

TORSIONAL STRENGTH OF STEEL FIBER REINFORCED CONCRETE

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The addition of steel fibers in reinforced concrete improves the toughness and the tensile strength of the obtained steel fiber reinforced concrete (SFRC). The latter property enhances the shear strength and the torque moment capacity of SFRC which mainly depend on the tensile strength.

The current study is targeted towards developing an expression that is based on the thin walled tube (space truss) analogy adopted by American concrete Institute (ACI). In the proposed expression, the effective tensile strength of concrete in pure torsion in addition to parameters that are in accordance with thin walled tube (space truss) analogy are introduced as independent input parameters.

Literature survey is carried out to collect experimental data pertinent to the torsional strength of SFRC beams. Based on regression analysis a new mathematical relationship that predicts the torsional moment for fiber reinforced concrete is derived.

1- INTRODUCTION

The addition of steel fibers to concrete mixes improves the properties of the obtained steel fiber reinforced concrete (SFRC). Aspects of the improved properties comprise tensile strength, shear strength as well as ductility and toughness of the SFRC. Such enhancements render using steel fibers attractive especially in high strength concrete.

Utilizing steel fibers as a technique for improving the properties of concrete has been the issue of several studies steered to acquire better understanding of the behavior of SFRC both in linear and nonlinear stages, and to attain detailed authenticated provisions for the design of such material.

Few studies have been targeted towards investigating the torsional capacity of SFRC concrete. According to Edington [1], the increase in both the direct tensile and the torsional strengths of unreinforced concrete because of the fibers is substantial compared to only a marginal increase in flexural strength.

Upon testing eight SFRC beams, of various fiber content proportions with dimensions 6in width, 12in height, 70in length, Craig [2] concluded that the addition of fibers shows a tremendously increased ductility over the plain concrete.

Romouldi [3] inferred that fibers act as crack arrestors by producing pinching forces that tend to close a crack. Sakai [4] concluded that the critical fiber transfer length, the fiber matrix interfacial bond, and the orientation factor for random fibers are the basic considerations in the transfer of stress from matrix to fiber.

Rao [5] tested 20 SFRC plain concrete beams of size 100 x 200 x 1000 mm under pure torsion. The volume fraction of fibers varied from 0% to 1.2%, the grades of concrete were 20, 30, 40, 50. He concluded that torsional failure of concrete members is initiated by the tensile stress that comes up due to a state of in plane pure shear developed by torsion. According to his study, inclusion of steel fibers may principally increase the tensile strength of the matrix to a moderate level but the toughness will be enhanced to a greater extent.

Mansur [6] conducted experiments on 30 beams, in which torsion to moment ratio varied from 0, pure bending to ∞ , pure torsion. Beams lengths were 1m, 2m, the sections depths were 100,150,200 mm while a constant width of 100mm was maintained.

Also Mansur [7] carried out experiments on 15 beams, each 1m. long with a rectangular cross section of 100mm by 155mm. The beams were divided into four groups according to the fiber volume fraction of 0, 0.75, 1.25 and 1.75%. Mansur [7, 8] concluded that increase in volume fraction of fibers adds to the torsional ductility, and the toughness of tested beams.

2- RESEARCH SIGNIFICANCE

Addition of steel fibers in concrete improves its mechanical behavior. The material ductility is enhanced significantly. The crack growth is considerably decreased. The material becomes a better energy absorbing. Such improvements support the use of SFRC concrete in many structural applications such as airports, highway paving layers, industrial floorings, and bridge decks. Its enhanced properties support its use in structures in earthquake prone regions, and for blast resistant structures. The authors strongly feel that this work will help to shed more light on the torsional capacity of steel fiber concrete.

3- DATA ANALYSIS

Experimental data obtained from testing SFRC plain concrete beams under pure torsion are listed in Table 1. Gathered data contain cubic compressive strength values for SFRC that range from 22 MPa to 61 MPa. These values practically cover all structural concrete grades used in construction works.

According to Rao [5], as the state of stress is pure shear accompanied by the same intensity of compressive and tensile stresses in orthogonal directions, the apparent tensile strength drops a little less than the actual tensile strength of concrete. So the effective tensile strength of concrete in pure torsion is taken as

$$\frac{1}{f_t} = \frac{1}{f_c} + \frac{1}{f_{spt}} \quad (1)$$

Where

f_t : the effective tensile strength of concrete in pure torsion

f_{spt} : Split cylinder tensile strength

f_c : Concrete cubic strength.

Moreover, according to ACI, a beam subjected to torsion is idealized as a thin walled tube with the core concrete cross section neglected, space truss analogy, the torsional moment is a function of $\sqrt{f'_c}, \left(\frac{A_{cp}^2}{p_{cp}}\right)$

where f'_c = specified compressive strength of concrete.

A_{cp} = area enclosed by outside perimeter of concrete cross section.

p_{cp} = outside perimeter of the concrete cross section.

The above parameters are exploited in introducing the general expression

$$T = \alpha \cdot \left(\frac{A_{cp}^2}{p_{cp}}\right) \cdot f_t \quad (2)$$

where f_t = effective tensile strength of concrete in pure torsion, Eq. (1), MPa.

T = torsional moment strength, KNm.

Regression analysis is conducted on the tentative equation. Ultimately the following equation is derived

$$T = 0.833 \cdot \left(\frac{A_{cp}^2}{p_{cp}}\right) \cdot f_t \quad (3)$$

The P-value for the coefficient (α) is less than 0.001, indicating that the predictor has a significant effect on the response variable. Also the adjusted coefficient of determination, R^2 is 0.9, implying that the predicted values are acceptably close to the observed data.

Up to the knowledge of the authors, and as was asserted through the literature survey, till now there is no authenticated mathematical expression concerning the torsional strength of fiber reinforced concrete. Thus, Fig. 1 illustrates a comparison between the calculated torsion according to the derived equation with the calculated value of torsion for plain concrete according to the American concrete Institute (ACI) equation for plain concrete:

$$T = \left(\frac{1}{3}\right) \text{sqr } t(f' c) \times \frac{(A_{cp})^2}{p_{cp}} \times 10^{-6} \quad (4)$$

where f'_c = specified compressive strength of concrete (MPa).

T = torsional moment strength, KNm.

As illustrated in Fig. 1, using the effective tensile strength in the case of steel fiber reinforced concrete enhances the calculated torsional strength values. Figure 2 illustrates the relationship of concrete compressive strength, effective tensile in pure torsion versus $T_{\text{exp}}/T_{\text{cal}}$.

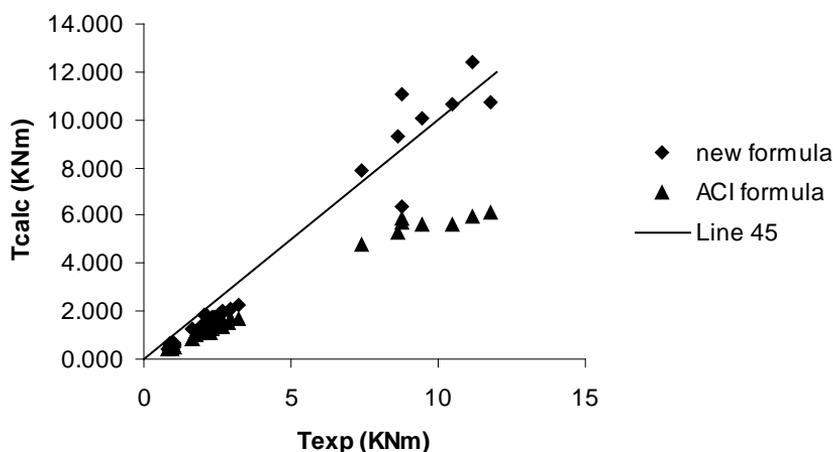


Figure 1 Experimental values of torsion (T_{exp}) versus calculated torsion (T_{cal}) according, first according to proposed equation, then according to ACI equation.

4- CONCLUSIONS

Addition of steel fiber into the concrete mix increases the tensile strength of concrete; nevertheless the compressive strength is slightly affected. Hence, based on experimental results, a general expression for SFRC beams subjected to torsion is suggested. This expression is deduced from the ACI equation for determination of torsional capacity in case of plain concrete beams. The tensile strength parameter that actually reflects the enhancement in torsional strength

of rectangular steel fiber reinforced concrete is used instead of the concrete compressive cylindrical strength presented in the original ACI equation. The final expression is concluded using regression analysis on experimental values. The calculated values utilizing the derived equation are in good agreement with experimental values.

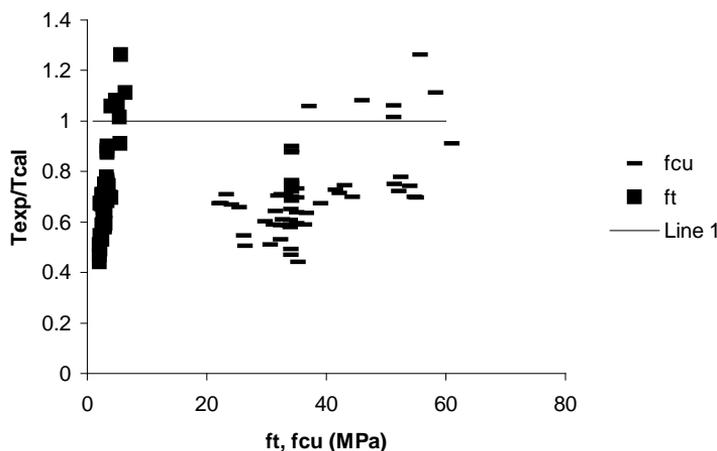


Figure 2 experimental f_{cu} , f_t values versus T_{exp}/T_{cal}

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APPENDIX

Table (1) Calculated and experimental torsional moments.

		mm	mm	Mpa	Mpa	Mpa	KNm	KNm	
		b	d	ft	Fcu	fsp	Texp	Tcal	Tcal/Texp
Rao [5]	1	100	200	2.12	22.00	2.35	1.753	1.179	0.672
	2	100	200	2.28	22.41	2.54	1.881	1.267	0.673
	3	100	200	2.46	23.26	2.75	1.924	1.365	0.710
	4	100	200	2.53	24.15	2.82	2.095	1.402	0.669
	5	100	200	2.68	25.41	3.00	2.266	1.490	0.657
	6	100	200	2.49	31.86	2.70	1.967	1.382	0.703
	7	100	200	2.79	32.41	3.05	2.180	1.548	0.710
	8	100	200	2.99	33.16	3.29	2.351	1.662	0.707
	9	100	200	3.35	34.21	3.71	2.522	1.858	0.737
	10	100	200	3.50	35.01	3.89	2.651	1.944	0.733
	11	100	200	2.74	38.99	2.95	2.266	1.523	0.672
	12	100	200	3.13	41.54	3.39	2.394	1.740	0.727
	13	100	200	3.25	42.20	3.52	2.522	1.804	0.715
	14	100	200	3.50	43.02	3.81	2.608	1.943	0.745
	15	100	200	3.66	44.31	3.99	2.907	2.032	0.699
	16	100	200	2.89	51.31	3.06	2.138	1.603	0.750
	17	100	200	3.24	52.38	3.45	2.309	1.797	0.778
	18	100	200	3.55	53.91	3.80	2.651	1.971	0.743
	19	100	200	3.71	54.75	3.98	2.950	2.060	0.698
	20	100	200	4.01	55.05	4.33	3.206	2.229	0.695
Craig [2]	21	152	305	3.24	52.12	3.45	8.779	6.337	0.722
	22	152	305	5.13	51.23	5.70	9.457	10.045	1.062
	23	152	305	4.75	45.93	5.30	8.609	9.305	1.081
	24	152	305	4.01	37.10	4.50	7.423	7.859	1.059
	25	152	305	5.66	55.65	6.30	8.779	11.082	1.262
	26	152	305	5.46	60.95	6.00	11.750	10.697	0.910

	27	152	305	5.42	51.23	6.06	10.451	10.612	1.015
	28	152	305	6.33	58.30	7.10	11.140	12.389	1.112
Mansur [6]	29	100	100	3.32	34.20	3.68	0.961	0.691	0.719
	30	100	100	3.32	34.20	3.68	0.990	0.691	0.698
	31	100	100	3.32	34.20	3.68	1.010	0.691	0.684
	32	100	150	3.32	34.20	3.68	1.668	1.244	0.746
	33	100	150	3.32	34.20	3.68	1.648	1.244	0.755
	34	100	150	3.32	34.20	3.68	1.624	1.244	0.766
	35	100	200	3.32	34.20	3.68	2.109	1.843	0.874
	36	100	200	3.32	34.20	3.68	2.050	1.843	0.899
	37	100	200	3.32	34.20	3.68	2.089	1.843	0.882
	Mansur [7]	38	100	100	2.04	26.40	2.22	0.844	0.426
39		100	100	2.13	26.20	2.32	0.814	0.444	0.546
40		100	100	2.02	30.60	2.16	0.824	0.420	0.509
41		100	100	2.56	36.30	2.76	0.905	0.533	0.589
42		100	100	2.54	32.30	2.76	0.902	0.529	0.586
43		100	100	2.73	36.60	2.95	0.893	0.568	0.636
44		100	100	2.82	35.00	3.07	0.923	0.588	0.637
45		100	100	2.87	34.10	3.14	0.922	0.598	0.649
46		100	100	3.06	35.00	3.35	0.915	0.637	0.696
47		100	100	2.08	34.10	2.22	0.923	0.433	0.469
48		100	100	2.18	34.10	2.32	0.922	0.453	0.491
49		100	100	2.03	35.20	2.16	0.963	0.423	0.440
50		100	100	2.55	33.60	2.76	0.903	0.530	0.587
51		100	100	2.54	32.30	2.76	0.996	0.529	0.531
52		100	100	2.71	33.90	2.95	0.932	0.564	0.606
53		100	100	2.81	32.70	3.07	0.959	0.584	0.609
54		100	100	2.84	29.70	3.14	0.981	0.591	0.602
55	100	100	3.03	31.50	3.35	0.981	0.631	0.643	
56	100	100	2.80	31.10	3.07	0.986	0.582	0.590	
57	100	100	2.97	33.70	3.25	1.055	0.618	0.586	
58	100	100	2.91	33.90	3.18	1.045	0.605	0.579	
59	100	100	3.00	35.00	3.28	1.050	0.624	0.594	

مقاومة اللي للخرسانة المضاف إليها ألياف فولاذية

إن إضافة الألياف الفولاذية إلى الخرسانة يؤدي إلى تحسين متانتها (toughness) وكذلك مقاومتها للشد. هذا ويرافق الزيادة في مقاومة الشد زيادة في مقاومة القص وكذلك زيادة في مقاومة اللي.

وتهدف هذه الدراسة إلى تقديم معادلة لمقاومة اللي لدى المقاطع الخرسانية المتضمنة ألياف الفولاذية. ومن أجل تحقيق هذا الغرض تم تطوير معادلة اللي الواردة في الكود الأمريكي والمبنية على مبدأ الجدران النحيفة (Thin walled tube analogy) حيث تم الاستعاضة عن مقاومة الخرسانة للضغط الواردة في الكود بمقاومة الخرسانة للشد إذ أن الدراسات أثبتت عدم تأثير مقاومة الخرسانة للضغط عند إضافة الألياف الفولاذية إليها بعكس مقاومتها للشد التي تتحسن بشكل واضح.

وعليه تم جمع البيانات للنتائج المخبرية لمقاطع خرسانية معرضة للي وتم إجراء تحليل إحصائي ارتدادي، وتم استنباط معادلة رياضية لحساب مقاومة اللي في حال المقاطع الخرسانية المتضمنة ألياف الفولاذ.

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