# A Numerical Analysis of Green Sustainable Concrete Using ANOVA

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**Abstract:** Significant studies were undertaken on the use and impact on tensile along with compressive strength of the recycled concrete aggregate (RAC). However, the combined result of recycled aggregate and fly ash (FA) on tensile and compressive strength of concrete has not been modelled properly. To contribute to this area, research was carried out in combination with Fly ash and substitution per cent of natural coarse aggregates by recycled aggregates along with different water-cement ratios. This study determines whether the numerical analysis can be performed on the experimental values of strengths or not. By the checking normality, one-way analysis of variance (ANOVA) is used as working method. The predictive model for reliability is trained and tested upon the available experimental data sets. Thus, the research work briefs about the numerical analysis by statistical methods and the corresponding result analysis. The linear relationship between the Concrete mix % and with & without fly ash provides the reliability of the model. 90 days Compressive and Tensile strength at 0.38 w/c for 20% RAC & 10% FA provides the best choice among all and can be further optimized on its various combinations.

**Keywords:** Recycled Aggregate in Concrete (RAC), Fly Ash (FA), Compressive Strength, Tensile Strength, ANOVA, Reliability, Normality Test by Shapiro-Wilk.

## 1. Introduction

Every year, the building and demolition industry generates large quantities of waste materials. Usually, recycled aggregate is combined with natural aggregate once utilized in new concrete **(Pradhan and Barai, 2017)**. Natural resource scarcity may be a growing problem for the world, and it is important for reducing the effects of present deficiency and takes the step to conserve an atmosphere. To reduce this effect, the utilization of construction and demolition wastes in concrete mixtures as a substitute for Natural Resources. Recycled aggregates (RA), that may be utilized as aggregates into concrete, are often generated by C&D waste, particularly concrete waste **(Limbachiy et al., 2012)**. Concrete utilization gains importance, as a result, it protects natural resources associated with it and it removes requirement of discarding via concrete victimizing as a supply for brand spanking newer concrete or alternative applications. Recycled aggregate concrete manufactures in the same manner as typical concrete. Special care is needed when using fine RCA. Solely up to ten to twenty % fine RCA is useful.

The ANOVA method gives the variance and reliability of any experimental data with particular relations. Analysis of variance (ANOVA) refers a technique for partitioning the variability of a collection of information to perform multiple significance tests. In experiments wherever solely one issue is investigated, the analysis of variance is remarked as one-way ANOVA. In applying ANOVA, the basic assumption is that the answer is generally distributed. The response variance is divided into the variance that can be attributed to the trait (or factor) investigated and thus the variance that can be attributed to the randomness which is seen to occur naturally for the response.

Using neural networks in civil engineering, several researchers attempted to use ANOVA to forecast properties of Recycled Aggregate concrete. **Khademi et al., (2016)** applied three various methods and non-dimensional variables like further input variables, the data-driven models were studied for their accuracy. **Deshpande et al. (2014)** found the RAC compressive strength prediction was larger than the ANN and the Medium and Model Tree Non-Regression. The results show that ANN reads mostly from experiences and understands the basic domain rules of concrete strength. **Ghasem and Zahediasl (2012)** concluded that normality ought to be assessed each visual normality test. Shapiro-Wilk test, using SPSS software package, is strongly counselled by the authors. **Armstrong et al. (2002**) have stated the type of experimental style and a statistical model utilised in the study. The benefits and limitations of the suitable ANOVA techniques are also mentioned with straightforward knowledge from clinical experiments in optometry. **Parmar et al. (2013)** studied ready-mixed concrete by utilizing self-reliant sample t-tests via SPSS software. **Duan et al. (2013)** have shown that ANN has fair potential to predict compression strength of RAC made through diverse forms and origin of recycled aggregate. **Abolpour et al. (2015)** presented statistically analysed findings through concrete experiments. **Limbachiya et al. (2012)** in their research found that 30 percent RCA NA replacement to optimal replacement level and 30 percent RCA FA concrete have shown very similar performance to NA concrete. In their study, **Poon et al. (2007)** concluded that the usage for a higher proportion of recycled aggregate in reinforced aggregate is reduced by an addition of 25 to 35 percent of fly-ash and some drawbacks arising from the usage for recycled aggregates in concrete. **Kou et al. (2012)** demonstrate a durability of concrete is often enhanced by the combined effect of recycled aggregate along with fly ash. **Kou et al. (2013)** studied log term durability and mechanical characteristics of concrete over ten years and found that, elasticity modulus and compressive strength of the concrete made by 100 per cent recycled concrete aggregate was smaller compared to control concrete. **Kim et al. (2013)** reported the lower compressive and tensile strengths of concrete was caused by a high recycled aggregates percentage. **Brend (2009)** noticed the durability and strength of concrete were significantly enhanced by adding recycled aggregate and fly ash in concrete. **Saravanakumar and Dhinakaran (2013)** found that 50 per cent cement replacement with FA and 50 per cent NA replacement with RA have acceptable results by sacrificing strength around 40 to 50 per cent with a substantial cost reduction. **Ashraf (2013)** in his research found that RAC properties composed of a combination of 75 per cent NA and 25 per cent RCA showed no noticeable improvement in concrete properties. **Saravanakumar et al. (2014)** found that up to 50 per cent of NA could be substituted with RA and up to 50 per cent of cement could be substituted with FA and it has a reasonable result. The mechanical characteristics of the RAC was studied and compared with the NAC by **Frondistou-Yannas (1997).** The the RAC achieves a compressive strength of 76 per cent and an elasticity modulus of at least 60 per cent compared to NAC. **Dhir et al. (1998**) studied concrete with 100 per cent coarse and 50 per cent fine recycled aggregates has 20 and 30 per cent lower compressive strength than normal concrete. **Hansen and Narud (1983)** noticed the water-cement ratio was primarily influenced by the recycled aggregate concrete strength. If this ratio for recycled aggregate concrete equals to or larger than natural aggregate concrete, the RAC strength will be higher than natural coarse aggregate concrete and vice a versa. **Hansen and Hedegkd (1984)** stated that the addition of concrete admixtures has a lower or zero effect on the properties of recycled aggregate concrete. **Jayasuriya et al. (2018)** in their numerical study concluded that an aggregate stiffness and mortar matrix stiffness were most greatly affected by compressive strength. The present research pioneers the empirical model obtained for compressive strength and tensile strength which can be used for optimizing the proportions of a concrete mixture using any acceptable method of optimization or tool for any regression analysis. The detailed outcomes from the ANOVA model are discussed in the subsequent sections.

## 2. Research Methodology

The aim of the present research is to analyze the given data of different concrete mix having a different water-cement ratio by statistical method. The objectives of the study include -

- To check if the given experimental data is consistent and follow the Normal distribution.
- To learn a combined effect of fly ash and recycled aggregate using one way ANOVA test for the given practical data.
- To select the best choice in terms of reliability of strength of the given sampled data by deriving a mathematical equation.

The four data sets collected for 16 different types of concrete mix, for 7, 28 and 90 days of testing respectively for compressive strength and tensile strength having w/c ratio 0.38 & 0.45 are given below:

**Table.1.**Four experimental data sets based on Compressive strength and Tensile strength

| Sr. No. | Mix Designation | Compressive strength (N/mm2) of Mix A w/c ratio 0.38 | | | Compressive strength (N/mm2) of Mix B w/c ratio 0.45 | | | Tensile strength (N/mm2) of Mix A w/c ratio 0.38 | | | Tensile strength (N/mm2) of Mix B w/c ratio 0.45 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days |
| 1 | NAC | 35.64 | 46.00 | 56.75 | 32.33 | 43.22 | 52.00 | 3.2 | 3.44 | 3.7 | 3.1 | 3.28 | 3.8 |
| 2 | RAC20 | 34.07 | 45.01 | 54.00 | 31.66 | 40.33 | 50.33 | 3.16 | 3.39 | 3.8 | 3.03 | 3.22 | 3.71 |
| 3 | RAC30 | 31.84 | 42.00 | 52.29 | 28.77 | 39.70 | 48.00 | 3.03 | 3.36 | 3.74 | 2.96 | 3.15 | 3.67 |
| 4 | RAC40 | 29.01 | 40.51 | 49.45 | 27.11 | 36.11 | 45.66 | 2.99 | 3.31 | 3.71 | 2.89 | 3.04 | 3.61 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | RAC50 | 27.18 | 37.65 | 47.00 | 23.99 | 33.99 | 43.99 | 2.89 | 3.27 | 3.68 | 2.85 | 2.97 | 3.49 |
| 6 | RAC100 | 23.91 | 34.59 | 46.96 | 20.59 | 29.77 | 42.21 | 2.81 | 3.21 | 3.64 | 2.79 | 2.94 | 3.34 |
| 7 | RAC20+F10 | 32.07 | 44.00 | 57.23 | 30.33 | 38.33 | 54.99 | 2.79 | 3.16 | 3.87 | 2.64 | 2.85 | 3.81 |
| 8 | RAC30+F10 | 29.00 | 42.14 | 55.00 | 27.77 | 37.11 | 51.11 | 2.75 | 3.09 | 3.81 | 2.61 | 2.79 | 3.8 |
| 9 | RAC40+F10 | 26.58 | 39.39 | 51.73 | 25.11 | 33.99 | 47.84 | 2.71 | 2.96 | 3.77 | 2.54 | 2.77 | 3.71 |
| 10 | RAC50+F10 | 25.00 | 35.99 | 48.77 | 19.62 | 30.44 | 45.33 | 2.68 | 2.89 | 3.71 | 2.49 | 2.72 | 3.65 |
| 11 | RAC100+F10 | 20.19 | 33.25 | 47.09 | 18.22 | 27.49 | 43.62 | 2.62 | 2.82 | 3.66 | 2.41 | 2.68 | 3.53 |
| 12 | RAC20+F20 | 30.07 | 42.23 | 51.33 | 29.00 | 36.11 | 49.11 | 2.58 | 2.74 | 3.58 | 2.32 | 2.63 | 3.39 |
| 13 | RAC30+F20 | 27.99 | 38.17 | 49.99 | 25.99 | 34.65 | 45.33 | 2.53 | 2.63 | 3.52 | 2.26 | 2.59 | 3.34 |
| 14 | RAC40+F20 | 25.19 | 35.66 | 45.77 | 23.95 | 30.99 | 42.01 | 2.49 | 2.58 | 3.44 | 2.21 | 2.51 | 3.24 |
| 15 | RAC50+F20 | 22.73 | 31.25 | 41.33 | 18.33 | 27.99 | 38.99 | 2.43 | 2.53 | 3.39 | 2.19 | 2.46 | 3.01 |
| 16 | RAC100+F20 | 20.44 | 28.77 | 39.33 | 17.03 | 25.77 | 34.11 | 2.36 | 2.47 | 3.31 | 2.01 | 2.41 | 2.87 |

Table 1 summarizes the concrete mechanical properties by means of compressive and tensile strength. It shows the experimental results conducted on Natural Aggregate Concrete (NAC) & concrete having recycled aggregate and fly ash with w/c 0.38 & 0.45 for compressive and tensile strength of concrete. Concrete was tested at 7 days, 28 days& 90 days of curing. In the first stage, the naturally occurring aggregate was replaced with recycled coarse aggregate by 20%, 30%, 40%, 50% & 100% and the test was performed. In the second stage, the naturally occurring aggregate was replaced with recycled coarse aggregate and cement was replaced with industrial waste material fly ash in 10% & 20% by weight of cement.

## 3. Statistical Data Analytics

This section includes three major analytics which determines the infer underlying the data sets. For hypothetical statements, the level of significance is 5% and the decision rule is- if any of the significant (p) value is greater than 0.05, then accept the given Null hypothesis H0, otherwise reject it. The details of the analytics and the respective interpretation are given below:

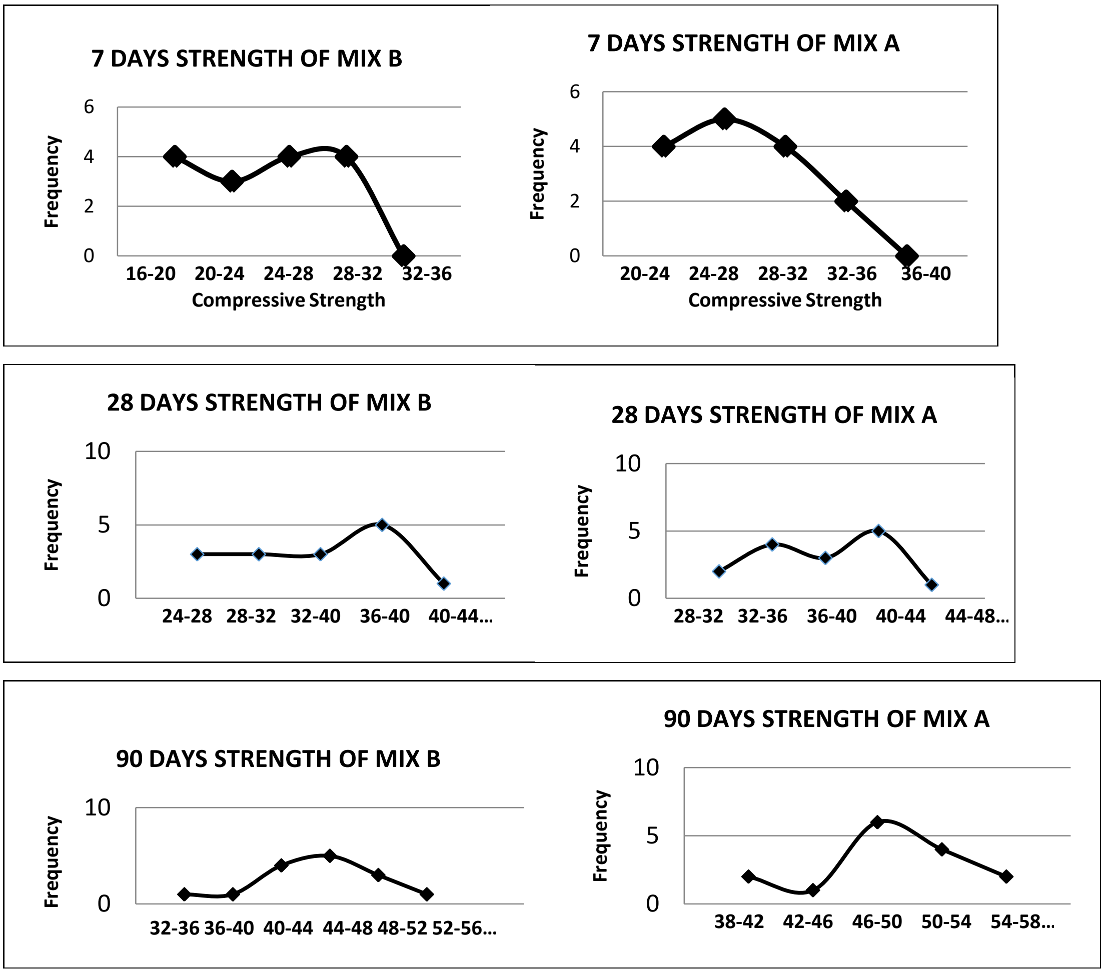
**3.1. Coefficient of variation:** Based on the ratio of dispersion (Standard Deviation) and central tendency (Arithmetic Mean) values, the coefficient of variation defines the comparative consistency of the data set. Low is the coefficient value and high is the consistency.

**Table. 2.** Coefficient of variation based on Compressive strength and Tensile strength

| Sr. No. | Mix Designation | Compressive strength (N/mm2) of Mix A w/c ratio 0.38 | | | Compressive strength (N/mm2) of Mix B w/c ratio 0.45 | | | Tensile strength (N/mm2) of Mix A w/c ratio 0.38 | | | Tensile strength (N/mm2) of Mix B w/c ratio 0.45 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days |
| 1 | **Arithmetic Mean** | 27.56 | 38.54 | 49.63 | 24.99 | 34.12 | 45.91 | 2.75 | 2.99 | 3.65 | 2.58 | 2.81 | 3.50 |
| 2 | **Standard Deviation** | 4.56 | 5.02 | 5.05 | 5.00 | 5.04 | 5.23 | 0.25 | 0.33 | 0.16 | 0.33 | 0.27 | 0.28 |
| 3 | **Coefficient of Variation%** | 16.55 | 13.03 | 10.17 | 19.99 | 14.77 | 11.39 | 9.17 | 11.09 | 4.36 | 12.88 | 9.55 | 8.07 |

The standard deviation could be an outline live of the variations of every observation from the mean. The mean and variance of a collection of information describe the central tendency (the average value) and therefore unfold a collection of data. Detail analysis of the coefficient of variation for all the experimental data is presented in Table 2. Both for Tensile and Compressive strength, Coefficient of variation for Mix A is more consistent as compared to Mix B. Internally, Coefficient of variation, in each set, 90 days composition stands least and hence most consistent, as compared to 7 and 28 days, Tensile strength mixes are low as comparing with compressive strength mixes. Tensile strength of Mix A Ratio 0.38 for 90 days, stands least among all the other and hence seems to be most consistent. Tensile strength of Mix B Ration 0.45 for 90 days stands second least among all the other and hence seems to be next most consistent.

**3.2. Normality test:** This test is conducted on four data sets, which includes two for Compressive and Tensile strength each. Based on frequency curves, the following are the graphs for the two data sets given in Figure 1 (a) for Compressive Strength for Mix A Ratio 0.38 and Mix B Ratio 0.45 respectively.

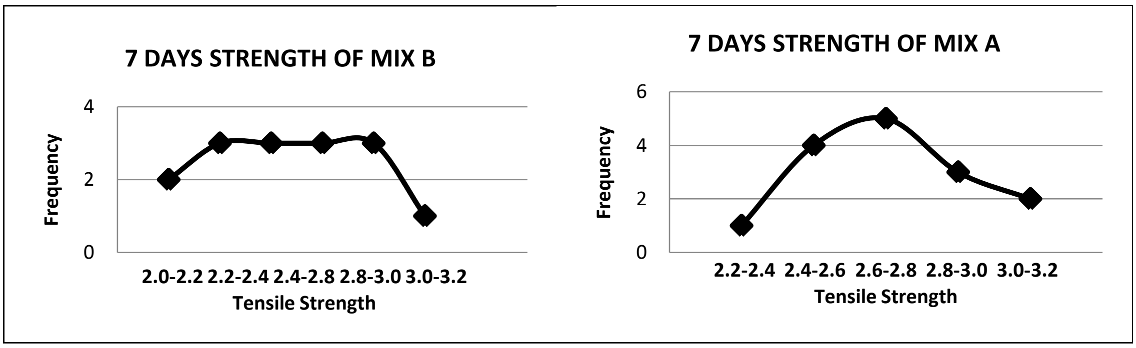


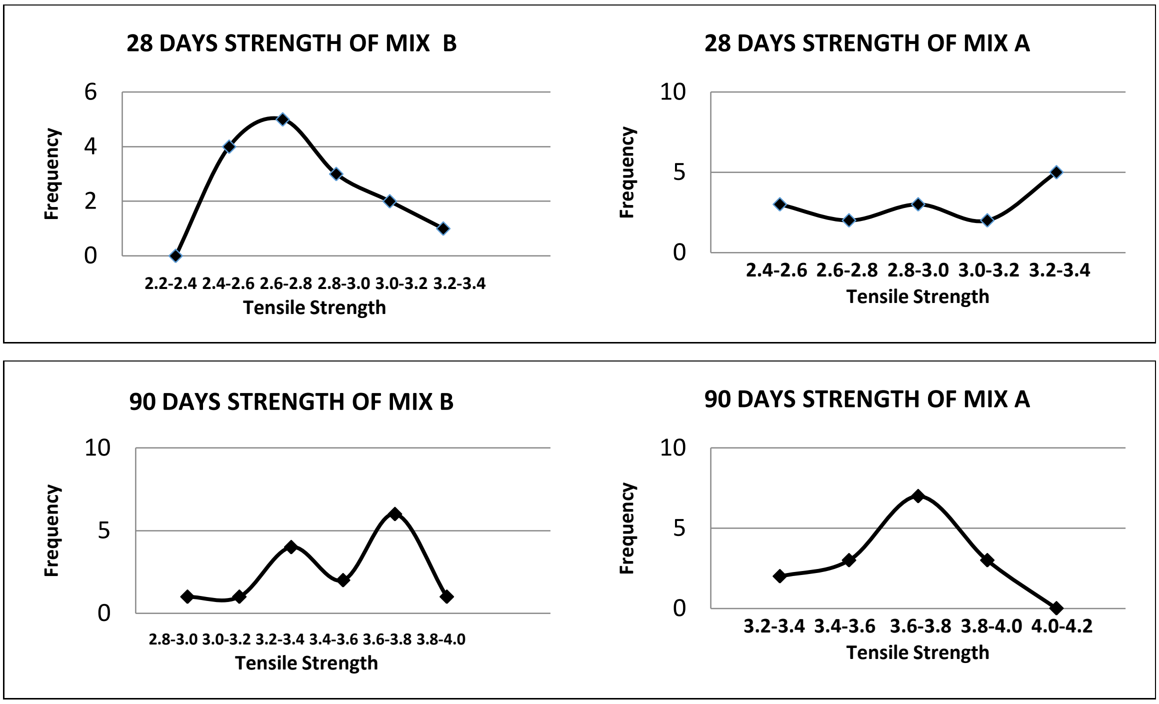

Compressive Strength
Mix A Ratio 0.38

Compressive Strength
Mix B Ratio 0.45

**Figure 1.(a).**Normality curves for the two compressive strength data sets

Figure 1(b) reflects frequency curves. Following are the graphs for the two data sets given for Tensile Strength for Mix A Ratio 0.38 and Mix B Ratio 0.45 respectively.






Tensile Strength Mix A Ratio 0.38 Tensile Strength Mix B Ratio 0.4

**Figure 1. (b). Normality curves for the two tensile strength data sets**

Fig.1 (a & b) shows that Compressive and Tensile strength of Mix A at 90 days reflects the bell shape curve to support the normality test. For the results of Tensile strength test, Mix A is the best case to support the normality curve.

**Normality test by Shapiro-Wilk:** The normality curve obtained above seems to be inadequate to reveal the normality test. As recommended by **AsgharGhasem and Saleh Zahediasl (2012**), Table No.3 provides the significant values obtained using the SPSS package.

At 5% level of significance, the hypothetical statements under consideration are:

$H_0$: The data follow the normal distribution vs $H_1$: The data do not follows normal distribution.

**Table. 3.** Significant values for Normality test by Shapiro-Wilk Test

| **Shapiro-Wilk Test** | **Compressive strength (N/mm$^2$) of Mix A w/c ratio 0.38** | | | **Compressive strength (N/mm$^2$) of Mix B w/c ratio 0.45** | | | **Tensile strength (N/mm$^2$) of Mix A w/c ratio 0.38** | | | **Tensile strength (N/mm$^2$) of Mix B w/c ratio 0.45** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days |
| **Statistics** | 0.978 | 0.971 | 0.966 | 0.941 | 0.976 | 0.981 | 0.969 | 0.927 | 0.932 | 0.964 | 0.965 | 0.905 |
| **Significant value** | 0.946 | 0.852 | 0.773 | 0.366 | 0.918 | 0.972 | 0.820 | 0.216 | 0.264 | 0.731 | 0.761 | 0.098 |

Significant values for Normality test by Shapiro-Wilk test are presented in Table 3. Since all the Significant values are greater than 0.05, we have enough evidence that all the data sets support normality test.

**3.3. ANOVA Test:** Since all the data sets have passed the normality test, the next stage is to perform ANOVA one way at 5% level of significance. To test the influence of different fly ash composition (treatment effect), and the design specification to perform one way ANOVA are

(i) Each data set is based on the no. of days of curing at 7, 28 and 90 days respectively.

(ii) The three treatments under consideration are RAC, RAC+F10 and RAC+F20. Here F10 and F20 are the partial replacement of cement with fly ash.

(iii) Each RAC combination has 5 replications RAC20, RAC30, RAC40, RAC50 and RAC100.

At 5% level of significance, the hypothetical statements under consideration are:

$H_0$: There is no significant difference between the three sets of treatments for given no. of days vs $H_1$: There is some remarkable difference between the three sets of treatments for given no. of days.

**Table. 4 .**Significant values for ANOVA Test

| Statistics | Compressive strength ($N/mm^2$) of Mix A w/c ratio 0.38 | | | Compressive strength ($N/mm^2$) of Mix B w/c ratio 0.45 | | | Tensile strength ($N/mm^2$) of Mix A w/c ratio 0.38 | | | Tensile strength ($N/mm^2$) of Mix B w/c ratio 0.45 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days |
| **F-Statistics** | 1.183 | 1.457 | 2.927 | 0.683 | 1.531 | 2.640 | 31.46 | 54.94 | 19.92 | 60.48 | 41.89 | 13.31 |
| **Sig. value** | 0.340 | 0.271 | 0.092 | 0.524 | 0.256 | 0.112 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **$H_0$ Decision** | Accept | Accept | Accept | Accept | Accept | Accept | Reject | Reject | Reject | Reject | Reject | Reject |

Significant values for ANOVA test are presented in Table 4. Since all the significant (p) values for Compressive strength are greater than 0.05, we have enough evidence to accept $H_0$ and conclude that there is no remarkable difference between the three sets of treatments for given no. of days. The mix of fly ash and its variant do not have any significant impact. On the other hand, since all the significant (p) values for Tensile strength are smaller than 0.05, we have enough evidence to reject $H_0$ and accept $H_1$. To conclude that there is some significant difference between the three sets of treatments for given no. of days. The mix of fly ash and its variant have a significant impact.

The post ad-hoc Turkey test reflects that in case of Tensile strength of both the Mix for 90 days composition showed significant variation is shown between the set of RAC without fly ash and RAC with F20. Similarly significant variation between the set of RAC with fly ash F10 and RAC with fly ash F20. Internally RAC without fly ash and RAC with F10 both the cases stand without any internal variation. These signify that RAC without fly ash and RAC with F10, both combinations are not too much effective as compared to the remaining two combinations.

**3.4. Model Building for Reliability of Strength**: The significant variation in the Tensile strength, due to the fly ash for 90 days in both the mixes, is future studied for their reliability of strength. The predictive model is trained using the first four data point of RAC20, 30, 40 and 50 respectively and then at last RAC100 is tested. The $R^2$ value and the error between the actual value and the predicted value are studied. The minimizations in absolute error % provide the optimum solution regarding the reliability of the Tensile strength.

**Table 5:**Model Building details

| Statistics | Tensile strength ($N/mm^2$) of Mix A w/c ratio 0.38 for 90 days | | | Tensile strength ($N/mm^2$) of Mix B w/c ratio 0.45 for 90 days | | |
|---|---|---|---|---|---|---|
| | **RAC** | **RAC+F10** | **RAC+F20** | **RAC** | **RAC+F10** | **RAC+F20** |
| **Equation** | y = -0.003x + 3.869 | y = -0.005x + 3.972 | y = -0.006x + 3.71 | y= -0.007x + 3.872 | y= -0.005x + 3.942 | y= -0.012x + 3.674 |
| **$R^2$ Value** | 0.965 | 0.994 | 0.992 | 0.939 | 0.929 | 0.901 |
| **Actual value of RAC100** | 3.64 | 3.66 | 3.31 | 3.34 | 3.53 | 2.87 |
| **Predicted value of RAC100** | 3.569 | 3.472 | 3.65 | 3.172 | 3.442 | 2.479 |
| **Absolute Error %** | 7.10% | 18.80% | 34.00% | 16.80% | 8.8% | 39.00% |

The significant variation in the Tensile strength, due to the fly ash for 90 days in both the mixes is future studied and presented in Table 5. All the six models reveal the linear relationship between waste mix and the without/with fly ash composition. All the $R^2$ values are above 0.90 which provide very good reliability of the model to predict the future value and avoid the over-fitting of the data. The absolute error percentage in case of without fly ash in case of Mix A is least and hence it is one of the best choices. Similarly, the absolute error percentage in case of fly ash F10 in case of Mix B is least and hence it is also one of the best choices. Thus, the error minimization reflects the optimum choice of the utility of fly ash composition in case of both the mixes.

**4. Conclusion**

The verticals and horizontals of statistical measures provide the insights for Recycled Aggregate in Concrete for reuse of materials in civil construction work. The major highlights are as follows-

i. The Compressive strength is ineffective in case of fly ash composition and it was less than 30%. This was verified by the facts and figures of the coefficient of variation and ANOVA one way test.

ii. Coefficient of variations for Tensile strength especially in the case of 90 days stood consistent.

iii. All the data set were passed in the normality test performed by Shapiro-Wilks test. Normality using graph was not enough for the normality test.

iv. ANOVA one way for the fly ash composition especially in case of Tensile strength for both the mixes for 90 days showed enough variation and was further tested for its reliability.

v. All the above four points reflect the vertical of the data sets. For horizontal measure, the linear relationship between the waste mix % and the without/with fly ash provided the reliability of the model.

v. The absolute error values in case of Tensile strength of mix A, without fly ash and in Tensile strength of mix B, with fly ash F10 seemed to be the best choice in terms of reliability of it’s strength.

Thus the 90 days mixes for Tensile strength provides the best choice among all and can be further optimized on its various combinations.

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