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Compression Failures in Brittle Materials Relating Observations to a Theoretical Model

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Abstract : In the case of brittle materials in compression, a recently proposed theoretical model, based on the assumption that a certain proportion of cracks must fail prior to the final fracture, the compressive strength should closely follow a normal distribution with its mean independent of volume and variants inversely proportional to the volume. Compressive testing of cement paste and mortar specimens carried out reveals that the observations closely fit the proposed theoretical model.

1. Introduction

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 the tests. Compression testing was carried out on cement paste and mortar specimens.

An attempt was made by Hobbs[2] to explain the compressive strength of concrete cubes using the theory proposed by Daniels[1] and Jellinek.[7] 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.

2. Theoretical Model

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 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.

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Jayatilaka and Trustrum[4,5,6] 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' joined 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.

3. Experimental Technique and Results

3.1 Preparation of Specimens

Two different types of brittle materials, namely, cement paste and mortar, were used for this investigation, considering their wide usage. In the case of cement paste 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 in the size influence on the compressive strength, two different specimen shapes (cubic and rectangular) were selected for the investigation. Rectangular samples were square cross-sectioned 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.[6] For a given material, shape and size 10 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.

3.2 Testing and Results

The 28th day compressive strength was measured using a Versa testing machine. The cross-head speed was maintained at 0.1 mm per minute for all the tests.

Generally, the specimens during testing showed a similar cracking behaviour with a large number of vertical cracks at the centre and inclined cracks at the ends of the specimens. There were some specimens which failed by diagonal cracks.

Figures 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 1/ square root of volume.

The results of the rectangular specimens also showed a similar behaviour but their mean compressive strengths were about 10 - 15% lower than those of the cubic specimens whose cross-sectional dimensions (length and breadth are similar) .

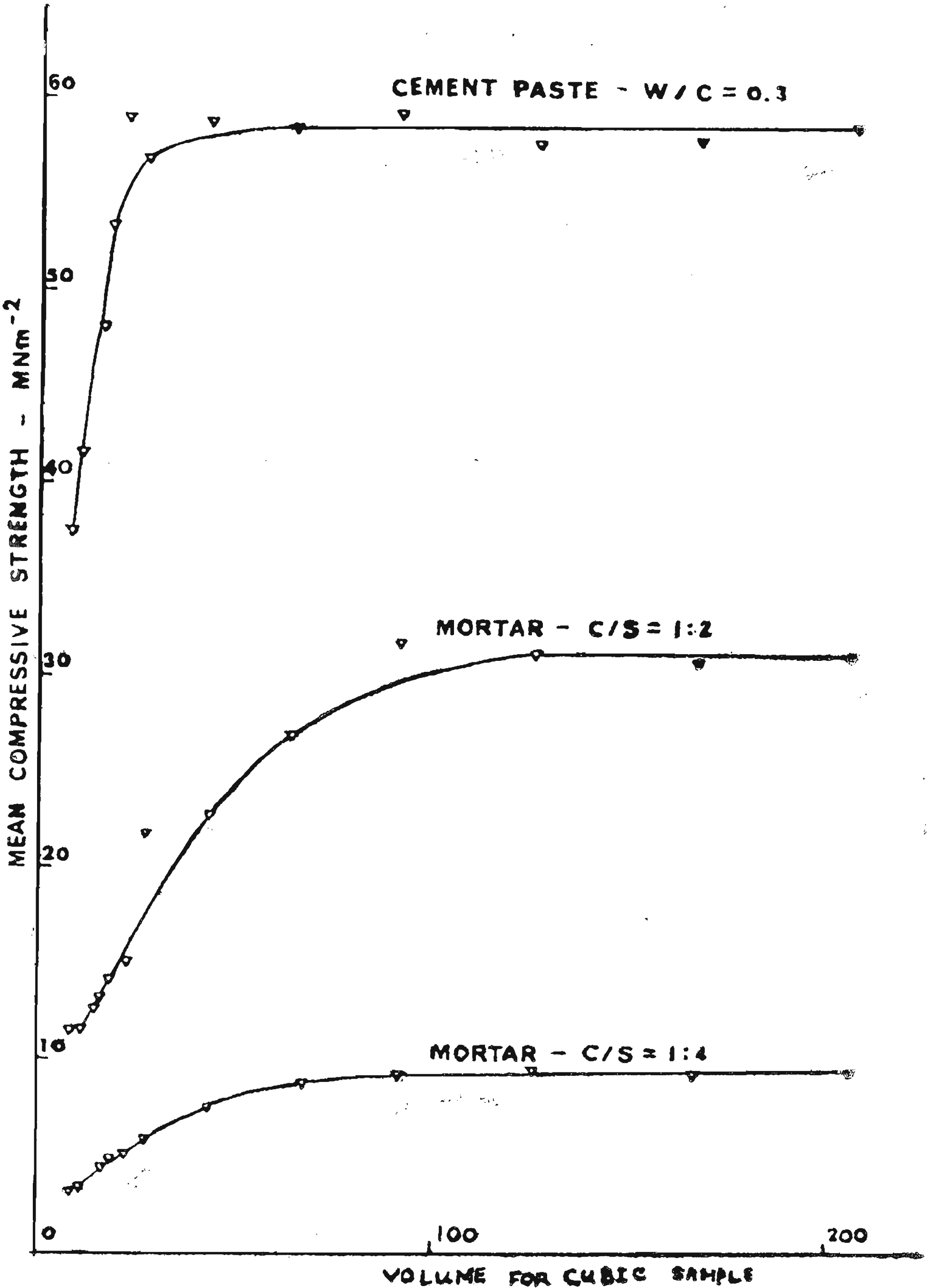

Figure 1. A plot of mean compressive strength versus the volume for cubic samples.

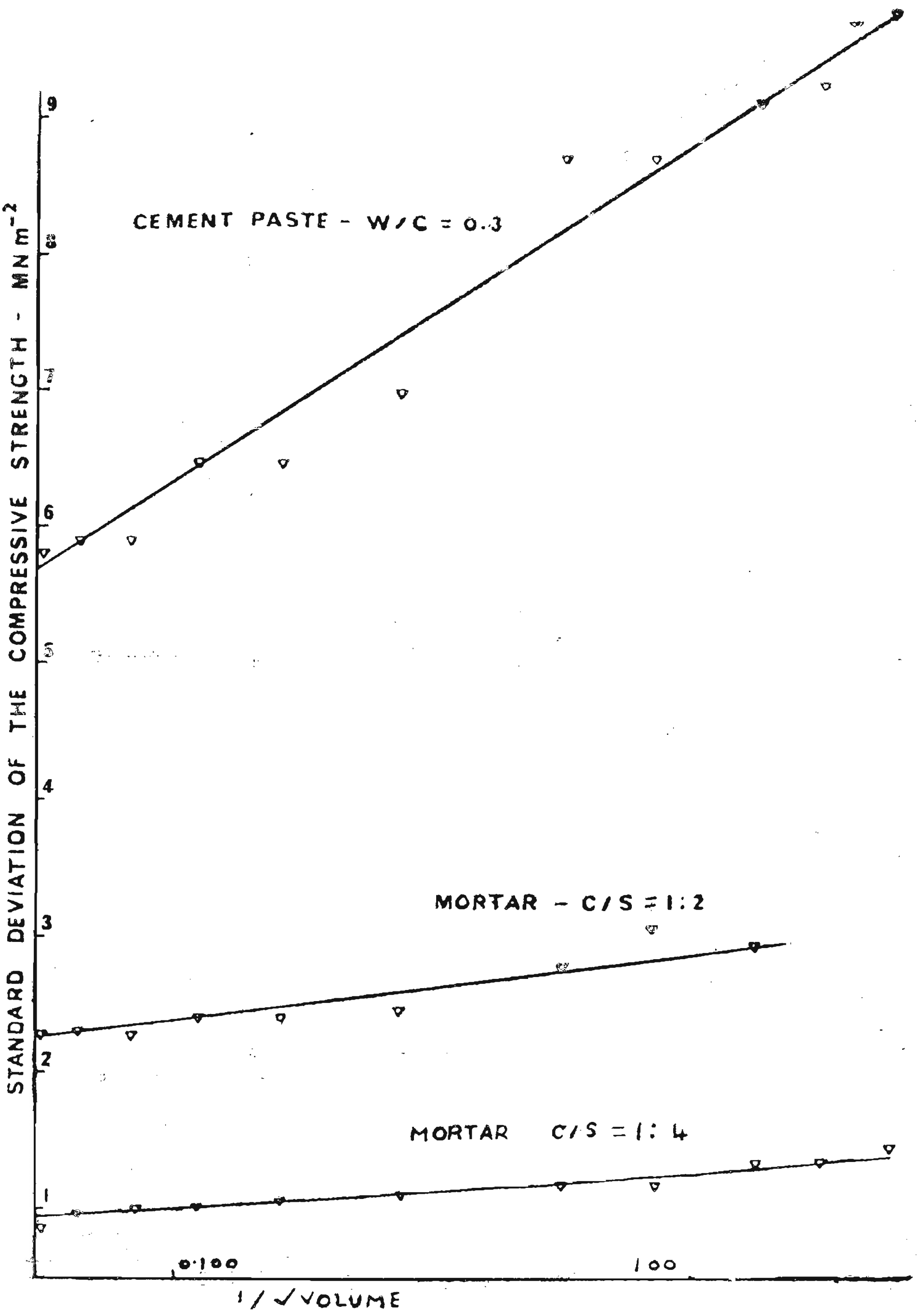

Figure 2. The standard deviation of compressive strengths for a given composition and size shows a linear variation as predicted by theory.

4. Discussion

The experimental work carried out was to investigate the effect of specimen volume. Hence it is vital to maintain the same testing technique for all the tests. As pointed out before, the shape factor should not be changed whenever the volume is changed. For example, if square-sectioned rectangular specimens are tested for the strength, the height to breadth ratio must be the same for different specimens (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 10-15% lower than that of cubes. This behaviour is due to a different stress distribution within the specimen arising from the friction at the loading plates.[6] 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 and on the shape of the specimens. The standard deviation plotted against 1/ square root of volume gives a linear variation, thus confirming the prediction of the theoretical model. The reasons for the observed higher gradient (see figure 2) for cement paste specimens are not clear. Lower strengths recorded when the specimen volume is small can be an experimental 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, using acoustic emission devices.

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