DURABILITY CHARACTERISTICS OF FLY ASH /SILICA SAND WITH FULL FACTORIAL DESIGN

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When the sand can no longer be reused in the foundry, it is removed from the foundry and this high quality silica sand in large volumes is used in making concrete as partial replacement of fine aggregate. In this paper investigations were carried out on the mechanical properties and durability studies of concrete by adopting silica sand and fly ash during the formation of concrete where, flyash is used as a partial replacement material of cement. Silica sand (SS) or foundry sand (FS) is incorporated (0%, 25% and 50%) along with fly ash (FA) in different proportions (0% and 25%) with water – cement ratio (w/c) as 0.5. The outcomes indicated that the inclusion of FA and SS improved the compressive as well as tensile strength of material. The study reveals the feasibility of using spent foundry sand as a partial replacement of M-sand and also that full factorial design method is a reliable tool to arrive the conclusion that the FA and SS can be replaced with 25% effectively. The statistical software was used with full factorial design to predict the values and to validate the results with true values.

Keywords: *Silica sand (SS), Fly ash (FA), Foundry sand (FS), Mechanical properties, durability, factorial design*

Highlights:

- *Full factorial design was adopted to evaluate the strength of concrete*
- *Mechanical and durability of concrete was studied to know the behavior of concrete*
- *Compressive and tensile strength of concrete was estimated using Minitab17 statistical software*
- *The regression equation was derived for the various strength of concrete using by products*

1. Introduction

Concrete is one of the most essential material utilized in the development of structures, which mainly consists of cement, fine aggregate, coarse aggregate and water. Utilization of waste byproducts has become a common part in the production of concrete to develop the sustainability and durability of the structures [1, 2]. The river sand is used as the fine aggregate which is in high demand in the present scenario. To overcome this scarcity, waste byproducts are introduced during the manufacturing of concrete. The high – volume fly ash concrete was found to be more durable and effective in the construction industry when compared with the concrete made up of ordinary Portland cement. The usage of fly ash in the cementitious material was considered between 50% to 60% of its mass [3]. Many researchers have studied on the waste byproducts which are likely to be utilized as the fractional swap material for the normal sand such as offshore sand, shore sand, quarry dust, washed soil, waste foundry sand, fly ash [4, 5]. Fly ash is used as one of the byproducts in the construction industry, which is obtained from coal from the thermal power plants. Many researchers have done the study on developing the strength of concrete and showed that the material act as a valuable product which can be used as a replacement material [6]. An experiment was carried out using the stone dust under various curing methods such as hot water, autoclaving and in normal condition. It was observed that under autoclave up to 40% replacement of stone dust gave the similar compressive strength results when related with conventional mix [7]. Strength and durability of concrete were evaluated by using the crushed fine aggregate, bottom ash and fine recycled aggregate as a sandy material during the production of concrete. From the investigation, it was found that usage of stone dust and bottom ash gave the higher strength in concrete, better resistant to chloride ion penetration and performing in low drying shrinkage [8]. Sewage sludge ash was used in the making of concrete. Based on the strength, several tests were conducted in mortars with the usage of sewage sludge ash and it was observed that 25% and 50% gave lower results with the other references which showed a constructive result related to the pozzolanic activity [9]. Many researches have also studied on the bottom ash to estimate the performance of concrete [10, 11]. Bottom coal ash was used in the concrete as a replacement with varying proportions. It was noted that 50% of bottom ash gave the satisfactory compressive results and it can be used for the structural application [12]. The effect of waste foundry sand was studied to know the micro – structural properties and durability parameters. It was observed that there was a good resistance to carbonation and chloride penetration by adopting

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the foundry sand [13]. Foundry sand was used in making the asphalt concrete. It was observed that by using 10% of foundry sand was found to be optimum [14]. Waste foundry sand was used as a replacement material in the concrete to evaluate the water absorption and void ratio. Tests were conducted after the curing period of 28 and 56 days, further it was detected that using 5% foundry sand, the water absorption was found to be higher when compared with the normal concrete at the time period of 56 days. It was noted that by adding 10% and 15% there is a decrease in the absorption ratio. More than 5% of foundry sand as a replacement, it was found that there is a decrease in void ratio with respect to aging [15]. The effect of foundry sand was studied in the concrete as a partial replacement material up to the age of 90 days. Further, they have adopted various proportions such as 0%, 25%, 50%, 75% and 100% with different sands namely white sand and waste sand. From the results, it was observed that by comparing with white sand the strength was quite similar to the waste sand with respect to increase in proportions [16].

2. Experimental program

2.1 Materials

Cement During the production of concrete the pozzolana portland cement is used as a binding material. Specific gravity of cement was 3.00 and was tested as per [17]. The physical and mechanical properties of cement are represented in the Table 1.

Fine aggregate Normal sand was used in making the concrete and SS was used as partial replacement material. The specific gravity of normal sand was 2.28 and for SS was 2.62 as per [18]. The Table 2 represents the granulometric characteristics of aggregates.

Coarse aggregate 20 mm size aggregates were used which was available easily in the market and it was tested as per [18] and found that specific gravity was 2.22.

Fly ash Fly ash class F was obtained from Ennore, Chennai. The specific gravity of fly ash is 2.50. The characteristics of fly ash was represented in the Table 3.

Concrete M25 grade was considered and set with 0.5 w/c as per [19] by using two byproducts. SS was used as a partial replacement material for normal sand with varying proportions such as 0%, 25% and 50%. Cement was replaced by FA with different ratio's such as 0% and 25%. The various mix proportions of concrete with FA and FS are represented in the Table 4.

Table 1

The physical and mechanical properties of cement

Physical Characteristics	Values obtained
Particle size range	7.9 μm to 35 μm
Normal consistency	30.26%
Initial setting time	160 minutes
Final setting time	315 minutes
Fine modulus	3.1%
Compressive strength, 7 days	36.2 N/mm²
Compressive strength, 28 days	52.45 N/mm²

2.2 Preparation of material

To study the effect of FA and SS in concrete with different proportions. The cube specimen was prepared for the size of 150 mm x 150 mm x 150mm by having 0.5 w/c. It was cured and tested at different curing periods such as 28, 56, 90 days. The specimens were allowed to dry in order to have the decrease in void content. Several tests were directed to study the strength parameters of the concrete such as mechanical and durability.

For the conventional concrete the proportions are taken as cement - 370kg/m³, fine aggregate – 600 kg/m³, coarse aggregate – 1150 kg/m³.

Table 2

Granulometric characteristics of fine aggregate

IS Sieve (mm)	Weight retained (g)	Percentage weight retained (%)	Cumulative percentage weight retained (%)	Percentage passing (%)
10	0	0	0	100
4.75	50	5	5	95
2.36	20	2	7	93
1.18	30	3	10	90
0.600	320	32	42	58
0.425	232	23.2	65.2	34.8
0.300	275	27.5	92.7	7.3
0.150	70	7	99.7	0.3

Table 3

Characteristics of fly ash

Chemical properties		Physical properties	
Constituents	Percentage (%)	Description	Value
SiO_2	60.48	Specific gravity	2.50
Al_2O_3	28.15	Colour	Dark grey
Fe_2O_3	2.98		
CaO	0.86		
K_2O	1.63		
MgO	1.02		
Na_2O	0.68		
L.O.I	1.19		

Table 4

Mix proportions of concrete

Mix	Binder (kg/m^3)		Fine aggregate (kg/m^3)		Coarse aggregate (kg/m^3)
	cement	FA	Sand	SS	
M 1 – Control concrete	370	-	600	-	1150
M 2 - 0% FA with 25% SS	370	0	450	150	1150
M 3 - 0% FA with 50% SS	370	0	300	300	1150
M 4 - 25% FA with 0% FS	277.5	92.5	600	0	1150
M 5 - 25% FA with 25% SS	277.5	92.5	450	150	1150
M 6 - 25% FA with 50% SS	277.5	92.5	300	300	1150

2.3 Methods of testing

2.3.1 Compressive strength

The specimens of size 150 mm x 150 mm x 150 mm were cast and testing was carried out in compression testing machine as shown in the Figure 1. The experiments were conducted at the age of 28, 56 and 90 days as per [20].

Fig. 1 - Compressive strength test

2.3.2 Tensile strength

It was tested on the compression testing machine (CTM). The specimen of size 100 mm x 200 mm was cast and experimented after the curing period of 28 and 90 days as per [21]. The cylinder specimen was placed in the CTM between the two plates and the load was applied along the longitudinal section as shown in the Figure 2.

Fig. 2 - Tensile strength test

2.3.3 Water absorption

The cube specimen was cast to a size of 150 mm x 150 mm x 150 mm and tested as per [22]. The cube specimen was immersed in water and the curing was done for a period of 90 and 180 days and weighed. Further, it was dried at a temperature of 105°C and it was weighed. From this, the saturated water absorption can be determined.

2.3.4 Acid attack

The acid test was conducted as per [23], the cube specimen was cast for a size of 150 mm x 150 mm x 150 mm. The specimen was prepared and immersed by a 5% of the Nitric solution by volume added to water and cured for a period of 90 and 180 days as shown in the Figure 3.

Fig. 3 - Acid attack test

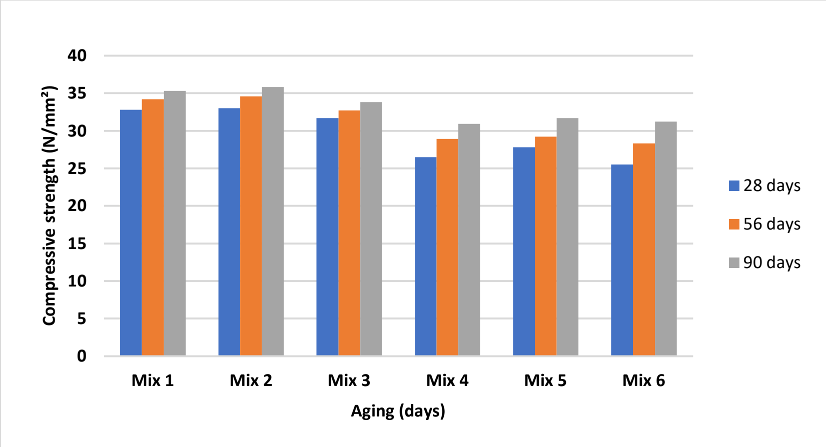


Fig. 4 - Compressive strength verses Aging

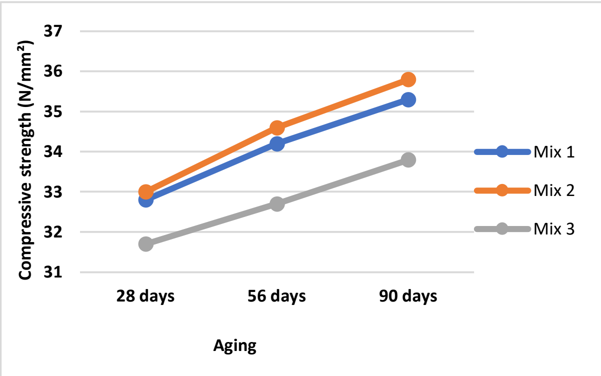


Fig. 5 - Compressive strength verses 0% FA with varying SS

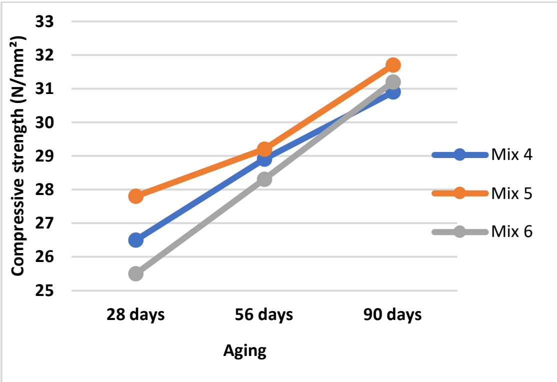


Fig.6 - Compressive strength verses 25% FA with varying SS

3. Results and discussion

3.1 Compressive strength

The compressive strength (CS) of concrete was found in all the mixtures with different curing periods. Figure 4 shows the CS of concrete with respect to varying proportions of FA and SS. This helps to know the effect of FA and SS which is embedded in material in developing the strength of concrete. From the outcomes, it was detected that the strength of the concrete increases with ages, using varying SS with 0% of FA, the mix 2 gave the optimum results when compared with mix 1. Similarly, using 25% of FA with varying SS, mix 5 gave the better result when compared with mix 1. It is also suggested that SS and FA can be used as a partial replacement material for the river sand and cement during the preparation of concrete. At 56 days in the mix 1 there was a variation of 4.09% . when compared with 28 days strength. Similarly, at 90 days, there was an increase in variation of about 3.11% with 56 days. In mix 2 and mix 3, it was noted that the strength gradually develops with a slight variation of 4.62% and 3.05% at 56 days when compared at 28 days. Similarly, there is a variation of 4.79% and 9.89% at 56 days in mix 5 and mix 6. It was observed that there is an increase in strength at 25% of SS with 0% of FA (mix 2) and 25% of FA with 25% of SS (mix 5) and found to be optimum. The increase in strength may be due to the change in particle size of SS and the reduction in size of FA particles will have a huge amount of silica content when compared with ordinary cement which results in pozzolanic action by improving the strength with increase in days. The surface area of fine particles of FA and SS would have reduced the w/c gel in the matrix where that would have affected the binding process of the aggregates [24,25]. Figure 5 and 6 denotes the CS with varying proportions of FA with SS.

3.2 Tensile strength

The tensile strength (TS) of concrete was evaluated for all the different proportions from mix 1 to mix 6. Figure 7 shows the TS of concrete with respect to varying proportions of FA and SS. Initially, there was an increase in strength with 0% of FA and it was found that mix 2 gave the best results when compared with mix 1. Similarly, in addition to 25% of FA with 25% of SS gave the better results when compared with mix 1 and further there was a slight reduction in the strength of concrete with the addition of SS. The variation of strength was found to be within 10.55% with respect to the compressive strength. From the

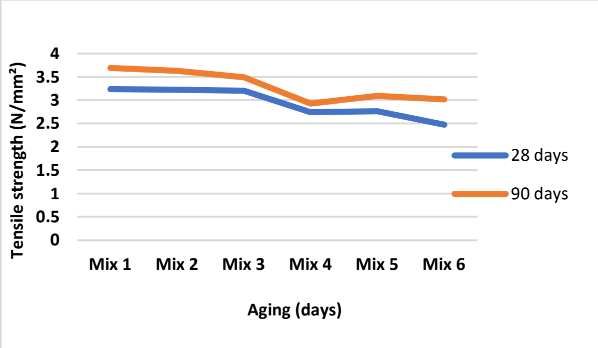


Fig. 7 - Tensile strength verses Aging

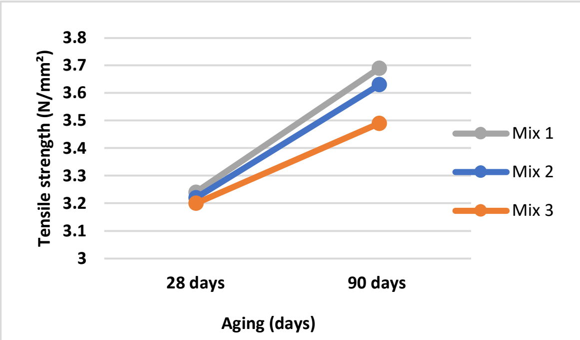


Fig. 8 - Tensile strength verses 0% FA with varying SS

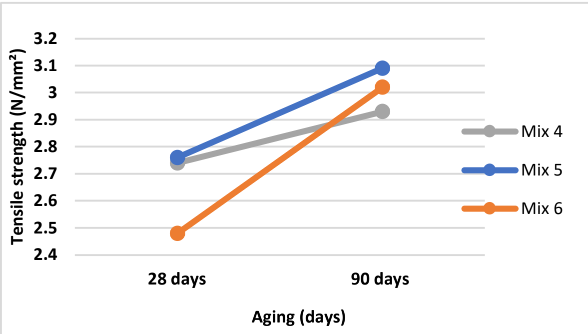


Fig. 9 - Tensile strength verses 25% FA with varying SS

results, it was observed that using 50% of SS as a partial replacement material for fine aggregate was found to be comparable with mix 1 result. It is also noted that inclusion of SS declines the thickness of concrete and where the strength of concrete also gets reduced. Due to improper hydration and insufficient binding of inert particles, the strength reduces. Comparable outcomes of consistent increases in strength at uniform higher replacement levels up to 60% of SS have been summarized with maximum strength with different mixes [26]. Figure 8 and 9 represents the tensile strength with varying proportions of FA with SS.

3.3 Water absorption

For the varying mixes, it was conducted and from the result, it was observed that there is a growth in the percentage of water absorption with rise in time period and the same is presented in the Figure 10. It was observed that, there is a variation of 6.54% in the mix 2 when related to mix 1. Similarly, in the mix 3 it was found that 6.96% in higher variation when compared with mix 2. With the presence of FA, there was an increase in variation of 9.09% and 8.33% in mix 5 and mix 6 respectively.

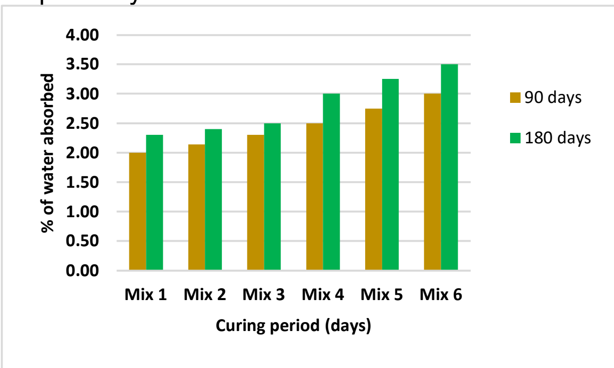


Fig. 10 - Percentage loss in water absorption

3.4 Acid attack

The compressive strength of the specimen was determined and from the result, it was detected that the strength of concrete gradually decreases with the increase in time and was presented in the Figure 11. From the observation, it was found that in mix 2 and mix 5 there is variation of about 4.26% and 4.55% with 25% of SS. Similarly, in the mix 3 and mix 6 gives the variation of 5.56% and 11.11% respectively. The loss in strength may be due to dissolution of acid susceptible constituents, especially $Ca(OH)_2$ from the cement paste of hardened concrete resulting in loss of cohesiveness and increased capillary porosity. Exposure of the sample also leads to decalcification of Calcium-silicate-hydrate gel giving relatively weak silica-gel.

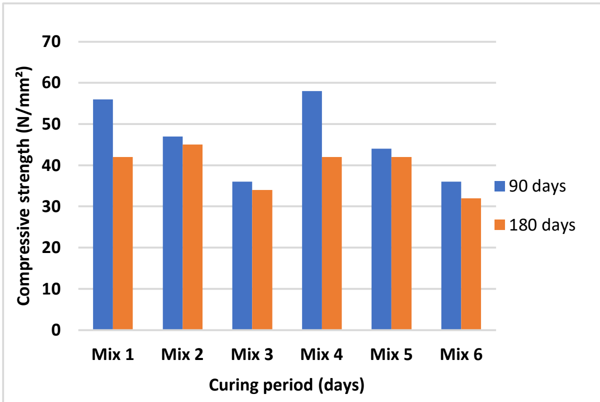


Fig. 11 - Percentage loss in acid attack

4 Analysis by full factorial design

In this paper, using Minitab 17 statistical software, the analysis is carried out with full factorial design. This model was conducted to understand the main effects between the parameters and their interactions. The major three parameters are fly ash (FA), Silica (or) foundry sand (FS) and curing period (days).

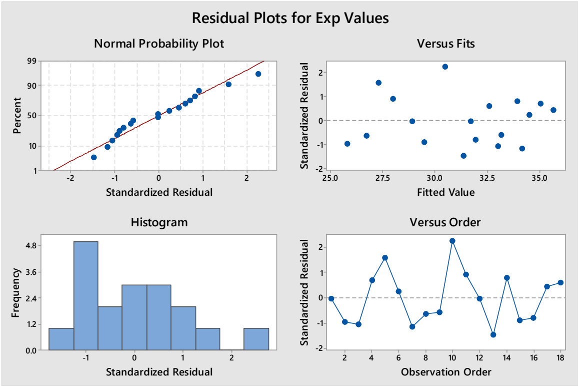
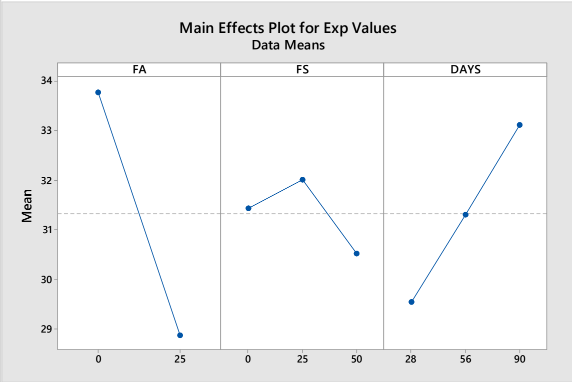


Fig. 12 (a) Residual plots for the experimental values



(b) Main effects plot – Compressive strength

4.1 Compressive strength

The compressive strength of concrete was evaluated by using full factorial design with varying combinations. The model was generated with 3 factors and 12 runs, the analysis was carried out based on the factors and levels taken. The effects and interaction between the parameters were studied, further the predicted results were obtained with the help of regression model. Using analysis of variance (ANOVA), the effects of parameter were studied. The P-values were lesser than 0.05 which indicates the parameters more significant. Figure 12 (a) and (b) shows the residual plot for the experimental values and main effects of parameter individually. The FA and FS parameter are more significant with respect to the days. The Min effect shows the higher and lower values of each factor. The main effect plot for the mean strength of concrete gradually increases with FA with respect to days and reduces at FS. The mean strength of concrete reduces gradually in the order of FA > days > FS. FA plays a vital role in improving the strength of the concrete. From the graph, it is observed the variation in strength at FS is not identical when compared to FA and days. The regression equation for compressive strength of concrete was:

$$CS = 31.328 + 2.439a - 2.439b + 0.106x + \\ +0.689y - 0.794z - 1.778y_1 - 0.011y_2 + 1.789y_3 + \\ +0511ay_1 + 0.078ay_2 - 0.589ay_3 - 0.511by_1 - \\ -0.078by_2 + 0.589by_3 \quad (1)$$

4.2 Tensile strength

The tensile strength of concrete was evaluated by using full factorial design with varying combinations. The model was generated with 3 factors and 8 runs. The fitted line plot between the true values and predicted values of concrete are shown in the Figure 13(a) and interaction between the parameters are shown in Figure 13(b). From the graph, it was observed that R^2 = 99.4%. From the figure 13(b), the interaction plot shows the effect of parameter individually. The non – parallel line indicates the interaction between the parameters i.e., FA and FS. The regression equation for tensile strength of concrete are:

$$TS = 3.16 + 0.28a - 0.28b - 0.01x + 0.01y - \\ -0.17y_1 + 0.17y_2 + 0.03ax - 0.03ay - 0.03bx + \\ +0.03by - 0.04ay_1 + 0.04ay_2 + 0.04by_1 - 0.04by_2 \quad (2)$$

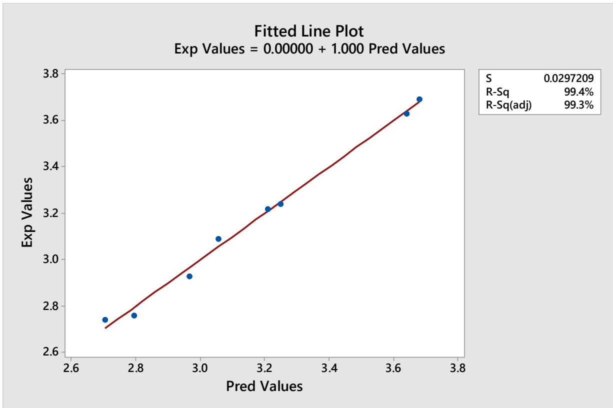


Fig. 13 (a) - Fitted line plot for the experimental values vs. predicted values – Tensile strength

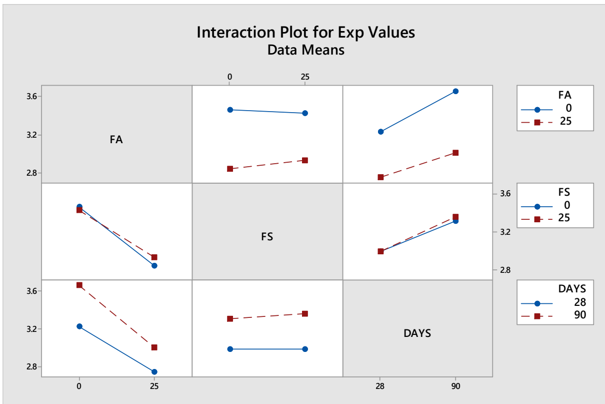


Fig. 13 (b) - Interaction plot for the experimental values – Tensile strength

5. Conclusions

The following are the conclusions drafted based on the tests conducted on the concrete using the various by-products with different proportions.

- From the CS, it was noted that strength increases with increase in curing period. When compared with 56 days the strength variation was increased by 4.09% from 28 days. From the outcomes, it was detected that mix 5 with 25% of FA and 25% of SS were found to be optimum

- The increase in compressive strength may be due to the change in particle size in FS and as well smaller sized particles of FA will have a high amount of silica content which results in pozzolanic action
- From the tensile strength results, it was found that variation was within 10.55% when compared to its compressive strength of concrete. 50% of SS can be used as a partial replacement material for normal river sand and was further found to have similar results with mix 1(control concrete)
- The inclusion of SS decreases the density of concrete. The decrease in strength is mainly due to the improper hydration and inadequate binding of inert particles
- The percentage of water absorption increases with ages, due to the presence of 50% FA with different proportions of SS make the specimen densest
- From acid test results, the compressive strength reduces with ages, which may be due to the loss of cohesiveness and increased capillary porosity
- From the full factorial design, it was observed that the optimum range for FA and FS is 25% which can be used effectively in the construction

Compliance with ethical standards:

Conflict of interest: On behalf of all authors, the corresponding author states that there is no conflict of interest.

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