Critical issues in the design-by-testing of annealed glass components

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A B S T R A C T

To assess the reliability of glass components, a common practice is to test full-scale prototypes in the lab, and verify that the failure load is higher than that predicted from the design strength by means of structural calculations. However, any procedure of design-by-testing should be considered with great care because the gross strength of glass, being governed by the opening of pre-existing cracks on the material surface, strongly depends upon the type of defectiveness, the specimen size, the load history and the type of stress field (uniaxial, bi-axial). A model based upon an assumed law of subcritical crack propagation and a distribution à la Weibull of pre-existing flaws is considered for the body strength of annealed glass. This allows to correlate the expected macroscopic strength of glass, measured from testing the prototype, with the target probability of failure, for any type of size and load history. The discussion of paradigmatic examples confirms that appropriate theoretical considerations are needed for the correct interpretation of the experimental results.

1. Introduction

The incessant investigation of ever greater transparency has led to an increasingly strong demand for glazed surfaces in modern construction works. Glass is being used in challenging elements, such as larger and larger panels, roofs, beams, floors, stairs and frames, where the brittle material is required to carry substantial loads, therefore achieving a definite “structural” role. Improvements in production and technologies, such as tempering, increase the macroscopic strength of this material. Lamination of glass plies sandwiching polymeric interlayers mitigates the effect of brittleness, because the shards remain adherent to polymeric interlayers after glass breakage. Considerable research [1–7] is being undertaken to improve the understanding of the load-carrying capacity of structural glass elements under the actions those elements are exposed to during their service life, in order to achieve the requirements in terms of safety and serviceability that are prescribed by construction standards.

The reliability of a structural design depends on the capability to determine the material failure strength with accuracy. At the macroscopic level, the most used methods to measure the mechanical strength of glass are the Four Point Bending (4PB) test and the Coaxial Double Ring (CDR) test, which are precisely defined by harmonized standards [8–10]. In general, the tests aim at inducing a uniform stress field in the loaded area of the specimen: the 4PB test [9] generates an almost uniaxial stress field,1 while in the CDR test [8] the stress field is assumed to be approximately uniform and equi-biaxial2 in the core of the specimens, so that edge effects have no influence. Results are often interpreted using a two-parameter Weibull distribution [13], which is traditionally considered the best statistical approach [14].

However, the strength of glass, the brittle material par excellence, is affected by some peculiar properties at the microscopic level, which are of minor importance in other building materials such as steel and concrete, but acquire a crucial role in this case. Glass does not exhibit any ductility and breaks as soon as the stress at a point overcomes a certain limit, but no theory of glass strength can disregard consideration of the underlying microstructure. In fact, the material strength is governed by the presence of existing microscopic surface flaws, which open and progress under the applied stress [15]. Therefore, Linear Elastic Fracture Mechanics (LEFM) is the most useful tool to investigate the mechanical property of glass and interpret its brittle character.

Surface treatments (especially along the edges) have a strong influence on the strength because they may alter the size and

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1 The stress field is in general not perfectly uniaxial, because a stress concentration occurs in proximity of the edges, where defectiveness is in generally greater that in the core of the specimen [11]. Therefore, the results may be strongly influenced by the type of edge working.

2 A recent study [12] indicates that the state of stress in the test configuration defined in [8] is far from being uniform and equi-biaxial. Therefore, the validity of such a procedure will need to be questioned on a theoretical ground.