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文 Ultimate Strength of Steel Shaving Fiber Reinforced Concrete

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;STRACT: In assembly halls and metal forming workshops, steel and iron shavings which are ulted from turnery have shape and other properties of machined steel fibers which is industrially ›duced. So as a new idea this steel shaving after cutting in desired length were used in concrete. sults of flexural experiments in comparing methods showed desirable improvement in concrete xural strength behavior. Experimental variables were steel shaving content in concrete volume, ding mode, size and span of specimens. By considering of such variables the ultimate strength of xural members could be predicted by establishing a general relation.
:YWORDS: Steel shaving fiber, third-point loading, center-point loading, failure, plain concrete, ›ect ratio.

INTRODUCTION

Fibers have been used to strengthen a weaker matrix for many centuries, such as straw in mud .cks and horse hair in gypsum plastering. For the last few decades many types of fibers have been roduced in both research and industry fields; steel, glass, polypropylene and so on are used to engthen the concrete and cement mortar.

Fiber reinforcement present to the concrete industry several advantages such as superior crack ntrol, ductility, energy absorption capacity, and improving the interior tensile strength of the ncrete due to the bonding force between the fibers and the matrix [1].

Arresting the microcracks in concrete structures has many potential applications. It is specially luable in hot climates where concrete shrinkage causes such cracks. Many practical applications for ›er reinforced concrete(FRC) have already taken place, such as in the tunneling in case of shotcrete, ling industry, in parking garages, airport strips and runways.

Steel shavings fibers which are produced by turnery in assembly hall and metal forming orkshops has mechanical and physical properties as like as industrial machined steel fibers [3]. So as :w idea, in order to introducing of applying this material as fiber, this research were investigated. nce fiber reinforced concrete is a subject, in many of its applications, primarily to bending rather an axial loading, performance in flexure is perceived as important. Often, the ultimate flexural :ength or ultimate strength is the only material characteristic determined. This is probably due to the mplicity and availability of the testing equipment needed and user familiarity with ultimate flexural rength and its significance for plain concrete.

An analytical approach based on experimental data were used to determine the ultimate flexural rength of steel shaving fiber reinforced concrete(FRC). Assuming a certain failure mechanism, ediction equations were developed that give the ultimate strength of flexural member. The analytical sults, using these equation, agree very well with the experimental data. This paper attempts to ›mmunicate to introduce steel shaving fiber and such an understanding in relation to the easurement of ultimate flexural strength of this fiber in order to show this material can be not only

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Table 1: Specification of test specimen

series and kind of specimens	*size of specimen* *width cm*	*height cm*	*span cm*	*mode of loading*	*shaving fiber contents in kg/m³ and corresponding average of ultimate strength in kgf/cm²* 0.	25	50	75	100	125	150
1.flexural	15	5	35	C.P.L[1]	43.5	56.6	62.6	67.2	73.8	83.6	---
2.flexural	5	15	45	T.P.L[2]	37.1	42.1	44.5	50.1	55.4	64.2	---
3.flexural	15	15	45	T.P.L[2]	38.3	40.9	47.4	---	53.6	---	61.3
4.splitting	cylinder 15.2×30.5			----	23.3	*26.7	28.0	---	30.9	---	37.8
5.compressive	cylinder 15.2×30.5			----	280.8	294.8	309.8	---	279.1	---	269.8

*1: Center-point loading 2: Third-point loading *: By interpolation*

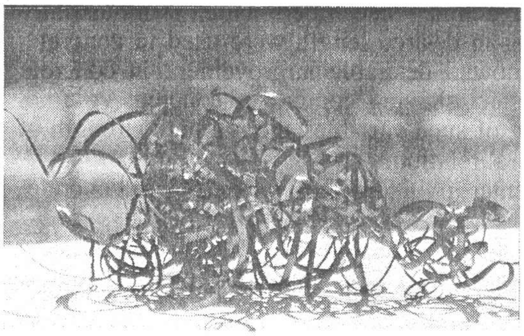

Fig. 1: A sample of steel shaving

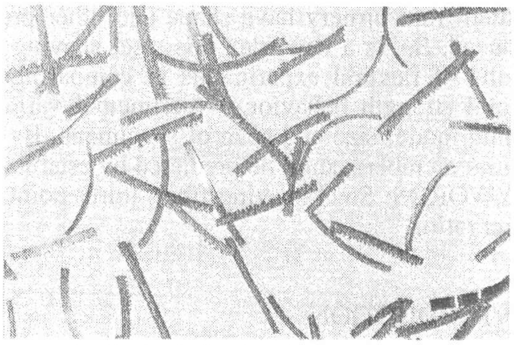

Fig. 2: Steel shaving fibers

used as fiber, but also in comparing with other industrial steel fibers is probably the cheapest one [10,11,12].

2. EXPERIMENTAL PROGRAM

The authors' experimental data which initially isolated the important factors were obtained using a mix with 1057 kg/m³ of 9.5 mm gravel, 686 kg/m³ of sand (for splitting and compressive specimens 715 kg/m³), 350 kg/m³ of normal portland cement, and 0.4 of *W/C* (water to cement ratio). Steel shavings fiber which were used, had below specification:

Length : 40~50 mm | Equivalent diameter : 0.8~1.0 mm
Average aspect ratio : 45 | Section : triangular and twisted
Ultimate tensile strength : 4000~6000 kg/cm² | Surface : roughness with teeth edges

To over come the probable errors of experiments recording, negligible variation of shaving fibers' length or diameter and of mixing each sample of each series were made in 4 specimens and the range of strength coefficient of variation for all series varied 2.6% to 6.9%. The first series sizes were based on Dramix Steel Fiber's laboratory specimen's sizes [2]. The second series sizes were selected by authors'. The third and the fourth series sizes are based on JSCE and the fifth series are based on ACI. All fibers in the third, fourth, and fifth series of specimens were space-oriented within the matrix. All specimens were left inside the mold for 24 hours after casting, then stripped off the mold and placed in the curing room for an additional 27 days. The plain concrete mix yielded an average of concrete compressive strength f'_c of 285.5 kg/cm² for flexural specimens and 280.8 kg/cm² for splitting and compressive specimens. Other consideration were selected based on JSCE-SF [4].

3. BEHAVIOR OF FLEXURAL SPECIMENS

Two stages of flexural behavior of fiber reinforced concrete have been observed in flexural beams. The initial stages, in a typical load-deflection relation, is linear. In this stage the composite material behaves elastically in both tension and compression zones, likewise, both the stresses and strains vary linearly across the specimens depth. Upon increasing the loading, the relation between load and deflection continues to be linear until the load reaches a point we will refer to as the first cracking load, when the graph of this relation starts to deviate from a straight line. The transition from the linear to the nonlinear behavior is usually smooth. To explain this behavior we believe that the transition point, making the end of elastic state, occurs when the flexural stress, in tension zone of the beam, equals the cracking stress of the composite material. Upon increasing the loading a crack will be initiated; this crack starts propagating as the applied load is increased. When the matrix cracks, the stress is transferred to the steel fibers crossing the propagating crack length, while the uncracked part of the matrix still carries its share of the flexural tensile strength.

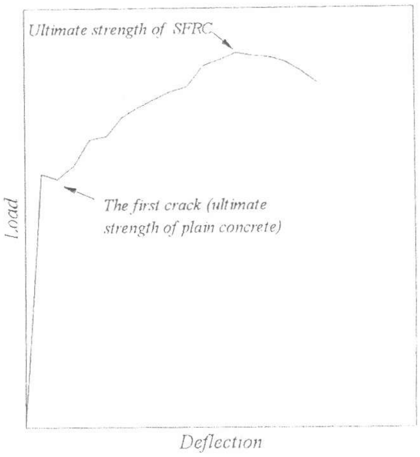

Fig. 3: Typical load–Deflection diagram in flexural test

As a consequence of the crack propagation across the matrix, the neutral axis will shift toward the compression zone of the beam, too. Moreover, due to inferior tensile strength of the composite material relative to its compressive strength, the compression stress remains almost linear up to failure. Finally, a complete collapse occurs when the fibers are pulled out of the matrix. The maximum value of the applied load will be called the ultimate load and denoted by P_u. The corresponding moment is called the ultimate moment and is denoted by M_u.

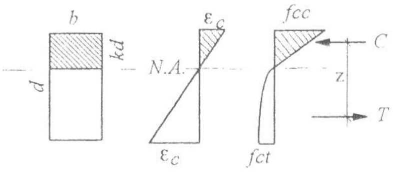

Fig. 4: Assumed stress distribution in FRC at ultimate strength

4. RELATION FOR ULTIMATE FLEXURAL STRENGTH OF STEEL SHAVING FRC

As mentioned above, by considering the behavior of flexural beam specimen and distribution of stress and strain in the whole of section of the beams, the ultimate flexural strength of steel shaving (FRC) may be obtain by assuming that:

1) The flexural stress distribution across the beam is linear for compression, while it has a constant value in tension.
2) Plane cross sections before bending remain plane after bending, Fig.4 [5]

Using the above assumptions, it follows that the resultant compressive force C, the resultant tensile force T and Z on the section is given by:

$$C = \tfrac{1}{2}kbdf_{cc} \quad (1) \qquad T = (1-k)\phi bdf_{ct} \quad (2) \qquad Z = d[\tfrac{2}{3}k + \xi(1-k)] \quad (3)$$

According to $T=C$ the value of k deciding neutral axis can be obtain by using below relations:

$$k = \frac{2\phi}{r+2\phi} \qquad (4)$$

Where ratio of f_{cc}/f_{ct} is defined as r. The ultimate resisting moment of cross section M_u in terms of the tensile stress equals :

$$M_u = d[\tfrac{2}{3}k + \xi(1-k)](1-k)\phi bdf_{ct} \qquad (5)$$

As shown in Fig. 4, in order to ease applying of relations, parabolic diagram of tension stress was assumed as a rectangular block stress diagram . And therefore ϕ and ξ were assumed 1.0 and 0.5 .

$$M_u = (\tfrac{1}{2} - \tfrac{k}{3})\phi bd^2 f_{ct} \qquad (6)$$

According to Fig.5 higher order terms of k were deleted. By substituting value of k in eq.6, we have

$$M_u = \frac{1}{6}\alpha b d^2 f_{ct} \qquad (7)$$

Where $\frac{2+3r}{2+r}$ is defined as α.

5. ANALYSIS OF THE EXPERIMENTAL RESULTS

According to specimens' specification the external ultimate moment were calculated in terms of the applied ultimate load in third-point loading and center-point loading respectively:

$$M_u^e = P_u^e \cdot l/6 \quad \text{and} \quad M_u^e = P_u^e \cdot l/4 \qquad (8)$$

where l is span of flexural specimen . In Table 2 the measured ultimate load P_u^e and the calculated external ultimate moment M_u^e accordance with mode of loading were written. It must be noted that these values are average of 4 specimens' results and external ultimate moment according to *the failure section of specimens* were calculated.

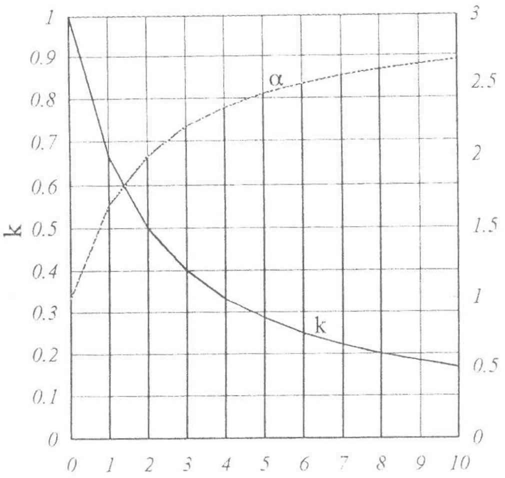

Fig. 5: Values of k and α

We assumed the stress distribution in the steel shaving FRC beams is according to Fig. 4 , furthermore, let the flexural tensile stress f_{ct} be a certain fraction of the splitting tensile strength of the steel shaving FRC , so

$$f_{ct} = \beta \cdot f_{sp} \qquad (9)$$

Where β is an unknown coefficient and must be founded. By combining eq. 4, 7 and 9, β is calculated as follow:

$$(f_{sp}^2 \cdot bd^2)\beta^2 + [\tfrac{3}{2}f_{cc} \cdot bd^2 f_{sp} - 6f_{sp}M_u]\beta - 3M_u f_{cc} = 0. \qquad (10)$$

In eq. 10 all quantities were already defined except for β .

Results of authors' experimental and others show that ultimate strength of FRC are affected by partial fiber alignment, mode of loading, size and span of specimen. It was observed that by decreasing size of section with the same span or increasing in the span with the same section, the ultimate strength of steel shaving FRC were decreased. Effect of mode of loading in this research and research of others show that the strengths for center-point loading in average 11~22 percent more than for third-point loading [1,7]. In small size specimens in the reason of partial fiber alignment increasing in the ultimate strength were observed It is evident that, effects of high aspect ratio or increasing amounts of steel shavings fiber in mixture increase the strength of matrix, therefore as clear subject , the effects of two recent factors were not discussed here. At this point, the discussion is restricted to 15 cm square specimen with 45 cm span and third-point loading as *a basis specimen (b.s.)* which is usually in most researches are used. Accordance with basis specimen behavior, effect of mentioned factors in different specimens were related to ***b.s.***. The purpose of this procedure was to obtain a general relation with widely application. So according to eq. 7, 9 and 10 the ultimate flexural strength of ***b.s.*** is proposed by this below relation:

$$f_{rb} = \alpha \cdot \beta \cdot f_{sp}(1 + w_f) \qquad (11)$$

Where f_{sp} is corresponding splitting strength of FRC and w_f *(ratio weight of steel shaving fiber to specific gravity of concrete)*. Eq. 11 is only simple form of the ultimate strength of steel shaving FRC without considering the mentioned factors. As, it was explained above, it needs a general relation by considering effects of partial fiber alignment, mode of loading, span and size of specimens.

$$f_r = f_{rb} \cdot \eta_{tot} \qquad (12)$$

Where η_{tot} is product of $\eta_{si} \cdot \eta_{sp} \cdot \eta_{ml} \cdot \eta_{fa}$.

Based on observation of experimental data and behavior of 3 series of specimens which were prepared by steel shaving fiber, the below empirical relation for three mentioned factors were derived.

$$\eta_{si} = \frac{4d_b}{5d_b-d} \quad , \qquad \eta_{sp} = \frac{l_b}{l} , \qquad \eta_{fa} = 1.1$$

$$\eta_{ml} = 1 \pm (\frac{M_t-M_{tb}}{M_{t,\max}})^2 \quad (+) \text{ for } M_t \geq M_{tb} \quad (-) \text{ for } M_t \leq M_{tb} \qquad (13)$$

Where :

f_r : ultimate strength of specimen in kgf/cm^2

f_{rb} : ultimate strength of ***b.s.***$(6M_{ub}/bd_b^2)$ in kgf/cm^2

η_{si} : factor of size

η_{sp} : factor of span

η_{ml} : factor of mode of loading

η_{fa} : factor of partial fiber alignment

d_b : height of ***b.s.*** in cm

d : height of specimen in cm

l_b : span of ***b.s.*** in cm

l : span of specimen in cm

M_{tb} : theory moment of loading mode of ***b.s.***

M_t : theory moment of loading mode of specimen

$M_{t,\max}$: theory moment of center–point loading

Table 2. Measured and calculated data for *basis specimen*

Specimen	Measured data				Calculated data		
	f_{cc} kg/cm^2	P^e_u kg	f_{sp} kg/cm^2	f_{rb} kg/cm^2	M^e_u kg–cm	β	f_{rb} kg/cm^2
3.flex.0.0	77.4	3,012	23.34	38.27	21,523	0.68	38.38
3.flex.25	82.6	3,275	26.65	40.88	22,995	0.63	43.75
3.flex.50	95.7	3,842	27.95	47.35	26,646	0.7	47.14
4.flex.100	108.2	4,325	30.88	53.55	30,122	0.72	53.29
5.flex.150	123.8	4,820	37.81	61.29	34,476	0.67	65.76

According to Table 2 , average of β=0.68 were selected for all specimens and the ultimate strength of ***b.s.*** with the corresponding f_{ct} were calculated. Also, by calculating effective factors, the ultimate strength of other specimens were determined. It must be notified , the amount of η_{fa} for specimens with 5 cm size of section 1.1 was selected.

Results of the measured ultimate strength of three series and the calculated ultimate strength based on

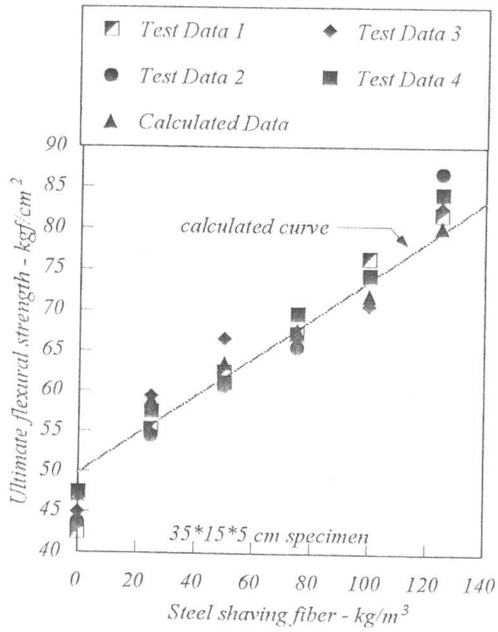

Fig. 6:Measured and calculated data

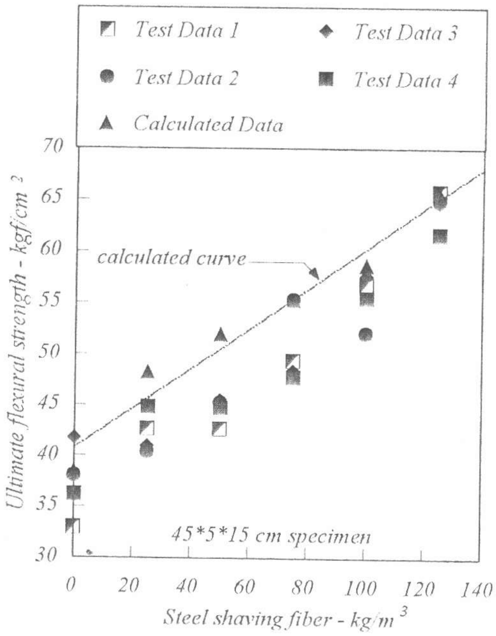

Fig. 7: Measured and calculated data

eq. 11 and 12 were shown in Fig. 6, Fig. 7 and Fig. 8 .

6. CONCLUSIONS

The following conclusions are drawn from the results of this investigation:

1. Steel shavings fiber as like as industrial fibers improve concrete strengths and are effective in resisting deformation at all stages of loading.

2. Ultimate strengths of steel shaving FRC are not only influenced by steel shaving amount in the mixture but also influenced by mode of loading, size and span of specimens.

3. Variation in size, span and mode of loading cause different effects in the ultimate strength results. So in order to consider all of these effects, general relation for predicting of the ultimate strength of steel shaving FRC based on **b**asis **s**pecimen were presented here, which is shown to give very good agreement with experimental data.

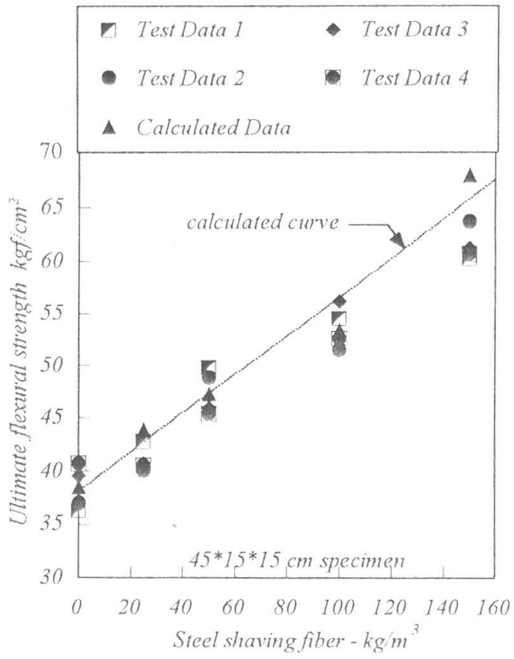

Fig. 8: Measured and calculated data

4. By using data of usual steel fiber which have been already done by others show, this general relation relatively gives a good agreement.

5. Steel shaving fiber almost with the same physical and mechanical properties as like as industrial steel fibers has cheaper price in comparing with other fibers.

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