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The influence of the brittleness index on fibrous normal strength concrete beams under pure torsion

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ABSTRACT :*The brittleness property is a common problem for concrete, and their influences on cracking torsional resistance did not study properly yet. Thus, the effect of brittleness index on cracking torsional resistance in fibrous normal strength under-reinforced concrete beams is highlighted in this investigation. For this reason, it was cast and tested four fibrous normal strength under-reinforced concrete beams under pure torsion.*

It was found that the cracking torsional resistance improves up to 7.25% due to enhancement in brittleness index around 18.35%, while the dimensions of the cross section of the concrete beams and volume fraction of steel fiber are still constants. In addition, the dimensional analysis was used to verify this improvement, and it found that the proposed model from the dimensional analysis has a good agreement with the test results.

KEYWORDS *Brittleness index, cracking torsional resistance, dimensional analysis, fibrous concrete, and pure torsion*

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I. INTRODUCTION

The bond strength between reinforcement and a fibrous concrete matrix influences on the strain in the reinforcement because the bond strength influenced by the aspect ratio and volume fraction of the fibers, the concrete cover surrounding the reinforcement, the diameter of the reinforcement bar and the square root of the concrete's compressive strength(1). Therefore, the bond strength is significant for improving stress in the reinforcement at peak load in under-reinforced fibrous concrete beams subjected to pure torsion, which affects the crack details as shown in Figure 1.

The non-fibrous concrete beams designed for resisting torsional loading based on the strength of materials such as reinforcement yield strength and compressive strength of concrete from the stress-strain curve and compression machine, respectively. Meanwhile, the amount of yield strength of embedded steel bar in concrete has been less than that obtained from the stress-strain curve(2). This behavior is known as Tension Stiffening. The value of tension stiffening is a function of the amount of reinforcement, the compressive strength of concrete, the thickness of concrete cover(3-6).

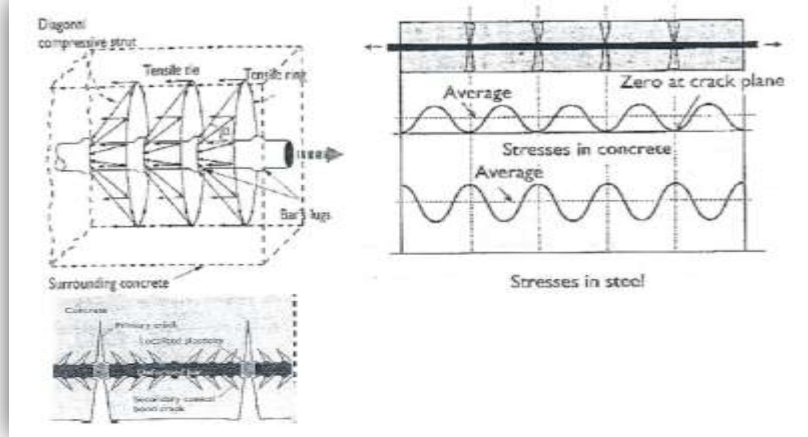

Fig.1.Effect of conical bond action of the stress in the reinforcement (2)

The term of brittleness index included the compressive strength of concrete, which is a property of concrete that fractures with little or no plastic flow(7). However, there is no standardized and universally accepted definition for brittleness index.

Hucka and Das (1974) suggested that the brittleness index might compute as a function of uniaxial compressive and tensile strength(8-10).

$$\mathrm{BI} = \frac{f_{c'}}{f_t} \quad (1)$$

However, the tensile strength of fibrous concrete a little bit differs by computing in different ways (direct tensile, flexural strength, and split tensile strength). The most affected type of tensile strength by steel fiber is flexural other than direct and split tensile strength. Thus, the brittleness index in this study becomes the ratio of cylinder compressive strength to the flexural strength of fibrous concrete, and it could express as follows:

$$\mathrm{BI} = \frac{f_{c'}}{f_r} \quad (2)$$

The non-uniformity of fiber distribution in concrete changes in the compressive strength and the bond strength as a result. Thus, this paper highlights the influence of non-uniformity of fiber distribution of varying brittleness index of the fibrous concrete, which directly affect the cracking torsional resistance of the beams under pure torsional loading.

II. EXPERIMENTAL WORKS

Four under-reinforced fibrous normal strength concrete beams were cast to study the influence of brittleness index of fibrous concrete on the cracking torsional resistance. The beam denoted as B-1*-N is a control beam and the others are denoted D-1-N, D-2-N, and D-3-N. The clear span to overall depth ratio and height to width ratio of the beam section are kept as 5.7 and 1.2, respectively. The load applied to the load spreader beam from the Universal Testing Machine. The action of the load spreader beam transferred to the end of the arms of the main beam. The load on the arms produced bending moment and shear force in the wings. The bending moment was then converted to torsional moment on the main beam, as shown in Figures 2.

III. MATERIALS, MIX PROPORTIONS, AND SPECIMEN PREPARATION

In the following sections describe the materials and the mix proportion between ingredients for producing fibrous normal strength concrete. Besides, the fabrication of specimens and torsional testing procedure are explained.

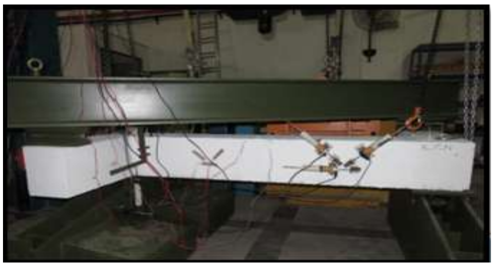

Fig.2.Experimental set-up of the beams

IV. MATERIALS AND MIX PROPORTION

The target strength of fibrous normal strength concrete beams was 25 MPa. For producing this fibrous concrete, ordinary Portland cement (Type I), granite crushed stone with 10 mm maximum size, silica sand, silica fume, tap water, HRWR SikaVicocreat 2199, retarder SikaPlastiment R with two sizes of micro steel fiber covered by copper used in this study. The mix proportion of these materials shown in Table1.

The main beams reinforced with 4-12 mm diameter bars as a longitudinal reinforcement, where each of them located at the corner of the stirrup. Diameter bars of 6 mm provided as 135º standard hooks stirrup with dimensions of 216 mm height and 166 mm wide, and the spacing between transverse reinforcement was 95 mm as shown in Figure 3. The measured dimensions of the four beams tabulated in Table 2.

TABLE.1. Mix proportioning of fibrous normal strength concrete

Materials	Quality, kg/m^3
Cement (Type I)	275
Silica sand	926.7
Crushed stone	763.8
Silica fume	13.75
Water	200.7
Super-plasticizer VC2199	5.5
Retarder-admixture (Plastiment R)	1.375
Micro steel fiber A (21mm X 0.35 mmΦ)	18.055
Micro steel fiber B (12 mm X 0.2 mmΦ)	72.22
Slump, mm	90

Φ: diameter of fiber, mm

TABLE.2. Measured dimensions of the fibrous concrete beam

Beam denotation	Concrete cover, mm	Width, mm	Height, mm	Span length, mm
B-1*-N	29	230	280	1587
D-1-N	26	224	274	1572
D-2-N	25	222	272	1561
D-3-N	23	218	268	1549

Span/depth=5.7 Height/ Width= 1.2

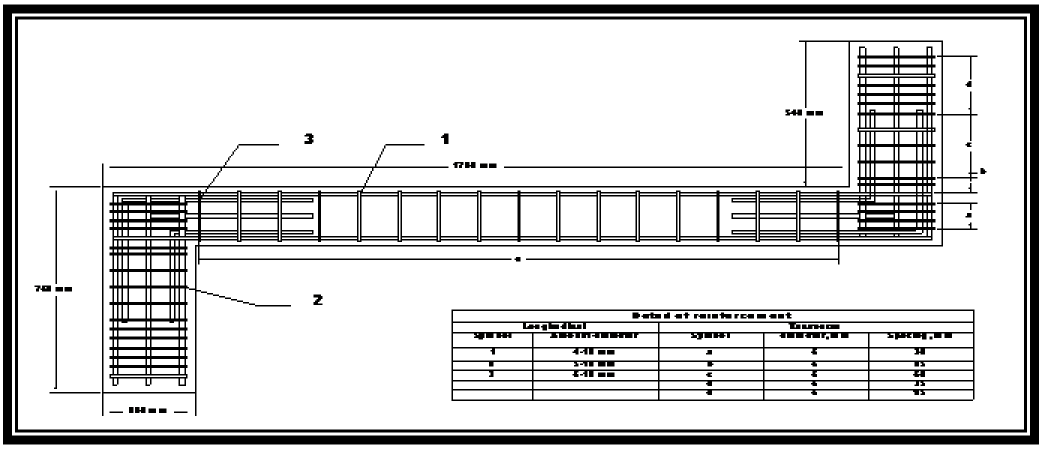

Fig.3.Detail of reinforcements in the fibrous concrete beam B-1*-N

Preparation Of Specimen And Fabrication Of Specimens

Pan mixer with 0.05 m^3 used for casting fibrous normal strength concrete. The following sequence of blending materials used: granite crushed stone, silica sand was mixed first for 90 seconds. After that, the ordinary Portland cement added to the blended materials, and the process of mixing continued for another 30 seconds. Next, the whole concrete mixing water plus HRWR added to the blending materials for 30 seconds. After that, silica fume and retarderPlastiment R added to the mixed materials for another 30 seconds. Afterward, the steel fiber added to the fresh concrete, which passed through steel wire mesh during 180 seconds. To verify the uniformity of fiber distribution, the mixing process continued for an addition 120 seconds.

The fibrous normal strength concrete cast in the plywood mold in four layers and each layer vibrated from the outside of the mold for 45 seconds at four points in the entire length of the beam. Considered three cubes for compression test, three cylinders for split tensile test, three prisms for flexural test and six cubes for bond test for checking the quality of the mix and the vibrating table used for compacting these molds(11-14).

V. TESTING OF BEAMS

The Universal Testing Machine of 500 kN capacity, which had reference code 4482, with loading rate 2kN/min., in the School of Civil Engineering, Structural Laboratory, UniversitiSains Malaysia (USM) was used for testing of fibrous concrete beams under a pure torsional moment. The beam was placed on two saddle supports, and the load transferred through the load spreader beam.

The load was applied and increased manually until the fibrous concrete beams failed under pure torsional loading.

VI. RESULTS AND DISCUSSIONS

The brittleness index for fibrous normal strength concrete beams was measured and tabulated in Tables 3.

TABLE.3. Mechanical properties of fibrous concrete beams

The torsional resistance and twisting angles measured during the loading of the beams. Also, the stiffness of the un-cracked section at crack load calculated based on elastic theory, as shown in Table 4.

Beam denotation	fc’, MPa	fr, MPa	fsp, MPa	Brittleness index
B-1*-N	29.5	7.571	4.473	3.896
D-1-N	24.65	5.457	4.159	4.517
D-2-N	25.82	5.6	4.244	4.611
D-3-N	24.74	6.011	4.041	4.116

TABLE.4. Results of pure torsion test in fibrous normal strength concrete beams at crack load

Beam denotation	T_{cr}, kN.m	Φ_{cr}, rad/m, $\times 10^{-3}$	K_{un}, kN.m/rad.
B-1-N	12.14	0.619	19623
D-1-N	12.81	2.078	6166
D-2-N	13.03	1.047	12442
D-3-N	12.43	1.087	11440

Torsional Moment At Crack Loads

The value of the yield stress of transverse reinforcement in the stress-strain curve has a marginal influence of the cracking torsional resistance. The torsional strength in crack load was improved up to 5.13% due to an increase in yield stress of transverse reinforcement from 417 to 603 MPa. Meanwhile, the cylinder compressive strength has not seriously influenced the cracking torsional resistance.

Besides, the cracking torsional resistance of fibrous concrete beams varied with the brittleness index of concrete, as shown in Figure 4. According to this figure, the value of the brittleness index based on compressive strength and flexural strength of the fibrous normal strength concrete. The torsional resistance was sensitive to these values proportionally.

Thus, the brittleness index has a proportional influence on the cracking torsional resistance, as shown in Figure 5. From this figure, it can be seen that the cracking torsional resistance varied with compressive and flexural strengths of the fibrous concrete in the same beam.

Twisting Angle

The relation between twisting moment and angles is nonlinearly changed due to changing the resisting cross-section area of the beam before and after cracking. Besides, the stiffness of the sections before and after cracking affect their relationship, as shown in Figure 4.

According to the figure, the value of twisting angle reduced prior to cracking, as in beam B-1-N, due to the high compressive strength of the concrete. The twisting angle based on the compressive strength of fibrous concrete matrix which used in the beams, as shown in Tables 3 and 4.

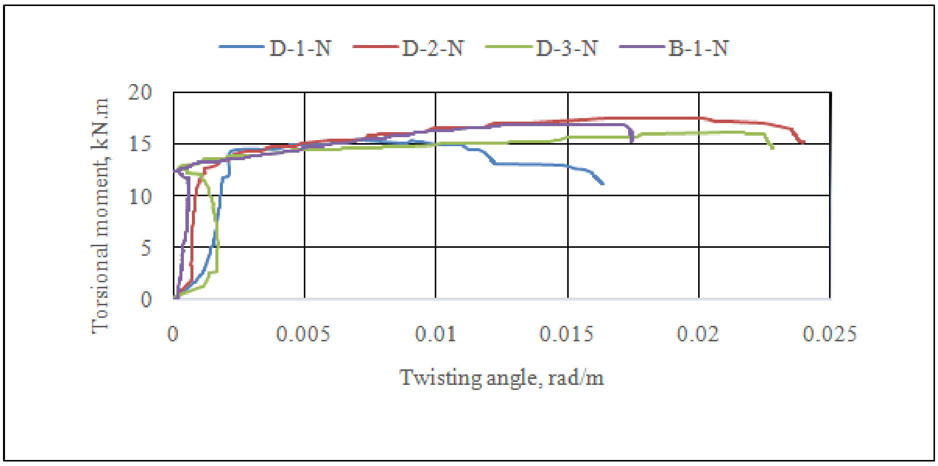

Fig.4.Torsional moment versus angle of twist

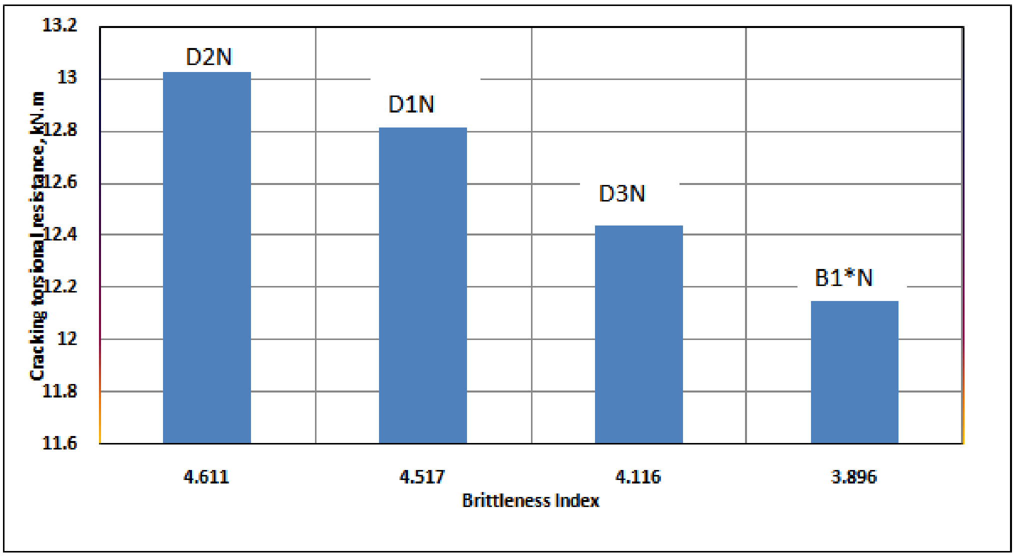

Fig.5.Cracking torsional resistance versus brittleness index

Cracking Patterns

The first crack will appear in the lower applied torsional moment on the long side of the cross-section of the beams if the brittleness index of fibrous concrete has a small value and vice-versa. While the angle of inclination of the first spiral cracks is merely affected by the amount of brittleness index. However, it depends on the transverse and longitudinal reinforcement ratios in the beams. Besides, the spacing between spiral cracks decreases as the number of cracks increases, as shown in Table 5. Moreover, the features of crack patterns for tested beams under pure torsional loading shown in Figures 6-9.

TABLE.5. Detail of the spiral crack of fibrous normal strength concrete beams tested under pure torsion

Beam denotation	BI	No. of spiral cracks	Θ, degrees	The minimum spacing between spiral cracks, mm
B-1*-N	3.896	6	45	125
D-1-N	4.517	6	48	100
D-2-N	4.611	7	47	90
D-3-N	4.116	9	52	50

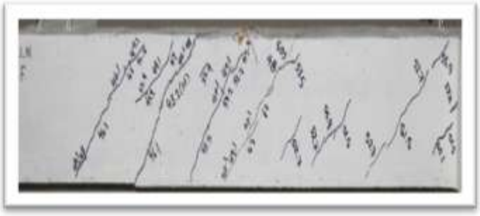

Fig.6. Side view of beam B1N at failureFig.7.Side view of beam D1N at failure

FIG.8.Side view of beam D2N at failureFig.9.Side view of beam D3N at failure

VII. THEORETICAL MODEL

The dimensional analysis (15) used as a tool to proposed equations to predict torsional resistance at crack load for under-reinforced fibrous normal strength concrete beams based on the data in this study and 33 data from previous researches(16-23). The Buchingham Pi technique used for evaluating the power of dimensionless parameters(24, 25).

The variables could be affected on the cracking torsional resistance are a brittleness index of fibrous concrete BI, area to perimeter ratio of the cross-section A_{cp}/P_{cp} and splitting tensile strength of fibrous concrete. The set of variables, including the dependent variable is the total number of variables inside of the set is n and equal to 4 (16-23). The primary dimensions listed in Table 6.

$$\{V\} = \left\{T_{cr}, BI, \frac{A_{cp}}{P_{cp}}, f_{sp}\right\}$$

Where,

BI: brittleness index of fibrous normal strength concrete, which could express as follows:

$$BI = \frac{f_{c'}}{f_r}$$

The number of primary dimensions is equal to 2 based on the FLT system, and the number of Π-dimensionless groups is equal to k=n-m=4-2=2. Consequently, the number of repeating variables is equal to two and selecting the common variable, which includes all possible primary dimension [M], [L], and [T]. Therefore, ${}^{A_{cp}}/_{P_{cp}}$, and

f_{sp} selected as a repeating variables.

The Π-dimensionless groups are

$$\Pi_1 = (T_{cr})\left({}^{A_{cp}}/_{P_{cp}}\right)^a (f_{sp})^b \quad (3)$$

$$\Pi_2 = BI \quad (4)$$

The dimensional form of Eq.(3) can be stated as

$$[M^0L^0T^0] = [M^1L^2T^{-2}][M^0L^1T^0]^a[M^1L^{-1}T^{-2}]^b$$

Then, equate the powers for primary dimensions

Equating exponents of mass M: $0 = (1).1 + (0).a + (1).b \Longrightarrow b = -1$

Equating exponents of length L: $0 = (2).1 + (1).a + (-1).b \Longrightarrow a = -3$

Equating exponents of time T: $0 = (-2).-1 + (a).0 + (-2).b = 0$ satisfy

Table.6.Primary dimensions in MLT and FLT systems for variables in {V}

Variable No.	Parameters	Primary dimensions in MLT system	Primary dimensions in FLT system
1	T_{cr}	$[M^1L^2T^{-2}]$	$[F^1\ L^1\ T^0]$
2	BI	$[M^0L^0T^0]$	$[F^0\ L^0\ T^0]$
3	A_{cp}/P_{cp}	$[M^0L^1T^0]$	$[F^0\ L^1\ T^0]$
4	f_{sp}	$[M^1L^{-1}T^{-2}]$	$[F^1\ L^{-2}\ T^0]$
	n=4	m=3	m=2

So the first Π-dimensionless group is

$$\Pi_1 = \frac{T_{cr}}{\left(\frac{A_{cp}}{P_{cp}}\right)^3 (f_{sp})}$$

The dimensional form for Eq.(4) can write as

$$[M^0L^0T^0] = [M^0L^0T^0]$$

Then, the second Π-dimensionless group is

$$\Pi_2 = BI$$

The final form of Π-dimensionless groups is

$$\Pi_1 = \beta_1 . \Pi_2^{\beta_2} \quad (5)$$

$$\frac{T_{cr}}{\left(\frac{A_{cp}}{P_{cp}}\right)^3 (f_{sp})} = \beta_1 . (BI)^{\beta_2} \quad (6)$$

Based on 19 data from previous researches and 4 data in this study of fibrous normal strength concrete beams, nonlinear multiple regression is used to predict the value of β_1 and β_2. The proposed equation (6) for predicting cracking torsional resistance in fibrous normal strength concrete beams becomes in the form (7) with a coefficient of determination 0.955 and a standard error 0.002.

$$T_{cr} = 11.15(BI)^{0.068} \left(\frac{A_{cp}}{P_{cp}}\right)^3 (f_{sp}) \quad (7)$$

VIII. CONCLUSIONS

Based on the test results of fibrous normal strength concrete beams under pure torsional loading and modeling the cracking torsional resistance including the effect of brittleness index, the following conclusions could be drawn:

1. It was found that the cracking torsional resistance improves up to 7.25% due to enhancement in brittleness index around 18.35%, while the dimensions of the cross-section of the concrete beams and volume fraction of steel fiber are still constants.
2. Twisting angle is inversely influenced by the stiffness of the un-cracked section.
3. It found that the proposed model from dimensional analysis for predicting torsional resistance at crack loads has a good agreement with the test results.

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REFERENCES

[1]. Harajli MH, Mabsout ME. Evaluation of Bond Strength of Steel Reinforcing Bars in Plain and Fiber-Reinforced Concrete. ACI Structural Journal. 2002:509-17.

[2]. Maekawa K, Pimanmas A, Okamura H. Nonlinear mechanics of concrete structures. London: E & FN Spon; 2002.

[3]. Belarbi A, Hsu TTC. Consistutive laws of concrete in tension and reinforcing bars stiffened by concrete. ACI Structural Journal. 1994:465-74.

[4]. Karim FK, Abu Bakar BH, Choong Kok Keong, Aziz OQ. Enhancement of torsional resistance in fibrous normal strength concrete beams. International Journal of Research in Engineering and Technology. 2016:123-32.

[5]. Karim FK, Abu Bakar BH, Choong Kok Keong, Aziz OQ, editors. Improvement of torsional resistance from bond strength and reinforcement indexes in fibrous normal strength concrete beams. Proceedings of the International Conference of Global Network for Innovative Technology and AWAM International Conference in Civil Engineering (IGNITE-AICCE'17); 2017; Penang, Malaysia: American Institute of Physics.

[6]. Lee JY, Kim SW. Torsional strength of RC beams considering tension stiffening effect. Journal of Structural Engineering, ASCE. 2010:1367-78.

[7]. Yagiz S. Assessment of brittleness using rock strength and density with punch penetration test. Journal of Tunnelling and Underground Space Technology. 2009;24:66-74.

[8]. Hucka V, Das B. Brittleness determination of rocks by different methods International Journal of Rock Mineral Sciences. 1974;11:389-92.

[9]. Mikaeil R, CGhadernejad S, Ataei M, Esmailvandi M, Daneshvar A. Investigating the relationship between various brittleness indexes with specific ampere draw in rock sawing process. International Journal of mining and Geo-Engineering. 2017;51(2):125-32.
[10]. Yap SP, Alengaram UJ, Jumaat MZ, Khaw KR. Torsional behaviour of steel fiber-reinforced oil palm shell concrete beams. Materials and Design. 2015;87:854-62.
[11]. ASTM C 496. Standard Test Method for Splitting Tensile Strength of Cylinderical Concrete Specimens. Annual Book of ASTM2004. p. 299-303.
[12]. British Standard BS EN. Testing hardened concrete-Part 3: Compressive strength of test specimens. BSI. 2002:15.
[13]. ASTM C1609. Standard Test Method for flexural Performance of Fiber-Reinforced Concrete (Using beam with third-point loading. Annual Book of ASTM. 4.012010. p. 846-54.
[14]. Indian Standard IS. Methods of Testing Bond in Reinforced Concrete: Part 1 Pull-out test. Bureau of Indian Standards2001. p. 10.
[15]. Bridgman PW. Dimensional Analysis: YALE UNIVERSITY PRESS; 2012.
[16]. Craig RJ, S D, Riaz J, Shirazi H. Torsional behavior of Reinforced fibrous Concrete beams. Special publication. 1984;81:17-50.
[17]. El-Niema EI. Fiber Reinforced Concrete Beams under Torsion. ACI Structural Journal. 1993;90:489-95.
[18]. Fuad O, Serkan E. Torsional behavior of steel fiber reinforced concrete beams. Construction and Building Materials. 2012;28:269-75.
[19]. Gunneswara Rao TD, Rama Seshu D. Analytical model for the torsional response of steel fiber reinforced concrete members under pure torsion. Cement and Concrete Composite. 2005;27:493-501.
[20]. Gunneswara Rao TD, Rama Seshu D. Torsional response of fibrous reinforced concrete members:effect of single type of reinforcement. Construction and Building Materials. 2006;20:187-92.
[21]. Nagataki S, Mansur MA, Lee SH, Oosumimoto Y. Torsional response of reinforced fibrous concrete beams. ACI Structural Journal. 1989;86:36-44.
[22]. Namiq ZF. Effect of steel fiber on the strength and behaviour of non-circular solid and hollow cross section beams under pure torsion. Erbil, Iraq: University of Salahaddin; 2012.
[23]. Narayanan R, Kareem-Palanjian AS. Torsion in Beams Reinforced with Bars and Fibers. Journal of Structural Engineering. 1986;112:53-65.
[24]. Apsley D. Dimensional Analysis2013.
[25]. Miragliotta G. The power of dimensional analysis in production system design. International Journal Production Economics. 2011;131:175-82.

Karim, F.R., et.al. “The influence of the brittleness index on fibrous normal strength concrete beams under pure torsion”. *American Journal of Engineering Research (AJER)*, vol. 9(01), 2020, pp 172-179.