OPTIMIZATION AND PROGNOSTIC MODEL FOR SPLITTING TENSILE STRENGTH OF CONCRETE PRODUCED FROM GRANITE AND RECYCLED CONCRETE AGGREGATE

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ABSTRACT

Using recycled concrete aggregates from structural demolition wastes is presenting a potential application in the building industry as a substitute for natural aggregates. It preserves natural resources and brings about a reduction in the space needed as landfill disposal sites. This research was aimed at developing a prognostic model for splitting tensile strength of concrete produced from granite and recycled concrete aggregate. Thirteen rounds of experiments were considered utilizing the Central Composite Response Surface method. Granite was replaced with Recycled Concrete Aggregate (RCA) in varying proportions from 0% to 100% while the water-cement ratio (w/c) was varied from 0.3 to 0.7. Samples were subjected to test after 7, 14 and 28 days curing. It was observed that with a surge in the fraction of RCA, the splitting tensile strength reduced at all levels of w/c ratio. 30% RCA at 0.5 w/c gave the optimum combination that resulted in the highest splitting tensile strength of 2.11 N/mm^2 at 28 days. This result is 7.9 % lesser than the control splitting tensile strength of 2.29 N/mm^2.

Keywords: *Concrete, Model, Optimization, Recycled Concrete Aggregate, Splitting Tensile Strength, Civil Engineering*

INTRODUCTION

A principal structural material globally used, and is widely utilized for many Civil Engineering projects including building infrastructures, military installations, and local domestic developments is concrete (Sadiq and Atoyebi, 2015; Atoyebi and Sadiq, 2018; Atoyebi *et al.*, 2018; Atoyebi, Aladegboye and Odeyemi, 2018; Anifowose *et al.*, 2019; Odeyemi *et al.*, 2019; Ajamu, Atoyebi and Oyeboade, 2020; Awolusi *et al.*, 2020). It is manufactured essentially from cement, aggregates, water and sometimes admixtures. Amongst these constituents of concrete, aggregates (fine and coarse) form the bulk of the matrix (Ramonu *et al.*, 2019). The concrete production process requires a huge quantity of natural resources that result in a considerable level of economic, environmental, and energy losses as it uses a lot of raw materials and energy and also generates unquantifiable volume of wastes in any community where it is produced (Anik, Boonstra and Mak, 1996; Odeyemi and Giwa, 2021). A major challenge globally is the protection of the environment through a decrease in the natural materials and energy consumption, and general use of waste materials. Considering this, the availability of natural resources for the use of posterity is also a necessity (Oikonomou, 2005; Atoyebi, Osuolale and Ibitogbe, 2019; Atoyebi, Gana and Longe, 2020).

Large amounts of solid wastes are produced in the process of constructing new buildings, demolishing old ones and building collapses all around the world (Malešev, Radonjanin and Marinković, 2010;

Atoyebi, Afolayan and Arum, 2019). Findings have revealed that in the last 20 to 30 years some countries have started the re-utilization of demolition wastes as innovative construction materials (Safiuddina *et al.*, 2013). Many scholars have investigated the potentials of utilizing recycled aggregates in concrete in a more productive mode, may be by modifying the product (Zakaira and Cabrera, 1996; De Juan and Gutiérrez, 2009; Pepe *et al.*, 2014; Mueller, Schnell and Ruebner, 2015; Shi *et al.*, 2016; Dimitriou, Savva and Petrou, 2018) or by characterizing and channelling the aggregates to an appropriate application (Oikonomou, 2005; Agrela *et al.*, 2011; Silva, De Brito and Dhir, 2017). Thus, the adoption of recycled coarse aggregate from demolished structures is presenting a better future application in building and civil works as a substitute to the crushed aggregates (Oikonomou, 2005; Rao, Jha and Misra, 2007; Muhammad Ali and Sankaranarayanan, 2016). This will help to prevent the depletion of natural resources and conserve space for future use instead of using them as landfill disposal sites. This article looked into optimizing and developing a predictive model for the splitting tensile strength of concrete made from a blend of Recycled Concrete Aggregate and Granite using Design–Expert 10.0, a software developed by Stat-Ease Inc., This package assists in the processing of more than one factor experiments by analyzing the inter-relationship of the factor by changing their values. The optimization process enables the user to infer the perfect operating parameters for a process (Odeyemi, Atoyebi and Ayo, 2020).

MATERIALS AND METHOD

The constituents utilized for the research are coarse aggregates (Crushed aggregate i.e. Granite and Recycled Concrete Aggregate (RCA) presented in Figure 1).

The RCA utilized for this study were broken down into smaller sizes and sieved. The coarse aggregates used (RCA and granite) are those that passes through 14 mm diameter sieve and suspended on 10 mm diameter sieve. The fine aggregate (sharp sand) used were those that passes through sieve size 4.75 mm and were suspended on 4 mm sieve. The aggregates were subjected to water absorption capacity, specific gravity and aggregate crushing strength test. Afterwards, cylindrical concrete samples were cast with varying percentages of RCA and granite to produce a Grade 25 concrete. These were subjected to test at 7-, 14- and 28-days duration of curing.

(a) RCA

(b) Crushed Granite

Fig. 1 Coarse Aggregates

In determining the water absorption for the aggregates, samples of the fine aggregate, granite and RCA were weighed and designated as ‘A’. These samples were inserted into an oven for drying for a period of 24 hours after which they were left to cool at room temperature. Then, the aggregate samples were taken from the oven and positioned in pans and submerged in water for a period of 24 hours for saturation. When the samples were fully saturated, the samples were surface-dried by rolling in a towel till all noticeable films of water were removed. The weight of the surface-dry saturated sample was determining and designated as 'B'. The water absorption capacity in percentage for the aggregates was obtained from Equation 1.

$$Water\ Absorption\ (\%) = \frac{B-A}{A} \times 100 \quad (1)$$

In determining the specific gravity for the aggregates, saturated surface-dry sand was taken and measured and designated as 'B'. It was then introduced into a measuring cylinder and filled with distilled water almost to the top. Entrapped air bubbles were eliminated by shaking the measuring cylinder in it whilst covering the top with a palm, and after which it was completely filled with water. The outer part of cylinder was dried and weighed and designated as 'A'. The measuring cylinder was cleansed and filled with distilled water to full capacity. The outer part was cleansed and weighed and designated 'C'. The apparent specific gravity of aggregate sample was gotten from Equation 2.

$$Specific\ gravity = \frac{B}{B+C-A} \quad (2)$$

The aggregate crushing value (ACV), which is the proportion by weight of the crushed material gotten when samples of aggregates are put under a predetermined load under standard conditions, was conducted on the granite and RCA. The value was calculated using Equation 3.

$$ACV = \frac{W-W1}{W2} \times 100 \quad (3)$$

The experiment was designed by means of Design Expert 10.0, using Response Surface Methodology (RSM) in a Central Composite Design (CCD) to obtain the optimum combination for the RCA and the water-cement ratio. -α, -1, 0, +1, +α are the five (5) different levels of experimentation considered. Two different independent factors (RCA and water-cement ratio) with 13 trial runs for splitting tensile strength and slump height of the designed concrete mix ratio of 1:1.5:3 (for a target compressive strength of 25 N/mm^2). The splitting tensile strength of the concrete were determined at 7-, 14- and 28-days curing duration to monitor the progression of the splitting tensile strength development. In determining the optimal combination for the factors considered, the plan was to maximize the splitting tensile strength at varying percentages of RCA with Granite varying from 0 – 100% while keeping the water-cement ratio in the range of 0.3 - 0.7. The breakdown of the experimental design is presented in Table 1. The experiment design layout is also presented in Table 2.

Table 1: Experimental Design

Designation	Factors	Unit	Codes	Grade				
				-α	-1	0	1	+α
A	RCA	%	X_1	0	25	50	75	100
B	Water - Cement Ratio	%	X_2	0.3	0.4	0.5	0.6	0.7

Three (3) samples each were cast from each design mix specification in a 100 mm diameter by 200 mm high cylindrical moulds. The concrete samples were detached from the cylindrical moulds after 24 hours of curing and submerged fully in water for a curing duration of 7, 14 and 28 days respectively when the hardened concrete were subjected to the tensile test. The cylinders were taken in batches and three (3) cubes were crushed per each case of observation at each maturing age.

RESULTS AND DISCUSSIONS

A. Perf *Water Absorption of Aggregates*

The findings obtained for the aggregate's water absorption are presented in Table 3.

Table 2: Mixing percentages used for the analysis.

S/No	% Granite	% RCA	Water/cement ratio
1 (Control)	100	0	0.5
2	50	50	0.5
3	75	25	0.5
4	50	50	0.6
5	100	0	0.3
6	0	100	0.7
7	50	50	0.4
8	100	0	0.7
9	25	75	0.5
10	0	100	0.3

Table 3: Water Absorption of Fine aggregate, Granite and Recycled concrete aggregate

Test samples	Water Absorption (%)
Sand	2.5
Granite	0.5
RCA	1.9

The values indicated in Table 3 indicated that the aggregate's water absorption is within the parameters stated in (BS EN 1097-6:2000, 2000). Granite has lower water absorption capacity owing to its little porosity. However, the bonded mortar on the RCA has larger porosity that permits the aggregate to grip extra moisture in its pores than granite. The results of the specific gravity on the samples are presented in Table 4.

Table 4: Specific gravity for fine aggregate, granite and RCA

Test Samples	Specific Gravity
Fine aggregate	2.55
Granite	2.75
RCA	2.58

The values contained Table 3 indicate that the aggregate's specific gravity is within the limits of 2.4 – 3.0 stated in BS EN 1097-6 (BS EN 1097-6:2000, 2000). The RCA contains original aggregate in combination with mortar. The bonded mortar is porous and light in nature. Consequently, it was observed that the RCA's specific gravity is lower when compared to that of granite. The ACV for the granite and RCA used in this work are displayed in Table 5.

Table 5: ACV of Granite and recycled concrete aggregate

Test Samples	ACV (%)
Granite	27
RCA	22.6

The Values from Table 5 indicates that the ACV of all the aggregates are lesser than 30% value conforming to the requirement in (BS 812-112, 1990). Laboratory outcomes for the workability and splitting tensile strength conducted on the fresh and hardened concrete respectively are displayed in Table 6.

These results were the data used for analyses in the Design Expert software.

Figure 2 shows the 3-D relationship between the slump height, w/c ratio and % RCA of the concrete for the fresh concrete. It is deduced that as the percentage proportion of RCA increased, there was a reduction in slump height until at 50% RCA where the lowest slump height was recorded. With further surge in the proportion of RCA, there was an increase in slump height.

Table 6: Results for the workability and splitting tensile test on the concrete containing varying percentages of RCA and Granite.

S/No	Granite (%)	RCA (%)	W/C ratio	Slump height (mm)	Splitting tensile strength (N/mm^2)		
					7 days	14 days	28 days
1 (Control sample)	100	0	0.5	80	1.34	1.53	2.29
2	50	50	0.5	40	1.25	1.76	2.04
3	75	25	0.5	40	1.36	1.59	2.01
4	50	50	0.6	20	1.25	1.66	1.59
5	100	0	0.3	0	1.59	1.97	1.74
6	0	100	0.7	300	0.68	0.8	1.06
7	50	50	0.4	0	1.49	1.97	1.95
8	100	0	0.7	300	0.64	0.98	0.93
9	25	75	0.5	45	1.55	1.93	1.97
10	0	100	0.3	0	0.44	0.53	0.56

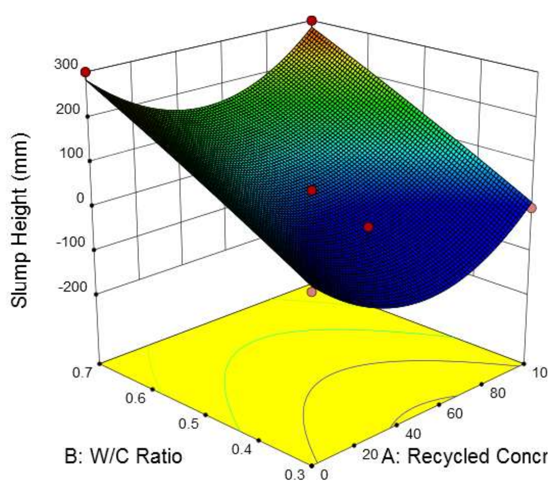


Fig. 2: Relationship between the Slump height, w/c ratio and percentage of recycled concrete.

It was also noticed that as the w/c ratio increased, the slump height of the concrete also continued to increase. The quadratic model relating slump height to the proportion of recycled concrete aggregate in the concrete and w/c ratio is given in Equation 4. This model has a p-value of 0.0007 indicating that it significantly reflects the slump height of the fresh concrete. It also has an R^2 value of 0.9273.

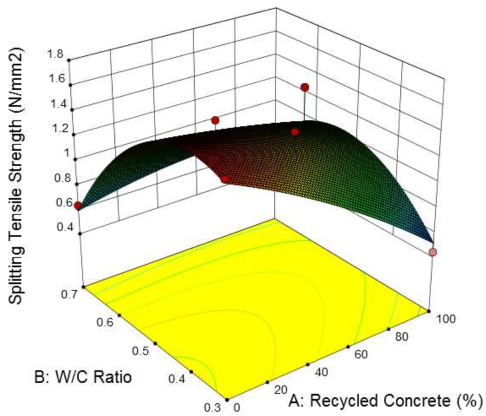
$$Slump\ height = 28.18 + 0.56A + 135.56B + 124.86A^2 - 5.14B^2 \quad (4)$$

Where: A = Recycled Concrete Aggregate;

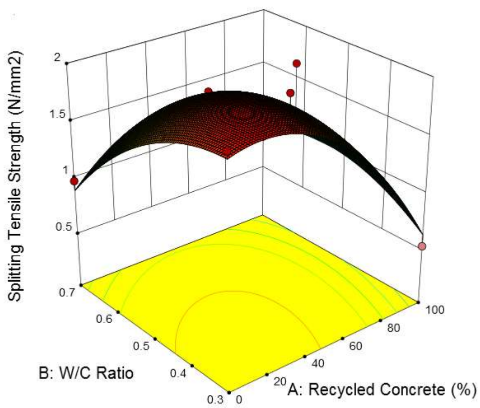
B = w/c ratio

Figure 3 shows the 3-D connection between the splitting tensile strength, w/c ratio and percentage quantity of RCA of the concrete at 7, 14 and 28 days. For all the days considered, it was discovered that with a rise in the percentage of RCA in replacement for granite, there was a consistent decrease in the splitting tensile strength with the least splitting tensile strength recorded at 100% replacement. It was also noticed that the splitting tensile strength increased with a rise in the w/c ratio until 0.5 w/c beyond which the strength began to decline for all the days considered. It was further discovered that the splitting tensile strength increased with the age of curing of the concrete samples.

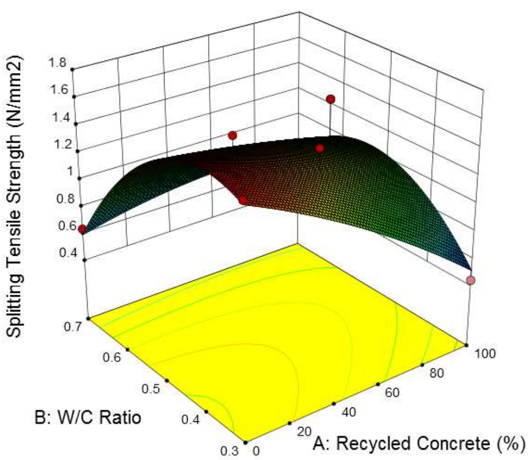
The quadratic model relating splitting tensile strength to the percentage of recycled concrete aggregate in the concrete and w/c ratio is given in Equation 5.



(a) 7 days duration of curing



(b) 14 days duration of curing



(c) 28 days duration of curing

Fig. 3: Relationship between the Splitting Tensile Strength, w/c ratio and percentage of Recycled concrete

This model has a p-value of 0.0001 indicating that it significantly reflects the splitting tensile strength of the hardened concrete. It also has an R^2 value of 0.9804.

$$Splitting\ tensile\ strength = 2.02 - 0.24A - 0.11B + 0.33AB - 0.037A^2 - 0.92B^2 \quad (7)$$

Where: A = Recycled Concrete Aggregate;

B = w/c ratio

In optimizing the proportion of Recycled Aggregate, Granite and water-cement ratio, the design was to maximize the use of the RCA and also achieve a maximum Splitting Tensile Strength while keeping the water-cement ratio in range. The optimal result shows that with 40% RCA, 60% Granite and 0.48 w/c, a slump height of 48mm and a splitting tensile strength of 2.11 N/mm^2 was achieved. The combined desirability value of the result obtained is 1.00 as presented in Figure 4. The optimal Splitting tensile strength for the combination is 7.9% lower than the control sample where 100% granite was utilized as aggregate and 40% lower than that reported for Grade M25 concrete by Akinpelu *et. al* (2019) respectively. However, the strength is in tandem with the projection for Grade M15 concrete by (Akinpelu *et al.*, 2019).

The connection between the predicted and experimental values for the splitting tensile strength is presented in Figure 5. The adequate precision value is 23.92. This is greater than the threshold of 4.0. This indicates that an appreciable signal to noise level is perceived. This signifies that the model is reliable to steer the design space, thus, validating the results obtained.

CONCLUSION

The under listed inferences were gotten from the research:

1. Recycled concrete aggregates have properties that falls within the recommended value for

coarse aggregate by BS EN 1097 (BS EN 1097-6:2000, 2000).

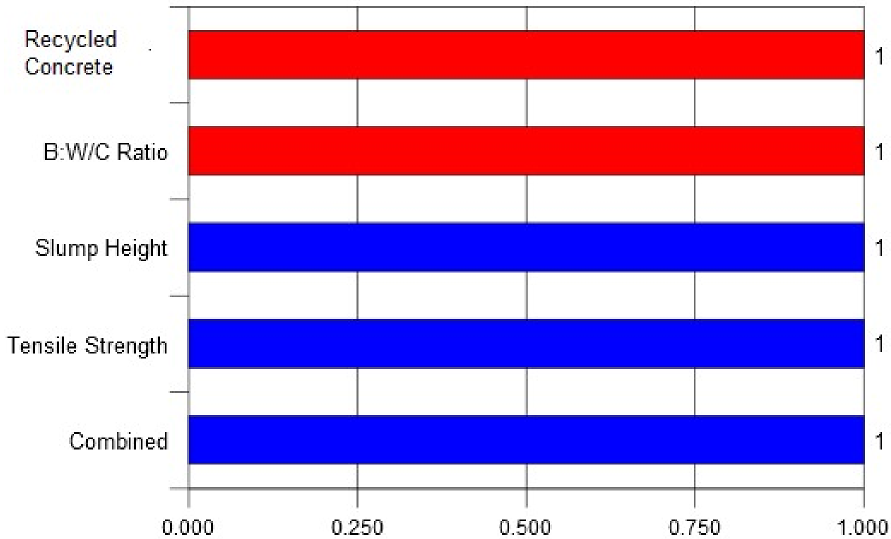


Fig. 4 Desirability value for optimum combination of RCA with Granite

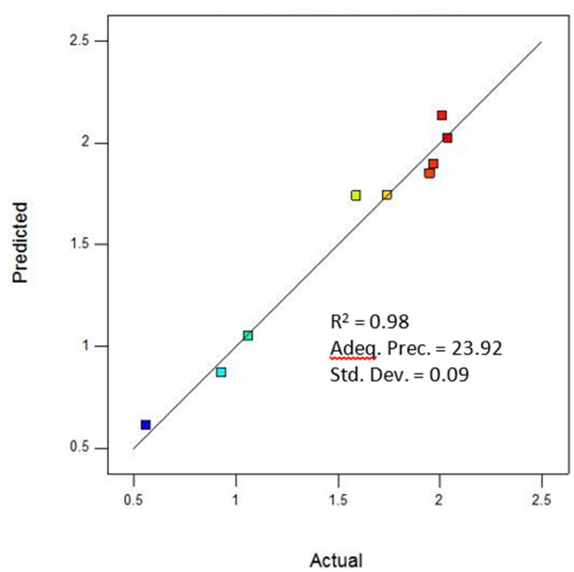


Fig. 5 Predicted versus actual splitting tensile strength

2. A surge in the percentage replacement of granite with RCA until 50% replacement brought about a decrease in slump height of concrete where the lowest slump height was recorded. With further increase in the percentage of RCA, there was an increase in slump height.
3. Increase in w/c ratio brought about a continual increase in the slump height of the concrete.
4. Increase in the proportion of RCA in replacement for granite brought about a consistent reduction in the splitting tensile strength with the least splitting tensile strength recorded at 100% replacement of granite with RCA.

5. Splitting tensile strength increased with increase in the w/c ratio until 0.5 w/c beyond which the strength began to decline for all the days considered.
6. The optimal combination from this research is 40% RCA, 60% Granite at 0.48 w/c. This gives a slump height of 48 mm and a splitting tensile strength of 2.11 N/mm^2.

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