Tensile and Flexural Behaviour of Fibre Reinforced Cementitious Composites

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ABSTRACT

An experimental study about the effect of fibres on the mechanical behaviour of fibre reinforced cementitious samples in tension and flexure is reported. Cementitious samples contain varying amounts of E-glass, Dolanit 10 and Dolanit 11 fibres. Results show that flexural and tensile strengths as well as toughness and ductility of fibre reinforced cement increased considerably with respect to that of cement alone. While the properties enhanced with time for PAN reinforced samples, properties of glass reinforced cementitious samples degraded with time. An empirical model is used to represent the test data.

Key Words

toughness index, tensile strength, flexural strength, cementitious composites, load-deflection behaviour.

INTRODUCTION

The use of fibrous reinforcement to improve the strength and deformation properties of cement and concrete is now well established [1,2].

Plain unreinforced cement or concrete has a low tensile and flexural strength and strain at fracture. These shortcomings are traditionally overcome by incorporating reinforcements [3].

Therefore, incorporation of fibre causes part of deformational stress in the matrix to be transferred to the fibre.

The mechanism of fracture and the strength to be expected can be discussed as follows:

There is a difference between tensile/flexural stress-strain curve of a fibre reinforced composite containing ductile matrix and that containing brittle matrix. As it is shown in Figure 1(a), the ductile matrix can benefit from inclusion of the high tensile strength fibre and, as a result, both the stiffness and the strength of the composite are increased. Since the failure strain of the matrix is higher than that of the fibre, it is possible to realise the full potential strengths of fibre, e.g., in strengthening the matrix [3]. As shown in Figure 1(b) the strain at fracture for the brittle matrix is considerably smaller than that for the fibre. As a result, when a fibre reinforced brittle matrix

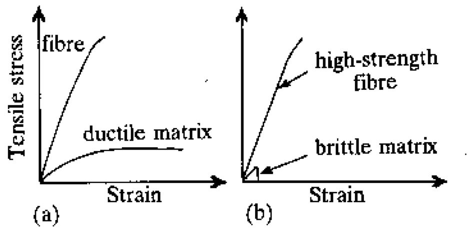

Fig.1. Tensile curves for fibres with ductile and brittle matrices [3].

composite is loaded, the matrix will crack long before the fibre can be fractured or pulled-out. Once the matrix has cracked, the composite fails in one of the following ways[3]:

- The composite is fractured immediately after the matrix cracking. This type of behaviour is shown in Figure 2(a).

- Although the maximum load on the composite is essentially the same as that on the matrix alone, the composite continues to carry decreasing load after the peak, as shown in Figure 2(b). The post-peak resistance is primarily provided by the pulling-out of fibres from the cracked surfaces. Although no significant increase in the tensile/flexural strength of the composite is observed a considerable increase in the toughness of the composite is obtained.

- As shown in Figure 2(c), even after the

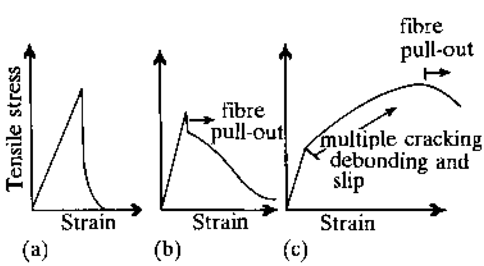

Fig.2. Three possible composite stress-strain curves for fibre reinforced brittle matrices [3].

cracking of the matrix, the composite continues to carry increasing tensile/flexural stresses. The peak stress and the peak strain of the composite are greater than those of the matrix alone, during the inelastic range (between the first cracking and the peak) multiple cracking of the matrix, fibre debonding and slip or fracture may occur. It is clear that this mode of failure results in the optimum performance of both the matrix and the fibres.

In this work, the effect of inclusion of glass and polyacrylonitrile fibres on tensile and flexural properties of cement is studied. Furthermore, an empirical model is used to suitably represent the test data obtained for tensile and flexural strengths as well as the toughness index.

EXPERIMENTAL

A portland cement with a specific surface area of about 2500 cm^2/g was used in making the specimens. The chemical compositions and physical properties of the portland cement have been given already [4].

Two types of PAN fibres of different diameters (Dolanit 10 and 11, Hoechst polyacrylonitrile fibre products) were used. The E-glass, Dolanit 10 and 11 were in the form of chopped rovings, 6mm long and 18 μm, 18μm and 104μm in diameters, respectively.

The E-glass and Dolanit 10 were used in volume fractions of 1%, 2%, 3% and Dolanit 11 was used in volume fractions of 1%, 3%, 5%, 6%. Mixing was carried out conventionally in an electrically driven mechanical mixer of epicyclic type which imparted both a rotary and a revolving motion to the mixer paddle. The cement matrix was mixed with fibres and water with 0.3 water to cement weight ratio. When cement was added to the water and mixed for two periods of 60 seconds with a 30 seconds rest interval, the fibres were sprinkled randomly into the cement matrix. Mixing was completed in two more 90 seconds time periods with 30 seconds in between.

All tensile and flexural specimens were prepared in steel moulds in two equal layers, each layer being externally vibrated for approximately 60 seconds. Flexural specimens had 160 x 40 x 40 mm dimensions according to ASTM C348 but tensile specimens had a dog-bone shape with 76.2 mm long and 25.4 x 25.4mm neck cross-section according to ASTM C109. The test specimens were demoulded after 24 hours at room temperature and they were tested after further cure in a water bath of 20±2 °C for two, six and twenty seven days.

At least nine specimens were prepared and tested for each fibre volume. All the flexural tests reported here were carried out at the same constant deflection rate (1mm/min) in three point bending mode using an Instron Universal Testing Machine, Model 6025, with 10KN load cell. The tensile tests were carried out at 44.5N/sec constant load rate using Test Lab. Engineering Testing Apparatus. Moreover, the fracture surface of different composite samples as well as the elemental composition of the hydrated cement deposit on glass fibres was studied by SEM, model S360, Cambridge.

RESULTS

The flexural and tensile strengths of fibre reinforced cementitious composites as a function of cement curing time are shown in Figures 3-8. Typical flexural load-deflection curves for samples of different types of fibres after 28 days cure are shown in Figure 9. It is seen that the post-cracking

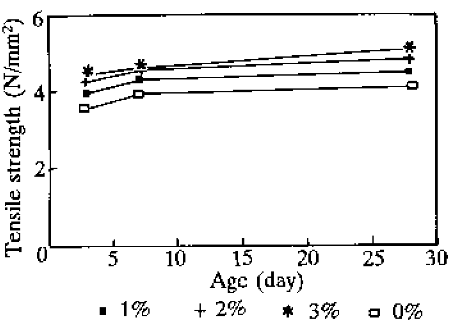

Fig.3. Variation of tensile strength with curing time for Dolanit 10 reinforced cementitious composites.

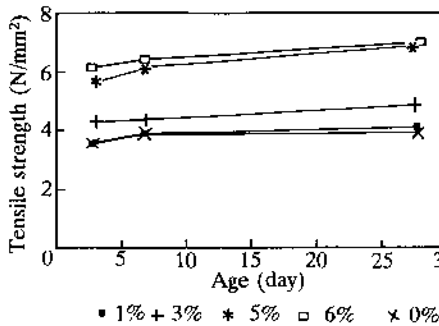

Fig.4. Variation of tensile strength with curing time for Dolanit 11 reinforced cementitious composites.

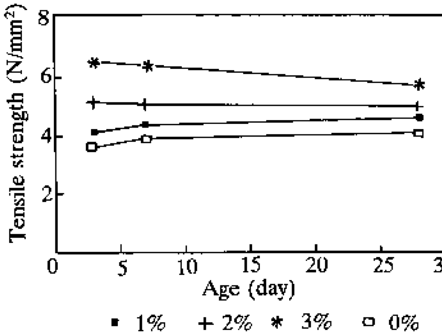

Fig.5. Variation of tensile strength with curing time for E-glass reinforced cementitious composites.

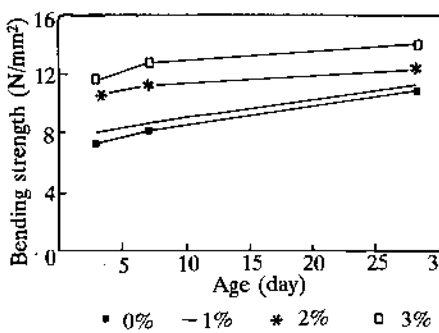

Fig.6. Variation of bending strength with curing time for Dolanit 10 reinforced cementitious composites.

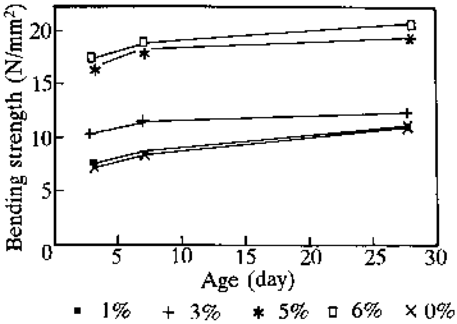

Fig.7. Variation of bending strength with curing time for Dolanit 11 reinforced cementitious composites.

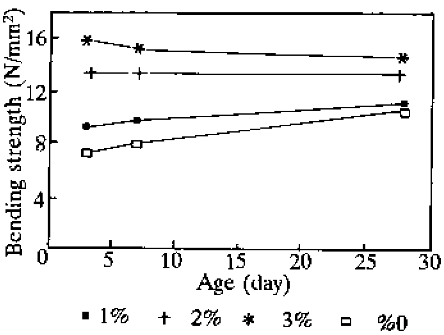

Fig.8. Variation of bending strength with curing time for E-glass reinforced cementitious composites.

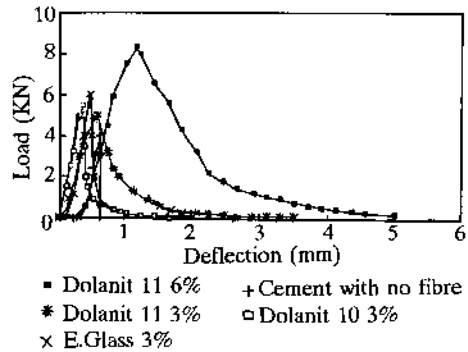

Fig.9. Load-deflection characteristics of several fibre reinforced cementitious composites.

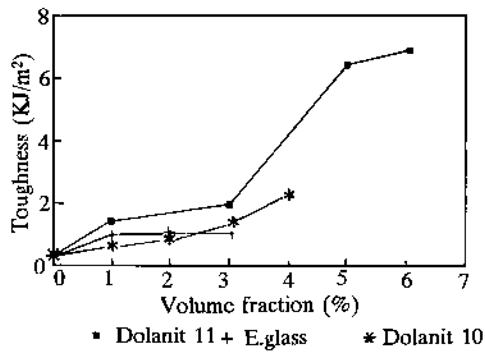

Fig.10. Variation of toughness with volume fraction for fibre reinforced beams in flexure.

behaviour, ductility (i.e.,the ability of a material to be plastically deformed by elongation without fracture) and toughness (i.e., capacity of energy absorption) of the beams are influenced by the type of fibre and fibre content. Bending toughness versus volume fractions of different fibres after 28 days cure is depicted in Figure 10.

DISCUSSION

While it is observed that the flexural and tensile strengths of Dolanit 10 and 11 reinforced cementitious composites increase with curing time of cement due to cement hardening and improvement of adhesion between cement and fibre, those of E-glass composites decrease with curing time. Apparently hydration of cement and its high alkalinity affects E-glass fibres.

There exist different views as to why E-glass fibres are corroded in cement matrix, e.g., water corrosion, stress corrosion, alkali corrosion, etc., but the precise factor is not yet clearly established [1,5,6,7].

Majumdar [6] believed that glass fibres are corroded not only by chemical corrosion, i.e. mainly by calcium hydroxide, but also the physical corrosion,i.e., the crystallisation of hydrates of cements will destroy glass fibres. He pointed out that water may dissolve the alkali in glass fibres and produce the hydroxy radical, thus destroying the silicon-oxygen skeleton. But $Ca(OH)_2$ is the main factor of the corrosion of glass fibres. It is observed in Figures 11 and 12 that something is deposited on and between the fibres. As shown in Figure 13 by X-ray elemental analysis, it was proved that the deposit phase is rich in calcium and oxygen, i.e., $Ca(OH)_2$.

It is expected that the strength of E-glass fibre reinforced cementitious composites decreases continuously with hydration time and gradually approaches to that value of unreinforced cement.

Fig.11. Electronmicrograph of hydrated cement deposit on E-glass fibres (2110x).

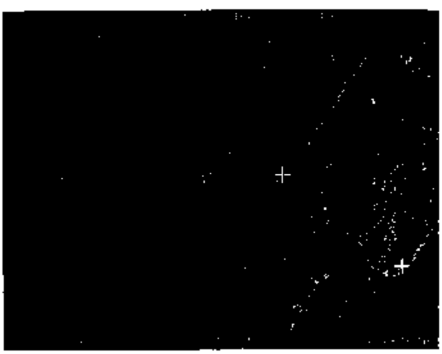

Fig.12. Electronmicrograph of hydrated cement deposit between E-glass fibres (2300x).

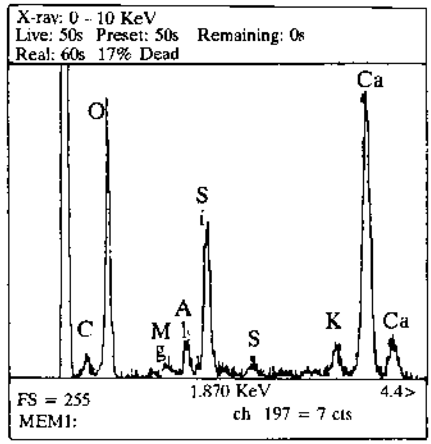

Fig.13. X-ray elemental analysis of hydrated cement deposit on the surface of E-glass fibres.

The amount of energy absorption or toughness of composites is related to the type of fibre failure.When fibres are pulled-out from the matrix, the composite absorbs much more energy (due to debonding, stretching and fibre pull-out) than when fracture of fibres occurs. From Figures 14-16, it appears that E-glass and Dolanit 10 are fractured but Dolanit 11 is pulled-out. Then as it is shown in Figure 10, Dolanit 11 reinforced composite absorbs much more energy in equal volume fractions than the other fibre reinforced

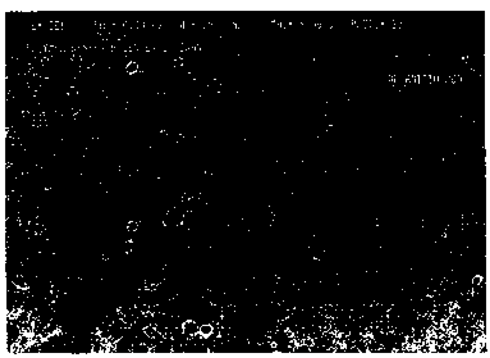

Fig.14. Electronmicrograph of fractured surface of Dolanit 10 fibre reinforced cementitious composite after 28 days curing (96.3x).

Fig.15. Electronmicrograph of fractured surface of E-glass fibre reinforced cementitious composite after 28 days curing (268x).

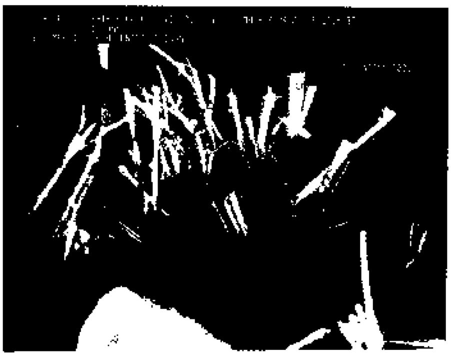

Fig.16. Electronmicrograph of fractured surface of Dolanit 11 fibre reinforced cementitious composite after 28 days curing (24.2x).

composites [4].

Although, cracking of the matrix, fracture or debonding and subsequent pull-out of fibres are all predictable phenomena in composites made from brittle matrix, e.g., real fibre reinforced cementitious composites, the behaviour has not been fully established yet in a quantitative way. However, an empirical relation is proposed based on the experimental results which may be helpful in these cases [5]. The ultimate strength of the composite, S_c, has been given as:

$$S_c = A.S_m.(1-V_f)+B.V_f.\ l/d \quad (1)$$

where S_c is tensile or flexural strength of composite, l/d is the aspect ratio of the fibre, V_f is volume fraction of fibre, S_m is tensile or flexural strength of matrix and A and B are constants whose values can be determined from graphs in which composite strengths are plotted against V_f. The relationship is applicable for both flexural and tensile strengths of fibre cement.

Furthermore, if toughness index defined as toughness of fibre reinforced cement to that of cement itself, it is possible to represent the toughness index (T.I.) as follows [8]:

$$T.I.=A.V_f\ .\ l/d\ +\ B \quad (2)$$

As depicted in Figures 17-24, it is clear that the model and the equations fit the test data for flexural and tensile strengths as well as for flexural toughness index appropriately.

CONCLUSIONS

It was observed that polyacrylonitrile and E-glass fibres can improve tensile strength, flexural strength and the post-cracking behaviour of cement with no fibre. Toughness and ductility of fibre reinforced cementitious beams are influenced by the type and fibre content. Due to pulling-out of Dolanit 11, composites reinforced with Dolanit

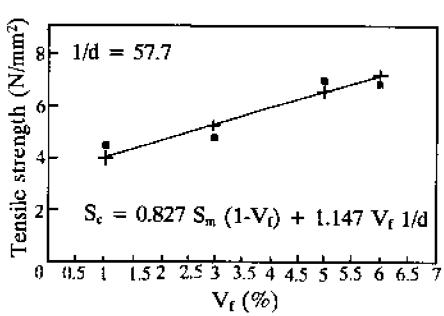

Fig.17. A model for predicting tensile strength of Dolanit 11 reinforced cementitious composites.

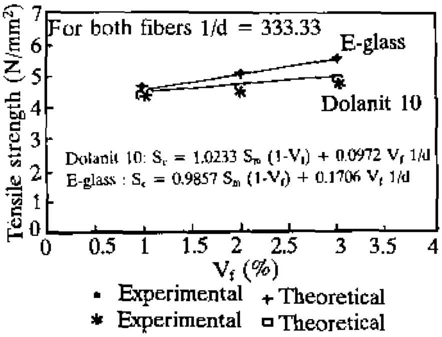

Fig.18. A model for predicting tensile strength of Dolanit 10 and E-glass reinforced cementitious composites.

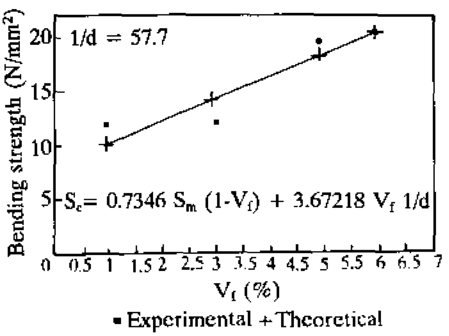

Fig.19. A model for predicting bending strength of Dolanit 11 reinforced cementitious composites.

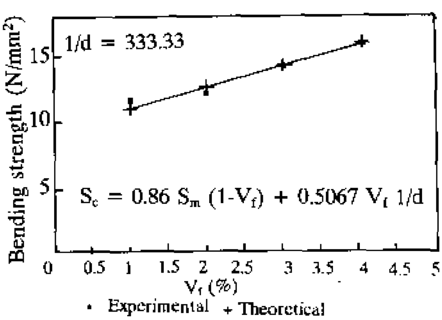

Fig.20. A model for predicting bending strength of Dolanit 10 reinforced cementitious composites.

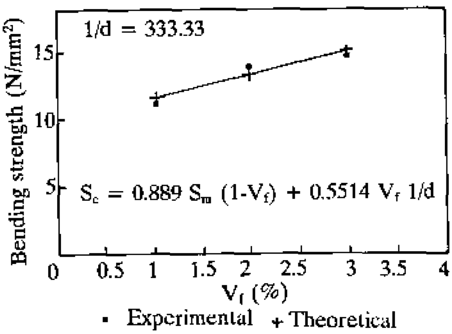

Fig.21. A model for predicting bending strength of E-glass reinforced cementitious composites.

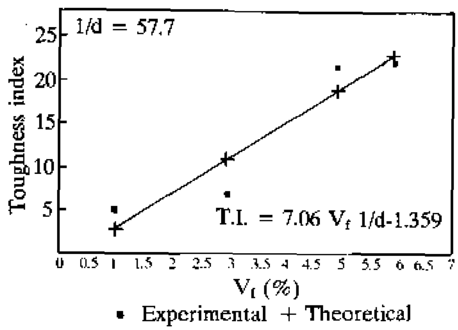

Fig.22. A model for predicting toughness index of Dolanit 11 reinforced cementitious composites.

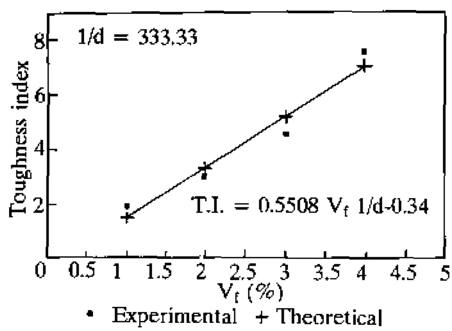

Fig.23. A model for predicting toughness index of Dolaint 10 reinforced cementitious composites.

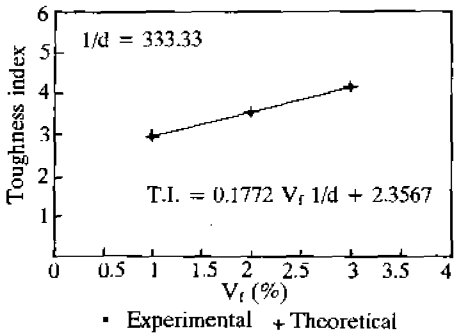

Fig.24. A model for predicting toughness index of E-glass reinforced cementitious composites.

11 absorbed much more energy than Dolanit 10 and E-glass fibre reinforced composites in equal volume fractions.

Furthermore, it was observed that the flexural and tensile strengths of PAN fibres reinforced cementitious composites increase with curing time but E-glass composites decrease with curing time due to corrosion of glass fibres by $Ca(OH)_2$.

The empirical models with proposed coefficients for tension, flexure and flexural toughness index of fibre reinforced cementitious composites was found to fit the test data well.

SYMBOLS AND ABBREVIATIONS

S_c: tensile or flexural strengths of composite
S_m: tensile or flexural strengths of matrix with no fibre
V_f: volume fraction of fibre
l : fibre length
d : fibre diameter
T.I. : toughness index
A,B : constants

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