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Review Article

An Overview of Tempered Glass Load Bearing Capability and Mechanical Behavior

Saddam Hussain[1*], Shifa Moiz[2]

[1] *Department of Civil Engineering and Architecture, Kyushu institute of technology, Kitakyushu 804-0015, Japan*
[2] *Department of Civil Engineering, NED University of Engineering & Technology, Karachi 75270, Pakistan*

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Abstract

The study explores if tempered or strengthened with wire meshes, a single glass layer can be termed protective glass. Tempered glass demolishes into small fragments with harsh corners when it fractures. Because of the fracture pattern (fractures in pieces), heat- or chemically pre-stressed glass panel cannot be called safety glass panel until laminated. Bending experiments were run, and the bending strength of single-layer tempered and float glass panel was calculated using well-known formulae. In the context of float and tempered glass panel, the computed values for surface complexation using ultimate strain were matched to the bending strength findings. The following question arises: are the strains measured in the centre of the glass and towards the edge comparable? Strain measurements were also taken on the surface of packed samples in the centre and towards the edge of the glass. Fractures with tiny sharp points characterize glass errors. Despite careful manufacturing and maintenance of glass panes, hits by sharp particles or environmental effects can produce surface flaws. Glass manufacturing processes, such as edge polishing, have an impact on glass strength and can produce defects that spread during the glass's lifespan.

1. Introduction

The float method yields glass sheets with consistent thickness and flawlessly fine surfaces that do not require additional polishing. The resultant glass will next be processed in a variety of methods [1]. For its high optical quality, float glass is

* **Corresponding Author:** Saddam Hussain
E-mail address: Saddam.hussain372@mail.kyutech.jp

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extensively utilized in architecture. Soda lime silicate glass is mostly used in architecture [2]. Based on the end product and application, sophisticated treatment procedures are used to float glass products. When using float glass as a load-bearing component, safety glass is required. A single glass layer can be termed protective glass if tempered or strengthened with wire meshes. Tempered glass demolishes into small fragments with harsh corners when it fractures. Because of the fracture pattern (fractures in pieces), heat- or chemically reinforced glass panel cannot be called safety glass panels until laminated. Bending experiments were run, and the bending strength of single layer tempered and float glass panel was calculated using well-known formulae and Nd compared to observed surface stresses in the example of non-float and tempered glass [3]. The following factors determine the bending strength of a single glass section: a) heat treatment, b) surface circumstance (e.g., non-slip characteristics), c) rate and length of time of loading, d) area of surface stressed in tension, e) relaxation, f) acoustic medium, g) age, i.e., elapsed time since the last mechanical surface modification, h) temperature range, I) edge work [4].

Tempered glass panes should be used to minimize extreme displacements, and the influence of temperature, particularly in outdoors situations, should be factored into the calculations [5]. glass is frequently utilized as a building material to make load-bearing structures, where the bending strength of the material performs an essential part in load carrying capacity. Heat-strengthened or heat-tempered glass must be utilized for safety glass systems. Only the use of tempered glass layers offers protection. As a result, the layers of tempered safety glass should be made of heat-strengthened and heat-tempered glass. Tempering raises the cost of the glass (approximately 1.5 times), thus individuals occasionally try to utilize regular float glass where heat-strengthened or tempered glass will be required [5-6].

To investigate the temperature-dependent behavior of tempering glass panel, an exploratory approach was conducted using a large number of single and tempering glass samples. In four-point bending, the difference in load-bearing capabilities between tempers made from conventional float (laminate glass) and tempered glass layers (safety laminated glass) was also investigated. When temperate glass breaks, the inter-layer can hold the shards together. In safety and non-safety tempered glass samples, several types of inter-layer compounds, both resins and foil (type EVA), were investigated. Glass panel are utilized not only on the inside but also outside. As a result, the effect of temperature at -20 C, +23 C, and +60 C on the bending properties of glass panel was studied.

2. Types of Glass

Glass kinds and commodities with varying characteristics can be created during the post-processing stage. The most popular glass kinds are mentioned are;

2.1. Laminated Glass

Laminated glass is made up of two or more glass pieces joined together by a plastic inter-layer. Glass panes can be of various thicknesses and heat treatments. Autoclave is the most frequent laminating method. For two reasons, the use of laminated glass in architectural glass is highly advantageous. To begin, if one glass panes break, the other panes can continue supporting the imposed stresses if the structure is appropriately built. Second, the scattered glass fragments can adhere to the inter-layer, preventing people from being harmed. The inter-layer is typically composed of polyvinyl butyral, or PVB. A single PVB foil has a minimum thickness of 0.38 mm. Two (0.76 mm) or four (1.52 mm) foils are commonly used to make one PVB inter-layer. PVB is a material property whose physical characteristics change depending on the temperatures and length of the load [6-9].

2.2. Annealed Glass

Without any further processing, annealed glass is ordinary float glass. Annealed glass breaks into huge pieces when broken. [10-12]

2.3. Glass that has been strengthened by heat

Heat toughened glass is manufactured in the same way as completely tempered glass, but the rate of cooling is slower. As a result of the reduced residual stress, the compressive modulus is lower than for completely tempered glass. The pieces are bigger at breakage than in completely tempered glass. Larger glass pieces, on the other hand, provide for a various successive maximum load than completely tempered glass [12-15].

2.4. Tempered Glass

Toughened glass is yet another word for completely tempered glass. Float glass is warmed and then swiftly cooled (ignited) by cold air jets while tempering. The goal of tempering is to generate a symmetrical leftover stress field with tensile stresses in the center and compressing stresses at the glass's surfaces. The surface of the glass is usually cracked. Fractures are permitted to develop in a tensile stress field. If the glass is loaded, fractures will not form until there is a net tensile stress field at the glass's interface. Because completely tempered glass generally fractures into little harmless fragments, it is also known as safety glass [16-19].

3. Stages of Fracture Process of Tempered Glass

The pressure vs deflection relationship in four-point bending of tempered glass specimens with three glass layers and an EVA inter-layer. The break may be detected in three phases (A, B, and C) in the tempered [20-23]

Stage A; The Bernoulli hypothesis may be applied to the glass layers whenever the tempered glass is not shattered. The elastic modulus of the tempered is affected by the processing temperatures, loading rate, and other factors. When the maximal intensity of the bottom glass layer under maximum strain is attained, the force instantly decreases to the lowest level, e.g., Fu23 [24-26].

Stage B; Non-fractured tempered glass sheets must support the pressure [27-30]

Stage C: The inter-layer material performs two functions: (1) attachment of broken glass layer pieces to the non-fractured glass layer and (2) force transmission between the glass layers. As a result, the force begins to rise until the full power of the following layer is achieved once more. When two glass layers are fractured, and the inter-layer material remains intact, it can function as reinforcement for the remaining non-fractured glass sheet in the form of 3 tempered glass [31-33]

3.1. The Effectiveness of Tempering

Most sources show that the load - carrying ability of tempered single glass panel is 3 to 4 times greater than that of float glass panel. The problem is whether the load bearing capability of tempered glass is always three to four times greater in the event of varied glass thicknesses or variable applied stress levels (I Siddique, 2018). The introducing the notion of tempering efficacy (heat treatment). The efficacy of tempering is demonstrated by the ratio of load bearing capabilities of tempered glass panel to non-heat-treated float glass panel of same thicknesses. The experimentally that the performance of tempering is dependent on glass thickness and loading rates. The using laboratory four-point bending tests, that the efficacy of tempering diminishes with increasing glass thickness at a stress rate of 20 mm/min. The connection between tempering effectiveness and glass thickness is proportional (Figure 1) [34-39].

In the situation of theoretical glass thickness of 6 mm, that the efficacy of hardening diminishes with decreasing loading rate from 20 mm/min to 1 mm/min (Figure 2) and there are no major differences with increasing loading rate from 20 mm/min to 50 mm/min. The reason for this is that the formation of cracks from surface scratching requires time, which is more available in the event of loading rates of 5 or 1 mm/min than in the situation of loading rates of 50 or 20 mm/min [40-42].

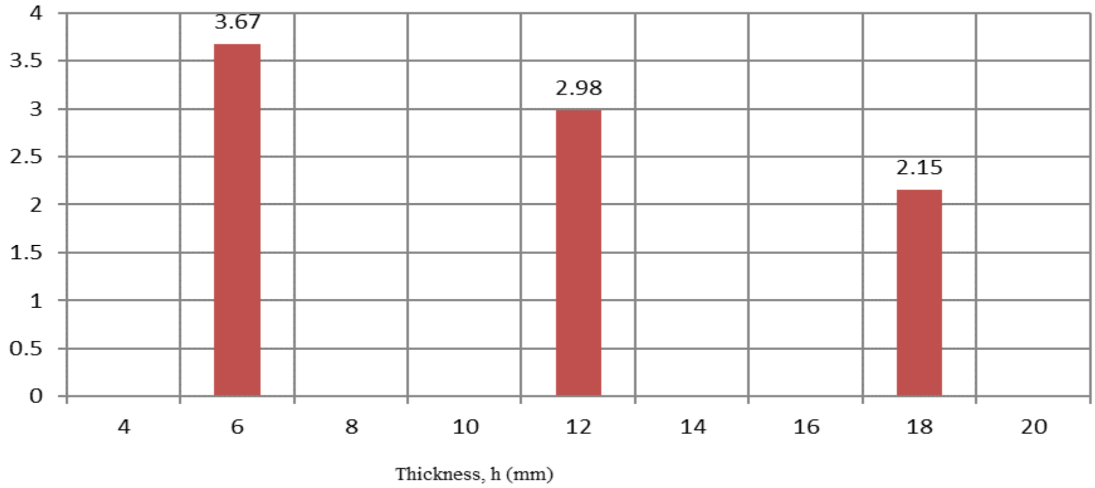

Figure 1. The connection between tempering efficiency and glass thickness is proportional

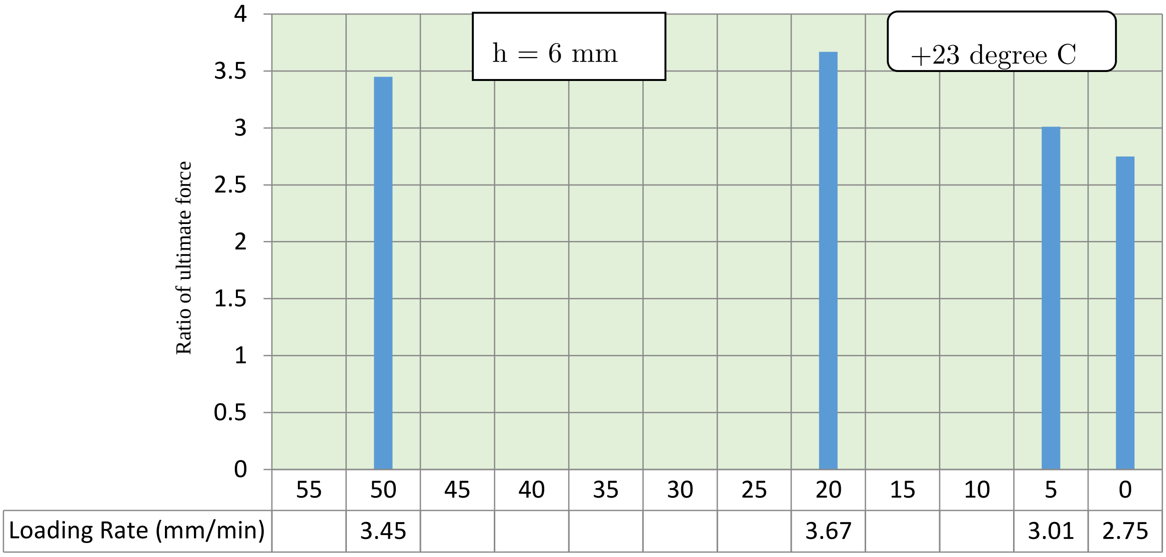

Figure 2. Tempering efficiency versus. loading rate by 6 mm glass thickness

With the performance of tempering (heat treatment), it is feasible to select acceptable and cost-effective glass thicknesses in the area of heat-treated glass panel (tempered or heat strengthened) [43-46].

3.2. The Effectiveness of Tempering Tempered Glass Panel

It is proposed that the concept of tempering efficacy be introduced (heat treatment). The efficacy of tempering is defined as the ratio of load-bearing characteristics (e.g., maximum force) of tempered glass panel to non-heated float glass panel of the same thicknesses (c Sun, 2018). The authors demonstrated experimentally that the efficacy of tempering depends on the glass thickness compared to single glass panel and the number of glass layers applied in the event of tempered glass panel. As per experimental data in four-point bending, tempering efficacy reduces with increasing thickness compared to single glass panel. It also decreases with the increasing applied amount of glass layers in the instance of suitable bonding. Indicates tempering efficacy as a result of the amount of glass layers and the thickness of a single glass sheet [47].

The lesser the efficiency of tempering in tempered with suitable bonded glass layers, the greater the size of glass layers. In the situation of tempered glass without bonded layers (as the lowest limit), the load-bearing capacity is controlled by the final force within each individual glass layer, and expanding the number of glass layers from two to three has no major effect on the ratios. The value dropped as the thickness of centralized single glass layers (as top limit) increased (from 6 to 12 and 19 mm). The number of flaws on the surfaces rises as the number of glass layer increases, affecting the load-bearing capability of the tempered. The height effect has a significant impact on the structure of reasonably thick glass layers (h > 10 mm) or with an increase in the number of layers. The scale effect is caused by the random dispersion of flaws in the glass panes Weibull type size effect, also known as statistical size effect [48-50].

4. The Impact of Temperatures on The Extreme Load of Tempered Glass panel with Varying Numbers of Panels of Glass

The research findings revealed that temperature influences the behavior of tempered glass, both non-heat-treated tempered glass and tempered laminated glass. The displacement increases as the temperature rises, but the final force decreases (K Lohr, 2018). This behavior is more prominent in resins inter-layer materials than in EVA foil inter-layer materials [51]. The maximum force of tempered glass samples is compared to the ratio of total thicknesses of inter-layer materials to total thickness of sample. When tempered glass with an EVA inter-layer is compared to resin tempered specimens, the load bearing capability is less influenced by temperature changes. The lab findings demonstrate that the temperature responsiveness of the resin inter-layer is greater than that of the EVA inter-layer. Under the instance of load bearing safety glass applications that require high maximum forces to be withstood, EVA inter-layer materials is more suitable in variable ambient temperature [52-54].

In the event of an adequate bond, the load bearing capacity of laminated glass can be enhanced by increasing the thickness of the inter-layer component. At room temperature, the load bearing capability of tempered glass rises as the thickness of the PVB inter-layer rises. At extreme temps, the resin inter-layer material softens, resulting in a loss in strength properties and, as a result, a considerable reduction in the final force of tempered glass. The effect of EVA's vinyl acetate level on the rheology of polymer-modified asphalt and indicated that the studied kind of EVA with low VA concentration would have a greater modulus (G 0) at high temperatures, which is preferable for warm environments [55-56]. Reduced flow activation energy decreases the amount of temperature sensitivity and, as a result, the increase in viscosity owing to temperature variations. As a result, when using EVA foil as an inner layer material in tempered glass, it is preferable to study EVA foils with low VA concentration. The influence of temperature on load bearing capacity and deflections should not be overlooked, particularly in the case of load-bearing tempered glass panel. When the service temperature or exposure class of tempered glass is known, the inter-layer thickness may be optimized [57].

4.1. Tempered Glass's Remaining Load Bearing Capability at Various Temperatures

Numerous factors might cause a glazing element to fail throughout its service life. The remaining load-bearing capability of one or more panes of glass of multi-layered tempered glass after loss (post-failure behavior) is an intriguing element, particularly when utilized in above regions such as roofs or canopies, as well as floors, where safety concerns are high [58]. The temperature sensitivity of the inter-layer material influences the remaining load-bearing capability of tempered glass throughout the fracture mechanics. If one glass layer of tempered glass with n glass layers breaks at a temperature of 23 C, the remaining load bearing capacity is greater than that of tempered glass with n 1 glass layers. The inter-layer on base of the broken glass layer acts as a type of reinforcement. The load bearing capacity of tempered glass panel with polymer inter-layers decreases significantly as the temperature rises from 20 C to +60 C. Tempered glass panel with an EVA inter-layer, on the other hand, have a cooler temperature tolerance. In the instance of the EVA inter-layer, there are minor reductions in load bearing when the temperature is reduced from +23 C to +20 C and increased from +23 C to +60 C. During in the fracture process, the influence of temperatures on the remaining load bearing capacity of tempered glass reduces. Single float glass has poor energy absorption capabilities and so provides something to the power consumption of the laminate structure, which is thus regulated by the inter-layer characteristics [59-62].

Single float glass can fail owing to a crucial fracture, but the statistical distribution of fractures in tempered glass mostly impacts the load bearing capacity. The extension behavior, adhesive characteristics, and ripping strength of the inter-layer materials are crucial in the event of large deformation and during the fracture process of tempered glass (S Wiederhorn, 2002). Tempered glass with EVA inters layer material requires more outside labor during breakage at extremely hot temperatures than polymer tempered glass [63-65]. The effectiveness of inter-layer material improves with decreasing temperature from +60 C to -20 C in the instance of polymer tempered samples. When the final pressure increased, the exterior organizational increases, but at low temperatures, the ultimate extension reduces. Cracks in the inner layer can occur in the presence of significant displacements and low temperatures, reducing the energy absorbing capacity. Fracture toughness of tempered glass is also influenced by the inter-layer's energy absorption ability [66-68].

As per the test findings, in the situation of polymer tempered glass, the relative overall activities (external work at various temperatures compared to +23 C) decreases with increasing temperature and number of glass layers, while it rises in the situation of EVA. At -20 C, resins tempered glass acts more firmly, due to smaller deformation and the development of bigger islands of broken samples. In the case of a resin inter-layer, the reduction in external stress after fracture of one glass layer is likewise greater at lower temperatures (-20 C). External organizational estimates for tempered glass panel that do not have connected layers. In the instance of non-glass layers, the numbers are low, and the overall activities rises proportionally to the number of glass layers put. [69, 70]

5. Conclusions

The research outcomes about Tempered glasses at various temperatures may be taken: We examine the many varieties of glass in this article, as well as the steps of the tempered glass fracture process. We investigate the efficiency of tempering description introduction (heat treatment). As per the experimental data in four-point bending, tempering efficacy reduces with increase in the thickness in the compared to single glasses, and it also reduces with increasing applicable number of glass layers in the situation of suitable bonding. We talk about the efficacy of modifying tempered glasses. We also investigate how the edges strength of the tempered is impacted by the edge strength of the glass layers, as well as the inter-layer characteristics. The surface strains at the bottom surface of tempered glass can grow up to roughly the strain values of tempered glass with non-bonded layers when the temperature of the glass is raised from 23 C to 60 C. In this topic we study too the impact of temperatures on the extreme load of tempered glasses with varying numbers of panes of glass and last, we examine Tempered glass's remaining load bearing capability at various temperatures.

Conflict of Interest Statement

The authors declare no conflict of interest.

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