Mechanical strength of soda-lime glass damaged by sand gravitation

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A damage of glass surface by sand has a remarkable effect on a mechanical properties and in the first place mechanical strength. For this our study is to analyse a superficial deterioration of soda lime-glass and its influence on the mechanical strength. A deterioration by gravitation from a fixed height consists in damaging the surface of specimens by fall free of different quantities of sand of which a grains size was selected and different angles of incline. To characterise the surface state, we measured a roughness criteria at different points on specimen surface by a profilometer. To determine the mechanical strength, we proceeded to two types of tests, one by ball shock (falling ball) and other by bending with a circular supports. Consequences of superficial deterioration on the mechanical strength are illustrated by graphs presented in this article.

I. Introduction

Today the weariness of the energy sources (hydrocarbons) oriented the world toward other types of energy whose sources are permanent as a solar energy; seen that a favourable regions are deserts for the investment of these panels, their glass protectors are submitted to the climatic aggressions that have an obvious effect therefore on their surface state and their properties (optics and mechanical) such is the case of all glasses used in desert (house windows, vehicles by-breeze, optics instruments...).

Indeed, it has been demonstrated that a mechanical strength of glass is influenced by[1-4]:

- The state of surface or damage of the surface.
- The length of load or speed of load.
- The environment.

II. Technique of deterioration by gravitation

Deterioration by gravitation is simple and economic method, it consists in damaging a surface state by a free fall of sand quantity of which a grain size is known, from a fixed height while using a deterioration device by sand gravitation of surface[5].

A deterioration by gravitation is governed by the faculty of a sand grain to create some small micro-cracks on specimen surface.

III. Experimental procedures

For our survey, we used a soda-lime glass flat of which the Young's modulus is 72Gpa, Poison's ratio is 0.22 and its chemical composition is given in table 1:

Oxides	SiO_2	Na_2O	CaO	MgO	Al_2O_3	others
Wt %]	72,2	15,0	6,7	4,0	1,9	0,2

Table 1. Chemical composition of the glass tested.

All specimens (100x100x4 mm^3) were taken from the same plate.

The experimental study essentially bent on:

-0 The measure of a roughness with a profilometer Hommel-test type T20DC for specimens in soda-lime glass bombarded by different quantities of sand (100g, 300g, 500g) of which grains size has been selected by sifting (diameter measured by a optical microscope "NEOPHOT 21" is: G=0.456±0.065mm), with a constant height of sand fall 1m, a constant debit 1,66 g/s and three incline angles of specimen (θ_1=15° ; θ_2=45° ; θ_3=60°).

-1 Rupture strength was determined by two tests types:

1. The test by ball shock was established by a device realised in our laboratory with a following parameters : step *P*=30mm ; ball mass *m*=24,84g.
2. The test by bending was made on the universal machine of test « DY22 5KN » with a following parameters: load speed *V*=5mm/min ; capacity *P*=500daN ; precision $\varepsilon=\pm$ 0,5% of the measure; load ring radius r_0=10mm ; radius of support ring fixes r=20mm.

IV. Results

Before proceeding to a deterioration, we determined mechanical strength by ball shock σ_{rc}, and by bending σ_{rf}, with circular supports, arithmetic mean of roughness Ra and maximum roughness Rmax that is given in the table 2.

σ_{rc}[Mpa]	σ_{rf} [Mpa]	Ra [μm]	Rmax [μm]
95,22±6,62	70,39±12,77	0,013	0,057

Table 2. mechanical strength and roughness of soda-lime glass surface before degradation.

Notice: For mechanical strength by ball shock a number of shock repeated is N_{cr}=8.

- **Roughness :**

roughness measures has been done from a superior side of inclined specimen until a centre with step of 10mm following a straight direction.

Figures 1, 2 and 3 show roughness variations (arithmetic mean) Ra and maximum roughness Rmax according to the distance of specimen impact for different quantities of sand (100g, 300g, 500g) and different angles of incline (15°, 45°, 60°).

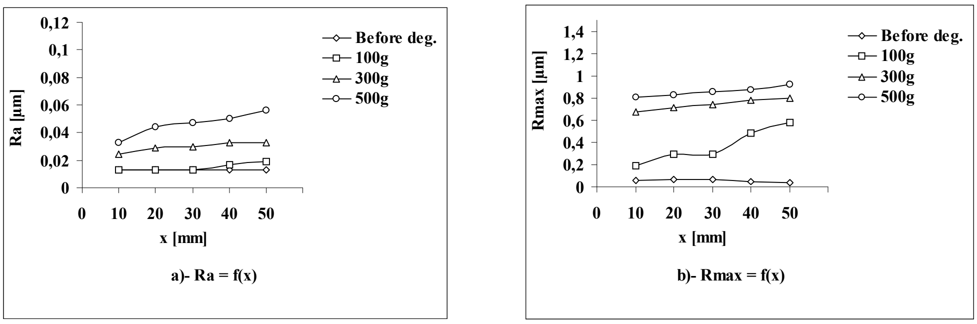

Figure 1 : Roughness Variation according to impact distance of sand (x) for θ = 15°.

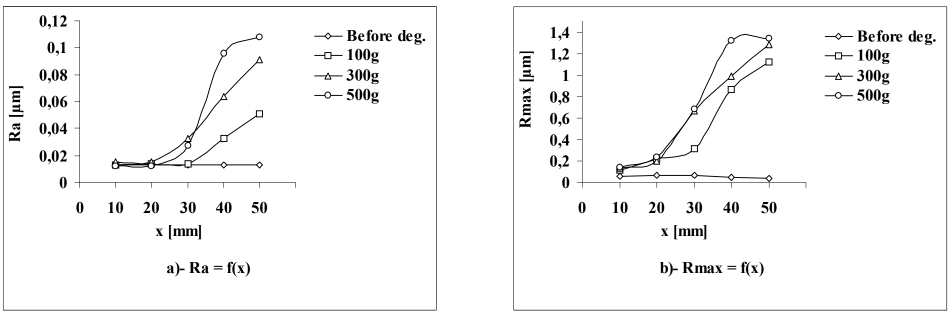

Figure 2 : Roughness Variation according to impact distance of sand (x) for θ = 45°.

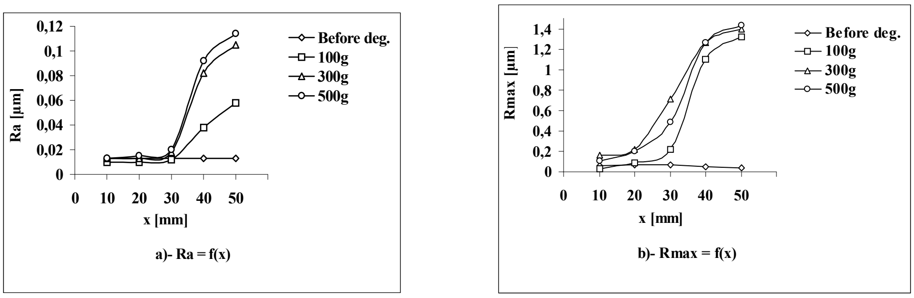

Figure 3 : Roughness Variation according to impact distance of sand (x) for $\theta = 60°$.

- **Mechanical strength:**
  - by ball shock:

Results of mechanical strength σ_{rc} by ball shock and its reduction $\delta\sigma_{rc}$ in percentage with regard to the state before degradation and number of shock N_{cr} are regrouped in table 3 :

M [g]		100	300	500
θ=15°	σ_{rc} [Mpa]	93,85 ± 5,06	93,66 ± 7,12	91,95 ± 5,64
	$\delta\sigma_{rc}$[%]	1,5	1,6	3,4
	N_{cr}	7	7	6
θ=45°	σ_{rc} [Mpa]	92,69 ± 6,44	91,13 ± 8,42	87,50 ± 8,21
	$\delta\sigma_{rc}$[%]	2,6	4,3	8,1
	N_{cr}	7	6	4
θ=60°	σ_{rc} [Mpa]	92,61 ± 7,39	90,38 ± 5,95	86,84 ± 4,83
	$\delta\sigma_{rc}$[%]	2,7	5,1	8,8
	N_{cr}	7	6	4

Table 3. Mechanical strength of soda-lime glass by ball shock of degraded specimens.

Results regrouped in table 3 are represented by figure 4:

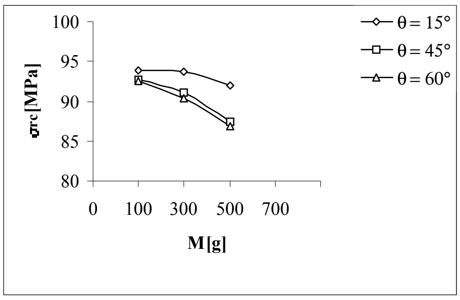

Figure 4 : Mechanical strength variations by ball shock of specimens in soda-lime glass according to a sand quantity for different incline angles (15°, 45°, 60°).

- by bending with circular supports:

Mechanical strength σ_{rf} by bending and its reduction $\delta\sigma_{rf}$ in percentage results with regard to the state before degradation are regrouped in the table 4:

M [g]		100	300	500
θ=15°	σ_{rf} [Mpa]	66,10 ± 7,85	58,33 ± 4,25	48,28 ± 3,33
	$\delta\sigma_{rf}$ [%]	6,1	17,1	31,4
θ=45°	σ_{rf} [Mpa]	63,93 ± 6,89	53,88 ± 4,13	44,54 ± 2,71
	$\delta\sigma_{rf}$ [%]	9,2	23,5	36,7
θ=60°	σ_{rf} [Mpa]	62,91± 5,72	51,31 ± 3,28	42,03 ± 2,72
	$\delta\sigma_{rf}$ [%]	10,6	27,1	40,3

Table 4. Mechanical strength by bending of degraded specimens in soda-lime glass.

Results regrouped in table 4 are represented by figure 5:

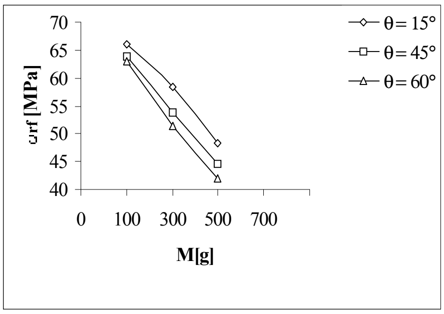

Figure 5 : Mechanical strength variations by bending of specimens in soda-lime glass according to a sand quantity for different incline angles (15°, 45°, 60°).

V. Discussions

- **Statistical interpretation :**

Tests showed that the two roughness criteria Ra and Rmax don't follow the normal law for incline angle 15°, but for the two other angles 45° and 60° they approach the normal distribution again better for the degraded states (100, 300, 500g), but they don't follow the normal law generally.

For a mechanical strength determined by two types of test, tests showed that it doesn't follow the normal law for different incline angles and different sand quantities.

- **Effect of sand quantity:**

For the state before degradation, one notices that a roughness (Ra or Rmax) some surface remain constant general on all surface; on the other hand the one of specimens degraded increases progressively with sand quantity.

To characterise the effect of different a sand quantities (100, 300, 500g) on the damage of surface state, one compares graphs represented by figures 1, 2 and 3.

Damages of the surface caused by sand quantities are near the one of a state before degradation from the side (x=10mm) until the point (x=20mm), after this a difference begins to appear distinctly while going toward a centre (x=50mm) ; what is explained by sand grains concentration in middle of specimen surface caused by a guidance of grains in glass tube (10) of the device represented on figure1.

From graphs of rupture strength (σ_{rc} or σ_{rf}) represented by figures 4 and 5, one clearly notices that mechanical strength of specimens degraded decreases to every time that sand quantity increases; which can be explained by: while increasing sand quantity a number of micro-cracks creates at surface by bombardment of grains increases and strength reduction therefore.

From the table 3, one notices that strength reduction by ball shock $\delta\sigma_{rc}$ increases and a number of repeated shock N_{cr} decreases while increasing a sand quantity for every incline angle of specimen.

One mentions that N_{cr} for different sand quantities and incline angles are less than 10 repeated shocks which confirms that we aren't in hardness phenomenon ($N_{cr} \geq 10$)[6].

From table 4, one notices that a reduction in strength by bending with circular supports $\delta\sigma_{rf}$ increases with increase of sand quantity.

Also, one mentions that a divergence of strength σ_{rf} decreases while increasing a sand quantity what can be to explain by a convergence of σ_{rf} to a corresponding vestigial value to the biggest sand quantity.

- **Effect of the incline of the surface :**

Graphs of roughness represented by figures 1, 2 and 3 show that damage of surface state increases with increase of incline angle, which means that sand grains bombard specimen surface present a reduction of sliding and an increase of scratching while increasing incline angle.

Figures 4 and 5 show that a mechanical strength by ball shock σ_{rc} respectively by bending with circular supports σ_{rf} decreases with increase of incline angle, which explains that scratching has a faculty to create more micro-cracks than sliding.

- **Comparison between the two types of test :**

To compare better two test, we determined ratio of mechanical strength by ball shock and by bending for different sand quantities and different incline angles. Calculated ratios are regrouped in table 5:

M [g]		100	300	500
θ=15°	**σ_{rc}/σ_{rf}**	1,42	1,60	1,90
θ=45°	**σ_{rc}/σ_{rf}**	1,45	1,69	1,96
θ=60°	**σ_{rc}/σ_{rf}**	1,47	1,76	2,06

Table 5. Ratio between mechanical strength by ball shock and by bending.

From experimental results of mechanical strength medium by ball shock and by bending that is given in tables 3, 4 and 5; we note that:

- The ratio between mechanical strength by ball shock and by bending is 1,35 for the state before degradation but for the damaged state varies between 1,42 until 2 ; what is in concordance with a one found by NOVOTNY(7) :

$$\frac{\sigma_{rc}}{\sigma_{rf}} = \begin{cases} 1{,}48 & \text{For a flat glass before damage} \\ 1{,}86 & \text{For the same glass after damage} \end{cases}$$

- Mechanical strength by bending is smaller with than the one determined by ball shock.

We can explain this in two points:

- Absence of hardness for the test of ball shock (instantaneous load) and a manifestation of hardness for the bending test because a load time is about ten (10) seconds.
    - The surface under load is bigger for bending, of where it has a great probability to find a critical micro-crack that causes a reduction of strength.

VI. Conclusion:

The work we did consists to determine the damage effect caused by a deterioration with sand gravitation on mechanical strength of sheet soda-lime glass.

On the experimental result basis obtained, we conclude that:

- Roughness of surface state (Ra or Rmax) and mechanical strength (σ_{rc} , σ_{rf}) don't follow normal law.
- Damage of surface state increases with the increase of sand quantity , and therefore a reduction of mechanical strength.
- Reduction in mechanical strength by ball shock $\delta\sigma_{rc}$ varies between 1,5% and 8,8%, but the one by bending $\delta\sigma_{rf}$ varies between 6,1% and 40% while increasing a sand quantity and incline angle.
- The number of repeated shock N_{cr} decreases with the increase of sand quantity for ball shock.
- Deviation of mechanical strength by bending σ_{rf} decreases with the increase of sand quantity and incline angle.
- Damage of surface state increases while increasing incline angle, and therefore a reduction of mechanical strength.

- Mechanical strength deducted by bending is smaller than the one determined by ball shock and the ratio between mechanical strength by ball shock and by bending is 1,35 for the state before degradation but for the damaged state varies between 1,42 until 2 while increasing a sand quantity and incline angle.
Therefore by this study, we could have led to information that are useful and very important for a good understanding of the influence of deterioration by sand gravitation on mechanical strength of the sheet soda-lime glass.

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1. J. Zarzycki in *Le verre et l'état vitreux*. Edition Masson, Paris,1982. Pp. 300-324

2. D. R. Uhlmann, N. Kreidel in *Glass Science and Technology. (Elasticity and Strength in glass),* Edition Academic Press, London, Vol.5, 1980, Pp.21-75.

3. H. Scholtze in *Le verre (Nature, Structure et Propriétés)*, Edition Institut de Verre, Paris,1980, Pp.218-238.

4. R. E. Mould, R. D. Southwick. J. Am. Cer. Soc. , 42, 1959, Pp.542-547.

5. Mark. A . Ludwig ; Robert. B. Stoner in *Quantitative abrasion resistance of optical coating and surfaces*, Publication Arizona. August 1987.

6. A. Sadi in *Influence de l'état de surface sur la résistance mécanique du verre*. Thèse de Magister, IOMP, U.F.A. Sétif, ALGERIE. 1987. Pp.45 - 47.

7. Novotny, Vich, Kubista , *Résistance en flexion et au choc de quelques verres industriels*, Silikaty, 1978, 22, Pp.329 - 346.

8. Manuel pour la fabrication du verre. Moscou, U.R.S.S.,1963, 1, Pp.5705-5729.

9. Reports by the technical committee of the society glass technology, 1969, 10(1), Pp.1.

10. Standard methods of flexure testing of glass. A.S.T.M.C.,1982, Pp.103 – 112.