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Strength Properties of Concrete Using Terrazzo Waste as Partial Replacement for Cement

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Abstract

Cement is regarded as the most expensive concrete ingredient. Reducing the quantity of cement used in concrete with Terrazzo Waste (TW), will reduce the cost of concrete and solve disposal and environmental challenges posed by TW. The effect of partial replacement of cement with TW in concrete was studied. The specific gravity, sieve analysis, water absorption, bulk density and moisture content tests were carried out on the aggregates. A terrazzo waste replacement of 0%, 10%, 20%, 30%, 40% and 50% by weight of cement was used to cast 150 x 150 x 150 mm concrete cubes as well as 500 x 100 x 100 mm concrete prisms. A mix ratio of 1:1.8:2.51 designed for an M30 concrete with water-cement ratio of 0.50 was used for all mixes. The weight of concrete increased with corresponding increase in the content of TW. Compressive and flexural strength tests were conducted on thirty-six (36) cubes and thirty-six (36) prisms after curing by full immersion for 7 and 28 days. The values of compressive strength ranged between 19.88 N/mm² to 37.63 N/m² while the flexural strength obtained range between 3.12 N/mm² and 4.52 N/mm² at 28days of curing. Different percentage replacement of TW satisfied different concrete grade requirement for structural design except for 50% replacement which recorded compressive strength of 19.88 N/mm². An optimum replacement level of %10 was recorded and the concrete is applicable for structural elements in buildings. Second order polynomial equations were developed for predicting compressive and flexural strength of concrete containing TW. Terrazzo waste was therefore recommended for use as a partial replacement for cement in concrete production.

Keywords: Aggregates, Cement, Concrete, Compressive Strength, Flexural Strength, Terrazzo waste.

1. Introduction

The spontaneous increase in the population of Nigeria has led to massive urbanisation and adjustments in economic policies. This has given rise to huge and capital-intensive infrastructural developments. Concrete which is made from a combination of aggregates, cement and water is the most widely utilised construction material in the world and particularly, in Nigeria. Ordinary Portland Cement (OPC) is the chief ingredient used in the production of concrete in Nigeria. The production of OPC is capital intensive demanding a lot of energy resulting in the release of carbon gases. It has been reported that the manufacture of one ton of OPC produces about one ton of CO_2 to the atmosphere (Shetty, 2008; Neville, 2000; Naidu and Pandey, 2014; Shahab *el al,* 2017). Furthermore, OPC has been reported to be the most expensive construction material in Nigeria today (Adesanya and Raheem 2007).

As a result of high cost of building materials particularly cement, engineers have been challenged to convert industrial and agricultural wastes into useful building and construction materials (Turgut & Algin, 2007; Abdullahi *el al*, 2017; Yusuf & Emmanuel, 2020). As such, several researches have sought to find alternative materials to wholly or partially replace cement in sandcrete and concrete production. Such materials include Rice husk ash, millet husk ash, corn cob ash, groundnut shell ash, fly ash, saw dust ash, and the likes (Elinwa and Mahmood, 2002; Waswa-Sabuni *et al*, 2002; Elinwa and Eje, 2004; Abdullahi, 2006; Oyetola and Abdullahi, 2006; Elinwa *et al*, 2008; Raheem and Adesanya, 2011; Neville, 2011). These materials are either industrial by-products or processed agricultural waste.

Many construction activities using terrazo as floor material are common in Nigeria today. This has resulted in the production of terrazo sludge in huge quantity. The disposal of terrazzo sludge on soils causes reduction in soil permeability and contaminates ground water when deposited along catchment areas. This will certainly lead to negative impacts on the environment (Chen *et al*, 2010). Therefore, a research into suitable and alternative use of terrazzo waste (sludge) to replace cement in concrete is of utmost importance. This research is however, focused on the utilisation of terrazzo sludge as partial replacement for cement in concrete production.

3. Materials and Methods

3.1 Materials

Cement: The Cement used was Ordinary Portland Cement categorised as grade 42.5R conforming to BS EN 197- 1 (2011).

Coarse Aggregate*:* The coarse aggregate used was crushed granite obtained from a quarry site in Pyata area of Maikunkele in Bosso Local Government, Minna, Nigeria. A maximum size of 20mm was used in the study as recommended by BS 882: Part 2: 1973. The specific gravity and water absorption recorded for the granite was 2.65 and 1.6 % respectively. The sieve analysis result shows that the granite was well graded with a Cc value of 1.38 (Neville, 2011).
River Sand*:* The fine aggregate used was fine river sand obtained from Kpakungu river, Niger state. The sand, free from clay was sieved to remove dirt and preliminary investigation was conducted in order to ascertain its suitability for use in concrete. Moisture content test, bulk density, specific gravity and sieve analysis test was carried out on the aggregate sample in accordance with BS EN 12620 (2009). The specific gravity and water absorption recorded for the sand was 2.61 and 2.78 % respectively. The sieve analysis result showed that the sand was also well graded with a Cc value of 1.02 (Neville, 2011).
Water: Potable water free from algae and deleterious substances obtained from tap of Civil Engineering Department, Federal University of Technology, Minna was used for mixing and curing. This water is suitable for concrete work as recommended by BS 3148; 1980.
Terrazzo wast*e:* The Terrazzo Waste (TW) was obtained as sludge from terrazzo works in the newly constructed Engineering Complex Extension, Federal University of Technology, Minna, Niger state. The terrazzo sludge was dried, grinded and the powder was sieved with 0.075mm sieve. X-Ray Fluorescence (XRF) results showed that the grinded powder contains SiO_2 (71.23%), Al_2O_3 (4.33%) and Fe_2O_3 (2.32%). A total of 77.88 % which is well above 70% specified by ASTM C618 for natural pozzolan.

3.2 Mixing Proportioning

Department of Environment (DOE) based on water/cement ratio and compressive strength relationships was used for mix design of concrete ingredients. The water-cement ratio used was 0.50 and a mix ratio of 1:1.8:2.51 for a M30 concrete grade was obtained. The required quantities of different ingredients as per mix design calculated using absolute volume equation (Equation 1) are given in table 1. Cubes of dimension 150 x 150 x 150 mm were produced for compressive strength test while prisms of 500 x 100 x 100 mm were produced for flexural strength test. A total of 36 cubes and 36 beams were produced respectively.

$$\frac{Ww}{1000Gw} + \frac{Wc}{1000Gc} + \frac{Wfa}{1000Gfa} + \frac{Wca}{1000Gca} + Vv = 1; \qquad (1)$$

where, Vw = volume of water, Vc = volume of cement, Vfa = volume of fine aggregate, Vca = volume of coarse aggregate, Vv = volume of air void

Table 1: Mix Composition for $1m^3$ of concrete

Ingredients	Cement	Fine aggregate	Coarse aggregates	Water
Quantity kg/m^3	410	738	1029.1	205
Ratio	1	1.8	2.51	0.5

3.3 Preparation of Test Specimens

The terrazzo waste replacement used was 0% to 50% with 10% interval. Required quantities of coarse aggregate, fine aggregate cement and TW were mixed thoroughly until the mixture was uniform. The measured quantity of water was added and mixed thoroughly until mix was of uniform consistency. The workability of the fresh concrete was determined and the concrete was cast in already buttered cube and prismatic moulds. After 24 hours, the concrete specimens were demoulded and cured in water curing tank for 7 and 28 days respectively.

Workability Tests: Slump test was carried out to determine the workability of each mix. The test was carried out in all cases in accordance with the requirements of BS 1881: Part 102 (1983).

3.4 Hardened Concrete

3.4.1 Compressive Strength Test on Sample Cubes

A 2000 kN compressive testing machine was used to crush the entire concrete cubes at 7 and 28 days respectively based on guidelines contained in BS1881, Part 116, 1983. The average crushing load of three test cubes was used to calculate the compressive strength in each case.

3.3.2 Flexural Strength Test on Sample Beams

A 1000 kN tensile strength testing machine was used to test the flexural strength of the concrete beams using the centre point loading method at 7 and 28 days respectively in accordance to specifications of BS1881, Part 118, 1983. The average crushing load of three test prisms was used to calculate the flexural strength in each case.

4. Results and Discussion

4.1 Workability of Concrete

The results of the slump of concrete prepared with different percentages of Terrazzo Waste (TW) are presented in Table 2. From the results, it was observed that slump value increased with increase in the percentage replacement of cement with terrazzo waste in the concrete mix. Since all mixes were made with the same water-cement ratio, the high surface area of the terrazzo powder ultimately leads to a reduction in the amount of mixing water to achieve a workable concrete. Thereby leading to increase in slump as TW content increases.

Table 2: Slump of Concrete containing different percentage of TW

Terrazzo waste Replacement (%)	Slump (mm)
0	5
10	8
20	12
30	12
40	14
50	20

4.2 Compressive Strength

Results of the compressive strength at 7 and 28 days curing for various percentage TW is presented in Figure 1. The results show that the compressive strength generally decreases with increase in percentage of terrazzo waste. Compressive strength in the range 33.93 - 19.88 N/mm² was recorded for replacement between 10 - 50 % against the control sample containing 0 % of TW (37.63 N/mm²). Results obtained shows that different percentage replacements conform to different grades of concrete and are applicable to different structural applications. The study moreover, arrived at an optimum replacement of 10 % corresponding to a compressive strength of 33.93 N/mm² at 28 days curing age. This result conforms with the findings of Yunusa (2011).

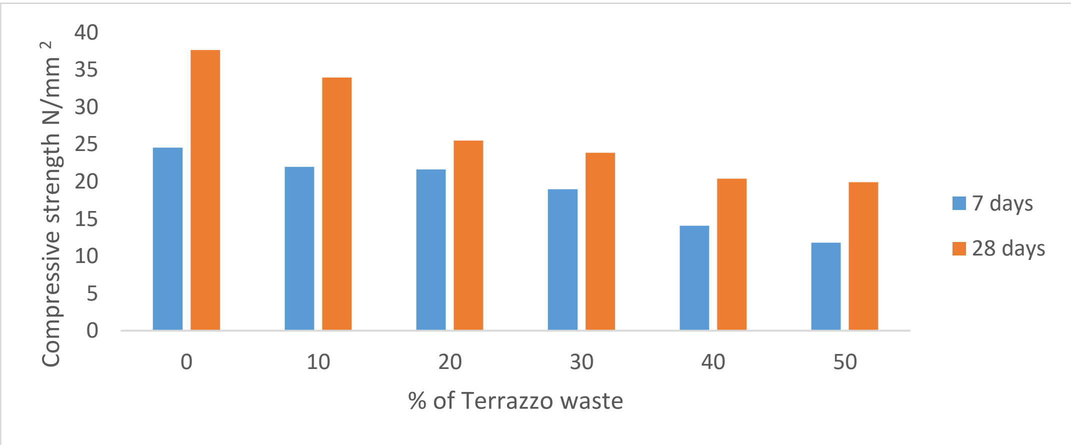

Figure 1: Compressive Strength Chart

4.3 Flexural Strength

Flexural strength results for different percentage replacement of cement with TW is presented in Figure 2. The control specimen recorded flexural strength of 4.52 N/mm². At 10 % to 50 % replacement, a flexural strength between 4.23 N/mm² to 3.12 N/mm² was recorded. It could be deduced from the result that the pattern of flexural strength follows that of compressive strength as discussed above. Concrete containing pozzolanic materials derives strength from the reaction between SiO_2 in the pozzolan and calcium hydroxide produced from the hydration of Ordinary Portland Cement (OPC). As the replacement level increases, the amount of SiO_2 also increase. This results in the reduction of C-S-H formed due to the liberation of little quantity of calcium hydroxide since small amount of OPC will now be available for hydration. This accounts for the progressive reduction in compressive and flexural strengths of concrete as the percentage of TW increased.

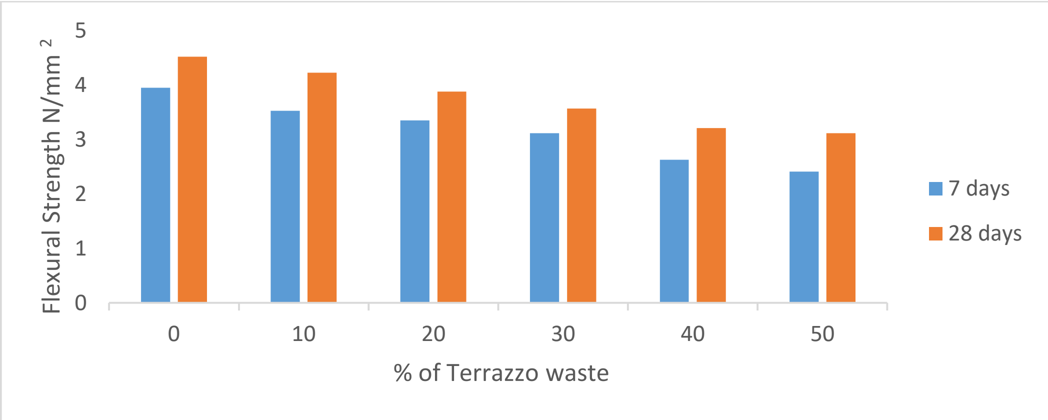

Figure 2: Flexural Strength of Concrete Prisms

4.4 Model Development

Polynomial regression model was developed using Minitab software. A second order polynomial was found to be sufficient in explaining the experimental data. % IOT was used as the predictor while the compressive and flexural strength were used as the response in each case. The Compressive Strength Regression Equation (C) obtained from a fitted line plot shown in Figure 3 is given in Equation 2. A measure S of how well the model describes the response C was 1.66. The lower the S value, the more accurate the model is in describing the response C. The compressive strength model gave a Correlation Coefficient (R) of 96.9%. This indicates that 96.9% of the variability in the compressive strength data is accounted for by the model equation. From the ANOVA results, a p-value of 0.006 was obtained which is less than 0.05 significance level. This suggests that the data possess distinct means. Furthermore, the residual vs fitted plots shown in Figure 4 does not follow a familiar pattern and depicts that the residuals are randomly distributed over the two sides of zero. Similarly, from the residual vs order plot, it is evident that the residuals do not follow a regular pattern and do not depend on each other. The normal probability plot showed that the residuals are close to the straight line. Therefore, the residuals are normally distributed. The actual compressive strength vs predicted compressive strength relationship is shown in Figure 5. The actual compressive strength graph was very close to that of the predicted compressive strength. This proves that minimal error exists between the actual and predicted compressive strength results and therefore serves as a further indication that the model is adequate in predicting the compressive strength data.

$$C = 0.0059(\%TW)^2 - 0.67(\%TW) + 38.25 \quad (2)$$

Where; C = compressive strength, %TW = percentage terrazzo waste

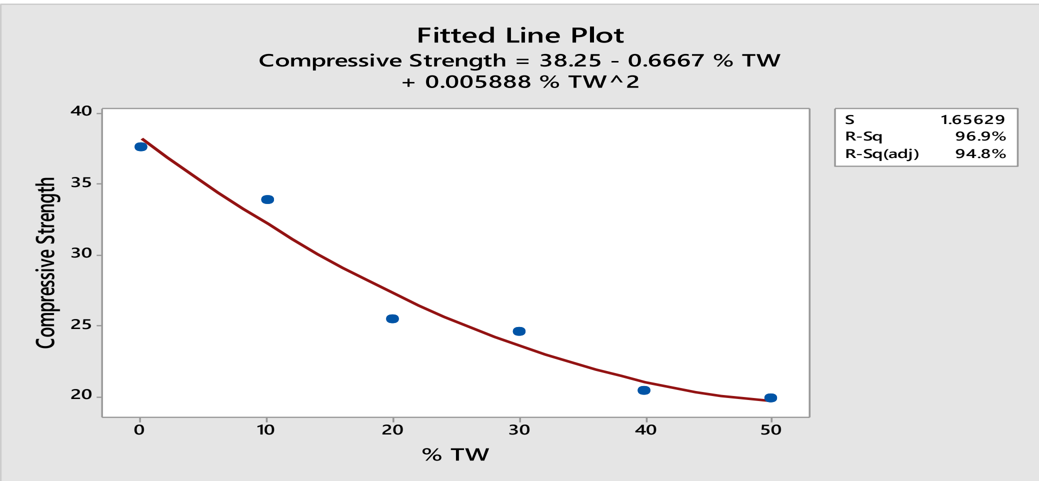

Figure 3: Fitted line plot for % TW vs compressive strength

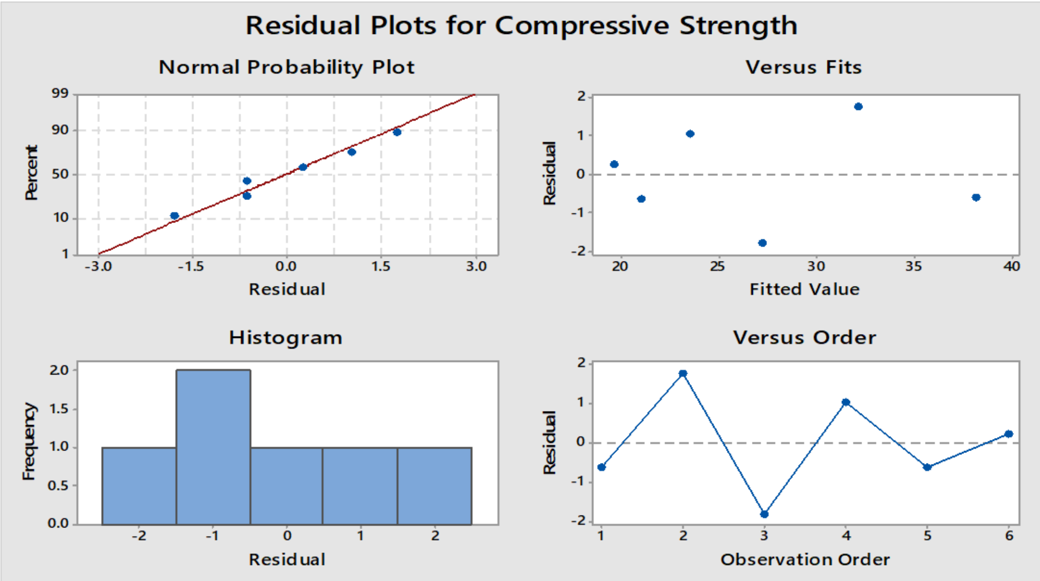

Figure 4: Residual plots for compressive strength

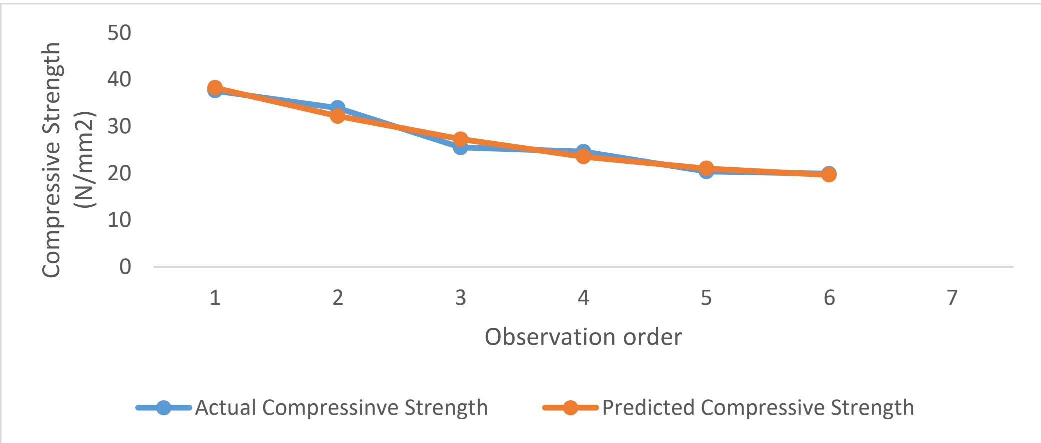

Figure 5: Actual vs predicted compressive strength relationship

The flexural strength regression equation (F) obtained from a fitted line plot shown in Figure 6 is given in Equation 3. A measure S of how well the model describes the response F was 0.068. The flexural strength model gave a Correlation Coefficient (R) of 99.1%. This indicates that 99.1% of the variability in the flexural strength data is accounted for by the model equation. From the ANOVA results, a p-value of 0.001 was obtained which is less than 0.05 significance level. This suggests that the data possess distinct means. Furthermore, the residual vs fitted plots depicted in Figure 7 does not follow a familiar pattern and depicts that the residuals are randomly distributed over the two sides of zero. Similarly, from the residual vs order plot, it is evident that the residuals do not follow a regular pattern and do not depend on each other. The normal probability plot show that the residuals are close to the straight line. Therefore, the residuals are normally distributed. The actual flexural strength vs predicted flexural strength relationship is presented in Figure 8. There seems to be very little dissonancy in the actual and predicted flexural strength results which is an indication that the model is adequate in predicting the flexural strength data with minimal error.

$$F = 0.000171(\%TW)^2 - 0.0382(TW) + 4.553 \quad (3)$$

Where: F = flexural strength, %TW = percentage terrazzo waste

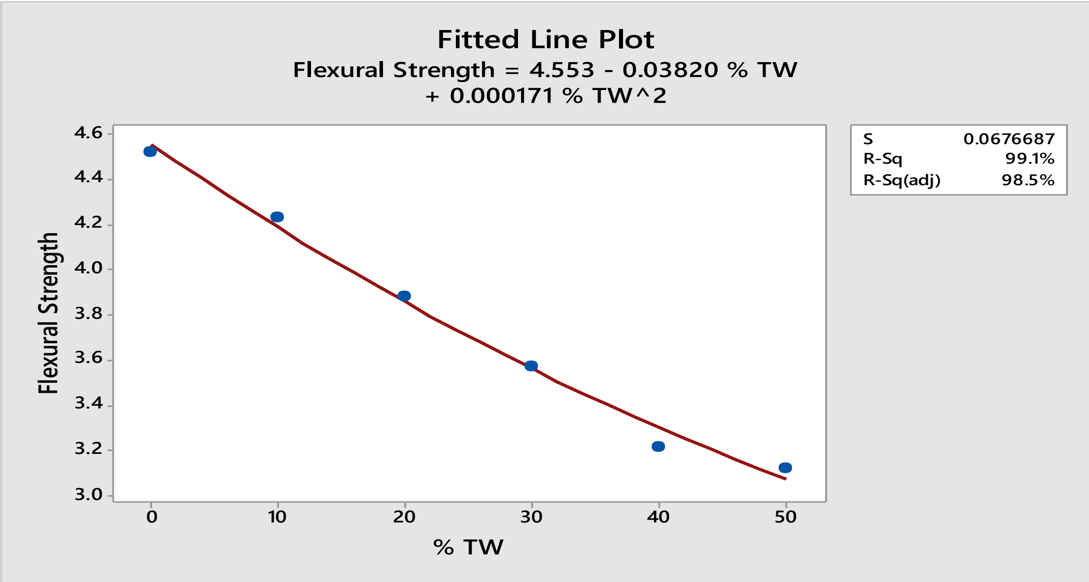

Figure 6: Fitted line plot for % TW vs flexural strength

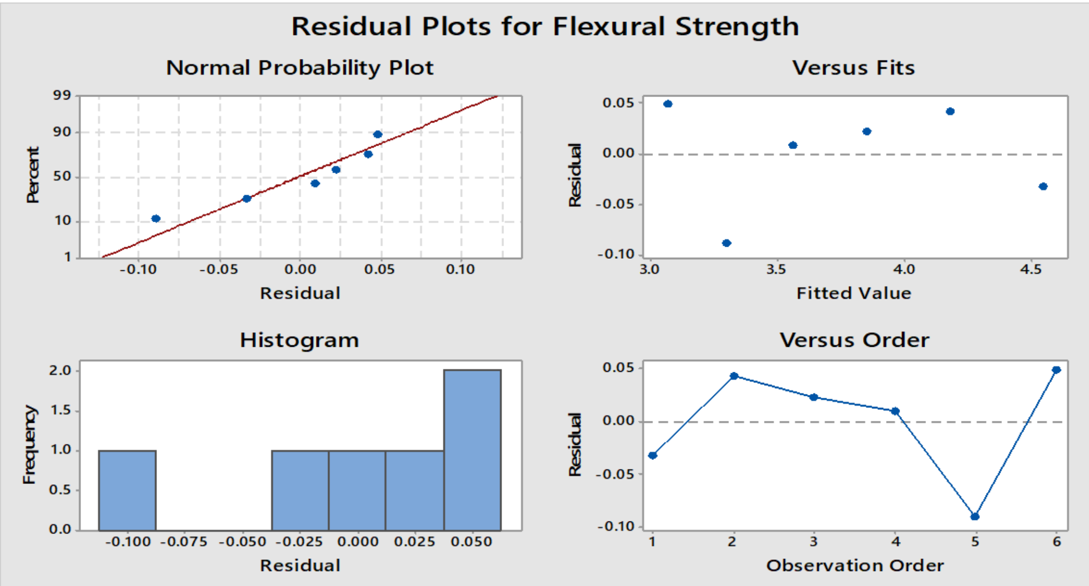

Figure 7: Residual plots for flexural strength

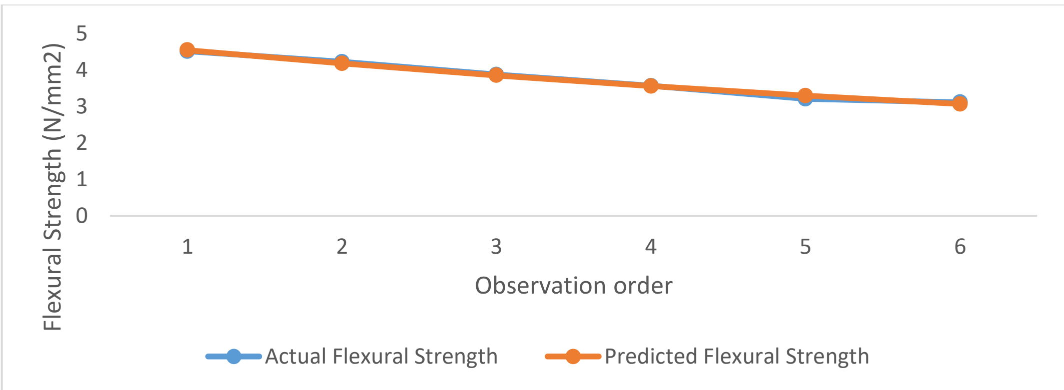

Figure 8: Actual vs predicted flexural strength relationship

5. Conclusion

Conclusions drawn from the outcome of this research include:

1) The higher the quantity of TW as partial replacement for cement, the higher the slump of concrete. Concrete with 50% terrazzo waste replacement recorded the highest slump of 20mm.
2) The compressive strength reduced with increase in the percentage of TW for 7 and 28 days cured concrete. A percentage decrease in compressive strength of concrete up to 10% exist between 0% and 10% and the concrete made with 10% terrazzo waste gave the optimum compressive strength of 33.96 N/mm^2.
3) The flexural strength also reduced with increase in the % of terrazzo waste. An optimum flexural strength of 3.53 N/mm^2 was obtained with 10 % replacement of cement with terrazzo waste.
4) Compressive and flexural strength polynomial regression model developed had R value of 96.9% and 99.1% respectively.

6. Recommendations

From the outcome of the study, the following recommendations are made;

1) Further studies should be carried out to determine the strength developments at late curing ages using TW as partial replacement for cement.
2) Other engineering properties such as the splitting tensile strength and modulus of elasticity should be examined for concrete using TW as partial replacement for cement.

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