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Test Methods and Applications of Steel Fibre Reinforced Concrete

Méthodes d'essai et applications du béton armé de fibres d'acier

Prüfmethoden und Anwendung von Stahlfaserbeton

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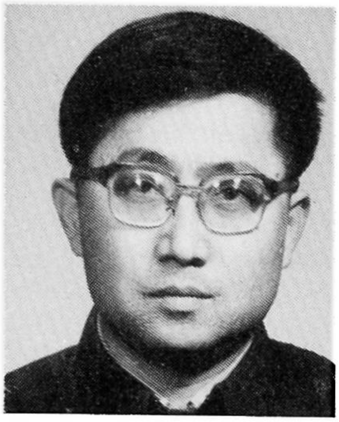

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SUMMARY
This paper reports the findings of a series of research projects carried out on steel fibre reinforced concrete (SFRC) which had the following objectives: to elucidate the special procedures required for the testing of SFRC; to investigate the mechanical properties and the cost of SFRC with three types of fibres; the behaviour of composite beams with a view to concrete pavements; the effect of steel fibres on the properties of lightweight concrete with respect to multistory buildings.

RÉSUMÉ
Cette contribution donne un aperçu sur les résultats d'une série de recherches effectuées sur le béton armé de fibres d'acier, en ce qui concerne les aspects suivants: les caractéristiques des méthodes d'essai, l'estimation du coût et les propriétés mécaniques de bétons renforcés de 3 types de fibres; les propriétés de poutres composites en béton de fibres; l'effet des fibres d'acier sur les propriétés du béton à agrégats légers, pour des applications dans la réparation de chaussées et dans le bâtiment.

ZUSAMMENFASSUNG
Dieser Beitrag beschreibt die Resultate von Forschungsprojekten über Beton mit Stahlfaserbewehrung. Die Ziele waren die folgenden: die Eigenarten der verschiedenen Prüfmethoden, die Untersuchung der mechanischen Eigenschaften und der Kosten von 3 verschiedenen Faserarten, das statische Verhalten von Betonbalken mit Stahlfasern und die Auswirkung von Stahlfasern auf die Eigenschaften von Leichtbeton, wie er im Strassenbau und im Hochbau angewendet wird.

1. INTRODUCTION

Considerable research efforts have been made on steel fibre reinforced concrete with the growth of its application in the last decade in China. In order to provide useful data for design and standardized testing to allow meaningful comparison of reported test results in the literature, the proposals for the trial edition of "Method of Test for SFRC" have been prepared. In this course a series of mechanical tests on SFRC has been carried out and it is found that most test methods for plain concrete are suitable for SFRC and some test procedures for SFRC are different from that for plain concrete.

An obstacle to use the SFRC is its cost higher than plain concrete, therefore to find the SFRC in high quality and low cost is very important. For this purpose, three types of steel fibres have been used in the tests to investigate and compare their influence on the mechanical properties and the cost of SFRC.

In order to develop more applications of SFRC to pavement and high-rise building, the flexural properties of the composite beams with SFRC and plain concrete layers and the mechanical properties of SFRC with lightweight aggregate made from expanded shale have been stadied experimentally.

2. TEST METHOD

Following suitable existing test methods, the authors have carried out many tests on mechanical properities of SFRC in recent years in the structural laboratory of Dalian Institute of Technology. It is recognized that most of test methods for plain concrete can be used in SFRC tests, such as compresive strength, splitting tensile strength, modulus of elasticity, shrinkage, creep and some other tests.

Some specialities of test motheds for SFRC have been found as follows: In specimen preparation external vibration should be used, rodding is not accepted, internal vibration may be used in some cases where the effect of fibre orientation and distribution caused by internal vibration on the test result is not important. Slump is not a good indicator of workability and the Vebe procedure is a good way to get it. In compressive strenth tests the standard specimens (150x150x150 mm cube or 150x150x300 mm prism) used coventionally in China are appropriate for SFRC ,sometimes smaller specimens (100x100x100mm, 100x 100x300mm) may be used, but the effect of size of SFRC specimens on test results is more severe than that of plain concrete. According to the statistics of 120 specimens, the ratio of the compressive strenth of 150x150x150 mm cube to that of 100x100x100 mm cube is 0.91 for SFRC , but it is 0.95 for plain concrete [2]. For evaluating the engineering property of SFRC, the stress-strain curve in tension and compression and the load-deflection curve in flexure should be obtained. It is well known that testing equipment may be a problem for obtaning the above curves, so the testing machine with closed loop and high rigidity shold be used in those tests. In China, conventional testing machines have been widely used in most laboratories, for avoiding abrupt failure and obtaining the descending portion of the curves, the testing machine should be stiffened by loading the specimens in parallel with two steel rods for tension and with four stiff springs for compression. In this manner, most tests might be successful. Potentionmeters or LVDT displacement transducers are prefered to dail gages or strain gages as transducers for measuring the deflection, elongation or strain and automatic dynamic data acquisition system with computer or X-Y recorder should be used to get data fast.

One of the properties of concrete which is improved by the addition of fibres is energy absorption, it can be represented by the toughness index. The toughness index is calculated as the area under the normalized load-deflection curve out to the reference deflecion Dr, Ti=(L/Lp)x(D/Dr)x100, were Dr=span/150, Lp=the peak of load.

3. THE MECHANICAL PROPERTIES OF SFRC

Three types of fibres have been used in the tests: (1) Hooked fibres made from sheared thin steel sheets in rectangulor cross section (H-fibre), (2) Melt extract fibres made from waste steel and iron in kidney shaped cross section (M-fibre), (3) Straight fibres produced by cutting the unraveled wire from scrap or wornout steel cables and wire ropes (S-fibre),which are much cheaper than the other two, the cost of S-fibres is approximately 50% of that of M-fibres or 30% of that of H-fibres. The aspect ratio (length to equivalent diameter) is about 50 for H-fibre and M-fibre,75 for S-fibre. To allow comparison the properties of SFRC with deffrent types and contents of steel fibres, the matrix of all specimens are the same for each group of tests.

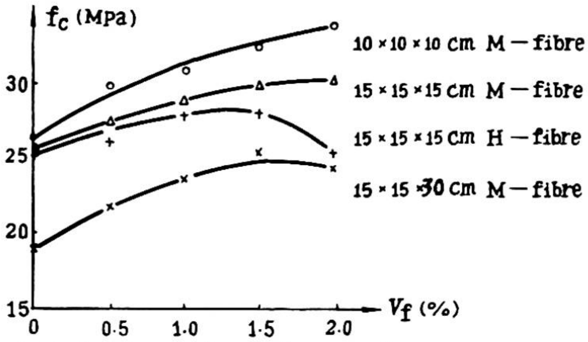


Fig.1 Relationship Between Compressive Strength of SFRC and Fibre Content

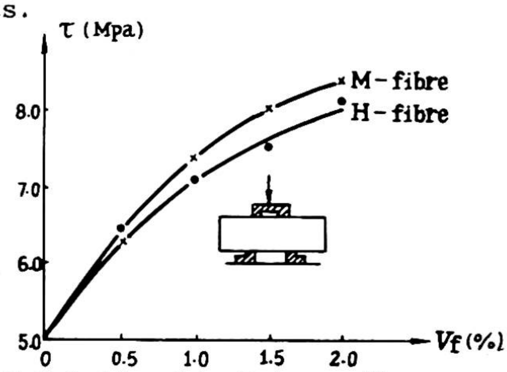


Fig.2 Relationship Between Shear Strength of SFRC and Fibre Content

Typical results of tests are shown in Fig. 1 to 7, which indicate that all mechanical strengths except compressive strength increase singnificantly with the increasing of steel fibre content. Refer to Fig.1, the compressive strength is likely maximum at Vf=1.5% and the improvement ranges from 0 to 21 percent, if the content of steel fibre by volume is more than 1.5%, the compressive strength decreases with the content increasing because the workability and density of SFRC is deteriorated.

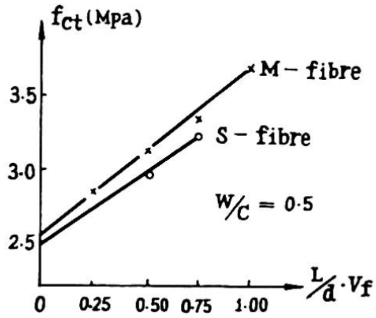


Fig.3 Typical Results of Splitting Tensile Test on SFRC

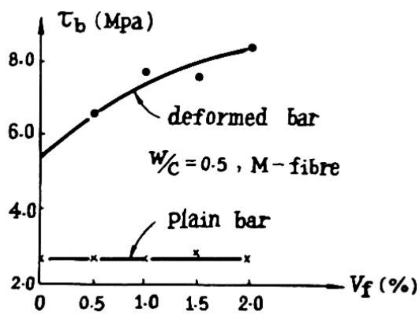


Fig.4 Ultimate Bond Strength of Reinforcing Bars in SFRC

The shear strength, splitting tensile strength and rupture modulus (Fig.2,3 and

6) are improved by addition of 2% fibres by 35 percent, 44 percent and 55 percent, respectively.

Referring to the property of beam-column joint, the bond strength around reinforcing bar should be examined, test data indicate that the improvements are more significant for deformed bars and negligible for plain bars.

The improvement for the thoughness and post-elasticity property of SFRC is more and more evident with the content of fibres increasing (Fig.5 and 6), the thoughness index of SFRC with 2% fibres is 41 times more than that of plath concrete.

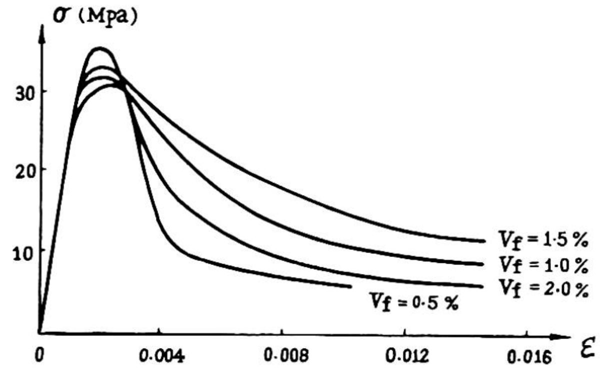


Fig.5 Stress-Strain Curves in Compresion for SFRC

On the basis of above mentioned properties, the melt extract fibres are prefered because of their high surface area/volume ratio, irregular contour and rough surface which improve the adhesive and frictional bonds, and the optimal content is about 1.5 percent by volume (1/d Vf=.75). But considering the cost, the cut wires made from waste steel wire rope are also accessible, and the economic content of fibres may be 1 to 1.5 percent by volume (1/d Vf=.75--1.00).

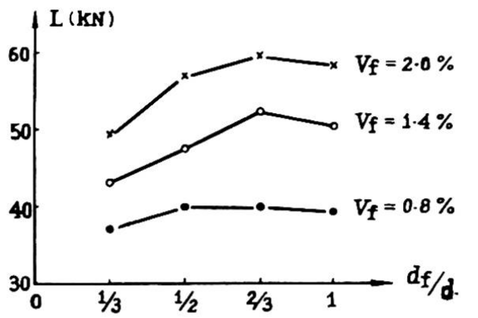


Fig.6 Modulus of rupture of SFRC as a Function of Fibre Content

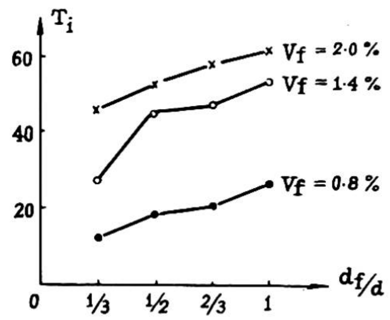
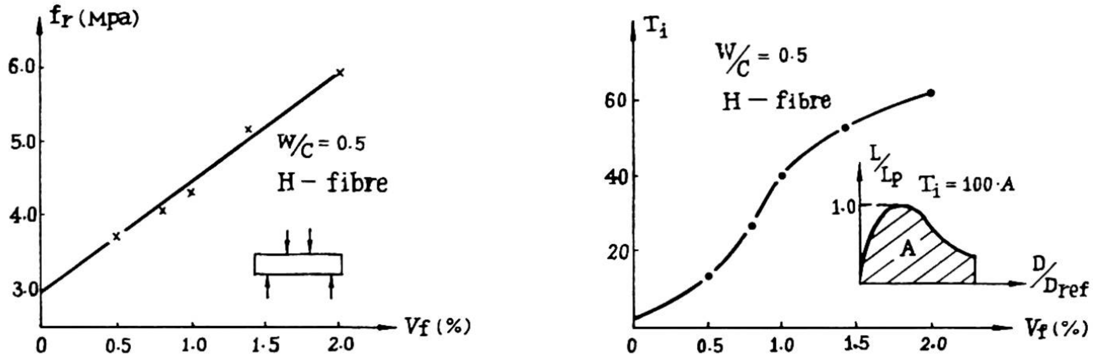


Fig.7 Tougthness Index of SFRC as a Function of Fibre Content

4. THE PROPERTIES OF COMPOSITE BEAMS

For simulating the pavement composed of two layers of concrete and SFRC, the authors have carried out the tests of composite beams on their flexural and shear properties. All the beams are 550mm long(span=450mm) in 150 150mm section. Two layers are adhered to each other and composed in three cases: ratios of depth of SFRC layer to the total depth of beam are 1/3, 1/2, 2/3, respectively.

The rupture modulus and toughness of composite beams varing with ratio of layer depths are illustrated in Fig.8. At the ratio of depths =1/2 and 2/3, the rupture moduli of composite beams are almost same as that of SFRC beams, and the toughness indexes of composite beam are lower slightly than that of SFRC beams . Therefore it implies that composite pavement with SFRC and plain concrete layers is applicable in repairing old pavement and constructing road and some engineering properties should be studied further.



(a) Modulus of rupture (b) Toughness Index

Fig.8 Test results for Composite Beams in Flexure as a Function of Ratio of Layer depths

5. SFRC WITH LIGHTWEIGHT AGGREGATE

In the tests, lightweight concrete (density 1.95)contains river sand and aggregate made from expanded shale of ball shaped in diameter smaller than 10mm. The formula of matrix are the same for each series of steel fibre reinforced lightweight concrete specimens

It has a strong appeal to the authors that the improvement in both compresive strength and other properties of lightweight concrete by addition of steel fibres is more significant than that of plain concrete. On the following data the emphasis should be puted: By addition of steel fibres of 2.0% the improvements are 40-50 percent in compressive strength, 65 percent in splipping tensile strength,95 percent in shiear strength and 90 percent in rupture modulus,respectively. On other hand, the failure behaviour of lightweight concrete is also improved by addition of steel fibres and appear in a more ductile manner.

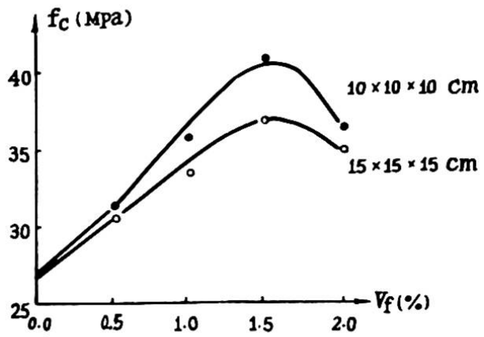


Fig.9 Compresive Strength of Lightweight Concrete Improved by Addition of Steel Fibres

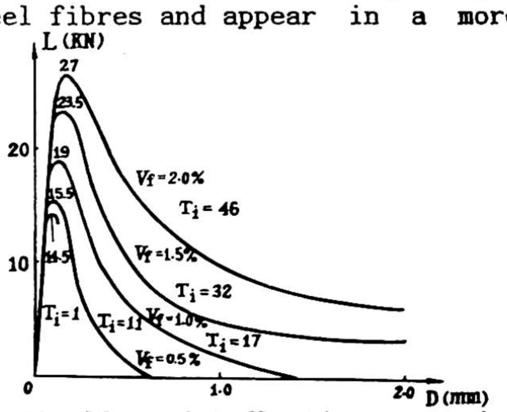


Fig.10 Load-Deflection Cuves in Flexure for SFRC with Lightweight Aggregate

The lightweight aggregate concrete reinforced by steel fibres will be beneficial to its uses in frames and shear walls in multistory buildings especially in beam-column joints and beams of coupled shear walls. In those cases, the shear strength, flexural strength and ductility of structures will be improved in a singnificant manner.

6. CONCLUSIONS

1). Most test methods for plain concrete are suitable for SFRC but some special procedures required by the nature of SFRC should be provided.
2). The melt extract steel fibres are in higher quality and lower cost.Using drawn wire fibres made from waste steel rope is also a good way to lower the cost of SFRC.
3). The test results of composite beams imply that combining the SFRC layer with plain concrete layer in pavement may be a ecnomic means.
4). The improvements in mechanical strength and failure behavior of lightweight concrete by the addition of steel fibres are in a more singnificant manner, which indicates potential extensive applications in multistory buildings.

7. ACKNOWLEDGEMENT

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