American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-03, Issue-02, pp-141-147
www.ajer.org

Research Paper Open Access

A Comparative Analysis of Modulus of Rupture and Splitting Tensile Strength of Recycled Aggregate Concrete

Akinkurolere Olufunke Olanike
Department of Civil Engineering, Ekiti State University, Ado-Ekiti, Nigeria.

Abstract: - In this experimental investigation, an attempt is made to report the comparative analysis of the modulus of rupture and the splitting tensile strength of recycled aggregate concrete. The two properties are usually used to estimate the tensile strength of concrete; however, they don't usually yield the same results hence need to investigate each of the properties. Taguchi optimization technique was employed to reduce the number of trials needed to get the results. The results showed that the splitting tensile strength ranges between 60-80% of the modulus of rupture which is also known as the flexural strength.

Keywords: - *Splitting Tensile Strength, Modulus of Rupture, Recycled Aggregate Concrete.*

I. INTRODUCTION

The modulus of rupture and splitting tensile strength are usually used to estimate the tensile strength of concrete although they don't usually yield the same results. Rohi [1] reported that the splitting tensile strength was approximately between 60-65% of modulus of rupture. Troxell [2] also reported splitting tensile strength ranging between 50-75% of modulus of rupture. Meanwhile, several works found no significant difference in modulus of rupture of conventional concrete and recycled aggregate concrete made with coarse recycled aggregate and natural sand;([3]- [5]).

Katz [6] concluded in his work that the ratio of the flexural and the splitting strengths to the compressive strength is in the range of 16–23% and 9–13%, respectively.

II. MATERIALS AND METHODS

Modulus of Rupture

Tests to determine the modulus of rupture were performed on 100 x 100 x 400 mm prisms according to GB/T 50081[7] using the three-point loading method. The samples were prepared under standard laboratory conditions. The modulus of rupture of concrete was determined using a three-point loading flexural testing machine with a loading capacity of 300 KN. The loading rate for the modulus of rupture was 0.5-0.8 MPa/s.

The modulus of rupture was then calculated by the following equation;

$$f_f = Fl/bd^2 \quad (1)$$

where:

f_f = modulus of rupture, MPa
F = maximum applied load indicated by the testing machine in kN
l= span length, in mm
b = average width of specimen, in mm
d = average depth of specimen, in mm

If fracture initiates in the tension surface (i.e., the bottom surface) outside the middle third of the beam by not more than 5% of the span length, the modulus of rupture was calculated as follows:

$$f_f = 3Fa / bd^2 \quad (2)$$

Where:

a = average distance between the line of fracture and the nearest support measured on the tension surface of the beam, in mm.

When the fracture occurs in the tension surface outside of the middle third of the span length by more than 5% of the span length, the results of the test was discarded. Fig. 1a –c, show the flexural test set-up.

Splitting Tensile Strength

The splitting tensile strength of concrete was measured by the application of a diametral compressive force on a cube concrete specimen placed with its axis horizontal between the platens of a testing machine. All the cubes were also prepared under standard laboratory conditions. This test was performed to compare with the modulus of rupture. It was also conducted in accordance with GB/T 50081[7] .The splitting tensile strength of the specimen was then calculated as follows:

$$f_t = 2F/\pi A = 0.637F/A \qquad (3)$$

Where:
f_t = splitting tensile strength, in kPa
F = maximum applied load indicated by the testing machine, in KN
A = Area of the specimen
The set-up is shown in Fig. 2. Taguchi orthogonal array L16 (4^5 Series) as proposed by Taguchi [8] was used to proportion all the tested samples. The results were analyzed and Regression analyses were performed on the modulus of rupture and splitting tensile strength results obtained in this study using the following formula:

$$f_t = \mu(f_f) \qquad (4)$$

Where, μ is coefficient that can be obtained from regression analysis

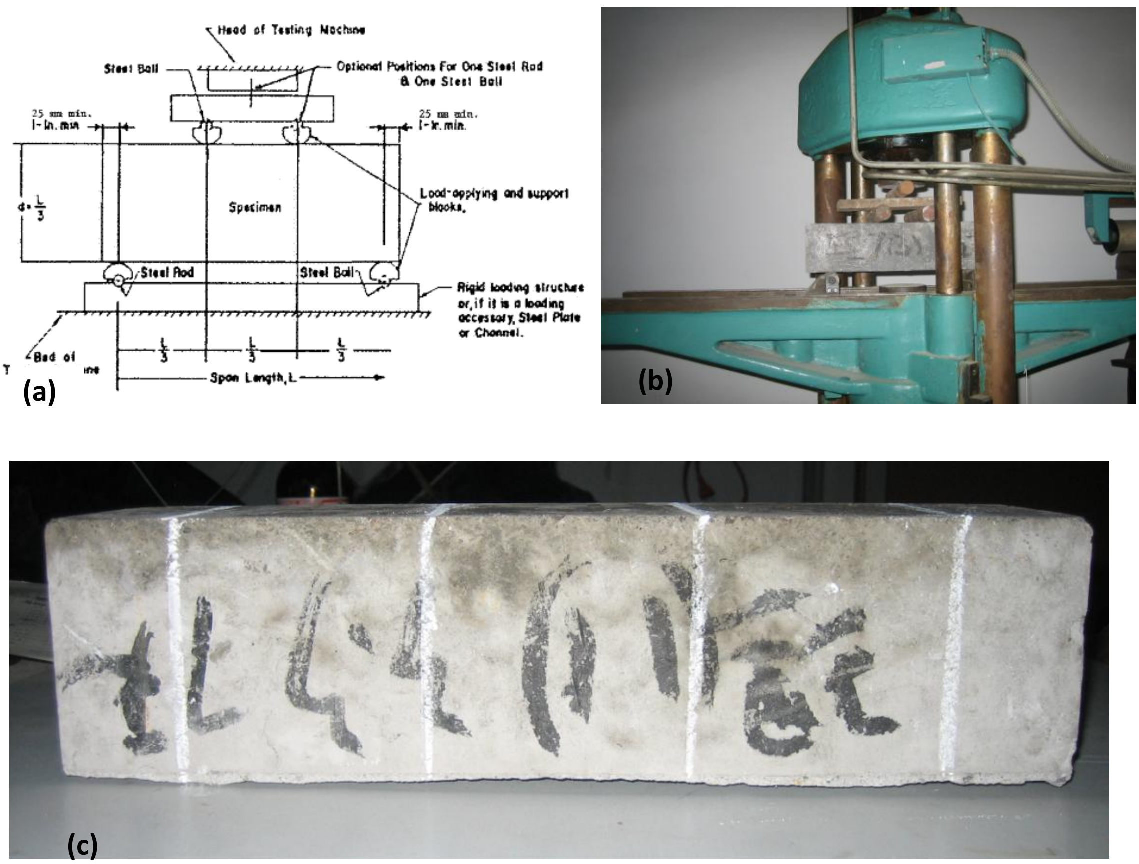

Fig. 1. Modulus of Rupture test set-up and beam sample. (a) General set-up for the three-point loading method (b) Three-point loading flexural testing device and set-up. (c) Flexural test beam.

Fig. 2. Test set-up for splitting tensile strength

III. RESULTS AND DISCUSSIONS

Modulus of Rupture (Flexural Strength)

Tables 1through 3 give all the physical properties and analysis for modulus of rupture for the mixes. As can be seen from the Table 1, the rate of development of strength was high at early ages but greatly reduced at later ages. This increase in strength at early ages and decrease at later ages may be attributed to the rough–textured recycled aggregates. According to Mehta[9] , a stronger physical bond between the rough-textured aggregate and the cement paste is responsible for the increased tensile strength at early ages. At later ages, however ,when chemical interaction between the aggregates and the paste begins to take effect, the effects of the surface texture may not be as important. The S/N ratio and the significance of the three factors follow the same trend (Tables 1 and 2).

Splitting Tensile Strength

The splitting tensile strengths results are given in Tables 4-6. As can be seen in Table 4, there is a sharp reduction in rate of strength development at later ages, the same explanation that was given for modulus of rupture applies to this trend as well. It should however be noted that at early ages, where there is a higher percentage of recycled aggregates, there was also a higher tensile strength compared to other mixes containing recycled aggregates. Also, for concrete containing high proportions of recycled aggregates the failure of the specimens occurred along the recycled aggregates having been the weakest point, Fig. 3 shows the failure pattern. The S/N ration also has the same pattern with previous results for modulus of rupture, and the same trend is observed in the analysis of variance along with the orthogonal analysis (Tables 5 and 6). Figure 4 also presents the summary of the relationship between modulus of rupture and splitting tensile strength, from the graph, given the same material and laboratory conditions the modulus of rupture is generally higher than the splitting tensile strength.

The Analysis of Variance (ANOVA) for the two properties also showed that significant factors in the development of both flexural and splitting tensile strengths are the water-cement ratios and recycled aggregate contents. Addition of fly-ash does not have a substantial effect on the final results.

Table 1 L16 (4^5 Series) orthogonal arrays used and test results for flexural strength

Test No.	Average flexural strength F_f(Mpa)			% Strength increment		S/N ratio for average flexural strength		
	7-Day	28-Day	90-Day	7-28 Days	28-90 Days	7-Day	28-Day	90-Day
1	2.48	4.09	4.36	64.92	6.6	7.9	12.23	12.79
2	2.42	3.87	4.31	59.92	11.37	7.65	11.73	12.68
3	2.31	3.74	4.2	61.9	12.3	7.21	11.45	12.46
4	2.26	3.72	4.1	64.6	10.22	7.08	11.39	12.25
5	2.11	3.72	4.06	76.3	9.14	6.48	11.4	12.15
6	2.05	3.31	3.93	61.46	18.73	6.17	10.36	11.85
7	2.04	3.26	3.9	59.8	19.63	6.2	10.24	11.81
S	1.92	3.22	3.87	67.71	20.19	5.65	10.11	11.73
9	1.89	3.20	3.34	69.31	4.37	5.54	10.01	10.37
10	1.89	2.97	3.26	57.14	9.76	5.52	9.35	10.15
11	1.86	2.92	3.03	56.99	3.77	5.39	9.3	9.62
12	1.88	2.83	2.96	50.53	4.59	5.45	9	9.32
13	1.88	3.04	2.95	61.7	-2.96	5.45	9.65	9.4
14	1.76	2.87	2.79	63.07	-2.79	4.86	9.14	8.88
15	1.69	2.83	2.81	67.46	-0.71	4.3	9.01	8.92
16	1.6	2.74	2.8	71.25	2.19	4.04	8.73	8.89

Table 2 Analysis of variance (ANOVA) for flexural strength

	Factor	DOF	SS	Contribution factors of SS (%)	F ratio	Prob >F
7-Day	W/C	3	0.88	89.80	103.54	<.0001*
	RA	3	0.07	7.14	7.96	0.0163*
	FA	3	0.01	1.02	0.86	0.5104
	Error	6	0.02	2.04	Prob >F	-
	Total	**15**	**0.98**	**100**	-	**0.0001***
28-Day	W/C	3	2.40	86.64	317.76	<.0001*
	RA	3	0.34	12.27	45.13	0.0002*
	FA	3	0.01	0.36	1.15	0.4031
	Error	6	0.02	0.72	Prob >F	-
	Total	**15**	**2.77**	**100**	-	**<.0001***
90-Day	W/C	3	5.19	96.65	289.80	<.0001*
	RA	3	0.14	2.61	7.97	0.0163*
	FA	3	0.00	0.00	0.1	0.9600
	Error	6	0.04	0.74	Prob >F	-
	Total	**15**	**5.37**	**100**	-	**<.0001***

Table 3 L16 (4^5 Series) orthogonal analysis for flexural strength

	Factors	E1	E2	E3	E4	R
7- Day flexural Strength f_f(Mpa)	W/C	2.37	2.03	1.88	1.74	0.63
	RA	2.09	2.03	1.98	1.92	0.17
	FA	2.00	2.03	1.97	2.02	0.06
28- Day flexural Strength f_f(Mpa)	W/C	3.86	3.38	2.98	2.87	0.99
	RA	3.51	3.25	3.19	3.13	0.38
	FA	3.27	3.31	3.26	3.25	0.06
90-Day flexural Strength f_f(Mpa)	W/C	4.24	3.94	3.15	2.84	1.4
	RA	3.68	3.57	3.48	3.43	0.25
	FA	3.53	3.53	3.55	3.55	0.02

Table 4 L16 (4^5 Series) orthogonal arrays used and test results for splitting tensile strength

Test No.	Average splitting tensile strength f_c (Mpa)			% Strength increment		S/N ratio for average splitting tensile strength		
	7-Day	28-Day	90-Day	7-28 Days	28-90 Days	7-Day	28-Day	90-Day
1	2.01	3.18	3.5	58.21	10.06	6.06	10.06	10.89
2	1.99	3.17	3.43	59.3	8.2	5.97	10.03	10.71
3	1.94	3.14	3.35	61.86	6.69	5.77	9.95	10.49
4	1.91	3.13	3.36	63.87	7.35	5.6	9.91	10.52
5	1.84	2.88	3.12	56.52	8.33	5.27	9.2	9.89
6	1.84	2.88	3.15	56.52	9.38	5.29	9.19	9.95
7	1.82	2.8	3.12	53.85	11.43	5.18	8.94	9.87
8	1.8	2.79	3.19	55	14.34	5.12	8.9	10.07
9	1.71	2.65	2.77	54.97	4.53	4.64	8.48	8.86
10	1.72	2.64	2.76	53.49	4.55	4.73	8.43	8.82
11	1.72	2.63	2.8	52.91	6.46	4.73	8.39	8.94
12	1.72	2.65	2.81	54.07	6.04	4.73	8.47	8.98
13	1.69	2.52	2.63	49.11	4.37	4.56	8.03	8.4
14	1.65	2.43	2.63	47.27	8.23	4.33	7.7	8.41
15	1.63	2.37	2.59	45.4	9.28	4.26	7.51	8.25
16	1.72	2.47	2.61	43.6	5.67	4.73	7.84	8.34

Table 5 Analysis of variance (ANOVA) for splitting tensile

	Factor	DOF	SS	Contribution factors of SS (%)	F ratio	Prob >F
7-Day	W/C	3	0.197	94.26	78.63	<.0001*
	RA	3	0.002	0.96	0.99	0.4602
	FA	3	0.005	2.39	2.11	0.2003
	Error	6	0.005	2.39	Prob >F	-
	Total	**15**	**0.209**	**100**	-	**0.0003**
28-Day	W/C	3	1.101	98.04	305.65	<.0001*
	RA	3	0.012	1.07	3.31	0.0990
	FA	3	0.003	0.27	0.75	0.5616
	Error	6	0.007	0.62	Prob >F	-
	Total	**15**	**1.123**	**100**	-	**<.0001***
90-Day	W/C	3	1.526	98.58	232.00	<.0001*
	RA	3	0.004	0.26	0.66	0.6071
	FA	3	0.005	0.32	0.77	0.5513
	Error	6	0.013	0.84	Prob >F	-
	Total	**15**	**1.548**	**100**	-	**<.0001***

Table 6 L16 (4^5 Series) orthogonal analysis for splitting tensile strength

	Factors	E1	E2	E3	E4	R
7- Day splitting tensile Strength f_f(Mpa)	W/C	1.96	1.82	1.72	1.67	0.29
	RA	1.81	1.80	1.78	1.79	0.03
	FA	1.82	1.80	1.78	1.79	0.04
28- Day splitting tensile Strength f_f (Mpa)	W/C	3.16	2.84	2.64	2.45	0.71
	RA	2.81	2.78	2.74	2.76	0.07
	FA	2.79	2.77	2.75	2.77	0.04
90-Day splitting tensile Strength f_f (Mpa)	W/C	3.41	3.14	2.79	2.62	0.79
	RA	3.01	2.99	2.96	2.99	0.05
	FA	3.02	2.99	2.99	2.97	0.05

Regression analysis was performed on the results and the following regression equations were gotten:

7-Day relationship

$\mu = 0.9684x_1 + 0.0699x_2 - 0.0901x_3 + 0.0901$; R=0.9159, n = 16 (5)

28-Day relationship

$\mu = -0.\ 52234x_1 - 0.\ 1069x_2 + 0.0229X3 + 1.4952$; R=0.8115, n = 16 (6)

90-Day relationship

$\mu = 1.2772x_1 + 0.0477x_2 - 0. 0.0495x_3 - 0.2152$; R=0.9395, n = 16 (7)

X_1 = W/C; X_2 = RA; X_3 = FA

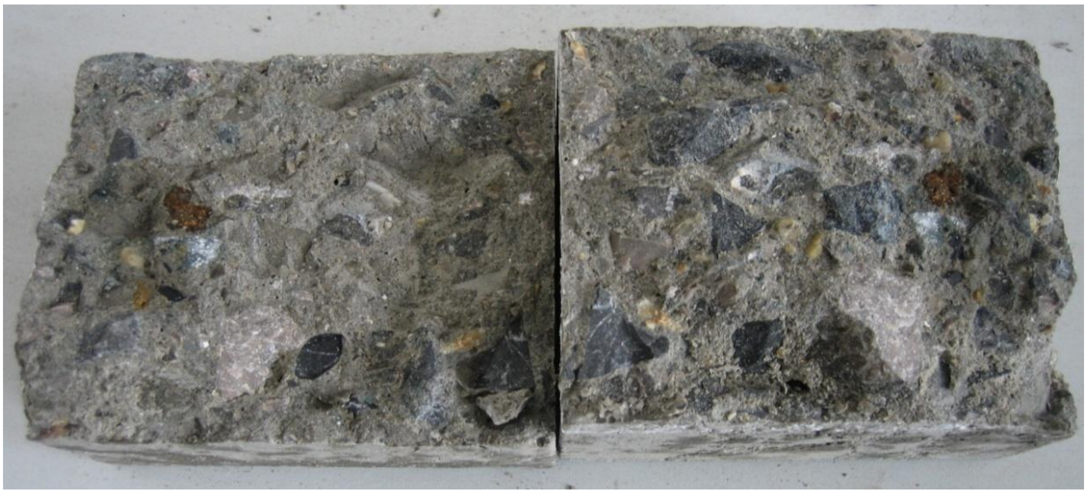

Fig. 3. Recycled Aggregate Concrete Failure by way of Tensile

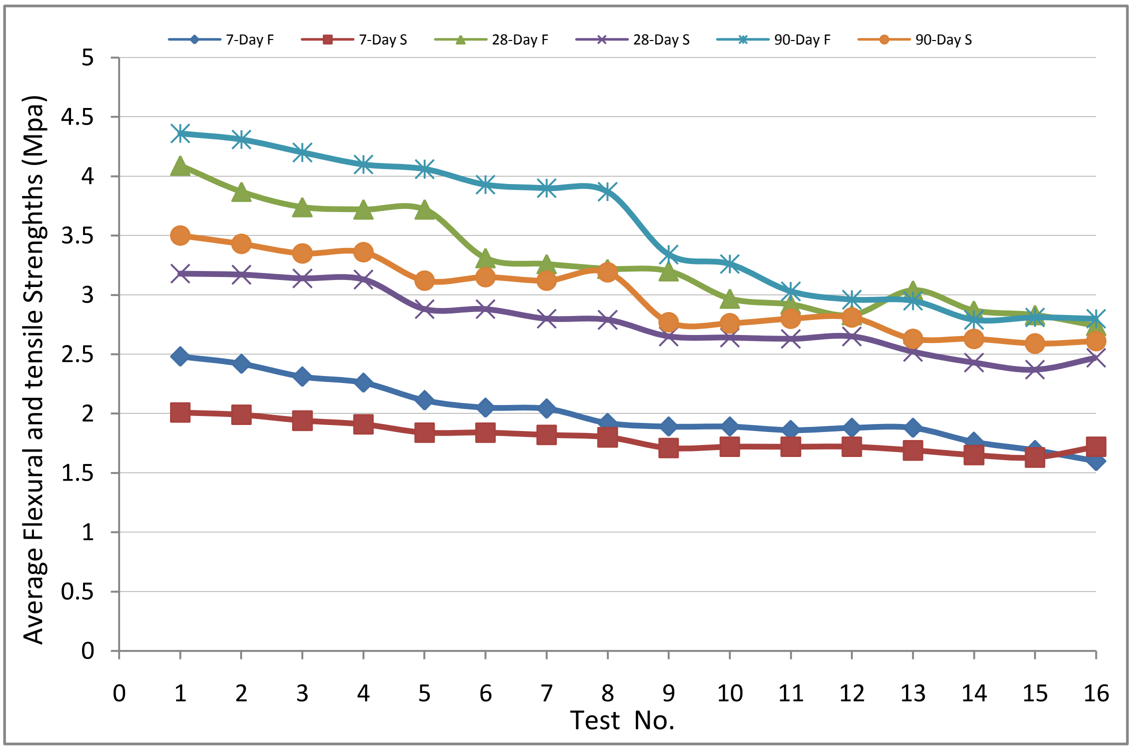

Fig. 4. Relationship Between Modulus of Rupture(Flexural Strength) and Splitting Tensile Strength
*F= Flexural Strength; S= Splitting Tensile Strength

IV. CONCLUSION

The splitting tensile strength is generally lower than the modulus of rupture ranging between 60-80% of modulus of rupture for both recycled aggregate concrete and conventional concrete. This assertion also agree with previous works ([1] - [4], [6]). Moreover, the rate of strength development in recycled aggregate concrete is similar to conventional concrete. The mathematical model generated can be used to estimate the relationship between the two properties investigated provided the factors are the same.

REFERENCES

[1] Rohi M.S. *Strength and Durability Characteristics of Recycled Aggregate*, doctoral diss, The University of Tennessee,Knoxville, 1996.

[2] Troxell G.E. (1968), *Composition and Properties of Concrete* (Mc Graw-Hill Companies, The XIX, 1968).

[3] Ravindrajah R.S. and Tam T.C., Properties of Concrete made with Crushed Concrete as Coarse Aggregate, *Magazine of Concrete Research, Vol. 37*, 1985, No.130.

[4] Tavakoli, M., and Soroushian, P., Strengths of Recycled Aggregate Concrete made Using Field-Demolishd Concrete as Aggregate, *ACI Mater. J.*, 93(2), 1996 182–190.

[5] Akinkurolere O.O. *Experimental Study on Engineering Characteristics of Recycled Aggregate Concrete (RAC)*, doctoral diss, Wuhan University of Technology, Wuhan, P.R.C**.** 2008.

[6] Katz A., Properties of concrete made with recycled aggregate from partially hydrated old concrete, *Cement and Concrete Research, Vol. 33,* 2003, 703–711.

[7] GB/T 50081, Standard for test method of mechanical properties on ordinary concrete, 2002.

[8] Taguchi G**.,** *Introduction to Quality Engineering: Designing Quality into Products and Processes*, (Asian Productivity Organization, Japan 1988).

[9] GB/T 50081, Standard for Test Method of Mechanical Properties on ordinary concrete. (China, 2002.).

[10] Mehta P.K. and Monteiro P.J.M. (2006). *Concrete; Microstructure, Properties, and Materials,* (McGraw-Hil, New York. 3rd edition, McGraw, 2006).