Influence of fibre size on the compressive and split tensile strengths of fibrous normal strength concrete

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Abstract*—In this paper, the existing methods for predicting compressive and split tensile strength of fibrous normal strength concrete are reviewed. This paper highlights the influence of volume fraction of combined fibre system with the same aspect ratio and ratio of long fibre to total fibre content on the compressive and tensile strength of fibrous normal strength concrete. It also studies the main variables which affect the strength of this type of concrete statistically. In this research, the predicted models confirmed that the steel fibre content and their aspect ratio affect the split tensile strength whereas the steel fibre, cement and sand contents affect the compressive strength. The most important point is the inverse effect of maximum size of aggregate on the splitting tensile strength. The proposed models in this investigation for predicting compressive and split tensile strength with the relation between them claim that they have a good agreement with results.

Keywords- micro straight steel fibre; short term properties of fibrous concrete; size of fibre

I. INTRODUCTION

In general, the main purpose of adding steel fibre into normal strength concrete is to improve of the mechanical properties. There are three properties of steel fibre which affect the concrete properties: they are volume fraction, aspect ratio and the length of fibre. Even though these properties of steel fibre affect the concrete behavior, there are many restrictions for the length, volume fraction and aspect ratio of fibre such as maximum size of aggregate, balling of fibres and the workability of green concrete.

Despite the fact that the interlocking and balling of fibres with maximum size of aggregate cause a reduction in the workability and flow-ability of fresh concrete and the strengths of concrete in the hardening state, the combination of two sizes of micro straight steel fibre with the same aspect ratio might improve the two or more properties of the concrete at the same time. In this paper, the influence of combined fibre with different sizes for improving the properties of fibrous normal strength concrete is highlighted.

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II. RESEARCH SIGNIFICANCE

This paper highlights the mix proportion and the size of steel fibre which affect the short term properties of fibrous normal strength concrete like compressive and split tensile strengths. Even though in the previous researches have been conducted on this kind of concrete and the models to predict their corresponding properties have been proposed, these models disregard the mix proportions of the fibrous normal strength concrete and the geometrical properties of steel fibre.

III. LITERATURE BACKGROUND

A. *Short term properties of fibrous normal strength concrete based on steel fibre type*

1) *Hooked ends steel fibre*

The compressive strength is improved slightly up to 10% due to addition of steel fibre with volume fraction 0.5% regardless of fibre length [1]. In fact, it was found that the shorter steel fibre performed better in compression if it is compared with the longer one [2].

Vairagade et al [1] and Yusof et al [2] have claimed that the split tensile strength of fibrous normal strength concrete has a proportional relation with the length of fibre and they have revealed that longer fibre performs better in improving splitting tensile strength. However, Shende and Pande [3] have claimed that the split tensile strength is further improved by using steel fibre of aspect ratio 50 rather than 60 and 67.

2) *Straight steel fibre*

Wafa [4] claimed that the inclusion of straight type of fibre did not improve the compressive strength while splitting tensile strength improved up to 57% due to addition of 1.5% of fibre to the concrete.

3) *Crimped steel fibre*

Murali et al [5] claimed that the compressive strength of fibrous normal strength concrete improved up to 32.14% with the inclusion of 0.8% steel fibre. This improvement was varied between 5% and 25% [4] due to inclusion of crimped steel fibre to the concrete while Vairagade et al [3] claimed that

increase in aspect ratio of fibre improved the compressive resistance.
The splitting tensile strength of fibrous normal strength concrete is found to be a function of steel fibre content [5, 6], aspect ratio and the length of fibre [3].

4) Deform steel fibre
The inclusion of deuform steel fibre is found to marginally improve the compressive strength whereas the splitting tensile strength is found to improve significantly by aspect ratio and inclusion of this kind of fibre [7, 8].

B. *Models for predicting compressive strength and split tensile strength of fibrous normal strength concrete:*

1) Compressive strength:
The compressive strength of fibrous normal concrete was influenced significantly by volume fraction of steel fibre as shown in (1) even though the compressive strength was dramatically influenced by the shape of molds [6].

$$f_{c'-cy} = 1.878(V_f\,\%) + 38.60 \quad (1)$$

Where,
$f_{c'-cy}$: Cylinder compressive strength, MPa
Vf : volume fraction of fibre, %
In other words, the standard cylinder concrete strength has been reduced to 45.38% of 6 inches (150 mm) cube concrete strength as shown in the (2)

$$f_{c'-cy} = 1.642 * f_{c'} - 39.32 \quad (2)$$

Where,
fc' : Cube compressive strength, MPa

2) Split tensile strength:
The split tensile strength was predicted using (3) by Nadiaya and Saffar [8]. Aspect ratio and volume fraction of fibre with compressive strength of concrete without fibre has been included to predict split tensile strength.

$$f_{sp} = 0.104 * f_{c'} + 0.00795 * V_f * \lambda \quad (3)$$

Where,
fsp : Split tensile strength, MPa
λ: aspect ratio of fibre

Likewise, Shende and Pande [3] proposed (4) for predicting split tensile strength considering the volume fraction and aspect ratio of the fibre and the compressive strength of concrete without fibre as well.

$$f_{sp} = 0.95 * f_{c'} * V_f * P * e^{Q.\lambda} \quad (4)$$

where

$$P = 1.29276 - 0.337235 * V_f$$

$$Q = -0.08029 + 0.01255 * V_f$$

3) Relation between compressive strength and split tensile strength:

The simple relation between cube compressive strength and split tensile strength of fibrous normal strength concrete as shown in (5) has been proposed by Nadiaya and Saffar [8]. The important point was that the split tensile of fibrous normal strength concrete is about 11.6% of cube compressive strength regardless of the length and type of steel fibre.

$$f_{sp} = 0.116 * f_{cf} \quad (5)$$

Where;
f_{cf} Cube compressive strength of fibrous concrete, MPa

IV. EXPERIMENTAL PROCEDURE

An experimental programme was designed to study the influence of volume fraction of combined fibre system and the ratio of long fibre to the total fibre content on the compressive and split tensile strengths. Two micro steel fibre, which have length of 0.47 inch (12 mm) and 0.82 inch (21 mm) and diameter of 0.0078 inch (0.20 mm) and 0.0137 inch (0.35 mm) were used, respectively. The volume fraction of micro steel fibre was varied from 0 to 1.5%. Two fibre lengths, namely, 0.47 inch (12 mm) and 0.82 inch (21 mm) was investigated for straight type with different ratio of longer fibre to total fibre content ranging from 0.0 to 0.50. The cylinder compressive strength for normal strength concrete was about 3626 psi (25 MPa). The compressive strength and split tensile strength for fibrous normal strength concrete were evaluated to determine the influence of various factors.

A. *Materials, mix proportions, and specimen preparation*

a) Materials
The materials used in fibrous normal strength concrete are Ordinary Portland Cement (Type I), silica sand, crushed stone 0.393 inch (10 mm) maximum size, silica fume, tap water, water reducing superplasticizer Sika VC2199 , retard-superplasticizer Sika Plastiment R, and two sizes of micro steel fibre.

b) Mix proportions
The proportion of the mix was chosen to include the independent variables in the experimental programme. The dependent variables were compressive strength and split tensile strength while the independent ones were volume fraction of combined fibre and the ratio of longer fibre to the total amount of fibre. The mix proportion of fibrous normal strength concrete is shown in Table (1). The characteristic and detail of the mixes including fibre are presented in Table (2).

TABLE 1. MIX PROPORTION OF FIBROUS NORMAL STRENGTH CONCRETE

Materials	Quantity kg/m^3
Cement (Type I)	258
Silica sand	950.8
Crushed stone	763.8
w/cm ratio	0.742
Water reducing super-plasticizer Sika VC 2199	5.16
Retard-super-plasticizer Sika Plastiment R	1.29
Silica fume	12.90
Micro steel fibre A(21mmX 0.35mmΦ)	0-58.875
Micro steel fibre B(12mm X 0.20mmΦ)	58.875-98.125

c) Specimen preparation

The fibrous normal strength concrete was blended in a 1.765 ft3 (0.05 m3) laboratory pan mixer using the following procedures: Crushed stone and silica sand were blended for one minute.

TABLE 2. DETAIL OF THE FIBRE CONTENT IN FIBROUS NORMAL STRENGTH CONCRETE MIXES

Mix designation	Fibre A content kg/m^3	Fibre B content kg/m^3	Total fibre content kg/m^3	Workability	% of fibre A in total amount of fibre
N-10	0	0	0	175**	0
F-N-1	58.875	58.875	117.75	50**	0.5
F-N-2	54.950	54.950	109.90	50**	0.5
F-N-3	51.025	51.025	102.05	55**	0.5
F-N-4	49.100	49.100	98.125	65**	0.5
F-N-40	0.00	98.125	98.125	110**	0
F-N-41	39.25	58.875	98.125	5.56*	0.4
F-N-42	31.89	66.250	98.125	9.22*	0.325
F-N-43	24.53	73.600	98.125	5.19*	0.25

*: Vebe test results, sec **: slump test, mm

Then, the cement and entire amount of water with super-plasticizers were added for another one minute. After that, the mixing process was continued for another 3 minutes. Lastly, the process of adding micro steel fibre by passing the fibre through steel wire mesh 0.393 inch (10 mm) in diameter to avoid the interlock between fibres, which was started with long fibre and then the short one during 3 minutes. The blending process was continued for an additional four minutes to improve the uniformity of distribution of fibres inside the concrete mix.

After casting of fibrous concrete in the molds, the green concrete was vibrated for 90 seconds in two layers (each layer 45 seconds) using vibrating table in order to confirm the reduction of voids. Afterwards, they were left in the molds for 24±4 hours. Six 4 inches (100 mm) cube and six cylinders with 4 inches (100 mm) in diameter and 8 inches (200 mm) in height were made to check for compressive and split tensile strengths at 7 and 28 days.

B. Test results and discussion

1) Influence of volume fraction of the combined fibre system

Figures 1 and 2 show the influence of the variation of volume fraction of combined fibre (0-1.5%) which contained the same amount of both types of micro steel fibres A and B. The maximum improvement in compressive strength and split tensile strength happens at (F-N-3) 1.3% of volume fraction. However, both strengths were reduced when the inclusion of micro steel fibre increased from 1.3% to 1.5% due to balling of fibres and increase of voids.

2) Influence of the ratio of long fibre to total amount of fibre

The influence of long fibre to total amount of fibre ratio ranging from 0.00 to 0.50 can be seen in Figure 3 and 4. The maximum improvement in compressive strength and split tensile strength happens at long to total volume fraction of fibre is 25% in (F-N-43). The compressive strength reduces due to increase in long fibre in order to increase the voids surround of fibres whereas the split tensile strength improves due to increase in long fibre to total fibre ratio till 0.4 then it is going to drop when the ratio of long fibre reduces to 0.5 as a result of the phenomenon of balling and interlock.

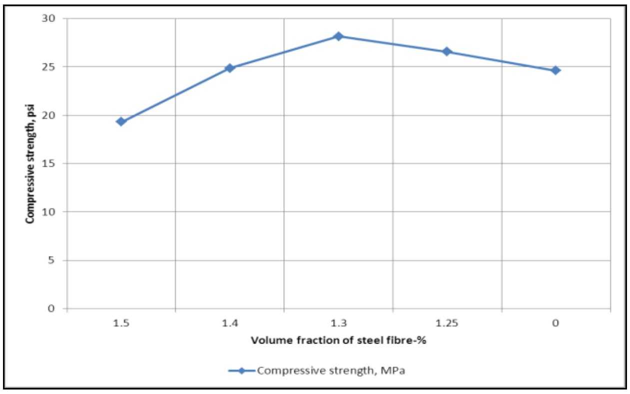

FIGURE 1. INFLUENCE OF VOLUME FRACTION OF COMBINED FIBRES ON THE COMPRESSIVE STRENGTH AT 28 DAYS

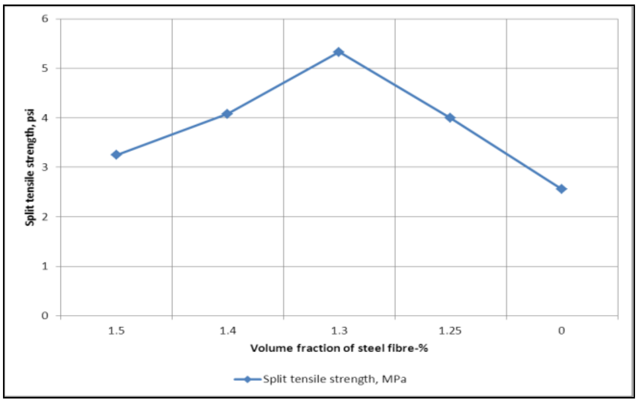

FIGURE 2. INFLUENCE OF VOLUME FRACTION OF COMBINED FIBRES ON THE SPLIT TENSILE STRENGTH AT 28 DAYS

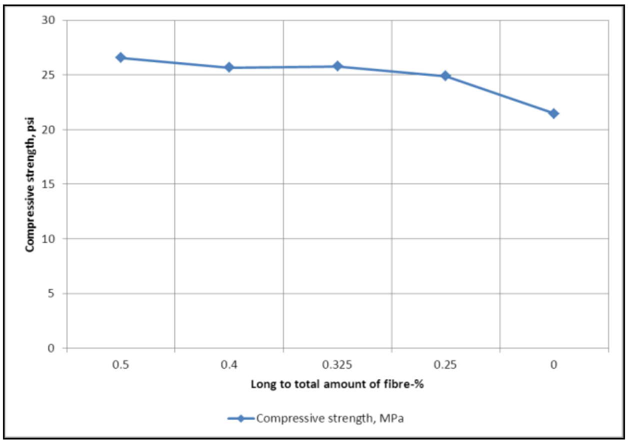

FIGURE 3. INFLUENCE OF LONG TO TOTAL FIBRE RATIO ON THE COMPRESSIVE STRENGTH AT 28 DAYS

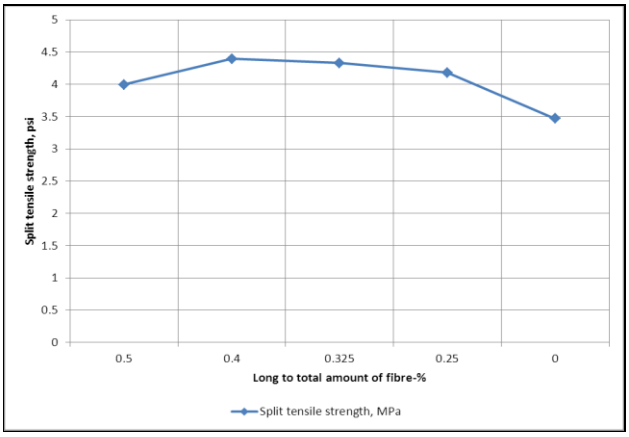

FIGURE 4. INFLUENCE OF LONG TO TOTAL AMOUNT OF FIBRE RATIO ON THE SPLIT TENSILE STRENGTH AT 28 DAYS

V. THEORETICAL MODELS

In this study, models to predict all of the compressive strength, split tensile strength from the mix proportions and the relation between them in fibrous normal strength concrete were proposed. Different software programme such as (SPSS V.19) and curve fitting software (V. 1.3) were used in the formulation of the proposed models.

1) Compressive strength

The SPSS package version 19 was used to predict the compressive strength of fibrous normal strength concrete considering the mix proportions. The backward method of linear stepwise regression in this software was used to develop (6) which contains all of the 92 data from different research studies [9, 10, 11, 12, 13, 14, 4, 5, 15, 16, 17 , 18 and 19].

$$f_{c'} = -2.463 + 0.059 * C - 0.002 * S + 0.015 * SF + 0.051 * W - 0.194 * SP \quad (6)$$

Where;

C: cement content, kg/m3
S: sand content, kg/m3
SF: silica fume content, kg/m3
W: water content, kg/m3
SP: amount of super-plasticizer, kg/m3

2) Split tensile strength

The SPSS package version 19 was used to predict the split tensile strength of fibrous normal strength concrete based on the mix proportions. The backward method of linear stepwise regression in this software was used to generate (7) based on 6 data from the current study and 56 data from other research studies [9, 10, 11, 12, 13 and 14].

$$f_{sp} = 29.755 - 0.007 * C - 0.014 * S - 0.008 * G + 0.012 * SF - 0.046 * SP + 0.008 * \lambda - 0.526 * MSA \quad (7)$$

Where;

G: gravel content, kg/m3
MSA: maximum size of aggregate, mm

3) Relation between compressive and split tensile strength

The curve expert software version 1.3 was used to predict the relation between split tensile strength and compressive strength of fibrous normal strength concrete. The modified power fit gave the best relation between them. The modified power fit as shown in (8) was developed based on 6 data from the current study and 56 data from other research studies [9, 10, 11, 12, 13 and 14].

$$f_{sp} = 1.87283 * 1.02569^{fc'-cy} \quad (8)$$

VI. MODEL EVALUATION

The statistically coefficients which are evaluated for the proposed models in this research and previous models proposed by other researches. The accuracy of the proposed models in this study is much better than that in previous models for the compressive and split tensile strengths. For example, proposed model represented by (6) has shown a good correlation coefficient which covers 78.8% of 92 data with small amount of standard error and coefficient of variation as well as mean value greater than 1.0. However, it slightly overestimates. In fact, this observation is opposite to the previously proposed model which was represented in (1). The Latter was under-estimated the value of compressive strength while standard error and coefficient of variation were high.

The proposed model (8), for predicting split tensile strength from the compressive strength of the same concrete has shown a good value of correlation coefficient and mean value as well while standard error and coefficient of variation are slightly less than the previously proposed model of (5). Furthermore, the proposed model (7) for predicting split tensile strength has excellent correlation coefficients which cover 91.7% of the data with small amount of standard error as shown in Table (3).

TABLE 3. EVALUATION OF THE PROPOSED MODELS

Equation No.	Correlation coefficient	Standard error	Coefficient of variation	mean
6	0.788	3.285	10.440	1.0347
1	-ve	8.354	25.965	0.8330
8	0.500	0.986	18.506	1.0006
5	0.076	0.886	20.549	0.9142
7	0.917	0.479	36.175	1.0418

VII. CONCLUSIONS

Based on the results and the models proposed in this study for prediction of both the compressive and split tensile strengths in fibrous normal strength concrete and the relation between them as well, the following conclusions could be made:

- The proposed models for predicting compressive strength, split tensile strength and the relation between split tensile and compressive strength show that the models have a good agreement with the results obtained in this research and those in other studies.
- The proposed model (7) in this research confirmed the inverse relation between maximum size of aggregate and split tensile strength. This relation comes from the weak bond between aggregate and the matrix of concrete which causes a reduction in the strength as a result.
- The compressive strength has proportional relation with volume fraction of steel fibre of single system. However if the system is changed to combination between two sizes of fibre with the same aspect ratio, the compressive strength reduces after maximum dosage of steel fibre.
- In the combined fibre system, the split tensile strength reduces after maximum dosage which means that any increase in the longer fibre will lead to the reduction in the split tensile strength.

FURTHER RESEARCH

Further study on the fibrous normal strength concrete which includes triple sizes of fibre to further improve the mechanical properties of fibrous normal strength concrete is recommended.

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