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Discussion

A discussion of paper "A novel indirect tensile test method to measure the biaxial tensile strength of concretes and other quasibrittle materials" by G. Zi, H. Oh, S.K. Park

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As it is well known, indirect methods such as splitting (Brazilian) tensile test or 3–4 point bending tests are often preferred to direct tensile test for determining tensile strength of concrete. Zi et al. [1] has proposed a biaxial flexure test method to measure the tensile strength of concrete indirectly. In this discussion, the similarities and dissimilarities of the proposed method with the well known biaxial flexure test method [2,3] will be compared. A biaxial flexure test method has already been used for ceramics and also some cement based materials like macro defect free (MDF) cements starting from the 1960s and even this method was standardized by ASTM [3] in 1978 (however, it was withdrawn in 2001). Therefore, I would like to contribute their study while giving a short history of biaxial flexure testing since the writers did not mention anything about these earlier efforts and I also would like to discuss some points in their article.

Biaxial flexure test method was first proposed by Wachtman et al. [2] and ASTM published a standard [3] according to their drawings and proposals. Actually, the biaxial flexure test method which involves supporting a plate on three or more points at bottom surface and loading on the upper central point has been started to be investigated in 1963 by Vitman and Pukh. [4] and also by other researchers such as Vitman et al. [5], Roark and Young [6], Kirstein and Wooley [7], Willshaw [8], Evans and Davidge [9], Ritter et al. [10] and Shetty et al. [11]. It looks obvious that Wachtman [3] was the first proposing a biaxial flexure test method by using equations and solutions of the previous scientists.

The only difference between the methods of Zi et al. [1] and Wachtman et al. [2] was the supporting and loading systems. Wachtman et al. used a three-ball support and loaded the plate with a piston while Zi et al. used an annular support and loaded the specimen through a circular edge. In this discussion, the system used by Zi et al. was called as "ring on ring" method and Wachtman's system as "piston on 3 ball" method for simplicity following the definitions used by Wachtman et al. [2]. These systems can be seen in Fig. 1. Dashed circles are the supports at the bottom of specimen while little dark circle is the loading piston at the top of the specimen in Fig. 1(a). Similarly, dashed circle is the support at the bottom of the specimen while dark circle is the loading piston at the top of the specimen in Fig. 1(b).

The latter (ring on ring) involves supporting a circular plate on a ring and loading with a small concentric ring. An exact elastic analysis is available for the case of small deflections (less than the plate thickness). However, it may not be suitable for specimens such as fiber reinforced concrete, which deflects more than the plate thickness before failing, so the small deflection elastic analysis is inadequate. The former (piston on 3 ball) has also been accurately analyzed for small deflections (less than the plate thickness). This former method has an advantage over the latter method in that support of the specimen on three balls allows the use of a slightly warped specimen. Thus no surface grinding or polishing is required, in contrast to the ring supported technique [2].

Zi et al. [1] explained why they choose this loading system in the last paragraph of page 753 in their article. However, according to Thiruvengadaswamy and Scattergood [12], the stresses are almost independent of the supporting configuration. Similar results are obtained for a continuous support ring compared to a symmetrically placed arrangement of discrete support balls. The three-ball support is advantageous according to them because it provides kinematic mounting for flat disc specimens. Kinematic mounting cannot easily be achieved when more than three balls are used, which could lead to spurious results [12].

Although, the former "piston on 3 ball" system was preferred in old sources [2–12] it can be considered that the ring on ring system maybe more precise since the cracks only propagate between supporting

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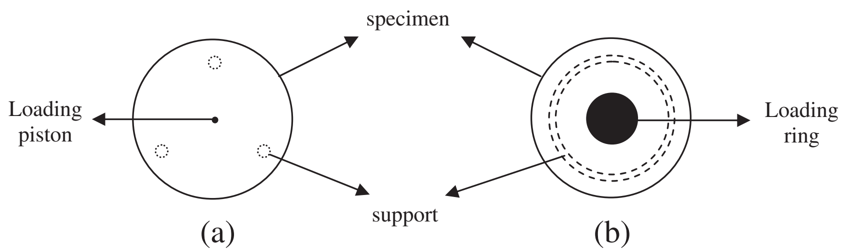

Fig. 1. Aerial view of a) piston on 3 ball system used by Wachtman et al. b) Ring on ring system used by Zi et al.

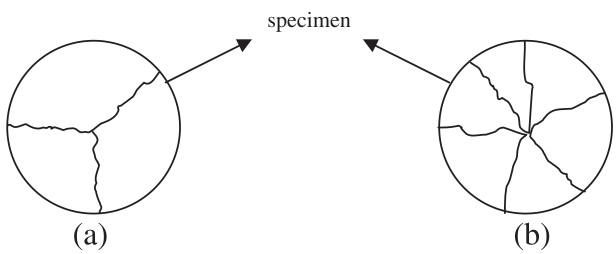

Fig. 2. Estimated crack distributions at biaxial flexure strength a) piston on 3 ball system b) ring on ring system.

directions and the results highly dependent on the quality of specimen over these 3 directions. In the latter the "ring on ring system", the direction of the first crack was arbitrary and it might form in the direction where the strength was a minimum as it is shown in Fig. 2.

On the other hand, Wachtman et al. [2] derived the equation of biaxial flexure stress given by Kirstein and Wooley [7] as shown in Eq. (1). Zi et al. [1] gave the similar formula for calculating the biaxial flexure stress in their paper according to Timoshenko [13] but it looks that they neglect to use the radius of specimen (C) in their formula if it is not a typing error. Current author of this paper would like to learn if they made any assumption.

$$S = -\frac{3}{4\pi}\frac{P}{d^2}(X-Y) \quad (1)$$

where;

$$X = (1+\upsilon)\ln(B/C)^2 + [(1-\upsilon)/2](B/C)^2 \quad (2)$$

$$Y = (1+\upsilon)\left[1+\ln(A/C)^2\right] + (1-\upsilon)(A/C)^2 \quad (3)$$

S	Biaxial Flexural Strength or MOR, MPa
P	Failure Load, N
υ	Poisson Ratio
d	Thickness of the specimen, mm
A	Radius of support circle, mm
B	Radius of loaded area or ram tip, mm
C	Radius of specimen, mm

Zi et al. [1] mentioned that the standard deviation of the biaxial flexure strength was 63% greater than the uniaxial strength. Ekincioglu et al. [14,15] also used piston on 3 ball system for measuring biaxial flexure strength of MDF cements and noticed that the standard deviation was also high. In addition, Zi et al. [1] found that the biaxial flexure strength results are about 19% greater than the 3 or 4 point bending test results. Russell et al. [16] also made the same comparison for MDF cements and reported that the biaxial flexure strength results were 15–20% higher than the 3 and 4 point bending tests respectively, which were in good agreement with the results of Zi et al.

Last of all, it can be concluded that biaxial flexure tests can be used for determining tensile properties of concrete because of its simplicity. But, both piston on 3 ball and ring on ring systems have high values of coefficient of variations. For this reason, the number of specimens tested should be increased.

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