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Fracture characterisation of float glass under static and dynamic loading

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ABSTRACT

This paper presents the study of float glass fracture under static and dynamic loading, with the use of experimental and numerical fracture mechanics methods. It has been shown that the value of notch fracture toughness under static loading depends neither on the kind of test nor on specimen geometry. This makes it possible to replace the three-points-bending specimens with the Brazilian discs which are, under certain test conditions, simpler and convenient to study. For both types of specimens, an analysis of the fracture strength, the notch stress intensity factor and fragmentation of specimens was carried out.

1. Introduction

Glass is one of the oldest materials discovered by the man, but it has had a rather late access to the state-of-the-art technology sectors. Besides the traditional applications such as packaging or building, glass appears in new industrial sectors where it brings original solutions, in particular in the fields of telecommunication, or nuclear power.

The use of glass is limited by its high brittleness and its low strength. Therefore, it is important to know its mechanical behaviour at different operating conditions. The first study of the glass was conducted by Griffith [1], who used this material to explain his fracture theory of linear elastic solids. Griffith showed that the result of the multiplication of the circumferential fracture stress $\sigma_{\theta\theta}^{c}$ by the square root of the crack half-length is always constant:

$$\sigma_{\theta\theta}^{c}\sqrt{a} = \text{Constant.} \quad (1)$$

He also suggests that, from a microscopic point of view, glass test specimens contain small surface defects resulting mainly from their handling. These microscopic cracks locally generate stress concentration. Griffith's experiments showed that this product is close to the theoretical value calculated by the relation:

$$\sigma_{\theta\theta}^{c}\sqrt{a} = \sqrt{\frac{2\gamma_s E}{\pi\lambda}} \quad (2)$$

E is Young's modulus, λ is the Poisson's ratio, and γ_s is the surface energy.

The interest in studying the fracture behaviour of glass material continues to increase [2]. The study here considers float glass fracture under static and dynamic loading, using experimental and numerical methods of fracture mechanics. We do tests that verify and determine fracture toughness of float glass. We also make recommendations on the specimen geometry depending on the mechanical characteristic to study.

2. Theory

2.1. Stress field at notch tip

Stress field at notch tip under static loading can be evaluated by analytic or numerical methods of mechanics of solids. The widely used relations [3–11] for such calculation are given in Table 1. Using some of these formulas, the distribution of the normal elastic stresses in the plane of notch in the SENB specimen made with glass was calculated (Fig. 1).

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Table 1
Expressions for calculation of the normal elastic stress distribution in the notch plane.

Local stress	Timoshenko and Goodier [3]	$\sigma_{yy}=\sigma_N\left[1+\frac{1}{2}\left(1+\frac{r}{2\rho}\right)^{-2}+\frac{3}{2}\left(1+\frac{r}{3\rho}\right)^{-4}\right]$ Circular notch in an infinite plate subjected to tension
	Neuber [4]	$\sigma_{yy}=\sigma_{\max}\sqrt{\frac{\rho}{\rho+4r}}$
	Chen and Pan [5]	$\sigma_{yy}=\sigma_{\max}\sqrt{\frac{\rho}{\rho+8r}}$
	Usami [6]	Generalisation of Timoshenko formula $\sigma_{yy}=\frac{k_t\sigma_N}{3}\left[1+\frac{1}{2}\left(1+\frac{r}{2\rho}\right)^{-2}+\frac{3}{2}\left(1+\frac{r}{3\rho}\right)^{-4}\right]$
	Glinka and Newport[7]	For blunt notch $k_t\le 4.5$ $\sigma_{yy}=k_t\sigma_N\left[1-2.33\left(\frac{r}{\rho}\right)+2.56\left(\frac{r}{\rho}\right)^{3/2}-0.907\left(\frac{r}{\rho}\right)^{2}+0.037\left(\frac{r}{\rho}\right)^{3}\right]$ For sharp notch $k_t>4.5$ $\sigma_{yy}=k_t\sigma_N\left[1-0.235\left(\frac{r}{\rho}\right)^{1/2}-1.33\left(\frac{r}{\rho}\right)+1.28\left(\frac{r}{\rho}\right)^{3/2}+0.037\left(\frac{r}{\rho}\right)^{2}\right]$
	Kujawski [8]	$\sigma_{yy}=f\frac{\sigma_{\max}}{2}\left[\left(1+\frac{2r}{\rho}\right)^{-1/2}+\left(1+\frac{2r}{\rho}\right)^{-3/2}\right]$ if, $(r/\rho)\le 0.2$, then, $f=1$ if, $(r/\rho)\succ 0.2$, then, $f=1+\frac{\tan(\pi/2k_t)}{2.8}\left(\frac{r}{\rho}-0.2\right)$
Global stress	ASTM [10]	$\sigma_r=\frac{3P_rS}{2WB^2}$, where P_r is the measured load at failure and S, W and B are the span distance, width and height of the rectangular shaped specimens.
	Hiramatsu and Oka [11]	$\sigma_{rr}=k(\lambda)\frac{2P_r}{\pi LD}$, where P_r is the applied load and L the length of the contact surface, $k(\lambda)$ is the equivalent to stress concentration factor.

If we use the curve obtained by FEM calculation as reference, it appears that the Timoshenko's model [3] overestimates on stress distribution and the results are about 25% above those obtained by finite elements calculation. For a distance on the ligament R less than twice the notch radius ρ, Glinka and Newport's distribution [7] is a good approximation to the values obtained by the FEM calculation. Beyond this value, this stress distribution presents a high deviation in comparison to the FEM calculation.

2.2. *Stress intensity factor K under static and dynamic loading*

In presence of a geometrical discontinuity (crack or notch), the stress field in the structure is completely modified. The failure process is not only controlled by the local stress amplitude, but also by the stress gradient. For these cases the stress intensity factor K_I is used as a basic parameter for description of the specificity of local stress field at the crack tip. The more useful formulae for K_I calculation found in literature [12–20] are presented in Table 2.

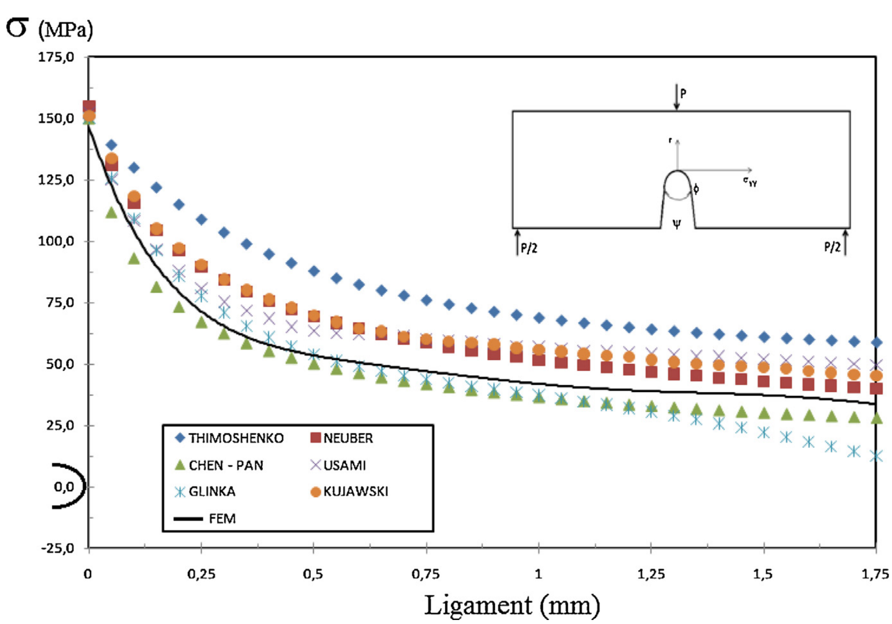

Fig. 1. Distribution of the normal elastic stress in the plane of notch in glass SENB specimen (notch radius ρ = 0.5 mm; notch width l = 6 mm; notch length L = 94 mm and applied nominal stress σ_N = 50 MPa).

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