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Prediction of Shear capacity and compressive strength for Recycled reinforced high strength concrete beams without stirrups

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Abstract: *This research raises the importance of using the recycled aggregates in constructions as an alternative solution to the conventional natural aggregates. Fourteen specimens were cast and tested, using two types of natural and recycled aggregates, four steel fibers-volume fractions (0,1,1.5, and 2%), three shear span-depth ratios a/d (2.5,3, and 3.5), and three silica fume percentage (SF) (10,15, and 20%). The necessity to enrich the literature with up-to-date sources has led to yield new equations to estimate RAC's compressive strength and the shear strength that is related to the beams which are made with the RCA. The statistical data system data Fit 9 (FT9) was used for this purpose with the help of the test results obtained from the current research and previous studies. After that, the applicability of the developed equations was evaluated against different international codified equations. Based on observed data from the present experimental tests and other investigations, non-linear regression models are proposed for predicting the compressive strength. The values of the Average (μ), Standard deviation (SD) and Coefficient of variation (COV) are 0.995, 0.128 and 12.89% respectively. Another formula for calculating shear capacity was proposed and added to the deferent codes. The formula added to the ACI Code gave more accurate results. The average, Standard deviation, and Coefficient of variation were 0.504, 0.197, and 39.1%, respectively*.

Keywords: *Shear capacity, Recycle Aggregate, High Strength Concrete, Steel Fiber*

I. Introduction

As the life span of an enormous number of concrete structures from the 20th century comes to an end, the scale of demolishing is expected to be relentless. This process will cause the areas of landfills to increase where the air and groundwater pollutions will be a challenge. Needless to say, that the economic perspective will be adversely affected by high expenses on the removal of concrete from the demolition sites to the landfill zones, and complex process to bury the concrete wastes. It is reported that the amount of demolition waste across the European Union is about 1 ton per capita with 450 million tons of concrete production per annum (**Matias et al. 2014**). However, the amount of demolition waste is believed to be much larger in some parts of the globe such as but not limited to the Middle East where destructive conflicts take place. One of the active missions to deal with the demolition wastes and protect the environment is to use the concrete wastes as recycled concrete aggregate in construction (see **Figure 1**). To date, the primary application related to the recycled concrete aggregates (RCAs) is limited to the secondary level activities such as road base and land filling materials (**Rao et al. 2007**). Research is still being undertaken to examine the durability and mechanical properties of RCA. It is found that the microstructure of RCA is more complicated than the one in conventional concrete. This is because the RCA involves two types that are related to the interfacial transition zone (ITZ), one of them is between new mortar and RCA, while the other between old adhered mortar and RCA (**Xiao et al. 2012**).

Fig. (1) Using of recycled aggregate

To date, the primary application related to the recycled concrete aggregates (RCAs) is limited to the secondary level activities such as road base and landfilling materials (**Rao et al. 2007**). Research is still being undertaken to examine the durability and mechanical properties of RCA. It is found that the microstructure of RCA is more complicated than the one in conventional concrete. This is because the RCA involves two types that are related to interfacial transition zone (ITZ), one of them is between new mortar and RCA, while the other between old adhered mortar and RCA (**Xiao et al. 2012**).

❖ **Benefits of Recycled Construction Materials**

1. It is used in pre-cast buildings in addition to casting in the Krebs and situation gutters.
2. Economic costs: Lower costs for recycled aggregates can offset the higher costs of cement.
3. 20% of cement has been exchanged by fly ash for controlling alkali-silica reaction (ASR).
4. Environmental protection: There has not been any exploration related to natural resources, and the need for transportation and space was minimal.

❖ **Drawbacks of Recycled Construction Materials**

1. Lower quality (for instance, the compressive strength decreases for about 10-30%).
2. Land, distinctive equipment has been needed (more costs).
3. Elevated-water absorption (up to 6.0%).
4. High drying, creep and shrinkage. **(Tushar, 2006)**.

II. Variables and Specimen Dimensions

The tests program involved Fourteen simply supported beams. All beams were made of 1300 mm in length and the same rectangular cross-section (100 × 150 mm) as can be seen in **Fig 2**. The parametric study is summarized as follows:

- ❖ Type of Aggregate (normal and recycle, recycle with two approaches (treated and untreated))
- ❖ Volume fractions of steel fibers
- ❖ Percentage of silica-fume (SF)
- ❖ Shear span-depth ratio(a/d)

All beams were simply supported and subjected to two-point loads (**Fig.2**)

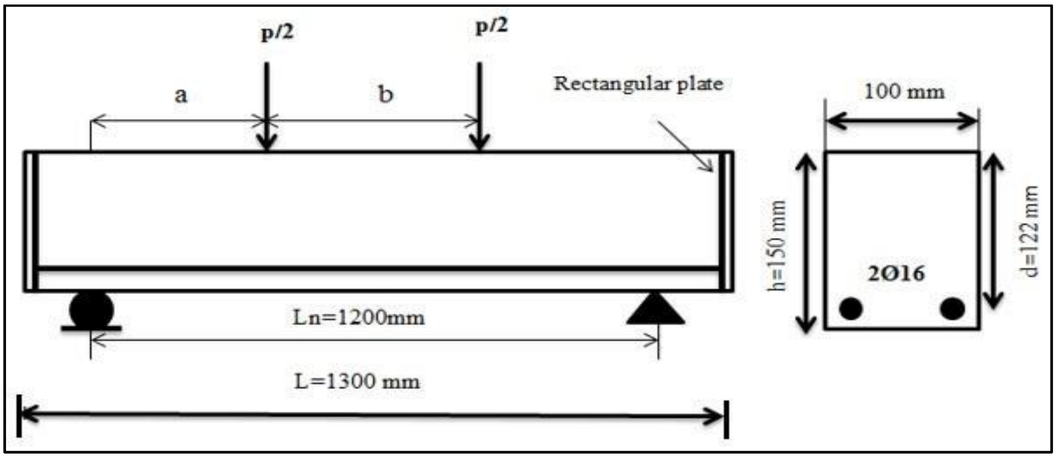

Fig. (2) Details related to commonly tested beam developed for fail in the shear

Table (1). Details of test program and parameters

Beam No.	Steel fibers	SP*	Silica fume	a\d	Steel reinforcement	Aggregate type
B1	2%	6%	20%	2.5	2Ø16	100% NCA
B2	2%	6%	20%	2.5	2Ø16	50%NCA+ 50%RCA (untreated)
B3	2%	6%	20%	2.5	2Ø16	100% RCA untreated
B4	2%	6%	20%	2.5	2Ø16	50% NCA+ 50% RCA treated
B5	2%	6%	20%	2.5	2Ø16	100% RCA treated
B8	1%	6%	20%	2.5	2Ø16	100% RCA treated
B9	1.5%	6%	20%	2.5	2Ø16	100% RCA treated
B10	2%	6%	10%	2.5	2Ø16	100% RCA treated
B11	2%	6%	15%	2.5	2Ø16	100% RCA treated
B12	2%	6%	20%	2.5	2Ø16+2Ø10	100% RCA treated
B13	2%	6%	20%	2.5	2Ø16+2Ø12	100% RCA treated
B14	2%	6%	20%	3	2Ø16	100% RCA treated
B15	2%	6%	20%	3.5	2Ø16	100% RCA treated
B16	0%	6%	20%	2.5	2Ø16	100% RCA treated

* Superplasticizer was taken as a percentage of binder (cement +silica fume) weight

III. Experimental work

3.1 Materials

Ordinary Portland cement (Type-1) produced by the United Cement Company (UCC), Bazian, Iraq, was used for the mixed concrete design. The cement was checked according to the Iraqi standard **IQ.S. No5/1984.** The fineness modulus (FM) of sand was 2.6, whilst the specific gravity of gravel was 2.62. The gradient tests for the utilized sand and gravel were according to Iraqi standards **IQ. S** (**No45:1984)**. The concrete mixture was advanced with the addition of silica fume and superplasticizer (Glenium-51) to achieve better performance and durability. Silica fume was added to all mixes as much as 20% from the volume of cement. For those mixes with steel fibers, hooked-ends mild carbon steel fibers with an aspect ratio ($L_f \backslash D_f$) of 80 were used for this purpose. All materials were mixed step by step with the help of tap water. With respect to the concrete mixtures involving recycled aggregates, old cubes and cylinders were used as recycled coarse aggregates after being crushed to small pieces. The source of those old specimens involved the structural lab at the engineering collage besides a local structural company for bridge girders. It should be mentioned that all old specimens used as a source for recycled aggregates had compressive strengths recorded between 25-35 MPa. The old specimens were initially placed in a crusher machine and turned into relatively chunk pieces by means of sharp blows. Furthermore, the chuck pieces were manually bashed into small particles with a big hammer. Finally, the small particles were sieved to obtained particular range of sizes (i.e. 4.75-14 mm) as shown in fig. (4).

Fig. (3) RCA after crushing and sieving

3.2. Recycled coarse aggregate treatment

It is well known that the result of recycled coarse aggregates is associated with a significant amount of impurities and slurry. This drawback would cause high water absorption and less bond between new mortar and recycled coarse aggregate. Eventually, the performance of the new generated concrete would be less satisfying in terms of many prospects such as compressive strength. To eliminate this adverse effect and enhance the RCA's quality, special chemical treatment was implemented in this research and split into two main stages.

The first stage (see **Fig. 4**) involved soaking the recycled coarse aggregates in a plastic container with a hydrochloric acid (HCl). The optimum concentration of the acid used was 0.5 mol as suggested by **Ismail and Ramli (2013)**. This process has been previously found to be capable of removing and cleaning any impurities and slurry attached to the RCA's surfaces (**Ismail and Ramli 2013, Tam et al. 2007**). The soaking step had lasted 24 hours before the RCA was rinsed and washed then left to dry. After the dehydration, the aggregates were filtered from any unfavored small pieces using sieve No.4 in order to maintain a desirable size of aggregates

Fig. (4) RCA Treatment with Acid

The second stage of treatment was accomplished by immersing the aggregates in a distilled water using a plastic container with 0.5 mol concentration of sodium meta-silicate pentahydrate (**see Fig. 5**). Using such acid was proved to coat the RCA's surfaces and fill the cracks and pores, which in turn, would lead to better bond strength between the aggregates and the new cement mortar. After one hour of coating, the aggregates were rinsed and left to dry so as to be used later to produce a recycled concrete. This essential process was successfully conducted by various studies (**Cheng and Wang 2005, Spaeth and Tegguer 2013)**.

Fig. (5) Coating the RCA in sodium metasilicate pentahydrate

IV. Result of tested specimens

4.1 Compressive strength results

The importance of the compressive resistance stems from the fact that it represents the concrete characteristics in the structural design. The relevant test was conducted from the mean value of 3 cubes (100*100*100 mm) and cast for every one of the concrete mixes and tested at same beam specimens' age as seen in **Table 2**.

Table 2. Compressive strength of hardened concrete

Beam No.	Type of aggregate	Compressive strength f_{cu} (MPa)
1	100% Normal	64
2	50% normal + 50% RCA untreated	58
3	100% RCA untreated	52
4	50% normal + 50% RCA treated	62
5	100% RCA treated	57
8	100% treated	56
9	100% treated	55
10	100% treated	51.3
11	100% treated	54.5
12	100% treated	57
13	100% treated	57
14	100% treated	57

15	100% treated	57
16	100% treated	55

4.2 Shear capacity results

Shear resistance results for the beams examined were recorded in Table 3.

Table 3. Test result of beams

Beam No	First crack load P_{cr} kN	Ultimate load P_u kN	Deflection mm	Max Crack width mm	Mode of failure
1	34	105	7.84	0.05	Diagonal tension failure
2	27	94	6.2	0.25	Diagonal tension failure
3	20	76	5.77	0.35	Diagonal tension failure
4	32	103	7.5	0.15	Diagonal tension failure
5	30.5	95.5	6.93	0.2	Diagonal tension failure
8	21	79	4.88	0.6	Diagonal tension failure
9	25	88	5.75	0.5	Diagonal tension failure
10	27.5	83	4.84	0.4	Diagonal tension failure
11	29	86	5.22	0.35	Diagonal tension failure
12	32	108	6.13	0.15	Diagonal tension failure
13	33	117.5	4.78	0.1	Diagonal tension failure
14	19	75	6.54	0.3	Diagonal tension failure
15	17.5	73.5	6.73	0.35	Diagonal tension failure
16	14	61	4	1.2	Diagonal tension failure

*DT: Diagonal tension failure

V. Analytical study

The compressive strength (f'_{cf}) is estimated in this research using data from the current study and previous studies. Also, an equation was created for the estimation of shear capacity that is related to the recycled high-strength reinforced concrete beams. The accuracy- related to the suggested equation is checked through put it to comparison with different codes.

5.1 Proposed Equation for the prediction the compressive strength of recycled high strength reinforced concrete

The regression equation was constructed based on (50) points from the experimental data obtained from the current research and previous research presented in Appendix A, with the use of the trial V9 related to data Fit software of Oakdale Engineering. The compressive strength of the data used ranges from (50-77) MPa. The proposed equation for estimating the compressive strength of recycled (RHSC) is given by Eqs (1) as follow:

$$f'cf = 0.95 * f'c + 6.93 * F^{1.2} \qquad \text{...... 1}$$

where:

$f'cf$ = Compressive Strength of fibrous RHSC, MPa
$f'c$ = Compressive strength of RHSC, MPa
F = Fiber factor given by $F = \left(\frac{L_F}{D_F}\right) V_F\, B_F$

This equation is plotted in a three-dimensional form in Fig. (6). To examine this equation, the relative compressive strengths ($f_{cf\ test}$ / $f_{cf\ proposed}$) were found using (50) experimental data from this research and others listed in Appendix. The values of Coefficient of variation (COV), Average (μ), as well as the Standard deviation (SD) have been 12.89, 0.995 and 0.128% respectively.

Fig. (7) shows test values versus proposed values of $f'cf$ for (50) experimental data using Eq. (1).

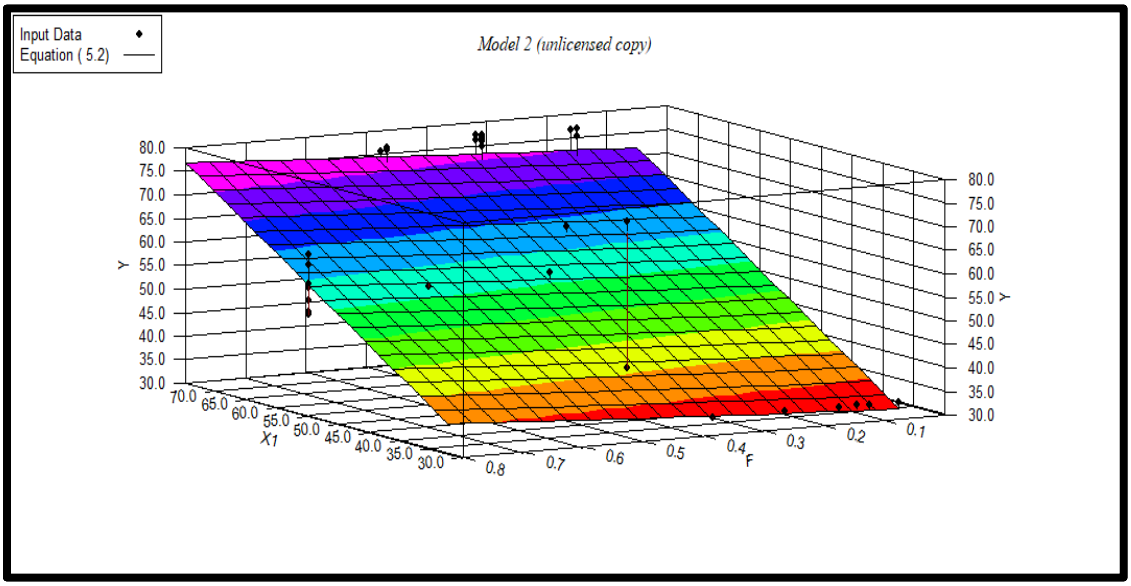

Fig. (6). Plot of the Suggested Regression Model for Compressive Strength of RHSC

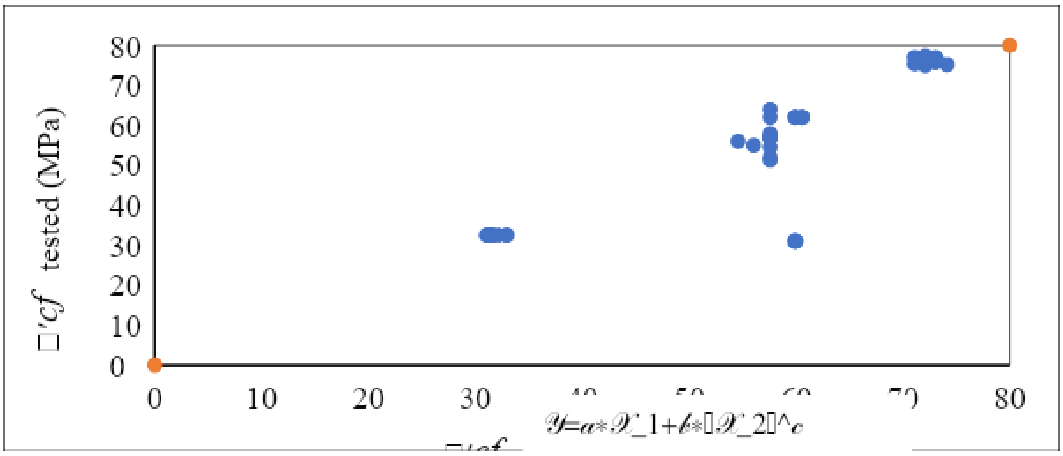

Fig. (7) Tests Values Versus Proposed Values of Compressive Strength of RHSC using Eq. 1

5.2 Proposed Equation for The Prediction of Shear Capacity of RHSC beams

In the present work, it considered proposing expressions for shear capacity of RHSC beams depend on the well-known Codes provisions for shear capacity by adding the effect of steel fibers to the proposed expressions.

Based on the data obtained from the current research and previous research in which fibers are used as shear reinforcement, where the ultimate load that fibers bear is extracted by subtracting the total ultimate load of the models with the fiber content from the models that do not contain fibers.

The proposed equation for estimating shear capacity with regard to RHSC fiber reinforced beams with no stirrup is in the **table (4).** It is clear from the table that the first equation [Eqs 3] has a lower error and a higher correlation rate than the rest.

$$V_{Fi} = \mathbf{0.2{+}0.03} * {F_{cF}}^{2.28} * \rho * \left(\frac{a}{d}\right)^{-2.14} * F^{8.26} \quad \textbf{MPa} \qquad \text{......2}$$

Where:

$\frac{a}{d}$ Representing the shear span to effective depth ratio

ρ Representing the longitudinal reinforcement ratio

Table 4. Proposed equations for estimating shear capacity

No.	Proposed equation of V_{Fi}	$V_{Fi\ test}$ / $V_{Fi\ proposed}$		
		µ	SD	COV (%)
1	$V_{Fi} = 0.2{+}0.03 * {F_{cF}}^{2.28} * \rho\left(\frac{a}{d}\right)^{-2.14} * F^{8.26}$	0.9801	0.099	10.1
2	$V_{Fi} = e^{(0.024 * F_{cF} + 31.93 * \rho + (-0.565) * \frac{a}{d} - 0.126 * F - 0.659)}$	0.991	0.481	48.54
3	$V_{Fi} = 1.86 * F_{cF} + 36.8 * \rho - 0.44 * \left(\frac{a}{d}\right) - 0.392 * F + 0.431$	0.989	0.536	54.2
4	$V_{Fi} = 2.4 * F_{cF} + 35.02 * \rho - 0.411 * \left(\frac{a}{d}\right) - 0.23 * F$	0.999	0.708	70.87

Then the proposed **equation (2)** is added to the different codes for the reinforced concrete beams found in **Appendix**. Code equations are (1) ACI, equation [Eqs.(B-1)], (2) ACI, equation[Eqs.(B-2)],(3) CAN, equation[Eqs.(B-3)],(4)NZ, equation[Eqs.(B-4)],(5) BS equation[Eqs.(B-5)]. Then the five equations are tested as follows:

$$V_{ACI\ 08} = \mathbf{0.17}\sqrt{f'cf} + \mathbf{0.2{+}0.03} * {F_{cF}}^{2.28} * \rho * \left(\frac{a}{d}\right)^{-2.14} * F^{8.26} \qquad \text{...... 3}$$

$$V_{ACI\ 08} = \mathbf{0.16}\sqrt{f'cf} + \mathbf{17}\rho_w\frac{d}{a} + \mathbf{0.2{+}0.03} * {F_{cF}}^{2.28} * \rho * \left(\frac{a}{d}\right)^{-2.14} * F^{8.26} \qquad \text{...... 4}$$

$$V_{CAN} = \mathbf{0.2}\sqrt{f'cf} + \mathbf{0.2{+}0.03} * {F_{cF}}^{2.28} * \rho * \left(\frac{a}{d}\right)^{-2.14} * F^{8.26} \qquad \text{....... 5}$$

$$V_{NZ} = (\mathbf{0.07{+}10}\rho_w)\sqrt{f'cf} + \mathbf{0.2{+}0.03} * {F_{cF}}^{2.28} * \rho * \left(\frac{a}{d}\right)^{-2.14} * F^{8.26} \qquad \text{...... 6}$$

$$V_{BS} = \mathbf{0.8}\left[(100\rho_w)^{\frac{1}{3}}\left(\frac{400}{d}\right)^{\frac{1}{4}}\left(\frac{F_{cF}}{20}\right)^{\frac{1}{3}}\right] + \mathbf{0.2{+}0.03} * {F_{cF}}^{2.28} * \rho * \left(\frac{a}{d}\right)^{-2.14} * F^{8.26} \qquad \text{...... 7}$$

* In all cases codes predictions, f_{cf} was replaced instead of F_c.

Some notes have been recorded for the above equations:

1. Non-use of reduction factor.

2. The symbol used for the compressive strength of non-fibrous concrete (F_c) used to calculate shear of reinforced beams has been replaced with the symbol (F_{cF}), which means resistance to the compressibility of fibrous concrete.
3. There is no upper limit with regard to the concrete's compressive strength was utilized contrary to the BS requirement.

   To examine these equations, shear stress value SSV (V_{test} /$V_{proposed}$) of 50 models for this research and other is found using these equations, and then the values of Coefficient of variation (COV), Standard deviation (SD), and average(μ) for such equations are found in the table (5).

Table 5. COV, SD, and μ values of shear strength values

No.	Proposed equation Vu	Vtest/Vproposed		
		?	SD	COV
1	V=V_c, (ACI), Eq. (B-1) +V_{Fi}, Eqs. (5-6)	0.504	0.197	39.1
2	V=V_c, (ACI), Eq. (B-2) + V_{Fi}, Eqs. (5-6)	0.475	0.19	40
3	V=V_c, (CAN), Eq.(B-3) + V_{Fi}, Eqs. (5-6)	0.453	0.186	41.1
4	V=V_c, (NZ), Eq.(B-4) + V_{Fi} Eqs. (5-6)	0.342	0.167	48.6
5	V=V_c, (BS), Eq.(B-5) + V_{Fi}, Eqs. (5-6)	0.403	0.173	43

It is clear from Table (6), that the proposed equation No. (1) [Eq. (3)] to calculate the shear capacity by the ACI 318-08 code (B-1) has the lowest value of COV, which equals 39.1.

By seeing figures from (8 to 14) it shows that the improved equation for the ACI Code 318 -08 can give estimates for calculating the shear capacity for RC beams.

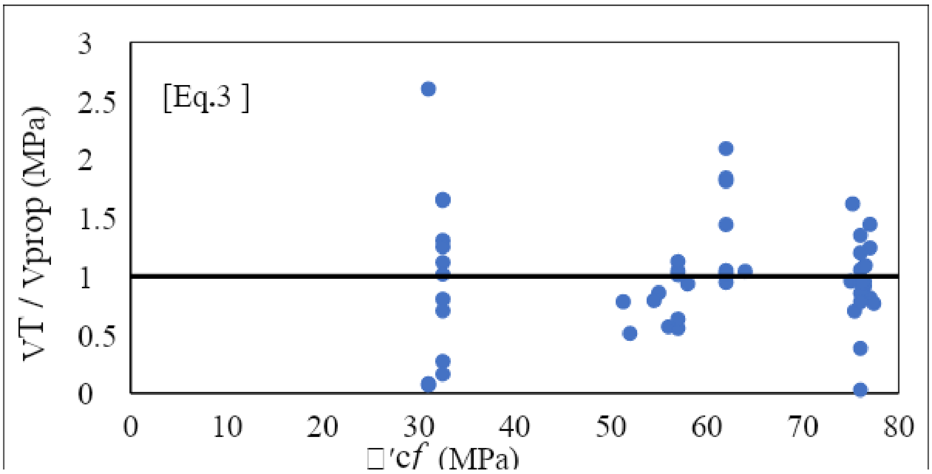

Fig. (8) f'_{cf} versus shear capacity predictions

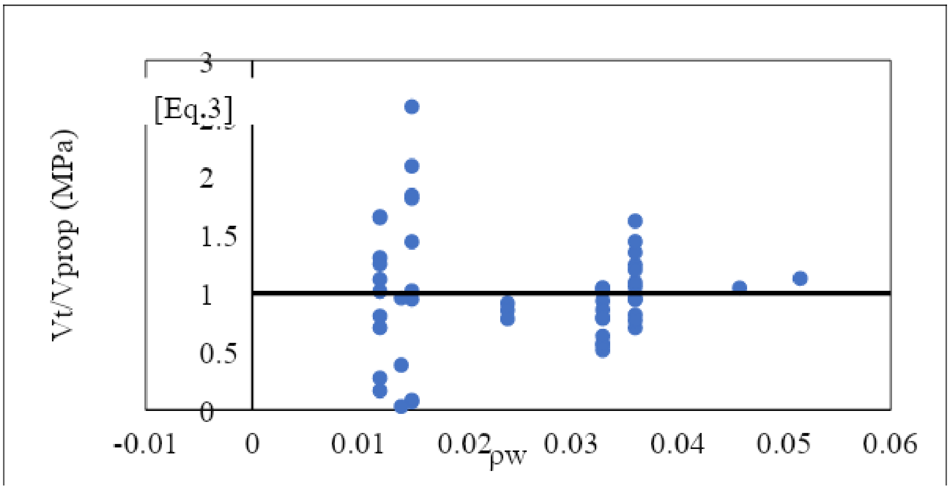

Fig. (9) ρ_w versus shear capacity predictions

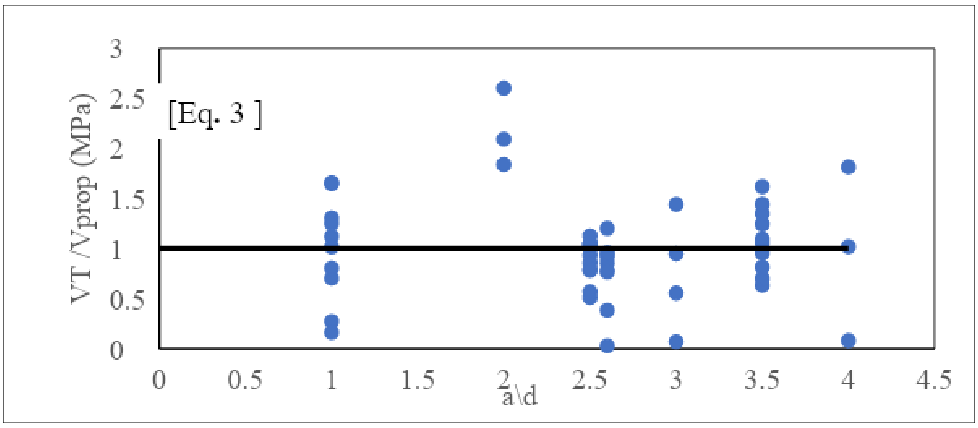

Fig. (10) a\d versus shear capacity predictions

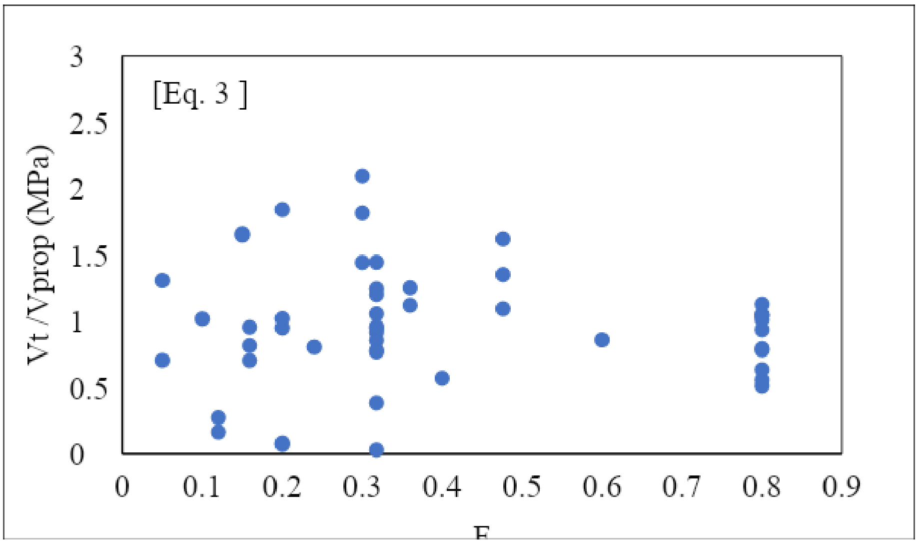

Fig. (11) Fiber ratios versus shear capacity predictions

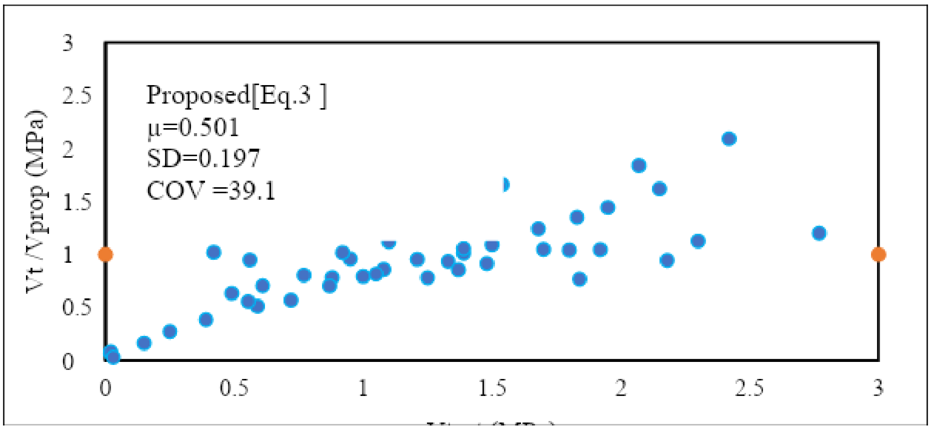

Fig. (12) Comparison between tested data and proposed

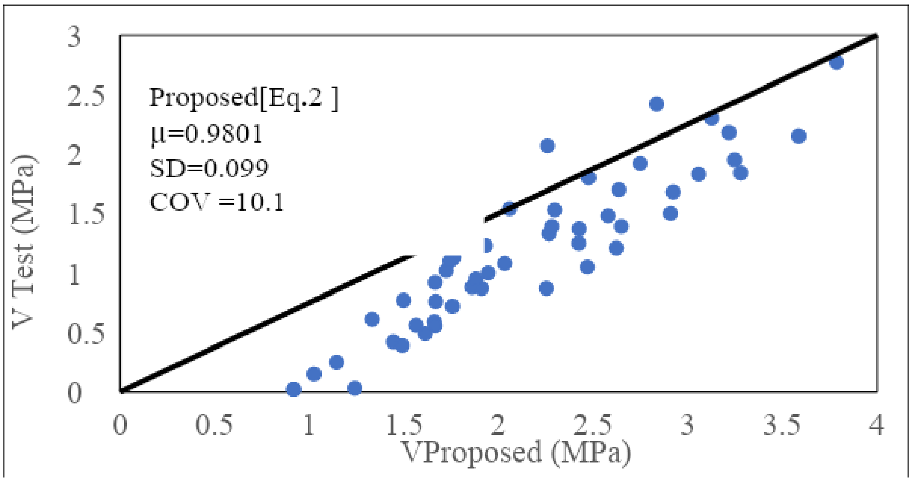

Fig. (13) Comparison between tested data and calculated

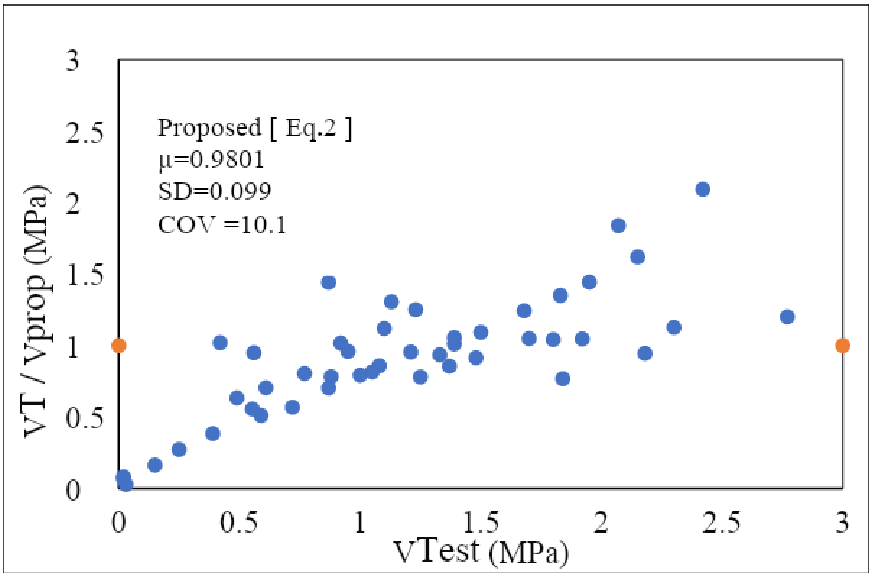

Fig. (14) Comparison between tested data and calculated

VI. Conclusion

Concerning the current research, 14 reinforced concrete beams instituted from recycling aggregate were examined to assess the amount of shear capacity in the slender beam. The study also involved the mechanical properties of the models, such as the compression resistance. The findings in this research were analyzed with other results of different studies by the statistical program (Data Fit 9) to yield new formulae. The analysis offered one formula to calculate the compression resistance a long with another to estimate the shear capacity of the high-strength concrete beams constructed from recycled aggregate and steel fibers. The effectiveness of the new formulae was validated with different international codes. Some significant points regarding this research can be presented below:

1. The use of RCA caused the compressive strengths to be generally lower than their companion obtained from the NCA. The percentage of reduction for cubic mixes having 50% treated and 100% treated was respectively 3.1% and 11.0% lower than the values taken from NCA. However, the further reduction was noticed when untreated RCA was used. For cubic mixes having 50% untreated and 100% untreated, 9.4% and 18.8% were reported to be the amount of reduction in compressive strength when compared to NCA.
2. The reduction in compressive resistance of samples containing 10% of silica fume by about 10% compared to samples with content of 20% for the same type of aggregate.
3. The values of the ultimate load of (NCA) are greater than the values of mixes used (RCA), when other parameters were kept constant. Because the angular shape of RCA, the RCA has a high porosity so that the bonding with the rest of the concrete components is fragile. The percentage of reduction in ultimate load for mixes having 50% untreated and 100% untreated was 10.5% and 27.6%, respectively when compared to NCA.
4. The negative effect of untreated coarse aggregate was subsided when the mixes were treated by hydrochloric acid (HCL). The sodium metasilicate pentahydrate is filling the crack and pores, while the acid is removing adhered mortar on the recycled aggregate. The discrepancy in ultimate load for mixing having 50% and 100% treated RCA was only 1.9% and 9 %, respectively as compared to the values taken from NCA.
5. Test results provided considerable enhancement in shear capacity along with considerable delay in the cracking load when steel fibers were added. The increment in the ultimate load regarding the beams that contain steel fibers by 2% is about 36% compared to the beams with a content of 0% for the same type of aggregate. Also, it was found that the decline in the ratio of steel fiber to 1% for B8 reduced the ultimate load by about 17%; while using steel fiber by 1.5% for B9 reduced the ultimate load about 7.8% compared with B5 for the same type of recycled treated aggregate.
6. The addition of silica fume with other factors being constant increased the concrete strength. The ultimate load further enhanced by 15% when the percentage of silica fume was changed from 10% and 20%.
7. An increase in the shear capacity was reported when adding extra reinforcement to the flexural region among B12 and B13. The percentage of increment for the latter beams was about 13% and 23%, respectively compared with **B5** for the same type of RCA.
8. The ultimate shear capacity was seen to be considerably lower for the beams with a/d of 3 and 3.5 as compared with other beams with a/d of 2.5.
9. The rate of decrease in the ultimate shear capacity was 21.5% and 23% for B14 and B15, respectively compared with B5.

- **Theoretical predictions of Compressive strength f'_{cf} *and shear capacity Vu***
    1. The regression equation was constructed based on (50) points from the experimental data obtained from the current research and previous research, with the use of the trial V9 related to data Fit software of Oakdale Engineering. The compressive strength of the data used ranges from (50-77) MPa. The values of coefficient of variation (COV), average (μ), as well as the standard deviation

(SD) have been 12.89, 0.995 and 0.128% respectively. The proposed equation for estimating the compressive strength of (RHSC) is given by Eqs (8) as follow:

$$f'cf = 0.95 * f'c + 6.93 * F^{1.2}$$ **MPa** **…… 8**

2. The proposed equation for estimating shear capacity with regard to the RHSC fiber-reinforced beams with no stirrup is given by Eqs (6.2). The values of coefficient of variation (COV), average (μ), as well as the standard deviation (SD) have been 10.1, 0.9801 and 0.099% respectively.

$$V_{Fi} = 0.2 + 0.03 * F_{cF}{}^{2.28} * \rho * (\frac{a}{d})^{-2.14} * F^{8.26}$$ **MPa** **…… 9**

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Appendix

Selected data from the current research and previous studies for Compressive Strengths

References	Fiber type	V*f* %	F	$f'_{cf\ MPa}$
Current research Ahmed. J. Hassan 2020	HS*	2%	0.8	64
	HS	2%	0.8	58
	HS	2%	0.8	52
	HS	2%	0.8	62
	HS	2%	0.8	57
	HS	1%	0.4	56
	HS	1.5%	0.6	55
	HS	2%	0.8	51.3
	HS	2%	0.8	54.5
	HS	2%	0.8	57
	HS	2%	0.8	57
	HS	2%	0.8	57
	HS	2%	0.8	57
	HS	0%	0	55
Kwak.et.al.2002	HS	0%	0	62
	HS	0.5 %	0.2	62
	HS	0.75%	0.3	62
	HS	0%	0	62

	HS	0.5%	0.2	62
	HS	0.75%	0.3	62
	HS	0.5%	0.2	31
	HS	0.5%	0.2	31
	HS	0.5%	0.2	31
High strength 1998. Ziyad Jinan	HS	0%	0	75.4
	HS	0.5%	0.159	76
	HS	1%	0.318	77
	HS	1.5	0.476	77
	HS	1%	0.318	76
	HS	1.5	0.476	76.4
	HS	1.5%	0.476	77.4
	HS	1%	0.318	76.4
	HS	1%	0.318	77
	HS	0.5	0.159	75.2
	HS	1%	0.318	76
	HS	1%	0.318	76
	HS	1%	0.318	76
	HS	1%	0.318	76
	HS	1%	0.318	76

Shear reinforced concrete beams Ahmed Saudi 2016	HS	0%	0	32.5
	HS	0.2%	0.05	32.5
	HS	0.6%	0.15	32.5
	Glass	0.2%	0.12	32.5
	Glass	0.6%	0.36	32.5
	HS	0.2%	0.05	32.5
	HS	0.4%	0.1	32.5
	HS	0.6%	0.15	32.5
	Glass	0.2%	0.12	32.5
	Glass	0.4%	0.24	32.5
	Glass	0.6%	0.36	32.5

*Fiber type: HS=Hooked ends steel

Abbreviations

Symbol	Description
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
B. S	British standards
COV	Coefficient of Variation
CSA	Canadian Standards Association
F	Fiber factor
HSC	High strength concrete
L.S.F.	Lime Saturation Factor
NCA	Normal coarse aggregate
NZS	New Zealand standards Association
RC	Reinforced concrete
RCA	Recycle coarse aggregate
RHSC	Recycled high strength concrete
SD	Standard Deviation
S. F	Silica fume
Vf	Steel fiber