Building Materials III
Lecture 7

Toughened Glass

We will start with Toughened glass, a small history. François Barthelemy Alfred Royer de la Bastille of Paris, France is credited with first developing a method of tempering glass by quenching almost molten glass in a heated bath of oil or grease Tempered glass, sometimes known as Bastie glass after de la Bastie. What this particular person did was, he bolted or quenched molten glass into a heated bath of oil, this resulted in a glass formed due to tempering and this toughened glass is also called as Bastie glass. The German Friedrich Siemens developed a different process, sometimes called compressed glass or Siemens glass, producing a tempered glass stronger than the Bastie process by pressing the glass in cool moulds. Though the underlying mechanism was not known at that time, the effect of 'tempering' glass have been known for centuries. Especially in modern architecture, when you think of frameless glass, bodies of frameless glass structures or frameless glass units, the first thing that comes to mind is Toughened glass because it is the most widely and commonly used glass in terms of formlessness. Toughened or tempered glass is a type of safety glass processed by controlled thermal or chemical treatments to increase its strength compared to normal glass. Tempering puts the outer surfaces into compression and the inner surfaces into tension. Such stresses cause the glass, when broken, to crumble into small granular chunks instead of splintering into jagged shards as plate glass creates. You can see there is compression and tension, so when the glass breaks or is forced to break or cracks, what happens is, it breaks into small splinters rather than becoming big shards. This is an important, very useful factor. As a result of its safety and strength, toughened glass is used in various applications, including passenger vehicle windows, shower doors, architectural glass doors and tables, refrigerator trays, mobile screen protectors as a component of bulletproof glass for diving masks, and various types of plates and cookware. As far as architecture is concerned, toughened glass will find its immediate use in glazing, structural glazing or more importantly, skylights. When you introduce skylights in any built form, the first option that goes into the glass choice is toughened glass, either a single layer of toughened glass is used or a double layer of toughened glass is used. Nevertheless, it is toughened glass or tempered glass.

Toughened glass is physically and thermally stronger than the regular glass. The greater contraction of the inner layer during manufacturing induces compressive stresses in the surface of the glass balanced by tensile stresses in the body of the glass. For the glass to be considered toughened, this compressive stress on the surface of the glass should be a minimum of 69 megapascals. For it to be considered a safety glass, which is what it is considered mostly, the surface compressive stress should exceed 100 megapascals (15,000 psi). Generally, in order to

use for skylights or glazing, you can use the toughened glass that denotes 69 megapascals, but in the case of safety glass or for it to be used in terms of emergency exits or vehicle windows, etc, it should exceed 100 megapascals. The greater the surface stress, the smaller the glass particles will be broken.

We talked about the frameless glass. Wherever frameless glasses come, when it needs to stand on its own, has to bear its own load, toughened glass is used. We will talk about its applications - In terms of buildings and structures, toughened glass is used in buildings for unframed assemblies, such as frameless glass doors. Structurally loaded applications and any other application that would become dangerous in the event of a human impact. Anything that is a possible cause of human impact, which can be broken and which kind of protection, Toughened glass is the first choice.

Tempered and heat strengthened glass can be three to seven times stronger than annealed glass. Plate glass is nothing but annealed glass, tempered glass or toughened glass can be seven times stronger. Building codes require tempered or laminated glass in several situations including some skylights, near doorways and stairways, large windows, windows which extend close to floor level, sliding doors, elevators, fire department access panels and near swimming pools. Since it is very important in terms of safety and actually called safety glass in certain cases, building codes and standard codes actually specify the use of toughened glass. As mentioned earlier, it is must compulsorily be used in skylights, near doorways and stairways, large windows, windows that extend close to floor level and of course emergency exits.

We can see how toughened glass is actually placed. The outer structure is subjected to compression and the inner or the other side is subjected to tension.

Laminated Glass

Laminated glass is similar as well. Laminated glass was actually a happy accident. There was this French chemist, Edouard Benedictus, he accidentally dropped a beaker which had a plastic cellulose structure. What happened was, instead of breaking and shattering into so many pieces, the glass actually broke into small pieces and stuck to the plastic cellulose that was there. This was actually an inspiration or a happy accident for him to invent or at least start the development of what is called as laminated glass. The Modern laminated glass is produced by bonding two or more layers of ordinary annealed glass, together with a plastic interlayer. What happens is, it is like a sandwich, we have to plate glasses, in between we have a plastic interlayer which is usually PB - polyvinyl butyral or ethylene-vinyl acetate (EVA). These are the two main cellulose structures that are used in between two plate glass to form Laminated glass. Laminated glass is also similar to toughened glass but it is a bit lesser in terms of strength and

different in terms of its composition. Laminated glass is normally used when there is a possibility of human impact or where the glass could fall if shattered and also for architectural applications. It's very similar to toughened glass.

Skylight glazing and automobile windshields, widespread use of laminated glass happened in windshields of cars and other four wheel automobiles. It was a very safe method of having to be protected from impact. In other cases, in geographical areas requiring hurricane-resistant construction, laminated glass is often used in exterior storefronts, curtain walls and windows. For example, even now when you have some sort of a social or civil problem, when people attack stores as such, you'd notice glass walls don't actually break, they shatter and form a spider web kind of cracks, this is because it is laminated glass. When the glass actually braces impact, what happens is, it does crack but it sticks to the cellulose structure in between. Laminated glass is also used to increase the sound insulation rating of a window. This offers a lot of advantages, being a cellulose structure in between, it offers thermal insulation, sound insulation and also protection against UV rays. Laminated glass is also used to increase the sound insulation rating of a window, where it significantly improves sound attenuation compared to non-laminated glass panes of the same thickness. Even if you had a glass with really large thickness, it would still not be as insulated to sound as Laminated glass. For this purpose a special 'acoustic PVB' compound. There are two types of cellulose structure we talked about. An acoustic cellulose structure is added or in case of EVA material, no additional acoustic is required because it serves as an acoustic itself. An addition property for laminated windows is that the PVB and EVA interlayer can block essentially almost most of the UV radiation coming in, 99% of the UV rays can be contained. It also has an increased safety factor compared to standard float glass. This can also be called a safety glass. It finds a wide product in places where there is a lot of impact or where glass could probably shatter.

This is used in skylights, Balustrades. The fashionable glass balconies or Balustrades that are made these days actually have either toughened glass or laminated glass. Solarium roofs, the first widespread use other than that of windshields was that of Solarium roofs. The first solarium constructed used a lot of Laminated glass. Recording studios, the glass in between the recording studio and the control room, the glass used is usually laminated glass which helps in the sound insulation. You also have glazed doors and side panels, the gymnasiums where a lot of glass walls or glass partitions are required, laminated glass in the best choice. Household furniture, kitchen cabinet glazed doors and shelving. Bathroom shelving, small items in which the glass could be used and also needed protection, laminated glass makes a good choice. Shop Windows, Shopping Centers, Public bar, shelving, partitions and of course, mirrors.

Adding two or more types of glass i.e toughened glass, laminated glass or even fire resistant glass, when you add these three, a better-tempered glass is formed. This can be more and more used in structural and places where loads need to be carried as such. Today's modern corporate buildings have a roof or a welcoming roof where it is completely made out of glass, this is actually facilitated by combining these types of glasses. Glass staircases are a very good example of these glasses. Glass structures especially in external environments, for example, Le Louvre, the glass pyramid is said to be very famous. There is no actual note of it being toughened but obviously, if there is an external glass like this, it faces a lot of threat from the impact as such. Toughened glass and tempered glass is used extensively, this is a very good example.

In case you want to use glass structures externally, toughened glass and tempered glass are very good solutions. Another very important aspect or property of laminated glass is the energy aspect. Laminated glass configurations are used to achieve low shading coefficients for solar heat gain reduction. These include - Laminated glass with coloured interlayers, Laminated body tinted glass, Laminated spectrally selective heat absorbing glass, Laminated metallic coated glass and Laminated low E-glass. You can apply a lot of energy efficient methods or energy efficient coefficients along with laminated glass to increase its energy efficiency or environment- friendliness. With the above scope of possible combinations, and with the available ranges of glass tints, interlayer colours and glass coatings, it can be seen that laminated glass offer the potential for a vast selection of options with regard to energy performance and aesthetics of building glazing. When comes to glass or external glass, it becomes really aesthetically pleasing and is a very important element in terms of design for modern architecture. This laminated glass is an important source for this element. Energy performance was also better in terms of laminated glasses.

Wired Glass

Now, we come to the third type. As mentioned earlier, the three types of glasses can be fused together to come up with a really efficient glass, that would be essential - toughened glass, laminated glass and the third is, wired glass. When you add these three along with heat and temper it more, it becomes a very good combined composite glass material. Let's look at the Wired glass, during the industrial revolution, rapidly developing new ideas and technologies fed off one another to create continuously evolving assembly-line machines and products. Glass saw a great evolution and production during the Industrial revolution. Industrial Revolution gave birth to the manufacture of glass that led to various glass inventions. You can look at the Pistol palace which is a huge palace made completely out of glass, the one thing they usually faced as a problem regularly was the breakage of glass. It came to a point where they needed to solve it very effectively, that is why the idea of using wire netting incorporated into two

layers of glass seemed to solve it initially at least. The difference between laminated glass and wired glass is that in the laminated glass, there are two plate glasses or annealed glass in between which there was a nitrate structure. In case of wired glass, it was actually fused together with a wire in between. So, it's not like two separate glasses that was fused into one single sheet. This gave an initial form to the present Wired glass.

The main purpose of wired glass is that it could handle breakage but more importantly, it can also handle fire. Wired glass is a type of glass into which a wire mesh is embedded during production. Wired glass has an impact resistance similar to that of normal glass but in case of breakage, the mesh retains the pieces of glass. This product is traditionally accepted as low-cost-fire-resistant glass. Laminated and toughened glass are probably better but this is low cost and the first one that came out this way. Wired glass can be tinted by aerosol or electricity. Tinting further gave it privacy in terms of its visual impact. Common colours are golden-yellow, green, light blue and violet-rose.

Wired glass is manufactured primarily as a fire retardant, with wire mesh inlaid in the glass to prevent it from shattering and breaking out under stress or when exposed to high temperatures. The first thing glass does when it is exposed to high temperatures is break or fall out, wired glass held it together. With the window intact, the glass keeps the fire at bay, protecting those on the other side from the harmful effects of smoke and flame. Wired glass is made as a part of the rolled glass manufacturing process. Rolled glass process is used to create wired glass, figured or patterned glass, and art/ opalescent/cathedral glass. It did find a lot of other uses, it is produced by continuously feeding wire mesh from a roller into the molten glass ribbon just before it undergoes cooling. Unlike laminated glass where there is a sheet in between, a wire mesh is continuously fed into molten glass. Fire Safety, Shock-resistant safety and Translucent decoration. This is the structure of the glass, you have a wire mesh or wire fencing when you have a glass fused over this, this will give you a wired glass.

Applications - Emergency exit windows or exit ways in staircases. You'd use it in industrial buildings, workshops, stores, basement and parking areas. Wired glass is well-rated to withstand both heat and hose streams and is used on service elevators to prevent fire ingress to the shaft. We noticed for a period of time, the rather very fancy elevators through which you could see people inside and the people inside could see you in return, the main glass that was supposed to be used is wired glass because it is considered safe just in case a fire hit the elevator. This is a small demonstration of how fire and smoke would be kept inside in terms of wired and laminated glasses.

Fire resistant glasses- toughened glass, laminated glass and wired glass are some way or the other developed fire resistant glasses. These three fall under fire resistant glasses. As mentioned earlier, toughened glass, laminated glass and wired mesh glass, these three can be combined to create more variations. Not only are they individually more efficient in their own ways, the three can be combined to form various types of glasses which can yield more strength and more uses. Another important or rather more interesting use of glass is through glass blocks. Glass blocks are used extensively in bathrooms, used in partitions, used a lot in making small shelves. Glass blocks had its origin in factories especially, factories that were rather dingy places and the only way to bring about light was glass. But they also had to use glass in a very efficient way such that it is not very easy to impact and also it had to ensure visual privacy. Glass blocks or bricks made out of glass was the first choice.

Glass brick also known as Glass block, is an architectural element made from glass. Glass bricks provide visual obscuration while admitting light. This was the dual function of Glass blocks. The glass block was originally developed in the early 1900s to provide natural light in manufacturing plants. These are produced for both walls as well as floor applications. They are used in floors which are normally manufactured as a single solid piece, or as a hollow glass block with thicker side walls than the standard wall blocks. These blocks are normally cast into a reinforced concrete grid work or set into a metal frame. Generally, these glass blocks were not standing on their own or bearing their own loads, they were mostly framed into metal or reinforced into other steel or concrete grid work. This helped to span over openings, basements and roofs. Other than walls, it is also used for spanning. They have high thermal insulation values, superior to double glazing and double brick walls. They can act as a thermal barrier. In addition, they are perfect for utilizing the low-lying winter sun for heating. These walls offer a high degree of light transmission up to 79% of the available light. This is equivalent to normal double-glazed insulating panes. Various effects can be achieved using different patterns and surface finishes, and the atmosphere of a room can be altered dramatically using coloured blocks. The image you saw earlier, a little bit of pigmentation or just the sides being coloured can induce a lot of colour and aesthetic capabilities to these glass blocks. You'd notice the other glasses had a lot of uses, they also could be used in case of formlessness, a rather more rich way of aesthetic use would be found in glass blocks. Transparency is one of the most important features of glass blocks. Virtually any degree of transparency or obscurity is possible with the use of clear, patterned or coloured blocks. They break up images and refract light as well as blocks with a satin finish on one or both sides which allow a soft light through, creating a discreet screen. Light is not harsh, it is transferred through, it is diffused and makes it very pleasant, at the same time it makes sure there is a lot of available light. Because of their robust character, glass blocks are a deterrent to burglary. Light toughened glass, laminated glass, glass blocks are also very resistant to a great extent to impact and can be used against burglary. Bullet-proof glass blocks

have also been developed and may be used where a high level of security is required. When you create glass blocks, there is a partial vacuum that is created within glass blocks during the manufacturing process. This internal air space together with their mass, guarantee that glass blocks offer a high level of sound insulation. It covers all the necessary things that glasses could do. It is also an important glass that can offer these things. Sound insulation, superior even to that of brick walls of identical thickness. Acoustic insulation properties of glass blocks provide a noise reduction of 40 and 50 decibels, depending on the size of the block.

You can see, it is very easily used in frameworks as partition walls. Architects for a very long time have encouraged other uses of glass blocks in buildings than only on staircases and the facades of industrial buildings. You can see its widespread uses in bathrooms and showers. The glass blocks have made themselves at home in ordinary buildings. Unlike toughened glass that has a lot of industrial use and safety use, this can be used normally in homes as well. Shower walls can be used in other rooms as partitions, skylights in kitchens, stairs, etc. With that, we come finally to structural glass.

You'd notice that glass developed from being just a small piece of decoration to a lot of very useful purposes, slowly it began to take loads and then finally it became a part of the structure, that's where we will be talking about structural glass. Structural glass or structural glazing is a wide reaching product term used to describe a large number of frameless glasses used. Yes, we talked about frameless glass in terms of toughened glass and laminated glass. When you reinforce this with brackets as such and make it a little more part of the structure, such that it carries the load of the actual structure or it can carry complete floors in glass, it is called structural glass.

These type of structural glass assemblies include walking on structural glass panels, to be used as floor lights, within a solid structure or as a full glass floor. You can have a completely full glass floor. Frameless glass balustrades are another well-used element of structural glass, used to create a clear, frameless glass safety barrier against a fall or level change. Balustrades are actually hazardous by causing people to fall over, even then glass is used since it is very strong.

Full structural glass constructions can be created using elevations of structural glass supported by minimal steel or laminated glass beams and fins. Apart from being frameless, adding minimal steel, glass beams and fins make it a part of the structure such that a whole structure can actually be made from the structural glass. This type of structural glass construction is used to create structural glass box extensions as well as frameless glass roofs. You can see a very typical modern architecture uses a lot of glass especially in the colder regions. You can see other than

the use of beams and columns, glass is actually used as the overall envelope of the building. You'd notice the steel and racquets on the fins that go into structural glazing.