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Experimental study on glass edge machining flaw characterization

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ABSTRACT

Knowledge of failure strength is the key to structural glass applications. However, the influence of the manufacturing process on the failure initiation at the glass edge is not well known. For this paper, small-scale glass specimens are tested in four-point bending, creating tensile stresses at the glass edge. Several edge finishings are investigated and their flaws detected concentrating on the failure initiating flaw. The characteristics of glass edge machining flaws are estimated by comparing obtained experimental values to existing time-dependent strength theory described in fracture mechanics. As a conclusion, typical edge flaws in industrial glass edge finishings are characterized and used as a basis for glass failure strength estimations.

1. Introduction

The failure strength of glass is influenced by all types of flaws, defects, imperfections and scratches that have been induced during machining, handling, service life, etc. The correlation between strength and flaws was first discussed by Griffith [1], describing the failure initiating flaw as a critical flaw or a Griffith flaw. Due to a manufacturing process, the glass surface is damaged creating a random surface flaw population, where the critical flaw will lead to a failure. In beam applications, glass is loaded in bending causing crack opening at the edge flaws under tensile stresses. Due to this failure initiation, the edge finishing plays an important role in strength determination.

A wide range of knowledge is already available concerning the theory of linear elastic fracture mechanics (LEFM) applied to any brittle material. However, it is not well known, how this theory is applied to cover real machining flaw configurations when the flaws are a result of a manufacturing process. Fracture mechanics provides a relationship between the strength and surface flaws: the larger the flaw, the lower the strength. Therefore, the study concentrates on as-received glass aiming at recognizing the edge flaws of manufacturing process. This is done by comparing five edge finishings and seven suppliers of glass products.

A study of edge flaws is carried out by illustrating the damage and the surface flaws at the glass edge. The critical flaws are characterized by estimating their size and shape using optical microscopy. As a result, a link between the theory of fracture mechanics and optically measured edge flaws is presented.

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Nomenclature

σ	stress perpendicular to the crack plain
σ_f	failure stress
σ_{eq}	equivalent failure stress
a	depth of a flaw
a_{f}	flaw depth at failure
c	flaw width
d	width of scoring damage
g	shape coefficient
K_{I}	mode I stress intensity factor
K_{Ic}	mode I fracture toughness
n	crack velocity parameter
S	failure stress
t	static loading time
v	crack velocity
v_0	linear crack velocity parameter
Y	geometry factor
Y_{calc}	calculated geometry factor

2. Related work

2.1. Fracture mechanics

The influence of flaws on failure strength is generally explained by means of the stress intensity factor (SIF) [2,3], described in the linear elastic fracture mechanics (LEFM) [1,4]. The SIF for mode *I* loading is defined as follows [5]:

$$K_I = Y\sigma\sqrt{\pi a} \tag{1}$$

where σ is a stress, Y a geometry factor and a is the depth of the critical flaw. The failure occurs when the stress intensity factor reaches its critical value $K_{Ic} = Y\sigma_f\sqrt{\pi a}$, here assumed as a material constant for glass $K_{Ic} = 0.75$ MPa$\sqrt{m}$ [6] and a failure stress σ_f. The geometry factor remain constant during loading time [7]. This conclusion was made based on microscope observations of the critical flaw before and after failure.

The inert strength is thus described by means of material toughness K_{Ic}, the depth of the critical flaw a and by the geometry factor Y, which is a property of the flaw configuration. These dimensions are defined similarly in the literature [8] and they are illustrated in Fig. 1 for both corner and surface cracks, where x-axis is the direction of the specimen thickness and y-axis the specimen height.

The surface flaw dimensions and their configurations are defined in several ways in the literature. The depth of the flaw, a, is either calculated as a function of time $a(t)$ [9] or defined experimentally by measuring the dimensions from specimens [10]. For the geometry factor Irwin [11] proposes a value $Y = 1.12$. Newman and Raju [12] defined the configuration of surface and corner flaws by numerous equations where Y is a function of a, c and the size of the specimen. The latter approach was applied by Porter [6] who arrived at a constant value of $Y = 0.722$ for corner cracks.

The glass failure occurs under tensile stresses creating a mode *I* crack opening stress along the longitudinal direction. This conclusion was made according to the assumptions below made for glass failure in fracture mechanics theory described in [13,14]. The assumptions contain following arguments. Glass material contains a large number of natural flaws that can be modeled using a Poisson distribution. The flaws are treated as a random surface flaw population. Alternatively, if the critical

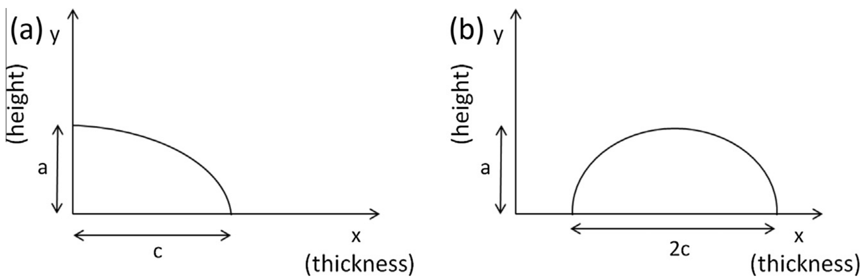

Fig. 1. Illustration of the dimensions of (a) a corner flaw (b) an edge surface flaw, where x-axis is the direction of the specimen thickness and y-axis the specimen height, for beam specimens.