements. The chemicals used to produce the foaming gas are compounded with a carrier resin or other substance. Care should be taken to confirm the compatibility of the CBA with the GE resin being used for the application.

GE Plastics has developed proprietary blowing agent concentrates to complement each grade of foamable resin. Supplied in pellet form, they can be used with virtually any type of plastic processing equipment. With these concentrates, and suitable equipment, most molders can develop the capability for foam processing.

GE blowing agent concentrates are physically and chemically similar to the resin being processed, helping assure compatibility. They can be blended and dried with the base resin with most parameters remaining constant. Easily measured, they provide accurate mixing ratios to accommodate varied application requirements. GE blowing agents are clean and dust free.

Several blowing agents are available for use with GE Plastics resins. Please contact the CBA suppliers directly for processing and other technical information.

Blowing Agents for LEXAN Resin FL Grade

There are a number of blowing agents available for LEXAN resins. To help you decide which agent to use for your specific application and resin choice, contact your Technical Development Engineer or Application Development Engineer.

Blowing Agents for NORYL Resin FN Grades

NORYL resin “X” grades, when used with certain blowing agents, can produce surface discoloration on parts). This surface discoloration (redish spots) tends to occur when the resin is foamed with common endothermic blowing agents. The surface discoloration results from a sodium phosphorous complexation reaction between sodium-based blowing agents and the flame retardant additives used in the “X” grades. The use of sodium-based blowing agents with “X” grades should be avoided. FNC30X has been formulated specifically for use with foam NORYL resin and has been found not to produce this surface discoloration in parts made with NORYL resin “X” grades.

Blowing Agent for VALOX Resin FV Grades

FVC60/65 blowing agent has been developed for VALOX resin and other polyesters, and helps assure uniform mixing, compatibility and melt dispersion. FVC60/65 is exothermic offering excellent cell formation and finished part quality.

Blowing Agents Technical Data

Technical Data for suggested blowing agents for foamable GE resins is shown in table 1-9.

	CBA for LEXAN resin	FNC30X	FVC60/65
Gasses Evolved, %		N ₂ /CO 60 CO ₂ 30 H ₃ 10	N ₂ 100
Gas Evolution Rate (ml/g of conc. @ STP at 210%)	Contact CBA suppliers directly.	18.0	10.0
Decomp. Temp. Range, °F		338-374	465-480
Specific Gravity		1.04	1.36

Table 1-9. Blowing Agent Technical Data.



GE Plastics

**GE Engineering Structural Foam
DESIGN & PROCESSING GUIDE**



Mechanical Properties

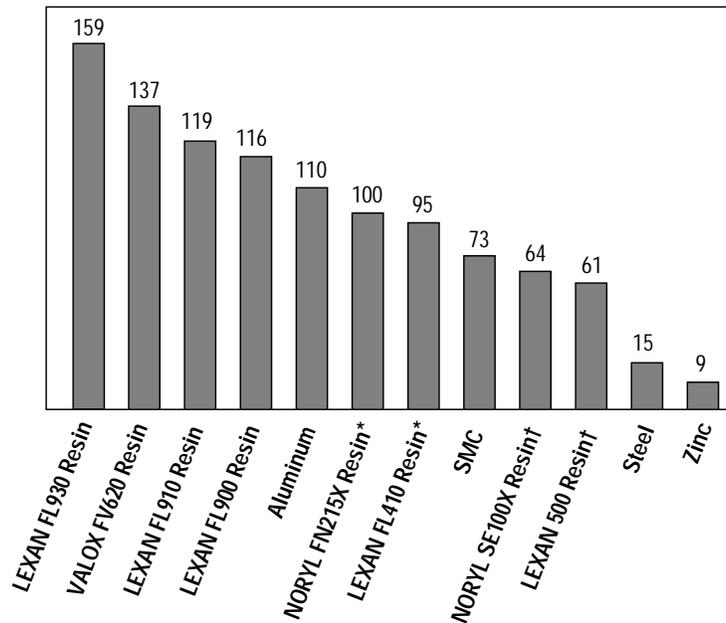
Stiffness-to-Weight

The high stiffness-to-weight ratio of Engineering Structural Foam is the primary advantage this material has over metal and standard (non-foamed) injection molded plastics. Stiffness is defined as the product of EI (modulus of elasticity times moment of inertia of the section). With NORYL FN215X resin at 100 for comparison, Figure 2-1 illustrates the advantage of Engineering Structural Foam over various alternate materials for equal weights of material.

An equivalent weight of 0.250 in (6.35 mm) thickness foam can have over seven times the rigidity of steel and thirteen times the rigidity of zinc. Compared to an equivalent weight of solid plastic, 0.250 in (6.35mm) thickness foam can have twice the rigidity.

Thinner wall structural foam parts can also have the advantage of a high stiffness-to-weight ratio, but to a somewhat lesser extent than 0.250 in (6.35mm) design. For comparison purposes a part made from LEXAN FL410 resin with a wall thickness of 0.157 in (4 mm) will have a stiffness-to-weight ratio of 95.

Figure 2-1. Ratio of Stiffness (EI) for Equivalent Weight.* (@ 0.250 in [6.4 mm] Thickness = 100)



*LEXAN FL410 Resin @ 0.157 in (4 mm) Wall Thickness.

† Injection Molded

Tensile Strength

When designing for pure tensile loading conditions, care must be taken to remain within the proportional limit of Engineering Structural Foam materials due to the nature of the cellular core. The retention of tensile strength over a wide range of temperatures is a feature of foamable GE resins.

Figure 2-2 illustrates this with variations in density and temperature. For example, foamable NORYL resin retains 70% of its room temperature tensile strength at 150°F (66°C), while foamable LEXAN resin retains 65% of its room temperature tensile strength at 200°F (93°C).

A significant effect on tensile properties occurs due to density reduction, as shown in Figures 2-2 through 2-5. This is one reason that density reductions greater than 35% are not generally recommended.

The tensile strength of a material will also vary with the wall thickness used. This will occur due to the lower density reductions and higher skin-to-core ratios seen in thinner walls compared to thicker wall design.

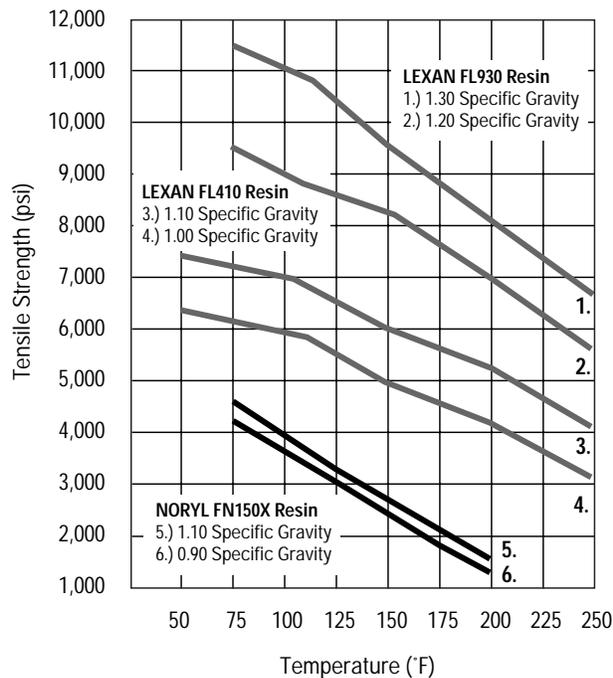


Figure 2-2. Tensile Strength vs Temperature.
(0.157 in [4 mm] Wall Thickness)

Properties

Figure 2-3. Tensile Strength vs. Temperature.
(0.250 in [6.35 mm] Wall Thickness)

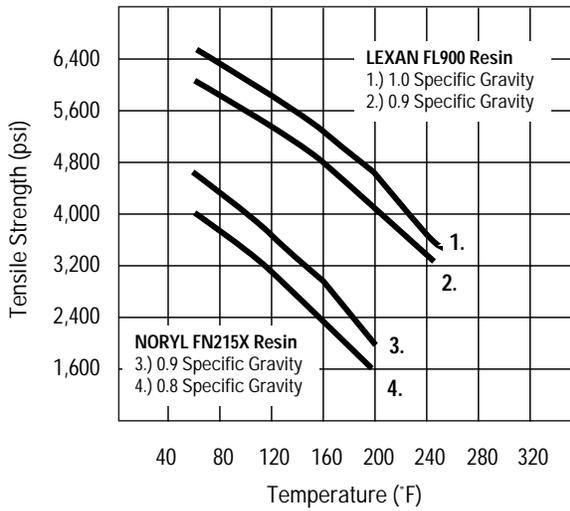


Figure 2-4. Tensile Strength vs. Temperature.
(0.250 in [6.35 mm] Wall Thickness)

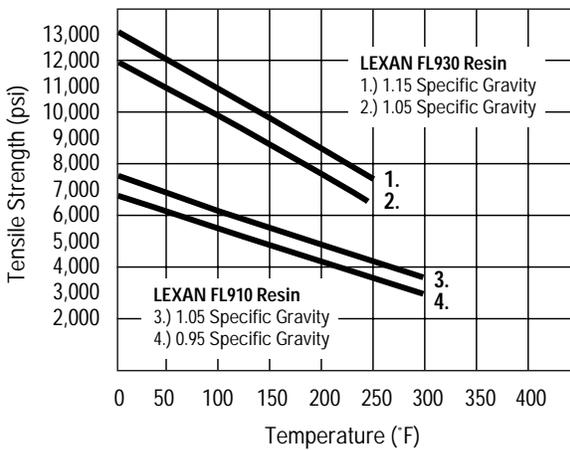
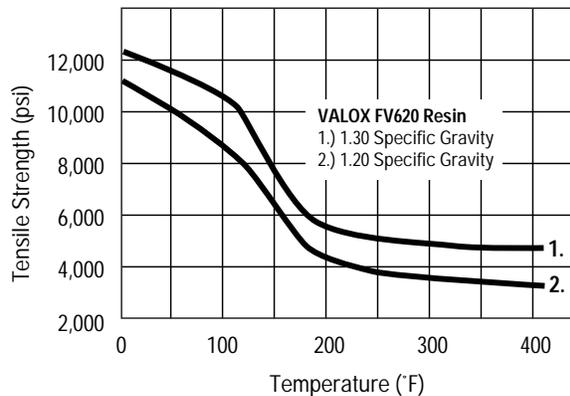


Figure 2-5. Tensile Strength vs. Temperature.
(0.250 in [6.35 mm] Wall Thickness)



Flexural Properties

Structural foam's distribution of material at any cross-section makes for excellent flexural properties. Solid resin is situated at the outer-most regions of the cross-section where maximum flexural stresses occur. Because of this distribution and the resin properties, high flexural modulus can be maintained at elevated temperatures.

Figures 2-6 through 2-8 demonstrate this with variations in density and temperature.

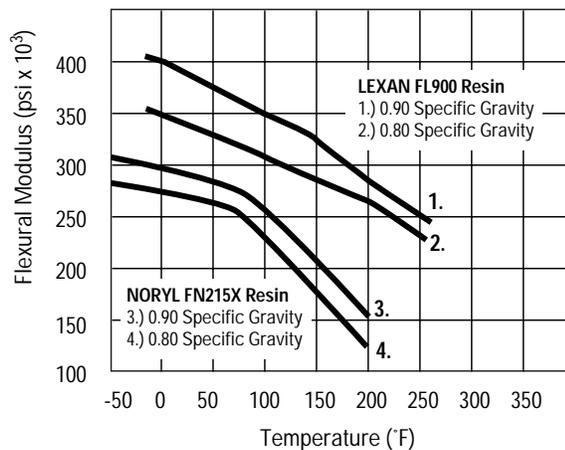


Figure 2-6. Flexural Modulus vs. Temperature.
(0.250 in [6.35 mm] Wall Thickness)

For example, foamable NORYL resin retains 80% of its room temperature flexural modulus at 150°F (66°C) while foamable. LEXAN resin retains 70% of its room temperature flexural modulus at 200°F (93°C). Density reductions greater than 35% reduce flexural properties significantly and generally are not recommended. Again, wall thickness will play a role in the flexural properties of a material. The effect of lower density reductions and higher skin-to-core ratios at thinner walls on these properties is shown in Figure 2-9.

Figures 2-10 through 2-13 on Pages 2-6 and 2-7 demonstrate the flexural strength of these resins.

Properties

Figure 2-7. Flexural Modulus vs. Temperature.
(0.250 in [6.35 mm] Wall Thickness)

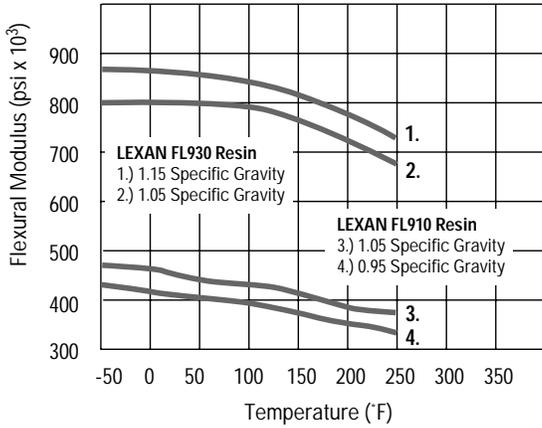


Figure 2-10. Flexural Strength vs. Temperature.
(0.250 in [6.35 mm] Wall Thickness)

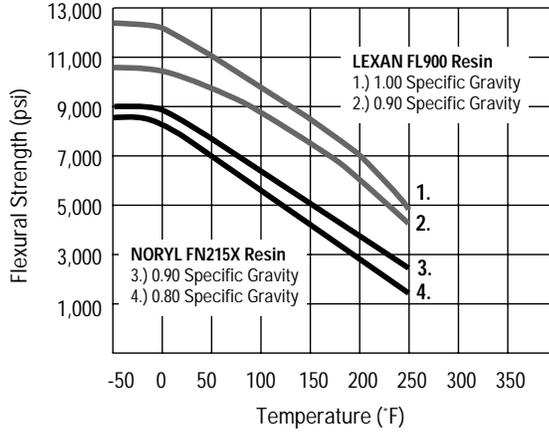


Figure 2-8. Flexural Modulus vs. Temperature.
(0.250 in [6.35 mm] Wall Thickness)

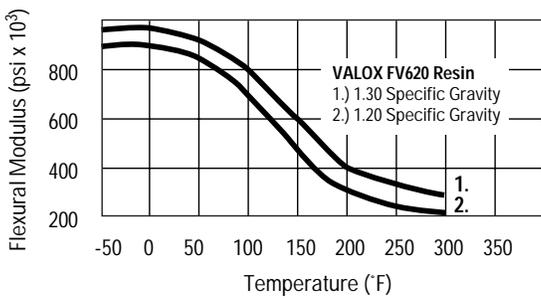


Figure 2-11. Flexural Strength vs. Temperature.
(0.250 in [6.35 mm] Wall Thickness)

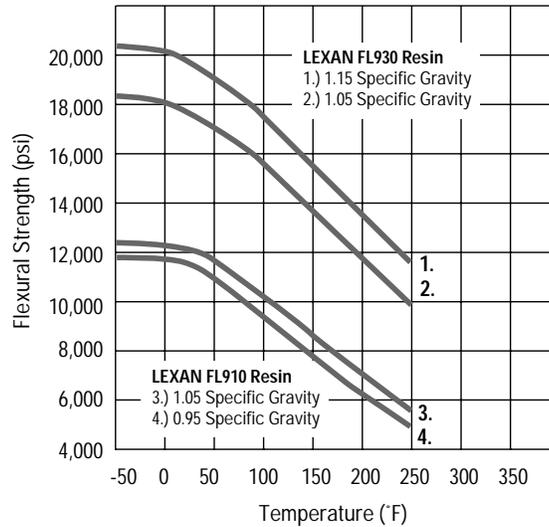


Figure 2-9. Flexural Modulus vs. Temperature.
(0.250 in [6.35 mm] Wall Thickness)

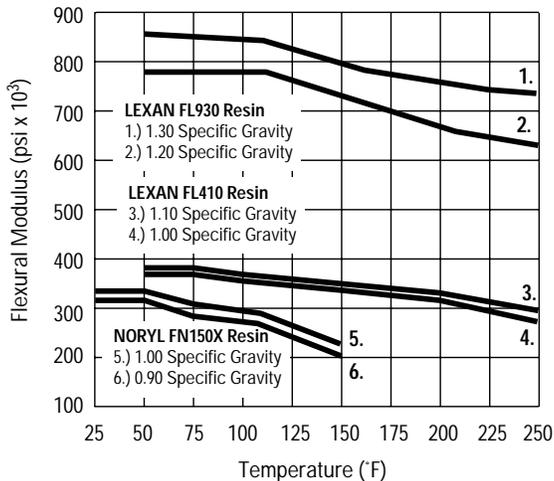
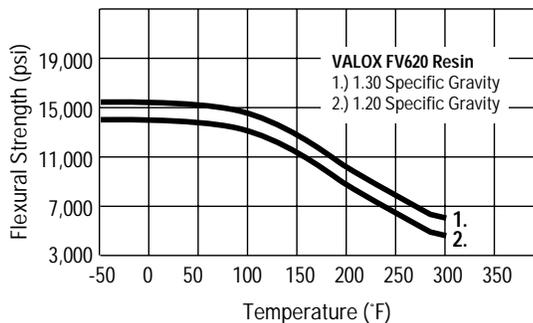


Figure 2-12. Flexural Strength vs. Temperature.
(0.250 in [6.35 mm] Wall Thickness)



Mechanical Properties

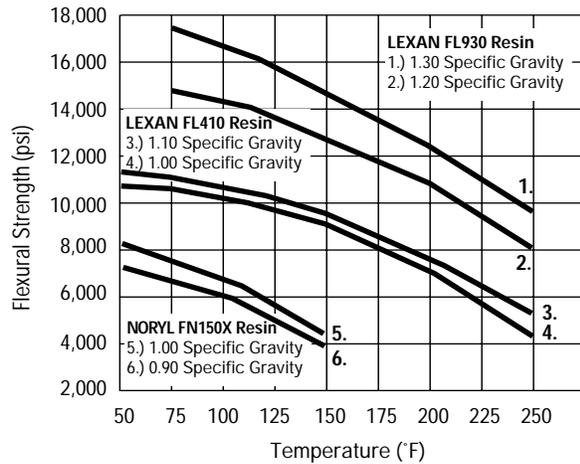


Figure 2-13. Flexural Strength vs. Temperature. (0.250 in [6.35 mm] Wall Thickness)

Impact Strength

The Charpy impact strength test commonly used for metals (similar to Izod swinging pendulum) ranges from 5 to 10 ft-lbs/in (267 to 534 J/m) for unnotched foam resins. Unfortunately, this data is difficult to translate directly into a prediction of the impact behavior of an end product since it sums all energy required to break the specimen, including energy to bend, draw and tear.

Falling ball impact tests are generally more realistic than pendulum tests because velocity, as well as the energy at impact, can be interpreted relatively easily. They will often more closely describe performance because they simulate the type of impact stress most commonly found in use.

Table 2-1 shows a typical falling ball impact test, in which a 10 lb weight with a 0.500 in (12.7 mm) radius nose is allowed to free fall onto a flat specimen. The modes of failure for this test are: 1) complete fracture of sample; 2) puncture of dart head through sample; 3) area opposite the impact cracks or forms a rift 0.010 in (0.254 mm) in height or greater.

	Falling Ball Impact (ft/lb)		
	Density Reduction Wall Thickness	15% .157 in (4mm)	25% .250 in (6.35mm)
NORYL FN150X Resin		10	–
NORYL FN215X Resin		8	18
LEXAN FL900 Resin		22	25
LEXAN FL910 Resin		14	30
LEXAN FL930 Resin		12	30
VALOX FV620 Resin		–	12
VALOX FV608 Resin		–	12
LEXAN FL410 Resin		18	–

Table 2-1. Falling Ball Impact Strength.*

*10 lb Weight, 0.500 in (12.7 mm) Radius Nose

Properties

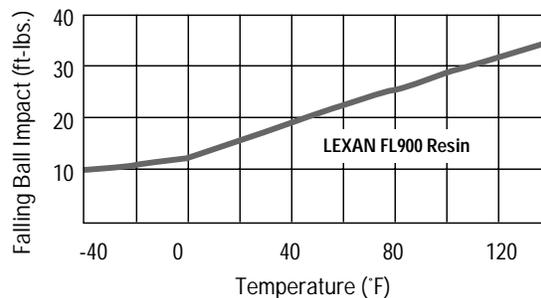
These criteria are useful, particularly in reinforced products where failure tends to be brittle in nature.

Wall thickness influences the impact strength of a material. As wall thickness increases, there will be a corresponding increase in falling ball impact strength. This is due to the greater amount of material present to absorb the energy at impact and the mode of failure of structural foam parts under impact. Impact values in excess of 50 ft-lbs (67.8 J/m) are achievable in LEXAN FL900 resin in 0.354 in (9 mm) walls. This has important implications for designers seeking to replace metal in parts subject to abusive conditions.

The amount of density reduction seen in a part will also influence the impact strength. As part density is increased, there will be a corresponding increase in impact strength.

The effects of temperature on falling ball impact strength are shown in Figure 2-14, indicating retention even at -40°F (-40°C).

Figure 2-14. Effect of Temperature on Falling Ball Impact.* (0.250 in [6.35 mm] Wall Thickness)

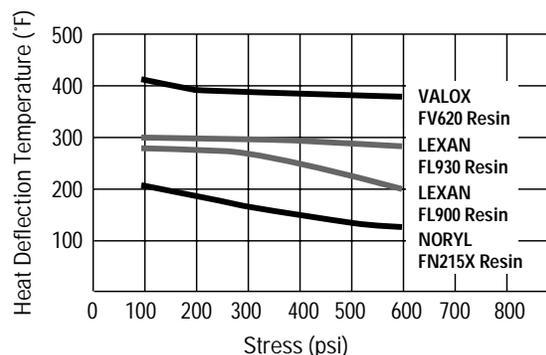


*25% Density Reduction, 10 lb Weight and 0.500 in (12.7 mm) Radius Ball

Heat Deflection Temperature

All GE Engineering Structural Foam resins are distinguished by outstanding thermal endurance properties. This indicates the suitability of these materials for application under load at elevated temperatures. (See Figure 2-15.)

Figure 2-15. Heat Deflection Temperatures vs. Bending Stress.



Thermal Conductivity

Engineering Structural Foam is also a good heat insulator, significantly better than solid plastics as seen from its lower thermal conductivity. In business machine housing design, for instance, higher operating temperatures can be tolerated without exposure of the machine operator to a hot surface, as would be the case with metal.

It should also be noted that as densities decrease, thermal conductivity also decreases. This is true because in the cellular core there is an increased content of air, which has lower thermal conductivity than the base resin.

UL Relative Thermal Index

UL relative thermal index rating* provides a means of comparing materials under long-term exposure to elevated temperatures. The high heat operating range of GE Engineering Structural Foam resins distinguishes them from commodity-type resins. Table 2-2 compares the UL relative thermal index ratings for various GE resins.

Underwriters Laboratories Ratings for Relative Thermal Index						
Product	Grade	in (mm)	Min Density c/cc	Relative Thermal Index		
				elec	w/imp	w/o imp
LEXAN Foamable Resin	FL400	0.125 (3.18)	1.06	80	80	80
		0.155 (3.94)	0.96	80	80	80
		0.248 (6.30)	0.95	80	80	80
	FL403	0.122 (3.10)	1.05	80	80	80
		0.154 (3.90)	1.00	80	80	80
		0.248 (6.30)	0.93	80	80	80
	FL410	0.125 (3.18)	1.11	80	80	80
		0.150 (3.80)	1.00	80	80	80
	FL900	0.154 (3.90)	1.10	80	80	80
		0.240 (6.10)	0.75	110	110	110
	FL903	0.247 (6.27)	0.71	80	80	80
	FL910	0.248 (6.29)	0.85	80	80	80
		0.149 (3.78)	1.11	80	80	80
		0.124 (3.15)	1.26	80	80	80
	FL913	0.152 (3.85)	0.97	80	80	80
		0.251 (6.37)	0.96	80	80	80
	FL920	0.236 (6.00)	0.85	110	110	110
	FL930	0.236 (6.00)	0.85	110	110	110
FL1000	0.125 (3.18)	1.15	80	80	80	
	0.247 (6.27)	0.94	80	80	80	
FL1003	0.120 (3.06)	1.05	80	80	80	
	0.199 (5.05)	1.09	80	80	80	
FL2000	0.155 (3.94)	0.99	80	80	80	
	0.256 (6.25)	0.94	80	80	80	
	0.247 (6.28)	1.03	80	80	80	
FL2003	0.236 (6.00)	1.12	80	80	80	
NORYL Foamable Resin	FN150X	0.156 (3.97)	0.90	50	50	50
		0.181 (4.60)	0.97	50	50	50
	FN170X	0.240 (6.10)	0.85	85	85	85
	FN215X	0.236 (6.00)	0.85	85	85	85
	FM3020	0.113 (2.88)	1.12	50	50	50
		0.192 (4.89)	1.09	50	50	50
	FM4025	0.113 (2.86)	1.26	50	50	50
		0.195 (4.95)	1.19	50	50	50
0.195 (4.95)		1.17	50	50	50	
FMC1010	0.156 (3.97)	0.96	50	50	50	
FMC3008A	0.159 (4.03)	1.15	50	50	50	
VALOX Foamable Resin	FV620	0.154 (3.90)	1.34	75	75	75
		0.191 (4.85)	1.20	105	90	100
		0.245 (6.22)	1.18	105	105	105
	FV649	0.122 (3.09)	1.00	75	75	75
		0.250 (6.35)	0.97	75	75	75
	FV699	0.154 (3.90)	1.12	75	75	75
0.195 (4.95)		0.99	75	75	75	

Table 2-2. UL Relative Thermal Index Rating.

*These ratings are not intended to reflect hazards presented by any material under actual fire conditions.

Flame Resistance

The flammability characteristics of polymeric materials are of increasing concern to the design engineer. Engineering Structural Foam resins listed in Table 2-3 have Underwriters Laboratories' recognition. Designers concerned with specifying these materials can easily review their suitability for specific applications by referring to GE Plastics' resins listed in UL File E121562.

Table 2-3. Flame Resistance.
UL 94 Flame Ratings.

Underwriter's Laboratories, Inc UL 94 Flame Rating*				
Product	Grade	in (mm)	Min Density c/cc	UL 94 Flame Rating*
LEXAN Foamable Resin	FL400	0.125 (3.18)	1.06	VO/5VA
		0.155 (3.94)	0.96	VO/5VA
		0.248 (6.30)	0.95	VO/5VA
	FL403	0.122 (3.10)	1.05	VO
		0.154 (3.90)	1.00	VO
		0.248 (6.30)	0.93	VO/5VA
	FL410	0.125 (3.18) 0.150 (3.80)	1.11 1.00	VO VO/5VA
	FL900	0.154 (3.90) 0.240 (6.10)	1.10 0.75	V1 VO/5VA
	FL903	0.247 (6.27)	0.71	VO
	FL910	0.248 (6.29)	0.85	VO/5VA
		0.149 (3.78)	1.11	VO/5VA
		0.124 (3.15)	1.26	VO/5VA
	FL913	0.152 (3.85) 0.251 (6.37)	0.97 0.96	VO/5VA VO/5VA
	FL920	0.236 (6.00)	0.85	VO/5VA
FL930	0.236 (6.00)	0.85	VO/5VA	
FL1000	0.125 (3.18)	1.15	VO	
	0.247 (6.27)	0.94	VO/5VA	
FL1003	0.120 (3.06)	1.05	VO	
	0.199 (5.05)	1.09	VO	
FL2000	0.155 (3.94)	0.99	HB	
	0.256 (6.25)	0.94	VO	
	0.247 (6.28)	1.03	V1	
FL2003	0.236 (6.00)	1.12	HB	
NORYL Foamable Resin	FN150X	0.156 (3.97)	0.90	VO/5VA
		0.181 (4.60)	0.97	VO
	FN170X	0.121 (3.07)	1.08	V1
		0.240 (6.10)	0.85	V1/5VA
		0.185 (4.69)	1.0	V1/5VA
	FN215X	0.118 (2.99)	1.00	V1
		0.153 (3.88)	0.90	V1/5VA
		0.236 (6.00)	0.85	VO/5VA
FM3020	0.113 (2.88)	1.12	V1/5VA	
	0.192 (4.89)	1.09	V1/5VA	
FM4025	0.113 (2.86)	1.26	V1/5VA	
	0.195 (4.95)	1.19	VO/5VA	
	0.195 (4.95)	1.17	V1/5VA	
FMC1010	0.156 (3.97)	0.96	V1	
FMC3008A	0.159 (4.03)	1.15	V1	
VALOX Foamable Resin	FV620	0.154 (3.90)	1.34	VO
		0.191 (4.85)	1.20	VO/5VA
		0.245 (6.22)	1.18	VO/5VA
	FV649	0.122 (3.09)	1.00	HB
		0.250 (6.35)	0.97	HB
	FV699	0.154 (3.90)	1.12	VO/5VA
0.195 (4.95)		0.99	VO/5VA	

*These ratings are not intended to reflect hazards presented by any material under actual fire conditions.

Environmental Properties

All GE structural foam resins are resistant to adverse environmental conditions in varying degrees. The environmental stability of the foam resins, although similar to their solid forms, will depend on time, temperature, and load conditions. Normally, foamed parts will exhibit lower molded-in stresses and better chemical resistance than parts made in solid resins. However, if parts are heavily stressed in assembly or heavily loaded in the end-use application, resistance to chemicals, depending on resin type, may decrease to solid resin values.

NORYL resin exhibits one of the lowest water absorption and dimensional change in water of any engineering thermoplastic. Recognized for outstanding hydrolytic stability, NORYL resin is unaffected by most aqueous media including hot and cold water, detergents, and weak and strong acids and bases. However, because it will soften or dissolve in halogenated and aromatic hydrocarbons, its use in contact with such materials is not recommended.

The versatility of LEXAN polycarbonate resin has led to its use in an ever-increasing variety of environments. Since its water absorption is extremely low under all practical use conditions, LEXAN resin has excellent dimensional stability, and its electrical properties are almost completely independent from effects of humidity. It is characterized by stability to mineral and organic acids and is insoluble in aliphatic hydrocarbons, ether and alcohols. LEXAN resin is partially soluble in aromatic hydrocarbons and soluble in many halogenated hydrocarbons. Chemical attack usually occurs when molded parts come in contact with alkali, alkaline salts, amines and ozone.

VALOX thermoplastic polyester has excellent resistance to a broad range of common solvents and chemicals. In laboratory tests, at moderate temperatures, VALOX resin resists gasoline, oils, alcohols, glycols, aliphatic hydrocarbons, trichloroethylene, carbon tetrachloride, ketones, and detergents. The highly crystalline nature of VALOX thermoplastic polyester makes it essentially unaffected by exposure to most chemicals. Care should be taken, however, when using aqueous solutions of acids and bases, and continuous exposure to water at 140°F (60°C) or greater is not recommended.

It is important to note that environmental and chemical resistance are complex phenomena; the many variables in part design, molding conditions, operational stresses, temperature levels and cycles are often difficult to predict. There is no dependable substitute for careful testing of prototypes or production parts in typical operating environments.

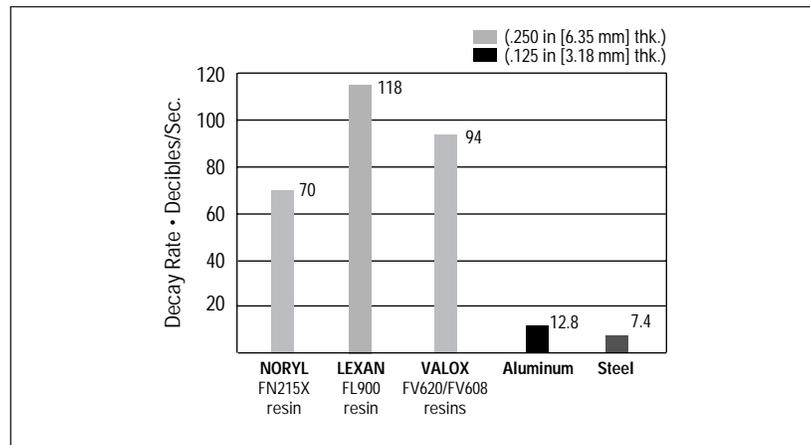
Acoustical Properties

Engineering Structural Foam resins can offer distinct advantages versus metal in noise reduction since they dampen vibrations much more rapidly. (See Figure 2-16.)

It should be noted that the manner in which structural foam is used to reduce noise plays an important role in its effectiveness. If the method of reducing noise is merely to enclose the sound source (sound attenuation), metal will be equally effective. However, if the actual source of noise can be made out of foam, the noise is dissipated up to 16 times faster than metal. Moreover, if the source continuously generates noise, as in the case of a printer housing, the use of structural foam can decrease the amplitude of vibration for an over-all reduction in noise level.

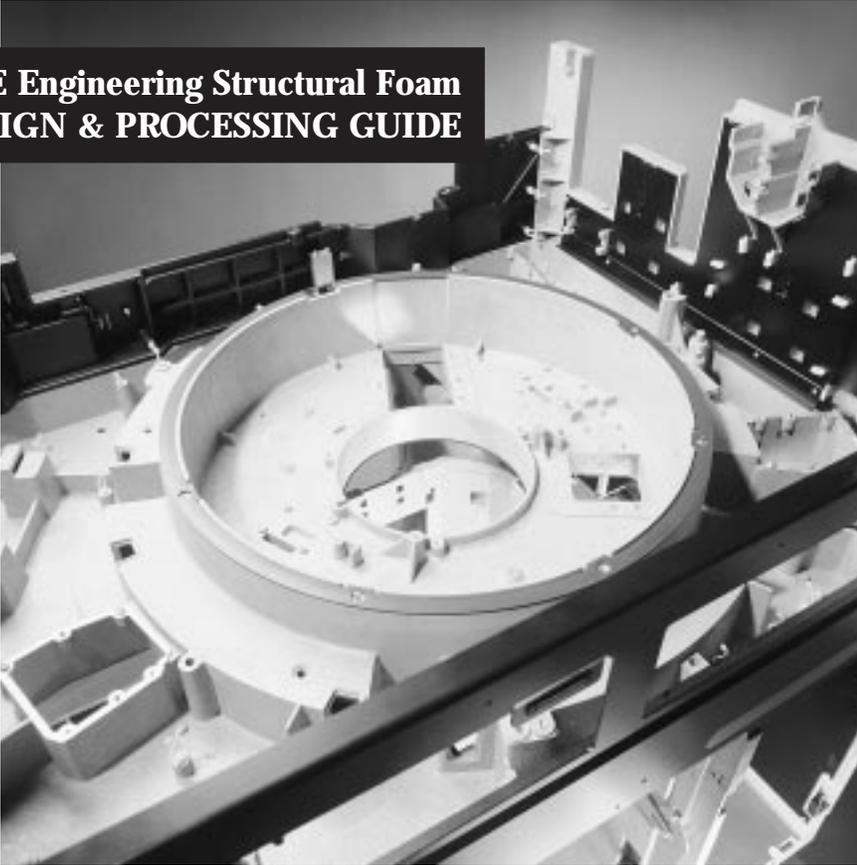
In many cases, to eliminate unwanted vibration or noise, it is necessary to add dampening to the system, or to design it so that the forcing frequency is well below the natural frequency. This can be done by either increasing stiffness or reducing mass, usually accomplished by the addition of ribs.

Figure 2-16. Sound Dampening Characteristics.





**GE Engineering Structural Foam
DESIGN & PROCESSING GUIDE**



Design Considerations

Photo Courtesy of:

FM Corp., Rogers AR – Molder
MSI, Cedar Rapids, IA – Moldmaker
Robert Luoma, Irving, TX – Designer
Abbott Diagnostics, Irving, TX – OEM

Design Considerations

Design

Designing parts in Engineering Structural Foam requires the same careful consideration of load, modulus, fatigue and stress conditions as given to any product design cycle.

Load Considerations

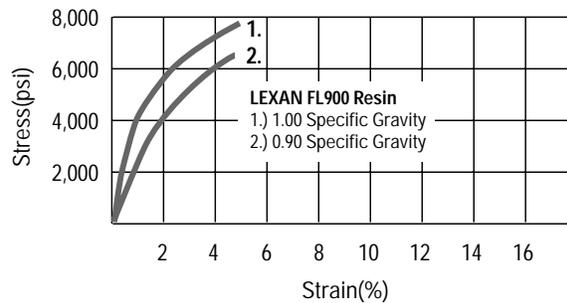
The mechanical properties of GE Engineering Structural Foam resins are relatively stable over a wide range of conditions and are predictable over a range of temperatures. Like all thermoplastics, structural foam resins exhibit viscoelastic behavior.

Therefore, the properties of strength and rigidity depend on the amount of stress, the rate of loading, and the length of time that the stress is applied, as well as the temperature and environment in which it is applied. In the structural foam molding process, the degree of density reduction, and the wall thickness will have an effect on the properties of the molded part.

Stress-Strain

The stress-strain curves, Figures 3-1 through 3-6, illustrate the capability of Engineering Structural Foam resins to withstand short-term loading and the effects of density on tensile properties, measured by ASTM D638. As seen from the diagrams, tensile properties and proportional limits increase as density increases. On this basis, the designer can determine the specific gravity of a part appropriate to fulfill performance requirements.

Figure 3-1. Stress-Strain Curve @ 73°F (23°C) (0.250 in [6.35mm] Wall Thickness).



Stress-Strain

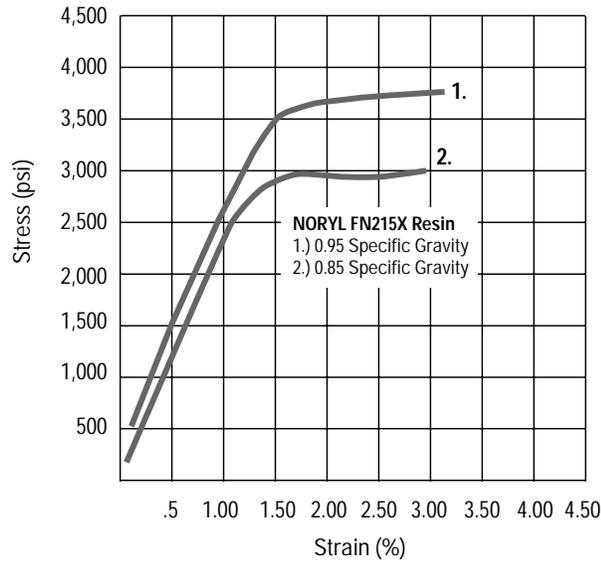


Figure 3-2. Stress-Strain Curve @ 73°F (0.250 in [6.35mm] Wall Thickness).

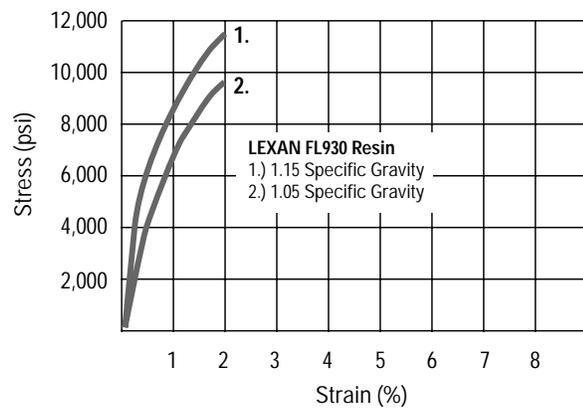


Figure 3-3. Stress-Strain Curve @ 73°F (0.250 in [6.35mm] Wall Thickness).

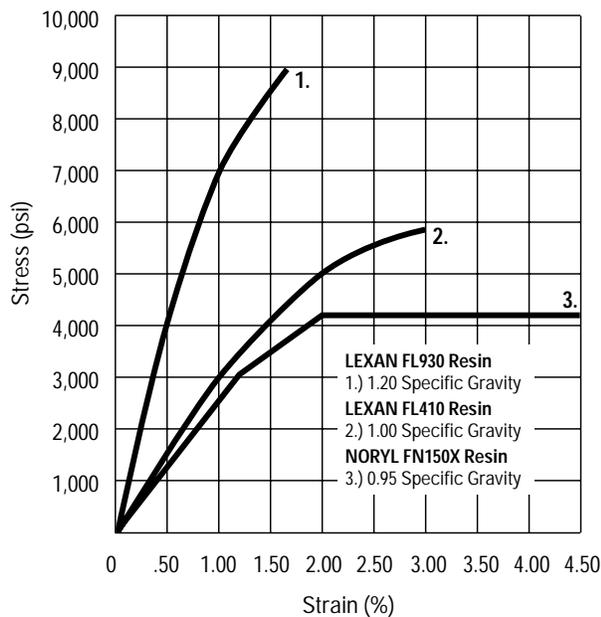


Figure 3-4. Stress-Strain Curve @ 73°F (0.250 in [6.35mm] Wall Thickness).

Design Considerations

Figure 3-5. Stress-Strain Curve
@ 73° F (0.250 in [6.35mm]
Wall Thickness).

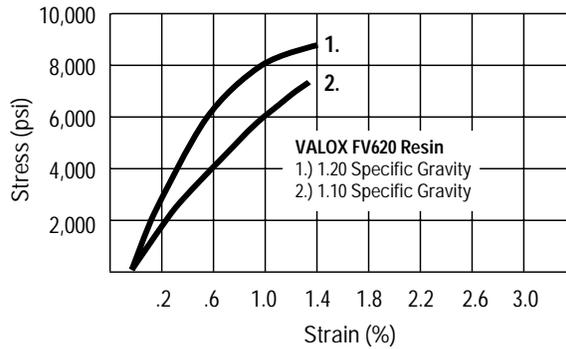
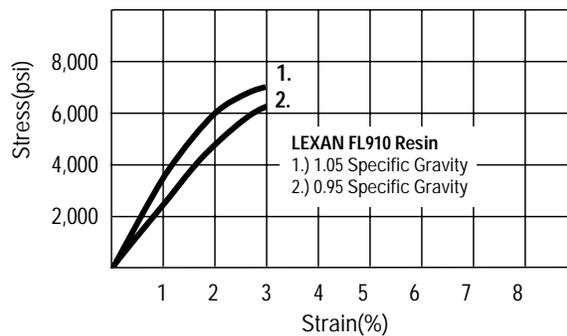
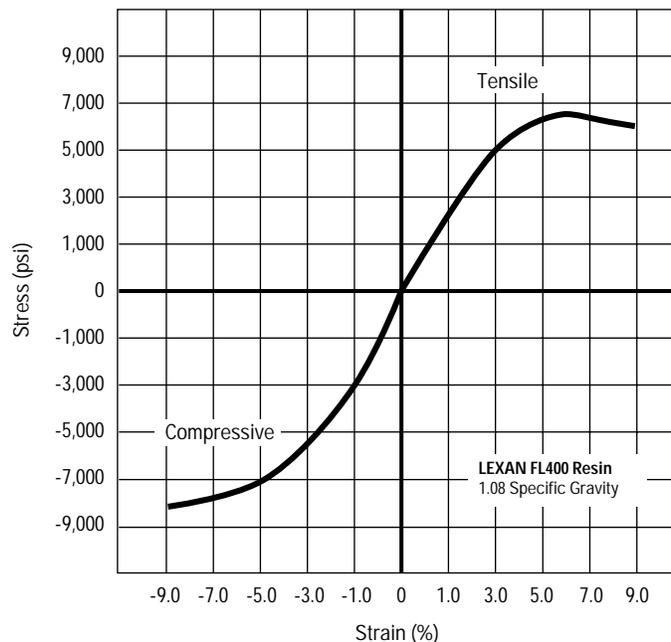


Figure 3-6. Stress-Strain Curve
@ 73° F (0.250 in [6.35mm]
Wall Thickness).



The effects of temperature on tensile properties are illustrated in Figures 2-2 to 2-5 on pages 2-3 and 2-4. The amount of energy the resin can absorb in tension is shown by the area under the stress-strain curve and can be used as a means of comparing materials. As seen in Figure 3-7, the compressive properties are higher than tensile properties. Therefore, higher compressive load-bearing capacities can generally be achieved.

Figure 3-7. Compressive, Tensile,
Stress-Strain Curve @ 79° F
(0.250 in [6.35mm] Wall Thickness).



Apparent Modulus and Creep

Following the immediate elastic deformation caused by a load, a slower deformation occurs which gradually approaches a nearly constant rate of flow. This time-dependent behavior is called creep.

The rate of creep in a part will vary with the temperature of the environment and stress in the part. The stress level where creep becomes negligible is called the creep limit of the material. Figures 3-8, 3-9 and 3-10 (see page 3-6) report constant stress creep results for NORYL FN215X and LEXAN FL900 resins plotted as % strain versus time. As seen, the creep behavior of LEXAN resin is more stable, especially at elevated temperatures, than NORYL resin, and as a consequence, LEXAN resin is normally preferred for use in long-term structural applications made from engineered structural foam.

The simplest method to compensate for the visco-elastic behavior of Engineering Structural Foam is to work with the apparent modulus rather than the instantaneous modulus. The apparent modulus is used to predict part performance at given points in time after initial application of external loads. It is expressed as:

$$E = \frac{S}{e_1 + e_2}$$

where

S = Induced stress (psi)

e_1 = Initial strain (in/in)

e_2 = Strain due to creep of
the material at a given stress
and time (in/in)

$$e_1 + e_2 = \text{Total strain}$$

For example, using total strain in Figure 3-10, the apparent modulus at 1000 hours for LEXAN resin at 0.9 specific gravity, 1000 psi and 140°F is:

$$E = \frac{1000}{.0035 + .0040} = 133,333 \text{ psi}$$

Therefore, under those conditions, 1000 hours after the part was loaded, it appears as though LEXAN FL900 resin had a flexural modulus of 133,333 psi. (919 mPa).

Design Considerations

Figure 3-8. Flexural Creep
@ 73°F (23°C)
(0.250 in [6.35mm] Wall Thickness).

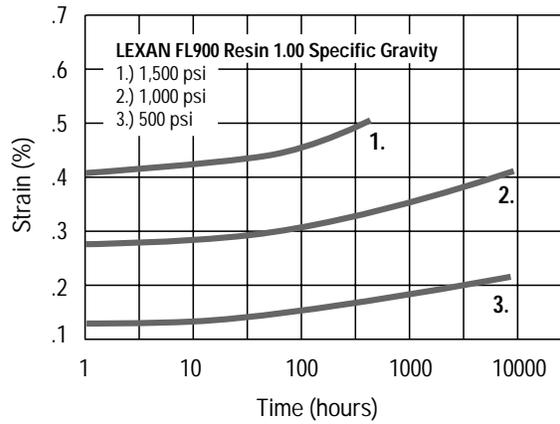


Figure 3-9. Flexural Creep
@ 73°F (23°C)
(0.250 in [6.35mm] Wall Thickness).

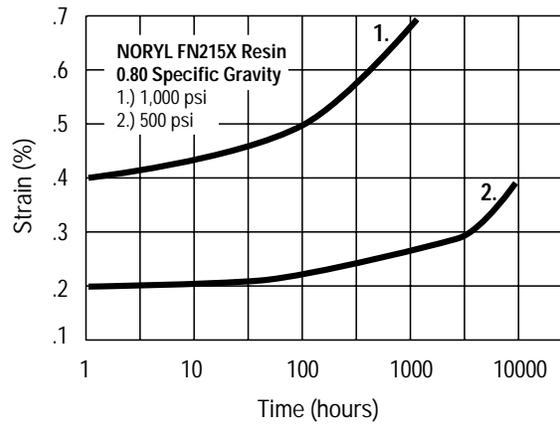
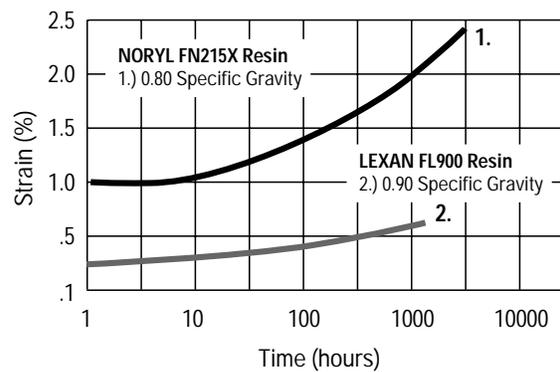


Figure 3-10. Flexural Creep
@ 140°F (60°C), 1,000 PSI (7mPa)
(0.250 in [6.35mm] Wall Thickness).



Fatigue

When parts are subject to cyclic loading, fatigue failure can occur below the yield point of a particular structural foam material. Figure 3-11 shows the results of fatigue testing conducted at 1800 cpm for LEXAN FL900 and NORYL FN215X resins. To determine the fatigue life of a part, the maximum stress of the part is calculated and compared to the fatigue endurance curve. Stress concentrations should be considered when calculating the maximum stress level. Since fatigue endurance in thermoplastic materials is dependent on cyclic frequency, this curve can be used as a guide. For all applications, however prototype testing or computer-aided methods are suggested to evaluate reliability. Fatigue strength can be expected to increase with decreasing wall thickness, due to the higher density seen in thinner wall parts.

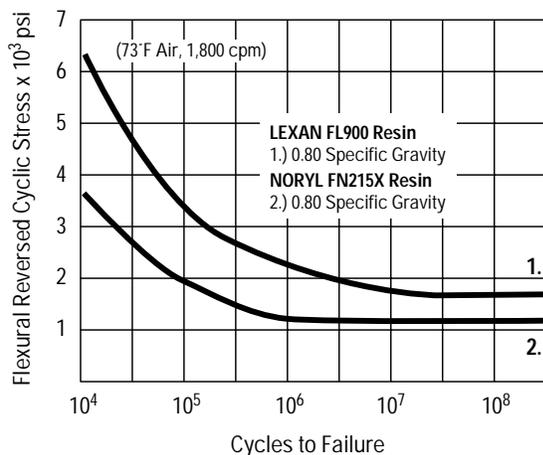


Figure 3-11. Flexural Fatigue—Fatigue Endurance (0.250 in [6.35mm] Wall Thickness).

Suggested Maximum Working Stress

Temperature, fatigue and chemical environment are the three critical factors that limit the load-bearing capabilities of structural foam. Although the actual design limits of foam applications can be determined only after careful evaluation of each of these factors in the specific end-use environment, maximum suggested working stresses as a function of density and wall thickness are offered as a guide. (See Table 3-1.)

Table 3-1. Suggested Maximum Working Stresses for Foamable GE Resins.*

	NORYL FN150X Resin		NORYL FN215X Resin		LEXAN FL410 Resin		LEXAN FL900 Resin		LEXAN FL930 Resin	
	0.156 in (4mm) Wall .95 S.G. psi (MPa)	0.250 in (6.35mm) Wall .85 S.G. psi (MPa)	0.354 in (9mm) Wall .75 S.G. psi (MPa)	0.156 in (4mm) Wall 1.0 S.G. psi (MPa)	0.250 in (6.35mm) Wall .90 S.G. psi (MPa)	0.354 in (9mm) Wall .80 S.G. psi (MPa)	0.156 in (4mm) Wall 1.15 S.G. psi (MPa)	0.250 in (6.35mm) Wall 1.05 S.G. psi (MPa)	0.354 in (9mm) Wall .90 S.G. psi (MPa)	
CONTINUOUS LOAD										
73°F (23°C)	1050 (7)	900 (6)	700 (5)	1900 (13)	1700 (12)	1450 (10)	2400 (16)	2100 (14)	1800 (12)	
140°F (60°C)	550 (4)	475 (3)	350 (2.5)	1350 (9)	1200 (8)	1000 (7)	1800 (12)	1600 (11)	1350 (9)	
160°F (71°C)	300 (2)	250 (2)	174 (1)	900 (6)	750 (5)	600 (4)	1250 (7)	1050 (7)	900 (6)	
200°F (93°C)	—	—	—	500 (3)	400 (3)	250 (2)	650 (4)	550 (4)	400 (3)	
INTERMITTENT LOAD										
73°F (23°C)	1900 (13)	1750 (12)	1300 (9)	2450 (17)	2200 (15)	1900 (13)	2850 (20)	2500 (17)	2100 (14)	
160°F (71°C)	900 (6)	800 (5)	650 (5)	1700 (12)	1500 (10)	1300 (9)	1950 (13)	1800 (12)	1500 (10)	
200°F (93°C)	—	—	—	1100 (7)	900 (6)	750 (5)	1300 (9)	1200 (8)	1100 (7)	

*Based on GE Plastics lab test data and empirical application data.

Design Considerations

Thermal Stress/Coefficient of Thermal Expansion

Thermal stress, caused by the thermal expansion and contraction of a material, can often be the cause of unexpected part failure. When two materials with greatly dissimilar coefficients of thermal expansion are combined in assembly, thermal stress is of the greatest concern. Differences in the thermal movement of the materials may cause problems in tight-tolerance and close-fit areas, particularly when press fits are used or inserts are molded-in. Thermal stress can be approximated using the equation.

$$\sigma_t = (\alpha_1 - \alpha_2) E \Delta T$$

where

α_1, α_2 are the coefficients of thermal expansion for respective materials

E = Modulus of Material

ΔT = Temperature Change

Table 3-2 compares the linear coefficients of thermal expansion of foamable GE resins with those of other materials.

Table 3-2. Linear Coefficients of Thermal Expansion (10^{-5} in/in/°F).

NORYL FN150X Resin.....	4.0
NORYL FN215X Resin.....	3.8
VALOX FV620 Resin*.....	1.3
VALOX FV608 Resin*.....	1.3
LEXAN FL900 Resin.....	2.0
LEXAN FL910 Resin.....	1.8
LEXAN FL410 Resin.....	1.8
LEXAN FL930 Resin.....	0.9
Zinc.....	1.5
Aluminum.....	1.2
Steel.....	0.7-0.8
Glass.....	0.4-0.5
*Mean of Flow and Cross-Flow Directions	

Structural Design

Unlike most commodity thermoplastic foams which are not linearly elastic, GE Engineering Structural Foam resins allow the designer to predict stresses and deflections resulting from external loads, enhancing the reliability of short- and long-term performance.

Stresses, strains and deflections can be determined using classical engineering methods. The structure of the cellular core and solid skin may be considered to be a composite and the stress analysis performed accordingly. In the composite analysis, an equivalent I-beam section of solid material serves as the cross-section for the foam part. (See Figure 3-12.)

Thermal Stress/Structural Design

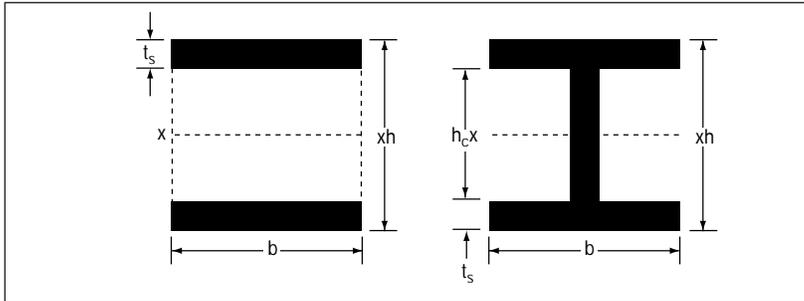


Figure 3-12. Beam Cross-Section.

The moment of inertia of the equivalent I-beam is then formulated as:

$$I_x = \frac{bh^3 - (b - b_C)(h - 2t_s)^3}{12}$$

where: $b_C = \frac{b E_C}{E_S}$

E_C = Modulus of Core

E_S = Modulus of Skin

t_s = Thickness of Skin

h_C = Height of Equivalent Core

This approach is technically correct; however, there are difficulties in measuring the core modulus and the as-molded variations in skin thickness. Incorrect assumptions in these areas can result in erroneous results. A more conservative approach to analyzing a structural foam part in a load-bearing environment would be to model the cross-section as two outer skins with no contribution of the cellular core. (See Figure 3-13.)

The equivalent moment of inertia is equal to:

$$I_x = \frac{b(h^3 - h_C^3)}{12}$$

Since the cellular core does provide some stress-absorbing characteristics, this analysis should provide a safety factor. When time or costs do not permit a more detailed analysis, an approximation can be obtained by consulting the structural foam cross-section to be homogeneous. (See Figure 3-14.)

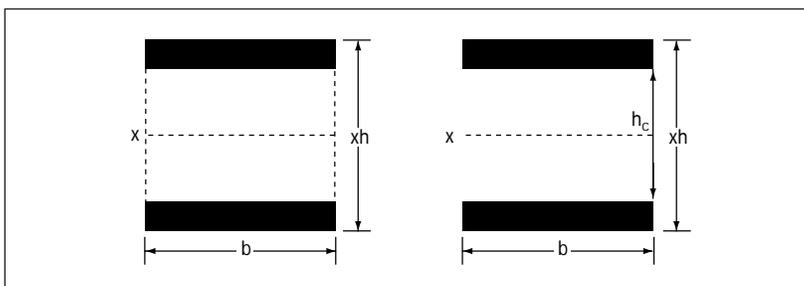
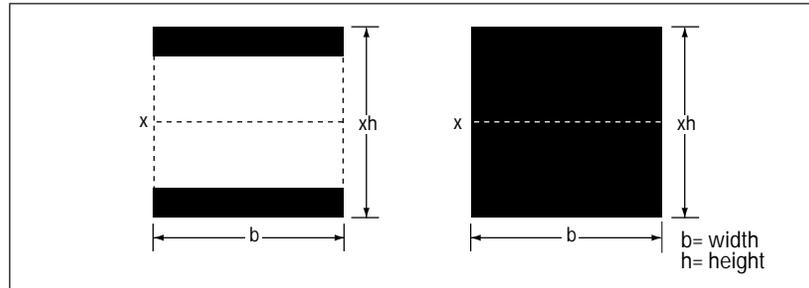


Figure 3-13. Two Skins with No Core – Cross-Section.

Design Considerations

(All mechanical properties reported in this handbook were determined with the test materials being homogeneous materials – not composites. Therefore, the reader should assume homogeneity when computing stresses or deflections, or when referencing this data. The section modulus or moment of inertia of a part's cross-section is then determined solely by the exterior dimensions of the part. Estimates of the property values as a function of the environment can be obtained from the graphs shown.)

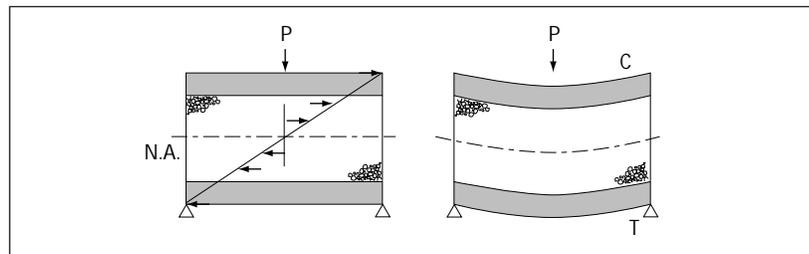
Figure 3-14. Homogeneous Cross-Section.



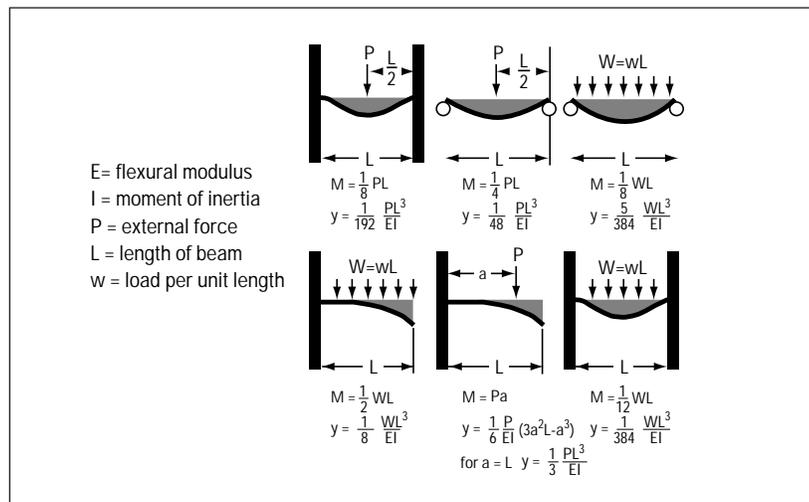
Bending

The efficient distribution of material in a structural foam cross-section contributes to its excellent flexural properties. The flexural strength of a structural foam material is significantly higher than its tensile strength, even though failure in bending is a result of tensile rupture, because the maximum tensile stresses occur in the outer fiber of the part, which is solid polymer or skin. (See Figure 3-15.) Figure 3-16 shows maximum bending movements and deflections for beams.

Figures 3-15. Foam Cross-Section in Bending.



Figures 3-16. Maximum Bending Moments, M, and Deflections, Y, for Beams.



When designing for ultimate failure of a part in bending, the engineer should be cautioned that flexural failure can occur at the tensile strength limits of the foam. The governing factor is the maximum tensile stress in the cellular core under flexure. If the distance from the neutral axis to the outer-most cellular core exceeds 0.500 in (12.7 mm), failure can be expected to occur approximately at the tensile strength of the material. The cellular core will yield and a stress crack will propagate through the adjoining skin. If that distance is kept under 0.500 in (12.7 mm), flexural failure will generally result closer to the reported flexural strength for a standard test specimen.

When optimizing structural members for bending, the designer should select a nonsymmetrical cross-section to allow the placement of the neutral axis so that the maximum bending stresses occur in compression.

Tension

The apparent tensile strength of any foam material is less than that of the same material in a solid configuration. Strength is reduced considerably because of the density reduction and stress considerations caused by each individual cell. (See Figure 3-17.) Therefore, tensile stresses should not exceed the proportional limit of the material.

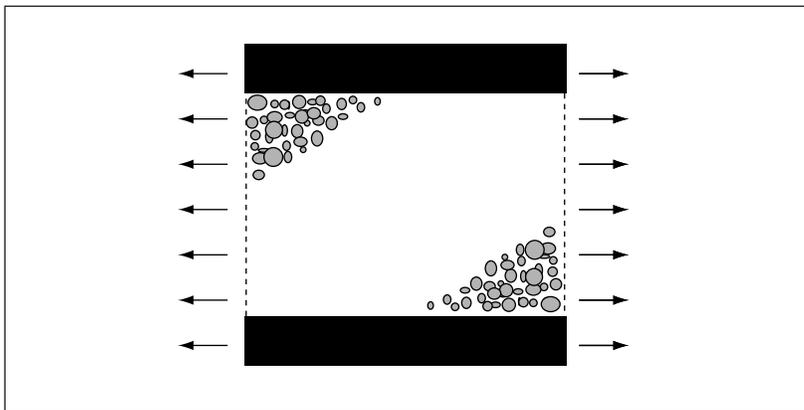


Figure 3-17. Foam Cross-Section in Pure Tension.

Compression

The compressive strength of a foam material is higher than its tensile strength. In bending, a compressive failure, although extremely rare, normally involves buckling of the skin and collapse of the cellular core. When pure compressive stresses are applied, structural foam parts will typically fail because of a crushed cellular core rather than from induced tensile stresses resulting from volumetric changes.

Design Considerations

Torsion

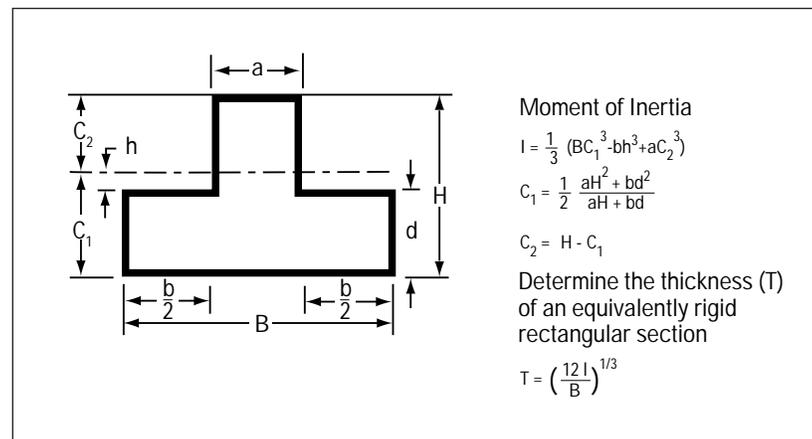
The distribution of material in a foam cross-section contributes to optimizing the torsional stiffness-to-weight ratio. In this case, the cross-section can be thought of as a hollow shaft similar to the analogy of the I-beam effect in bending. A foam part will have less torsional stiffness than a solid part of the same dimensions. But as weight is reduced with the introduction of a cellular core, the polar moment of inertia is only decreased a fraction of that same amount because the inertia is a function of the fourth power of the ratio of the inner diameter to the outer diameter.

Twisting and racking of structural foam parts can be reduced with the use of molded-in ribs. For example, a square plate would resist torsion if diagonal ribs were molded-in to help avoid deflections. In this case, the ribs would be put into tension and compression, and strains would be significantly reduced because of the increased polar moment of inertia.

Flat Plates and Ribs

Very often a plate analysis is required for a foam structural design. As with beams, plates can be analyzed using standard engineering methods. However, a foam structure requiring rigidity will normally consist of a cross-pattern of ribs rather than a uniformly thick wall. Since handbooks will give plate equations in terms of uniform thickness, ribbed plate design thickness must be calculated and is based on equivalent moments of inertia between the flat and ribbed sections. (See Figure 3-18.)

Figure 3-18. Unit "T" from Rib Cross-Section.



Sample Rib Calculation

A 24 in x 24 in Pencil utility cover is being designed to withstand a 9000-lb load caused by one wheel of a tractor-trailer parked on it. LEXAN FL900 resin is chosen with a maximum working stress of 1500 psi (10.3 mPa) at 73°F (23°C) and a 0.8 specific gravity.

To determine the wall thickness expected to withstand this load, the equation for a simply supported rectangular plate with a uniformly distributed load is employed:

$$\sigma = \frac{\beta q b^2}{t^2}$$

$$1500 = \frac{(.2874) \left(\frac{9000}{24 \times 24} \right) (24)^2}{t^2}$$

$$t = 1.31"$$

where $\beta = 2874^*$ for $a/b = 10$

q = load per unit area

b = plate dimension

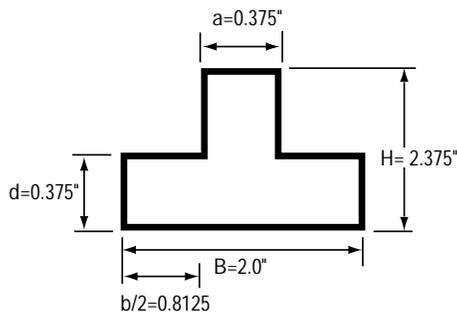
t = wall thickness

σ = working stress

*Roark, R., and Young, W.:

"Formulas for Stress and Strain," p. 386.

A wall thickness of 0.375 in (9.53mm) is selected for cycle time reasons and a 0.375 in (9.53mm) thick, 2.0 in (50.8mm) high rib spaced every two inches on the part is chosen to determine the effective wall thickness.



$$C_1 = 0.78$$

$$C_2 = H - C_1 = 1.595$$

$$h = C_1 - d = 0.405$$

$$I = 1/3 [(2) (0.78)^3 - (1.625) (0.405)^3 + (0.375) (1.595)^3]$$

$$I = 0.79 \text{ in}^4$$

$$T = \left(\frac{12 (0.79)}{2.0} \right)^{1/3}$$

$$T = 1.68 \text{ in}$$

This equivalent wall thickness is greater than the thickness determined to be necessary for a properly functioning part, which should be able to withstand the stresses caused by the 9000-lb. load.

Wall Thickness

The structural foam process can permit molded parts with sections thicker than can be realized in injection molding without sink marks and warpage problems. Traditionally, structural foam parts were designed with 0.250 in (6.35 mm) wall thicknesses. Now with engineering resins, parts can be designed with wall sections as low as 0.157 in (4 mm) and up to 0.500 in (12.7 mm) or higher. The design criteria of a structural foam part must be considered before choosing the optimum wall thickness and material for an application. The main considerations are impact strength, rib design, boss design, and the strengths and moduli required for a properly functioning part. Flexural strength, flexural modulus, and tensile strength increase with decreasing wall thickness. This is due to lower density reductions

Design Considerations

and higher skin-to-core ratios seen in thinner walls than in thicker ones. Rigidity, load-bearing ability, and impact strength decrease with decreasing wall thickness, since they are more dependent on part cross-section than density reduction. The effect of wall thickness on rib and boss design will be covered later in this section.

Wall Thickness and Material Flow Lengths

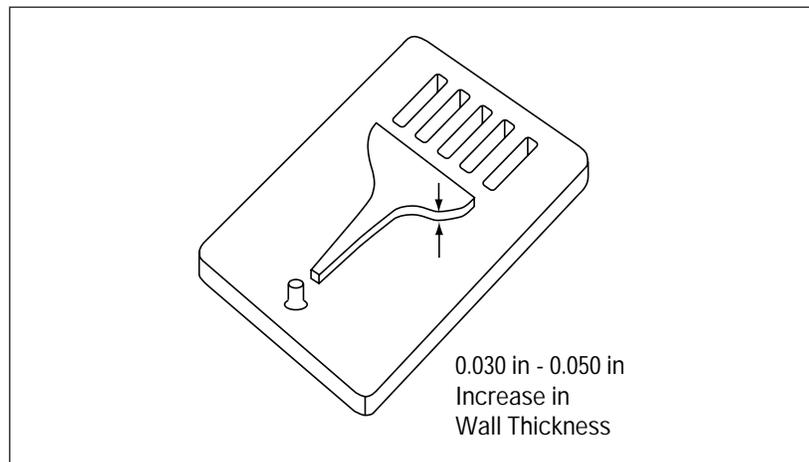
In order to achieve thicker wall sections than injection molding with lower stresses and no sinks, it is important to maintain a good and consistent density reduction throughout the part. To obtain these characteristics, the part must be designed so the material can flow and readily fill the mold. (See Figure 3-19.)

In molding wall thicknesses below 0.250 in (6.35 mm), there is a higher resistance to flow which must be overcome by increasing injection pressure. Wall sections above 0.250 in (6.35 mm) have reduced opposition to flow. These variations in resistance to flow could result in lower achievable density reductions and shorter flow lengths in thinner walls than thicker wall sections.

If flow lengths for the chosen material exceed the recommended values, two methods can be employed to increase flow capability:

- The cross-section-to-material flow can be increased by adding flow ribs or runners. These should not become too large or the material will flow down the rib and have trouble filling the flat sections, and part cycle time may be increased.
- By slightly increasing wall thickness by 0.030 to 0.050 in (0.76 to 1.27 mm), material flow capabilities may be enhanced to alleviate molding problems in difficult-to-fill areas such as between louvers, where a flow runner is not sufficient.

Figure 3-19. Material Flow.



Wall Thickness/Fillets and Radii

Transition Sections

Transition sections from thick to thin walls are more easily achievable without sink marks in structural foam than in injection molding. Still, uniform wall thickness should be maintained whenever possible to minimize restrictions to material flow.

Transition from thick to thin walls should be tapered for proper processing of the structural foam part. In molding parts with wall sections of varying thicknesses, it is often better to gate the part in the thin section and allow the material to flow into the thicker area. (See Figure 3-20.)

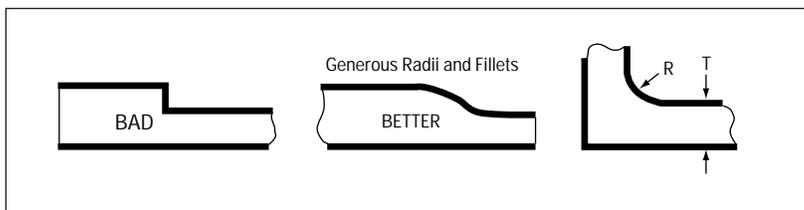


Figure 3-20. Wall Thickness Transition.

Fillets and Radii

Sharp corners create points of stress concentration and restrict material flow in a structural foam part. They are often a major cause of part failure. The effect of fillet radius on stress concentration is shown in Figure 3-21.

K_t , the concentration factor, should be included in the equations for stress calculations. R/T is the ratio of the fillet radius to the part section thickness. Use as large a radius as possible on inside and outside corners to minimize this stress concentration and aid in mold filling. In most parts, the minimum inside radius should be 0.060 in (1.52 mm). If the section is under load or subject to impact, a minimum radius of 0.125 in (3.18 mm) should be strongly considered. A radius equal to 0.6 times the wall thickness will typically provide a desirable fillet for practical purposes.

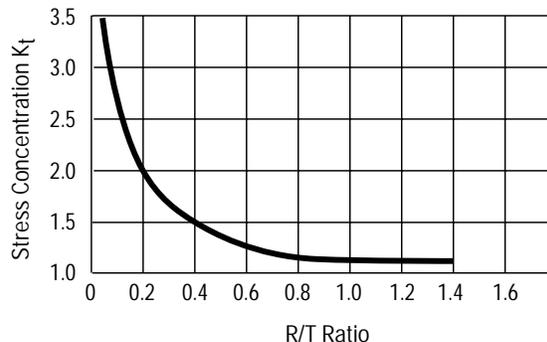


Figure 3-21. Stress-Concentration Factors.

Design Considerations

Tolerances/Warpage Control

Tolerance specification (Table 3-3) is extremely important in product design as it can directly affect both part cost and the ability to perform properly. The practice of blanket tolerancing on a drawing can result in unnecessary cost, both in the part and the tool.

The final dimensions on a part are affected by:

- Thermal expansion and contraction
- Processing conditions
- Mold dimensions and design
- Material selection

The key to tolerance and warpage control in a structural foam part is to achieve a good and consistent density reduction throughout the part. Some general guidelines for obtaining this density reduction and thus flatness are:

- Maintain uniform wall thickness throughout the part. Thick sections will not only cause increased cycle times, but may contribute to part warpage.
- Minimize restrictions to material flow. Omit ribs unless absolutely necessary and orient louvers in the direction of the flow.
- Remain within the flow lengths of a material to reduce the chances of part overpacking.
- Add flow ribs or gate close to openings to minimize overpacking.

Tighter tolerances and flatter parts can be realized by means of the structural foam process rather than injection molding, since lower induced stresses result from lower cavity pressures.

Table 3-3. Tolerances for Fine Conditions, Plus or Minus.

	LEXAN Resin	NORYL Resin	VALOX Resin
0 to 5 in (0 to 127mm)	0.005 in (0.13mm)	0.005 in (0.13mm)	0.005 in (0.13mm)
Over 5 in (127mm)	0.005 in (0.13mm) +0.001 in (0.0254mm) for each additional inch	0.005 in (0.13mm) +0.001 in (0.0254mm) for each additional inch	0.005 in (0.13mm) +0.001 in (0.0254mm) for each additional inch

Draft Angles

As in injection molding, draft angles are necessary in structural foam molding. Because of the lower pressures involved in foam molding, smaller draft angles can be tolerated in certain cases. The wall thickness of a part will influence the amount of draft necessary to release a part. As wall thickness decreases, larger draft angles will be required. This is due to the higher cavity pressures in the mold which will make the part more difficult to release from the tool. Generally, an angle of 0.5 to 3° can provide sufficient draft to release a part. (Figure 3-22 and Table 3-4 show the resultant taper per inch for varying draft angles.)

On very deep draws such as tall standoffs and ribs, the increase in base width due to draft must be considered. A base that is too thick can result in sink marks, postblow conditions*, or increased part cycle time. In certain situations, 0° draft can be incorporated, depending on part configuration, material shrinkage, wall thickness, mold design and mold material. (See Figure 3-23.)

Textured surfaces generally require an additional 1° draft per 0.001 in (0.0254 mm) depth of texture. For best results, consult your engraver for depth versus pattern before specifying the draft requirements.

* Postblow: Bulging of part surface caused by differential cooling of cellular core and solid skin. This problem is more common in thicker sections.

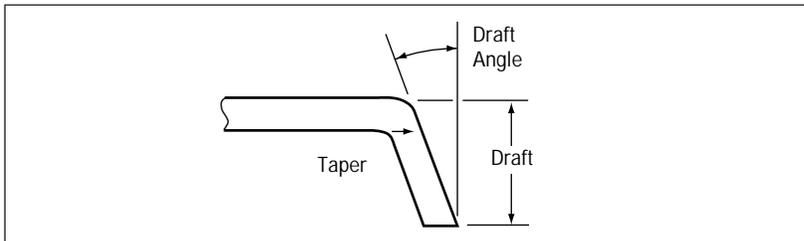


Figure 3-22. Draft Angle Taper per Inch.

Taper per inch	DEGREES						
	1/8°	1/4°	1/2°	1°	2°	3°	4°
	0.0022	0.0044	0.0087	0.0175	0.0349	0.0524	0.0699

Table 3-4. Draft Angles.

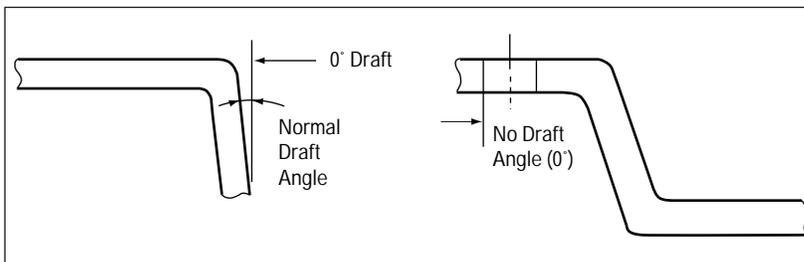


Figure 3-23. 0° Draft Angles.

Design Considerations

Snap Fits

The rigidity and strength of structural foam parts permits increased utilization of snap fits for assembly and for mounting heavy components in bases. A quick and extremely economical assembly method, snap-fitting can eliminate the need for added screws, brackets, and fasteners, significantly reducing labor and assembly costs. (See Figure 3-24.) Snap fits provide limited drawing action to pull a joint together.

Figure 3-24. Snap Fits.

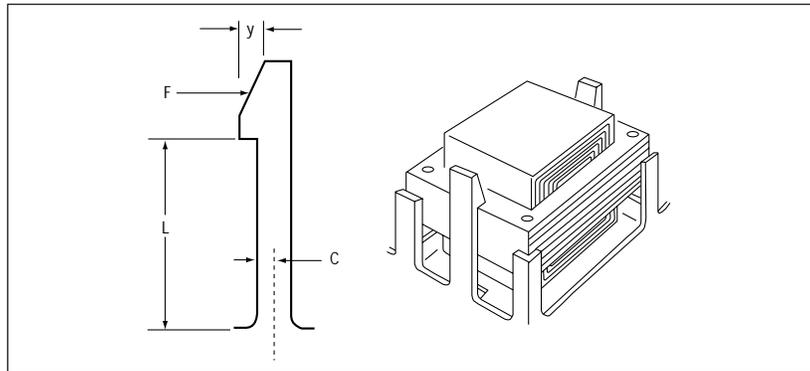
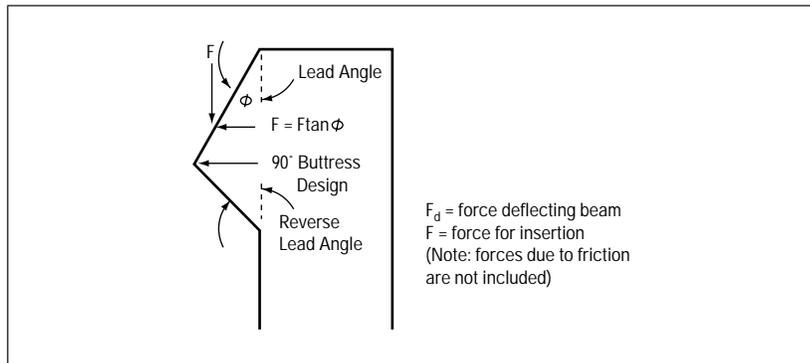


Figure 3-25. Pull-Off Lead Angle.



Stress, deflection and strain are the primary criteria in determining the stiffness and assembly force required for optimum performance of snap fits. Equations for a cantilevered beam with constant cross-section are used as models when designing snap-fits in structural foam parts:

$$\sigma = \frac{FLC}{I} \quad y = \frac{FL^3}{3EI} \quad \xi = \frac{3yC}{L^2}$$

Where: σ = stress
 y = deflection
 ξ = strain
 I = Moment of inertia of cross-section
 F = Load
 L = Length of Beam
 E = Modulus of material
 C = Distance from neutral axis to extreme fiber

To facilitate pull-off, an angled lead can be designed to function in the same way as the push-on lead angle (Figure 3-25). To stay within the maximum allowable strain, the height of the lead ramp should not exceed the calculated deflection.

If the snap fit is designed as a tapered beam, a separate set of beam equations is used. The primary design criteria in this analysis are given by the following equations:

$$y_t = \frac{-6F}{EB} \left[\frac{LR}{h_0(1-R)} \right]^3 \left[2 \ln R + 3 + R^2 - 4R \right]$$

Where $R = \frac{h_0}{h_s}$ $\sigma = \frac{6FL}{bh^2}$ $\xi = \frac{3yh_s}{2k_s L^2}$

Where b = Beam width
 h_0 = Height of tapered beam at tip
 h_s = Height of tapered beam at base
 k_s = Proportionality Constant = (y_t / y_c) (See Figure 3-26)
 y_t = Deflection of tapered beam
 y_c = Deflection of constant thickness beam

The analysis considers the theoretical perpendicular force required to deflect the beam a specified distance. In actual performance the force is applied via a lead-in angle. Thus the actual force required to bend the beam is a function of the tangent of the lead angle (i.e., $F_{insertion} = F_{bending} \tan \theta$). A smaller lead angle gives a lower assembly force. For example, changing the lead angle from 45° to 30° decreases the lead-in force by 42%

The maximum stress level can be varied by changing the required deflection for insertion (Y), the length of the beam (L), the thickness of the beam (h), or a combination of all three. For multiple assembly, the maximum fiber strain should be kept within 2% for LEXAN FL900 and FL910 resins, within 1.5% for NORYL FN215X resin and within 0.6% for VALOX FV608 resin. For one-time assembly, the maximum fiber strain can be up to 3% for LEXAN FL900 resin, 2% for NORYL FN215X resin, and 1% for both VALOX FV608 and LEXAN FL930 resins.

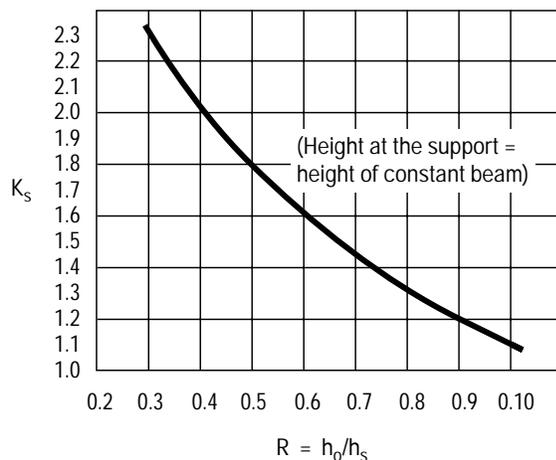


Figure 3-26. Proportionality Constant – Tapered Beam.

Design Considerations

Hinges

Properly designed, integral structural foam hinges can offer fatigue strength comparable to metal, while eliminating costly bracketry and assembly time. Hinges can be designed to be either hidden or visible, depending on their location in the part. A number of basic hinge designs are practical for structural foam parts, several of which are discussed below.

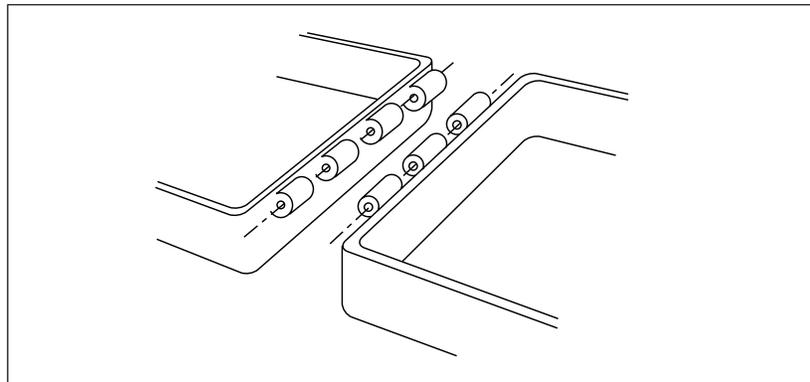
Full Pin Hinge

Design. The full pin hinge (Figure 3-27) usually consists of barrels molded on each mating piece. Each of these barrels is cored through and a metal pin is extended the full length of the part. Since disassembly requires removal of the pin, the lift-off feature is not practical with this type of hinge. The length of the hinge and the diameter of the metal pin are the determining factors in whether the full pin hinge can be molded. When the length of the hinge is restricted by the permissible length of the side pull, a partial pin hinge may be necessary.

Load-bearing ability. The full pin hinge has the highest load-bearing ability of any of the types discussed, because the metal pin distributes the loading the full length of the part.

Cost. This type of hinge also has the highest tooling cost. Both mating pieces require side pulls to produce a throughhole the entire length of the part.

Figure 3-27. Full Pin Hinge.



Partial Pin Hinge

Design. The design of the partial pin hinge (Figure 3-28) is similar to the full pin hinge except that the center barrels are cored to produce a U-shaped section, and pins are inserted from each end. This type of design permits long hinges to be molded with side pulls only at each end. The partial pin hinge does not allow a lift-off door.

Load-bearing ability. When the hinge is in the open position, the U-shaped sections assist in load bearing and provide a uniform appearance along the length of the hinge.

Cost. The tooling cost for this design is less than for the full pin hinge because only the two barrels at the ends require side pulls. The central barrels can be molded with straight pull tooling.

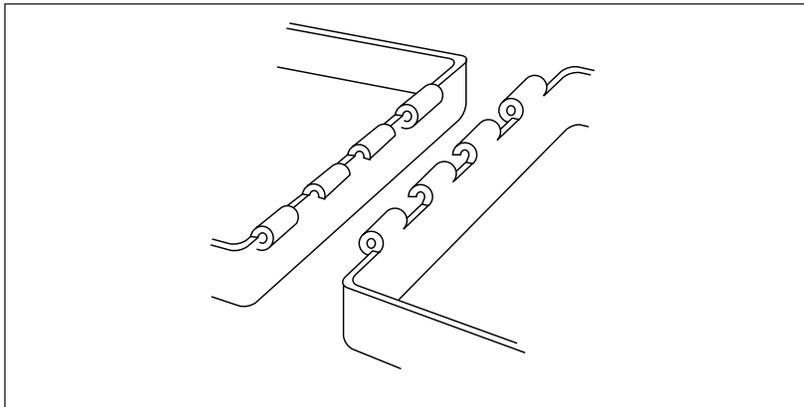


Figure 3-28. Partial Pin Hinge.

Design Considerations

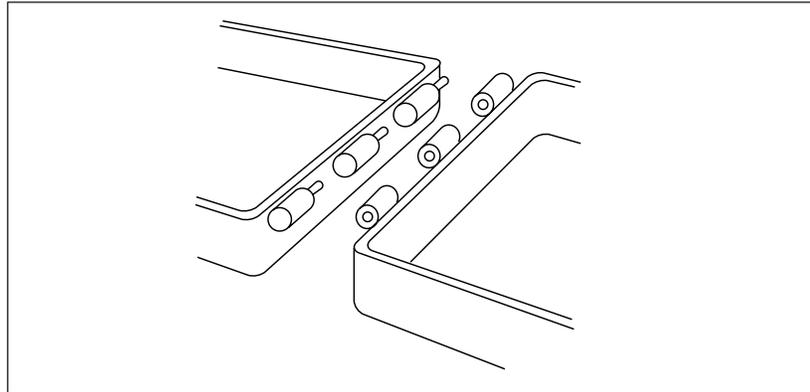
Projected Pin Hinge

Design. The projected pin hinge (Figure 3-29) normally has two barrels molded on each mating piece. Pins projecting from the barrels on one piece fit into holes in the other piece. In this design, the part with the pins is easily removed to facilitate access for repairs, etc.

Load-bearing ability. When both mating surfaces are flush and a load is applied, the latch and hinges assist in load-leveling. However, when the mating surfaces and hinge are in the open position, the load-bearing ability of the hinge is relatively low, since only the small cross-sectional area of the projected pins are withstanding the load in shear.

Cost. Tooling cost for projected-pin-type hinges is relatively low, since only the part with holes requires side pulls in the tool.

Figure 3-29. Projected Pin Hinge.



Simulated Hole Hinge

Design. This design incorporates a hole in the barrel-shaped pieces without the use of side pulls (Figure 3-30). This is accomplished by coring U-shaped areas on the outsides of the barrels, two facing downward and one facing upward. Mating the barrels creates a throughhole to accept a metal pin. This type of hinge does not permit easy lift-off, since the entire pin must be removed. Also, completely hidden hinges are not possible with this design due to tool pull.

Load-bearing ability. The load-bearing ability of the simulated hole hinge can be improved by increasing the bearing surface on the outside U-shaped portions of the barrel.

Cost. The tooling cost for this type of hinge is potentially the lowest of the types discussed, since no side pulls are required for either mating piece.

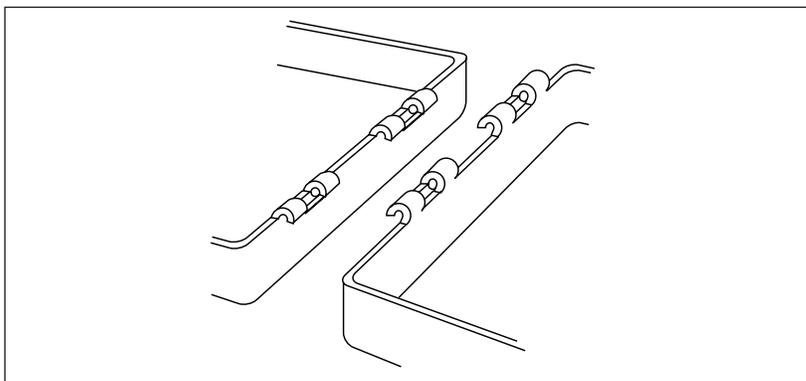


Figure 3-30. Simulated Hole Hinge.

Bosses

Bosses can typically be easily incorporated into structural foam parts to accept fasteners and support components. In many applications, the addition of molded-in bosses, mounting pads, stand-offs and retainers can replace costly brackets and miscellaneous small metal part assemblies.

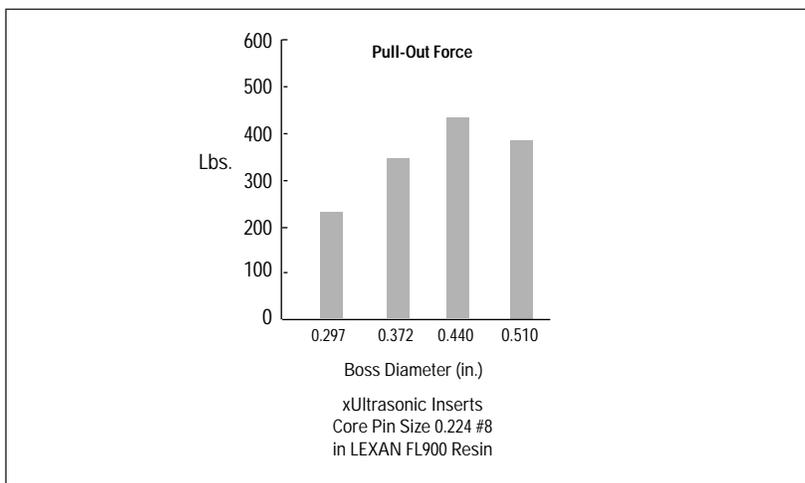


Figure 3-31. Bosses – Insert Performance.

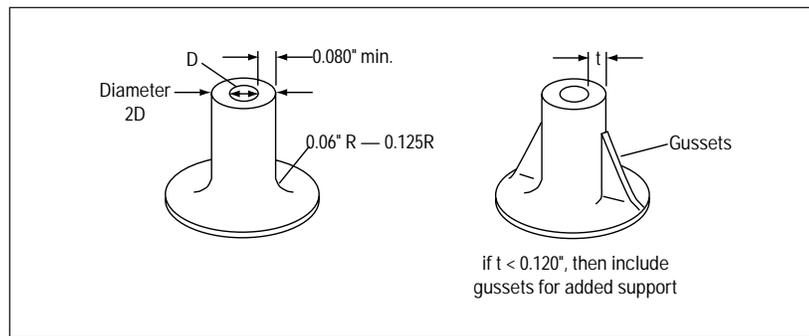
In Engineering Structural Foam, there appears to be an optimum boss diameter for the best insert performance. (See Figure 3-31) Experimentation has shown the optimum boss diameter to be 1.6 to 2.0 times the diameter of the cored hole, with a minimum boss wall thickness of 0.080 in (2 mm). When a boss wall thickness becomes too thin, the walls can have higher stress concentration and can be subject to breakage. If the boss wall becomes too thick, there is a greater chance of voids in the boss and it can behave somewhat like a pressure vessel.

Design Considerations

Hoop stresses can increase with increasing wall thickness due to the distribution of material in a cross-section. Thicker bosses are not necessarily stronger; they can result in an increased cycle time and ensuing part cost.

When utilizing bosses with wall thicknesses less than 0.120 in (3 mm), gussets or connecting ribs should generally be used for added strength (Figure 3-32). Bosses should be cored whenever possible to help prevent the formation of a thick section in the part. Generous fillets should be designed in order to help avoid stress concentration and resist torque loading.

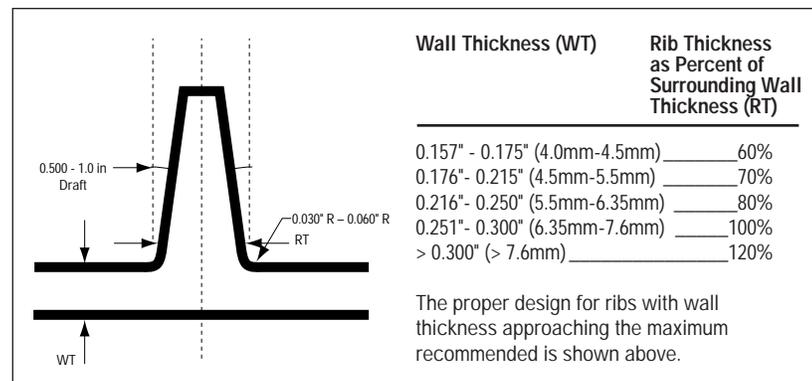
Figure 3-32. Bosses.



Ribs

The addition of ribs will typically increase the rigidity and load-bearing capability of a structural foam part without increasing the wall thickness. In addition, ribs can reduce the cycle time and materials cost associated with thicker wall sections. Unlike injection molding, the structural foam process permits the use of thicker, and thus shorter, ribs for maximum rigidity opposite appearance surfaces with minimal risk of sink marks. The surrounding wall thickness and resulting density reduction determines the thickness of ribs that can be designed without sink marks. Tall ribs that become very thin at the tip may cause problems with mold filling and will be areas of higher stress concentration. (See Figure 3-33.)

Figure 3-33. Rib Design.



Guides

Molded-in structural foam guides can be used to locate printed circuit boards or any modular units, eliminating the need for metal bracketry or metal bending operations. Because of the strength and rigidity of the material, guides can be designed with snap-stops (Figure 3-34). The formulas given for snap-fits can be used to determine performance criteria for molded-in snap-stops. Horizontal card guides can also be molded in the center of a part with straight pull tooling using the technique sketched in Figure 3-35.

Zero degree draft on guides is possible over limited areas when the wall section of the part is over 0.200 in (5 mm). With wall sections less than 0.200 in, the draft angle should generally be increased to 0.5°, since cavity pressures are higher and the part will have a greater tendency to stick to the mold. (See Figure 3-36.)

A technique to get the solid fit that 0° draft provides on a card guide without pulling it a long distance is to start with 0° draft for 1.0 in (25.4 mm) where the card meets with the mother board and then increase the draft 0.5 to 1.0° for the remaining distance.

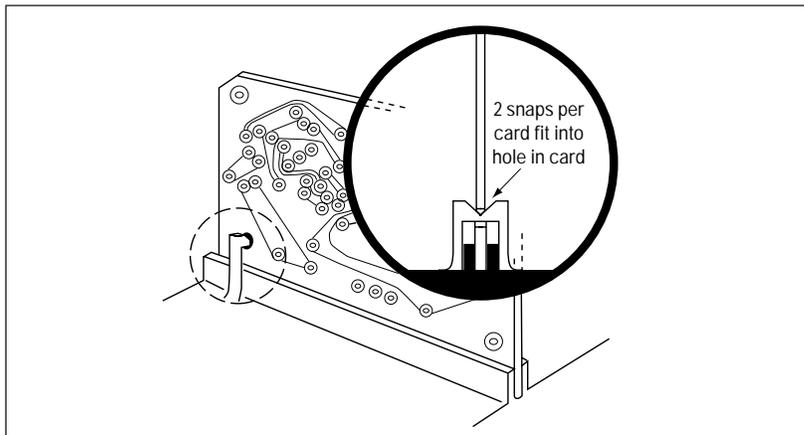


Figure 3-34. Snap Stop.

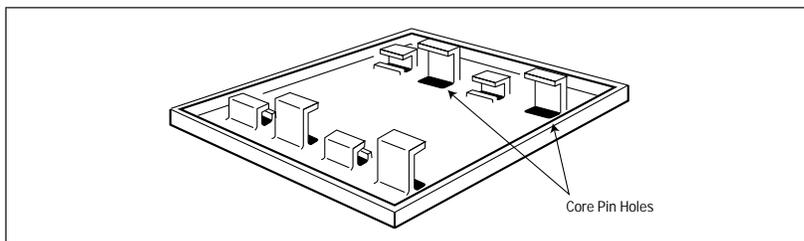


Figure 3-35. Card Guide.

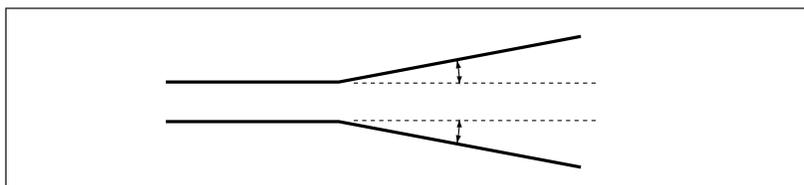


Figure 3-36. Tapered Draft.

Design Considerations

Louvers

Molding-in louvers in structural foam parts can eliminate costly metal stamping operations. In addition, louvers provide cooling capabilities to help offset the insulative properties of plastic. Deflectors can also be molded-in to channel the flow of air for maximum cooling.

Whenever possible, louvers should be oriented in the direction of material flow (Figure 3-37). In designs where this is not feasible, a runner should be located between louvers to channel the material to the outside of the louvers.

To utilize straight pull tooling for louvers located on the side of a structural foam part, the louvers can be designed to extend over the top corner of the part (Figure 3-38).

When louvers are molded with a side pull, a witness line results around the core. Costly sanding operations are usually required to remove this line. Recess the area 0.020 in (0.51 mm) and witness lines may appear to be designed-in, thus reducing finishing costs (Figure 3-39).

Figure 3-37. Louvers with material Flow.

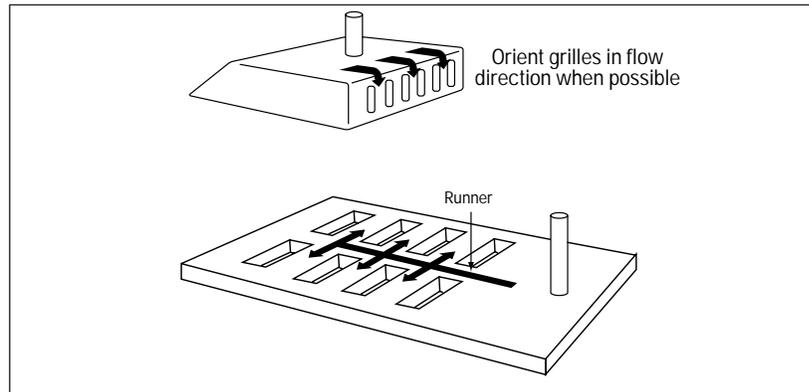


Figure 3-38. Louvers Around Corner.

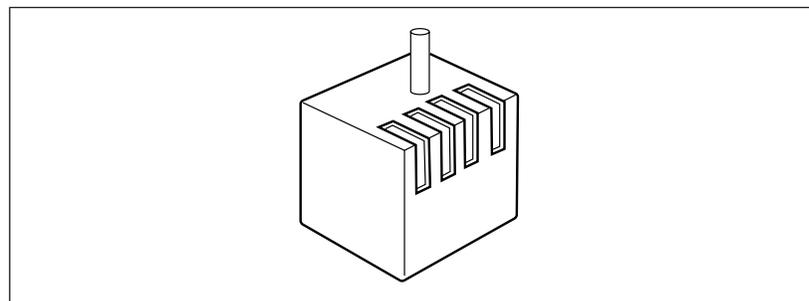
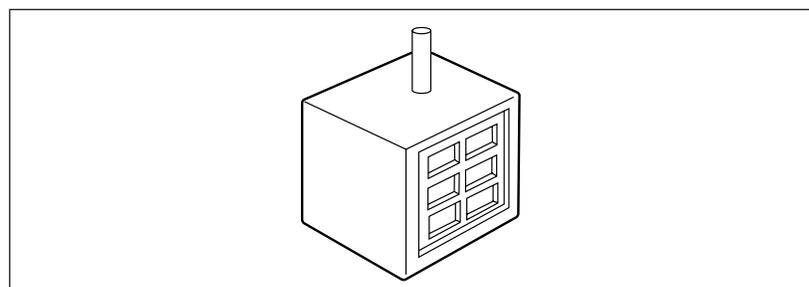


Figure 3-39. Louvers in Recessed Area.





GE Plastics

**GE Engineering Structural Foam
DESIGN & PROCESSING GUIDE**



Engineering Structural Foam Assembly

Photo Courtesy of:
Dekalb Molded Plastics Electronic Bowling Score-keeping Console

Assembly and Fastening

Virtually all fastening systems associated with thermoplastic assembly can be used on structural foam parts. When selecting a fastening system, GE Plastics or the supplier of any particular system can make suggestions for optimizing performance of that system in Engineering Structural Foam. The actual testing of a system in an application will always be the best method to ensure reliability.

Self-Tapping Fasteners

Self-tapping fasteners can be specified for permanent assemblies or when the number of anticipated field assembly/disassembly operations will be less than ten. Structural foam's relative freedom from molded-in stresses, coupled with its compressible cellular core, make thread-rolling screws preferable to the thread-cutting variety. Cored holes should be molded whenever possible to obtain maximum performance. Figures 4-1 through 4-6 show the performance of Plastite® screws in Engineering Structural Foams.

Figure 4-1. Self-Tapping Fasteners.

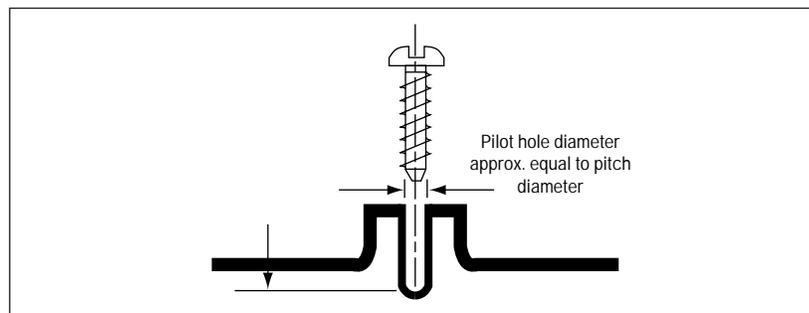


Figure 4-2. Seating Torque vs. Thread Engagement for LEXAN FL900 and NORYL FN215X Resins.

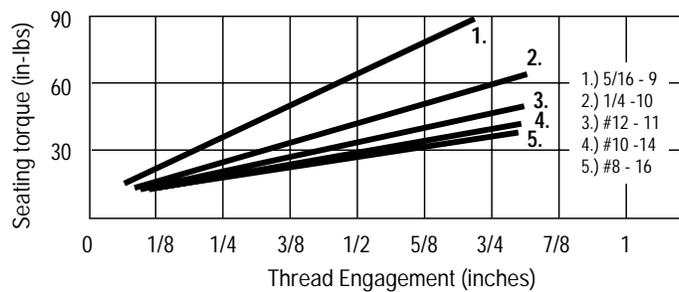
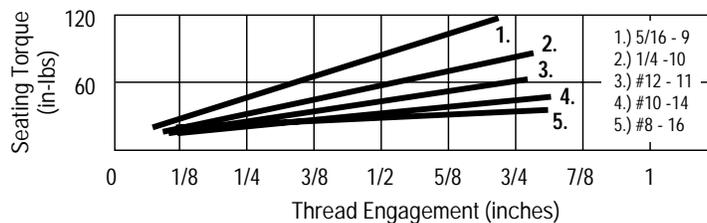


Figure 4-3. Seating Torque (in-lbs) vs. Thread Engagement for VALOX FV620 Resin.



*Registered Trademark of Continental Screw Company, New Bedford, MA.

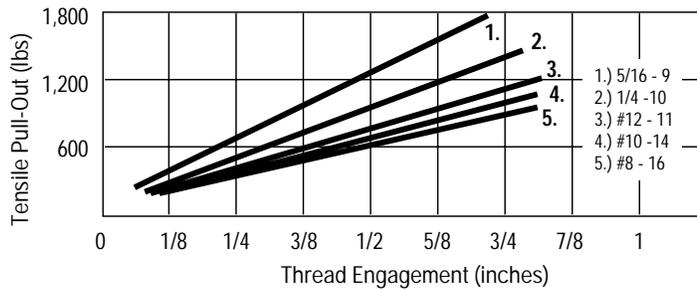


Figure 4-4. Tensile Pull-Out Strength vs. Thread Engagement for LEXAN FL900 Resin.

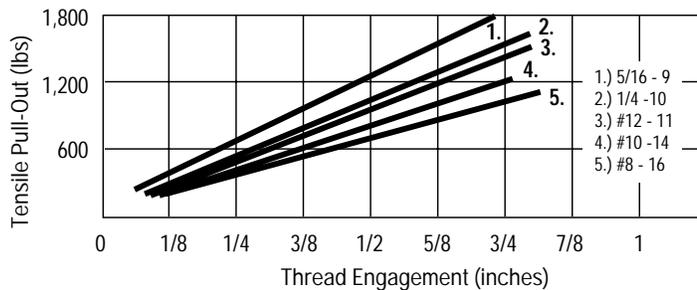


Figure 4-5. Tensile Pull-Out Strength vs. Thread Engagement for NORYL FN215X Resin.

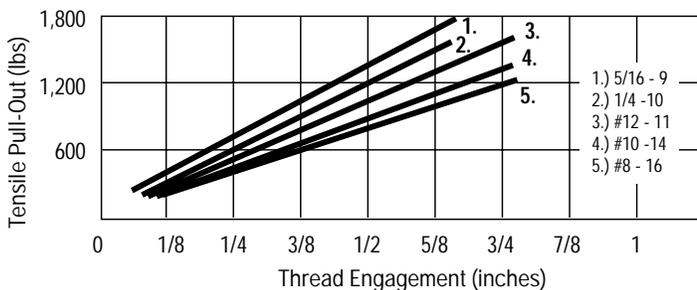


Figure 4-6. Tensile Pull-Out Strength vs. Thread Engagement for VALOX FV620 Resin.

Ultrasonic Inserts

One of the most popular methods of assembling Engineering Structural Foam parts is via ultrasonic inserts. These inserts perform very well plus provide the flexibility of repeated assemblies/disassemblies for the foam parts.

In order to obtain maximum performance from ultrasonic inserts, correct hole sizes are critical. The suggested hole geometries for Dodge Ultrasert II* inserts are given in Figure 4-7 and Table 4-1. Whenever possible, the hole should be molded into the foam part. Drilled holes will yield much lower performance values because their interior surface will not have a continuous skin surface.

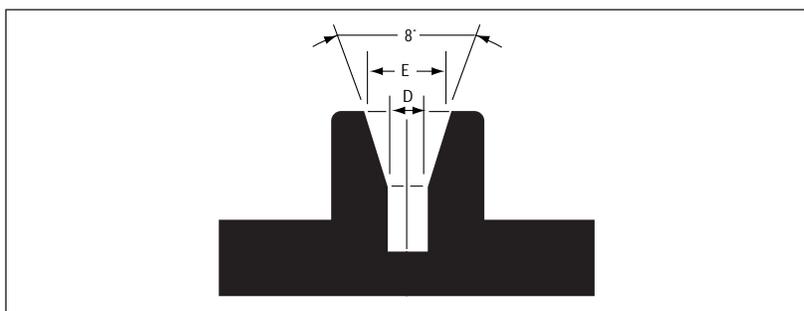


Figure 4-7. Hole Sizes for Ultrasonic Inserts.

*Registered Trademark of Heli-Coil Products, Danbury, CT, Division of Mite Corp.

Assembly

Table 4-1. Suggested Hole Sizes for Ultrasonic Inserts.

Insert Size	Insert Length	LEXAN/ NORYL resins D Max	LEXAN NORYL resins E Max	VALOX resins D Max	VALOX resins E Max
#4	0.219	0.138	0.156	0.140	0.158
#6	0.250	0.182	0.203	0.182	0.205
#8	0.312	0.205	0.231	0.207	0.233
#10	0.375	0.243	0.274	0.245	0.276
1/4"	0.500	0.318	0.360	0.320	0.362
5/16"	0.562	0.398	0.445	0.400	0.447
3/8"	0.625	0.485	0.537	0.487	0.539

The data in Table 4-2 indicate the average values obtained for each series of tests as they apply to a given size Ultrasert II and foam material.

Table 4-2. Ultrasonic Insert Performance.

	INSERT SIZE						
	#4	#6	#8	#10	1/4"	5/16"	3/8"
Tensile Strength (Pounds)							
LEXAN resin	256	413	637	748	1190	1562	2082
NORYL resin	228	336	562	882	1120	1570	1785
VALOX resin	121	298	527	734	985	1080	1337
Rotational Torque (Inch-Pounds)							
LEXAN resin	8	12	24	28	122	127	199
NORYL resin	8	11	22	32	87	166	185
VALOX resin	6	8	21	28	83	127	130
Jack-Out Torque (Inch-Pounds)							
LEXAN resin	3	6	17	26	71	74	134
NORYL resin	6	13	26	42	68	138	193
VALOX resin	2	5	21	33	34	103	127

Performance Definitions

Tensile Strength – Axial force required to pull an insert out of the material at least 0.020 in (0.51 mm).

Rotational Torque – Twisting force required to turn the insert in the parent material.

Jack-Out Torque – Rotational torque applied to a mating screw which pulls the insert out of the material through a washer that has adequate clearance for the insert outside diameter.

Expansion Inserts

Expansion inserts are placed in preformed holes and expanded against the side of the hole by insertion of a screw. These inserts offer lower performance than ultrasonic inserts, but are more economical to use and can be suitable for many common assemblies. (See Table 4-3.)

Expansion inserts cause cold-forming of the material, and while the compressible cellular core makes Engineering Structural Foam parts less susceptible to residual stress, the following general guidelines are suggested to help minimize insertion and high hoop stresses:

1. Boss diameters should be approximately two times the diameter of the insert.
2. When designing component parts for clearances, be sure that the insert and not the plastic carries the load.
3. Heating cycles associated with finishing a structural foam assembly may cause relaxation and loosening of inserts. Finished parts should therefore be checked during production to guard against insert failure.

	INSERT SIZE					
	#4	#6	#8	#10	1/4"	5/16"
Tensile Strength (Pounds)						
LEXAN resin	125	154	158	235	300	315
NORYL resin	138	163	150	230	206	146
VALOX resin	132	202	199	232	318	258
Rotational Torque (Inch-Pounds)						
LEXAN resin	6	4	5	9	19	31
NORYL resin	8	4	5	7	16	12
VALOX resin	4	6	7	8	19	24
Jack-Out Torque (Inch-Pounds)						
LEXAN resin	8	14	18	30	47	66
NORYL resin	11	12	15	26	27	39
VALOX resin	10	17	24	30	56	59

Table 4-3. Expansion Insert Performance.

Assembly System Suppliers

Branson Sonic Power Company
Eagle Road
Danbury, Connecticut 06810
Jim Mengason (203) 744-0760

C.E.M. Company
Danielson, Connecticut 06239
Ward Walker (203) 744-8571

Continental Screw Company
New Bedford, Massachusetts 02742
Jim Braden (617) 993-2621

Heli-Coil Products
1564 Shelter Rock Lane
Danbury, Connecticut 06810
Al Mussnug (203) 743-7651

IN-X Fastener Corporation
230 Verona Avenue
Newark, New Jersey 07104
Rich Fuller (201) 484-2000

*This listing (and others in this brochure) represent suppliers whose products and services have worked successfully with GE Engineering Structural Foam resins in specific applications. The listing does not necessarily represent all suppliers whose products and services would be compatible with Engineering Structural Foam materials, nor is it a guarantee that the listed suppliers' products and services will work with other applications.

Molded-In Inserts

Molded-in inserts are generally compatible with Engineering Structural Foam resins. When you use these inserts, reinforced grades of material are generally preferable due to their lower coefficients of thermal expansion. Suitably-designed inserts can be used in unreinforced grades of material. If molded-in inserts are required, thorough testing for any possible part cracking or insert loosening is required.

Press Fits

Press fits can be used to attach metal pins, bushings, or inserts to an Engineering Structural Foam part, provided correct diametrical interferences are predetermined in the design. In applications which require long-term holding power, reliability of the press fit will depend on the creep behavior of the materials used.

Assuming the metal shaft does not deform greatly when pressed in, a simplified Lamé equation for thick-walled cylinders can be used to approximate the amount of diametrical interference:

$$\Delta D = \frac{S_d D_s}{L} \left(\frac{L + \nu_{\eta}}{E_h} \right)$$
$$L = \frac{1 + (D_s / D_h)^2}{1 - (D_s / D_h)^2}$$

Where

- D = Diametral interference
- S_d = Design Stress
- D_h = O.D. of hub
- D_s = O.D. of shaft
- E_h = Tensile modulus of hub
- L = Geometry factor
- ν_η = Poisson ratio of hub
(typical value of ν for GE ESF Resins is .35)

The holding and assembly force may be approximated by multiplying the joint pressure, joint area, and coefficient of friction of the materials together.

$$F = PA m_f = \frac{S_d (\pi D_s l) m_f}{L}$$

Where:

- F = Assembly force
- P = Joint Pressure
- A = Joint Area
- D_s = Shaft diameter
- l = Length of press fit
- m_f = Coefficient of friction
- L = Geometry factor
- S_d = Design stress
- π = pi (or 3.14)

If the press fit assembly must operate at elevated temperatures, the strength of the interface will be reduced due to change in thermal expansion and the resin's modulus of elasticity. To calculate the loss

of interface due to thermal expansion of a metal shaft pressed into a structural foam hub:

When examining long-term performance, the apparent modulus of the structural foam resin determined from the creep curves must be utilized.

$$D - D_0 = (\alpha_h - \alpha_s) D_0 \Delta T$$

Where

- D_0 = Original diameter
- D = Diameter at operating temperature
- α_h = Coefficient of thermal expansion of hub
- α_s = Coefficient of thermal expansion of shaft
- ΔT = Change in temperature

Ultrasonic Bonding

Engineering Structural Foam can allow the designer to use ultrasonic assembly methods (Figures 4-8 to 4-10), including:

- Insertion – the process whereby a metal piece is implanted in the plastic.
- Staking – the process of melting and forming the upper portion of a stud so as to retain another material, usually metal.
- Spot Welding – the process of creating small localized bonds between two parts.

Continuous and large-area welding techniques are not generally recommended for use with foam, since the cellular core tends to dissipate much of the ultrasonic energy in a far-field weld.

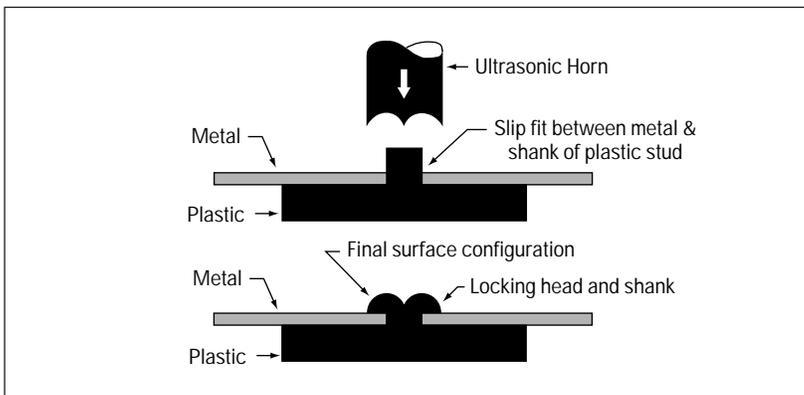


Figure 4-8. Ultrasonic Insertion.

Assembly

Figure 4-9. Ultrasonic Spot Welding.

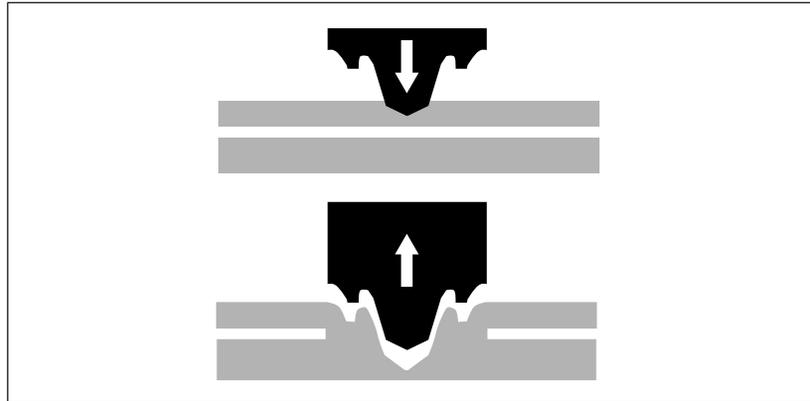
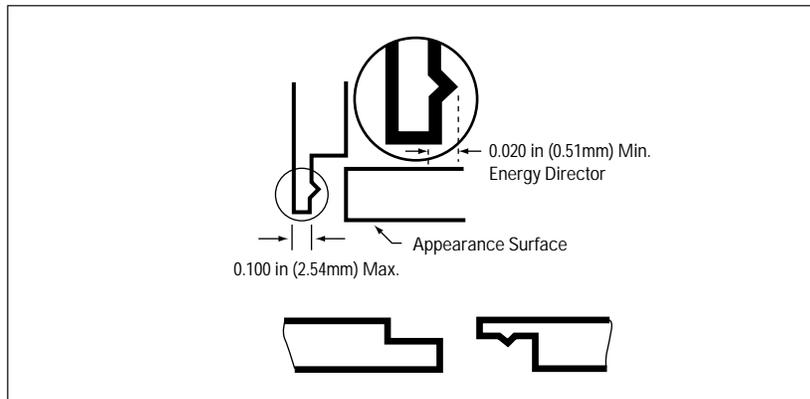


Figure 4-10. Ultrasonic Joint Design.



Vibration Welding

Vibration welding is a relatively new process for bonding large parts. Basically a low-frequency friction weld, it is capable of producing strong, pressure-tight joints. This method lends itself very well to Engineering Structural Foam parts that require permanent loads over large areas. Although butt joints are normally used in this process, the geometry of the part may require a flange to increase rigidity. Since the process resembles ultrasonic welding, there may be considerable flash during bonding, and cosmetic flash traps are recommended on critical appearance surfaces. Sonic and vibration welding techniques generally perform better in thinner wall designs than in thicker ones. As the wall section is widened, a greater amount of energy is absorbed by the cellular core, and bonding becomes more difficult to achieve.

Solvent Bonding

Engineering Structural Foam NORYL and LEXAN resins can be solvent-cemented to themselves or to other plastics using a number of commercial solvents, mixtures of solvents, or light solutions of resin (1 to 5%) in acceptable solvents. (See Table 4-4 on Page 4-12.) Solvent bonding is not recommended for VALOX resins, since these materials have such significant solvent resistance.

General Techniques

Mating ends of parts are coated with enough solvent to saturate the local joint area. Moderate pressure [(10 to 60 psi) (0.069 to 0.414 MPa)] is applied for a minimum of one minute after parts are properly positioned. Locating pins, tongue-and-groove shapes or flanges may be used to align bonding areas to effect rapid matching after the application of solvent. These devices should be kept shallow in order to avoid trapping solvent in the mating surfaces.

The bond cure rate is a function of the evaporation of the solvent and temperature conditions. At room temperature, the optimum bond strength is usually obtained within 24 to 48 hours. Although elevated temperatures can accelerate this process, the curing temperature should be raised gradually to avoid the formation of bubbles and a weakened bond. Final bake temperatures should be equal to or slightly lower than maximum service temperature for the plastic employed.

Adhesive Bonding

Adhesive bonding is a technique for bonding Engineering Structural Foam resins to themselves, to other plastics, and to other materials such as glass, aluminum, brass, steel and wood.

Generally, better results are obtained with solventless materials, such as epoxies and urethanes. However, each application has unique requirements, e.g., flexibility, temperature resistance, ease of application and appearance, and therefore requires careful adhesive selection. The following precautions should be considered when selecting an adhesive:

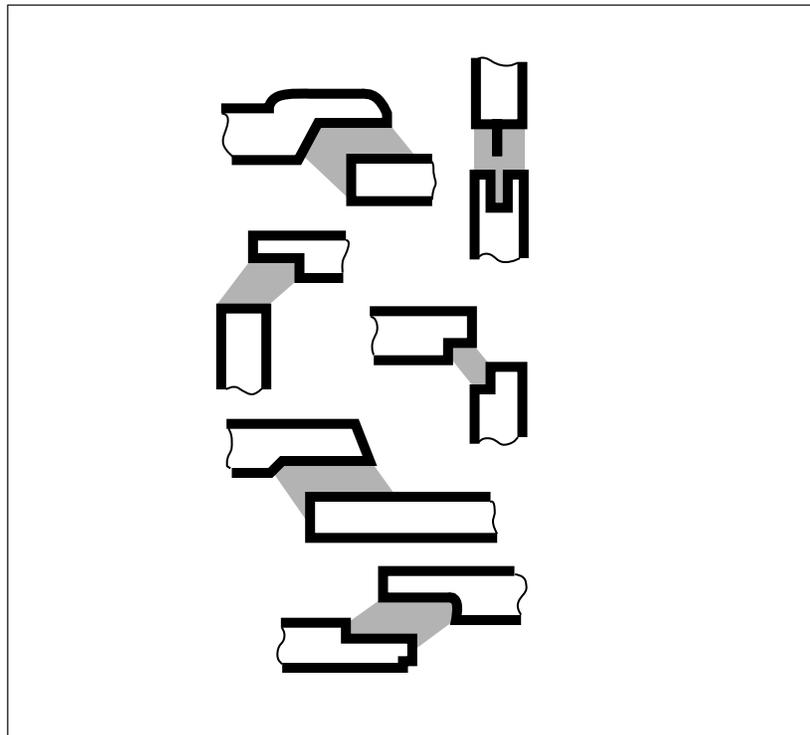
- Avoid solvents or catalysts that are incompatible with the materials to be joined.
- Cure temperatures should not exceed the recommended bake temperatures for each particular grade of structural foam resin.
- Test for compatibility and bonding strength under expected operating conditions.
- Follow accepted practices for joint design.

Joint Design

Joint design should be considered early in the design of parts to be bonded (Figure 4-11). Conventional joint designs can be used with structural foam resins, but bonding areas should carry the load equally, placing major stresses in shear or tension to minimize cleavage and peel stresses.

For optimum performance, joint surfaces should be free from contamination. All oil, grease, paint, mold releases, rust and oxides must be removed by wiping with compatible solvents such as petroleum ether, isopropyl alcohol, heptane, VM&P naphtha, or a light solution of detergent. Abrasion of surfaces by sand blasting, or vapor honing can also help assure maximum bond strength.

Figure 4-11. Adhesive and Solvent Joint Design.



Types of Adhesives

Epoxies. Epoxies can yield a high tensile strength, maintain their shape under load, and have very low shrinkage. Their resistance to water, organic solvents, heat and cold is generally good. However, epoxies generally have low peel and impact strength due to their brittle nature after cure.

Urethanes. Polyurethanes can offer good peel strength and have very high impact resistance. They have good low temperature properties, but are limited at elevated temperatures. These adhesives can suffer from excessive creep under load at room temperature and show deterioration in properties on aging.

Silicones. The silicones are generally characterized by their ease of handling, low temperature cure and high temperature properties. They can be limited by their low shear strength, and adhesion must sometimes be promoted by the use of primers.

Assembly

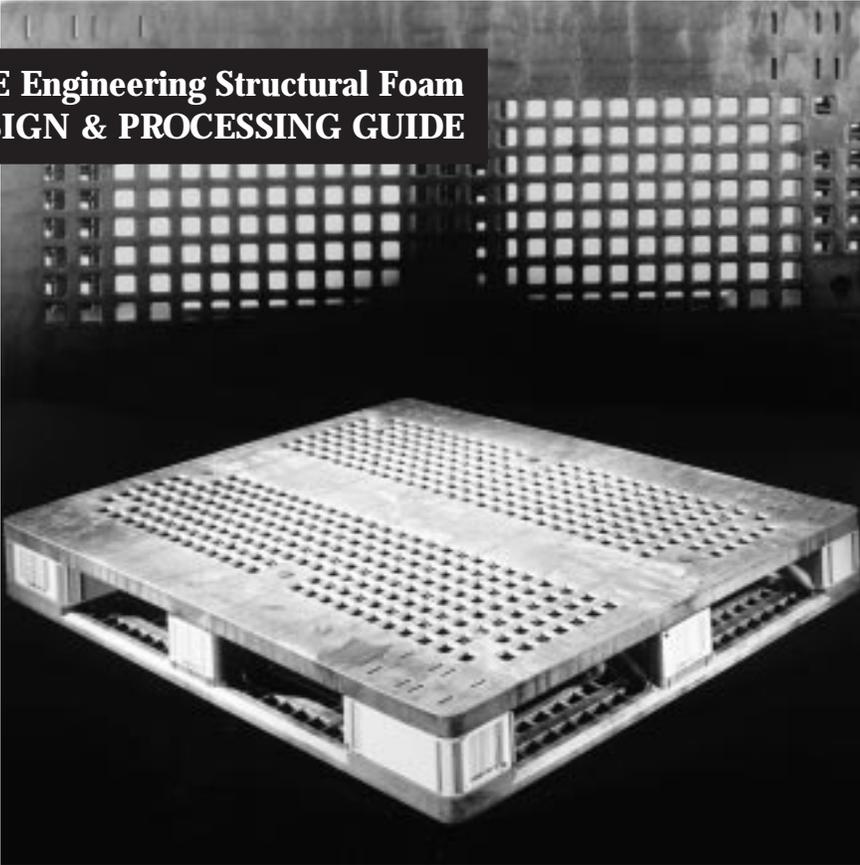
Table 4-4. Solvents and Adhesives for Bonding.

Adhesive or Bonding Solvent	Supplier	Type	Set Time @ RT	Cure Time @ RT	Bonding Strength		
					Foamable LEXAN resin	Foamable NORYL resin	Foamable VALOX resin
Hysol Super Drop I IEC-1500	Hysol Div. Dexter Corp., Pittsburg, California	Ethyl Cyanoacrylate	25 sec.	1 hr.	V High	V High	V High
Hysol Super Drop II 2C-100	Hysol Div. Dexter Corp., Pittsburg, California	Cyanoacrylate	25 sec.	1 hr.	V High	V High	V High
Hytrust EA 9446	Hysol Div. Dexter Corp., Pittsburg, California	2-Part Acrylic	1 Hr.	8 hrs.	V High	High	High
Super Bonder 430	Loctite Corp., Newington, Connecticut	Methyl Cyanoacrylate	40 sec.	1 hr.	High	V High	High
Scotch-Grip Plastic Adhesive 1099	3M Corporation, St. Paul, Minnesota	Single Component	4 hrs.	48 hrs.	Low	Low	Low
Scotch-Weld 1838B/A	3M Corporation, St. Paul, Minnesota	2-Part Epoxy	16 hrs.	24-48 hrs.	V High	High	High
Scotch-Weld 2216B/A	3M Corporation, St. Paul, Minnesota	2-Part Epoxy	16 hrs.	24-48 hrs.	High	Med	Med
Scotch-Weld 3520B/A	3M Corporation, St. Paul, Minnesota	2-Part Epoxy	16 hrs.	24-48 hrs.	High	High	High
Depend	Loctite Corp., Newington, Connecticut	2-Part Acrylic	5 min.	4-24 hrs.	High	Med	
Nusil R-1140	McGhan Nusil Corporation, Carpinteria, California	Silicone	16 hrs.	24-48 hrs.	Low	Low	Low
RTV 108	General Electric Company, Waterford, New York	Silicone	24 Hrs.	24-48 hrs.	Low	Low	Low
Bond 5073	Bond Adhesive Company, Jersey City, New Jersey	Single Component	2 hrs.	24 hrs.	Med	Low	Low
Pilogrip 6500 with 6036 Primer	Goodyear Chemicals, Ashland, Ohio	Urethane	24 hrs.	24-48 hrs.		Med	V High
Permabond 101	Permabond International, Englewood, New Jersey	Cyanoacrylate	30 secs.	1 hr.	V High	V High	V High
Versilok 506 with Accelerator #4	Hughson Chemicals, Erie, Pennsylvania	2-Part Acrylic	15 min.	24 hrs.	High	Med	High
Versilok 510 with Accelerator #4	Hughson Chemicals, Erie, Pennsylvania	2-Part Acrylic	11 min.	24 hrs.	High	High	V High
Tra-Bond 2112	Tra-Con, Inc. Medford, Massachusetts	2-Part Epoxy	16 hrs.	24-48 hrs.	High		
Tra-Bond 2143D	Tra-Con, Inc., Medford, Massachusetts	2-Part Epoxy	16 hrs.	24-48 hrs.	High		
Methylene Chloride	Fischer Scientific Co., Fair Lawn, New Jersey	Solvent	1 min.	24 hrs.	High	High	
RTV 108 with SS4004 Primer	General Electric Company, Waterford, New York	Silicone	24 hrs.	24-48 hrs.	Low	Low	
A1404B	B.F. Goodrich Co., Fabricated Polymers Div. Akron, Ohio	Synthetic Polymer	1 hr.	24 hrs.		Low	
A1186B with A1186B CAT A	B.F. Goodrich Co., Fabricated Polymers Div. Akron, Ohio	2-Part Epoxy	16-24 hrs.	5 days	Med	High	
Clear Bond 5760 A/B	Furane Products Div., M&T Chemicals, Inc. Los Angeles, California	2-Part Polycarbonate	6 hrs.	24-48 hrs.	Med		
EPO-TEK 730	Epoxy Technology, Inc., Billerica, Massachusetts	2-Part Epoxy	3 hrs.	12-24 hrs.		High	
#34N	Synthetic Surfaces, Inc., Scotch Plains, NJ	Urethane	30 min.	48 hrs.	High	Med	
#34N with 62MT Add.	Synthetic Surfaces, Inc., Scotch Plains, NJ	2-Part Urethane	5 min.	24 hrs.	Med	Med	
#34 x 50 with 62MT Add.	Synthetic Surfaces, Inc., Scotch Plains, NJ	Urethan	30 min.	48 hrs.	High	Med	
Tough Instant Adhesive Special #12829	Loctite Corp., Newington, Connecticut	Cyanoacrylate	15 min.	24 hrs.	High		
R & D 9004.1 Resin with R & D 9004.1 Hardener	R&D Chem. Co., Kansas City, Missouri	2-Part Modified Epoxy	1.5 hrs	16 hrs	Med	Med	High
RP5540 Resin with RP5541	R Plastics, East Lansing, Michigan	2-Part Urethane	20 min.	24 hrs.	High	High	High



GE **Plastics**

**GE Engineering Structural Foam
DESIGN & PROCESSING GUIDE**



Engineering Structural Foam

Prototyping

Photo Courtesy of:
Cookson Plastics Molding

Prototyping

Prototyping

Even after all of the calculations have been made and engineering principles applied, there is still no substitute for actually building and testing a design. This is especially true for complex designs where the assumptions used in the calculations over-simplify the actual loadings and stresses.

Various methods can be employed in arriving at a sample part in Engineering Structural Foam.

Fabrication

If one or two samples are required for appearance models or for simple testing, fabrication from foam panels is one option. These panels can be cut, drilled, machined and adhesive or solvent-bonded in a model shop to produce a prototype sample at minimum cost.

Molds

Low-cost prototype tooling can be employed for producing a small number of actual parts molded in structural foam.

- Plaster – Low-cost molds used to produce one part; limited by size and complexity.
- Silicone – Produces one to five parts; limited to somewhat simple shapes.
- Epoxy – Low-cost method of producing one to twenty-five parts, depending on size and complexity.
- Spray Metal Epoxy – Epoxy molds which have been metallized – usually with zinc – whose hardened surfaces allow the production of up to a few thousand parts, depending on complexity and size.
- Kirksite® – Molds made by this process have been utilized to produce pre-production samples, as well as production quantities up to as many as several thousand parts.
- Cast Aluminum – Used for prototype tools and in some cases, for limited production.

*Registered Trademark of NL Industries.

Converted Tools

In metal replacement products, die-cast tools may be successfully used for shooting sample parts. Some modifications are usually required including:

- Increasing wall thickness to a value acceptable for structural foam.
- Adding a sprue bushing and closing the shooting pot in aluminum die-cast tools.

Frequently, zinc die-cast molds can be used with no modifications except for necessary wall section revisions.



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Engineering Structural Foam
PROCESSING

Moisture Control

The amount of moisture present in a resin is dependent on three factors: the type of resin, the size and shape of the pellets, and the temperature/humidity conditions during transport and storage. These variables will determine the amount of time and temperature required to adequately dry the resin.

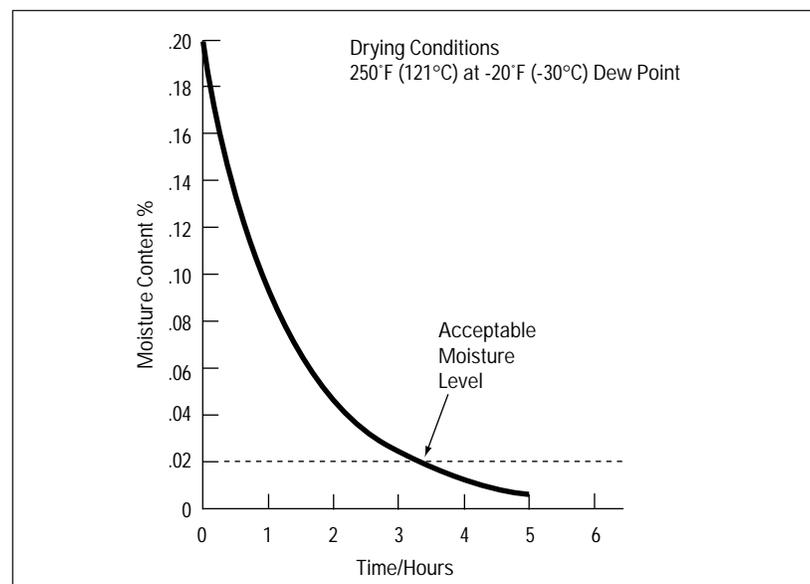
LEXAN[®] and VALOX[®] resins are both hygroscopic. These materials absorb moisture. The primary effect of residual moisture is reduction in impact strength. Moisture in NORYL[®] resins, which are non-hygroscopic resins, typically will not affect physical properties. The conditions required to dry hygroscopic resins are:

- Adequate residence time
- Good airflow distribution through the resin hopper
- Adequate drying temperature
- Adequate delivery air dew point

Residence time will be determined by the size of the resin hopper compared to the amount of resin being processed per hour. The amount of time the resin is in the hopper at the required temperature must meet or exceed the minimum drying time recommendations.

As shown in Figure 6-1, three to four hours of drying time are normally required after the drying environment has reached 250°F (121°C) at -20°F (-30°C) dew point

Figure 6-1. Equilibrium Moisture Control for LEXAN and VALOX, resins.



The airflow the dryer delivers to the hopper must be high enough to deliver moist wet air back to the dryer desiccant beds. Too low an airflow will effect the length of time required as well as the amount of moisture removed from the pellets.

The dry air temperature should be at the suggested temperature for the resin being dried. When drying both resin and blowing agent in the same hopper, temperature reduction of 10 to 15°F (-12 to -9°C) may be required to avoid the CBA from becoming sticky.

Dew point determines how readily the hot air will absorb moisture from the pellets. -20°F(-30°C) dew point or lower is typically required.

Moisture in the pellet can be determined by conducting a TVI test or by testing with a moisture analyzer. A reading of 0.02% or below is desirable.

Table 6-1 gives suggested drying temperatures and time for GE Plastics foamable resins.

Product	Drying Temperature	Drying Time/Hrs.
LEXAN resin	250°F(121°C)	3-4 hours
NORYL resin (unfilled)	170°F(77°C)	none required
VALOX resin	250°F(121°C)	4 hours

Table 6-1. Suggested Drying Temperatures and Time.

Inlet and outlet air filters can trap high concentrations of fines or dust. This can act as a contaminant and cause surface burning or discoloration. A preventative maintenance schedule is strongly suggested to ensure all heaters, hoses, filters and desiccants are clean and in good working order.

Determining the Proper Amount of Blowing Agent Concentrate

Table 6-2 gives recommended usage levels for GE blowing agents. The actual amount used will depend on the application. Wall thickness, flow lengths and part geometry all affect the amount of CBA required. Generally, long flow lengths and thinner walls require more blowing agent than thicker walls and short flow lengths. When mixing concentrates with the base resin, start with an amount in the mid range. Adjust the amount of CBA to suit the conditions after producing and testing several parts.

Higher levels of blowing agent do not necessarily result in higher amounts of weight reduction. Blowing agent dosage should be determined by cell structure, surface appearance and flow. When using recycled foam material, treat the virgin/regrind mixture as virgin material. Residual blowing agent in regrind is normally insignificant.

Proper Blending of Concentrates

Blending CBAs with base resins can be accomplished by using several methods. In some cases where short runs or sample moldings are going to be produced, the resin and CBA can be mixed in a clean drum. For larger volumes, a mixer or tumbler is more suitable. The amount of time required for a thorough mix will depend on the bulk density of the CBA and the amount being mixed. CBAs with a bulk density lower than the base resin will tend to float to the top of the mixer if blended too long. In most cases, mixing for ten minutes or more is suggested.

The most convenient method of blending CBA with resin is with an automatic auger type color feeder. Mounted between the feed throat of the molding machine and the resin hopper, a variable speed auger meters in a precise amount of CBA during shot size recovery. The speed and duration can be adjusted to optimize the dosage.

CBAs that require drying can be mixed with the base resin prior to drying or pre-dried and then mixed with the base resin using a color mixer.

Blowing Agent Compatibility

Care should be taken to ensure proper CBA is blended with the base resin. Blowing agent contamination can cause reduced impact properties as well as other physical property reductions. For instance, FNC30X, blowing agent, used for NORYL resin is not compatible with LEXAN resins. Likewise, several other commercial CBAs are only compatible with certain resins. For recommendations on the use of these CBAs contact should be made with the respective supplier.

Recycling Materials

Sprues, runners and short-shot moldings of GE thermoplastic resins can be reground and reprocessed with minimal reduction in properties, providing the regrind is not degraded, is clean and free from impurities and is used with the same base resin. Up to a maximum of 15% regrind may be used with virgin resin.

When using reground materials, the following guidelines apply:

- Do not recycle materials if there is the slightest possibility that degradation or contamination may have occurred.
- Do not use painted or metallized regrind.
- Do not use regrind for impact critical applications.
- Use the same amount of blowing agent as for all virgin material.
- Regrind material should be as dry as the base resin.
- LEXAN resin regrind suspected of being improperly dried should not be considered as recyclable.

Physical or Nitrogen Process

The physical or nitrogen process requires a specially designed, oversized platen, foam molding machine in which nitrogen gas is introduced directly into the barrel of the extruder. A screw containing one or more mixing sections blends the nitrogen gas with the hot polymer melt. The mixture is fed into a large holding area called a melt accumulator and held under pressure. Shot sizes of 100 pounds or more are not uncommon with this type of equipment. When a predetermined shot is attained, the melt is forced through an external hot manifold system to one or several hydraulically actuated shut-off nozzles. The number, size and location of nozzles are determined by part configuration. Low pressure nitrogen presses have lower injection pressure capabilities than standard injection machines. The platens can be fitted with very large molds or several smaller ones. Nozzles can be independently controlled to adjust timing and flow.

Product	Concentrate	Suggested Start
NORYL resin	1-3% FNC30X	2%
VALOX resin	3-10% FVC60/65	5%

Table 6-2. Suggested Usage Levels for Blowing Agents.

Chemical Blowing Agent Process

In this type of process a chemical blowing agent is first blended with the plastic pellets. The mixture is then delivered to the feed section of the barrel. During the process, heat decomposes the blowing agent allowing it to release a gas. The gas is mixed with the resin in the screw of the machine.

Molding equipment used to produce structural foam parts with chemical blowing agents include specially designed, large shot capacity, foam molding machines as well as standard injection molding equipment. Quality parts can be produced using most injection molding equipment if special attention is given to:

- Distance of flow from the nozzle. Injection machines typically have only one nozzle. Hot manifold systems in the mold may be required. Flow runners, gate size and wall thickness are other considerations.
- Platen sizes for injection machines are normally smaller than for foam equipment. Keep molds centered for better results.
- Shot size will be limited to the free space in front of the injection screw.
- A shut-off nozzle is recommended to avoid material drooling that can cause inconsistent shot sizes.

In most cases, if the mold will fit between the tie bars and the machine has adequate shot capacity, the part can be molded using that press.

Blowing Agents for LEXAN Resin FL Grade

There are a number of blowing agents available for LEXAN resins. To help you decide which agent to use for your specific application and resin choice, contact your Technical Development Engineer or Application Development Engineer.

Nozzle Design

The structural foam process requires control of the nozzle to help eliminate drooling and to maintain a good flow rate. With injection molding machines, the most desirable method of nozzle control is via a non-restrictive shut-off nozzle. One that shuts off at the tip and that is hydraulically or pneumatically operated generally works best. Those having an extended tip are still prone to drool. If a shut-off nozzle is not available, drooling can be minimized by controlling the very tip of the nozzle. At least two separate heat zones should be used on the nozzle. One to maintain melt temperature and the other to control the tip temperature. Adjust the tip lower to reduce drooling and higher to address freeze off. On structural foam machines, a thermally conductive nozzle tip cap can be installed to insulate the hot nozzle from the cold mold. Without the insulator, the mold becomes a heat sink making temperature control more difficult.

Gas Counterpressure Process

In the gas counterpressure method, inert gas charged in molten polymer is contained until the entire shot is injected into the cavity. This prevents simultaneous expansion and produces a molded part with a smooth skin. This method requires a sealed mold in order to control the gas pressure during injection. Sealing the mold usually involves machining an O-ring groove around the parting line to accept sealing material such as neoprene. Suggested groove dimensions are 0.170 in deep by 0.182 in wide (0.432 by 0.463 cm), for a 0.188 in (0.476 cm) O-ring. It may also be necessary to seal ejector pins, the sprue bushing and moving slides or cores to maintain a seal adequate to hold 50-500 psi (0.35 – 3.45 MPa) counterpressure. Thus, the process should be considered as a tooling modification rather than one that requires specialized molding equipment.

The general steps in the process are as follows: clamping the mold, pressurizing the cavity, injecting the resin, depressurizing and ejecting the part. This sequence has no significant effect on either cycle or cure time.

Pressurization is accomplished by connecting the mold to a supply of filtered, dry compressed air or, more frequently, nitrogen. Solenoid-controlled valves regulate both gas intake and venting to depressurize the cavity. The amount of gas is controlled by pressure transducers or regulators. (Figure 6-2.)

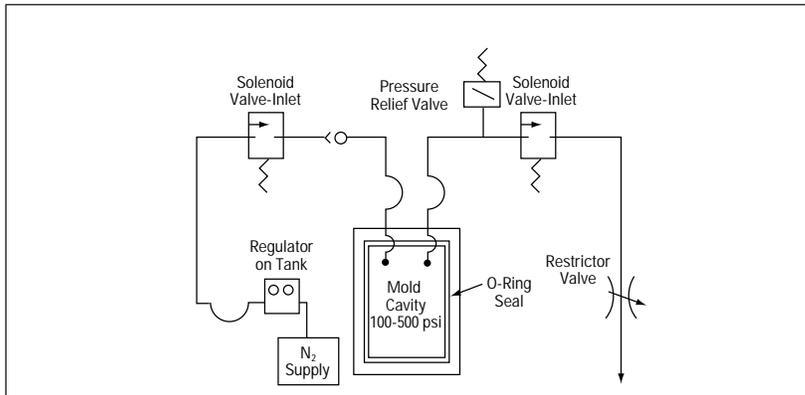


Figure 6-2. Counterpressure Foam Schematic.

The more blowing agent used, the higher the counterpressure required to contain bubble growth, although 300 psi (2.07 MPa) is usually sufficient. Table 6-3 shows the relationship of wall thickness and counterpressure requirements.

Wall Thickness in (mm)	Blowing Agent %	Pressure Required psi (MPa)
0.150 (3.81)	3	400-500 (2.76-3.45)
0.200 (5.10)	3	300-400 (2.07-2.76)
0.250 (6.35)	3	200-300 (1.38-2.07)
0.300 (7.62)	3	300-500 (2.07-3.45)

Table 6-3. Normal Counterpressure Range.

With a tightly sealed mold, gas counterpressure processing produces a part with a cellular core and a smooth surface. Although a Class A surface is difficult to achieve, slight imperfections are typically easily masked with a mist coat of paint. Density reduction is normally less than that of a similar part molded with the low pressure foam process. The exact amount of density will be determined by wall thickness, flow length, part configuration and processing conditions.

The gas counterpressure method does offer a number of advantages over other methods. Because expansion of the polymer does not occur until the entire shot is injected, cell structure is evenly distributed throughout the part, providing a more predictable, uniform mechanical property profile and reducing the possibility of over-packed and over-stressed sections that can result in poor dimensional control and warping. Counterpressure produces a much thicker and non-porous skin, sealing in the gases that usually permeate the porous skin of conventional foam parts. This means that parts usually can be painted directly from the mold without blistering. In addition, volatiles that sometimes rise to the surface of parts are kept in solution, greatly reducing liquid build-up in vent areas and on the parting line.

Machine Settings

To achieve optimum results when foaming GE engineering resins, certain basic criteria must be maintained and monitored. These include:

- Sufficient clamping force
- Proper melt temperature
- Proper mold temperature
- Proper injection, hold and back pressures
- Proper injection speed

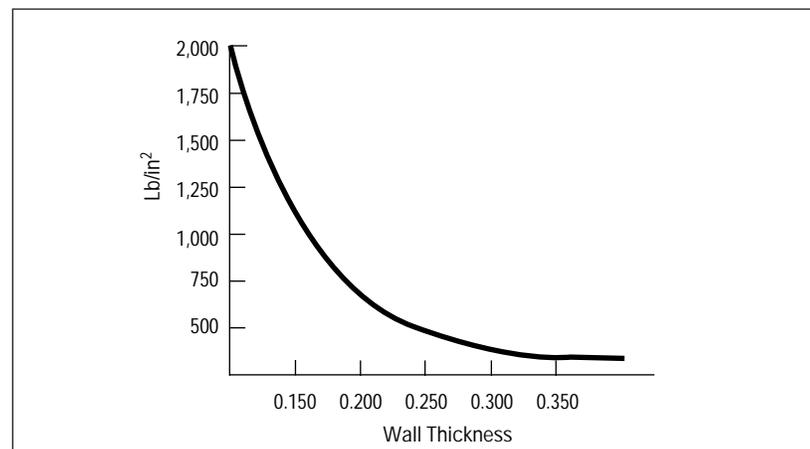
Each application will require independent determination of optimum machine settings within the ranges described for each material.

Clamping Force

Clamp tonnage requirements for structural foam molding are significantly lower than those for conventional injection molding. This is due primarily because foam molding is a short shot process. Clamping force is the amount of pressure required to keep the mold tightly closed during the injection of the molten resin/blowing agent mixture into the mold cavity. Mold cavity pressure is generated as the mold is filled with resin. Cavity pressure is affected by the projected surface area of the part, wall thickness, flow length and resin viscosity. The clamping pressure must be higher than the mold cavity pressure to avoid the mold from separating causing flash.

Clamp tonnage is determined by calculating the part projected area. That is the area of the molded part which is projected onto a plane at right angles to the direction of the mold. In other words, the area of the shadow it can cast. Divide the projected area by a factor determined by the nominal wall thickness of the part as shown in Figure 6-3.

Figure 6-3. Typical Clamping Requirements.



Melt Temperature

Melt temperature is that of the molten resin prior to being injected into the mold cavity. It is measured using a hand held pyrometer or other device. Do not rely on the set temperatures to be accurate. The optimum melt temperature for any given part will depend on several factors. Ideally, that temperature will ensure good flow characteristics, provide a melt consistency that enables good cell structure formation, ensure good weld line strength and produce a suitable surface finish.

Factors that influence determining the proper melt temperature are:

- The type of molding machine used
- Screw and barrel configuration
- Type of resin
- Part geometry
- Flow lengths
- Gate size and location
- Blowing agent concentrate
- Dimensional requirements
- Surface finish requirements

Flow

As wall thickness and injection pressure increases, the flow length of GE foamable resins increases. Higher melt and mold temperatures also add to the ability to increase flow. Using recommended process temperature ranges will help ensure optimum physical properties. The chart in Figure 6-4 shows a relationship of wall thickness to flow length at nominal process parameters.

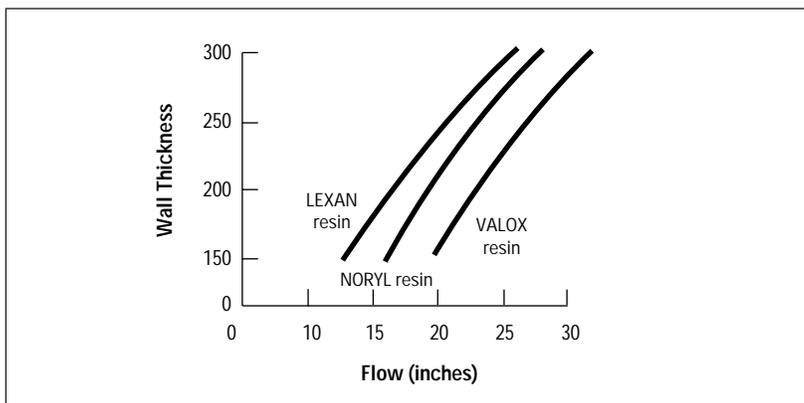


Figure 6-4. Wall Thickness vs. Flow.

Temperature Setting

Melting of a resin is obtained by introducing a solid resin pellet to a heated screw and barrel. The barrel is divided into several zones that are electrically heated by heater bands. The melt temperature is reached by adjusting the temperature of each zone. Every type of molding machine will have a feed zone just below and slightly forward of the hopper, and a zone to control the nozzle/nozzles. The number of zones between the feed and nozzle zone depends on the molding equipment.

The melt temperature should be obtained by increasing or decreasing the set temperatures at each zone, not by inducing shear heat generated by high back pressure or very fast injection speeds.

The feed zone temperature should be set below the decomposition temperature of the blowing agent, normally between 100 and 150°F (38 and 66°C) below the desired melt temperature. At these temperatures the blowing agent does not release its gas too early allowing some of it to escape via the machine throat and hopper.

With conventional injection machines, the temperatures should generally be set so that the center zone is the hottest. This will help the resin and blowing agent see a high enough temperature to provide proper decomposition and mixing. The front and nozzle zone can be set lower initially and then adjusted for adequate flow and cycle time optimization. If the press is not fitted with a shut-off nozzle, the nozzle tip should be controlled separately to control drooling.

With multi-nozzle structural foam machines, the temperature settings should be set at the desired melt temperature throughout the screw, heat pipes, accumulator and manifold areas. The nozzles can be adjusted to help balance mold filling.

With molds having an internal hot manifold system, the machine barrel and nozzle should be set at the desired melt temperature. The manifold and nozzle temperatures should be adjusted to control drooling and/or to balance flow.

Table 6-4. Suggested Foam Molding Parameters for LEXAN Resin Products.

		FL1000 FL1003 FL1600		FL2000 FL2003		FL400 FL403		FL410		FL900 FL903 FL920 FL910 FL930 FL913 FL933	
Processing Conditions	Units	(min.)	(max.)	(min.)	(max.)	(min.)	(max.)	(min.)	(max.)	(min.)	(max.)
Drying Temperature*	°F(°C)	—	250(121)	—	250(121)	—	250(121)	—	250(121)	—	250(316)
Drying Time – min	hrs.	3	4	3	4	3	4	3	4	3	4
Drying Time – max	hrs	—	48	—	48	—	48	—	48	—	48
Melt Temperature	°F(°C)	555(291)	590(310)	555(291)	590(310)	525(274)	570(299)	550(288)	590(310)	550(288)	600(316)
Nozzle	°F(°C)	520(271)	560(293)	540(282)	580(304)	510(266)	550(288)	510(266)	550(288)	520(271)	560(293)
Front	°F(°C)	550(288)	580(304)	560(293)	600(316)	530(277)	570(299)	570(299)	580(304)	560(293)	590(310)
Middle	°F(°C)	550(288)	580(304)	560(293)	600(316)	530(277)	570(299)	570(299)	580(304)	560(293)	590(310)
Rear	°F(°C)	490(254)	540(282)	460(238)	500(260)	520(271)	560(293)	490(254)	510(266)	490(254)	510(266)
Mold Temperature	°F(°C)	160(71)	200(93)	160(71)	200(93)	160(71)	200(93)	160(71)	200(93)	160(71)	200(93)
Blowing Agent Options											
Nitrogen Gas (physical system)		✓		✓		✓		✓		✓	
Blowing Agents for LEXAN Resin FL Grade											
There are a number of blowing agents available for LEXAN resins. To help you decide which agent to use for your specific application and resin choice, contact your Technical Development Engineer or Application Development Engineer.											

* Drying conditions for the base resin only.

Drying of **blowing agents is NOT recommended unless close color control is required.

Note: These are general suggestions only. End-use environment testing of manufactured parts is required to determine settings for a given application.

Table 6-5. Suggested Foam Molding Parameters for NORYL Resin Products.

		FM3020 FM4025		FMC1010		FMC3008A		FN150X FN170X FN215X	
Processing Conditions	Units	(min.)	(max.)	(min.)	(max.)	(min.)	(max.)	(min.)	(max.)
Drying Temperature*	°F(°C)	220(104)	230(110)	200(93)	220(104)	200(93)	220(104)	160(71)	180(82)
Drying Time - min	hrs.	2	4	2	4	2	4	2	4
Drying Time - max	hrs.	—	8	—	8	—	8	—	8
Melt Temperature	°F(°C)	520(271)	590(310)	460(238)	540(282)	520(271)	570(299)	520(271)	590(310)
Nozzle	°F(°C)	520(271)	580(304)	510(266)	540(282)	520(271)	570(299)	520(271)	580(304)
Front	°F(°C)	520(271)	580(304)	500(260)	540(282)	520(271)	570(299)	520(271)	580(304)
Middle	°F(°C)	520(271)	580(304)	480(249)	500(260)	520(271)	550(288)	520(271)	580(304)
Rear	°F(°C)	500(260)	550(288)	460(238)	480(249)	500(260)	540(282)	450(232)	500(260)
Mold Temperature	°F(°C)	150(66)	180(82)	150(66)	200(93)	160(71)	200(93)	80(27)	130(54)
Blowing Agent Options									
Nitrogen Gas (physical system)		✓		✓		✓		✓	
FNC30X (chemical system)									
Concentration Range		1-3%		1-3%		1-3%		1-3%	
Recommended Concentration		2%		2%		2%		2%	

Note: These are general suggestions only. End-use environment testing of manufactured parts is required to determine settings for a given application.

Processing

Table 6-6. Suggested Foam Molding Parameters for VALOX Resin Products.

Processing Conditions	Units	FV608 FV620		FV649 FV699	
		(min.)	(max.)	(min.)	(max.)
Drying Temperature	°F(°C)	—	250(121)	—	250(121)
Drying Time - min	hrs.	—	4	—	4
Drying Time - max	hrs	—	24	—	24
Melt Temperature	°F(°C)	—	495(257)	470(243)	500(260)
Nozzle	°F(°C)	470(243)	490(254)	480(249)	510(266)
Front	°F(°C)	480(249)	500(260)	480(249)	510(266)
Middle	°F(°C)	470(243)	490(254)	470(243)	490(254)
Rear	°F(°C)	400(204)	450(232)	400(204)	450(232)
Mold Temperature	°F(°C)	160(71)	200(93)	160(71)	200(93)
Blowing Agent Options					
Nitrogen Gas (physical system)		✓		✓	
FVC60/65 (chemical system)					
Concentration Range		3-10%		3-10%	
Recommended Concentration		5%		5%	

*Drying of **blowing agents** is NOT recommended unless close color control is required.

Note: These are general suggestions only. End-use environment testing of manufactured parts is required to determine settings for a given application.

Cylinder Purging

Normal purging procedures using acrylic, polystyrene or high quality polyethylene can typically be followed with NORYL and VALOX resins.

Due to high molding temperatures, it is essential to purge thoroughly before and after using LEXAN resins in machines used for other thermoplastics. Failure to purge the machine thoroughly can result in delamination, black specs, weak spots and even degradation of the material. Both appearance and performance of resultant parts can be adversely affected.

Among the appropriate purging materials for LEXAN resin are scrap acrylic and crystal clear polystyrene. High density polyethylene can also be used. Avoid low density polyethylene as it may break down or degrade the LEXAN polymer. Better results are typically achieved by using a regrind of LEXAN resin after the initial purge.

When other materials are to be used after LEXAN resins, thorough purging must be accomplished before the barrel has cooled. It is recommended that the purging process be reversed when switching from LEXAN resin to other polymers, particularly ABS or nylon.

Caution: Extra care must be taken with acetals, since they degrade rapidly at even at the lowest temperatures used for molding LEXAN resin, producing excessive quantities of formaldehyde. Flame resistant polymers containing nitrogen must be purged completely; otherwise, contamination can cause a chemical reaction and degrade LEXAN resin.

Mold Temperature

Proper mold temperature is important for several reasons. It can influence surface finish, part release, resin shrinkage, dimensions and skin thickness. The mold temperature is determined by measuring several locations of the mold cavity and core with a hand held pyrometer or similar device. Variations in temperature throughout the mold are not uncommon. In some instances it is desirable to have different temperatures in certain regions of the mold. Temperatures should be measured before molding begins and again after the process has reached a steady state.

Product	Minimum	Maximum
LEXAN resin	160°F (71°C)	200°F (93°C)
NORYL resin (unfilled)	80°F (27°C)	130°F (54°C)
VALOX resin	160°F (71°C)	200°F (93°C)

Table 6-7. Suggested Mold Temperatures.

The mold is initially heated with water or oil that is pumped through internal channels in the mold. After the mold reaches the desired temperature, injecting the foam resin can begin. From this point on, the mold temperature is maintained primarily by cooling since the melt temperature of the resin will heat the mold.

Warp Control

Mold temperature can be used to help control warp. The skin thickness on a structural foam part can be slightly modified by increasing or decreasing the mold temperature. The outer skin begins forming as soon as the molten resin makes contact with the mold surface. Cooler molds allow the skin to form and freeze quicker than a warmer or hot mold surface. Relatively cool molds produce thin skins and hotter molds produce thicker skins. Typically, heating the concave side of the molded part can help to reduce or eliminate the warping. A 40°F (4°C) temperature differential is usually sufficient. Higher differentials can cause galling or mold mismatch.

Shrinkage/Release

Too low of a mold temperature with LEXAN resin, can cause the part to shrink too fast and bind on features in the mold. Deep ribs and bosses can become potential areas for hang ups. In some cases, cored holes can become elongated because of this condition.

Pressure Settings

Pressure settings for both standard injection and structural foam molding machines are described as Injection Pressure, Back Pressure and Hold Pressure. With structural foam molding, fill speed of the resin into the mold cavity will be determined by the resin's resistance to flow and the pressure applied. Factors that influence this resistance are the type of resin, melt temperature, mold temperature, gate size and location, and part design.

Injection Pressure is the oil pressure in the injection cylinder. The flow rate of this oil will determine the injection speed. In most cases pressure settings should be adjusted in order to maintain a constant injection speed. Initial injection pressure should be set to about 3/4 of the available pressure. On injection presses that have 20,000 psi (138 MPa) available, 12,000 to 15,000 psi (83 to 103 MPa) settings will usually be sufficient.

Back Pressure will be determined by what type and how much blowing agent is being used. The back pressure should be set high enough to avoid the screw or plunger from drifting. Screw drift is when the screw or plunger continues to travel backwards after the selected shot size has been plasticized. Insufficient back pressure will allow the resin/CBA mix to foam. Increasing the back pressure will eliminate premature foaming causing the drift. Better shot to shot consistency will typically result as well as better mixing of the resin and CBA. In most cases, back pressure settings will be between 100 and 300 psi (.7 and 2.1 MPa).

Hold Pressure is usually not used in structural foam molding. Hold pressure is not required because the part will be packed by the expansion of the foam. Hold pressure time may be used as a means of adding delay time to plastic extrusion. If so a very low pressure setting is all that is required.

Injection Speeds are faster with structural foam molding than with conventional injection molding. The foaming occurs only after the resin is injected into the mold cavity. The speed in which the mold is filled can have an effect on several part characteristics:

- **Part Weight** – Slow fill speed may allow the flow front to cure and be more resistant to flow. When this happens, the last material injected will tend to compress and become more dense. Injecting faster will help to control the density variation within the part.
- **Flow Length** – Faster injection speeds will increase flow lengths. The foaming resin will flow best when it is the hottest. Fast injection times can shear heat to the resin. Take caution so as not to overheat the material.
- **Part Performance** – Injection speed can be used to help assure certain areas of the mold are filled with resin. Too fast of a speed may cause air entrapment or create a back filling condition creating voids.

- **Surface Appearance** – Slow injection speeds may create a rough surface at the end of flow. Elephant skin as it is referred to is a series of fold marks from semi-cured resin. Fast injection speed can cause small depressions near the gate. These heat sink marks are caused by an extreme increase in temperature via friction/shear.

Cooling Time

The cooling time is defined as the elapsed time between the end of injection and the opening of the mold. Mold cooling for structural foam is of utmost importance. Tool temperature has a significant effect on the overall surface finish and can be used to adjust the thickness of the skin. Difficult to cool areas such as deep cores or thin blades should receive special attention. Cooling or cure time is the amount of time required for the molten resin to solidify. Several factors contribute to the required cooling time:

- **Wall Thickness** – The thickest area in the part can determine the cure time. This area can be the base of a rib or boss, a radius at a corner, a thick wall section or the base of the sprue. If the cooling time is too short, the part will swell in the thick area. Post blow is the result of a hot molten center surrounded by a semi-cured skin. The skin will not be able to contain the pressure of the hot center. The part will continue to swell until the skin is cured.
- **Chemical Blowing Agent (CBA)** – Some blowing agents can help to reduce cooling times. *Endothermic* CBAs absorb heat while *Exothermic* create heat.
- **Part Geometry** – Some applications require longer cooling times in order to control part dimensions. Long cool times will take advantage of the mold's ability to act as a cooling fixture for warpage control.
- **Tool Design** – The material used to construct the mold as well as the size, number and location of the water channels can effect the overall cure time.
- **Auxiliary Equipment** – The size and condition of the mold temperature controllers or oil heaters will effect the heating and/or cooling efficiency. Inadequate water/oil flow will increase cooling times.

Shot Size

Establishing the optimum shot size depends on several factors including; desired part weight, acceptable surface finish and the elimination of sink marks. A suggested method to optimize the shot size follows: First, fill the mold partially full, about 60%. Increase the shot size incrementally until the part just fills. Examine the part for surface quality. If the part appears to be rough at the extreme of flow, increase the weight until a desirable surface is achieved. Check for sink marks. If sink is visible, REDUCE the shot size or increase the blowing agent concentration. Do NOT increase shot size.

Balancing the Flow

A balanced filling pattern will help produce parts with a more uniform cell structure, optimal physical properties and increased dimensional stability. Establishing the approximate fill pattern involves producing several short shots incrementally, until the part is full. Ideally, the last to fill area will be furthest from the resin gate. In some instances, the last to fill section might be the top of a thin rib or in a louvered area.

Inspect each short shot noticing how the flow front advances. Take special note when it appears that the part is nearly full but it requires a great deal more shot size to complete the filling. This situation can cause “over-packing” in locations close to the gate. The foam structure is generally easier to compress than it is to push resin into a hard to fill area.

Several methods of balancing resin flow can be used to optimize the filling process:

- **Controlled Venting** – The foaming process relies on a pressure drop to allow for expansion. During the filling, the foaming melt will travel towards vents. Strategically placing the larger or deeper vents in the harder to fill areas can help to “steer” the resin in that direction. The same procedure can be used to restrict flow to easy to fill sections by reducing the size of the vent.
- **Flow Runners** – Increasing the wall section in certain areas can help in delivering more material to hard to reach places. This procedure can be used strategically to get material to flow into thin areas or to reduce flow lengths around openings. The part must be able to accommodate the increase in wall section so as to not interfere with other components. Keep in mind that increasing the wall will also increase cooling time.
- **Flow Restrictors** – Decreasing the wall section in certain areas can help to stall the resin from filling easy to fill places. The theory is to create a path of least resistance to the problem areas by creating a diversion.
- **Tool Temperature** – Increasing the mold temperature in the last to fill areas will help to keep the resin from cooling thus enhancing the flow characteristics. Only a slight increase in flow can be obtained.
- **Injection Speed** – Too fast of an injection speed can cause air entrapment. The flow front will contact the tool vents before all of the internal air escapes. This will appear as a short/no fill. Slowing the injection speed should allow proper venting.
- **Gate Location** – Improper gate location can create a flow imbalance. Changing or adding additional gates can reduce flow lengths and help to balance the fill.

Troubleshooting Procedures

Troubleshooting procedures for GE foamable resins are much the same as for other thermoplastics. Table 6-8 is presented as a quick reference guide. Only one solution to a given problem should be tried at any one time; never attempt to combine possible remedies.

Table 6-8. Troubleshooting Procedures.

	STOCK TEMP	MOLD TEMP	GATE SIZE	MOISTURE	CLAMP PRESSURE	INJECTION PRESSURE	BACK PRESSURE	SCREW SPEED	CONTAMINATION	COOLING TIME	FILL RATE/SPEED	SHOT SIZE	VENTING	BLOWING AGENT	REGRIND
HEAVY PART	▲	▲	▲									▼		▲	
POST BLOW	▼	▼								▲				▼	
ELEPHANT SKIN	▲	▲				▲					▲	▲			
SHORT SHOT	▲	▲	▲			▲					▲			▲	
FLASH	▼	▼			▲	▼					▼	▼			
WARPAGE	▼	▼				▼				▲	▲				
SINKS	▲	▼	▲			▲					▲	▼	▲	▲	
VOIDS	▼	▲	▲			▲	▲			▼	▼		▲	▼	
SLOWING SPEED	▲										▲		▲		
POOR SURFACE	▲	▲	▲								▲	▲	▲		
BRITTLENESS	▼			▼		▼	▼	▼					▲	▼	▼
BROWN STREAKS	▼		▲	▼			▼	▼	▼		▼				
CHARRED AREAS						▼			▼		▼				
PART STICKING	▼	▼				▼				▼	▼			▲	
POOR WELD LINES	▲	▲	▲	▼		▲			▼		▲		▲		
DELAMINATION	▼	▲	▲								▼				

Mold Design

Molds for Engineering Structural Foam are constructed using similar techniques and guidelines as with conventional injection molding. Faster fill times and longer cycle times typically require the use of larger gate and runner systems as well as strategic use of venting and cooling methods. Structural foam molds are usually designed to withstand relatively low internal pressures, between 250 to 1000 psi (1.72 to 6.89 MPa) are normal ranges. These low mold pressures allow for several options when choosing a construction material.

Materials of Construction

The construction material used for manufacturing a structural foam mold will largely depend on the part size, complexity and the total number of parts expected to be produced. For instance, if only a few parts are required for a prototype, a hand poured urethane, epoxy or RTV (room temperature vulcanization) silicone mold is feasible. Overall part complexity may be limited to straight pull design or limited undercuts if the mold can be stretched to allow for part release. Hand loaded inserts are also options.

When better accuracy and longevity are required for higher production needs, materials such as cast aluminum, Kirksite and machined aluminum are options. These materials offer better durability and can produce parts with tight tolerances higher functionality.

As parts become more complex and the number of expected parts increase, machined steel molds should be considered. Pre-hard steels, such as P-20, have good wearability, excellent machinability, are easy to weld and/or insert.

Cooling Lines

Temperature control is a very important consideration when processing structural foam. Proper cooling will help to optimize surface quality, skin thickness and overall cycle time. General guidelines are to place 0.563 in (14.3 mm) diameter cooling lines up to 3 inches (76.2 mm) apart throughout the cavity and core area. On hard to reach areas, the use of bubblers, baffles or thermal pins can be used to aid in temperature control. The cooling line layout should allow for isolating high heat areas for separate temperature control.

Vents

The importance of proper venting cannot be emphasized enough. Besides providing the function of allowing internal air and blowing agent gases to exit the mold, a well designed vent system will help to control the mold filling pattern. Generally, vents should be placed in the obvious air entrapment locations, i.e., the extremes of flow, knit line locations and hard to fill areas. Alternative venting methods are shown in Figures 6-5 through 6-7.

The following guidelines are suggested when venting the mold:

- Machine relief slots on 3 in (76.2 mm) centers around the parting line, 0.500 to 0.750 in (12.7 to 19.0 mm) wide by 0.032 in (0.8 mm) deep.
- Machine vents 0.002 to 0.006 in (0.05 to 0.15 mm) deep at the extremes of flow and other known air entrapment locations connecting the cavity to the relief slot.
- Progressively open vent depth to optimize part fill.
- Machine additional vents as required and connect to relief slots.

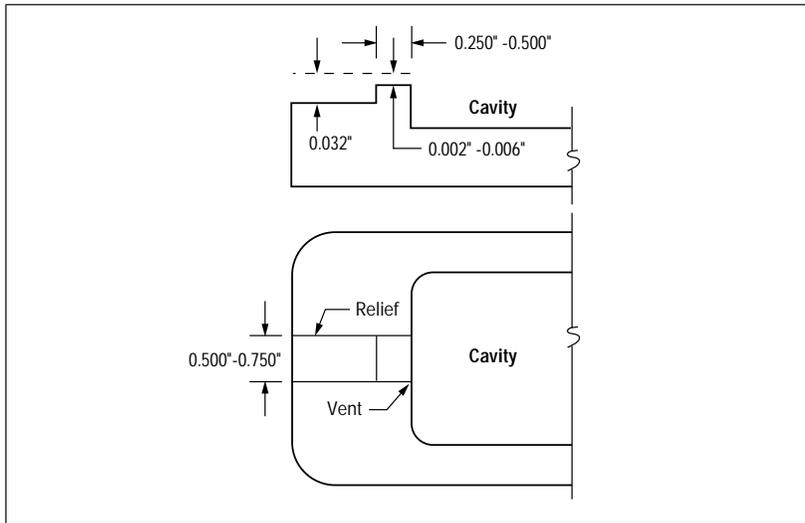


Figure 6-5. Vent Details.

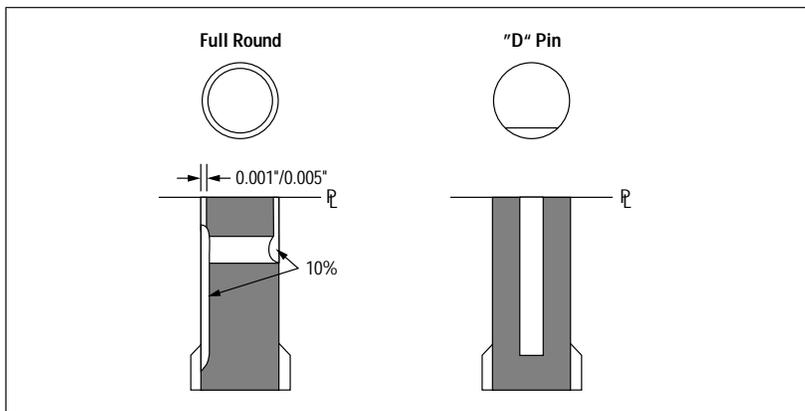


Figure 6-6. Ejector Pins and Sleeves Venting Methods.

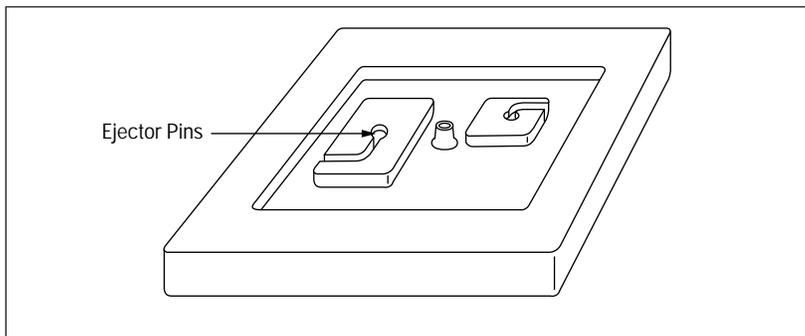


Figure 6-7. Openings Venting Methods.

Injection speed can affect venting results. Adjustments in injection speeds should be made at the same time vents are being modified.

The clearance between the tool construction material and ejector pins, moving cores and lifters can also be considered venting locations. Ejector pins can provide a convenient means for venting deep pockets, bosses, ribs and louvers.

Gates

Gates should not restrict flow effecting injection speed. Gates size and shape can impact surface quality and density reduction. Gates also function as a means of balancing flow to various parts of the mold. Engineering structural foam resins can be molded using common gate designs. The most frequently used is the direct sprue and edge gates. The overall size of the gates are generally larger than with injection molding. Tunnel and pinpoint gates have been used but only in small parts with short flow lengths. Beware of too large a sprue for it may cause a longer cure time. Too short a cure may cause the sprue to break away from the part during ejection. Sprue bushings having a 0.05 to 0.75 in (12.7 to 19.05 mm) taper per foot are typical. "O" dimensions of 0.200 in (5.08 mm) or more are generally required to provide adequate flow.

Gates should be designed for uniform flow length and should favor flow into thin areas. If possible, gate into a thin area and flow toward thicker sections. This should allow the resin to foam somewhat while in the thin section and to continue to expand once into the thicker areas. The reverse approach would cause the foam in the thick sections to compress while trying to force material into a thin section resulting in reduced density reduction.

Table 6-9. Gate Sizes per Pound of Part.

	Min. In ² (cm) ²	Max. In ² (cm) ²
LEXAN resin	0.05(0.32)	0.20(1.3)
NORYL resin	0.04(0.26)	0.15(0.97)
VALOX resin	0.05(0.32)	0.20(1.3)

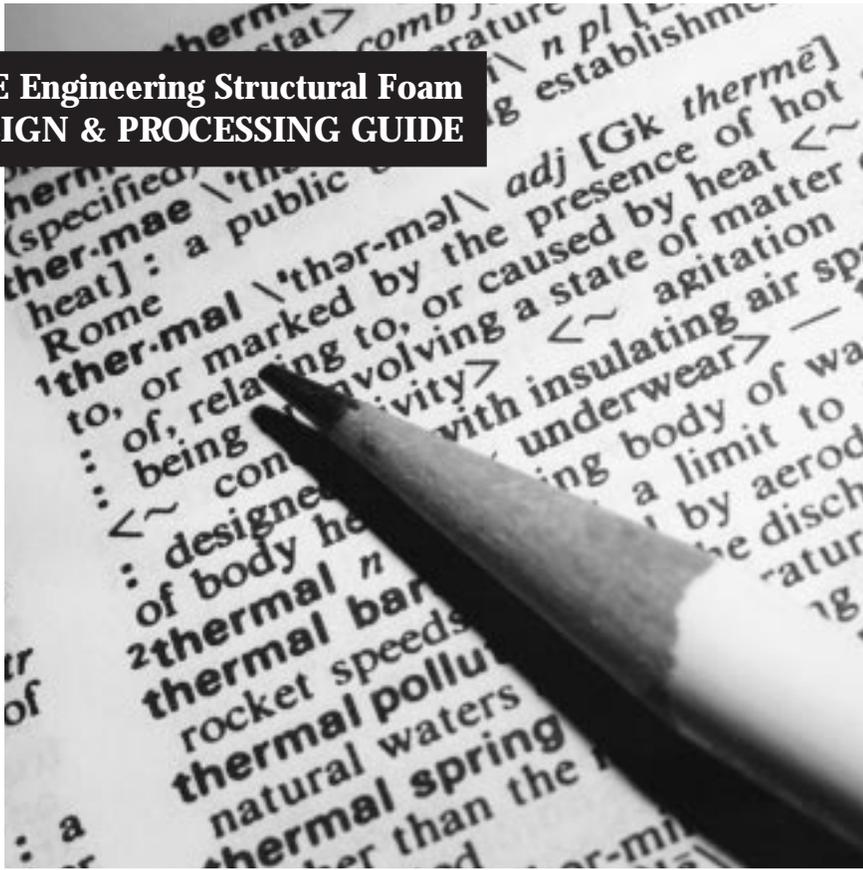
Gates should be located so as to not trap air and to move weld lines away from critical impact and appearance areas. Also, gates should be located in areas which will allow for easy degating and finishing.

Runners

Full round and trapezoidal runners are most common with structural foam molds. Generally speaking, as long as the runner can supply the volume of resin to the mold cavity without reducing the injection time, any type runner will work. Full round runners usually begin in size at 0.375 in (9.53 mm) diameter and depending on part weight and flow length can go up to 0.750 in (19.1 mm) diameter. Beware of oversized runners. A large diameter runner can increase cure time requirements.



**GE Engineering Structural Foam
DESIGN & PROCESSING GUIDE**



Engineering Structural Foam
Glossary

Glossary of Terms

Air Shot: To shoot or inject resin into a puddle. Done to inspect the molten material for consistency, to measure melt temperature or as a means of purging.

Back Pressure: The applied hydraulic pressure used to restrict the shot size formation. Applied to the back of a melt accumulator or reciprocating screw. Used to control screw drift, mixing and shot size adjustments.

Carrier: The pellet of resin, wax or other mechanism used to compound the active ingredient in manufacturing the chemical blowing agent.

Cavity Pressure: The pressure generated in the mold cavity during the resin injection phase of the process.

CBA: Chemical Blowing Agent: A powder, liquid or pellet form blended with resin at a ratio to produce adequate foaming. The blowing agent decomposes during plastification resulting in a release of an inert gas. The gas is mixed with molten resin in the barrel and is held under pressure until injection.

Clamp Tonnage: The pressure required to keep the mold closed during resin injection. Usually between 3 to 5 tons per square inch of projected area.

Cold Slug: A hard piece of semi-cured resin usually a result from a nozzle drool. A surface imperfection close to the resin gate often resembling a nail.

Contamination: To make impure via non-compatible substances. Examples are non-compatible blowing agents or other resins, degraded regrind, dirt, metal inserts and painted regrind.

Controlled Venting: Strategically using mold vents to control mold filling. Vents cause pressure drops. Foam expands toward pressure drops.

Cure Time: The amount of time required for the molten resin to cure and solidify prior to mold open and part ejection.

Decomposition Temperature: The temperature in which a chemical blowing agent releases gas. Most CBAs rely on time and temperature to fully decompose.

Degradation: A decline to a lower condition, quality or level. Typically caused by over heating via high temperature settings, shear, non-drying or chemical attack during processing.

Delamination: The separation or peeling away of a thin layer of skin from the part surface. Caused by contamination or high heats.

Density Reduction: Also referred to as weight reduction. The amount of weight savings when a foamed part is compared to a solid injection molded part having the same design and wall thickness.

Dew Point: The temperature in which moisture is formed. A means of measuring the dryness of process air used to dry resin.

Drooling: Foaming resin leaking from the machine nozzle. Pre-foamed resin injected into the mold can result in a surface imperfection.

Elephant Skin: A rough surface condition caused by cold resin folding over itself. Usually at the ends of flow.

Endothermic: A term that describes CBAs having heat absorbing characteristics. These blowing agents tend to release lower amounts of gas pressure, shorten cooling times, require less outgas time and have smoother surface finishes.

Exothermic: A term that describes CBAs having heat producing characteristics. These blowing agents tend to release higher amounts of gas pressure, longer cycle times and increased flow lengths.

Feed Section: The section of the screw just under and slightly forward of the feed hopper.

Flash: Resin that is forced out of the mold cavity area and onto the parting line or into the vents of the mold. A very thin film of cured resin attached to the molded part.

Flow: The ability of the molten resin to move or travel during injection. Flow can be influenced by temperature, part design, process conditions and tool design.

Flow Leader: A small area in the mold which usually thickens the wall to allow material to flow easier to select areas of the mold. A molders “trick” to get a few more inches of flow from the material. Usually not designed in the initial stage of tool construction.

Flow Restrictor: A small area in the mold which usually thins the wall to stall the flow of resin to select areas of the mold. Used to steer the material in another direction.

Gas Counterpressure: A surface enhancement process requiring a pressurized mold cavity. A method of controlling the resin flow, cell formation and exterior surface appearance.

Gate: The area of the mold where the resin enters the mold cavity.

Hold Pressure: The applied hydraulic injection pressure maintained after the completion of mold filling. Also referred to as secondary pressure.

Hopper: The device above the machine barrel used to store the resin pellets.

Hot Manifold: A heated resin distribution system that attaches to the outside of the stationary platen on a structural foam machine or is designed as part of the mold. An extension of the hot melt system.

Hygroscopic: Having the ability to absorb moisture. Resins that are hygroscopic require drying before being processed.

Injection Pressure: The applied hydraulic pressure used to push the resin into the mold cavity.

Injection Speed: The elapsed time required to fill the mold cavity.

Melt Accumulator: Also referred to as a plunger. A large capacity holding area for molten resin. The area of a structural foam molding machine that determines the shot size.

Melt Temperature: The actual temperature of the molten resin injected into the mold cavity. Melt temperature should be measured from a purge shot having the same residence time as in the production process.

Mold Temperature: The temperature of the mold before resin injection.

Outgas: The release of gas from the core of the molded part. Outgas time is dependent on skin thickness, type of resin, type of blowing agent and processing conditions.

Over Packing: Injecting too much resin into the mold. Sometimes unbalanced filling can cause only certain sections of the mold to be over packed. Dense areas having little density reduction or cell structure. Usually close to the gate.

Glossary

Physical Process: A structural foam process that uses nitrogen gas as the blowing agent.

Platen: The large metal plates the mold attaches to on a plastic molding machine.

Post Blow: The opposite of sink. The swelling or blistering on the part surface. Found over thick areas. Caused by premature mold opening. The blowing agent pressure in the hot molten center of the thick area pushes the non-cured skin outward. A void can be seen beneath the swelled area.

Projected Surface Area: The area the molded part projected onto a plane at right angle to the direction of the mold. The area of the shadow the part can cast. Used to calculate clamp tonnage

Purge: To clean the screw and barrel. To remove unwanted resin from the barrel by introducing a new resin to push out the old.

Regrind: Resin that has been previously molded and ground into small pieces for reprocessing. Regrind is usually comprised of sprues, runners and unfilled parts.

Residence Time: The amount of time the resin is at process temperature prior to being injected into the mold.

Runner: A means of distributing resin from the sprue to one or more gates.

Screw: A rotating auger that uses a helical thread and a varying channel depth to convey, melt, mix, and pump resin. Consists of a feed section, transition zone, metering section and in some cases a mixing zone/zones.

Short Shot: The amount of resin injected into a mold cavity at a volume less than required to fill the mold. A short shot of 90% of the mold cavity volume will produce a part with a 10% weight reduction.

Shrinkage: The percentage of reduction in overall part dimensions. Shrinkage occurs during the cooling phase of the process.

Shut-Off Nozzle: A device attached to the front of the molding machine barrel or hot manifold system. It opens to allow resin flow into the mold cavity. It closes after injection to help prevent drooling.

Sink: A depression on the part surface over a thick wall feature i.e., a rib, boss, thick sprue gate or change in wall section. Caused by the delayed cooling effects of the center of the thick area. When the hot center cools, it shrinks and pulls down the skin on the surface.

Sprue: The transition point between the molding machine nozzle and the mold. A tapered cylindrical shaped runner that feeds material from the machine to the mold cavity, runner system or hot manifold.

Vent Relief: The deep channel that connects the mold vent to the atmosphere.

Voids: A large hollow section between the inner and outer skin. Caused by trapped gas or air.

Warp: To twist or deform from a desired shape. Often caused by molded in stress or shrinkage.

Weld Line: The point at which two flow fronts merge resulting in a visible line on the part surface.



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