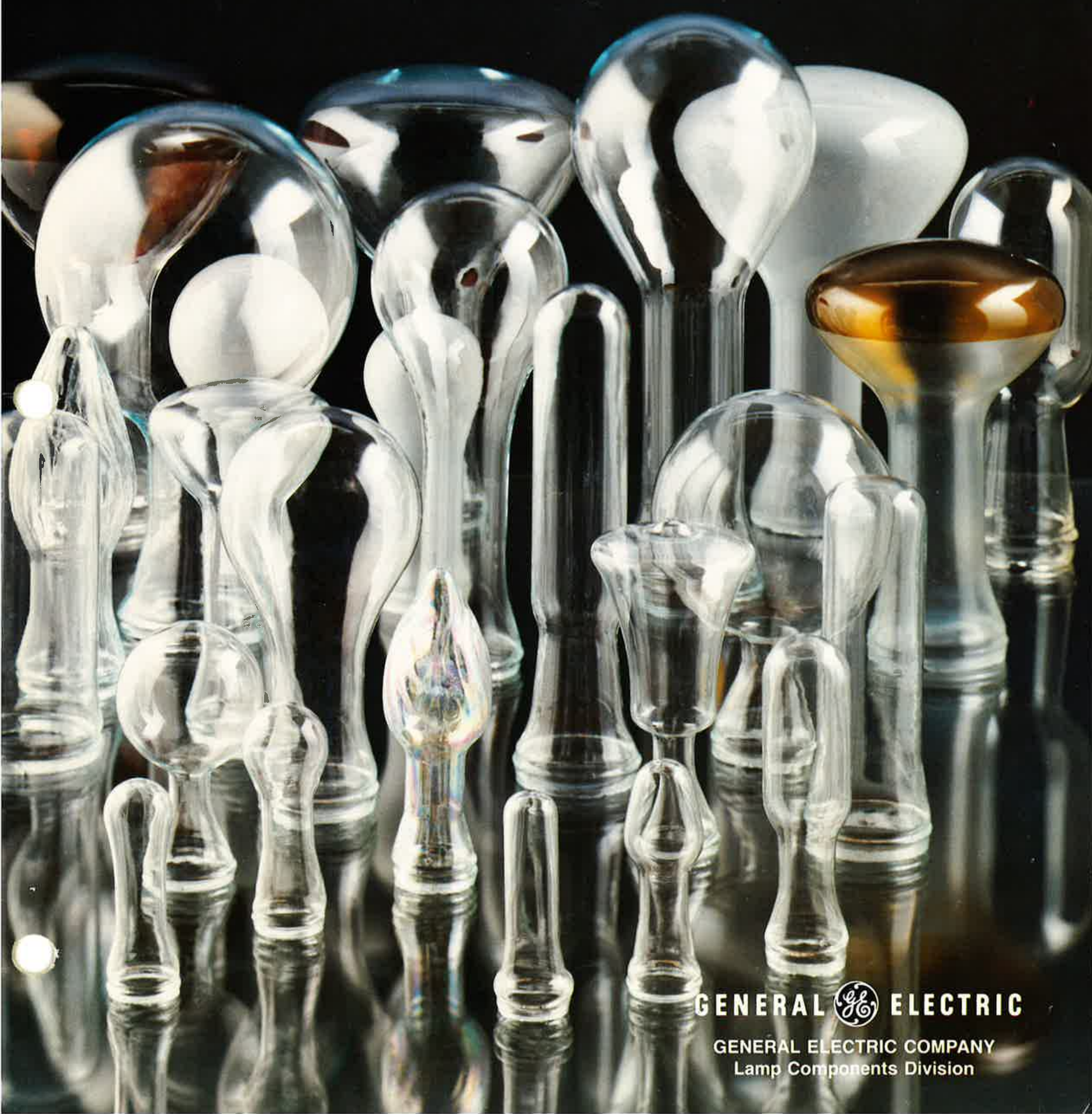
Glass Products



GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY
Lamp Components Division

General Electric's capability in glass manufacture is well illustrated by its role in the automotive industry. Major uses are reflectors, lenses, and covers for headlamps and support lighting; bulb blanks and glass tubing for various types of signal and warning lights.

Broad Capability In Glass Products

Few materials have stood the test of time as well as glass. Even in our space age, it continues to find new and challenging uses.

Glass is an ideal engineering material. It has well-defined properties. It can be used in conjunction with other materials to provide certain characteristics. In its viscous state, it can be worked and formed into virtually any shape. It is highly adaptable to mass production. It has optic and light transmission properties that make it invaluable in a number of highly specialized applications. Furthermore, glass is low in cost.

No one recognizes the tremendous potential of glass more than General Electric Company. Through our research, we are expanding our knowledge about the material . . . developing new applications . . . and continually improving the older glasses for current uses.

GE is also taking the necessary steps to meet market requirements for higher quality glass with a wider range of product options. We have recently expanded capacity in those markets where demand is the greatest and modernized facilities to maintain our product quality. Our continuing goal is the manufacture of glass that is dimensionally accurate, has uniform properties, and is capable of meeting the highest standards of performance.

At GE we have complete facilities for off-the-shelf delivery of production items, and fast response on customized orders. You will find application engineers with broad experience in glass processing and technology ready to assist you in designing new products, developing efficient fabricating processes, and specifying or developing special glasses for critical applications. Competent technical assistance is available to support your glass utilization needs.

Types Of Glasses

Glasses are classified into several families according to their characteristics. Each offers specific advantages, limitations, and economies, depending upon the application.

The more common glasses are:

SODA LIME GLASSES

These are the most common types of glass and are composed primarily of silica, soda and calcia, with relatively small additions of other constituents. These "soft" glasses have moderate chemical durability and relatively poor resistance to thermal shock, but they are low in cost and easily worked.

LEAD GLASSES

By replacing the lime of the soda lime glass with lead oxide, another family of "soft" glasses is created. As the lead oxide content is increased, electrical resistivity, density, refractive index, and x-ray absorption also increase. The fluxing action of the lead oxide also tends to lower the softening point of the glass below that of the soda lime glasses. Lead glasses are moderately priced, easily worked, have good resistance to weathering, and low resistance to thermal shock.

BOROSILICATE GLASSES

The major constituents of this family of glass materials are largely silica and boric oxide with smaller amounts of other additives. Compared to most other glasses, borosilicates have a much lower alkali content. This allows these "hard" glasses to retain many of the excellent properties inherent in silica—low thermal expansion, high resistance to thermal shock, and good chemical durability.

ALUMINOSILICATE GLASSES

Substantial additions of alumina and other constituents to silica create this group of glasses. These glasses possess low thermal expansion with good electrical and chemical properties at elevated temperatures. High softening points allow use at high temperatures, but high working temperatures are also required. These "hard" glasses are more costly than the borosilicates, but provide significant advantages in certain applications.

SPECIAL GLASSES

The composition of glass can be altered to meet the requirements for unusual or specialized applications.

For example, "Moon Glass", a critically controlled combination of silicon dioxide and sodium, iron and magnesium oxides, was developed by General Electric for use on three soft-landing moon missions. Antimony-molybdenum-borate glasses were developed for the manufacture of improved wire-sealing beads; barium glasses have been produced for extremely critical electronic video requirements, and calcium-alumino silicate glasses have been especially designed for highly loaded flashtubes and halogen regenerative cycle lamps.

Two low alkali level glasses recently developed by GE are used in high temperature service lamps. Types 177 and 180 glass tubing effectively seal with tungsten and molybdenum, respectively. Their compositions provide the right combination of strength, optical quality, and workability characteristics for these high temperature lamp applications.

Available Forms

In addition to different chemical compositions, General Electric glass products are available in three basic forms:

Blown bulb blanks, made chiefly for the manufacture of lamps, are also used for plastic molds and decorative ornaments.

Glass tubing also finds its major application in lighting, being used for fluorescent lamp envelopes, as a starting material for the manufacture of small lamps and for exhaust tubing used to evacuate lamp assemblies just prior to sealing. But glass tubing is also widely used outside the lamp industry, including two very fast growing markets, electronic devices and solar collectors.

Pressed glass is the third of the basic forms offered by GE. Pressed glass shapes also find a major application in lighting. The common automobile headlamp is made from two pressed pieces, a reflector and a lens. As the name implies, pressed glass shapes are formed by pressing in specially designed tooling. The process can create very intricate design, detail, and when borosilicate glasses are used, parts that function well in high temperatures. Lenses, reflectors and lamp covers are the major products produced by this process.

Glass Tubing

Tubing is probably the most versatile in terms of usage of the glass shapes which GE produces. It finds its way into literally hundreds of different applications.

General Electric produces tubing by both of the recognized processes of manufacture, the Danner process and the Modified Down Draw process (MDD).

In the Danner process glass tubing is made by "flowing" a continuous stream of molten glass of a precise viscosity onto the surface of a downwardly sloping, rotating, hollow mandrel ("sleeve") where it levels or "marvers" to form a thick cylinder of molten glass. Air is blown through the center of the sleeve to maintain the size of the tubing. The combination of glass quantity, glass temperature, speed of drawing and air pressure determine the size of the tubing. Glass rod is produced in a similar manner by eliminating the use of blowing air.

The MDD process of making tubing involves "flowing" the molten glass through an annular orifice in the bottom of a bowl and blowing air through the interior of the resulting tubing. Glass temperature, drawing speed and the air pressure are all tightly controlled to produce a continuous length of tubing to precise diameters and wall thicknesses.

Tubing diameters are available from GE in a wide range of standard sizes from .085" to 3.50". Wall thicknesses are held to a tolerance of ± .002" to ± .010" depending on size and glass type and forming method used.

In the electronics industry, GE glass tubing is used as a packaging and encapsulating material. The dark granules are glass powders used for many applications: enamels, beads, and encapsulation, while the large diameter tubing and cut rings are for television applications. The smaller rings and tubing are used chiefly in electronic tubes.

Various types of fluorescent lamp tubing

Heavy walled glass tubing is supplied to the electronics industry for redrawing into diameters as small of .010". These small sizes are used for packaging capacitors, diodes, and other devices.

General Electric produces fluorescent tubes by the millions, but not all of them end up in lighting products. Similar tubing is part of a highly efficient solar energy collector which consists of an outer tube and an inner tube sealed together at both ends enclosing an evacuated space.

Pressed Glass

Distinctive surface details and an almost unlimited latitude in shapes are the hallmarks of pressed glass parts.

General Electric utilizes machine-pressing to produce parts for a number of high temperature and high strength applications.

Machine-pressed shapes, weighing from one ounce to sixteen pounds, include such commonly produced parts as terminal insulators and interior light covers for electric ovens, and refractors for lighting systems. Automotive headlamp and tail light components, such as those illustrated on page 2 of this publication, represent another major market for GE's pressed glass capability.

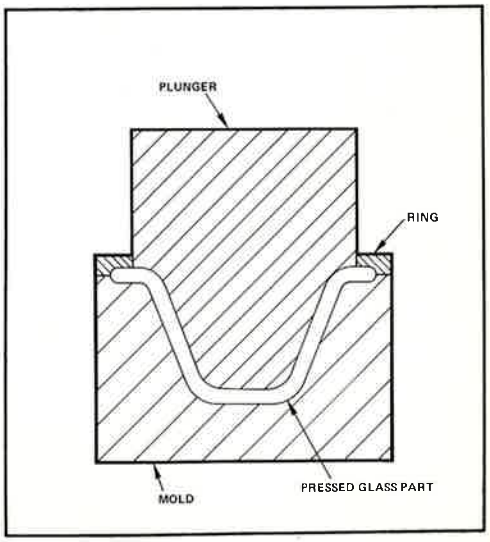
This efficient mass-production method eliminates expensive grinding and polishing in many instances, and is very economical because molds can be reused thousands of times.

Pressing provides a wide range of glass shapes. While there is the capability to produce an unlimited number of glass compositions for pressing, the need for heat resistance has made borosilicate glass the most widely used for industrial applications.

In machine pressing, molten glass leaves the orifice of the furnace in a highly viscous consistency, similar to that of honey. The "gob" of glass from which a specific part is to be pressed must be of an exact weight, volume and shape. This gob is then placed in the mold which has been individually designed for a particular shape. The tooling consists of the mold, the plunger and the ring (see diagram at right).

The plunger is forced into the mold causing the glass to flow into the space enclosed within the cavity. When this cavity is filled, the movement of the plunger ceases, remaining immobile until the glass "sets up." The time required for "setting up" is a few milli-seconds for thin items and longer as the thickness of the part increases. Then the plunger is withdrawn and the glass is cooled until it can be removed and conveyed to a lehr for annealing.

TOOLING FOR PRESSED WARE



Blown Shapes

Lamp envelopes, blanks for Christmas ornaments, and other enclosed shapes are made by the modern version of glass blowing called the ribbon process.

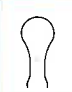
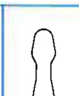
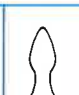
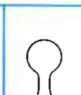
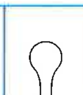
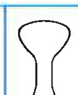
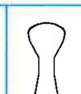
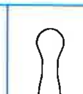
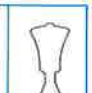
In the ribbon process, a stream of molten glass from the furnace is fed between rolls to form a ribbon. One roll has indentations which form evenly spaced "biscuits" on one side of the ribbon. The formed ribbon is picked up and carried away by a series of steel plates, each having an orifice hole located exactly below a "biscuit". As the molten glass moves along, the glass sags through the orifice. A blow tip is centered over the biscuit and pressed down. Air is blown through the blow tip into the glass globule causing it to elongate. Then the molds, made in two halves and hinged together, come in line and close to contain the glass globule. The globule is blown into the mold. All this occurs as three separate conveyors join for a few critical seconds. One carries the ribbon and plates, another the air nozzles, and the third the molds for the glass. After cooling, the completed envelope is knocked off the ribbon and is ready for use or subsequent operations (frosting, staining, enameling). The operation is so fast that several hundred envelopes are created every minute.

A lineup of General Electric bulb blanks

Thin-wall GE bulb blanks function as molds for making plastic globes used in decorative flower arrangements. The glass "thinness" provides easy breakability and easy removal of the glass mold. Plastic molders have discovered that soda lime incandescent lamp envelopes can withstand the temperatures generated in curing most plastic resins, that they impart an extremely smooth surface to the plastic, and are very low in cost.

Brightly colored Christmas decorations start with GE bulb blanks.

TABLE I

Bulb Shape											
Designation	A	B	C	F	G	PS	R	RP	S	GEX	RBX
Available Nominal Diameters (Eighths of an Inch)	15 19 21 23	6 9½ 10 11 12 13	7 7½ 9½	10 15	16½ 19 25 30 40	25 30 35 40	12 14 20 30 40	11	6 8 11 14	Ornaments 14 16 18 21 26	Bell Shape 16

Designing With Glass

Many designers familiar with the characteristics of metals find their experience of little value when it comes to glass. Most glasses are the reaction product of silica (silicon dioxide) with one or more of the oxides of sodium, potassium, calcium, barium, lead, aluminum and boron. The material is made by mixing these inorganic materials and melting them at temperatures from 1300 to 1600°C.

Glasses that soften at relatively low temperatures (up to approximately 700°C) are called "soft", while glasses that soften at higher temperatures are called "hard". "Soft" and "hard" are generic terms which apply exclusively to the workability of the glass rather than to mechanical hardness.

Glass does not exhibit a definite melting point. It softens gradually over a range of temperatures. During cooling, the viscosity increases over a broad temperature range allowing the glass to be formed or worked.

Glass is an amorphous material. Unlike metal it does not have a crystalline structure. Because there are no grain boundaries and no slip planes, there are no stress-accommodating mechanisms as there are in metals. Although glass does elastically deform under stress, it does not exhibit plastic flow in reasonable time periods. Thus, the net effect is to transfer, undiminished, all stresses imposed on the part to its surface.

Imperfections on these surfaces act as stress risers and crack initiation sites and, in the presence of high tensile stresses, lead to fracture of the part. Glass has high compressive strength, but little resistance to tensile stresses. It will fracture before there is any permanent deformation.

External loads are not the only source of stresses in glass. Anytime glass cools from the viscous state, residual stresses are trapped within the part. The magnitude of these stresses depends on the rate of cooling, the expansion characteristics of the glass, and the thickness of the section. Severe residual stresses can be set up by rapidly cooling thick section parts made of high-expansion glass. If the glass is homogeneous, these residual stresses can be reduced to low levels by raising its temperature to the annealing point, maintaining this temperature until residual strains are relieved, and slowly cooling to prevent the re-development of undesirable levels of residual stresses.

Stresses can only be reduced to some lower level—not eliminated—if the glass is nonhomogeneous or contains any of the defects referred to later in this section.

In normal production, glass is usually not annealed, but "conditioned" to develop a preferred pattern and intensity of compressive surface stress to help withstand the effects of further processing or service loads. A condition of mild compressive stress on the surface tends to counteract the effects of thermally or externally induced tensile stresses.

SURFACE STRESSES

The level of surface compressive stress developed in a part must be carefully controlled. Since the summation of all stresses within a glass part must algebraically balance, a high level of compressive stress of one surface can result in a high level of tensile stress in some other region of the part. The interaction of this tensile stress and either defects or stress-prone areas resulting from the shape or thickness of the part can lead to failure if the stress is sufficiently high.

Glass is usually supplied from a manufacturer in a pre-formed shape, such as tubing, rod or ribbon, or a blown or press-formed part that may be subsequently reheated and reformed to final shape. Since thermal stresses are set up each time glass is heated and cooled, proper conditioning should precede and follow each heating operation to provide added strength to the part.

When stresses are high—either from temporary thermal conditions, from service loads or residual stresses left after manufacture—the surface condition of a glass part becomes very important.

Surface defects include easily identified cracks and fractures and the more insidious small checks and scratches that commonly result from mild abrasion. Internal defects such as inclusions, bubbles, and material inconsistencies are important because they present a boundary between differing materials within the glass. This boundary is technically a "surface" and a potential failure site.

The best defense against defects is to understand what they are, how they develop, and how they can be prevented.

TYPES OF DEFECTS

A word of caution: these types of glass imperfections and "defects" are not necessarily causes of failure. Severity levels are more critical than the presence of an imperfection.

Scuffs and **scratches** are relatively mild surface abrasions characterized by a scraping out of surface material. These defects can be avoided by keeping glass away from abrasive materials during reworking. They can be minimized through the use of suitable external lubricants.

Checks and **fractures** are all similar in that they are separations in the glass that form a sharp re-entrant angle. These surface defects are always potentially dangerous.

Fractures are relatively easy to see. They extend completely through the part from one surface to another and usually render the part unserviceable.

Checks—small, shallow cracks in the glass surface penetrating only partially through the article—are probably the most insidious type of defect because they are hard to detect, and yet present a functional "stress riser" condition. Checks can be seen by rotating the part under a non-diffusing incandescent light and looking for a reflecting tell-tale sparkle. However, even under light, checks will not sparkle if the opening of the check is less than one-quarter of the wavelength of the light used.

Cord is an optical defect caused by inhomogeneity of the glass. The refractive index of the cord is different from that of the main body of glass, making it visible.

Cord can usually be identified by immersing the part in a liquid with the same refractive

Designing With Glass (cont'd.)

index as the glass and viewing the sample in polarized light. In this test, the compositional cords will remain visible and can be identified by their strain patterns. Tension and/or compression strain relates to the difference in coefficient of expansion between the cord and the matrix glass. This is a useful tool in identifying the cause of the cord.

Stones are nonvitreous inclusions, such as raw material particles that are too large to completely melt, or crystalline particles produced by holding temperatures below the liquidus point of the glass.

Bubbles in glass act as stress risers, prevent consistent glass-to-metal seals, and give rise to the possibility of optical distortions in certain applications. Common types of bubbles are blisters (large gas bubbles trapped during *working* of glass), seeds (smaller bubbles formed during the *melting* of glass) and reboil (the formation or trapping of tiny bubbles from dissolved gases during reworking of glass or from an oxidation-reduction of a glass constituent).

Other defects in glass are sometimes encountered, but these are usually inconsequential and in most cases only rarely affect performance. These include: *chill marks*—a wrinkled surface condition sometimes seen in pressed ware due to uneven thermal contact in the mold; *shear marks*—marks or scars left by the cooling action of a cutting shear; *laps*—surface folds due to incorrect flow during forming; *fins*—similar to flashing on castings, formed by flow of glass between mold parts.

In applications involving high levels of stress, these defects are detrimental because they provide a surface which may be the site of a stress-induced failure.

SURFACE CONTAMINATION

Surface contamination of glass during working and final forming can be a source of defects. Care must be taken to keep glass away from materials that can leave debris on the glass, such as hard rubber, asbestos or plastics. If the glass is to be reworked, this foreign material can be imbedded in the surface and act as a defect. Soft or volatile particles can lead to the formation of bubbles within the glass as it is heated.

Fingerprints are a common source of foreign material on glass surfaces. Soft cotton gloves should be worn when handling glass, particularly if the part is to be reheated.

OPTICAL QUALITY

It is often tempting to try to eliminate defects by specifying "optical quality" or defect-free glass. But this is not recommended because optical-quality glass requires special production and inspection techniques and could result in an expensive over design.

Because of the complexity of glass characteristics, designers are advised to discuss their requirements with their supplier before the design is formalized.

Glass has a softening point which permits it to be worked and shaped into almost any configuration. The operation above shows the fabrication of specialized laboratory ware.

(Photo courtesy of Kontes Company)

Properties Of Glass

Glass is not one material but many. Each type is designed to meet specific requirements in terms of product shape and physical and mechanical properties.

The properties of glass should not be compared to those of metal. For instance, shear strength means a great deal with metals, but has little or no significance in glass. Hardness of glass must be measured and reported in terms that rarely, if ever, apply to ductile materials.

In addition to the usual mechanical, electrical, and thermal properties of glass, there is considerable interest in the optical characteristics, chemical durability, viscosity-temperature relation, and the composition and density of glass.

MECHANICAL PROPERTIES

Ductility

Glass does not plastically deform before failure and therefore breaks in a brittle fashion.

In practice, it can be considered to break only from tensile stresses. Failure due to pure shear or compressive stresses is rare.

Strength

The intrinsic or theoretical strength of glasses is considerably higher than is normally measured, but stress concentrations caused by surface imperfections resulting from manufacturing or handling limit the ultimate strength to around 10,000 p.s.i.

Laboratory tests have shown glass fibers with tensile strengths of up to one million p.s.i. The practical tensile strength of glass however, is about 5000 p.s.i. Between 70 and 80% of the failures occur in commercial glass near this value. To preserve a safety factor, a prolonged working stress of 1000 p.s.i. is the maximum that should be used. Rate of loading is also important. Glass fatigues under constant load and the faster the loading rate, the higher the apparent strength.

These "values" can be used for current commercial glasses since the composition of glass has little practical effect on its strength. Most borosilicate glasses, though, tend to resist scratching and therefore usually give better mechanical service.

Young's Modulus (Modulus of Elasticity)

Young's Modulus is the ratio between stress and strain, and is determined by measuring the sonic or ultrasonic frequencies of a simple beam at room temperature. Most commercial glasses have values between 9 and 10 million p.s.i. By comparison, steel is 30 million, copper 17 and aluminum 10.

Poisson's Ratio

The longitudinal stretching of any elastic material is accompanied by a lateral contraction, and the ratio of the contraction to the proportional stretching is known as Poisson's Ratio. It is measured in a similar method to that used to measure Young's Modulus. A Poisson's Ratio of 0.20 is usually given for glass since the actual value is very seldom less than 0.18 or greater than 0.22.

Hardness and Impact Abrasion Resistance

Glass hardness cannot be measured by the methods and scales (Brinnel or Rockwell) used for metals. One of three other scales is usually used:

MOHS—scratch hardness. Glasses lie between apatite (5) and quartz (7). On this scale glasses are softer than (i.e., can be scratched by) sand, hard steel, agate, emery; and are harder than mica, aluminum and copper.

KNOOP (AND VICKERS)—penetration hardness. Typical values for commercial glasses range from 300-600 Kg/mm (Knoop Scale) when a load of 50 grams is used.

ZEISS—grinding or impact abrasion. Impact abrasion resistance is evaluated by measuring the glass' resistance to sandblasting under standard conditions. All values are relative. Unity is assigned to soda lime plate glass (standard window glass) and all other values are assigned relative to this standard.

Generally accepted values on the impact abrasion resistance of glasses are as follows:

Soda Lime Plate	1.0
Soda Lime (ribbon and tubing)	1.2
Lead	0.6—0.8
Borosilicate	3.0—4.0
Aluminosilicate	2.0

DENSITY

Density is defined as the mass per unit volume. For glass, density depends upon its composition (primarily) and its thermal treatment (density for a particular glass composition will be greatest when the glass has been stabilized at the lowest practical temperatures). It is measured by one of several buoyancy methods, usually a hydrostatic weighing procedure.

WEATHERING

While the effects of weathering can be minimized by washing the surface in dilute hydrofluoric acid, or warm water, the treatment does not afford lasting protection from future weathering. The best protection for glasses subject to weathering is to store them in dry places, keep them from contact with moisture absorbing materials (i.e. paper), and control the turnover of stored products.

TABLE II—TYPICAL GLASS PROPERTIES

1	2	3	4	5	6	7	8	9	10	11
					Mechanical Properties			Thermal Properties		
Glass Type	Description/Use	Color	Forms Usually Available	Density (g/cc)	Young's Modulus (10^6 psi)	Poisson's Ratio	Impact Abrasion Resistance	Expansion (10^7cm/cm/°C) 0-300°C	Thermal Endurance Ratio	Conductivity
Soda Lime:										
008	General	Clear	T,B,F	2.48	10	.24	1.2	93	1	See
Lead:										
001*	Lamp, Electronic	Clear	T,B,F	2.81	9	.21	—	92	1	Footnote
012*	Lamp, Electronic	Clear	T,B,F	3.04	8.6	.22	0.6 - 0.8	89	1	
821*	Radiation Shielding	Clear	T,B	4.00	—	—	0.6 - 0.8	88	—	For
Borosilicate:										
706	Kovar Sealing	Clear	T	2.24	8	.22	3 - 4	47	2.2	Data
725	General	Clear	P	2.25	9	.21	3 - 4	37	2.5	
772*	Lead Borosilicate	Clear	T,B	2.33	9	.20	3 - 4	34	—	
776	General	Clear	T,B,P	2.23	9	—	3 - 4	33	2.5	
777	Lead Borosilicate	Clear	T	2.30	9	—	3 - 4	37	—	
Aluminosilicate:										
174	Alkali Free, Tungsten and Molybdenum Sealing	Clear	T	2.64	12	.25	2.0	43	2	
177	Alkali Free Tungsten Sealing	Clear	T	2.70	—	—	—	38	—	
180	Alkali Free, Molybdenum Sealing	Clear	T	2.74	—	—	—	45	—	
Special:										
250	Encapsulation for capacitors	Clear	Ft.	2.94	—	—	—	60	—	
351	Encapsulation for diodes	Lgt. Yel.	Ft.	3.78	—	—	—	44	—	
355	Automotive Signal	Amber	T,B	2.57	—	—	—	92	—	
540*	UV Transmission	Dk. Blue	T,F	2.56	—	—	—	91	—	
980	General	Clear	T,B	2.71	10	.20	—	91	—	
982	UV Transmission	Clear	T	2.72	10	.20	—	92	—	

Column	Item	Comments
1 & 2	Glass Type, Description, Use	All forms not always available nor in all sizes.
3 & 4	Color, Forms usually available	T = Tubing & Cane, B = Blown, Ft = Frit or Powder, P = Pressed, F = Formed
5	Density	
6	Young's Modulus	Data shown in table are estimates to show relative values. They are to be used for reference only.
7	Poisson's Ratio	Data shown in table are estimates to show relative value. They are to be used for reference only.
8	Impact Abrasion Resistance	Using soda lime plate glass as a base of unity, relative values for other glasses are shown.
9	Thermal Expansion	
10	Thermal Endurance	Using soda lime as a base of unity, relative values for other glasses are shown.
11	Thermal Conductivity	Most glasses are between .002 and .003 cal per sec x cm x ° C.
12	Viscosity	

***CAUTION: FABRICATION OF LEAD-CONTAINING GLASSES**

On March 1, 1979, an OSHA standard regulation, "Occupational Exposure to Lead", went into effect. This rule, and appendices to it published in October of 1979 contain stringent requirements for compliance with very low exposure levels, specified air sampling, blood-analysis, and medical programs, respiratory protection, engineering and work practice controls, employee notification of exposures and employee education.

There is evidence that the heating of sufficient quantities of any lead glass to working temperatures (regardless of manufacturer) may result in the release of some lead fumes into the working environment in concentrations subject to one or more of the requirements briefly outlined above. You should avail yourself of the final rule and appendices available from your local OSHA office to determine if any of these requirements would be applicable to your process.

12			13			14	15	16	17	18	19	20
Viscosity			**Electrical Properties**						**Optical Properties**			
Strain Point °C	**Anneal Point °C**	**Softening Point °C**	**Electrical Resistivity (Log_{10} ohm-cm)**			**Dielectric Constant At 1 MHz and 20°C**	**Loss Tangent At 1 MHz and 20°C**	**Loss Factor At 1 MHz and 20°C**	**Refractive Index n_d**	**Dispersion**	**Useful Transmittance Nanometers**	**Resistance To Weathering**
			250°C	**300°C**	**350°C**							
475	515	700	6.2	5.6	5.0	7.2	.009	.065	1.512	.0089	290 - 4600	C
395	435	625	8.5	7.6	6.6	6.7	.0015	.010	1.534	—	300 - 4700	B
395	435	625	9.7	8.6	7.6	6.7	.0014	.009	1.559	.0083	300 - 4600	B
400	440	595	11.6	10.4	9.4	8.9	.0005	.004	1.667	—	—	B
440	485	705	10.0	9.0	8.1	—	—	—	1.480	—	300 - 2800	B
505	550	775	7.9	7.1	6.4	4.7	.003	.013	1.478	.0069	290 - 2700	A
475	520	760	8.8	7.9	7.2	4.7	.003	.013	1.484	.0076	340 - 2700	B
485	535	785	8.5	7.7	7.0	4.5	.002	.008	1.471	.0073	290 - 3500	B
485	530	770	9.0	8.1	7.3	—	—	—	1.480	.0074	300 - 2700	A
690	710	930	12.4	11.5	10.8	—	—	—	—	—	—	A
805	865	1125	12.2	11.3	10.5	—	—	—	1.522	—	270 - 4800	A
745	800	1015	12.7	11.8	11.1	—	—	—	1.536	—	280 - 4800	A
510	545	680	12.3	11.4	10.6	—	—	—	1.568	.0093	—	—
520	550	638	12.7	11.7	10.8	7.97 - 8.15	—	—	1.680	.0323	360 - 2700	—
430	475	690	7.5	6.6	5.9	—	—	—	1.511	—	520 - 4600	—
440	475	670	7.8	6.8	6.1	—	—	—			See Note 19a	—
470	515	700	9.9	8.9	7.9	—	—	—	1.522	—	220 - 4400	—
470	515	695	9.8	8.7	7.8	—	—	—	1.522	—	220 - 4400	—

Column	Item	Comments
13	Electrical Resistivity	
14	Dielectric Constant	
15	Loss Tangent	This is sometimes expressed as a percent (.009 = 0.9%).
16	Loss Factor	This is sometimes expressed as a percent (.065 = 6.5%). Of the standard glasses, lead and borosilicate are the better insulators.
17	Refractive Index	Values at 589.3 nm
18	Dispersion	Dispersion is shown at $n_f - n_c$
19	Useful Transmittance	Useful transmittance (exceeding 10%) range is shown in nanometers for 1 mm thicknesses. 19a. Type 540 has selective transmittance bands. Its useful transmittance is: 310 - 450 690 - 1100 1100 - 4600
20	Resistance to Weathering	A. Seldom affected by weathering. B. Could occasionally show weathering effects. C. Weathering can be a problem.

All data subject to normal manufacturing variations

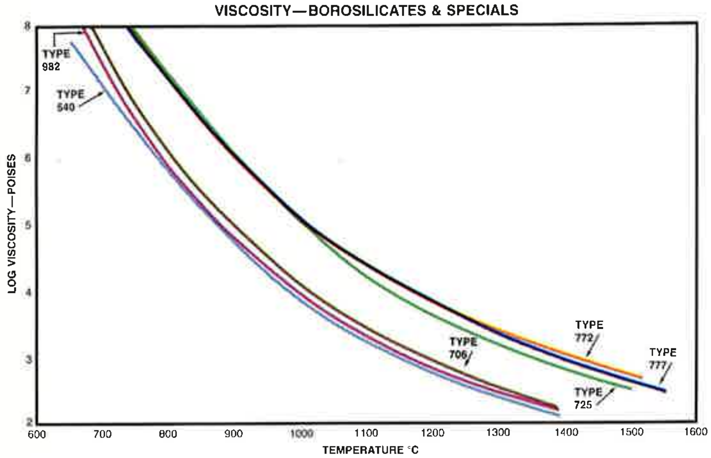
Viscosity

Metals have a melting point below which they are solid, above which they are liquids. Glasses behave differently. As they are heated from room temperature, they become softer—or less viscous. Viscosity is the measure of the resistance to flow of a material when exposed to a shear stress.

Since the range in "flowability" is extremely wide, the viscosity scale is logarithmic, and measured in the "poise" expressed as a power of 10. Viscosity data for glass is given with three (and sometimes four) points from a viscosity temperature curve: strain point, annealing point, softening point, and, occasionally the working point.

Viscosity of glass is measured by a fiber elongation method (at low temperatures) and by rotating cylinder methods (at high temperatures).

VISCOSITY—BOROSILICATES & SPECIALS



VISCOSITY—SODA LIME, LEAD & ALUMINOSILICATES

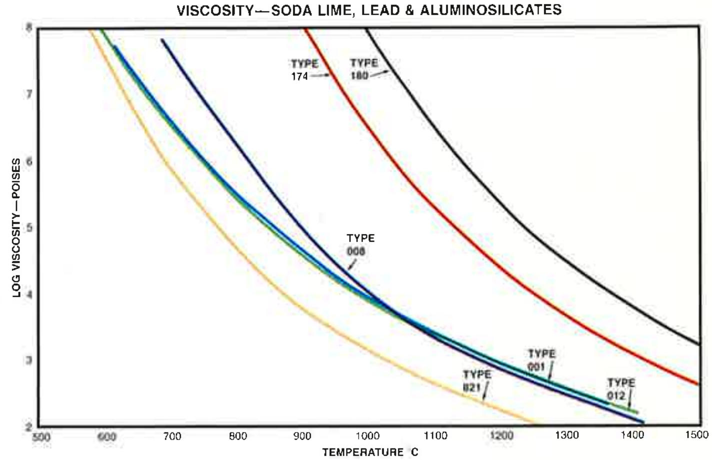


TABLE III—VISCOSITY DATA

	Temperature	Viscosity of Glass (Poises)	Comments
	Room Temperature	10^{22+}	
	Maximum Service Temperature	10^{15+}	Below this point, the glass is thoroughly rigid.
Annealing Range	Strain Point	$10^{14.5}$	The temperature at which the internal stress in a glass is substantially relieved in four hours.
	Transformation Point	$10^{13.3}$	The boundary above which glass is plastic, below which glass is elastic. It is also the breaking point of the curves of thermal expansion and electrical conductivity.
	Annealing Point	$10^{13.0}$	The temperature at which the internal stress in a glass is substantially relieved in 15 minutes.
Working Range	Softening Point	$10^{7.6}$	The temperature at which a glass will deform under its own weight and start to adhere to other bodies.
	Working Point	$10^{4.0}$	The temperature at which the glass is soft enough for hot working by most conventional methods.

WEIGHT FORMULA

Pieces/Pound Calculation

Formula: $P = 224/LW(D-W)d$

Let: P = pieces/pound
L = length in millimeters
W = wall thickness in inches
D = outside diameter in inches
d = density gm/cc.

Electrical Properties

As with thermal properties, metals are electrical conductors while glasses are insulators. Because of exacting requirements, industry identifies glasses in terms of property specifications rather than by types of compositions. The electrical behavior of glass that makes it desirable for specific electrical applications can be described in terms of the following properties.

RESISTIVITY

Volume resistivity is the resistance of a cube of material to the flow of current through its interior when placed between two electrodes which differ in DC potential. Volume resistivity is drastically affected by temperature. High volume resistivity is a desirable property of electrical glass.

DIELECTRIC CONSTANT

This is the ratio of the capacity of a condenser whose plates are separated by a specific dielectric to the capacity of the same system whose plates are separated by a vacuum. This property determines the energy storage in a polarized dielectric. ASTM D150 is the standard testing procedure.

LOSS TANGENT

Also called the dissipation factor, this represents the irrecoverable portion of the electrical energy through a material which shows up as heat. A low loss tangent is desired for glasses used in electrical applications. ASTM D150 is the standard testing procedure.

LOSS FACTOR

This is the product of the loss tangent and dielectric constant. It is a measure of the actual loss in the insulator since the loss tangent is the fraction of energy lost during a cycle and the dielectric constant is proportional to the energy stored in the dielectric.

Optical Properties

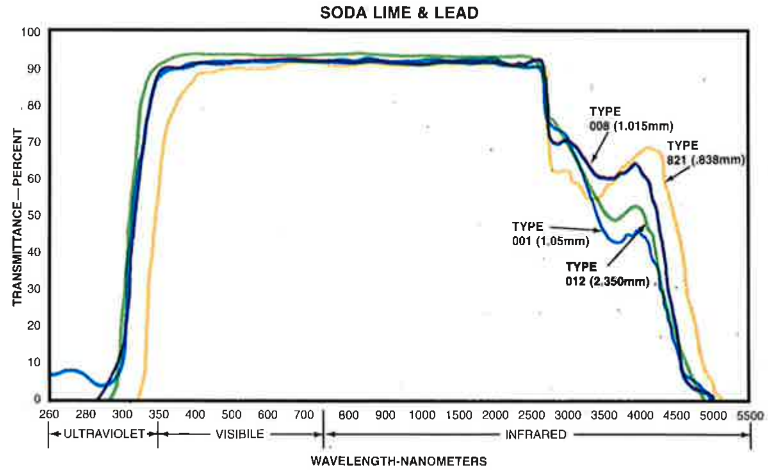
Glass is usually a transparent material whether it is clear or colored. Glass types are available, however, that have selective transmission or absorption characteristics when these are of special importance. In general, the optical capabilities of a glass are defined in terms of the following properties.

TRANSMITTANCE, ABSORPTANCE, REFLECTANCE

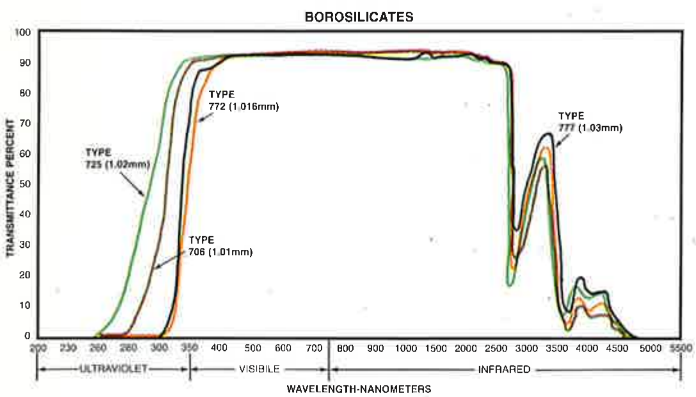
Transmittance is the fraction of incident energy transmitted through a thickness of material. Absorptance is the fraction of incident energy absorbed by the material, and reflectance is the fraction reflected. All of these values are calculated from or measured on a spectrophotometer. In glass, if X is the total amount of energy directed (at any given wavelength) toward a glass sample, some is transmitted (T), some absorbed (A), some reflected (R).

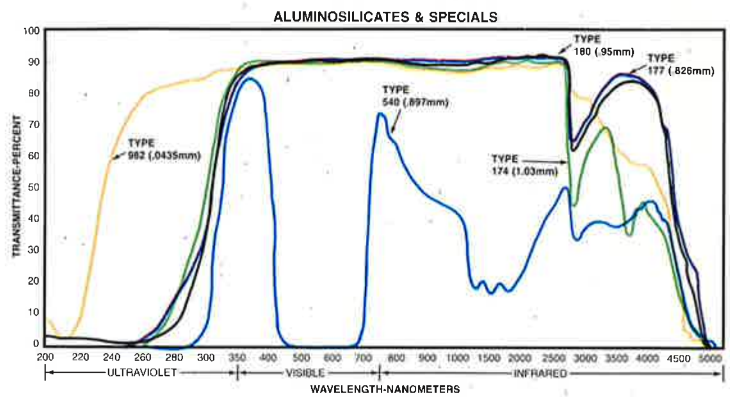
$$T + A + R = X$$

The transmittance is measured (and plotted) directly by the spectrophotometer. The amount of energy lost due to the reflection at the glass surface is calculated (from Fresnel's Law) for glass in air.



(Glass thickness shown in parentheses on graphs.)





At the sodium D line (589.3 nanometers) the reflectance as a function of the refractive index is shown in Table IV below:

TABLE IV

n	Loss by reflection at one surface
1.0	0 %
1.2	0.8
1.4	2.8
1.478 (725 glass)	3.7
1.5	4.0
1.513 (008 glass)	4.1
1.539 (001 glass)	4.5
1.560 (012 glass)	4.8
1.6	5.3
1.651 (821 glass)	6.0

The third value, absorptance, accounts for the remainder of the incident energy.

REFRACTIVE INDEX

The index of refraction is the ratio of the velocity of light through a vacuum to the velocity of light through the material. The light used for glass is generally monochromatic light with a wavelength of 589.3 nanometers (the sodium D line). The greater the index, measured on an Abbe Refractometer, the slower the velocity of light.

DISPERSION

The difference between the refractive index for any two wavelengths is the dispersion for those wavelengths. This property value has significance primarily in lenses produced from glass. Dispersion is a mathematical calculation from values obtained on the Abbe Refractometer.

STRESS OPTICAL COEFFICIENTS

The stress optical coefficient is a unique number associated with a particular glass. It is used to relate the birefringence per unit length to the stress present in the glass.

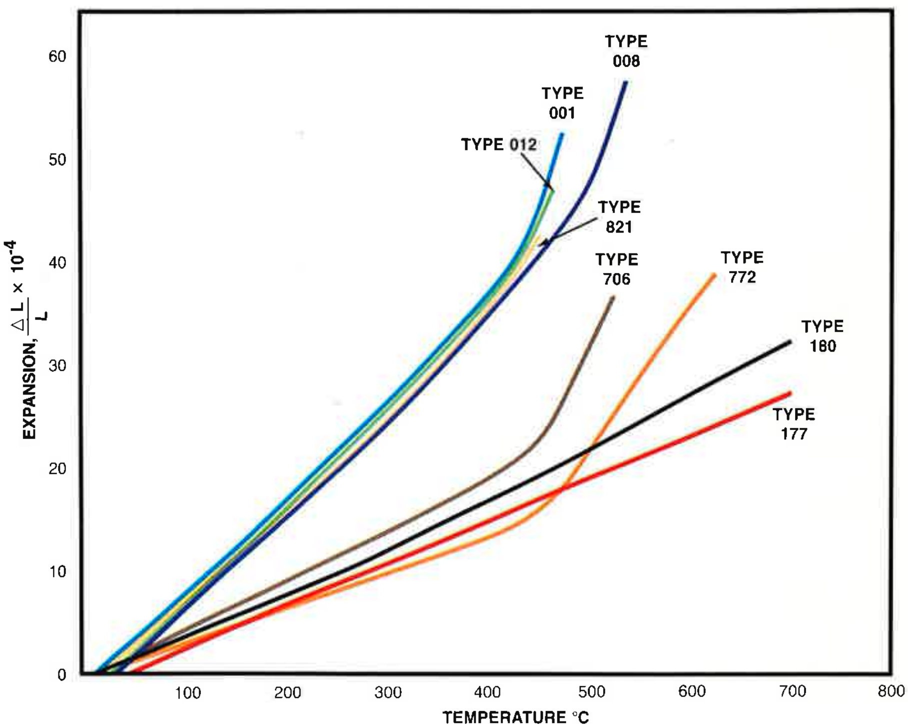
Glass Type	Stress Optical Coefficient (Brewsters)
001	2.8
008	2.4
012	2.8
706	3.7
725	3.5
772	2.9
821	2.0

Thermal Properties

THERMAL EXPANSION

Like most materials, glass expands as it is heated. The linear coefficient of thermal expansion defines the fractional change in length for a unit change in temperature. For general purposes and ease of recording data, the mean coefficient of expansion is usually given for glass over a temperature range of 0-300°C. Above 300°C glass expands more rapidly with increasing temperature and may have a coefficient two or three times larger than that measured below 300°C. Thermal expansion of glasses is measured on a dilatometer or inteferometer.

EXPANSION VS. TEMPERATURE



THERMAL ENDURANCE

Thermal endurance is the ability to undergo a change in temperature without breaking and is expressed as the temperature difference that can be endured. Also defined as resistance to thermal shock, thermal endurance is sometimes referred to as thermal stress resistance.

The ability of glass to withstand temperature changes depends upon the surface condition of the glass, the glass thickness, the thermal expansion, and the rate and amount of heating or cooling.

With this wide range of variables and possibilities, a test should be designed to duplicate the customer's requirements if this is of critical importance. However, some basic understanding of the mode of thermal endurance will be helpful to designers. There are several major points to be considered.

Although glass retains its mechanical strength to temperatures approaching its strain point, useful operating temperatures are more frequently determined by stresses set up by temperature differentials within the glass part itself.

If one surface of an unrestrained relatively thin glass part is maintained at a higher temperature than the other surface, the expansion of the heated surface will cause the part to bend slightly, allowing for some relaxation of the thermal stresses which would otherwise develop. If, however, the part is restrained so that it cannot bend (either by clamping or by the shape of the part) internal stresses develop which are compressive on the warmer side and tensile on the cooler side, and failure may result.

When the temperature of the glass part is changed rapidly, a tensile stress is developed on the cooler surface and a compensating compressive stress on the warmer surface. When a part is cooled rapidly (quenched), tensile stresses develop on the surfaces and the interior is under compression. On rapid heating, the outer surfaces will be in compression and the interior under tension.

The magnitude of the stress developed by a given thermal shock depends upon many factors, including: the thermal conductivity, thermal expansion, elasticity and thickness of the glass, and the thermal conductivity of the medium applying the thermal shock. High values of the glass thermal conductivity will increase the thermal endurance while high values of the other four factors will decrease this endurance.

Of the factors relating to the properties of the glass, the expansion can be varied over the widest range through composition change. Elasticity and thermal properties change only slightly. As a result, it is a general rule that the thermal endurance of a glass is inversely proportional to its coefficient of thermal expansion.

THERMAL CONDUCTIVITY

The thermal conductivity of a material is the measure of the transfer of heat through the material during a time interval. In general, most metals are heat conductors while glass is an insulator. Thermal conductivity is measured on a thermal conductometer.

TABLE V

Material	Thermal Conductivity (cal per sec x cm x° C)
Copper	0.91
Lead	0.09
Molybdenum	0.35
Tungsten	0.38
Glass	0.002—.003

Glass Sealing

One of the most important characteristics of glass is its ability to be effectively sealed to a variety of metals and other glasses. The key property is the thermal coefficient of expansion (or contraction).

GE has developed glass compositions that are compatible with all the common metals used to create a vacuum tight seal in all of the major product categories. These include fluorescent and incandescent lamps, cathode ray tube equipment, television components, and a vast number of electronic devices.

In considering glass-to-metal seals, two major areas should be considered: (1) properties which affect the success and economics of sealing, and (2) properties which affect performance and life of the seal. There is often considerable overlap between these two areas.

In making glass seals, whether to another glass or to a metal, it is necessary to know the total contraction from about 15°C below the anneal point of the lowest temperature glass (or of the glass in a glass-to-metal seal) to room temperature.

In making a glass-to-metal seal, a glass should be selected which contracts the same amount as the metal over the temperature range from approximately the anneal point to room temperature. For proper seal design, complete contraction curves provide the best information, rather than simply using the 0-300°C data.

Conventional sealing temperatures are 800-900°C. When the design of the parts, or the metal to be used, cannot accommodate these high temperatures, solder glasses may be recommended.

Outgassing is another potential problem area. Temperatures high enough for efficient outgassing may require a glass with a higher softening point.

In the making of glass-to-metal seals, it is important that both the glass and metal be free of lubricants, corrosion products, residue of cleaning compounds, organic material, or other foreign matter. In most cases, standard cleaning procedures will provide good results.

ELECTRICAL RESISTIVITY

When this property is required, it presents special consideration in glass-to-metal sealing. Resistivity can be increased by changing to a lower alkali content glass. But since these glasses usually seal at higher temperatures, electrical resistivity requirements are usually met by using a lead glass. These glasses provide a long working range, but sealing of lead glass should be done in an oxidizing or neutral atmosphere because a reducing atmosphere will cause lead glass to darken.

In many cases this darkening is of no consequence, but appearance or transmission requirements may demand that it be avoided. Since the lead oxide is reduced to metallic lead on the glass surface, an undesirable effect on surface resistivity can result under extreme conditions. If reducing conditions cannot be avoided, changing to a barium type of glass can eliminate the problem, but this will result in higher sealing temperatures.

The metal being sealed can also have a profound effect on the glass-metal interface. Because of the tendency of lead oxide to be reduced by ferrous metals, it may be necessary to coat the metal being sealed in order to prevent this reaction. Usually copper or platinum is used.

In making a seal, a metal oxide must be developed on the surface of the metal and it must adhere tightly. When glass and metal are joined, some of the metal oxide will be dissolved in the glass. Certain combinations of metal and glass will have undesirable chemical reactions and necessitate a change in materials.

RADIATION FACTORS

In some applications, it is necessary to consider resistance to X-ray and nuclear radiation. Most glasses will darken with exposure to radiation, and this causes a change in its transmission characteristics. Other changes may also occur that affect seal serviceability.

Glasses can be selected or developed to provide for absorption of certain wave lengths or for transmission of infra-red or ultraviolet. These glasses may shift working temperatures somewhat, but they do not ordinarily present any sealing problems.

GRADED SEALS

When expansion characteristics of the two materials in the seal are quite different, intermediate or graded seals provide the answer. Graded seals are used, for example, when it is necessary to incorporate electrical leads into quartz laboratory ware. Another application is in glass-to-glass sealing, such as fused quartz to borosilicate glass. These two materials are permeable to some gases, such as helium and hydrogen. The choice of glass and its thickness can be limited depending on whether or not such diffusion is desired. When diffusion is a critical problem, it is apparent that added flexibility may have to be introduced into other property requirements or sealing conditions.

Sealing requirements should be reviewed early in the design stage, not after materials have been selected and other engineering considerations have been met.

Technical Assistance

For technical and application engineering assistance, contact:

General Electric Company
Lamp Glass and Components Dept.
Marketing Section
24400 Highland Road
Cleveland, Ohio 44143
(216) 266-3468/3666

Ordering Information

For Product Data Sheets which provide detailed availability and ordering information on the glass products covered in this General Catalog, contact Lamp Components Sales Operation headquarters shown below.

General Electric's Lamp Components Division is the source for tungsten, molybdenum, glass, fused quartz, Lucalox® ceramic, phosphors, chemicals, Dumet and Cumet wire, leads, bases and other components used by the lamp, electronic and cemented carbide industries. Technical and engineering assistance is available on all products. For information contact:

General Electric Company
Lamp Components Sales Operation
21800 Tungsten Road
Cleveland, Ohio 44117
(216) 266-2451
Telex: 985569

GENERAL ELECTRIC

General Catalog 7600
December, 1980
4M