Analysis of Improving Impact Resistance and Heat Treatment Method of Tempered Glass

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Abstract. At present, glass is common in our lives. Glass has excellent physical and chemical properties. It has high compressible strength, high hardness, transparency, good stability, and is not easily deformed. It is an inorganic non-metallic material with a wide range of uses. With the development of science and technology, the scope of application of glass is more and more extensive, and the strength requirements for glass are also getting higher and higher. How to improve the impact resistance of tempered glass, this article studies the heat treatment processing technology and parameter adjustment, and the appropriate process route through appropriate heat treatment methods, so as to improve the impact resistance of tempered glass. Inspection has verified the rationality of the process.

1. Introduction
Glass is an amorphous inorganic material with an irregular structure formed by high temperature melting, low temperature cooling, and solidification. It has good physical and chemical properties and is widely used in various fields. However, glass is a typical brittle material. There are a large number of cracks on the surface and inside of the glass. When the external force and the environment affect the cracks, it is very easy for cracks to propagate. This causes the glass to break and limits the application of the glass. Various glass strengthening technologies have emerged at the historic moment, among which the tempering technology is the most widely used. The method of improving the impact resistance of tempered glass is that the heat treatment process is currently recognized as a measure that can effectively improve the performance of tempered glass [1]. The process principle of the heat treatment process seems simple. In fact, the heating uniformity of the heat treatment process system has been put forward a relatively high requirement this article introduces this [2].

2. The process of tempered glass
The production process of tempered glass can be simply summarized as heating the glass to a certain temperature and then rapidly cooling it to increase the mechanical properties and thermal stability of the glass [3]. The principle is: the glass is heated below the softening temperature in a heating furnace, and then quickly sent to the cooling device, quenched with a certain pressure of normal temperature air flow, the outer layer of the glass shrinks and hardens first, due to the small thermal conductivity of the glass, at this time The interior of the glass is still at a high temperature [4]. When the interior of the...
glass begins to harden, the hardened outer layer will prevent the shrinkage of the inner layer, which will cause compressible stress in the first hardened outer layer and tensile stress in the later hardened inner layer [5]. The existence of such compressible stress on the surface. When an external force acts on the surface, this part of the compressible stress must first be offset, which greatly improves the mechanical strength of the glass. Therefore, the performance of tempered glass is enhanced and the impact resistance is enhanced. Control is actually the control of heating and cooling processes [6].

3. Tempered glass heat treatment process system and process requirements
Tempered glass heat treatment process system consists of the following: hot dip furnace, glass support, and the partition between glasses. The hot dip furnace must use forced convection to heat the glass, which can minimize the temperature difference of the glass, but the temperature difference is still inevitable. The electric heating element is arranged in the air duct, the air is heated in the air duct, and then enters the furnace through the fan to realize the hot air circulation [7]. The effect of forced convection heating depends on the circulation route, air flow rate and temperature of hot air in the furnace, so the airflow strands in a homogeneous furnace must be carefully designed. In principle, the airflow in the furnace should be as smooth as possible, even if the temperature when glass breaks, debris cannot block the airflow path. There is a convection channel of hot air between the glasses in the hot dipping furnace, so the glass stacking method is extremely important. The stacking direction of the glass should follow the direction of the hot air flow, and it must not obstruct the hot air flow. Special attention should be paid to the direction of the curved surface of the bent tempered glass; the distance between the glass will affect the air heat flow, heat conduction and heating time [8].

![Figure 1. Tempered glass heat treatment principle flow](image)

Objects cannot block the heat flow channel, and glass cannot directly contact each other. The heat flow between the glasses in the hot dipping furnace is divided into turbulence and laminar flow. Turbulence is the main flow, but laminar flow also occurs. The heat is transmitted from the air to the glass, and the air temperature decreases along the direction of the air flow between the glasses. Therefore, the heating rate is different in the direction of the glass height [9]. According to tests, the 2.2m high glass will have a temperature difference of about 35°C in the height direction. The temperature of the glass near the hot air inlet is faster than other parts. The glass at the edge of the glass holder heats up faster than the glass in the middle. The lowest temperature of the glass is generally at the end of the glass and at the thickness Direction, heat is conducted in a conductive manner, and the temperature is relatively uniform [10].

3.1. Setting process parameters of tempered glass heating process

3.1.1. Setting the upper and lower temperature of the heating furnace. Furnace temperature setting includes upper temperature setting and lower temperature setting. The main setting of furnace temperature is the thickness of the glass. The tempering temperature of the glass gradually decreases with the increase of the thickness of the glass. The thicker the glass to be tempered, the higher the
temperature setting. Low, the thinner the glass, the higher the temperature setting. When the glass is air-cooled and tempered, the glass itself must be in a semi-plastic state, so that the residual stress in the glass can be eliminated. The tempering temperature of flat glass is around 630°C, which means that when the glass is air-cooled and tempered, its temperature must reach 630°C. For the setting of the upper and lower temperature of the tempering furnace heating section, the ultimate purpose is to make the temperature of the upper surface and the lower surface of the glass consistent [11].

![Figure 2. Temperature control and analysis of tempered glass heat treatment](image)

When tempering to produce thick glass with a thickness of 10 mm or more, if the heating temperature is not properly controlled, when the glass is air-cooled, the phenomenon of glass cornering is likely to occur, especially for glass with holes at the edges. When such problems occur, the rationality of the glass heating temperature setting should be considered. If the temperature is set too high and the glass is heated too quickly, the thick glass will fall off.

3.1.2. Setting of heating time for tempered glass. The setting of the heating time of tempered glass also depends on the thickness of the glass. At the same time, the size of the glass, the color of the glass, the state of the glass opening and the shape of the glass must be considered. The reasonable setting of the heating time must first consider the thickness of the glass. The heating power of the tempering furnace is certain. In theory, the heating time of glass is about 40-45s per millimeter of thick glass. However, if there are holes or openings in the glass, heat the time can be increased by 2.5%-5%, and the heating time for glass of 15,19mm thickness can be increased by 5%-15%. In addition, the larger the glass surface, the heating time should be extended accordingly. The heating section of the general tempering furnace has a heating balance function. The heating of glass in a heating furnace is made up of multiple ways, namely radiation, convection and heat conduction.

![Figure 3. Relationship between heat treatment temperature and impact resistance of tempered glass](image)
The opening of the heating balance can increase the flow rate of the air in the heating furnace, change the flow state of the air in the furnace, improve the efficiency of convection heating, and make the temperature in each area of the heating furnace relatively uniform. For a large area of glass, turning on convection heating in a closed tempering furnace can increase the rate of glass heating on the one hand and help more uniform heating of various areas on the glass surface. To heat the glass with the middle opening, sometimes it is necessary to fine-tune the temperature in the heating furnace. At this time, it is recommended to open and close the heating balance.

3.1.3. Setting of thermal swing speed of tempered glass. The speed of the thermal pendulum has an effect on the uniform heating of the glass. An unreasonable thermal pendulum speed will affect the flatness and tempering effect of the tempered glass, resulting in roller track marks and uneven fragments after tempering of the glass, and it is not good for the glass. Heat evenly. The process of glass swinging in the heating furnace is also the process of heat exchange between the glass and the conveying roller table. The faster the glass swings in the furnace, the more the heat conduction area between the glass and the conveying roller table can be increased. Can accelerate the rate of temperature increase of glass. In addition, the thinner the thickness of the glass, the faster the heating rate of the glass itself, and the stricter the temperature requirements of the glass itself during air-cooling tempering. Correspondingly increase the thermal swing speed of the glass in the heating furnace. The thicker the glass, the slower the heating rate of the glass itself, which can reduce the thermal swing speed of the glass accordingly.

![Figure 4. Relationship between heat treatment temperature and properties of tempered glass](image)

4. Relationship between the improvement of impact resistance of tempered glass and heat treatment

The high-speed camera was used to capture the image of the changes in the impact resistance of the hollow tempered glass. Because the hollow tempered glass specimen was transparent in the experiment and could not diffuse reflect the LED light source, the result chart observed in the high-speed image was dark. When cracks are generated by impact, the crack surface of tempered glass is perpendicular to the horizontal plane and the crack propagation angle is random, which can improve the reflection intensity to the light source. Wise cracks can be observed in high-speed images, and other fine cracks cannot be observed. The form of cracks can be clearly observed by adjusting the brightness and contrast of pictures through image processing software. Now combining the images taken by the high-speed camera with 20,000 frames and the final modal diagram of the glass specimen
after the impact test, observe the cracks. Fine radial cracks centered on the impact point appear at the center of the impact of the glass panel; as the impact resistance improves, the radial cracks widen and increase, showing a large number of ring-shaped cracks around the outside of the glass, improving the impact resistance. Gradually deepened; small diameter annular cracks appeared near the impacted location and gradually increased.

4.1. Analysis of impact resistance of tempered glass
Toughened glass specimens have modal dimensions similar to those of the specimens. When the impact resistance is improved, the upper tempered glass panel contacts the upper tempered glass panel, causing it to break. The impact strength is increased at the center of the upper tempered glass panel, which shows that the impact begins to crack. The point is a fine radial crack. As the impact resistance improves, the radial crack increases at the center of the downward movement, and the width of the crack increases; it shows that a large number of ring-shaped cracks appear around the outside of the glass, and then the impact resistance will continue to move downward. The cracks appeared gradually deeper; small-diameter ring cracks appeared near the impacted location and gradually increased, and finally the impact resistance hit the lower glass.

![Image](image_url)

Figure 5. The photo of damaged impact resistance of tempered glass

4.2. Study on crack modal specimen of impact resistance of tempered glass
We can see that the cracked modal specimens of the tempered glass test specimens are similar. When the impact resistance is improved and the upper tempered glass panel is contacted to cause it to break, the cracks start to appear at the center of the upper tempered glass panel, which is the impact resistance. The appearance of fine radial cracks centered on the impact point. As the impact resistance improves, the radial cracks at the center of the downward movement increase and the width of the crack increases; it shows that a large number of ring-shaped cracks appear around the outside of the glass, and then the improvement of impact resistance will continue to decrease. During the movement, cracks appeared gradually deeper everywhere; small-diameter ring cracks appeared near the impacted location and gradually increased, and finally the impact resistance hit the lower glass.
4.3. Time curve analysis of tempered glass impact force

Under the same fixed support conditions, with the impact energy increasing, the impact resistance of the hollow tempered glass test piece increased, and the three sizes of the test pieces were cracked in the upper glass panel. As the side length of the test piece increased, the hollow glass test piece was broken. The impact load decreases and the impact time increases; the initial impact energy, the initial impact speed, the value of the second impact force, and the upper glass break time are considered together. The impact force time curve is calculated by formula to obtain the relationship between displacement and time during the experiment.

Figure 6. Energy and stress displacement of impact resistance of tempered glass in various sizes

According to the need, the impact force and displacement are obtained simultaneously to obtain the area under the curve to obtain the impact energy. In the impact test air thickness group, under the same fixed support conditions, the impact-resistant hollow tempered glass specimen is close to the critical state of breaking. As the tempered glass air thickness increases, the peak impact load increases, and the impact duration decreases. Tempered glass specimens have the lowest peak impact load and the largest impact duration. When the glass with the same supporting condition is broken by impact, only the upper layer of tempered glass of the tempered glass air-thickness specimen is broken, and the two layers of tempered glass of the remaining air-thickness specimen are cracked. There are dense radioactive cracks in the center of the broken glass panel, and obvious crack rings are displayed on the panel. With the exception of tempered glass air thickness test specimens, as the air thickness increases, the peak impact load increases, the initial impact energy increases, and the energy absorption efficiency improves. The impact peak load and energy absorption efficiency of the tempered glass air thickness test piece are relatively low, and the overall performance will be better.
4.4. *The relationship between impact force of tempered glass and heat treatment*

Whether the heat treatment process system is truly effective and can meet the process requirements of the heat treatment process must be verified. The standards for the heat treatment process of tempered glass were previously seen in German DIN18516, the Chinese version of the tempered glass 05 standard and JGJ102 "Glass Curtain Wall Engineering Technical Specifications" have also added requirements for the heat treatment process of tempered glass, but the verification of the heat treatment system has not been clear. With the implementation of the European Union EN14179-1: 2005, with its detailed discussion of heat treatment process and system verification, it has become the most authoritative hot-dip standard at present, and is increasingly widely used.

| Glass Type          | Area | Span |
|---------------------|------|------|
| Ordinary Annealed   | 1.0  | 1.0  |
| Sandblasted Annealed| 0.5  | 0.7  |
| Wired               | 0.5  | 0.7  |
| Laminate            | 0.8  | 0.9  |
| Patterned           | 1.0  | 1.0  |
| IGU Units           | 1.5  | 1.2  |
| Heat Strengthened   | 1.6  | 1.3  |
| Toughened           | 2.0  | 1.4  |

The verification of the heat treatment process system must be carried out under the conditions of 100% loading and 10% loading, and meet the time-temperature standard curve requirements. The heat treatment process, glass separation distance, position, partition material and shape, support type and Location, and specifies the operating conditions used in the production process. The arrangement of measuring the surface temperature of the glass differs depending on the position of the glass and the type of support, and the arrangement of different loading capacity levels is also different. The hot end of the temperature measurement must be close to the glass surface, otherwise the measured temperature is air temperature instead of glass temperature. Usually high temperature glue is used to achieve the adhesion to the glass surface, but after a high temperature heat treatment process of about 300°C, the adhesion stains on the glass surface are difficult to remove. In daily production, it is not appropriate to measure the glass surface temperature every day. Yes, the daily tedious procedures are avoided by verifying the system. The full load test depends on the glass size, thickness, and furnace volume, and is usually determined on the basis of tempered glass. When calibrating, the minimum distance between glasses is required to be 20mm. The size of the glass distance involves an optimization problem. The large distance, the good heat transfer effect, and the uniformity of the surface temperature of the glass are increased, but the load of the heat treatment process is affected and the thermal efficiency is reduced. Do not use metal materials for the separator between the glasses,
so as to avoid the local temperature rising too fast due to the contact between the glass surface and the metal.

5. The key points of impact resistance test for tempered glass

5.1. The Points for inspection of impact resistance and inspection of tempered glass.
When the thickness of the rectangular flat tempered glass is 3, 4, 5, 6mm, and the length of the rectangular tempered glass is within 1000mm, the deviation of the side length should be controlled within ±1-2mm; the length of the rectangular tempered glass is within 1000-2000mm The deviation of the side length should be controlled within ±3mm; when the length of the rectangular tempered glass is within 2000-3000mm, the deviation of the side length should be controlled within ±4mm; when the length of the rectangular tempered glass exceeds 3000mm, the deviation of the side length should be controlled between ±5mm. When the thickness of rectangular flat tempered glass is 8, 10, 12mm, and the length of rectangular tempered glass is within 1000mm, the deviation of the side length should be controlled within ±2-3mm; when the length of rectangular tempered glass is within 1000-2000mm, The side length deviation should be controlled within ±3mm; when the length of rectangular tempered glass is within 2000-3000mm, the side length deviation should be controlled within ±4mm; when the length of rectangular tempered glass exceeds 3000mm, the side length deviation should be controlled between ±5mm.

5.2. The Inspection points of impact resistance thickness and deviation of tempered glass.
When the nominal thickness of tempered glass is 3, 4, 5, 6mm, the allowable deviation should be controlled within ±0.2mm; when the nominal thickness of tempered glass is 8, 10mm, the allowable deviation should be controlled within ±0.3mm; when the nominal thickness of tempered glass is 12mm, the allowable deviation should be controlled within ±0.4mm; when the nominal thickness of tempered glass is 15mm, the allowable deviation should be controlled within ±0.6mm; When the nominal thickness of tempered glass is 19mm, the allowable deviation should be controlled within ±1.0mm; when the nominal thickness of tempered glass is more than 19mm, the allowable deviation should be determined by the supplier and the buyer. Inspection points of bending and impact resistance of tempered glass. When testing the bending degree of tempered glass, the bending degree of flat tempered glass should be controlled within 0.3% in the bow shape and within 0.2% in the waveform. When testing the impact resistance of tempered glass, 6 tempered glass should be taken for the test. The number of failures of the sample is not more than one, which is qualified, and more than or equal to three, it is unqualified. When the number of failures is 2, take another 6 pieces for testing. All the samples must not be damaged to be qualified.

5.3. The key points of quality inspection of toughened glass for impact appearance.
When inspecting the appearance quality of tempered glass, attention should be paid to the inspection of cracks and chippings of tempered glass. Once cracks and chippings of tempered glass appear, it is unqualified. When performing tempered glass edge detection, each piece of glass is allowed to have a length of less than 10mm per meter of side length, the depth of extension from the glass edge to the surface of the glass plate is within 2mm, and the depth of extension from the plate to the glass
thickness does not exceed the thickness 1 / The number of burrs is 3, and only 1 defect is allowed. When performing tempered glass scratch detection, slight scratches with a scratch width of less than 0.1mm, four scratches with a length of less than 100nm per square meter are allowed; scratches with a scratch width of more than 0.1mm per square meter Within the area of 4 meters, 4 scratches with a width between 0.1 and 1 nm and a length within 100 nm are allowed.

5.4. The key points for inspection of tempered glass fragments.
When we are testing the condition of the tempered glass fragments, we should take 4 tempered glass for testing. For flat tempered glass, the minimum thickness of each tempered glass sample in any 50mm×50mm area should be controlled within 30 pieces when testing the status of the fragments, the tempered glass with a nominal thickness of 3mm or a nominal thickness of 15mm or more; Tempered glass with a nominal thickness of 4-12mm, the minimum number of pieces of each tempered glass sample in any 50mm×50mm area should be controlled within 40 pieces. For curved tempered glass, the minimum number of fragments of any tempered glass sample in any 50mm×50mm area should be controlled within 30 pieces when testing the state of the fragments. At the same time, when detecting the horizontal state of tempered glass, a small amount of strip-shaped fragments with a length of less than 75mm is allowed.

6. Conclusion
During the production of tempered glass, in order to ensure the performance of tempered glass, in order to improve the impact resistance of tempered glass, ensure that the tempered glass is heated to the temperature requirements, at the same time, cool the tempered glass at the fastest cooling rate, and ensure that the tempering process keeps moving. It is the process of heat treatment. When the tempered glass is inspected after the heat treatment, attention should be paid to dimensional inspection and deviation inspection, thickness and deviation inspection, bending and impact resistance inspection, appearance quality inspection, and debris condition inspection inspection to ensure tempered glass. Quality, thereby verifying the impact resistance of the tempered glass.

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