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Deformational behaviour of concrete specimens in uniaxial compression under different boundary conditions

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Abstract

This paper reports experimental data produced by a series of uniaxial compression tests on cylindrical specimens of concrete. The specimens were tested under four different boundary conditions, with their deformational behaviour carefully recorded to study the ensuing strain-softening behaviour. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Compressive strength; Concrete; Degradation; Mechanical properties; Strain softening

1. Background

Many experimental attempts have been made in the past to assess the difficulties associated with experimentally obtaining the full stress-strain curve (FSSC) (i.e., both pre- and postpeak branches of the curve) of concrete in uniaxial compression (for a comprehensive bibliography, see references [1–3]). In the past, such experiments had generated conflicting evidence and considerable debate, especially regarding the postpeak part of the FSSC, which is influenced by such factors as the shape and size of the specimen, height-to-diameter (h/d) (or width for prisms) ratio, the stiffness of the testing machine, and the effect of the frictional forces between the loading platens and the specimen. These factors were the subject of a recently completed international programme of research carried out by RILEM TC 148SSC, with the conclusions summarised by Van Mier et al. [2]. The present note describes the authors' contribution to this programme, which consisted of a study of the effect of the frictional forces mentioned above that aimed to establish that the descending branch is due to the interaction between the specimen and the loading machine structure and, hence, concrete can be described as a brittle material (i.e., as a material characterised by a complete and immediate loss of load-carrying capacity as soon as the peak stress is exceeded).

2. Experimental apparatus and programme

The experimental setup, which employs a double-acting ram operating in displacement mode, is described in detail elsewhere [1]. Axial strains were derived via two LVDTs measuring platen-to-platen displacement and with four equidistant strain gauges glued on the surface (at midheight) of the specimen. Lateral strains were obtained via four horizontal LVDTs, which measured lateral displacements at midheight using a fixed ring of the loading frame around the specimen as a point of reference (see Fig. 1).

Cylindrical specimens, 150 mm in height and 75 mm in diameter (2/1 height/diameter ratio) were employed, and they were cast from two different mixes, the details of which are given elsewhere [1]. These specimens were subjected to varying degrees of frictional restraint, which was achieved by introducing "antifriction" media at the interface of the specimen and the steel loading platens. Three cylinders from each mix were tested under the following types of loading arrangements [1]: (1) hardened steel platens with no antifriction medium; (2) a layer of synthetic rubber (neoprene) 0.75 mm thick; (3) MGA pads (consisting of 0.2 mm thick hardened steel placed adjacent to the specimen, Molyslip grease (containing 3% MoS_2), and a Melinex polyester film, gauge 100, placed against the steel platen), with new MGA pads used for each test; and (4) brush platens developed by splitting a steel platen longitudinally and transversely to form a large number of individual bristles. The effectiveness of each method has been established from tests on cubes, as described elsewhere [3].

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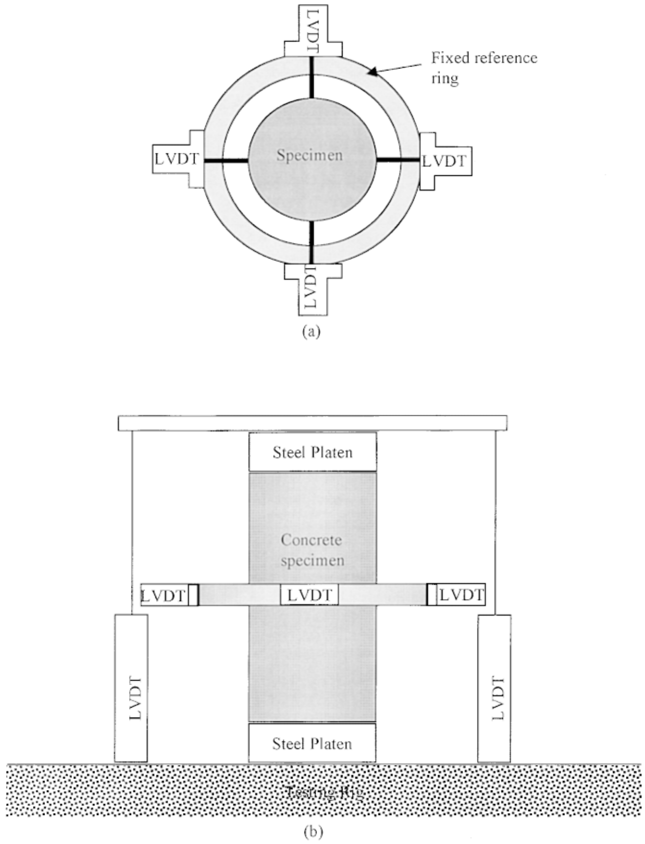


Fig. 1. Strain measuring arrangements: (a) plan view at midheight and (b) side view.

3. Discussion of results

All results reported herein represent the mean value of the corresponding set of three cylinders. Figs. 2, 3, and 4 also include data (where available) from mixes 3 and 4 described previously [3]. Fig. 2 shows the variation of the uniaxial compressive strength. In the case of mix 1 (f_{cy} = 41.2 MPa) the ultimate stress sustained, σ_u, is reduced by 17.5% when antifriction media are introduced. However, σ_u appears to be unaffected by the type of the antifriction media. On the other hand, in the case of the higher strength mix (f_{cy} = 48.5 MPa) the specimen strength is reduced by 6% when brush platens and MGA pads are employed, and by 22% when rubber platens are used.

The above results are not in agreement with the data reported previously [3], where it was found that the compressive strength is independent of the frictional restraint when cylinders of h/d = 2.5 were used, but they are in agreement with some of the data in a different work [2]. Their differences may be due to the fact that when the h/d is reduced to 2 and steel platens are employed, the end zones under triaxial conditions extend throughout the specimen so that the development of a central "uniaxial" zone is not achieved. Therefore, the behaviour of the whole cylinder is governed by these frictional forces resulting in an increase in σ_u. On the other hand, when brush platens and MGA pads are utilised, the frictional forces are sufficiently reduced for a central zone, under essentially uniaxial conditions, to be developed, so that σ_u reduces to its true value. For the rubber platens and the higher strength mix, the high compressive stresses cause the rubber to expand laterally to a high degree: tension cracks are then initiated in the end zones that accelerate the fracturing process and fail the cylinder at an early stage in a brittle manner. In view of the above observations, one may conclude that provided that a central zone in the specimen exists and that the frictional forces are compressive, the ultimate strength of the specimen is virtually unaffected by the loading means.

Fig. 3 indicates that the axial strains, as recorded from the LVDTs, are roughly comparable in magnitude for the cases of steel platens, brush platens, and the MGA pads. On the other hand, the axial strains for the rubber platens are much lower because of the tension cracks described previously.

It is the lateral strains at the point of maximum stress (Fig. 4) that appear to be significantly dependent on the loading means. Interestingly, the lateral strains for the brush platens are noticeably lower than those for the steel platens and the MGA pads.

For all the mixes, the axial-strain values at ultimate strength seem to be essentially independent of the concrete strength (considering the 2/1 cylinder as one set, and the 2.5/1 cylinder as another) in contrast with the lateral strains, which for mixes 1 and 2 increase with increasing strength but have the opposite behaviour for mixes 3 and 4.

The combined effect of all the above remarks is shown in Fig. 5, which indicates that the Poisson's ratio at ultimate stress is higher in the case of the higher strength concrete mix (unexpectedly, when one considers that the higher the strength of a mix, the lower its triaxiality) and, except for the brush platens, is greater than 0.5.

It is important to note that the LVDT readings for the lateral displacement correspond to the lateral expansion of the cylinder surface as recorded at four points on the circumference. It is, therefore, questionable whether these readings can be relied upon to represent the material behaviour for the whole of the cylinder cross section at a given height, and this explains the relatively high lateral strains at the ultimate stress point and the high rate of increase of the lateral strains in the postpeak region. However, the LVDTs produce more reliable data when compared to the strain gauges because, when the separation of the outer part from the inner core of the specimen becomes more pronounced, the outer portion (i.e., the surface with the strain gauges) of the cylinder ceases to be a representative part of the specimen [1,2].

In the case of the brush platens, the lateral strains appear to be low in the prepeak region up to σ_u. It is likely that the brush platens delay the separation of the inner core from the outer portion of the cylinder. This results in lateral strains, as recorded by the LVDTs, which represent the true material behaviour up to that stress level. This is supported by the fact that the fracturing of the cylinders loaded via brush platens, as indicated at the loaded surfaces, is very well dis-

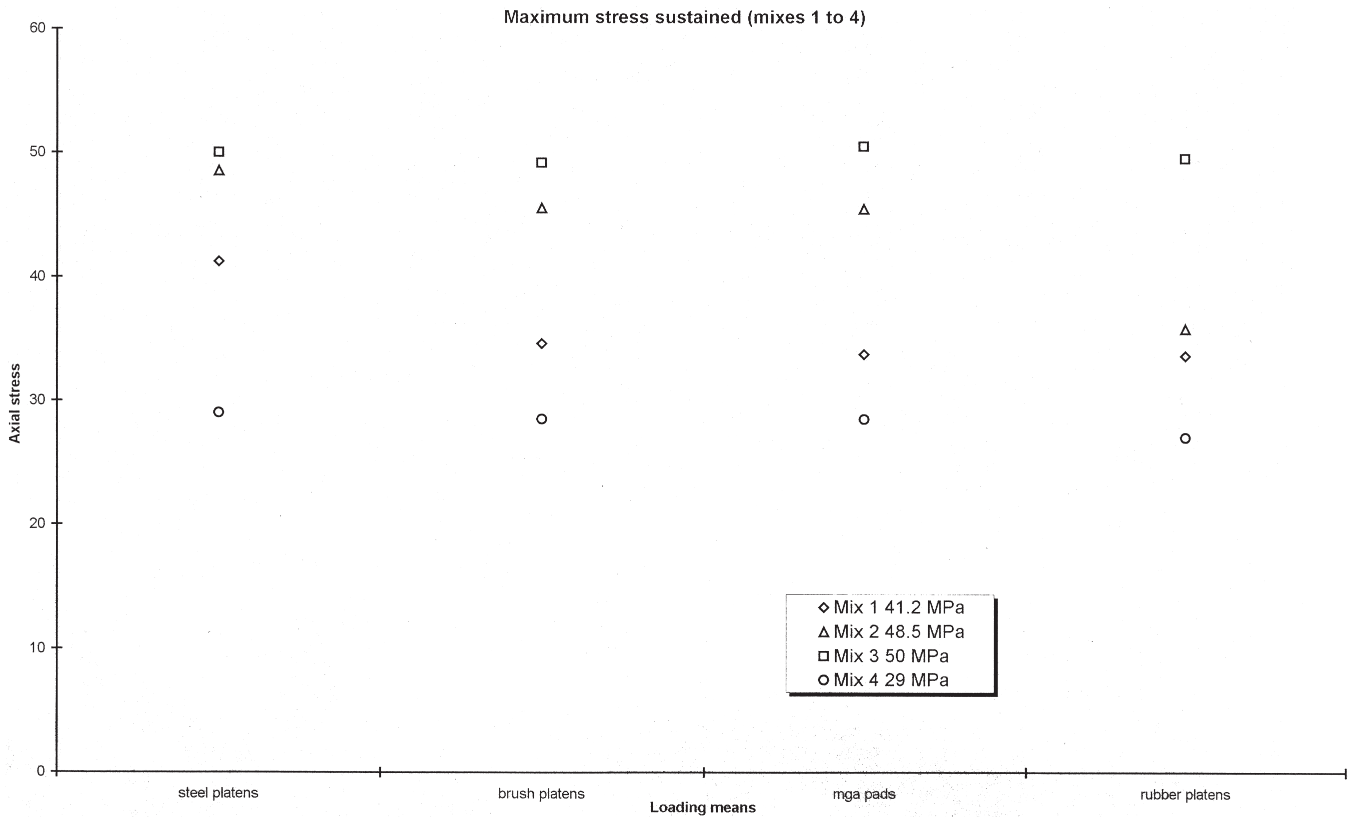


Fig. 2. Maximum stresses sustained by mixes 1 to 4.

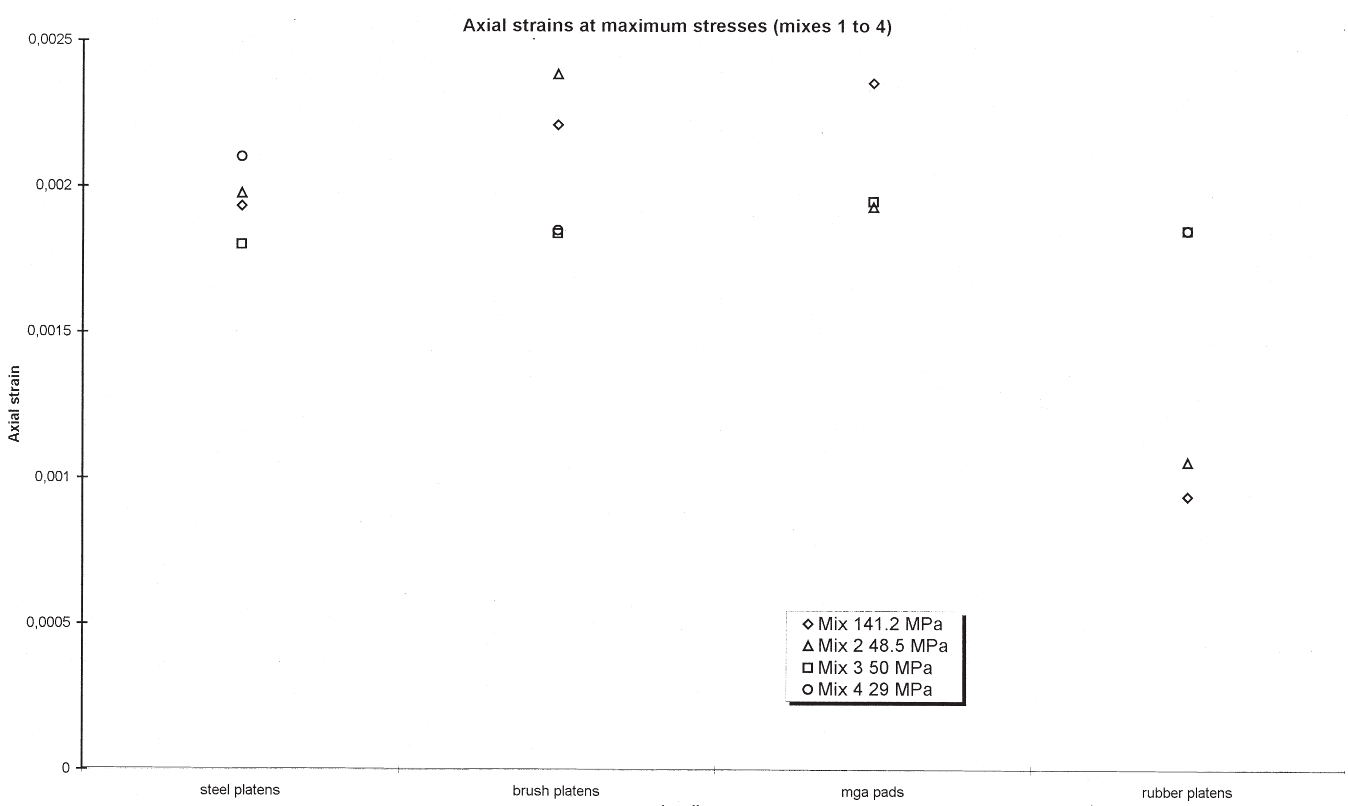


Fig. 3. Axial strains at maximum stresses.

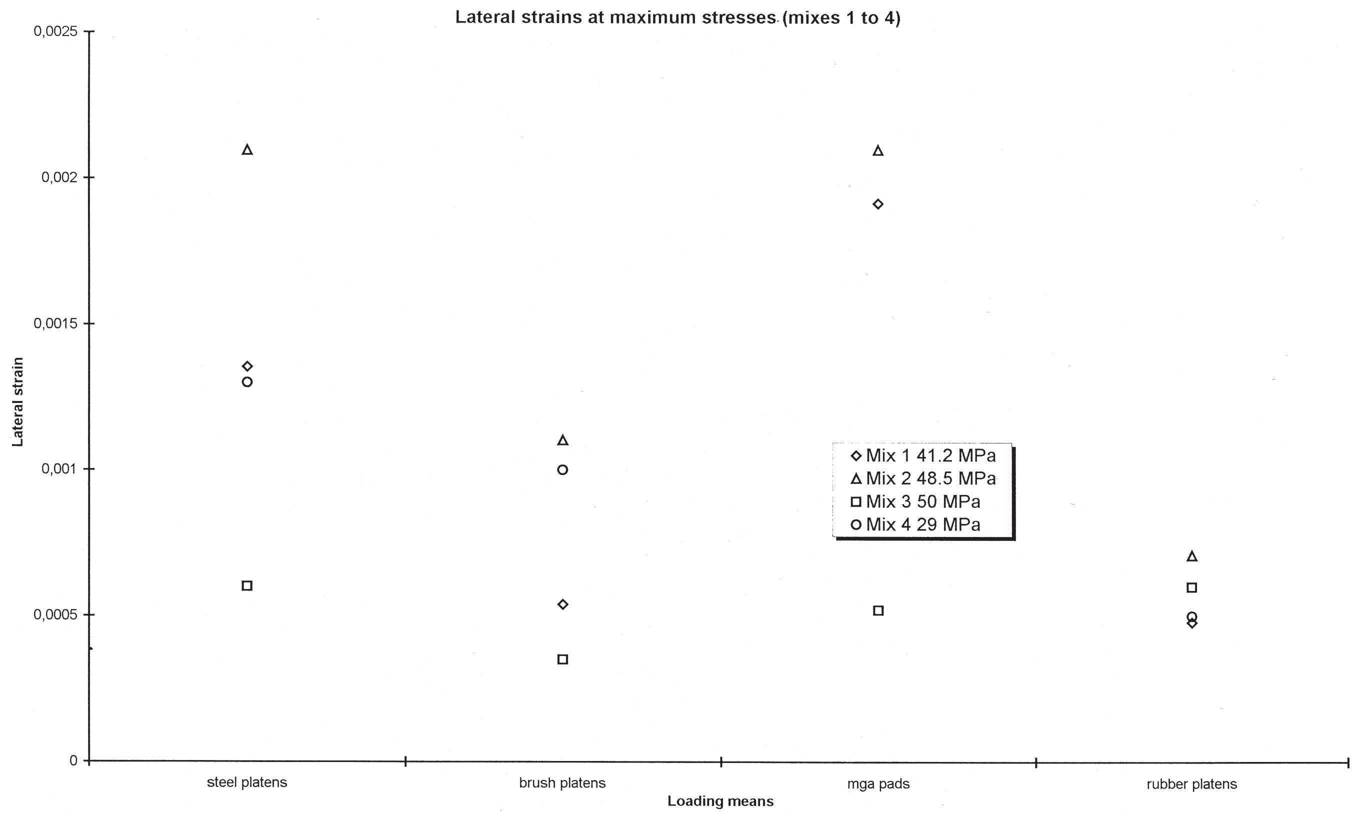


Fig. 4. Lateral strains at maximum stresses.

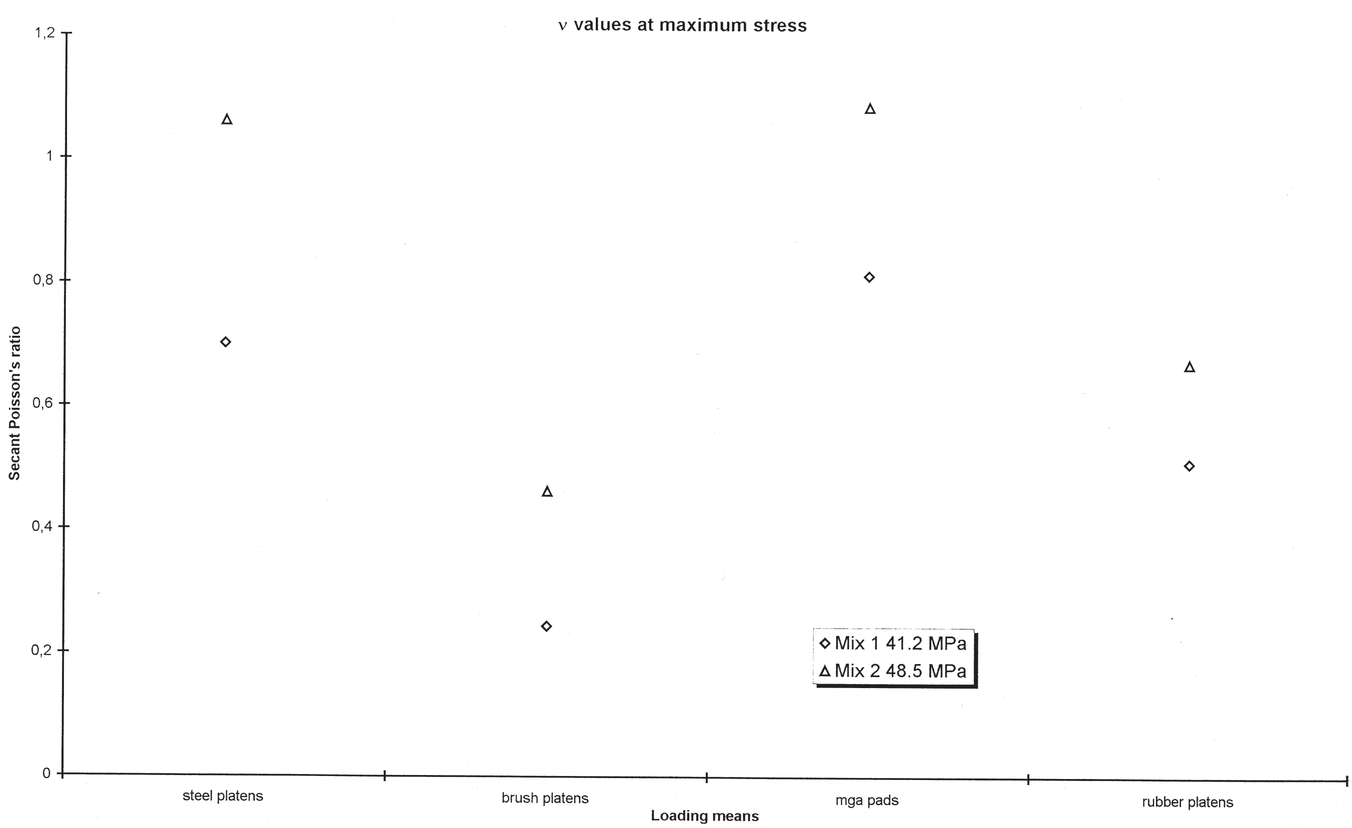
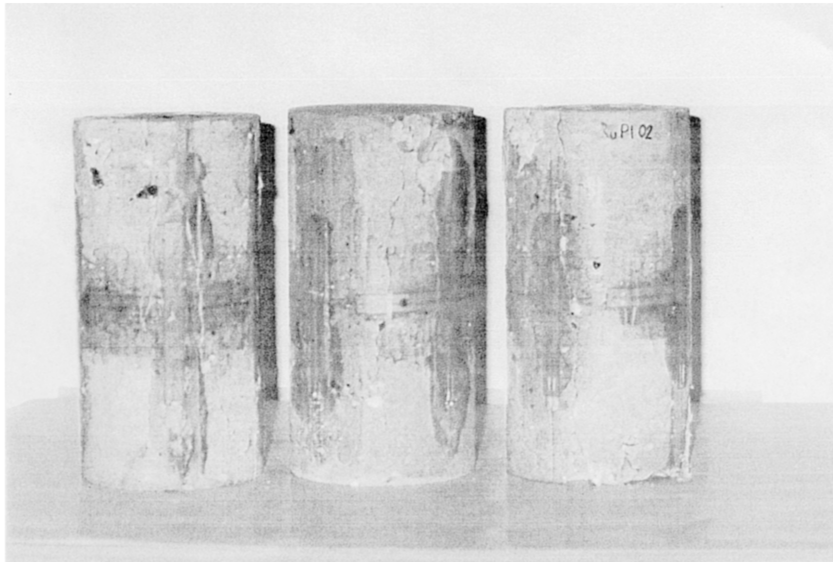


Fig. 5. Poisson's ratio at ultimate stress for mixes 1 and 2.



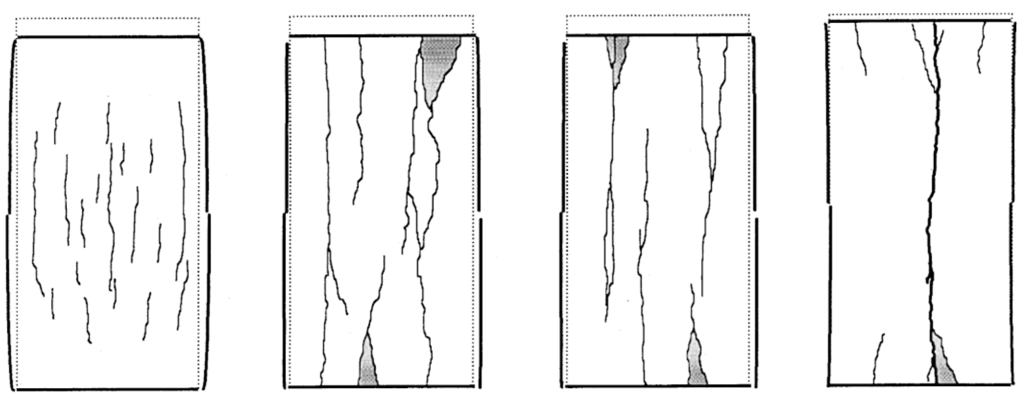


Fig. 6. Crack patterns for each loading platen. (Top) MGA pads, brush platens, and rubber platens. (Bottom) Steel platens, MGA pads, brush platens, and rubber platens.

tributed with no large cracks apparently dividing the cylinder (see Fig. 6).

Figs. 7 and 8 show the complete stress-strain curves (normalised with respect to σ_u and its corresponding strain) of the cylinders for mixes 1 and 2, respectively. These curves are very similar to those reported elsewhere [3] for comparable data. The slopes of the descending branches of the various curves do not appear to vary between mixes 1 and 2 (Fig. 8), because these mixes do not cover a wide range of strengths and are both classified as middle-strength mixes. The least ductile behaviour of concrete is obtained when MGA pads are employed as the antifriction media and are the most ductile when no such media is used.

The descending branch becomes gradually steeper as the friction at the interface of the platens and the specimen is reduced. The highest compressive frictional forces are introduced by the steel platens, followed by the brush platens, and then the MGA pads. It should be noted that the brush platens appear to apply a smaller frictional force than the MGA pads for stresses up to immediately after the peak stress. Beyond this point and at approximately -2.4 to -3 of the normalised lateral strain, the steel sheet of the MGA pads fails, because of excessive lateral deformation [1].

4. Conclusions

The results stemming from the present series of tests differ in some respects from the ones reported earlier [3]. However, most of these differences can be attributed to the

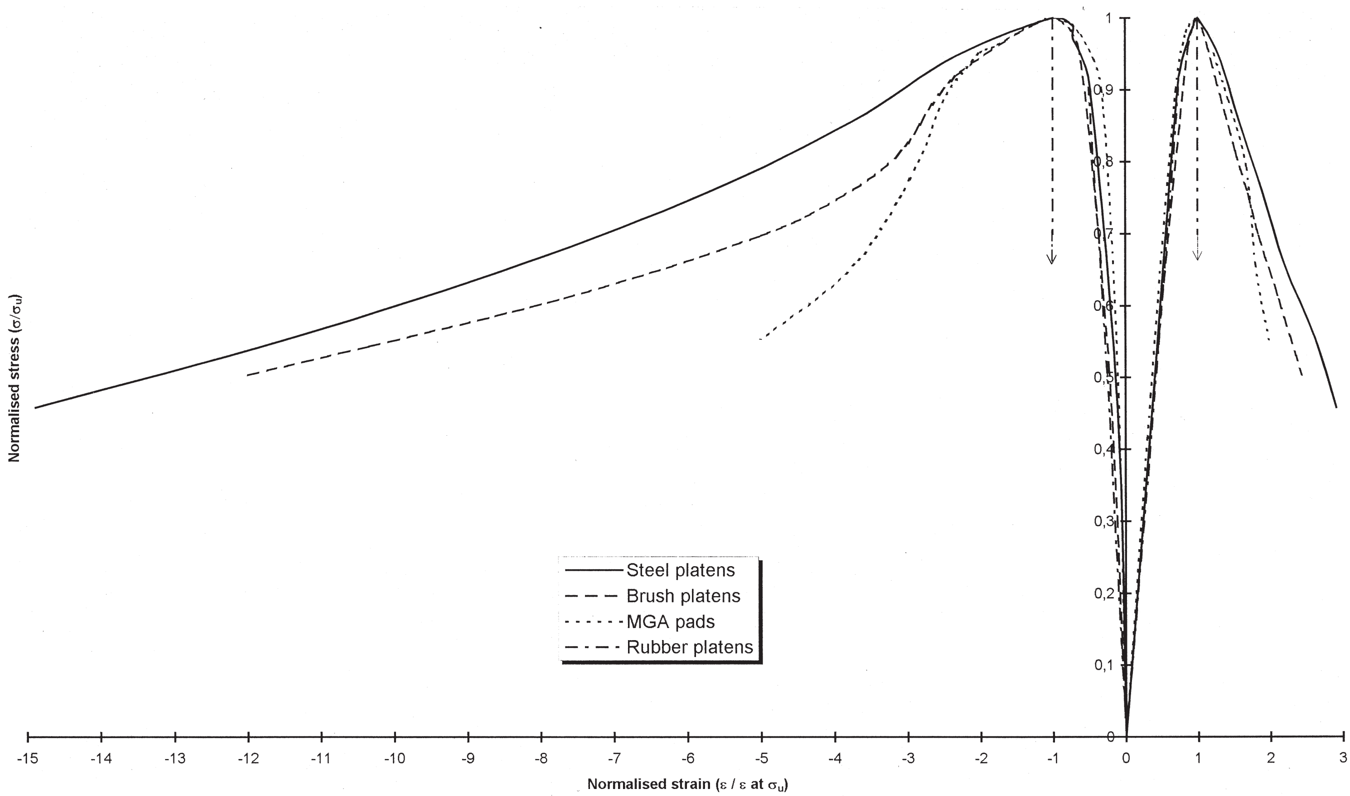


Fig. 7. Stress-strain curves for mix 1.

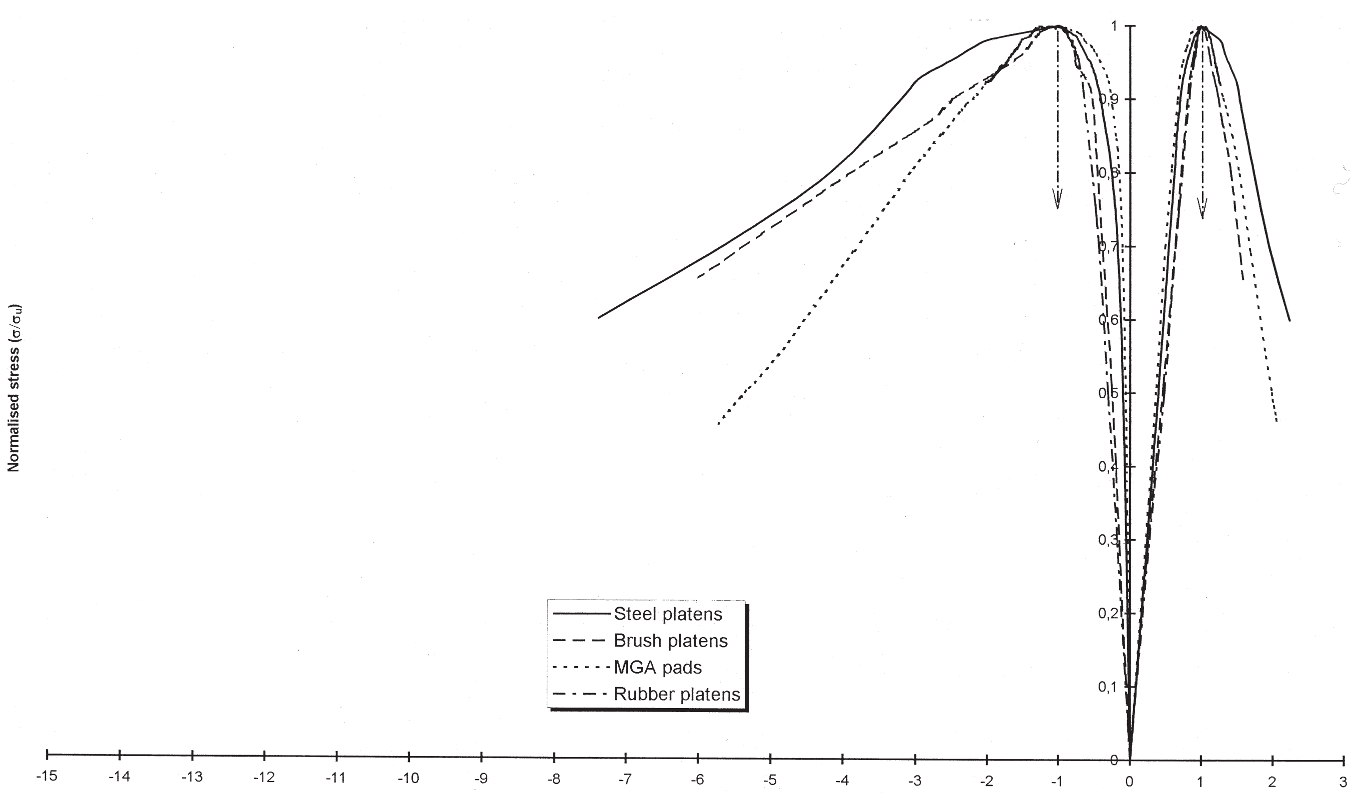


Fig. 8. Stress-strain curves for mix 2.

different testing equipment and specimen size and shape. The loading machine incorporated a double-acting ram with very accurate displacement control (1.2 μm with 1.1 μm smallest step), which is superior to that used previously [3]. The specimen size was 150 mm in height by 75 mm in diameter (2/1 ratio), which is different from the 250-mm height by 100-mm diameter (2.5/1 ratio) described elsewhere [3]. The variation in size and shape affects the formation of the inner core: more specifically, while for h/d = 2.5 the middle "uniaxial" zone always exists and is not swamped by the effect of the frictional forces, this is not exactly the case for h/d = 2/1. Moreover, the lateral strains were presently measured by LVDTs, which record the lateral deformation of the cross section as a whole rather than the deformation of the outer surface recorded by the strain gauges used previously [3].

The above tests yield experimental data that confirm that concrete can be described as a brittle material, since as the frictional forces reduce, concrete suffers a faster loss of its load-carrying capacity. Moreover, it becomes clear from the tests that a complete and immediate loss of load-carrying capacity can only be achieved with the development of a testing setup that completely eliminates friction at the specimen-platen interfaces.

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