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Compression failures in brittle materials: relating observations to a theoretical model

Brittle materials are often used as structural materials in compression, rather than in tension, since tension gives rise to catastrophic failures. When these materials are subjected to compressive loads they show a variability in strength depending on the manner in which they are tested. The work described in this paper investigates only the effect of specimen volume. In order to do so the factors that influence the strength as a result of the chosen method of testing need to be the same for all tests. Compression testing was carried out on cement paste and mortar specimens.

An attempt was made by Hobbs [1] to explain the compressive strength of concrete cubes using the theory proposed by Daniels [2] and Jellinek [3]. In order to use this theory, Hobbs assumed the Weibull modulus, m, to be an index of the relative number of flaws in the material. In recent studies, Jayatilaka and Trustrum [4] showed that m is an index of the variability of flaw size rather than the relative number of flaws.

Observed strengths in compression and tension have different characteristics. It follows that the mechanism of fracture in compression has to be different in order to explain such behaviour. In a brittle material we have a population of cracks of different shapes, sizes and orientations (with respect to applied load). In tension, failure of a single crack leads to total failure, whereas in compression failure of one crack does not lead to total failure.

Jayatilaka and Trustrum [5–7] proposed a theoretical model based on the fact that the final failure of a brittle material, under compression, occurs only after the failure of a certain proportion of cracks, which will be a material property. The splitting of the brittle material can then be explained when several of the "failed cracks" join to form the fracture surface.

The theory is based on a statistical approach and its two main deductions are:

(1) when the volume of a material is large, its mean strength is constant;

(2) the standard deviation is inversely proportional to the square root of the volume.

Two different types of brittle materials, namely, cement paste and mortar, were used for this investigation, considering their commercial usage. In the case of cement past specimens a water: cement (w/c) ratio of 0.30 was used and for the mortar specimens cement: sand: water ratios of 1:2:0.60 and 1:4:0.47 were used.

Since the work was involved with the size influence on the compressive strength, two different specimen shapes (cubic and rectangular) were selected for the investigation. Rectangular samples were of square cross-section and their height-to-breadth ratio was 2:1. This particular dimension was used taking into account the frictional effects of the loading surfaces on the specimen surfaces [7]. For a given material, shape and size, ten samples were made. Standard methods of preparation were employed. All specimens were vibrated mechanically during the preparation stage and were cured for 28 days in water.

After 28 days the compressive strength was measured using a Versa testing machine. The cross-head speed was maintained at 0.1 mm min^{-1} for all the tests.

Generally, the specimens during testing showed a similar cracking behaviour with a large number

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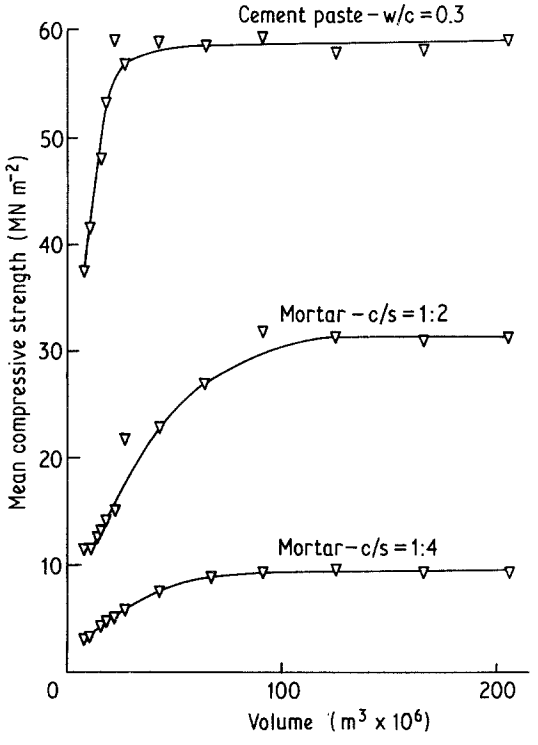

Figure 1 A plot of mean compressive strength against the volume for cubic samples.

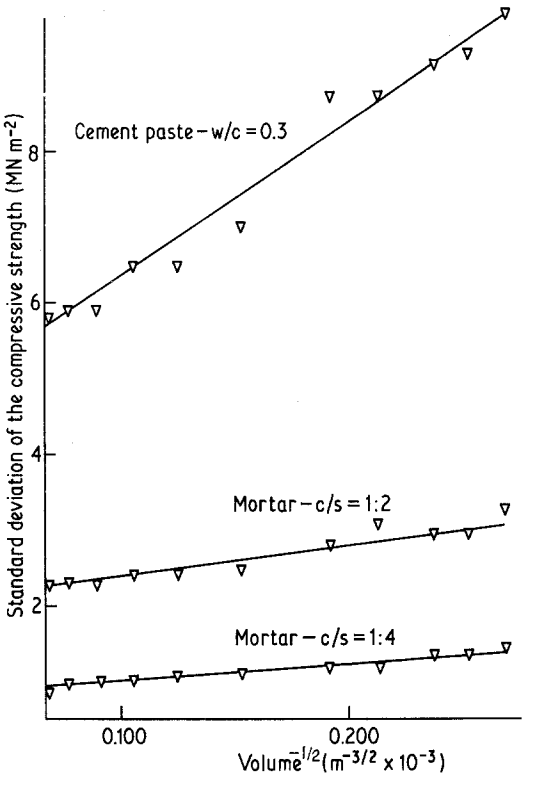

Figure 2 The standard deviation of compressive strengths for a given composition and size shows a linear variation as predicted by theory.

of vertical cracks at the centre and inclined cracks at the ends of the specimens. There were some specimens which failed by diagonal cracks.

Figs 1 and 2 refer to the cubic samples. The former shows a plot of the mean compressive strength against the volume while the latter shows a plot of the standard deviation of the compressive strengths against (volume)$^{-1/2}$.

The results of the rectangular specimens also showed a similar behaviour but the mean compressive strength was about 10 to 15% lower than that of the corresponding cubic specimen.

The experimental work was carried out to investigate the effect of specimen volume. Hence it is vital to maintain the same testing technique for all the tests. Also, as pointed out before, when specimen volume is changed, the shape factor must necessarily be the same. For example, if square-sectioned rectangular specimens are tested for strength, the height-to-breadth ratio must be the same for different specimens (the volume is changed).

The results of the tests carried out on cubes show that when the volume is greater than a certain critical volume, the mean compressive strength is constant. The same is true for rectangular specimens but the mean compressive strength is about 10 to 15% lower than that of cubes. The reason for this behaviour is the different stress distribution within the specimen arising from the friction at the loading plates [7]. The practical significance of the constant mean strength observed is that it is possible to compare the results of others provided the specimen volume is greater than the critical volume and a similar testing technique is employed. The critical volume will depend on the material. The standard deviation plotted against (volume)$^{-1/2}$ gives a straight line variation, thus confirming the prediction of the theoretical model. Lower strengths recorded when the specimen volume is small can be an expiremental artefact. When these specimens are cast, any irregularities on the surfaces would have a pronounced effect when the overall specimen volume is small.

The theoretical model proposed by Jayatilaka and Trustrum enables the compressive strength

to be related to the tensile strength provided that the Weibull modulus, the number of cracks per unit volume and the exact proportion of cracks that should fail prior to material failure, are known. This information may be experimentally forthcoming, in the near future, using acoustic emission devices.

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Diamond synthesis from carbon precursor by explosive shock compression

Several reports deal with the conversion of graphite to diamond by shock compression treatment [1, 2]. The transition between the two carbon phases has been described in terms of a diffusionless mechanism, i.e., a martenstic transformation. Therefore, natural and artificial graphite powders have been used as starting materials for diamond synthesis using explosive shock compression.

In this experiment, an attempt was made to produce diamond from a carbon precursor containing a small amount of vapour by shock compression since this area has remained previously unstudied.

The carbon precursors used as starting materials were produced from furfural resins. The resins were heat-treated at 500 and 600° C for 3 h in a nitrogen atmosphere. The carbon precursors contained a small amount of oxygen, hydrogen and nitrogen in addition to carbon as shown in Table I.

The carbon precursors were ground and passed through a 300 mesh sieve. The powders were mixed with 300 mesh Cu powder in a ratio of 4:96 by weight. The mixture was mechanically compacted in a stainless steel capsule at 392 MPa to form a disc 4.0 mm thick and 12 mm in diameter with a density of about 6.8 g cm^{-1}. The capsule was shock compressed by a plane-wave generator, sometimes called the "mouse-trap" [3–5]. A projectile of 3.2 mm thick iron plate was propelled at a velocity of 3.6 km sec^{-1} against the capsule. The impact pressure induced in the capsule was estimated to be about 100 GPa using an impedance matching method [5].

The shock compressed disc specimens were immersed in dilute HNO_3 for 24 h to dissolve the copper matrix. The remaining black powder was oxidized for several hours with a hot solution of concentrated HNO_3 with a small amount of sodium chlorate to dissolve unconverted carbon. Light grey silver powder was obtained. When fractions of these powder specimens were rubbed

TABLE I Chemical analysis of the carbon precusors heat-treated at 500 and 600° C

Component	Percentage component	
	500° C	600° C
Carbon	87.45	92.13
Oxygen	8.83	5.08
Hydrogen	3.52	2.53
Nitrogen	0.20	0.26

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