Basic Types of Glass

1. Float / Annealed Glass
2. Toughened/Tempered Glass
3. Laminated Glass
4. Fire Resistant Glass by Golden Glass

Float / Annealed Glass

In 1952 Alistair Pilkington invented the float glass process. This process used a horizontal method whereby glass was drawn over top of a bath filled with molten tin. This method is still the most common method of glass manufacture today.

Float Glass Manufacture

This process involves pouring recycled glass, silica sand, lime, potash and soda from a furnace onto a large bed of molten tin. In the float process, a continuous ribbon of glass
moves out of the melting furnace and then floats across the surface of an enclosed bath of molten tin. The semi-molten ribbon is held in a chemically controlled atmosphere at a high temperature for a long enough time for the irregularities to flow out and for the surfaces to be flat and parallel. Because the surface of the molten tin is dead flat, the glass also becomes flat. The ribbon is then cooled down while still advancing across the molten tin until the surfaces are hard enough to be take out of the bath without the rollers marking the bottom surface; so a ribbon is produced with a uniform thickness and bright polished surfaces without the need for further processing.

The Raw materials are mixed and heated to around 1500º C, as the ribbon of glass leaves the furnace and enters the float bath the temperature comes down to around 1050º C. The glass continues to cool as it is drawn along the bath of molten tin and enters the cooling lehr at approx 600º C. As it progresses along its journey it continues to cool and leaves to cooling lehrs at 200º C. It is now cool enough to cut and stack.

**Toughened/Tempered Glass**

Toughened glass is essentially made in the same way as normal, annealed glass. The only difference is that there is an extra stage at the end of the manufacturing process which adds around 3~5 times greater strength than the ordinary annealed glass.

Firstly, we talk about the *Glass Breakage*:

**How Does Glass Break?** Glass will break when it is under a stress that it cannot withstand. This stress can be caused by sudden impact, increasing pressure upon certain points of the glass, or by cracks developing in the glass' surface.

**How Do These Cracks Affect Glass?** The strength of a piece of glass is impaired by tiny cracks, known as 'Griffith Cracks' on the surface of the glass. These Griffith cracks are very small, usually between 1µm to 1nm long (0.000,001 metres to 0.000,000,001 metres). These cracks distort the stress pattern within the glass' structure, from their normal (1.) to concentrating the stress in the area around the tip of the crack (2.).

![Diagram of stress patterns](image)

These cracks propagate through the glass, increasing the stress on ever-decreasing surface areas the crack gets deeper. As the stress at the tip of the glass increases, the bonds between
the molecules at the tip of the crack are put under such high stresses that they break. This increases the stress in the next set of molecules below, and as the surface area under this higher stress is smaller, these bonds break too, extending the crack deeper into the glass until it has broken all the bonds through the glass. This breaks the glass with a visible crack, examples of which can sometimes be seen in doors where they have been flung open and hit a wall and caused a crack in the glass. There is a visible line because there are no longer any bonds between those molecules, and new surfaces have formed at the edges of the broken pieces of glass.

How Can Toughened Glass Resist This?

Any cracks in the surface of the glass serve to raise the stress in a particular part of the glass. But, cracks can only grow in areas of tensile stress, where adjacent molecules are already being pulled apart. This makes it easy for the cracks to spread. Because the surface of toughened glass is in compression, these small cracks have little effect upon the glass, because the internal compression forces act against their force upon the glass.

When toughened glass does break, the compressive and tensile energies within the glass are used to make the small pieces of glass. It takes a lot of energy to form a new surface or edge, and because the forces in the glass are so high, it produces lots of small 'dice' of glass, each with many faces. Also, as the glass breaks, some of the energy is released as sound energy, in the form of a loud 'bang,' and some of it becomes kinetic energy, which sometimes makes the small 'die' fly out in many directions. The sorts of things that can make toughened glass are large dynamic loads, things such as bricks, .22 rifle pellets, hammers, Boeing 747 wheel-nuts, albatrosses dying at 9000 feet, and hail-stones like saucers (!).

Now we look back to the toughening process
The Toughening Process

Toughened glass is essentially made in the same way as normal, annealed glass. The only difference is that there is an extra stage at the end of the manufacturing process which adds the greater strength to the glass.

Whilst the glass is still hot from production (at about 650 degrees centigrade), the outside surfaces of the glass are rapidly cooled to room temperature by jets of water or cold air jets. This cools the surface of the glass quicker than the glass in the centre.

Because it is cooling quicker, the surface molecules have less time to organise themselves into a regular pattern, and settle whilst they are still dis-organised and random. The centre of the glass however, which cools down more slowly, is able to arrange into a more regular pattern, allowing more 'shrinkage' to occur in the centre of the glass than the outer surfaces.

This has the effect of putting the surface molecules of glass into compression, whilst putting the centre part of the glass into tension.

This change in internal tension and compression is what makes toughened glass between 3 to 5x stronger than ordinary glass. If change the time, wind pressure control, then the float glass will become heat strengthened glass of lower surface compression range between 24 to 52 Mpa.

When toughened glass breaks, it breaks into small dull-edged pieces. This happens because of the compression and tension forces on the glass. The energy that is stored in the glass through the compression and tension is released as the glass breaks, breaking the molecule's bond's, forming lots of new surfaces (hence the large number of small pieces), providing kinetic energy for the small pieces to 'fly out' in all directions and also producing a loud bang sound. The properties that the glass gains from the extra heating and cooling process at the end of manufacture which puts different parts into compression and tension make it stronger and also increase the glass' maximum tolerances for compressive stress and tensile stress.

What these properties do for the glass

This enables toughened glass to be used in applications where higher stresses and forces will be encountered, such as vehicle wind screens, sky-light/roofing type applications and also building design, where glass is sometimes used to cover a large part of one of a building's sides.
These are some of the properties of toughened glass:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
<th>NOTES / COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>2.5 Kg/m²</td>
<td>(Per 1 mm thickness)</td>
</tr>
<tr>
<td>Young’s Modulus (E)</td>
<td>70 GPa (N/mm²)</td>
<td>(Giga Pascal’s)</td>
</tr>
<tr>
<td>Compressive</td>
<td>1000 MPa (N/mm²)</td>
<td>This high value means that a compressive force of 10 tonnes is needed to shatter 1 cm³ cube of glass.</td>
</tr>
<tr>
<td>Strength</td>
<td>120 - 200 MPa (N/mm²)</td>
<td>(MegaPascal’s) Dependant upon thickness of glass and types of edge work and holes.</td>
</tr>
<tr>
<td>Thickness</td>
<td>Commonly 6.4 mm</td>
<td>Never &lt;6 mm</td>
</tr>
<tr>
<td>Thermal Stability</td>
<td>Withstands &lt;295°c</td>
<td>Also withstands differentials of up to 250 degrees across the thickness of the glass.</td>
</tr>
</tbody>
</table>

Ordinary Annealed glass when broken shatters into dangerous, Razor sharp shards and splinters. Toughened Safety glass when broken breaks into small harmless granules, reducing the risk of injury.

Before the toughened glass ex-factory, we will randomly check/measure the surface & edge compression for each batch lot of glass panels by using an optical instrument called a differential surface refractometer (dsr). It measures the twist of polarized light from the glass surface and this can be converted to a surface stress.

**Dealing With Distortion**

By its very nature of heating sheet glass to a level of soft pliability, the tempering process always causes distortion to some degree. Its severity is largely a function of the furnace and tempering conditions. Though usually imperceptible to the consumer, optical distortion can be unacceptable for architectural applications, especially those with tinted or coated products. Distortion is also a critical problem when glass is to be treated (e.g., with lamination) after
toughening. Therefore, optimization of the tempering process to minimize distortion represents a constant challenge for manufacturers.

In tempering, glass is heated by radiation, convection or a combination of both. Through this heating, glass enters a transition range, during which typical transition problems such as roll-wave distortion or bow and warp can occur.

"During the heating, glass will sag very slightly between the carrier rolls (in a roller hearth or gas hearth furnace), or from the tongs in a vertical furnace. The result is a slight deviation from optically flat glass, usually seen as ripples or roller wave. Glass thickness and size affect the amount of distortion: generally, the thicker the glass, the less deviation from perfect flatness, while larger glass sizes tend to have more deviation.

To minimize distortion, many issues must be considered in optimizing the tempering process. Three most important considerations in optimizing the process involve the conveyor system, temperature uniformity throughout the furnace and the quench design.

Distortion will vary depending on how flat the conveyor bed is maintained and how precisely motion is controlled via conveying rollers. Flatness is a function of roll spacing and roll speed, and sometimes it's best to have a lot of small rollers close together. Roll spacing and line speed should be optimized to avoid distortion during the quenching process.

According to Tamglass Group, a leading glass machinery manufacturer from Finland agrees that temperature uniformity is critical. Most important is focusing and controlling heat according to the glass type and loading. Their systems use an optimized heating control method whereby sensors detect where the glass is located and only that area is heated. This is an improvement over the more common open-type heating system that heats the entire furnace.

Therefore, according to our experience, different thickness or types of glass required different control on the time, wind pressure during the toughening process.

Common industry practice and MasterSpec®, a compendium of specifications produced by the American Institute of Architects, require that roll-wave distortion be parallel with the bottom edge of glass as installed. However, this is only possible if the width of lites falls within the widths that can be handled by the tempering furnace (typical maximum width is 2440mm). Further, loading capabilities through the furnace often make it inefficient to produce a large quantity of glass with distortion in the same direction.

**Work Toward a Distortion Standard**

ASTM C 1048 Standard Specification for Heat-Treated Glass includes limitations for bow and warp distortion, but the current requirements for flatness does not limit the kind of visually unacceptable roll-wave distortion produced by the horizontal tempering process.

In the meantime, a great number of float glass manufacturers and temperers have developed in-house standards for distortion tailored to meet the needs of their markets. For example, the visual 'zebra board' method reflects lines off of the glass surface. We also use a small roll-wave gauge that measures distortion, which is a small dial calliper, detects any high or low points on the glass surface.
Avoiding Inclusions

Approximately 50 different types of dirt or other inclusions found in glass have been identified, according to GANA. Most of these are blemishes that do not in any way affect performance of the glass. However, much has been made of very rare but harmful glass inclusions such as nickel sulfide stones, which are contaminants that may cause spontaneous breakage at some point after tempering—even years later.

Inclusions large enough to be detected visually on the float production line are cut out. Most other harmful inclusions that get through will cause breakage at the tempering facility but with an exceptional case, nickel sulfide causes breakage, and only if the stone is located in or near the tension zone of fully tempered glass. During tempering, the nickel sulfide inclusions are transformed into a state wherein they will expand with time and temperature. Nickel sulfide stones typically range in size from three to 15 thousandths of an inch, making online detection of every tiny inclusion impractical. ASTM C 1036-90 Standard Specification for Flat Glass permits stone inclusions from less than 16 up to 125 thousandths of an inch in float glass.

The practice of cutting visible blemishes from glass before it ever reaches the tempering furnace is usually motivated by the desire to produce the most aesthetically perfect glass possible, rather than because the inclusion might cause spontaneous breakage.

We must say that the best defense against inclusions of all types is inspection. Glass is inspected at several stations. It is visually inspected when it is taken out of the manufacturer's pack and placed on the cutting line, during the breakout procedure, after it is washed, when it is loaded into the furnace and again when it comes out of the furnace. We have a final inspection for picky customers where the glass is examined on a light rack."

It should be emphasized that apparently spontaneous breakage is not always caused by an inclusion. Surface or edge damage, for example, can eventually result in breakage for no apparent cause. We have rarely heard of customers experiencing spontaneous breakage. We believe that physical damage, which weakens the glass and/or mechanical stress, is responsible for most tempered glass breakage. Glass is glass and it can be broken by a number of causes, some of them not readily detected.

"We All Wash Our Glass and Our Hands"

Washing flat glass prior to tempering is another issue. Encouraged by experts to avoid the scratched, pockmarked and dented glass that can result from tempering unwashed glass, washing also serves the basic purpose of keeping the tempering furnace clean. Once dirt or particles from the edging process are introduced into the furnace, it can build up on the conveyance rollers, eventually damaging glass as it flows through the system. Other times, particles such as glass fines from the cutting or edging process and handling smudges that are not washed off the surface of glass before tempering will bake onto the surface, causing blemishes.

Quality Control is Paying Off

Glass manufacturers and temperers are to be commended for their extraordinary efforts to eliminate the problems inherent in tempered glass. Through quality control measures including furnace design improvements, tempering optimization and detection efforts, the industry has come a long way toward this goal. All our tempered glass will meet BS6206, ASTM C1048 and ANSI Z97.
**Laminated Glass**

Laminated safety glass is produced by bonding or laminating together two or more layers of glass with a layer of polymer film in between. By using heat and pressure, air bubbles are eliminated from the laminate so that it appears optically as a single sheet of glass. Mechanically, however, it is more robust: If the laminate is fractured, the broken glass shards are held together and are less likely to cause injury.

Good quality of laminated glass is avoiding the bubble and delamination.

*Reasons for bubble and delamination:*

- The bad roller wave of tempered glass can result in bubble and delamination.
- The moisture content of PVB may cause the delamination.
- The temperature and humidity of lamination room may not meet with the requirement.
- The cleanliness of tempered glass may cause the delamination.
- The failure in controlling the parameters of pre-press may cause the penetration of the autoclaving medium into the edge during manufacturing.

The rules of workmanship and procedure ensure the desirable quality of glass:

*Clean:* Inspect the thickness and size of glass, washing machine. No traces of water and contaminations should remain on the glass.

*Lamination:* Inspect the temperature and humidity of lamination room. In addition, test the moisture content and thickness of PVB.

*Unload point:* Control the height of roll.

*Pre-press:* The heating temperature and the linearity speed of glass are not unique. The parameters vary according to different glass combinations as well as thickness.

*Autoclaving:* Select the right parameters and processing procedure according to the thickness and quantity of glass.
We will follow the procedure of ASTM C1172 to inspect the finished laminated glass but we also meet more tight requirements than this standard from our client by project based before ex-factory.

**Fire Resistant Glass**

Generally, any type of glass that can withstand the fire test and therefore resist the passage of smoke, flames and hot gases, is considered "fire-resistant glass". However all of these can be than further categorized depending on their performance during a fire. They can be classified into two categories: heat-transmitting (integrity only) glass and heat-insulating glass (insulation & integrity). The basic difference is that heat-transmitting glass will contain flames and inflammable gas for a short period of time, but does not prevent the transmission of heat to the other side of the glazing while fire-insulating glass will not only contain flames and inflammable gas for a longer period of time but will also prevent the transmission of flames, heat and smoke to the other side of the glazing. The most successful brand names are Pyran, Pyrostop, and Pyrobel from Schott Glass, Pilkington and Glaverbel etc. We also developed our own single glazed fire resistant glass and are popularly used in China.

Golden Glass Fire Resistant Glass is a monolithic float glass which has been created through special heat treatments, high performance toughening and Heat Soak testing, combined with a rigorous manufacturing process which gives it excellent fire resistance qualities. It is designed to provide an effective barrier against the passage of flames, smoke and hot toxic gases. It can be supplied in large panel sizes or cut-to-size and shape but cannot be cut or worked after delivery.

We have successfully tested in China for 30 to 120 min. fire resistant (integrity) but our fire resistant tempered glass can have 8~10x strength than normal ordinary glass. Therefore we believe that it can be used in structurally design glass wall. Our fire resistant tempered glass conforms to GB9963 (for tempered glass) and GB17841-1999 (tempered glass/heat strengthened glass used in curtain wall/glass wall). The surface stress is 3x than normal tempered glass so we can assure that it should fulfill the structurally requirement of glass used in curtain wall or glass wall. For example, a 8mm thick clear fire resistant tempered glass can withstand a high loading weight to 2500kgf.
Below is the fire testing and bending test on our fire resistant glass:

The relationship between temperature and time: \( T-T_0=345\log_{10}(8t+1) \);

\( T \)—the growing up of temperature in oven, \( \square \);
\( T_0 \)—start rate of temperature in oven, \( \square \) (in between 5 ~ 40 \( \square \));
\( t \)—testing time period, min. 

\textbf{Relationship between temperature and time}
The bending value (N/mm$^2$)

<table>
<thead>
<tr>
<th>Type</th>
<th>Float Glass</th>
<th>Tempered Glass</th>
<th>Golden Glass</th>
<th>Fire Resistant Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (mm)</td>
<td>6 ~ 12</td>
<td>6 ~ 12</td>
<td>6 ~ 12</td>
<td></td>
</tr>
<tr>
<td>Strength: fg</td>
<td>Face strength</td>
<td>28.0</td>
<td>84.0</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>Edge strength</td>
<td>19.5</td>
<td>58.8</td>
<td>88</td>
</tr>
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</table>

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