Soda Lime Glass Erosion

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Abstract

In order to find a solution to the problem of windshields damaged by sandstorms in the Saharan regions of Algeria, sandblasting tests were conducted in laboratory on a soda lime glass in its as-received state and when strengthened by thermal treatment. The sand particles were projected by an air flow with a speed of 56 Km/h and a sand mass flow of 10 g/min. The impact angle was maintained at 90°. The erosion tests show that the roughness Ra for the as received glass increases until a maximal value of 2.95 µm after being eroded with a mass of 200 g. of sand. The strengthened glass roughness reaches the same value (2.97 µm) but using a mass twice higher (400 g). The optical transmission decreases sharply for the as received glass from 92% to 10% after being eroded with 200 g of sand. The strengthened glass reaches the same level of the optical transmission, but after being eroded with a mass of 600 g.

Microscopic observations show that the induced damage is similar to that of the windshields exposed to real situations in the Sahara. The erosion is of brittle kind and the material removal mechanism is in form of chipping or craters. The morphology of this chipping corresponds to that is usually observed on glass when submitted to Vickers indentation.

Key Words: Sandblasting, glass, erosion, roughness, optical transmission.

1. Introducion

The usual way used for reducing impact damage on glass is to put its surface in compression. This can be achieved by thermal tempering, ion-exchange, vitreous enamelling or by cladding with a material of lower thermal expansion [1]. The thermal tempering or cladding methods give a relatively thick compressive surface layer in comparison with the two other methods. It was shown that the compressive surface stress field produced by thermal glass tempering does not improve significantly the glass erosion resistance to sharp particles [2] as was noticed in sand blasting or by Vickers indentation, but it could certainly improve the material erosion resistance caused by Hertzian cracking. The extent of the lateral cracks produced by Vickers indentation can be more pronounced if the glass is thermally tempered [3]. Other studies showed that glass tempering can have a small effect on its hardness and its elasticity modulus by reducing them while the fracture toughness seems to remain unchanged.[4, 5] This effect is due to the more open structure of the glass obtained by rapid cooling.

Ion-exchange is a chemical treatment which consists of exchanging small ions by larger ions in the glass surface using a molten salt bath. The expansion of the glass structure generates a compression at the surface and a balancing tension in the interior. This treatment is simple but costly when used industrially. According to I. W. Donald [6] the thickness of the compressive layer varies from a few micrometers up to several hundreds micrometers in dependence of the glass composition, the treatment conditions and the sample thickness. Among the main advantages of this treatment is that we can obtain higher mechanical strengths and avoid glass distorsion since it is usually made at a temperature lower than the transition point. To our knowledge, the effects of structural changes obtained by chemical strengthening or by coating techniques on the mechanical properties (K_{IC}, Hv, E) and thus on the glass erosion resistance, are not completely established [7, 8].

2. Experimental Procedure

2.1. Characteristic of the Glass and Sample Preparation

A 5 mm thick soda lime-silica flat glass was used in our tests. It was delivered by Algerian company of glass (glass-Africa, Jijel). The samples were cut from the same plate.
The following tables show the average chemical composition of glass used and some physical properties.

Table 1. Mean chemical composition of the glass used

Oxides	SiO_2	CaO	Na_2O	MgO	Al_2O_3	Fe_2O_3	Others
Mass (%)	72.56	7.92	12.73	4.11	1.42	0.095	1.162

Table 2. Some of the physical glass properties.

Properties	Values
Thermal dilatation coefficient α	8.410^{-6} K^{-1}
Young modulus E	72 GPa
Poisson's coefficient ν	0.22
Density ρ	2.49 g/cm^3
Transition temperature Tg	532 °C

3. Results And Discussion

3.1 Influence of Thermal Quenching on the Erosion Resistance

We have, thermally hardened the samples at the Algerian company of glass (glass-Africa, Jijel) using a horizontal tempering furnace. The tempering temperature (680 °) was followed by rapid cooling with compressed air.
In this industrial furnace, the minimum dimensions required for quenching are 250x40 mm^2 . Mass loss for samples thermally toughened was found insignificant according to the balance used. The samples are better suited for strength tests. That is why we determined the bending strength.

3.2 Strength of Thermally Tempered Glass

In order to examine the effect of thermal quenching behavior of the mechanical strength, four-point bending tests were conducted on two sets of respectively annealed and heat treated samples. These tests were performed on a Shenck type tensile testing machine.. The average tensile strength obtained from a batch of fifteen samples was respectively σr = 65 ± 23 MPa and σr = 217.5 ± 9 MPa for annealed and tempered glass.
Subsequently, we conducted a shock test of a falling steel ball of mass 220 g from a height of 2 m. In fact ISO 3537 recommends a steel ball of 227 g and a drop height of 2 or 2.50 m. We found that crack initiation starts within the ball-target contact area and then propagate in all directions forming a large number of small non-sharp fragments. The fragmentation occurs throughout all the glass volume. This is one of the advantages of thermally tempered glass which protects vehicle drivers following accidents that happen so sudden and unexpected. In terms of comparison, Takahashi [9] found an average strength of 172 MPa and an apparent toughness 5.2 MPa√m on a 10 mm thickness thermally tempered glass.
Counting the number of fragments per unit area, we found an average of 270 fragments per 25 cm^2. According to ISO 3537 on car windows, it is recommended a number of fragments between 40 and 450 per 25 cm^2 for a good quality of thermal quenching, provided that no fragment exceeds an area of 3.5 cm^2 and a length of 7.5 cm. Zarzycki [10] had reported that the degree of fragmentation depends on the

density of elastic energy stored in the thermal quenching. Indeed, a high degree of thermal quenching leads to further fragmentation.

3.3 - Roughness

Figure 1 shows the average roughness Ra versus the projected mass of sand (not cumulative). It is found that the peak of Ra for annealed glass is about 2.95 microns. This value is reached for 200 g projected mass of sand. While for a glass reinforced thermal quenching, the curve of the roughness Ra is practically below that of the annealed condition and reached its peak of 2.97 microns for 400 g projected mass of sand. For comparison, Buijs [11] found an average roughness Ra = 3 microns and a maximum roughness Rt = 15 m for a speed of 300 m / s and a size of 30 microns of the particles.
When the peaks are reached, the roughness drops slightly and continues to oscillate as a sine wave of small amplitude around this level. This probably corresponds to the creation of a new rough surface layer . The optical quality is highly dependent on this new layer. Those defects govern the geometric surface light scattering and transmission loss

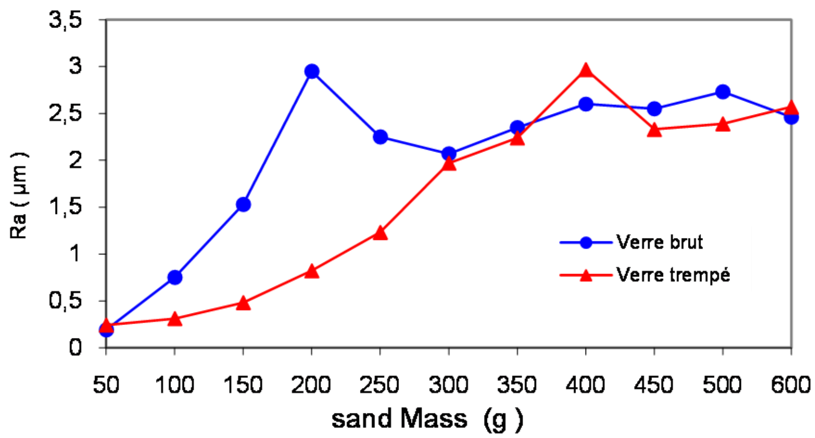


Figure 1: Variation of the roughness Ra (microns) of annealed glass and thermally toughened glass versus the projected mass of sand

3.4 Optical Transmission:

Parallel to the measurement of roughness, we measured the loss of transmission by using a light beam of length 550 nm. Figure 2 shows the difference between the transmission curve of an annealed glass and that of a thermally tempered glass. The transmission loss of an annealed glass fell from 92% to 10% at 200 g of projected sand, then it goes to a level that reflects the state of saturation. This bearing is contributing to the transmission loss curve of a thermally tempered glass at the point corresponding 600 g of projected sand. This is a good index, which reflects the positive contribution of thermal quenching and its ability to prolong the service life of a glass eroded by sand particles projected.
Wilantewicz et al. [12] reported that the lateral cracks that govern the optical quality of glass are longer for a chemically tempered glass as a heat tempered glass. These authors added that after sandblasting glass-reinforced thermal tempering, annealing and chemical, mechanical strength determined for thermally tempered glass fell about 50% of its initial value, but remains higher than that of a chemically tempered glass (compressed layer = 150 microns) and an annealed glass, which fell by 70% and 80% of their initial values.

In the same field Telling et al. [13] found, for ceramic materials used as infrared windows in aeronautics and reinforced by a layer of ZnS, the transmission loss is about 60%. This loss is proportional to the size and speed of erosive particles. Another confirmation made by Jilbert [14] which indicated that the transmission loss of windows ZnS eroded sand particles of 10 microns at a speed of 30 m/s during 50 seconds was about 50%. While this loss is 7% for a speed of 10 m /s. So speed is the most relevant parameter to the erosion of materials by solid particles.

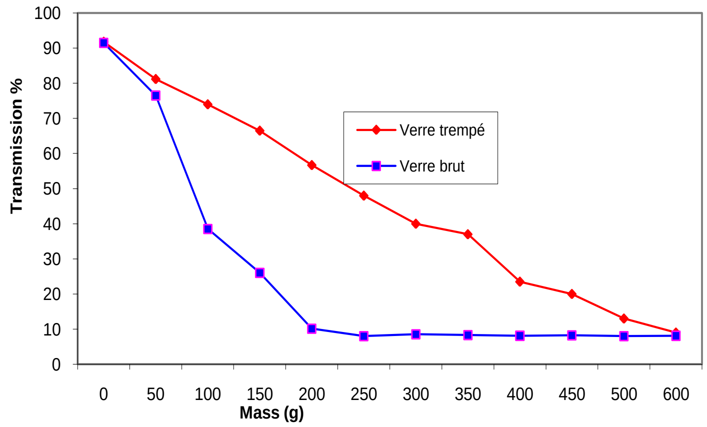
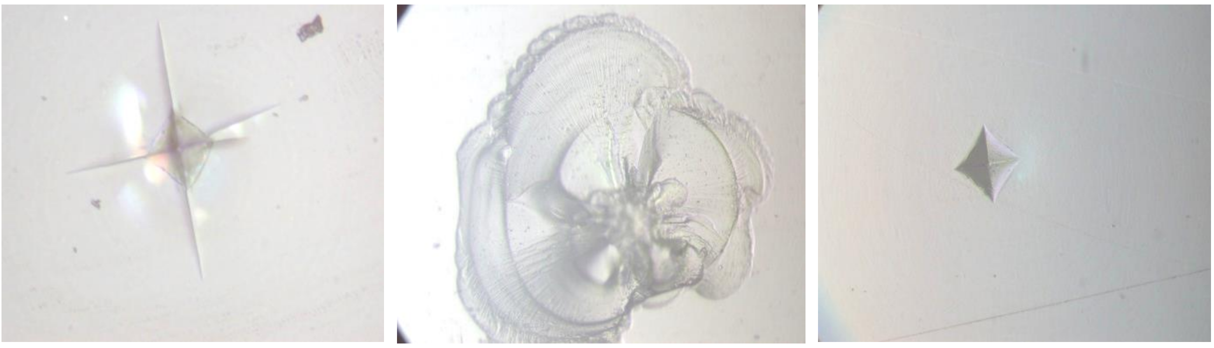


Figure 2: Comparison of transmission loss of two glasses treated by annealing and thermally tempered

3.5 Effect of Fracture Toughness

In this study, we compared the lengths of cracks produced for the same charge and under the same conditions. Figure 3 shows that up to a load of 9.8 N, radial or lateral cracks were not observed for thermally tempered glass. The initiation of cracks occurs for loads slightly higher than 9.8 N. This shows that the resistance to cracking and erosion resistance are significantly improved. In the case of chemically tempered glass, there is formation of radial cracks and lateral cracks followed by chipping for loads below 9.8 N. This strongly affects the optical quality and aesthetics of the glass. Although for an annealed glass, there is formation of radial cracks without rapid development of lateral cracks leading to chipping. This much influence on the mechanical strength of glass. From these micrographs, it seems clear that the thermal quenching treatment is best suited to resist the initiation and propagation of radial cracks and lateral to moderate loads. Therefore, it preserves the mechanical strength and optical quality by reducing the size of the defect.

This result is in good agreement with that of Holtmann et al. [15] which indicated that the thermally tempered glass is more resistant against erosion because of its high apparent toughness. Wellman [16] also reported that erosion is not governed by the relative hardness of the particle erosion and the target, but by their relative tenacity. Evans and Wiederhorn [17] both found that the toughness of a material is the most important factor influencing the resistance to erosion. According to Wilantewicz et al. [12], this very positive behavior of the thermally tempered glass with respect to resistance to erosion is attributed to the depth of the layer compression remains an essential element in the process of tearing material.



a) b) c)

Figure 3: Micrographs showing three glasses indented by the same load 9.8 N
a) annealing, b) chemically toughened, c) thermally toughened (photos 230 µm x215 µm)

Conclusion:

In conclusion, from the experimental results, it appears that the hardness has no positive effect for holding against erosion. The fracture toughness remains a key parameter that governs the resistance to cracking and erosion.

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