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Effect of water on the transmittance of glass plates with eroded surfaces

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Abstract

The corrosion is a chemical phenomenon which can affect the quality of a glass surface, since the glass can fail as a result of its continuous exposure to a corrosive environment. If a glass surface is put into contact with water or with any aqueous solution, it may chemically react with this medium and this chemical exchange may spread all over the surface of the glass, hence causing some undesirable effects, particularly a change in mechanical strength as well as the transmittance.

Therefore, the objective of this work was to study the effect of water attacks on the transmittance of glass plates, which have been damaged by sand and then immersed in water at different temperatures and for different immersion times.

Keywords: Corrosion; Surfaces; Optical properties; Glass

1. Introduction

One of the most important properties of glass is its durability and any dissolution on its surface may lead to a rough surface of the glass altering therefore its mechanical and optical properties.[1]

The ageing of glass in an aqueous environment is a function of the kinetic approach to equilibrium and the final thermodynamical equilibrium with the environment.[2]

The dissolution kinetics depend on many experimental parameters such as surface area, time, and temperature of the surrounding medium, while the thermodynamic contribution is a function of the composition of glass and its structure.[3,4]

Dissolution mechanisms involve generally two steps. The first step is an exchange on the glass surface between an alkali atom with a hydrogen atom from water through the following reaction:

$$(\mathrm{Si{-}O{-}R})_{\mathrm{glass}} + \mathrm{H_2O} \rightarrow (\mathrm{Si{-}O{-}H})_{\mathrm{glass}} + \mathrm{R^+} + \mathrm{OH^-}_{\mathrm{solution}}$$

The glass surface is then dealcanized, and a layer of silica can be formed. This process depends on whether this aqueous system is an open or a closed one, and secondly on whether or not the surface of glass is in contact with the solution. In a closed system, the pH of the solution increases with the increasing of the concentration of OH groups, which can attack Si–O links and dissolve silica through the following reaction:

$$(\mathrm{Si{-}O{-}Si})_{\mathrm{glass}} + \mathrm{OH^-} \rightarrow (\mathrm{Si{-}OH})_{\mathrm{glass}} + (\mathrm{Si{-}O^-})_{\mathrm{solution}}$$

In a closed system, the dissolution rate increases with increasing pH. However, in an open system, the pH of the solution remains constant, and hence silica dissolution cannot take place.[5]

The effect of water attack on the geometrical shape of the crack depends also on the mechanical stresses. The crack will grow deeper if the material is subject to tensile stresses. This is illustrated in Fig. 1.

The objective of this work consists to investigate the effect of a combination of two phenomena, namely degradation caused by sand gravitation, and corrosion of soda-lime glass that has been exposed to climatic attacks under laboratory conditions. The aim was to study the effect of water attacks on one of the most important properties of the surface of glass which is the transmittance.

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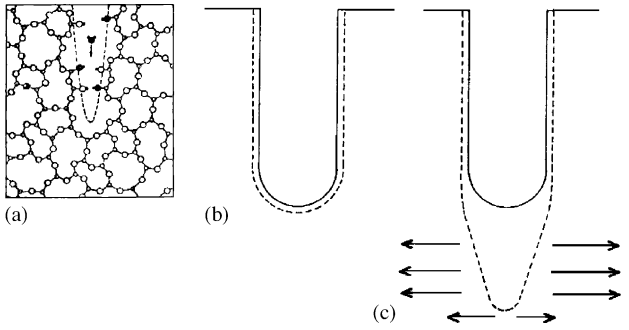


Fig. 1. Illustration of the static fatigue of glass: (a) two-dimensional model of a crack induced by water in silica glass; (b) uniform attack of cracks in the absence of stresses; (c) preferential attack at the bottom of cracks under tensile stresses.[6–8]

Measurement was carried out on windows glass, which has been damaged by sand gravitation and immersed in water at three different temperatures and four different immersion times.

2. Materials and experimental procedures

In this study, the soda-lime glass plate used was supplied by the Algerian glass manufacturing company ENAVA (Entreprise Nationale du Verre et Abrasifs). It has a Young's modulus equal to 72 GPa, a Poison's ratio equal to 0.22, and a hardness of 4.19 Gpa. Its chemical composition is given in Table 1.

The square specimens which were all prepared from the same plate were 10 cm long and 4 cm thick. Their surface was damaged by means of a fixed amount of sand with known particle size. The sand was allowed to freely fall from a fixed height.[7–9]

The sand particles damaged the surface of glass by creating microcracks.

Test conditions were as following:

- The soda-lime glass plates were inclined at an angle of 45° and were bombarded vertically with 200 g of sand.
- The sand grains were sifted through two sieves with mesh diameters of 0.4 and 0.5 mm, respectively. Its particle size was measured using a NEOPHOT-21 optical microscope. The average particle size was found to be equal to 0.456 ± 0.065 mm and the hardness was found to be equal to 7.32 ± 2.94 GPa.

Table 1
Chemical composition of soda-lime glass

Oxides	Wt.%
SiO_2	71.5
Na_2O	13.7
CaO	7.9
MgO	4.2
Al_2O_3	1.3
K_2O	0.9
SO_3	0.25
Balance	0.25

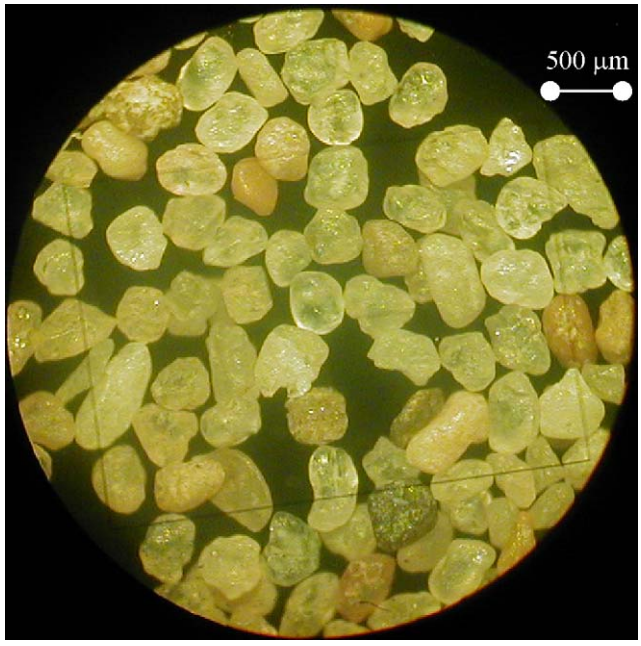


Fig. 2. The morphology of the sand.

The mass flow rate at which the sand was channeled from a funnel on the specimen was 1.66 g/s, which corresponds to a velocity of 4.44 m/s from a falling height of 1 m.

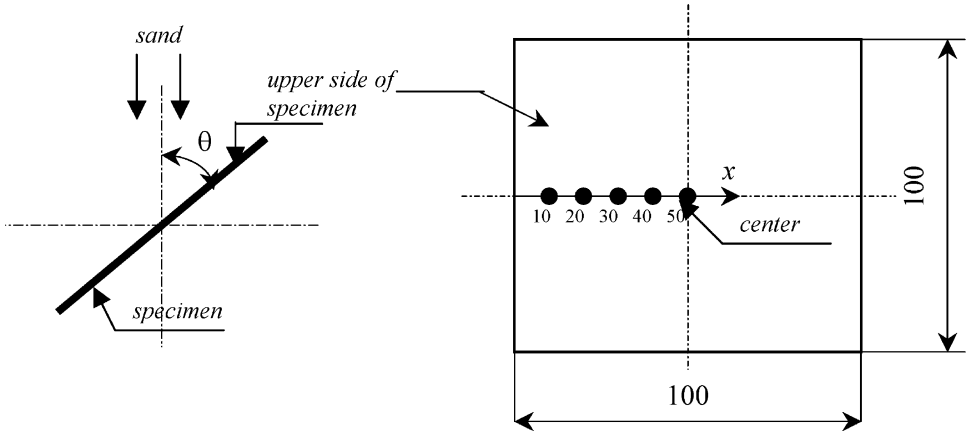
A NEOPHOT-21 optical microscope was also used, to characterize the morphology of the sand, which is shown in Fig. 2.

- The samples were immersed in a trough of water at three different temperatures, namely $T_1 = 50\,^{\circ}C$, $T_2 = 70\,^{\circ}C$, $T_3 = 90\,^{\circ}C$, and four immersion times, which were $t_1 = 30$ min, $t_2 = 60$ min, $t_3 = 90$ min, and $t_4 = 120$ min. The trough of water which was 90 cm long, 60 cm wide, and 40 cm deep was equipped with three electrical heaters, a thermostat, and an agitator. The city tap water used has a pH of 6.5.
- A Hommel-test profilometer (type T20-DC) was used to measure roughness before and after immersion in water.

  The measurements were carried out on the upper side of the specimen, which were inclined at an angle of 45° as illustrated in Figs. 3 and 4. Readings of the roughness were taken at a regular interval of 10 mm starting from the side and moving toward the center of the glass plate.
- The transmittance was determined using a model MD 100 microdensitometer and measurements were carried out on the same spots as those of the roughness.

3. Results

In order to characterize the quality of the surface, the following parameters were measured: the arithmetic mean of the



Figs. 3 and 4. Position of the specimen with respect to the direction of the sand. Schematic representation of the measurement of roughness.

Table 2
Roughness, transmittance of soda-lime glass before degradation and before immersion

R_a (μm)	0.013 ± 0.001
R_q (μm)	0.014 ± 0.001
R_{max} (μm)	0.057 ± 0.008
Tr (%)	89.18 ± 1.62

roughness R_a, the quadratic mean of the roughness R_q, the maximum roughness R_{max}, and the transmittance Tr. These parameters which were all measured before degrading the glass are represented in Table 2.

The above parameters were measured again after degradation and before the immersion of samples in water.

3.1. Roughness

The results of roughness before immersion in water and which are referred to as "Av. Immer." are compared to those after immersion and are presented in Figs. 5–7.

3.2. Transmittance

Similarly, the results of transmittance are presented in Figs. 8–10, where the transmittance of samples not damaged and not immersed are referred to as "Etat. Initial".

4. Interpretations of results

4.1. Statistical interpretation

The statistical treatment of the data showed that the roughness, in terms of the arithmetic mean R_a, or the quadratic mean R_q, or its maximum R_{max} as well as the transmittance do not follow a normal distribution for the three different water temperatures and the four different immersion times.

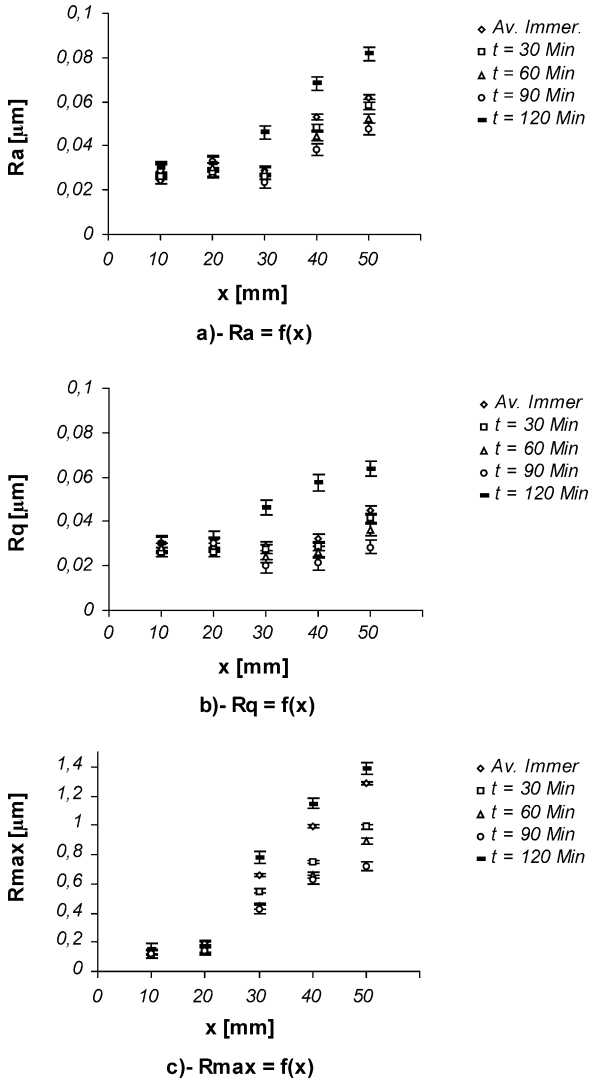
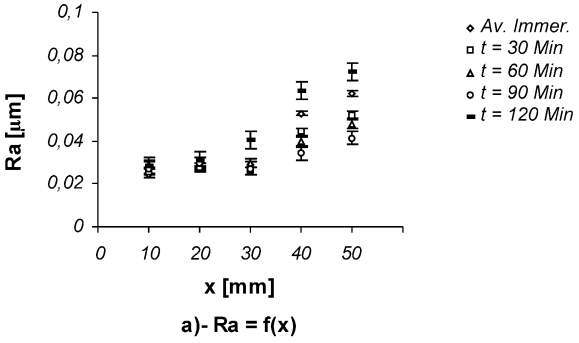
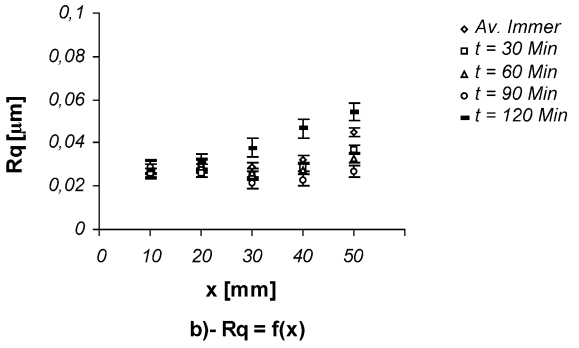


Fig. 5. Variation of the roughness with distance from the side of the sample (x) at $T_1 = 50\,^{\circ}C$.





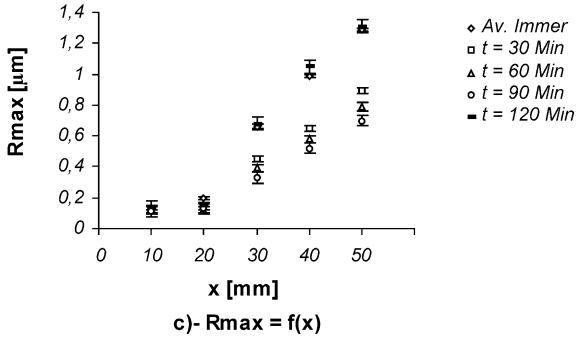
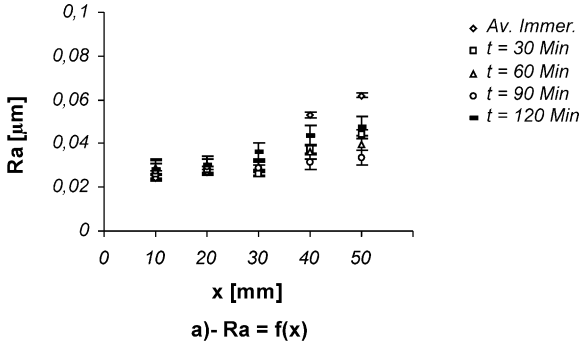
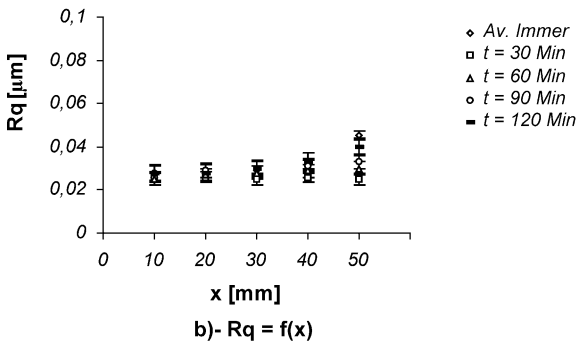


Fig. 6. Variation of the roughness with distance from the side of the sample (x) at $T_2 = 70\,^{\circ}\mathrm{C}$.





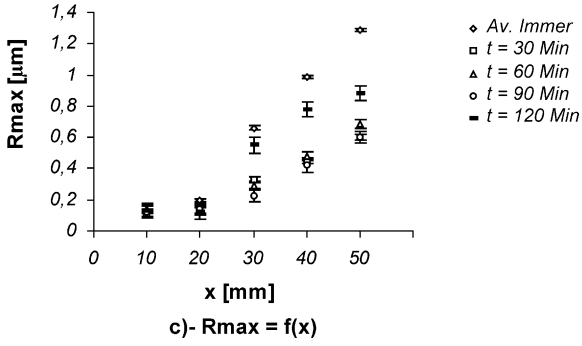


Fig. 7. Variation of the roughness with distance from the side of the sample (x) at $T_3 = 90\,^{\circ}\mathrm{C}$.

4.2. *Effect of immersion time*

The effect of the immersion time on the damage caused to the surface of the glass plates is shown in Figs. 5–7, where the roughness is plotted as a function of the impact distance from the side.

According to these figures, it is noted that at the impact point of $x = 20$ and at $T_1 = 50\,^{\circ}\mathrm{C}$ except for an immersion time of $t_4 = 120$ min where there was an increase in roughness, increasing the immersion time from $t_1 = 30$ min to $t_3 = 90$ min did not alter the state of the surface. This is explained by the fact that at $T_1 = 50\,^{\circ}\mathrm{C}$ and at immersion times of $t_1 = 30$ min, $t_2 = 60$ min, and $t_3 = 90$ min, water attacks on the surface leads to weakening of the Si–O links, but to a reinforcement of the Si–OH links. This causes the formation of silica gel on the specimen surface.

However, at water bath temperatures of $T_2 = 70\,^{\circ}\mathrm{C}$ and $T_3 = 90\,^{\circ}\mathrm{C}$, the roughness of the degraded samples decreases with increasing immersion times. This is attributed to the progressive attack of water on the whole surface, and particularly inside the microcracks, rendering them curved at both ends. Consequently, it was concluded that the corrosion takes place in a progressive manner.

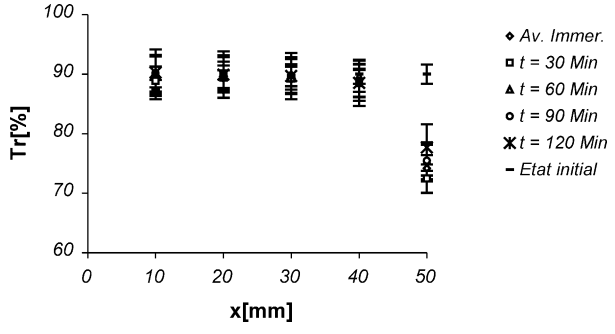


Fig. 8. Variation of the transmittance with distance from the side of the sample (x) at $T_1 = 50\,^{\circ}\mathrm{C}$.

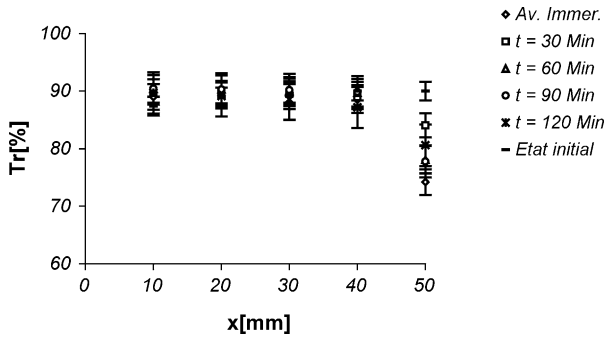


Fig. 9. Variation of the transmittance with distance from the side of the sample (x) at $T_2 = 70\,^{\circ}\mathrm{C}$.

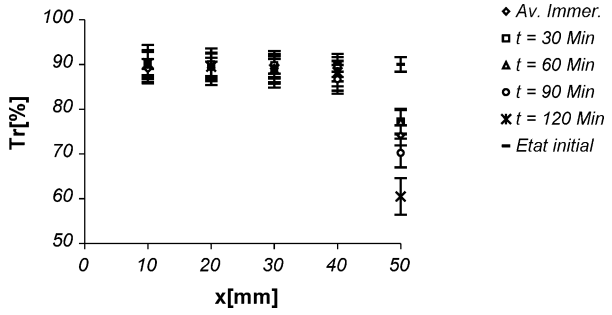


Fig. 10. Variation of the transmittance with distance from the side of the sample (x) at $T_3 = 90\,^{\circ}\mathrm{C}$.

As shown in Figs. 8–10, it is clear that at impact distance ranging from 20 to 50 mm, increasing the immersion time decreases the transmittance. This is explained by the fact that the microcracks widen and open up with increasing the immersion time. The resulting decrease in the transmittance is attributed to the reflection and the diffusion of light inside the microcracks (on the flanks of microcracks).

In order to check whether the opening up of the microcracks increases in water when increasing the time of immersion, samples were indented using a Vickers indentor under a load of 10 N, and were then immersed in water at 20.4 °C for different immersion times (30, 60, 90, and 120 min). The resulting prints, caused by indentation, were then photographed and their average diameter measured d_{moy} (d_{moy} is twice equal the length of the radial crack). These photographs are shown in Fig. 11.

According to these photographs, we note that the average diameter d_{moy} for samples, which were not immersed, did not change for all times (30, 60, 90, and 120 min). However, the mean print diameter d_{moy} of the indented samples increased with increasing immersion times for immersed specimen. This confirms the deduction that the opening up of the microcracks increases with the increase of the immersion time leading to a reduction of the transmittance.

4.3. Effect of temperature

As shown in Figs. 5–7, it is noticed that when increasing the water temperature, the roughness of the immersed samples decreased compared to that of degraded but not immersed samples. This is explained by the fact that as the water temperature is increased, the attack of water is accelerated and gets even more severe on both ends of the microcracks. This effect is most seen on the surface of samples damaged at $T_3 = 90\,^{\circ}\mathrm{C}$ and for an immersion time $t_4 = 120$ min. Consequently, it was deduced that the corrosion of degraded specimen accelerates with increasing both temperature and time leading to increase the opening up of the microcracks, and therefore to a decrease of the transmittance.

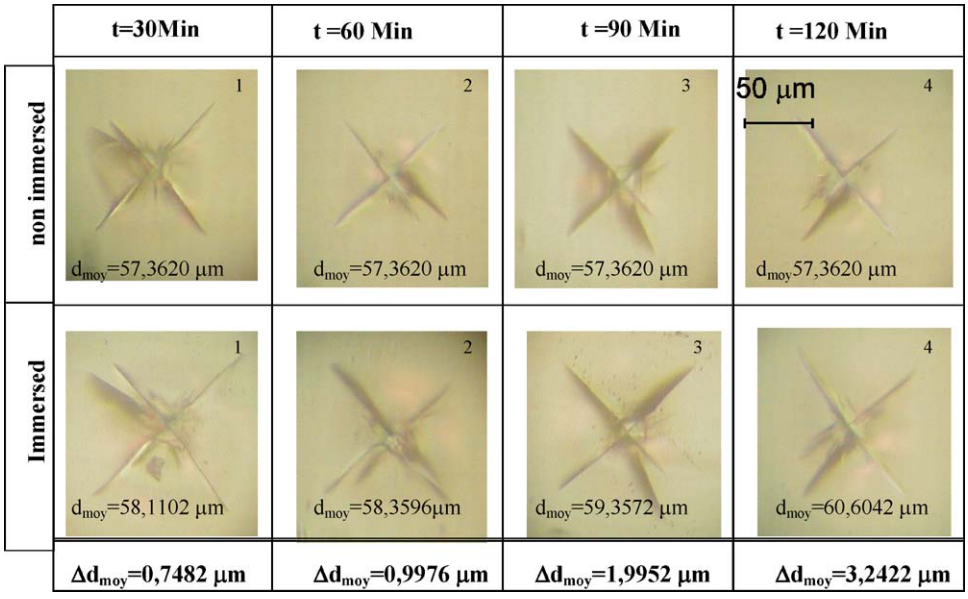


Fig. 11. Microscopic observation of indented and immersed specimens at different immersion time.

5. Conclusion

The present work consisted of the determination of the effect of the damage caused by the gravitational force of free falling sand on the surface of soda-lime glass, immersed in water at different temperatures and immersion times on the transmittance.

Experimental results showed that the statistical parameters of roughness (R_a, R_q, R_{max}) as well as the transmittance (Tr) do not follow a normal distribution. It was also concluded that the corrosion of the surface was accelerated by the water temperature and time of immersion leading to increase the opening up of the microcracks, and therefore to reduce the transmittance.

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