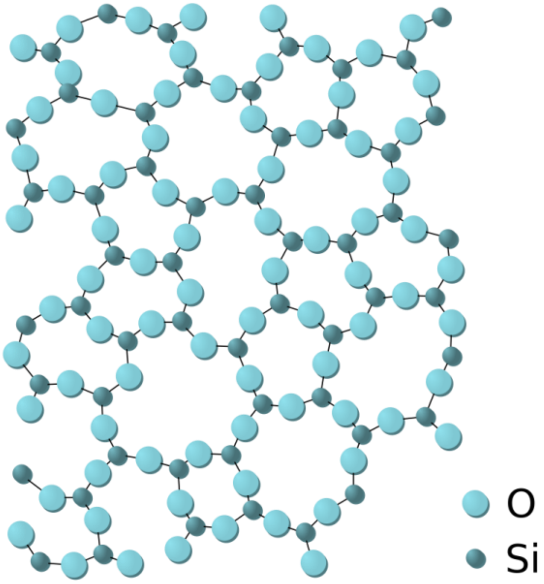
What is Glass?

Glass is a non-crystalline, often transparent amorphous solid, that has widespread practical, technological, and decorative use. The standard definition of a *glass* (or vitreous solid) is a solid formed by rapid melt quenching. However, the term "glass" is often defined in a broader sense, to describe any non-crystalline (amorphous) solid that exhibits a glass transition when heated towards the liquid state. Glass is an amorphous solid. Although the atomic-scale structure of glass shares characteristics of the structure of a supercooled liquid, glass exhibits all the mechanical properties of a solid. As in other amorphous solids, the atomic structure of a glass lacks the long-range periodicity observed in crystalline solids. Due to chemical bonding constraints, glasses do possess a high degree of short-range order with respect to local atomic polyhedra. The notion that glass flows to an appreciable extent over extended periods of time is not supported by empirical research or theoretical analysis (see viscosity in solids). Laboratory measurements of room temperature glass flow do show a motion consistent with a material viscosity on the order of 10^{17}–10^{18} Pa s.

Formation from a supercooled liquid

Unsolved problem in physics :

What is the nature of the transition between a fluid or regular solid and a glassy phase? "The deepest and most interesting unsolved problem in solid state theory is probably the theory of the nature of glass and the glass transition." —P.W. Anderson



For melt quenching, if the cooling is sufficiently rapid (relative to the characteristic crystallization time) then crystallization is prevented and instead the disordered atomic configuration of the supercooled liquid is frozen into the solid state at T_g. The tendency for a material to form a glass while quenched is called glass-forming ability. This ability can be predicted by the rigidity theory. Generally, a glass exists in a structurally metastable state with respect to its crystalline form, although in certain circumstances, for example in atactic polymers, there is no crystalline analogue of the amorphous phase.

Glass is sometimes considered to be a liquid due to its lack of a first-order phase transition where certain thermodynamic variables such as volume, entropy and enthalpy are discontinuous through the glass transition range. The glass transition may be described as analogous to a second-order phase transition where the intensive thermodynamic variables such as the thermal expansivity and heat capacity are discontinuous. Nonetheless, the equilibrium theory of phase transformations does not entirely hold for glass, and hence the glass transition cannot be classed as one of the classical equilibrium phase transformations in solids.

Definition of glassy state

"Glass is a nonequilibrium, non-crystalline condensed state of matter that exhibits a glass transition. The structure of glasses is similar to that of their parent supercooled liquids (SCL), and they spontaneously relax toward the SCL state. Their ultimate fate, in the limit of infinite time, is to crystallize." This definition is for experts who understand the meaning of glass transition.

The glassy state of matter is ubiquitous in nature. Glass-forming ability of chalcogenide elements (S, Se, and Te) have been known for several decades but compared to oxide based glasses; this type of materials is rising from their infancy. Despite the outstanding chemical durability, ChGs possess fairly weak thermal and mechanical properties. As frequently pointed out by various researchers if ChGs are converted to nanocrystalline glass-ceramic by controlled crystallization technique, the thermal, optical, and mechanical properties might be enhanced. The most important challenge in oxide as well as ChG technology lies in controlling the equilibrium between glassy phase and crystalline phase with the aim of fabricating glass-ceramics. Complete crystallization of glass material by this technique is really a distinctive job. In fact, for ChG glasses, we get composite type glass-ceramic based materials, which can exhibit outstanding thermo-mechanical properties such as wide thermal expansion value, while benefiting from interesting transparency properties.

As the optical properties are mainly concerned for ChG glass-ceramics (CGCs) the formation of nanocrystalline grains inside a ChG matrix can be a source of optical loss due to the scattering of light, particularly in the shorter wavelength regions (UV and visible). During the last decade, CGCs possessing nanocrystalline structure became promising material because of many potential applications as well as unique attributes for many current optical products. Glass-ceramics generally combine the ease of production of glass with much improved thermal and mechanical performances, which was the interesting choice to solve the intrinsic weakness of the IR-glasses (poor resistance to thermal shock and crack propagation). Moreover, starting from their wide transmitting spectral region (0.8-22 μm), CGCs also present interesting characteristics for active optical applications as doping the RE metals or permanent second-order nonlinear optical effects. In addition, these materials have attained much interest due to the usefulness in temperature monitoring, thermal imaging, and CO/CO_2 laser power delivery.

In the fabrication and characterization study of GeS_2-Ga_2S_3-Tm_2S_3 glass-ceramics, Lin and his coworkers [40] developed Ga_2S_3 nanocrystals (~ 50 nm) by thermal treatment. From the element mapping data, they argued that the enhancement in the mid-IR emission intensity was related to the formation of Ge-rich region in the glass-ceramics. Jijian et al. has studied the mechanism of controlled crystallization of the As-Ge-Se glass nucleated by single nucleant ($ZrSe_2$) and mixed nucleant ($ZrSe_2$ + SnSe). With both nucleants, they prepared the new glass-ceramics possessing high toughness as well as better mechanical behavior.

Failure of amorphous polymers in the glassy state results from the competition between shear yielding and crazing. When crazing can be suppressed, for instance under compression, the bulk material shows a localized plastic deformation through shear bands related to softening upon yielding followed by progressive strain hardening as the deformation continues. Crazing involves also some localized plasticity, albeit at a smaller scale, and precedes crack propagation. After initiation for a critical stress state, the crazes widen by the growth of fibrils which break down for a critical width resulting in the nucleation of a crack. In a numerical study featuring a viscoplastic model for shear yielding and a viscoplastic cohesive zone for crazing, it was demonstrated that the competition between shear yielding and crazing is governed by the time scales involved in each mechanism. This competition together with the condition for craze fibrils breakdown and crack propagation determines the level of toughness and governs the ductile to brittle transition with increasing loading rate. A ductile response is related to the development of some plasticity in the bulk prior to crack propagation while a brittle response corresponds to the development of crazing only, the bulk remaining elastic.

Although the failure properties for metals have been widely investigated, for which standard experimentations are available, attention to glassy polymers has been focused later on. Due to their intrinsic softening response, no analytical results are available for such materials. For a properly designed specimen and configuration test, linear elastic conditions need to be ensured while non linear deviations have to remain confined at a small scale. Under these conditions, classical linear elastic solution can be used for the analysis of failure and the estimation of the toughness. The characterization of the fracture features has then required the development of appropriate test configurations and specific preparation rules of the specimen, and related standards are now emerging.

Glass transition phenomenon

Understanding glass transition phenomenon is of primal importance in the study of glasses. To begin with, we note that in the supercooled region the viscosity increases exponentially to values as high as 10^^^ poises. At this stage the supercooled liquid rapidly transforms into a glass, although viscosity itself suffers no discontinuity at Tg. Nevertheless one should expect a proper theory of viscosity of liquids to be able to account for the glass transition and associated features. The first major development in this direction has been the formulation of free volume theory of liquid viscosities.

The **glass–liquid transition**, or **glass transition**, is the gradual and reversible transition in amorphous materials (or in amorphous regions within semicrystalline materials) from a hard and relatively brittle "glassy" state into a viscous or rubbery state as the temperature is increased.[1] An amorphous solid that exhibits a glass transition is called a glass. The reverse transition, achieved by supercooling a viscous liquid into the glass state, is called vitrification.

The **glass-transition temperature** T_g of a material characterizes the range of temperatures over which this glass transition occurs. It is always lower than the melting temperature, T_m, of the crystalline state of the material, if one exists. The glass transition temperature (T_g) is the temperature of amorphous polymers at which increased molecular mobility results in significant changes in the thermal properties. Plastic products molded with oriented molecules expand differentially, as long as the glass transition temperature is not reached. The glass transition temperature is the temperature at which increased molecular mobility results in significant changes in the thermal properties of an amorphous resin. Above the glass transition temperature, the polymer tends to expand isotropically, and hysteresis is noted in the expansion or dimensional changes upon cooling, when the material will be rubbery and ductile.

Hard plastics like polystyrene and poly(methyl methacrylate) are used well below their glass transition temperatures, i.e., when they are in their glassy state. Their T_g values are well above room temperature, both at around 100 °C (212 °F). Rubber elastomers like polyisoprene and polyisobutylene are used above their T_g, that is, in the rubbery state, where they are soft and flexible.

Despite the change in the physical properties of a material through its glass transition, the transition is not considered a phase transition; rather it is a phenomenon extending over a range of temperature and defined by one of several conventions. Such conventions include a constant cooling rate (20 kelvins per minute (36 °F/min)) and a viscosity threshold of 10^{12} Pa·s, among others. Upon cooling or heating through this glass-transition range, the material also exhibits a smooth step in the thermal-expansion coefficient and in the specific heat, with the location of these effects again being dependent on the history of the material. The question of whether some phase transition underlies the glass transition is a matter of continuing research. In a more recent model of glass transition, the glass transition temperature corresponds to the temperature at which the largest openings between the vibrating elements in the liquid matrix become smaller than the smallest cross-sections of the elements or parts of them when the temperature is decreasing. As a result of the fluctuating input of thermal energy into the liquid matrix, the harmonics of the oscillations are constantly disturbed and temporary cavities ("free volume") are created between the elements, the number and size of which depend on the temperature. The glass transition temperature T_{g0} defined in this way is a fixed material constant of the disordered (non-crystalline) state that is dependent only on the pressure. As a result of the increasing inertia of the molecular matrix when approaching T_{g0}, the setting of the thermal equilibrium is successively delayed, so that the usual measuring methods for determining the glass transition temperature in principle deliver T_g values that are too high. In principle, the slower the temperature change rate is set during the measurement, the closer the measured T_g value T_{g0} approaches.

IUPAC definition

glass transition (in polymer science): Process in which a polymer melt changes on cooling to a polymer glass or a polymer glass changes on heating to a polymer melt.

The glass transition of a liquid to a solid-like state may occur with either cooling or compression. The transition comprises a smooth increase in the viscosity of a material by as much as 17 orders of magnitude within a temperature range of 500 K without any pronounced change in material structure. The consequence of this dramatic increase is a glass exhibiting solid-like mechanical properties on the timescale of practical observation. This transition is in contrast to the freezing or crystallization transition, which is a first-order phase transition in the Ehrenfest classification and involves discontinuities in thermodynamic and dynamic properties such as volume, energy, and viscosity. In many materials that normally undergo a freezing transition, rapid cooling will avoid this phase transition and instead result in a glass transition at some lower temperature. Other materials, such as many polymers, lack a well defined crystalline state and easily form glasses, even upon very slow cooling or compression. The tendency for a material to form a glass while quenched is called glass forming ability. This ability depends on the composition of the material and can be predicted by the rigidity theory.

Below the transition temperature range, the glassy structure does not relax in accordance with the cooling rate used. The expansion coefficient for the glassy state is roughly equivalent to that of the crystalline solid. If slower cooling rates are used, the increased time for structural relaxation (or intermolecular rearrangement) to occur may result in a higher density glass product. Similarly, by annealing (and thus allowing for slow structural relaxation) the glass structure in time approaches an equilibrium density corresponding to the supercooled liquid at this same temperature. T_g is located at the intersection between the cooling curve (volume versus temperature) for the glassy state and the supercooled liquid.

The configuration of the glass in this temperature range changes slowly with time towards the equilibrium structure. The principle of the minimization of the Gibbs free energy provides the thermodynamic driving force necessary for the eventual change. At somewhat higher temperatures than T_g, the structure corresponding to equilibrium at any temperature is achieved quite rapidly. In contrast, at considerably lower temperatures, the configuration of the glass remains sensibly stable over increasingly extended periods of time.

Thus, the liquid-glass transition is not a transition between states of thermodynamic equilibrium. It is widely believed that the true equilibrium state is always crystalline. Glass is believed to exist in a kinetically locked state, and its entropy, density, and so on, depend on the thermal history. Therefore, the glass transition is primarily a dynamic phenomenon. Time and temperature are interchangeable quantities (to some extent) when dealing with glasses, a fact often expressed in the time–temperature superposition principle. On cooling a liquid, *internal degrees of freedom successively fall out of equilibrium*. However, there is a longstanding debate whether there is an underlying second-order phase transition in the hypothetical limit of infinitely long relaxation times.

Different operational definitions of the glass transition temperature T_g are in use, and several of them are endorsed as accepted scientific standards. Nevertheless, all definitions are arbitrary, and all yield different numeric results: at best, values of T_g for a given substance agree within a few kelvins. One definition refers to the viscosity, fixing T_g at a value of 10^{13} poise (or 10^{12} Pa·s). As evidenced experimentally, this value is close to the annealing point of many glasses.

In contrast to viscosity, the thermal expansion, heat capacity, shear modulus, and many other properties of inorganic glasses show a relatively sudden change at the glass transition temperature. Any such step or kink can be used to define T_g. To make this definition reproducible, the cooling or heating rate must be specified.

The most frequently used definition of T_g uses the energy release on heating in differential scanning calorimetry (DSC, see figure). Typically, the sample is first cooled with 10 K/min and then heated with that same speed.

Yet another definition of T_g uses the kink in dilatometry (a.k.a. thermal expansion). Here, heating rates of 3–5 K/min (5.4–9.0 °F/min) are common. Summarized below are T_g values characteristic of certain classes of materials.

Properties of glassy state

Relative to many other materials, glass possesses high hardness values. However, most types of glass tend to be naturally brittle, which makes them vulnerable to breakage or fracturing in applications where impacts, pressures, or stresses are present. In order to eliminate this inherent brittleness, engineers and manufacturers must thoroughly process glass according to optimal strengthening/tempering protocols.

Glass types can be divided by their mechanical and thermal properties to determine which applications they will most suitably match. The following properties of glass materials are important to consider during the selection process.

1.MECHANICAL PROPERTIES

- **Density : 2500 kg/m3**

A 4mm thick pane of glass weighs 10kg/m2

- **Hardness : 470 HK**

The hardness of float glass is established according to Knoop. The basis is the test method given in DIN 52333 (ISO 9385).

- **Compression resistance : 800 - 1000 MPa**

The compression strength defines the ability of a material to resist a load applied vertically to its surface

- **Modulus of elasticity : 70 000 MPa**

The modulus of elasticity is either determined from the elastic elongation of a thin bar, or from bending a bar with a round or rectangular cross section.

- **Bending strength : 45 MPa**

The bending strength of a material is a measure of its resistance during deflection. It is determined by bending tests on glass plate using the double ring method according to DIN EN 1288-5.
The main characteristics of glass are transparency, heat resistance, pressure and breakage resistance and chemical resistance.

Strength

Many glasses—depending on their specific composition—boast a high theoretical structural strength. However, certain practical considerations tend to significantly reduce their workable strength. For instance, the following factors may lead to sub-optimal strength in the glass type:

- Flaws or defects on the glass surface
- Thermal stresses introduced during a rapid cooling process
- The introduction of tiny crystals into the surface through annealing

Flaws on the surface of glass can act as focal points for stress. Concentrated stress introduced by a load that exerts more pressure than the theoretical strength of the glass can bear will usually cause a fracture or breakage. Thus, flaws or defects on the glass's surface greatly reduce the fracture strength of the product. Nevertheless, manufacturers can eliminate or prevent the occurrences of these surface flaws and cracks through precision and care in the manufacturing process.

Glasses vary as to their level and type of strength. For example:

- Tempered soda lime glass—also known as Type-III glass—has high mechanical strength.
- Aluminosilicate glass has high compressive strength, which makes it ideal for use in solar cells, cover glass and touch displays, among other applications.
- Borosilicate glass boasts exceptional structural strength and is frequently used in glass tubing, medical devices and devices for space exploration.

THERMAL PROPERTIES

- **Transformation range : 520 - 550°C**

- **Temp&Softening temperature : approx. 600°C**

Contrary to solid bodies of crystalline structure, glass has no defined melting point. It continuously transforms from the solid state to the viscous plastic state. The transition range is called the transformation range and according to DIN 52324 (ISO 7884), it lies between 520°C and 550°C. Tempering and bending require a temperature of a further 100°C.

- **Specific Heat : 0.8 J/g/K**

The specific heat (in joules) defines the amount of heat required to raise the temperature of 1g of float glass by 1K. The specific heat of glass increases slightly the temperature is increased up to the transformation range.

- **Thermal conductivity : 0.8W/mK**

Thermal conductivity determines the amount of heat required to flow through the cross sectional area of the float glass sample in unit time at a temperature gradient.

- **Thermal expansion : 9.10-6 K-1**

Glass tends to expand with increasing temperatures. The thermal expansion curve for glass provides three crucial properties to engineers and manufacturers for the glass in question. There is a difference in the expansion behaviour of a body under the effect of heat between linear expansion and volumetric expansion. With solid bodies, the volumetric expansion is three times that of linear expansion. The main characteristics of glass are transparency, heat resistance, pressure and breakage resistance and chemical resistance. **Thermal expansion coefficient** measures the rate of expansion with temperature. **Transition temperature** sees the onset of viscoelastic behavior and a period of sudden expansion. Glasses vary as to their thermal expansion behavior and their related workability. For example, silica glass has a low coefficient of thermal expansion, and is therefore more difficult to shape or distort relative to other glass types.

3. OPTICAL PROPERTIES

Glass has several strong points concerning optical properties:
- It can be produced in large and homogeneous panes
- Its optical properties are not affected by ageing
- It is produced with perfectly flat and parallel surfaces.

- **Refractive index n = 1.52**

If light from an optically less dense medium (air) meets an optically denser medium (glass), then the light ray is split at the surface interfaces. The measure of deflection determines the refractive index. For float glass, this refractive index is n=1.52.

The main characteristics of glass are transparency, heat resistance, pressure and breakage resistance and chemical resistance.

4. TECHNICAL PROPERTIES

Chemical resistance against

- Water = class 3 (DIN 52296)
- Acid = class 1 (DIN 12116)
- Alkaline = class 2 (DIN 52322 and ISO 695)

The surface of glass is affected if it is exposed for a long time to alkalis (and ammonia gases in damp air) in conjunction with high temperatures. Float glass will also react to compounds that contain hydrofluoric acid under normal conditions. These are used for treating glass surfaces.

5. Viscosity

Viscosity is a measure of a liquid's internal friction, or resistance to flow. When glass is in its molten liquid state, most processing techniques that manufacturers employ require its viscosity to be within a certain range at a specific temperature. This is referred to as the working point—or the level of viscosity at which manufacturers can shape the glass by means of blowing, pressing, or other operations.

Types of glasses:

1. Silicate glasses:

Composition: Quartz sand (silica) is the main raw material in commercial glass production. Silicon dioxide (SiO2) is a common fundamental constituent of glass. Fused quartz is a glass made from chemically-pure silica.

Structure: The structure of pure vitreous SiO_2 is generally agreed to be a continuous random network of corner sharing SiO_4 tetrahedra. Each oxygen bridges two tetrahedra. When alkali oxide (known as a modifier) is added, the extra oxygen introduced causes some breaking of the network. Each Si remains four-fold coordinated to O but some of these O are not shared (non-bridging). Tetrahedra with *n* bridging O are known as Q_n species. The proportions of these can be determined by Magic Angle Spinning ^{29}Si Nuclear Magnetic Resonance (MASNMR) (Murdoch *et al.*, 1985). In the first work of its type, MASNMR data has been used quantitatively in constructing RMC models of $(K_2O)_x(SiO_2)_{1-x}$ glasses (Wicks, 1993). The initial configurations have been constructed in the following manner.

1. Si atoms at the appropriate density are introduced at random and then HSMC is run with constraints on *n*-fold Si–Si coordination equivalent to the proportions of Q_n species determined from NMR. For instance, in the case of $(K_2O)_{0.2}(SiO_2)0.8$ the ratios of Q_4:Q_3:Q_2 are 0.57:0.35:0.08. The coordination that is achieved is 98–99% perfect.

2. O atoms are added at the mid-point of each Si–Si bond. Single O atoms are then added close to those Si that now have only two or three neighbours (two-fold or three-fold Si–Si coordination). HSMC is run with a constraint on four-fold Si–O coordination. In the 'ideal' modified random network model (Greaves *et al.*, 1981) the ratio of non-bridging to bridging oxygens is given by $2y/(2 + y)$ where $y = x/(1 - x)$; it can be checked that the resulting model is close to this prediction.

3. Alkali atoms are added at random and RMC is run, keeping the Si–O coordination constraint.

In the same way as for the $(AgI)_x(AgPO_3)_{1-x}$ glasses, the model is now free to change its conformation, but not its topology. However the topological constraint is more severe in this case since it is 'three-dimensional', rather than 'one-dimensional' for the phosphate chain structure. Nevertheless good fits to the data can still be obtained, even in the low *Q* region of the structure factor which becomes quite complex for intermediate *x* ($x \approx 0.3$). This result suggests that the structures of such covalent glasses are largely determined by packing considerations (i.e.

macroscopic density) and simple topological bonding constraints. Details such as the preferred bond angles then determine the details of the structure.

Properties: It has very low thermal expansion and excellent resistance to thermal shock, being able to survive immersion in water while red hot, resists high temperatures (1000–1500 °C) and chemical weathering, and is very hard. It is also transparent to a wider spectral range than ordinary glass, extending from the visible further into both the UV and IR ranges, and is sometimes used where transparency to these wavelengths is necessary. Fused quartz is used for high-temperature applications such as furnace tubes, lighting tubes, melting crucibles, etc. However, its high melting temperature (1723°C) and viscosity make it difficult to work with. Therefore, normally, other substances (fluxes) are added to lower the melting temperature and simplify glass processing.

Silicate glasses have a very long tradition as popular materials for the application of optical devices. Recently silicate glass has become even more attractive, because of the usefulness of optical components in communications. Nowadays our communications, such as telephone, fax, Internet and etc., are almost completely dependent on transmission by optical fiber, largely replacing copper wire. Optical communication is the fastest among the variety of available communication methods; the weak point of this method, however, is lack of good amplifiers of the optical signals. Since presently the optical signals need to be converted to electronic signals, then amplified electronically and reconverted, the total communication speed becomes slow. When good optical amplifiers become available, the communication could become much faster and more useful. Thus, many people have been studying optical amplification in the past several years. One approach is the development of non-linear optical materials. Furthermore, non-linear optical devices are expected to be critical for the application of optical switching and optical memory devices in order to construct optical computers. The non-linear optical properties of a glass depend not only on the occupied electronic states but also on the unoccupied orbitals, demanding a theory which can treat both sets of states. The unoccupied molecular orbitals are typically diffuse in nature, a “local excitation” involving atomic orbitals of a considerable group of neighboring ions. So crystal field or highly localized models may seem inappropriate. Electronic states of oxide glasses, moreover, are difficult to study by all traditional theoretical methods because of their structural randomness; i.e., lack of long-range order. Taking silicate glasses as a typical case, the glass structure is defined by SiO_4 tetrahedral units which are connected by sharing one corner oxygen ion. This structural unit is very similar to that occurring in corresponding silicate crystals; i. e. the short-range structure of silicate glasses is similar to that of silicate crystals.

Silicate glass-ceramics:

Silicate glass-ceramics include those based on lithium metasilicate (Li_2SiO_3), lithium disilicate ($Li_2Si_2O_5$), diopside ($CaMgSi_2O_6$), enstatite ($MgSiO_3$), and wollastonite ($CaSiO_3$).

There are two groups of commercially important lithium silicate glass-ceramics. One group yields high-expansion lithium disilicate glass-ceramics that match the thermal expansion of several nickel-based superalloys and are used in a variety of high-strength hermetic seals, connectors, and feedthroughs. Related materials based on a microstructure of fine-grained lithium disilicate crystals with dispersed nodules of quartz crystals have been extensively evaluated for use as magnetic disk substrates for computer hard drives.

The second group is nucleated with colloidal silver, gold, or copper, which in turn are photosensitively nucleated. By suitably masking the glass and then irradiating with UV light, it is possible to nucleate and crystallize only selected areas. The crystallized portion consists of dendritic lithium metasilicate crystals, which are much more soluble in dilute hydrofluoric acid than is the glass. The crystals can thus be etched away, leaving the uncrystallized (masked) portion intact. The resulting photoetched glass can then be flood-exposed to UV rays and heat treated at higher temperature, producing the stable lithium disilicate and quartz phases. The resulting glass-ceramic is strong, tough, and faithfully replicates the original photoetched pattern. These chemically machined materials have been used as fluidic devices, lens arrays, magnetic recording head pads, and charged plates for inkjet printing.

Reactivities: All silicate glasses are decomposed under attack with a mixture of hydrofluoric and other mineral acids. Hydrofluoric acid is very effective because, even at room temperature, hexafluorosilicic acid is formed, which is decomposed at higher temperatures into silicon tetrafluoride and hydrofluoric acid. Both these products are removed from the reaction mixture by evaporation. Some other fluorides (BF_3, AsF_3, SeF_4) are also volatilized.

Glass network modifiers form fluorides and complex fluorides. Heating with a mineral acid such as sulfuric or perchloric acid before analysis will decompose the fluorides formed. Perchloric acid has an advantage because perchlorates are very water soluble, but in the presence of some constituents (TiO_2, ZrO_2, Sb_2O_3), sulfuric acid is preferred. Sulfuric acid cannot be used in the presence of constituents forming insoluble sulfates ($PbSO_4$, $BaSO_4$).

For decomposition of a number of fluorides, it is essential that the fuming step, commonly accompanied by rinsing of the vessel's walls with water, must be thorough and repeated not less than three times. The greater the content of metal(III) and metal(IV) oxides, the more tenaciously is fluoride likely to be retained in the sample.

The decomposition of glasses with hydrofluoric and perchloric or sulfuric acids is carried out customarily in platinum dishes of ∼100 ml capacity. Unless hydrogen sulfide, free chlorine, or nitrous oxide is evolved during the decomposition, the corrosion of platinum is negligible.

The sample solution obtained this way serves for the determination of alumina ($A1_2O_3$), iron oxide (Fe_2O_3), titania (TiO_2), lime (CaO), magnesia (MgO), and alkali metal oxides.

A. Soda-lime

Sodium carbonate (Na_2CO_3, "soda") is a common additive and acts to lowers the glass-transition temperature. However, Sodium silicate is water-soluble, so lime (CaO, calcium oxide, generally obtained from limestone), some magnesium oxide (MgO) and aluminium oxide (Al_2O_3) are other common components added to improve chemical durability. Soda-lime glasses (Na_2O) + lime (CaO) + magnesia (MgO) + alumina (Al_2O_3) account for over 75% of manufactured glass, containing about 70 to 74% silica by weight. Soda-lime-silicate glass is transparent, easily formed, and most suitable for window glass and tableware. However, it has a high thermal expansion and poor resistance to heat. Soda-lime glass is typically used for windows, bottles, light bulbs, and jars.

B. Borosilicate

A Pyrex borosilicate glass measuring jug

Borosilicate glasses (e.g. Pyrex, Duran) typically contain 5–13% boron trioxide (B_2O_3). Borosilicate glasses have fairly low coefficients of thermal expansion (7740 Pyrex CTE is 3.25×10^{-6}/°C] as compared to about 9×10^{-6}/°C for a typical soda-lime glass). They are, therefore, less subject to stress caused by thermal expansion and thus less vulnerable to cracking from thermal shock. They are commonly used for e.g. labware, household cookware, and sealed beam car head lamps.

C. Lead

The addition of lead(II) oxide into silicate glass lowers melting point and viscosity of the melt. The high density of Lead glass (silica + lead oxide (PbO) + potassium oxide (K_2O) + soda (Na_2O) + zinc oxide (ZnO) + alumina) results in a high electron density, and hence high refractive index, making the look of glassware more brilliant and causing noticeably more specular reflection and increased optical dispersion. Lead glass has a high elasticity, making the glassware more workable and giving rise to a clear "ring" sound when struck. However, lead glass cannot withstand high temperatures well. Lead oxide also facilitates solubility of other metal oxides and is used in colored glass. The viscosity decrease of lead glass melt is very significant (roughly 100 times in comparison with soda glass); this allows easier removal of bubbles and working at lower temperatures, hence its frequent use as an additive in vitreous enamels and glass solders. The high ionic radius of the Pb^{2+} ion renders it highly immobile and hinders the movement of other ions; lead glasses therefore have high electrical resistance, about two orders of magnitude higher than soda-lime glass ($10^{8.5}$ vs $10^{6.5}$ Ω·cm, DC at 250 °C).

D. Aluminosilicate

Aluminosilicate glass typically contains 5-10% alumina (Al_2O_3). Aluminosilicate glass tends to be more difficult to melt and shape compared to borosilicate compositions, but has excellent thermal resistance and durability. Aluminosilicate glass is extensively used for fiberglass, used for making glass-reinforced plastics (boats, fishing rods, etc.), top-of-stove cookware, and halogen bulb glass.

E. Other oxide additives

The addition of barium also increases the refractive index. Thorium oxide gives glass a high refractive index and low dispersion and was formerly used in producing high-quality lenses, but due to its radioactivity has been replaced by lanthanum oxide in modern eyeglasses. Iron can be incorporated into glass to absorb infrared radiation, for example in heat-absorbing filters for movie projectors, while cerium(IV) oxide can be used for glass that absorbs ultraviolet wavelengths. Fluorine lowers the dielectric constant of glass. Fluorine is highly electronegative and lowers the polarizability of the material. Fluoride silicate glasses are used in manufacture of integrated circuits as an insulator.

F. Fluorosilicate glass (FSG)

It is a glass material composed primarily of fluorine, silicon and oxygen. It has a number of uses in industry and manufacturing, especially in semiconductor fabrication where it forms an insulating dielectric. The related fluorosilicate glass-ceramics have good mechanical and chemical properties. **Fluorosilicate glass** (**FSG**) is a glass material composed primarily of fluorine, silicon and oxygen. It has a number of uses in industry and manufacturing, especially in semiconductor fabrication where it forms an insulating dielectric. The related fluorosilicate glass-ceramics have good mechanical and chemical properties. Fluorosilicate glass-ceramics are crystalline or semi-crystalline solids formed by careful cooling of molten fluorosilicate glass. They have good mechanical properties.

Potassium fluororichterite based materials are composed from tiny interlocked rod-shaped amphibole crystals; they have good resistance to chemicals and can be used in microwave ovens. Richterite glass-ceramics are used for high-performance tableware.

Fluorosilicate glass-ceramics with sheet structure, derived from mica, are strong and machinable. They find a number of uses and can be used in high vacuum and as dielectrics and precision ceramic components. A number of mica and mica-fluoroapatite glass-ceramics were studied as biomaterials.

G. Safety glass

It is glass with additional safety features that make it less likely to break, or less likely to pose a threat when broken. Common designs include toughened glass (also known as tempered glass), laminated glass, wire mesh glass (also known as wired glass) and engraved glass. Wire mesh glass was invented by Frank Shuman. Laminated glass was invented in 1903 by the French chemist Édouard Bénédictus (1878–1930).

These four approaches can easily be combined, allowing for the creation of glass that is at the same time toughened, laminated, and contains a wire mesh. However, combination of a wire mesh with other techniques is unusual, as it typically betrays their individual qualities.

Toughened glass is processed by controlled thermal or chemical treatments to increase its strength compared with normal glass. Tempering, by design, creates balanced internal stresses which causes the glass sheet, when broken, to crumble into small granular chunks of similar size and shape instead of splintering into random, jagged shards. The granular chunks are less likely to cause injury.

Laminated glass is composed layers of glass and plastic held together by an interlayer. When laminated glass is broken, it is held in place by an interlayer, typically of polyvinyl butyral (PVB), between its two or more layers of glass, which crumble into small pieces. The interlayer keeps the layers of glass bonded even when broken, and its toughening prevents the glass from breaking up into large sharp pieces. This produces a characteristic "spider web" cracking pattern (radial and concentric cracks) when the impact is not enough to completely pierce the glass.

Wire mesh glass (also known as Georgian Wired Glass) has a grid or mesh of thin metal wire embedded within the glass.

Wired glass is used in the US for its fire-resistant abilities, and is well-rated to withstand both heat and hose streams. This is why wired glass exclusively is used on service elevators to prevent fire ingress to the shaft, and also why it is commonly found in institutional settings which are often well-protected and partitioned against fire. The wire prevents the glass from falling out of the frame even if it cracks under thermal stress, and is far more heat-resistant than a laminating material.

H. Photosensitive glass

It is also known as photostructurable glass (PSG), or photomachinable glass, is a crystal-clear glass that belongs to the lithium-silicate family of glasses, in which an image of a mask can be captured by microscopic metallic particles in the glass when it is exposed to short wave radiations such as ultraviolet light. Photosensitive glass was first discovered by S. Donald Stookey in 1937. **Photosensitive glass** contains microscopic metallic particles. These microscopic metallic ion nanoparticles are made of gold or silver which is responsible for the refractive index change. **Photosensitive glass** is similar to photographic film.

I. stained glass (coloured glass):

The term stained **glass** can refer to coloured **glass** as a material or to works created from it. Throughout its thousand-year history, the term has been applied almost exclusively to the windows of churches and other significant religious buildings.

Here are some common additives and the colors they produce:

- Cobalt Oxide: blue-violet.
- Cadmium Sulfide: **yellow**.
- Gold Chloride: red.
- Antimony Oxide: white.
- Sulfur: **yellow**-amber.
- Uranium Oxide: fluorescent **yellow**, green.
- Chromic Oxide: emerald green.

J. Armoured glass

One-way **bulletproof glass** is **composed of** two layers. The outside layer – on the threat side – is **made of** a brittle **glass** and the inside layer is a flexible polycarbonate. A bullet that strikes the brittle external layer first causes the **glass** to break inward toward the polycarbonate layer. Newer, stronger kinds of bulletproof glass use a sandwich of glass and plastic made of acrylic glass, ionoplast polymers (such as SentryGlas®), ethylene vinyl acetate, or **polycarbonate**, with the thick glass and plastic layers separated by thinner films of various plastics, such as PVB or polyurethane.

2. Non-Silicates

Non-silicates are minerals that do not include the silicon-oxygen units characteristic of silicates. They may contain oxygen, but not in combination with silicon. Their structure tends to be more variable and less complex than that of the silicates, although they too can be subdivided into different classes based on their composition. Sulfates, for example, include the sulfate anion, SO4 with a minus 2 charge, while oxides include oxygen in partnership with a metal like aluminum. Many of the non-silicates are economically important, especially those that include valuable metals. Besides common silica-based glasses many other inorganic and organic materials may also form glasses, including metals, aluminates, phosphates, borates, chalcogenides, fluorides, germanates (glasses based on GeO_2), tellurites (glasses based on TeO_2), antimonates (glasses based on Sb_2O_3), arsenates (glasses based on As_2O_3), titanates (glasses based on TiO_2), tantalates (glasses based on Ta_2O_5), nitrates, carbonates, plastics, acrylic, and many other substances.[5] Some of these glasses (e.g. Germanium dioxide (GeO_2, Germania), in many respects a structural analogue of silica, fluoride, aluminate, phosphate, borate, and chalcogenide glasses) have physico-chemical properties useful for their application in fibre-optic waveguides in communication networks and other specialized technological applications.

Silica-free glasses may often have poor glass forming tendencies. Novel techniques, including containerless processing by aerodynamic levitation (cooling the melt whilst it floats on a gas stream) or splat quenching (pressing the melt between two metal anvils or rollers), may be used increase cooling rate, or reduce crystal nucleation triggers.

Examples

Common examples of silicate minerals include quartz, olivines and garnet minerals. Quartz is especially common; sand, for example, is composed primarily of quartz. One abundant non-silicate mineral is pyrite, or "fool's gold," a compound of iron and sulfur well known for its deceptive metallic luster. Others include calcite, from which limestone and marble are formed, hematite, corundum, gypsum and magnetite, an iron oxide famed for its magnetic properties.

NON-SILICATE MINERALS (6 classes)

- A. Oxides.
- B. Sulfides.
- C. Carbonates.
- D. Sulfates.
- E. Halides.
- F. Phosphates.

Manufacture

Have you ever wondered how is glass made? The glass – float glass as we know - is manufactured by the PPG process. This process was invented by Sir Alistair Pilkington in 1952 and is the most popular and widely used process that describes how to make glass for architectural purposes in the world today.

It consists of the following steps:

Stage 1- Melting & Refining:

Fine grained ingredients closely controlled for quality, are mixed to make a batch, which flows into the furnace, which is heated up to 1500 degree Celsius. This temperature is the melting point of glass.

The raw materials that float glass is made up of are:

- SiO_2 – Silica Sand
- Na_2O – Sodium Oxide from Soda Ash
- CaO – Calcium oxide from Limestone / Dolomite
- MgO – Dolomite
- Al_2O_3 – Feldspar

The above raw materials primarily mixed in batch helps to make clear glass. If certain metal oxides are mixed to this batch they impart colors to the glass giving it a body tint.

For e.g.

- NiO & CoO – to give grey tinted glasses (Oxides of Nickel & Cobalt)
- SeO – to give Bronze tinted glasses (oxide of Selenium)
- Fe2O3 – To give Green tinted glasses (oxides of iron which at times is also present as impurity in Silica Sand)
- CoO – To give blue tinted glass (oxides of Cobalt)

Apart from the above basic raw material, broken glass aka cullet, is added to the mixture to the tune of nearly 25% ~ 30% which acts primarily as flux. The flux in a batch helps in reducing the melting point of the batch thus reducing the energy consumed to carry out the process.

Stage 2 - Float Bath:

Glass from the furnace gently flows over the refractory spout on to the mirror-like surface of molten tin, starting at 1100 deg Celsius and leaving the float bath as solid ribbon at 600 deg Celsius.

Stage 3 - Coating (for making reflective glasses):

Coatings that make profound changes in optical properties can be applied by advanced high temperature technology to the cooling ribbon of glass. Online Chemical Vapour Deposition (CVD) is the most significant advance in the float process since it was invented. CVD can be used to lay down a variety of coatings, a few microns thick, for reflect visible and infra-red radiance for instance. Multiple coatings can be deposited in the few seconds available as the glass flows beneath the coater (e.g. Sunergy)

Stage 4 - Annealing:

Despite the tranquillity with which the glass is formed, considerable stresses are developed in the ribbon as the glass cools. The glass is made to move through the annealing lehr where such internal stresses are removed, as the glass is cooled gradually, to make the glass more prone to cutting.

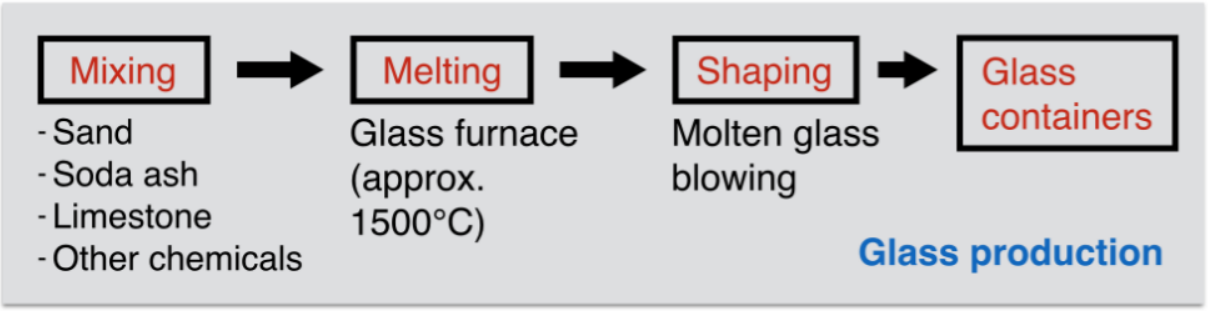
Stage 5 - Inspection:

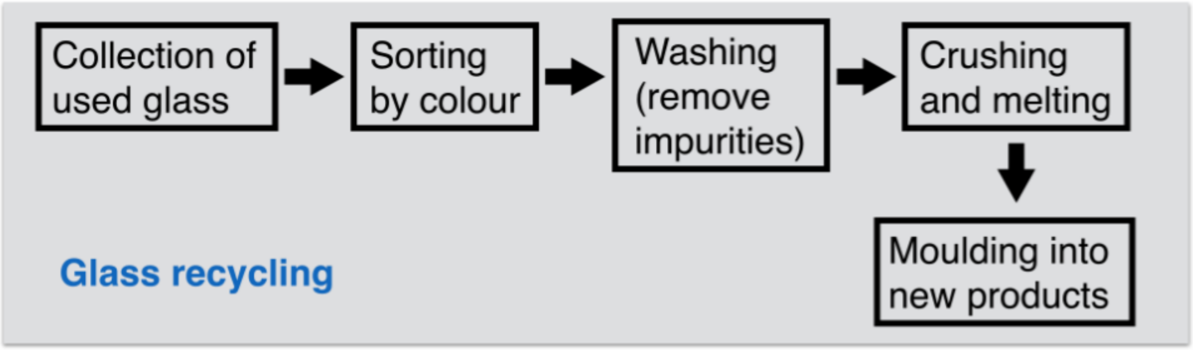
To ensure the highest quality, glass manufacturers carry out inspection at every stage. Occasionally a bubble that is not removed during refining, a sand grain that refuses to melt or a tremor in the tin puts ripples in the glass ribbon. Automated online inspection does two things. It reveals process faults upstream that can be corrected. And it enables computers downstream to steer round the flaws. Inspection technology now allows 100 million inspections per second to be made across the ribbon, locating flaws the unaided eye would be unable to see.

Stage 6 - Cutting to Order:

The entire process of glass making is finally complete when diamond steels trim off selvedge – stressed edges- and cut ribbon to size dictated by the computer. Glass is finally sold only in square meters.

The diagrams below show how glass containers, such as bottles, are produced and recycled.





Processing:

Batch processing system (batch house)

Batch processing is one of the initial steps of the glass-making process. The batch house simply houses the raw materials in large silos (fed by truck or railcar) and holds anywhere from 1–5 days of material. Some batch systems include material processing such as raw material screening/sieve, drying, or pre-heating (i.e. cullet). Whether automated or manual, the batch house measures, assembles, mixes, and delivers the glass raw material recipe (batch) via an array of chutes, conveyors, and scales to the furnace. The batch enters the furnace at the 'dog house' or 'batch charger'. Different glass types, colors, desired quality, raw material purity / availability, and furnace design will affect the batch recipe.

The batch is fed into the furnace at a slow, controlled rate by the batch processing system. The furnaces are natural gas- or fuel oil-fired, and operate at temperatures up to 1,575 °C (2,867 °F). The temperature is limited only by the quality of the furnace's superstructure material and by the glass composition. Types of furnaces used in container glass making include *end-port* (end-fired), *side-port*, and *oxy-fuel*. Typically, furnace size is classified by metric tons per day (MTPD) production capability.

Forming process

There are currently two primary methods of making glass containers: the *blow and blow* method for narrow-neck containers only, and the *press and blow* method used for jars and tapered narrow-neck containers.

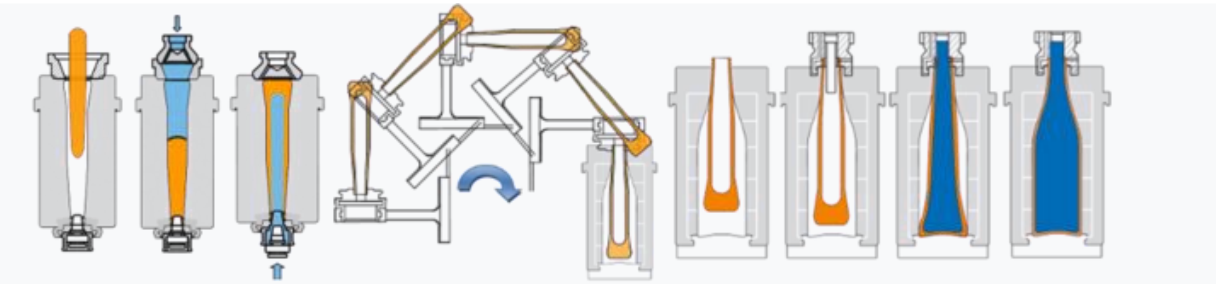
In both methods, a stream of molten glass at its plastic temperature (1,050–1,200 °C [1,920–2,190 °F]) is cut with a shearing blade to form a solid cylinder of glass, called a *gob*. The gob is of predetermined weight just sufficient to make a bottle. Both processes start with the gob falling, by gravity, and guided, through troughs and chutes, into the blank moulds, two halves of which are clamped shut and then sealed by the *baffle* from above.

In the *blow and blow* process, the glass is first blown through a valve in the baffle, forcing it down into the three-piece *ring mould* which is held in the *neckring arm* below the blanks, to form the *finish*. The term "finish" describes the details (such as cap sealing surface, screw threads, retaining rib for a tamper-proof cap, etc.) at the open end of the container. Then compressed air is blown through the glass, which results in a hollow and partly formed container. Compressed air is then blown again at the second stage to give final shape.

Containers are made in two major stages. The first stage moulds all the details ("finish") around the opening, but the body of the container is initially made much smaller than its final size. These partly manufactured containers are called *parisons*, and quite quickly, they are blow-molded into final shape.

The "rings" are sealed from below by a short plunger. After the "settleblow" finishes, the plunger retracts slightly, to allow the skin that's formed to soften. "Counterblow" air then comes up through the plunger, to create the parison. The baffle rises and the blanks open. The parison is inverted in an arc to the "mould side" by the "neckring arm", which holds the parison by the "finish".

As the neckring arm reaches the end of its arc, two mould halves close around the parison. The neckring arm opens slightly to release its grip on the "finish", then reverts to the blank side. *Final blow*, applied through the "blowhead", blows the glass out, expanding into the mould, to make the final container shape.



Steps during *blow and blow* container forming process

In the *press and blow* process, the parison is formed by a long metal plunger which rises up and presses the glass out, in order to fill the ring and blank moulds. The process then continues as before, with the parison being transferred to the final-shape mould, and the glass being blown out into the mould.

The container is then picked up from the mould by the "take-out" mechanism, and held over the "deadplate", where air cooling helps cool down the still-soft glass. Finally, the bottles are swept onto a conveyor by the "push out paddles" that have air pockets to keep the bottles standing after landing on the "deadplate"; they're now ready for annealing.

The forming machines hold and move the parts that form the container. The machine consists of 19 basic mechanisms in operation to form a bottle and generally powered by compressed air (high pressure – 3.2 bar and low pressure – 2.8 bar), the mechanisms are electronically timed to coordinate all movements of the mechanisms. The most widely used forming machine arrangement is the *individual section* machine (or IS machine). This machine has a bank of 5–20 identical sections, each of which contains one complete set of mechanisms to make containers. The sections are in a row, and the gobs feed into each section via a moving chute, called the *gob distributor*. Sections make either one, two, three or four containers simultaneously (referred to as *single*, *double*, *triple* and *quad* gob). In the case of multiple gobs, the *shears* cut the *gobs* simultaneously, and they fall into the blank moulds in parallel.

Forming machines are largely powered by compressed air and a typical glass works will have several large compressors (totaling 30k–60k cfm) to provide the neecessary compressed air. Furnaces, compressors, and forming machines generate large quantities of waste heat which are generally cooled by water. Hot glass which is not used in the forming machine is diverted and this diverted glass (called *cullet*) is generally cooled by water, and sometimes even processed and crushed in a water bath arrangement. Often cooling requirements are shared over banks of cooling towers arranged to allow for backup during maintenance.

Internal treatment

After the forming process, some containers—particularly those intended for alcoholic spirits—undergo a treatment to improve the chemical resistance of the inside, called *internal treatment* or dealkalization. This is usually accomplished through the injection of a sulfur- or fluorine-containing gas mixture into bottles at high temperatures. The gas is typically delivered to the container either in the air used in the forming process (that is, during the final blow of the container), or through a nozzle directing a stream of the gas into the mouth of the bottle after forming. The treatment renders the container more resistant to alkali extraction, which can cause increases in product pH, and in some cases container degradation.

Annealing

As glass cools, it shrinks and solidifies. Uneven cooling causes weak glass due to stress. Even cooling is achieved by annealing. An annealing oven (known in the industry as a lehr) heats the container to about 580 °C (1,076 °F), then cools it, depending on the glass thickness, over a 20 – 60 minute period.

Cold end

The role of the ***cold end*** of glass container production is to complete the final tasks in the manufacturing process: spray on a polyethylene coating for abrasion resistance and increased lubricity, inspect the containers for defects, label the containers, and package the containers for shipment.

Coatings

Glass containers typically receive two surface coatings, one at the *hot end*, just before annealing and one at the *cold end* just after annealing. At the *hot end* a very thin layer of tin(IV) oxide is applied either using a safe organic compound or inorganic stannic chloride. Tin based systems are not the only ones used, although the most popular. Titanium tetrachloride or organo titanates can also be used. In all cases the coating renders the surface of the glass more adhesive to the *cold end* coating. At the *cold end* a layer of typically, polyethylene wax, is applied via a water based emulsion. This makes the glass slippery, protecting it from scratching and stopping containers from sticking together when they are moved on a conveyor. The resultant invisible combined coating gives a virtually unscratchable surface to the glass. Due to reduction of in-service surface damage, the coatings often are described as strengtheners, however a more correct definition might be strength-retaining coatings.

Inspection equipment

Glass containers are 100% inspected; automatic machines, or sometimes persons, inspect every container for a variety of faults. Typical faults include small cracks in the glass called *checks* and foreign inclusions called *stones* which are pieces of the refractory brick lining of the melting furnace that break off and fall into the pool of molten glass, or more commonly oversized silica granules (sand) that have failed to melt and which subsequently are included in the final product. These are especially important to select out due to the fact that they can impart a destructive element to the final glass product. For example, since these materials can withstand large amounts of thermal energy, they can cause the glass product to sustain thermal shock resulting in explosive destruction when heated. Other defects include bubbles in the glass called *blisters* and excessively thin walls. Another defect common in glass manufacturing is referred to as a *tear*. In the *press and blow* forming, if a plunger and mould are out of alignment, or heated to an incorrect temperature, the glass will stick to either item and become torn. In addition to rejecting faulty containers, inspection equipment gathers statistical information and relays it to the forming machine operators in the hot end. Computer systems collect fault information and trace it to the mould that produced the container. This is done by reading the mould number on the container, which is encoded (as a numeral, or a binary code of dots) on the container by the mould that made it. Operators carry out a range of checks manually on samples of containers, usually visual and dimensional checks.

Secondary processing

Sometimes container factories will offer services such as **labelling**. Several labelling technologies are available. Unique to glass is the *Applied Ceramic Labelling* process (ACL). This is screen-printing of the decoration onto the container with a vitreous enamel paint, which is then baked on. An example of this is the original Coca-Cola bottle.

Packaging

Glass containers are packaged in various ways. Popular in Europe are bulk pallets with between 1000 and 4000 containers each. This is carried out by automatic machines (palletisers) which arrange and stack containers separated by layer sheets. Other possibilities include boxes and even hand-sewn sacks. Once packed, the new "stock units" are labelled, warehoused, and ultimately shipped.

Lifecycle impact

Glass containers are wholly recyclable and the glass industries in many countries have a policy, sometimes required by government regulations, of maintaining a high price on cullet to ensure high return rates. Return rates of 95% are not uncommon in the Nordic countries (Sweden, Norway, Denmark and Finland). Return rates of less than 50% are usual in other countries.[*citation needed*] Of course glass containers can also be reused, and in developing countries this is common, however the environmental impact of washing containers as against remelting them is uncertain. Factors to consider here are the chemicals and fresh water used in the washing, and the fact that a single-use container can be made much lighter, using less than half the glass (and therefore energy content) of a multiuse container. Also, a significant factor in the developed world's consideration of reuse are producer concerns over the risk and consequential product liability of using a component (the reused container) of unknown and unqualified safety. How glass containers compare to other packaging types (plastic, cardboard, aluminium) is hard to say; conclusive lifecycle studies are yet to be produced.

Glass Material Applications:

Glass as a primary source material is used across an extremely broad range of applications and industries. The following is a list of some common glass material applications:

- Glass is vital to the production of semiconductor wafers. Glass wafers act as a carrier substrate, facilitating the safe handling of thinner and more delicate silicone materials.
- Oven doors and stove tops are typically comprised of glass material.
- The biotech sector relies on borosilicate glass wafers for a variety of medical devices because of its clear optical transparency and resistance to high temperatures, radiation, and energy. Glass wafers also act as a carrier substrate to protect silicone devices used in nanotechnology.

- **MEMs and Electronics.** TV, computer, and smartphone screens are all made from glass. Engineers use special glass types for touchscreen displays. Glass wafers are also used as substrate carriers and wafer packaging for sensitive components in microelectronic mechanical systems (MEMs) and electronics.
- **Automotive and transportation.** Windshields, headlights, and backlights make use of specific glass materials. Glass is also used as a source material for many lightweight, reinforced structural components found in automobiles, airliners, helicopters, ocean cruisers, and other vehicles.
- **Medical technology.** As an example of the use of glass in the medical field, X-ray machines contain glass.
- **Renewable energy.** Low-iron or extra-clear glass has extremely limited light reflection properties, which makes it an excellent fit for solar cell covers. Maximum amounts of sunlight can come through the glass cover and help charge the solar battery.
- **Integrated Circuit (IC) Packaging.** Glass vias (TGV) and wafer-level glass capping (WLC) are used to ICs against corrosion or impacts to ensure optimal functionality. They serve a dual purpose of holding contacts to external circuits in place.

Properties of glasses like the density, viscosity, thermal expansion coefficient, chemical durability, electrical resistivity, and refractive index, as a function of bulk composition define the common structure models. The concepts of phase separation, bridging and non-bridging oxygen formation, network structures, and elemental effect on composition properties further explain the characteristic of a particular glass. Thermal history has a profound effect on density and viscosity of a vitreous glass. Therefore, it is essential to fully understand a glass composition and thermal history, to produce glasses of desirable mechanical, optical, and electrical properties for a particular application.. Hasanuzzaman, Muhammad & Rafferty, Aran & Sajjia, Mustafa & Olabi, Abdul Ghani. (2015). Properties of Glass Materials. 10.1016/B978-0-12-803581-8.03998-9. Properties of glasses like the density, viscosity, thermal expansion coefficient, chemical durability, electrical resistivity, and refractive index, as a function of bulk composition define the common structure models. The concepts of phase separation, bridging and non-bridging oxygen formation, network structures, and elemental effect on composition properties further explain the characteristic of a particular glass. Thermal history has a profound effect on density and viscosity of a vitreous glass. Therefore, it is essential to fully understand a glass composition and thermal history, to produce glasses of desirable mechanical, optical, and electrical properties for a particular application.

Properties of manufactured glass Glass tubes made from three types of glass are utilized for the production of laboratory volumetric glassware and other types of laboratory glassware that are in the production program of the Company. Borosilicate glass Excellent physical and chemical properties of this type of glass enable using of this glass not only for production of laboratory glassware but for various others purposes, as for instance in the pharmacy (vials), medicine (glass syringes), at production of brilliant lighting unit, at various branches of the textile industry (fingers) and in other further ranges where is required higher temperature and chemical resistance. Soda-lime glass This glass has good chemical as well as physical properties and it is suitable for the products that resist momentarily the impact of chemical medium and limitedly also temperature differences. Both types of pipettes are produced from the soda-lime glass. Neutral glass This glass is very good resistant to alkalis and acid. It is suitable for contact with food.