International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 05 | May-2018 www.irjet.net p-ISSN: 2395-0072

MODELING SUGGESTION ON RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND TENSILE STRENGTH OF HIGH STRENGTH CONCRETE

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Abstract -*Most of the studies previously focused on studying the relationship between the compressive strength and tensile strength in the case of normal strength concrete, the high strength concrete it has not been fulfilled in the study of the relationship between the compressive strength and tensile strength, studies in this aspect is limited, In this study, a high-resistance concrete mixtures were produced from local materials and tested in the laboratory. We analyzed the results through a computer program to find the optimal mathematical formula for the relationship as a first step. as a second step, we created a general mathematical formula by combining the study results and the results of the previous studies to reach a more comprehensive mathematical formula, Study summarized the results in the presence of a significant relationship between the compressive strength and tensile strength of the high strength concrete, we found that relationship between compressive and split tensile strength is more strong than the relationship between compressive and flexural tensile strength, We also noted in this study that the smaller coarse aggregate significantly affects the tensile strength of high strength concrete.*

Key Words: high strength concrete, compressive strength, split tensile strength, flexural tensile strength, coarse aggregate.

1. INTRODUCTION

At present, high strength concrete is a necessary material in the implementation of large projects and high buildings such as bridges and towers, in general, high strength concrete means a large numerical value for resistance to compression, most important properties of concrete are strongly correlated with this numerical value [1]. The high strength concrete is a concrete that has a great pressure resistance exceeding a certain limit. The value of this limit increased with the development of the concrete works. In 1950, it was known as the compressive strength concrete (fc) greater than 34MPa, currently the minimum limit ranges from (fc = 40 mpa) to (fc =50 mpa) according to most specifications [2]. For the production of high strength concrete we need to choose the proper materials for mixing, reduce water-cement ratio by using supper-plasticizer and use of cement replacement materials such as fly ash[3].Compressive Strength is important property of concrete, which is the main indicator of many properties of concrete. It is known as the maximum stress that concrete can withstand before the collapse begins. Compressive strength is not an independent property but is affected by other properties, including concrete mix components, mixing proportions, compaction degree, treatment conditions, age and loading rate. The tensile strength of concrete has an effect on the properties of concrete, as it is a major factor in the resistance of cracking thus has a major role in the durability of concrete. It is measured by the tensile stress of the concrete at the beginning of the collapse, in the normal strength concrete the tensile strength is low (10 %) of the compressive strength. in the case of high strength concrete, tensile strength is higher than in normal strength concrete. there are three methods to calculate the resistance of concrete to tensile, the direct tension method is difficult to apply and there are no standard specifications for this type, splitting tensile strength method according to standard specifications (ASTM C 496) and Flexural tensile strength method or modulus of rupture method according to standard specification (ASTM C 78) [1].In ACI Materials Journal, 1989, Chern and others said that the concrete with compressive strength(41.1MPA , at 28 days) as a minimum is a high strength concrete[4].In 1992, the concrete with compressive strength (50MPA, at 28 days) as a minimum was considered a high strength concrete, [5].In 2002, the American Concrete Institute (ACI) determined the minimum compressive strength is (41MPA) for high strength concrete,[2].

2. LITERATURE REVIEW

The studies reviewed are as follows: In 1958, the American Concrete Institute (ACI) concluded that the general formula for the relationship between compressive strength f_c and tensile strength f_t of high strength concrete is the square root formula and is represented by: $f_t=0.63\sqrt{f_c}$, $(21\leq f_c \leq 84)$ MPA[6]. In 1964, Dore, determined that tensile strength is equal to 10% of compressive strength of normal strength concrete (NSC) and approximately 8% of the compressive strength of high strength concrete (HSC) [1].A 1989 study by(ACI Building code 318-89) to find the relationship between compressive strength (13.79- 61.38MPa) and tensile strength was as follows: $f_t= 0.556 \sqrt[2]{f_c}$, [7]. in1991. a study by (Oluokun) to find the relationship between compressive strength up (62.07MPa) and tensile strength were:$f_t = 0.206\, f_c^{0.79}$,[7].In 1997, Zia et al, found that there are no specifications for which direct tensile strength can be calculated on concrete. Therefore, we measure the tensile strength by indirect test with the determination of the tensile strength of the spilt and bending, [1].In 2001, Edward said that the smaller the size of the aggregates used, the higher tensile strength of the concrete can be up to twice the expected strength, [6]. In 2005, Bhinga and others conducted a laboratory study on the tensile strength of HSC using Sica Fume, the power formula, which combines compressive strength (51 to 82 MPa) with tensile strength, is:$f_t = K\, f_c^{\,n}$,where N, K coefficients based on the concrete mixture ,he found that $f_t = 0.25\, f_c^{.0.72}$&$f_f = 0.28 f_c^{.0.8}$,where f_f flexural tensile strength, [8].In 2007. ACI 363R-92 found that the split tensile strength of high tensile strength concrete is about 70% of the flexural tensile strength the age of 28 days, [1]. In 2008. Sekhar and Rao conducted a laboratory study on self-compacting concrete (SSC) and found that the relationship between compressive strength (34- 82 MPa) with tensile strength represented in relation to:$f_t = 0.08\, f_c^{1.04}$&$f_f=0.12 f_c^{.0.8}$, [7].In 2008. Slim Paul conducted a laboratory study on the tensile strength behavior of HSC, direct tensile testing was performed despite difficulty and no criteria for calculation, he reached the following:: flexural tensile strength of HSC is approximately1/8 of compressive strength, split tensile strength of HSC is approximately1/12 of compressive strength and direct tensile strength of HSC is approximately1/15 of compressive strength, The properties of tensile strength of HSC were not widely studied except for limited studies,[9]. In 2010 Al-Azzawi found that HSC with fibers has a higher tensile strength than HSC concrete without fibers as in the following relationship:$f_t= 0.47\sqrt[2]{f_c}+4.2F$&$f_f= 0.93\sqrt[2]{f_c}+4.5F$, where F fiber factor, [10]. In 2014, A. Mohd said that the power model are more accurate than the square root model in the relationship between the compressive strength and tensile strength of the concrete [11].

3. EXPERIMENTAL STUDY

It included technical tests on concrete mixing components, concrete mix design, production of concrete mixtures and fresh &hard concrete tests.

3.1 Mixing materials

The graded coarse aggregate of(5-20mm) size was used for all concrete mixtures except mix M`45used in rough aggregates of 10 mm size, and sand was used as fine aggregate for all mixes, these aggregates have been tested according to(BS882:1973-1965). The cement used is ordinary Portland cement according to(BS12:1996),drinking water used in mixing, and we used the super-plasticizer(Sikament-163) as high range water reduction material (HRWR).It conforms to British and American specifications: ASTM C 494 type F & B.S.5075 part 3 for super plasticizer, table (1) shows the physical and mechanical properties of aggregates

Table (1) the physical and mechanical properties of aggregates

The properties according to :BS882:1973-1965	Fine aggregate	Coarse aggregate
Maximum aggregate size	4mm	20mm
Percentage of clay and fine materials	1.04%	0.5%
Specific gravity	2.67	2.6
Absorption ratio	1.9%	1.54%
Humidity ratio	1.12%	0.15%
abrasion factor Los Angeles ratio	-	21.7%
Impact factor	-	18.6%

3.2 Concrete mixtures

Concrete mixtures are designed based on the British design method to determine the mixing proportions of components for the required compressive strength, these mixtures were produced and others with lower water-cement ratio and workability compensation by adding super-plasticizer, table (2) shows the components and mix ratios of the concrete.

Table (2) the components and mix ratios of the concrete.

Target f_c MPA	Mix No.	w/c *	Cement kg/m³	Fine agg. kg/m³	Coarse agg. kg/m³	s/c * %	notes	Slump mm
M45	A1	0.51	412	650	1060	0		Values between 30 mm to 60 mm Medium workability
	A2	0.5				0.7		
	A3	0.48				1.1		
	A4	0.46				1.5		
M´45	B1	0.51	412	650	1060	0	Coarse aggregate size10 mm In this case only	
	B2	0.5				0.5		
	B3	0.48				.8		
	B4	0.46				1.2		

M50	C1	0.48	438	625	1065	0		
	C2	0.44				1		
	C3	0.4				1.9		
	C4	0.36				2.5		
M55	D1	0.46	457	600	1070	0		
	D2	0.45				0.5		
	D3	0.41				1.4		
	D4	0.37				2.4		
M60	E1	0.4	525	560	1040	0		
	E2	0.35				1.2		
	E3	0.33				2.1		
	E4	0.3				2.4		
	E5	0.28				3.1		
	E6	0.27				3.9		
M65	F1	0.37	534	430	1255	0		Values between 10 mm to 30 mm low workability
	F2	0.35				2		
	F3	0.34				2.6		
M68	G1	0.35	540	420	1240	0		
	G2	0.32				1.9		
	G3	0.3				2.8		

* W/c: water /cement ratio, s/c: super-plasticizer /cement ratio

3.3 Concrete Strength Tests

The tests were performed at 28 days on the cubes by pressing machine at the rate of loading (15 MPa) per minute. The indirect tensile test was performed on the cylinders and the bending tensile test was tested on the beams for each mixture, that (28) mixes were tested. And table (3) show the results of the concrete strength tests.

Table (3) the tests results of the compressive strength, split tensile strength and flexural tensile strength of (28 mixes) of HSC.

Mix No.	Compressive strength f_c (MPA)	Split tensile strength f_t (MPA)	Flexural tensile strength f_f (MPA)
A1	42.71	2.76	4.11
A2	43.50	2.79	3.90
A3	45.91	2.91	4.15
A4	48.33	3.08	4.35
B1	46.70	3.11	4.33
B2	48.4	3.25	4.41
B3	51.4	3.56	4.70
B4	52.3	3.68	4.88
C1	47.67	2.97	4.21
C2	50.88	3.22	4.64
C3	51.50	3.41	4.72
C4	54.70	3.78	5.10
D1	56.58	3.80	5.13
D2	57.80	4.01	5.24
D3	60.51	4.23	5.86
D4	61.30	4.41	5.97
E1	62.60	4.8	6.90
E2	63.80	4.65	7.12
E3	65.50	4.73	7.64
E4	67.20	4.96	8.31
E5	69.30	5.10	8.55
E6	60.10	4.15	5.80
F1	66.40	4.8	7.92
F2	67.70	4.93	8.11
F3	70.40	5.17	8.78
G1	69.40	5.10	8.61
G2	72.10	5.44	8.80
G3	75.50	5.55	9.01

4. ANALYSIS& DISCUSSIONS

The results of the experimental study were analyzed in terms of the effect of the coarse aggregates size on the tensile strength and compressive strength of HSC, and suggesting a mathematical model of the relationship between compressive strength and tensile strength (split & bending), Then analyze the combined data which is contained from (results of previous published research and the results of our experimental study) to reach a more comprehensive relationship.

4.1 Experimental Study Results

From table (2) M45& M´45 mixes having same material properties except the coarse aggregate size The maximum aggregate size of M45 mix was (20)mm, and the maximum aggregate size of M´45 mix was (10) mm, from table (3) we compared between(M45&M´45) results to find the effect of coarse aggregate size on HSC strength, table 4 shows the comparison of the results and the calculation of the increase rate in the concrete strength, for example the mixes A1&B1, the rate of compressive strength increase $=\frac{B-A}{A} * 100 = \frac{46.7-42.71}{42.71} * 100$ = %9.3.

Table (4) the comparison of the results and the calculation of the increase rate in the concrete strength

f_c (MPA)		f_t (MPA)		f_t (MPA)		Rate of Increase %		
A 1,2,3,4	B 1,2,3,4	A 1,2,3,4	B 1,2,3,4	A 1,2,3,4	B 1,2,3,4	f_c	f_t	f_f
42.71	46.70	2.76	3.11	4.11	4.33	9.3	12.7	5.4
43.50	48.4	2.79	3.25	3.90	4.41	11.3	16.5	13.1
45.91	51.4	2.91	3.56	4.15	4.70	11.9	12	13.3
48.33	52.3	3.08	3.68	4.35	4.88	8.2	19.5	12.2
The Average rate of increase of strength						10	15	11

From Table (4) we can say that for the same concrete mixes using coarse aggregate maximum size (10mm) instead of coarse aggregate maximum size (20mm) increases compressive strength by 15% and tensile strength by 10%. By using the results data from table (3) and Microsoft Excel program we have fitted the curves of results with tree modeling, the best (3) models were selected, the best relationship model that has a statistic factor (R^2) closer to one. Figure (1) & (2) show the relationship between compressive strength and tensile strength (split) & (flexural) in study result

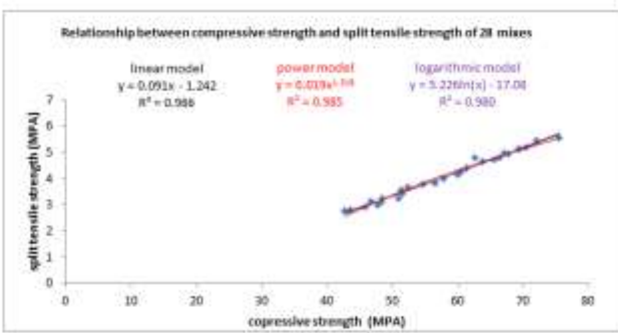

Figure (1) the relationship between compressive strength and split tensile strength of 28 mixes.

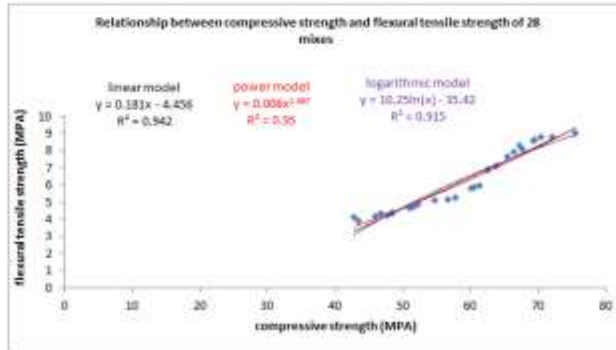

Figure (2) the relationship between compressive strength and flexural tensile strength of 28 mixes

From Figure 1, 2 the best modeling of relationship as follow: Linear model for f_c&f_t , power model for f_c&f_f . To find the best modeling or relationship between compressive strength f_c and both tensile strength (f_t&f_f), we need to determine the best (R^2) of them as shows in table (5).

Table (5) Statistical factor (R^2) for different models of (28 mixes)

	Linear model	Logarithmic model	Power model
f_c&f_t	0.986	0.98	0.985
f_c&f_f	0.942	0.915	0.95
Average	0.964	0.948	0.968

From table (4) we note that the proper model of relationship between compressive strength and tensile strength is the (power model) as follow:
$f_t = 0.019 \times f_c^{1.318}$, $f_f = 0.006 \times f_c^{1.687}$, where42MPA $\leq f_c \leq$ 76 MPA

4.2 Combined Results

Several results were collected on high strength concrete from published research, combined with the results of our experimental study, and then we found mathematical models to reach a more general relationship, as shown in Appendix (A).

Finding the mathematical model of the relationship between the compressive and tensile strength of the combined results (91mixes),which is the total of the experimental results (28 mixes) and results obtained from previous published studies(63 mixes) .It was as in Figs. (3) and (4).

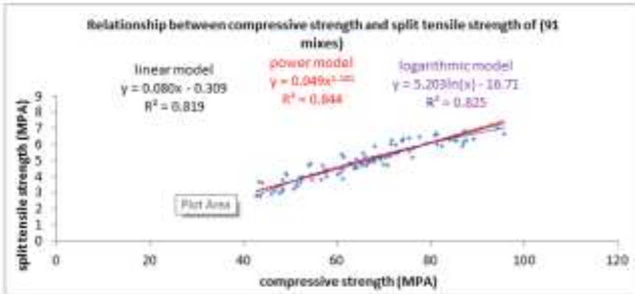

Figure (3) the relationship between compressive strength and split tensile strength of (91) mixes

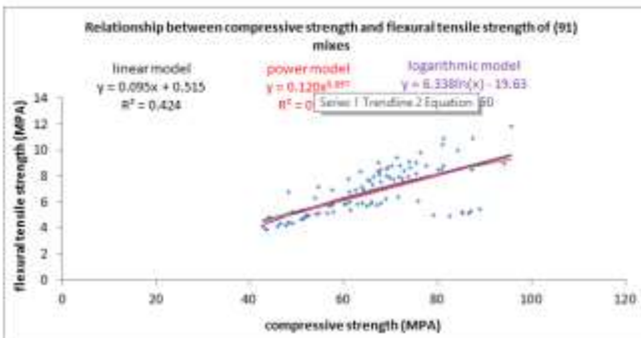

Figure (4) the relationship between compressive strength and flexural tensile strength of (91) mixes

As we shown in figure (3), (4) the models of combined results(91mixes) was as follows : the model of relationship between f_c&f_f is power model $f_t = 0.049 \times f_c^{1.101}$, $R^2 = 0.844$, and the model of relationship between f_c&f_f is power model $f_f = 0.120 \times f_c^{0.957}$, $R^2 = 0.47$ this correlation is not enough accurate , this confirms that there are other factors affecting on the relationship between f_c&f_f, such as type and size of aggregate and concrete admixtures.

By comparing the curves of relationships as in Figures 1, 2, 3 and 4, in terms of the statistical factor (R^2) and the distribution of data in the curves, we note that: The relationship between f_c&f_t is stronger than the relationship between f_c&f_f of the results of the experimental results (28mixes), but for combined results (91 mixes) the relationship between f_c&f_t is much stronger than the relationship between f_c&f_f

5. CONCLUSIONS

Through the study and analysis of the results we reached the following:

- HSC with a 10 mm coarse aggregate increases the compressive strength by 15% and tensile strength by10% compared to HSC with a 20 mm course aggregate.

- The general mathematical model suitable for the correlation between compressive strength, tensile strength of HSC is the power model , f_t or f_f= a $f_c^{\,b}$, where a, b are constant, f_c is compressive strength, f_t is split tensile strength and f_f is flexural tensile strength.

- Mathematical models of the relationship between compressive strength and tensile strength for the experimental study of 28 mixes were as follows:

$f_t = 0.019 \times f_c^{1.318}$, $f_f = 0.006 \times f_c^{1.687}$ where: $42MPA \le f_c \le 76$ MPA.

- Mathematical models of the relationship between compressive strength and tensile strength for combined results (91mixes) were as follows:

$f_t = 0.049 \times f_c^{1.101}$, $f_f = 0.120 \times f_c^{0.957}$, where: $42MPA \le f_c \le 96$ MPA.

- The compressive strength - split tensile strength correlation is better than the compressive strength - flexural tensile strength correlation of high-strength concrete.

- The relationship between compressive strength and flexural tensile strength of experimental (28) mixes Is good but it is not accurate of combined results (91mixes).

- The use of different concrete mixtures in the combined results (91mixes) has weakened the relationship between compressive strength and split tensile strength and is much weaker in the relationship between compressive strength and compressive strength due to the significant difference in the properties of mixing materials and additives for concrete.

6. RECOMMENDATION

We recommend further research on the relationship between compressive strength and tensile strength using more data and other concrete types such as ultra-high strength concrete, as well as studies on the factors that influence the relationship between compressive strength and compressive strength to obtain more accurate models.

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APPENDIXES

● **Appendix (A):**

Table (6) the collected results of high strength concrete from published research

Data Source (Reference)	Compressive strength f_c (MPA)	Split tensile strength f_t (MPA)	Flexural tensile strength f_f (MPA)
[7]	43.44	3.68	3.9
	49.24	4.12	4.36
	54.22	4.81	5.02
	61.48	5.18	5.37
	65.7	5.48	5.87
	71.5	6.04	6.38
[8]	48.3	3.82	6.8
	57.5	4.46	6.93
	63.7	4.53	8.32
	54.5	4.10	7.17
	67.6	5.21	9
	71.4	5.26	9.4
	76.3	5.75	9.8
	81.3	6.01	10.87
	84.2	6.27	10
	87.6	6.25	10.93
	95.7	6.65	11.87
[9]	44	3.6	4.8
	49	4.2	5.2
	54	4.7	6.3

	61	5.4	7.8
	68	5.9	8.5
	74	6.2	9.1
	81	6.6	10.4
[12]	52	3.95	5
	52.55	3.98	5
	57.5	4.25	5.75
	63	4.8	5.8
	68	4.95	5.9
	56.85	4.7	5.68
	64	5.1	5.9

Table (6) the collected results of high strength concrete from published research (continued)

Data Source (Reference)	Compressive strength f_c (MPA)	Split tensile strength f_t (MPA)	Flexural tensile strength f_f (MPA)
[12]	66	5.2	5.96
	76	5.2	6.1
	69	5.25	6.25
	65	4.95	5.7
	67	4.98	5.75
[13]	61.33	3.89	6.8
	64.24	4.58	6.92
	66.22	4.72	7.29
	68.02	5.14	7.52
	69.32	5.28	8
	72.96	5.42	8.43
[14]	79.2	6.06	4.96
	85.4	6.3	5.17
	89.1	6.33	5.43
	86.7	5.9	5.12
	87	6.13	5.26
	85.2	6.2	5.24
	82.5	5.89	4.89
[15]	69.91	4.75	7.84
	77.63	6.47	8.77
	65.20	4.76	7.68
	72.51	5.98	7.75
	80.92	6.57	8.45
	87.24	6.82	8.46
	74.14	6.35	8.62
	75.42	6.37	8.19
	71.73	6.25	7.94
	80.14	8.53	8.5
	70.81	4.72	7.69
	73.84	6.3	7.9
	81.32	6.62	8.83
	94.14	7.02	8.92
Total number of collected mixes are 63			