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Prediction of strength properties of concrete with jute fibres, kenaf fibers and silica fumes: a response surface methodology (DOE) approach

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ABSTRACT

The Design of Experiment (DOE) approach was employed to determine the optimum combination of progression variables, which included Jute fibres (JF), Kenaf fibres (KF), and Silica fumes (SF), aimed at improving the mechanical properties of concrete. To achieve this, the Central composite design (CCD) of Response Surface Methodology was used. The results indicated that the inclusion of KF, JF and SF contributed positively to enhancement of mechanical properties. However, it was observed that a higher level of 0.75% of Jute and kenaf fibres incorporation led to a reduction in strength. The analysis, which involved surface plots, Pareto charts, and regression models, demonstrated that the presence of silica fumes was the most influential factor affecting compressive strength at both 14 days and 28 days. On the other hand, for split tensile strength, both jute and kenaf fibres played significant roles. To assess the accuracy of the models, validation tests were conducted, and the percentage of error was found to be less than 3.5% for compressive strength and split tensile strength. This indicates the reliability of models in predicting the strength properties based on the chosen progression variables.

Keywords: Jute fibre; Kenaf fibre; Silica fumes; Response surface methodology; Analysis of variance.

1. INTRODUCTION

Natural fiber reinforced concrete (NFRC) is a composite material that combines the benefits of conventional concrete with the mechanical properties of natural fibers. In traditional concrete, the primary reinforcement is provided by steel bars or mesh, but in NFRC, natural fibers are incorporated to enhance the material's performance and characteristics. These natural fibers are typically derived from plants, animals, or minerals, and they can be used in various forms, such as discrete fibers, fabrics, or mats. Examples include jute, hemp, sisal, coir (coconut husk), bamboo, and flax. These fibers are abundant, renewable, and biodegradable, making them eco-friendly choices. Natural fibres can improve the mechanical qualities of concrete since they are affordable, promising renewable resources [1]. Natural fibre reinforced concrete reinforced by discrete, small-diameter jute and bamboo fibres dispersed at random in the concrete. It improves mechanical characteristics and slows crack formation [2–4]. To increase the strength of cement composites, natural fibres including bamboo, sisal, hemp, jute and kenaf fibres are frequently added. The mechanical characteristics, fracture dissemination, and energy absorption of cement concrete are improved by adding natural fibres [5].

The mechanical characteristics of KFRC are similar to those of regular concrete control samples, especially while considering the impact of the higher w/c ratio needed for workable KFRC, they generally displays a greater distribution of cracks and higher toughness compared to plain concrete [6]. To get the best rheological qualities for shotcrete, it was envisaged that 1 cm-long jute fibres at 2% by volume would be used. However, owing of fibre aggregation, using 3 cm-long jute fibres at 1% by volume produced the worst rheological results [7]. Higher kenaf cellulose microfibers ratios resulted in a 33% rise in relative humidity and a 63% decrease in autogenous shrinkage [8]. Jute fibre inclusion increases the M25 compressive strengths of concrete. The ultimate compressive strength in concrete of grade M25 was attained at a 1.5% addition of jute fibre, at 19.7%, 9.7%, and 8.1%, respectively [9]. Addition of 0.5% jute fibre to concrete had a negative effect on its fresh characteristics. However, jute fibre in a lower dose of 0.25% had a beneficial effect on the concrete toughened qualities [2].

Furthermore, the ideal Jute fibre content in concrete is important because a greater dose might negatively influence strength and durability due to a lack of fluidity. Contingent on dia of the jute fibres, the usual range of the optimal dose of Jute fibre ranges from 1% to 2% [10]. Jute fibres can marginally increase the compressive strength up to 7% at low fibre content (0.1–0.2%), depending on the length, content, and surface characteristic.

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A higher fibre content reduces workability and strength [11]. The strength due to compression of concrete is increased by addition of 10% of silica fumes by weight of to concrete mixtures. Regardless of whether silica fume is used, an increase in the W/C ratio lowers the strength of concrete [12]. In terms of mechanical qualities under dynamic tensile loading, SF in concrete performs better. Due of the superior physical and mechanical characteristics of SF, specimens' dynamic tensile strength rises as the strain rate increases [13].

An approach for optimising responses in the combination of various or more quantitative parameters is known as response surface methodology (RSM). The RSM technique cannot produce an optimal condition without a goal for each parameter [14]. Compressive strength predicted with RSM Box–Behnken test model showed that Super plasticizer had the biggest impact on the strength strength of the manufactured sand concrete, followed by Pulverised fuel ash (PFA) and Silica fumes (SF). When looking at interactions, SP and PFA had the biggest impact, and the interactions between SP and SF, PFA and SF had the same impact on compressive strength [15]. The findings of the ANN and RSM models, developed using factual data, demonstrated that these models had the ability and utility to provide an accurate simulation of the concrete strength of with tin can fibre and glass waste. Models of RSM outperform ANN in terms of higher coefficient (R2) that is nearly 1 [16]. When RSM and ANN were compared, it became clear that RSM outperformed ANN since its coefficient of determination (R2) was closer to 1 with a score of 0.9959. Additionally, all of the RSM predictions compared to the experimental findings were within a 10% margin [17]. The results of the regression analysis from RSM shows that nano-Fe_2O_3 which contributed 99.81% and 75.75% for compressive strength and split tensile strength respectively at 28 days and PVA [18].

Based to the optimisation carried out using RSM, 15% Marble waste and 50% Stone dust produced mixes with higher strengths than any other combination. With an inaccuracy of less than 5%, the experimental validation of the projected optimised data was performed [19]. Conferring to the RSM model optimum combination of 1.16% of date fibre and 7.7% of silica fume as replacement for cement is achieved [20]. The outputs of RSM and ANN models using real data show that the models can make precise predictions of concrete qualities. RSM models surpass ANN prediction, based on results from contrasting the two methods, with a determination coincident of almost 1 [21]. The research findings indicate that there have been relatively few studies exploring the collective impact of KF, JF and SF on the mechanical properties of concrete. This investigation aimed to evaluate the influence of different proportions of KF, JF with SF in concrete on its mechanical properties during fourteen and twenty eight days of curing. The forecast of mechanical properties for concrete reinforced with natural fibres (kenaf and jute) was carried out using Response Surface Methodology. DOE was employed to design a concrete mix with the optimal proportions of KF, JF and SF. By utilizing the DOE method, the influence of self-governing variables on the experimental results could be analysed. By employing this method, it was possible to optimize the test variables, establish a association between the self-governing variables and experimental model, and ultimately achieve the best response for the trial data [22]. To examine the influence of independent parameters on outcomes with a minimal no. of tests, a mathematical and statistical approach known as DOE, employing RSM, was adopted. For the determination of the ideal composition of progressive variables (KF, JF and SF) and to inspect their effect on compressive strength and split tensile strength, statistical analysis using Central composite Design (BBD) in conjunction with RSM was conducted. The independent variables in this analysis were the weight fractions of kenaf fibres, Jute fibres and silica fumes.

2. MATERIALS AND METHODS

2.1. Materials used

This test used OPC of grade 53, as defined by IS 12269-2013 [23]. It had a specific gravity of 3.1 and a 35-minute initial setting time. The mixture contained 20 mm of 2.78 specific gravity coarse aggregate and a fine aggregate with a specific gravity of 2.67 conforming to zone II as per IS 10262 2019 [24]. Concrete admixtures made of 2.3 specific gravity dark grey powdered silica fume are employed. To create the concrete specimen, untreated regionally available kenaf fibres and jute fibres are used as shown in Figures 1a and b. Kenaf and jute fibre mechanical characteristics are listed in Table 1.

2.2. Mix proportion

The concrete mixture, designed for M25 grade according to IS10262:2019 [24], follows a specific proportion of 1:1.62:3.06 with a W/C of 0.47. To create fiber reinforced concrete (FRC), kenaf fibers and jute fibers, each having a length of 25 mm, are used. The percentages of kenaf and jute fibers vary based on their weights concerning the cement. Before mixing them into the concrete, the kenaf and jute fibers are soaked in water for one day and then dried for half an hour. This preparation helps in achieving uniform distribution and prevents the formation of fiber clumps (balling effect). The addition of fibers is done in layers during the mixing process

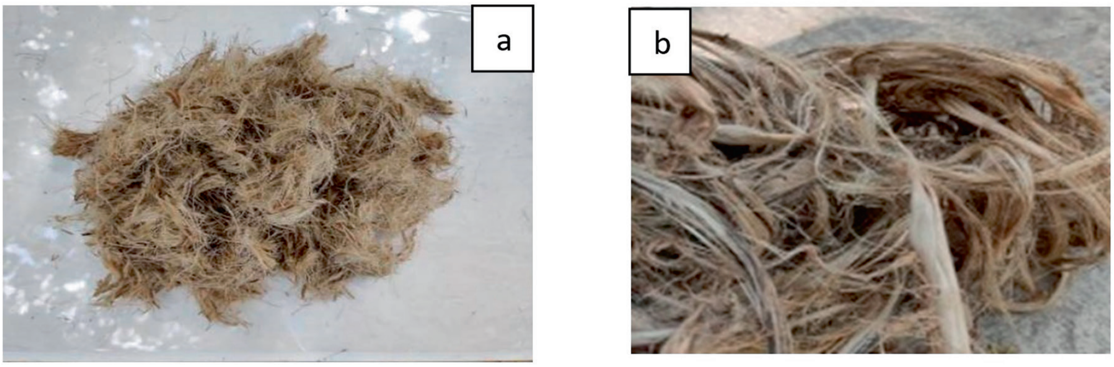


Figure 1: a) Kenaf fibres b) Jute fibre.

Table 1: Properties of fibres.

CHARACTERISTICS	KENAF FIBRES	JUTE FIBRES
Fiber length (mm)	25	25
Tensile strength (MPa)	250	430
Diameter (mm)	0.1	0.2
Density	1.32 g/cm^3	1.45 g/cm^3

to ensure even distribution. These measures are taken to assess the strength properties of Fibre Reinforced Concrete (FRC) mixture.

2.3. Test methods

The concrete mixture was poured into a cubical mould measuring 150 × 150 × 150 mm for the compressive test, while for the split tensile strength test, cylindrical moulds with height of 30 cm and a dia of 15 cm were used. Following casting, the concrete samples were left to dry in the molds for 24 hours. A total of 60 concrete cube specimens and 60 cylindrical specimens were prepared for experimental testing. For each mix, three samples were tested at 14 days and 28 days, respectively. The average of the three strength values was considered as the concrete strength. After fourteen and twenty-eight days pond curing, the concrete specimens were demoulded from the moulds and subjected to testing using a CTM of 100 kN to measure their compressive and split tensile strengths.

2.4. Response surface methodology

RSM includes a set of arithmetical techniques employed to optimize and improve the performance of a system, process, or product. It is commonly applied in engineering, manufacturing, and experimental research to study the association between several input variables (factors) and an output response. Central Composite Design (CCD) is one of the popular experimental designs used in RSM to efficiently model and analyse the response surface. RSM is an arithmetical and scientific technique for solving situations when various influencing variables have an impact on the outcomes [20]. The Response Surface Methodology successfully utilises the relationship between a group of autonomous variables in situations where the output parameters are suggestively influenced by a large number of parameters. CCD was used to study the effects of mix factors, specifically KF (n_1), JF(n_2), and SF(n_3), on the compressive strength and split tensile strength properties of concrete. The independent variables were KF(n_1), JF(n_2), and SF(n_3). The computed response includes compressive strength fck_{14}, fck_{28} and split tensile strength $fts_{14}\, fts_{28}$. Equation 1 [21] shows how to express the obtained response.

$$y = f(n_1, n_2, n_3) \tag{1}$$

A second-order model, represented by Equation 2 [21], was assumed and utilized to elucidate the relationship between the combination of variables and response function. This model helps explain the variations in the strength properties of concrete.

Table 2: Levels of variables.

VARIABLES	MINIMUM (%)	MAXIMUM (%)
Kenaf fibres	0	1.5
Jute fibres	0	1.5
Silica fumes	0	15

Table 3: Combinations obtained from RSM model.

MIX	KENAF (%) (n_1)	JUTE FIBRES (%) (n_2)	SILICA FUMES (%) (n_3)	FIBRE LENGTH (mm)	COARSE AGGREGATE (kg/m³)	FINE AGGREGATE (kg/m³)	CEMENT (kg/m³)
KJSF01	0	1.5	0	25	1214	643	400
KJSF02	0.75	0.75	20	25	1214	643	320
KJSF03	0.75	0.75	0	25	1214	643	400
KJSF04	2	0.75	7.5	25	1214	643	370
KJSF05	0	0	0	25	1214	643	400
KJSF06	0.75	0	7.5	25	1214	643	370
KJSF07	0	0.75	7.5	25	1214	643	370
KJSF08	1.5	1.5	0	25	1214	643	400
KJSF09	0	0	15	25	1214	643	340
KJSF10	0.75	0.75	7.5	25	1214	643	370
KJSF11	0.75	2	7.5	25	1214	643	370
KJSF12	1.5	0	0	25	1214	643	400
KJSF13	0.75	0.75	7.5	25	1214	643	370
KJSF14	0.75	0.75	7.5	25	1214	643	370
KJSF15	0	1.5	15	25	1214	643	340
KJSF16	0.75	0.75	7.5	25	1214	643	370
KJSF17	0.75	0.75	7.5	25	1214	643	370
KJSF18	1.5	0	15	25	1214	643	340
KJSF19	1.5	1.5	15	25	1214	643	340
KJSF20	0.75	0.75	7.5	25	1214	643	370

$$y = z_0 + \sum z_i n_i + \sum z_i n_i^2 + \sum \sum z_{ij} n_i n_j \tag{2}$$

where, y = response variable; z_0, z_i, z_j, z_{ij} = regression coefficients. The R^2 coefficient of determination can be used to determine whether the derived equation is accurate. The factors and levels of variables which are considered for the considered four responses are shown in Table 2. In order to evaluate the impacts of KF, JF and SF on the strength properties of concrete, 3 factor CCD technique was used on 20 mixes, as arrayed in Table 3.

The most effective response was determined using a regression equation that included linear, interactive, and quadratic coefficients. 20 trials were collected from RSM in order to conduct this experiment, and Table 2 displays the mix composition of those trials.

3. RESULTS AND DISCUSSION

3.1. Compressive strength

The results, which are represented in Figure 2, presented that the strength properties of the concrete were enhanced by the inclusion of kenaf and jute fibres. Figure 2 displays the concrete mixture's compressive strength characteristics at 14 and 28 days of age. The study investigated the effects of adding KF, JF fibres and substituting

SF for cement on the compressive strength of concrete. The use of kenaf and jute fibre was anticipated to weaken the concretes strength qualities. Contrarily, the addition of fibres slightly increased the strength of the concrete; nevertheless, after a certain volume proportion, the strength of the concrete mixture reduced as the amount of fibres improved. Concrete's compressive strength may first increase, then after a given amount of inclusion, the strength may decline. Moreover, literature has indicated that the impact of fiber inclusion on the compressive strength of concrete is minimal, but it can considerably enhance the concrete's tensile strength [18, 25]. The results of the current investigation also supported this. According to Figure 2, the concrete combination KJSF10 with fibres that are 7.5% silica fumes, 7.5% kenaf fibres, and 7.5% jute fibres had a 24.2% stronger strength than the concrete mixture without fibres or silica fumes. The inclusion of silica fumes greatly increased the concrete's compressive strength, and the weight fractional rise in silica fume further increased compressive strength. For instance, the concrete's compressive strength was increased to a high of 24.2% at 28 days when 7.5% of silica fumes were added in place of 0.75 percent of kenaf and jute fibres. The higher compressive strength may be a result of the silica fume particles' increased reactive capacity. The increase was lessened when more silica fumes and fibres were used. The concrete's poor compaction could also be caused by the increased volume of fibre, the concrete's high porosity from the addition of kenaf and jute fibres, and the concrete's lower specific gravity when compared to the reference concrete.

3.2. Split tensile strength

The inclusion of KF, JF and SF considerably increased the tensile strength of concrete, as depicted in Figure 3. Figure 3 illustrates the strength of fiber-reinforced concrete with diverse combinations of KF, JF along with SF after conducting the split tensile strength experiment under 14 days and 28 days of curing. The findings reveal that, when compared to KJSF04, concrete with 0.75% kenaf fibres and 0.75% jute fibres and 7.5% silica fumes by weight demonstrates split tensile strength increases of 32% and 35% for 14- and 28-days curing. The findings

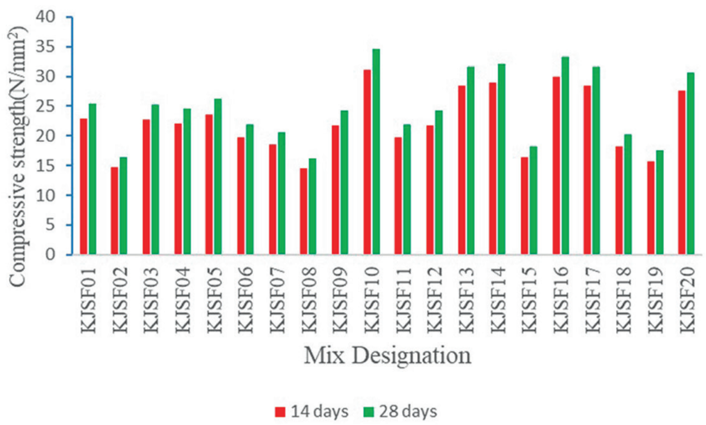


Figure 2: Compressive strength of fibre reinforced concrete.

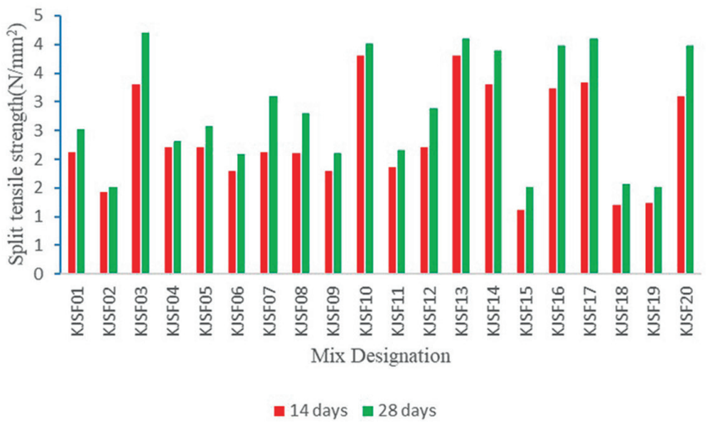


Figure 3: Split tensile strength of fibre reinforced concrete.

show that kenaf and jute fibres lead to an increase in split tensile strength. Moreover, the split tensile strength of concrete specimens containing more kenaf and jute fibres than 0.75 percent by weight of cement decreases due to the uneven spreading of fibre in the concrete. Jute and kenaf fibre may provide a bridging effect or act as an anchor, increasing the tensile strength of the material. The existence of dispersed fibers in the concrete facilitated a bridge effect between the fibers and the concrete matrix, leading to an enhancement in the tensile strength of the hardened material [2,21].

3.3. RSM model

The investigation was carried out to determine how the variables kenaf fibres (n_1), Jute fibres (n_2) and silica fumes (n_3) affected the forecast of the compressive and splitting tensile strength of concrete mixes at 14 and 28 days, according to the CCD. To accomplish this, 20 experiments were taken into account for each response, and the mix proportions are reported in Table 2. The experimental findings were used to express the reactions with respect to kenaf fibres (n_1), Jute fibres (n_2) and silica fumes (n_3) leading to the development of the quadratic equation. Below is a representation of the model equations Equation (3)–(6) in terms of coded factors.

Regression Equation in Uncoded Units

$$fck_{14} = 23.04 + 6.84\ n_1, +\ 7.66\ n_2 + 0.624\ n_3 - 5.35\ n_1^2, -\ 5.74\ n_2^2 - 0.0639\ n_3^2 - 0.80\ n_1,{*}n_2 + 0.130\ n_1,{*}n_3 + 0.003\ n_2 * n_3 \quad (3)$$

$$fck_{28} = 25.60 + 7.60\ n_1, +\ 8.51\ n_2 +\ 0.693\ n_3 - 5.94\ n_1^2 -\ 6.38\ n_2^2 - 0.0710\ n_3^2 -\ 0.89\ n_1 * n_2 + 0.145\ n_1 * n_3 + 0.003\ n_2 * n_3 \quad (4)$$

$$fts_{14} = 2.381 + 1.238\ n_1, +\ 1.564\ n_2 + 0.0699\ n_3 - 0.902\ n_1^2, -\ 1.113\ n_2^2 - 0.00780\ n_3^2 + 0.151\ n_1 * n_2 - 0.0102\ n_1 * n_3 - 0.0107\ n_2 * n_3 \quad (5)$$

$$fts_{28} = 2.936 + 1.370\ n_1, + 1.874\ n_2 + 0.0676\ n_3 - 0.927\ n_1^2 - 1.297\ n_2^2 - 0.00832\ n_3^2 + 0.113\ n_1 * n_2 - 0.0251\ n_1 * n_3 - 0.0104\ n_2 * n_3 \quad (6)$$

Figure 4 makes it clear that all of the residuals from all of the replies are close to the straight line, signifying that errors are dispersed equally. ANOVA, a set of statistical models, is used to examine the association between progression variables and responses. The results are reported in Table 5. It is clear from Table 5 that the models were very suitable because the p value for the lack of fit was less than 0.005. Given that there was less than a 20% difference between the projected R2 and the adjusted R2 for every response, that the models' predictions were accurate. The coefficient of determination (R2), which evaluates how effectively the input variables considered for the measured output variable, determines the level of model fitness [26]. Additionally, the relative R^2 values for fck_{14}, fck_{28}, fts_{14}, fts_{28} were 96.33%, 97.37%, 93.33%, and 97.39%. The correlation between anticipated and experimental values is shown in Table 4. It is clear that predicted values agree with experimental findings, supporting the idea that the model may be used to forecast fck_{14}, fck_{28}, fts_{14}, fts_{28}. The F value of the model and its significance based on higher values of F can be used to validate the model's accuracy. Table 5 shows that the responses to the fck_{14}, fck_{28}, fts_{14}, fts_{28} have F values of 29.44, 29.43, 60.21, and 91.23, respectively, indicating that the models are more substantial.

3.3.1. Pareto analysis and surface plot analysis

Determining the significance of progression factors is aided by the p value. The F test's likelihood value, which is expected to be minimized, represents the p-value of the model. If the p-values for the independent variables are 0.005 and 0.001, respectively, it indicates that the independent variable can be considered significant and highly influential. If the p-value of the progression variable exceeds 0.005, it is considered to be trivial. Using the ANNOVA as shown in Table 5 the p values of the linear n_1 and n_2 were higher than 0.005, whereas the p values of the n_3, n_1^2, n_2^2, n_3^2 for fck_{14}, fck_{28},were less than 0.005. The influence of kenaf and jute fibres is negligible, and the p values of both linear n_1 and n_2 are more than 0.005, clearly demonstrating that kenaf and jute fibres have less of an impact on compressive strength at 14 days and 28 days. Figures 5a and 5b Pareto chart which indicates that silica fume is more important than kenaf and jute fibres for compressive strength at 14 days and 28 days of curing because its value was higher when compared to that of the other linear. In a comparable way, ANOVA as arrayed in Table 5, finding shows that for linear n_3, p value is lower than those of n_1 and n_2 indicates that silica fumes may be the most important consideration when determining the compression strength of concrete. The findings are consistent with earlier research, which shows that adding fibres to concrete has no effect on its compressive strength [16]. However, adding fibres may dramatically increase its tensile strength. When taking into account the tensile strength at 14 and 28 days, KF and JF being more significant, contributing to the

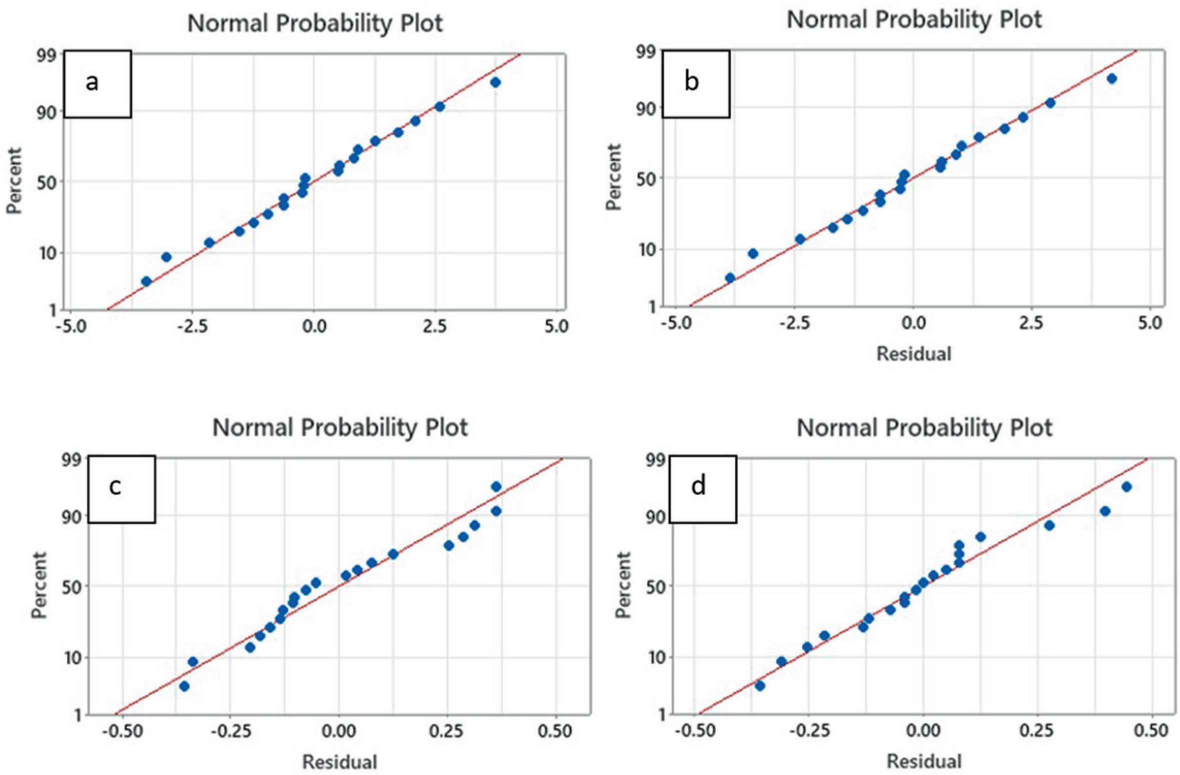


Figure 4: Normality probability graph a) fck_{14} b) fck_{28} c) fts_{14} d) fts_{28}.

Table 4: Actual and predicted data obtained by RSM.

MIX DESIGNATION	COMPRESSIVE STRENGTH				SPLIT TENSILE STRENGTH			
	14 DAYS		28 DAYS		14 DAYS		28 DAYS	
	EXP	RSM	EXP	RSM	EXP	RSM	EXP	RSM
KJSF01	22.86	21.62	25.40	24.01	2.12	2.22	2.52	2.83
KJSF02	14.68	16.14	16.32	17.93	1.42	1.43	1.52	1.67
KJSF03	22.68	23.23	25.20	28.25	3.30	3.47	4.20	4.18
KJSF04	22.14	21.69	24.60	21.89	2.21	1.98	2.32	2.42
KJSF05	23.58	23.04	26.20	25.60	2.20	2.38	2.58	2.94
KJSF06	19.71	17.98	21.90	22.98	1.80	2.86	2.09	2.34
KJSF07	18.54	18.66	20.60	21.61	2.12	2.95	3.10	3.59
KJSF08	14.58	16.04	16.20	18.04	2.10	2.46	2.80	3.05
KJSF09	21.78	18.02	24.20	20.02	1.80	1.67	2.10	2.08
KJSF10	31.14	29.06	34.60	32.29	3.80	3.44	4.02	4.02
KJSF11	19.71	18.18	21.90	20.19	1.86	1.61	2.15	1.91
KJSF12	21.78	21.26	24.20	23.64	2.20	2.28	2.89	2.91
KJSF13	28.44	29.06	31.60	32.29	3.80	3.44	4.10	4.02
KJSF14	28.89	29.06	32.10	32.29	3.30	3.44	3.89	4.02
KJSF15	16.43	16.67	18.26	18.50	1.12	1.28	1.52	1.74
KJSF16	29.97	29.06	33.30	32.29	3.23	3.44	3.98	4.02
KJSF17	28.44	29.06	31.60	32.29	3.33	3.44	4.10	4.02
KJSF18	18.23	19.17	20.25	21.32	1.21	1.34	1.56	1.48
KJSF19	15.77	16.01	17.52	17.79	1.23	1.28	1.52	1.40
KJSF20	27.54	29.06	30.60	32.29	3.10	3.22	3.98	3.83

Table 5: ANOVA for fcs_{14}, fcs_{28} $fSTS_{14}$ and $fSTS_{28}$.

SOURCE	COMPRESSIVE STRENGTH fcs_{14}			COMPRESSIVE STRENGTH fck_{28}			SPLIT TENSILE STRENGTH fts_{14}			SPLIT TENSILE STRENGTH fts_{28}		
	DF	F-VALUE	P-VALUE	DF	F-VALUE	P-VALUE	DF	F-VALUE	P-VALUE	DF	F-VALUE	P-VALUE
Model	9	8.11	0.002	9	8.11	0.002	9	15.84	0.000	9	24.09	0.000
Linear	3	3.45	0.060	3	3.45	0.060	3	10.90	0.002	3	22.03	0.000
n_1	1	0.79	0.396	1	0.79	0.396	1	0.09	0.764	1	1.39	0.266
n_2	1	2.86	0.005	1	2.86	0.004	1	0.43	0.528	1	0.39	0.546
n_3	1	6.70	0.004	1	6.69	0.003	1	32.19	0.006	1	64.32	0.007
Square	3	20.57	0.000	3	20.57	0.000	3	36.23	0.000	3	49.36	0.000
n_1^2	1	20.61	0.001	1	20.62	0.001	1	39.58	0.000	1	46.53	0.000
n_2^2	1	23.78	0.001	1	23.79	0.001	1	60.21	0.000	1	91.23	0.000
n_3^2	1	29.44	0.000	1	29.43	0.000	1	29.56	0.006	1	37.54	0.007
Two way Interaction	3	0.31	0.817	3	0.31	0.817	3	0.40	0.755	3	0.87	0.488
$n_1 * n_2$	1	0.25	0.625	1	0.26	0.625	1	0.62	0.451	1	0.39	0.548
$n_1 * n_3$	1	0.68	0.429	1	0.68	0.429	1	0.28	0.607	1	1.90	0.198
$n_2 * n_3$	1	0.00	0.987	1	0.00	0.987	1	0.31	0.592	1	0.33	0.579

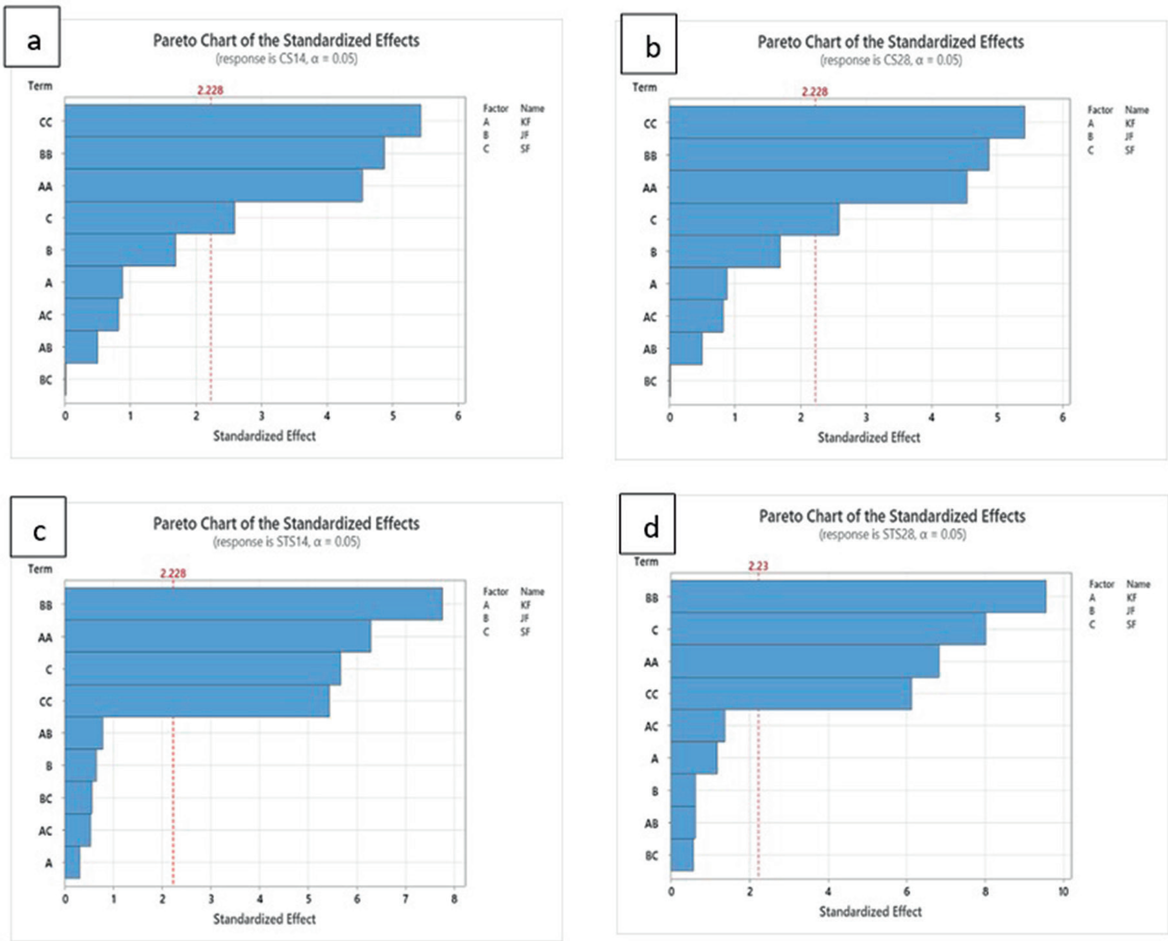


Figure 5: Pareto chart a) fck_{14} b) fck_{28} c) fts_{14} d) fts_{28}.

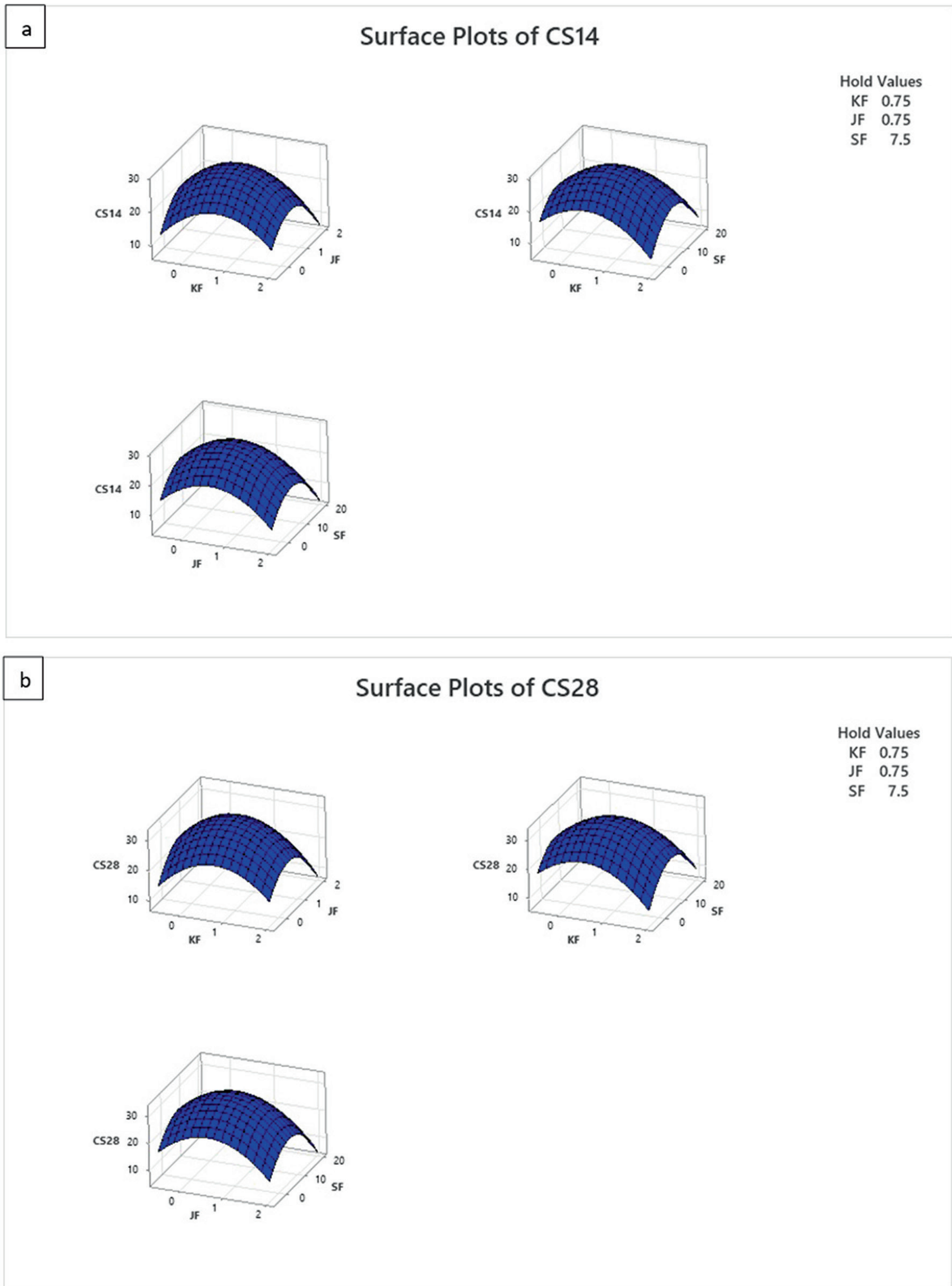
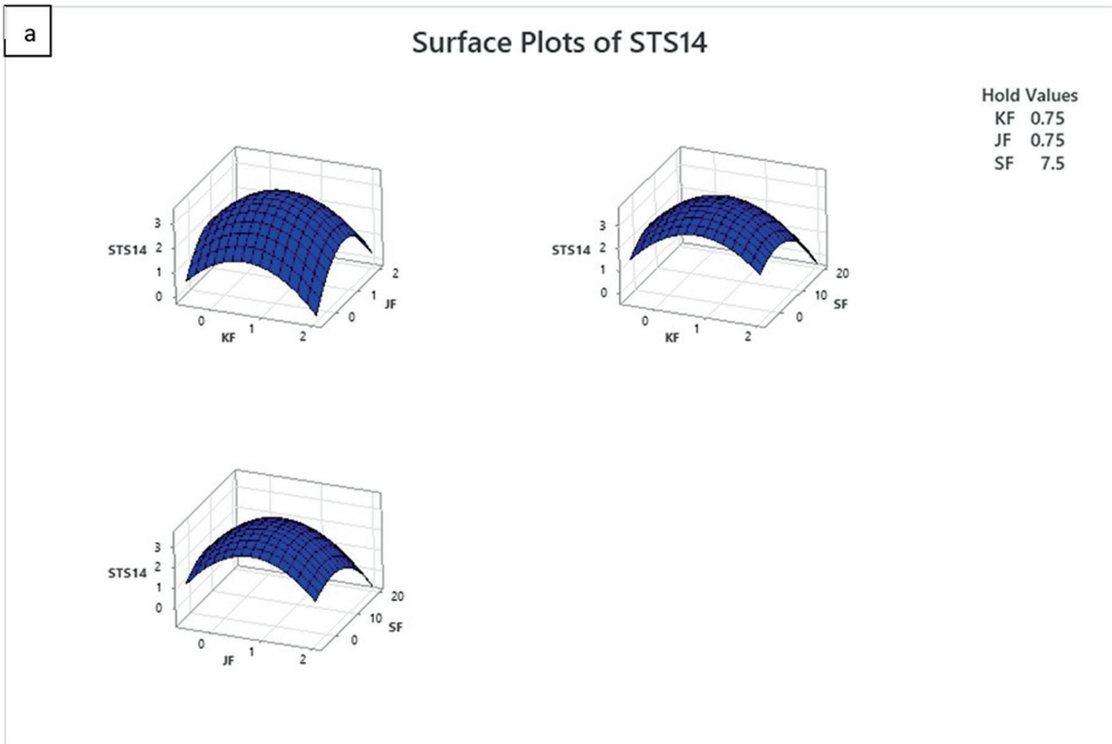


Figure 6: Contour plot a) fck_{14} b) fck_{28}.

tensile strength, and the p value is less than 0.005. According to Figures 5c and 5d, the homogeneous effect of jute fibre and surrounding kenaf fibres was greater than the standard values of 2.23 for both fts_{14} and fts_{28}. The linear effect of jute fibre (B) was also larger when compared to (A&C). The tensile strength of concrete surges due to the bridging action that occurs between the concrete and the fibers. The addition of silica fumes in the concrete effects or increases the compressive strength qualities, and the addition of kenaf and jute fibres greatly increases the tensile strength, based on to the responses of fck_{14}, fck_{28} fts_{14}, fts_{28}.



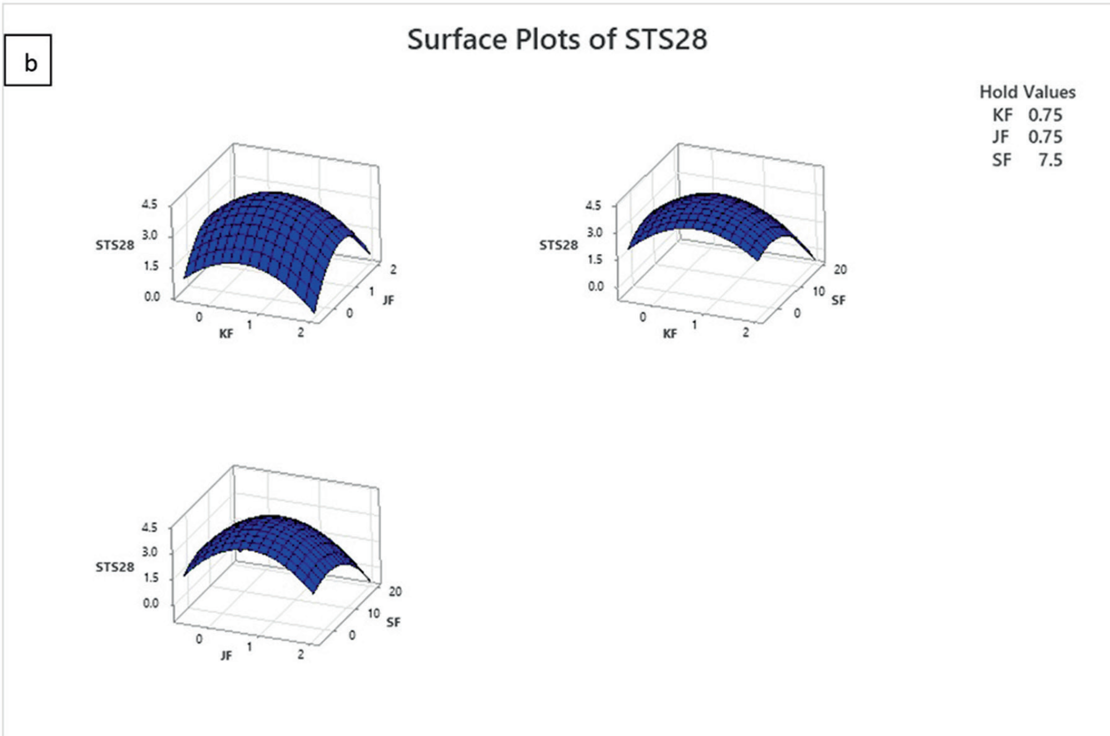


Figure 7: Contour plot a) fts_{14} b) fts_{28}.

In Figures 6 and 7, 3D contour plots were generated to understand how progression variables affected the responses. The response was represented in the 'z' axis of the surface plot, while the progression variables (KF, JF and SF) were plotted in the 'x' and 'y' directions. Figure 6 demonstrates that jute fibres of 0.75%, kenaf Jute fibres of 0.75%, and silica fumes at 7.5% have the highest compressive strengths at 14 days and 28 days of curing, respectively. Above 0.75%, the strength declined. Even if the addition of silica fumes increased the compressive strength of concrete, kenaf and jute fibres have a significant impact during the 14 days and 28 days curing stages. In addition, the compressive strength has been lowered when silica fume is replaced with more than 7.5% by the fraction of cement. The highest compressive strength of fck_{14} and fck_{28} was reached for the concrete mix congaing 0.75% of KF, 0.75% of JF and 7.5% of SF. According to the 3D surface plot shown in Figure 7 increasing the amount of kenaf and Jute fibres, the tensile strength enhances for fts_{14} and fts_{28},there by it is clear that, kenaf and Jute fibres had a considerable effect on the rise in tensile strength. Additionally, the tensile strength of concrete decreases when weight fraction exceeds 0.75 percent for jute and 0.75 percent for kenaf fibres.

3.3.2. Optimization of progression variables

According to Figure 8, the ideal amounts of KF, JF and SF to achieve the maximum compressive strength and split tensile strength at 14 days and 28 days were 0.686%, 0.686%, and 4.569%, respectively. The justification test was run to validate the results, which are displayed in Table 6. According to Table 6, the percentage of error for fck_{14}, fck_{28} fts_{14} and fts_{28} was less than 3 percent.

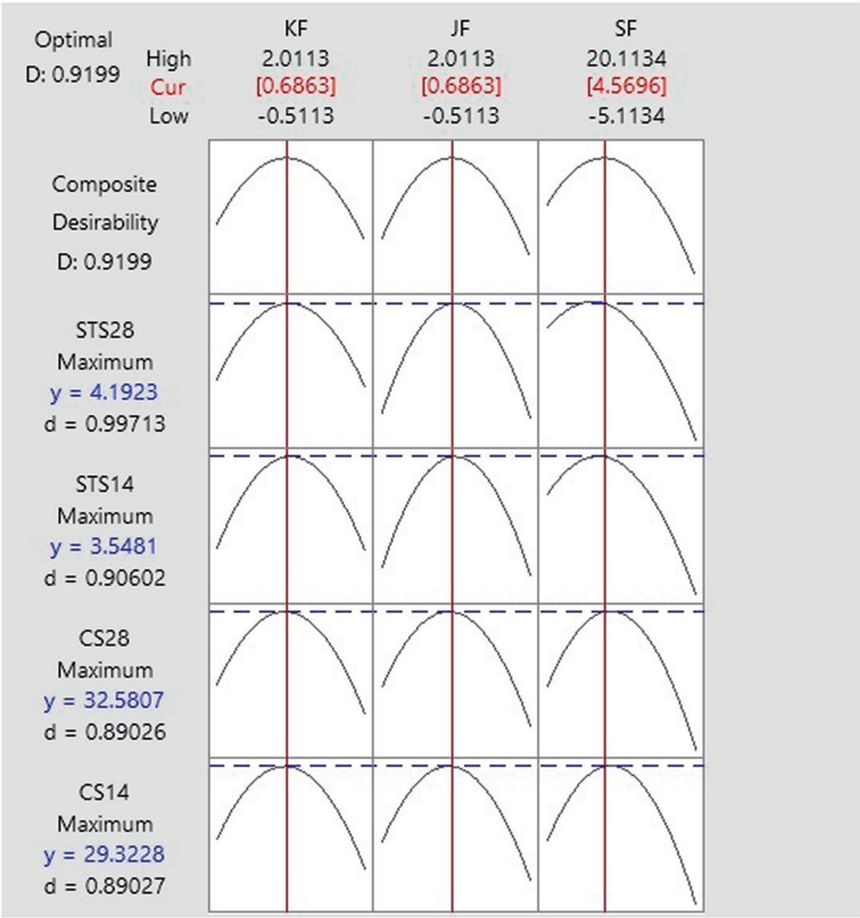


Figure 8: Optimisation chart fck_{14}, fck_{28} fts_{14}, fts_{28}.

Table 6: Validation of test results and percentage of error.

STRENGTH PROPERTIES	KENAF FIBRES (%)	JUTE FIBRES (%)	SILICA FUMES	PREDICTED RESULT RSM	CONFIRMATION RESULTS	ERROR
fcs_{14}	0.686	0.686	4.569	29.33	30.32	3.27%
fcs_{28}	0.686	0.686	4.569	32.58	32.65	3.06%
$fSTS_{14}$	0.686	0.686	4.569	2.38	2.31	3.03%
$fSTS_{28}$	0.686	0.686	4.569	2.94	2.85	3.15%

4. CONCLUSION

The following results were reached after optimising the strength qualities of concrete including KF, JF and SF using the Central Composite design of RSM:

- The inclusion of silica fumes at a rate of 7.5% each has enhanced the compressive strength properties of concrete. Moreover, the test results indicate that beyond 7.5% addition of silica fumes with higher percentage of fibres the compressive strength reduces.
- The incorporation of kenaf and Jute fibers in concrete has resulted in improvements in its split tensile strength. However, it should be noted that at higher levels of fiber addition, the tensile strength of the concrete decreases.
- The regression analysis model developed to predict fck_{14}, fck_{28} fts_{14} and fts_{28} demonstrates a close agreement between the forecasted values and the experimental results.
- ANOVA results indicate that silica fumes were the most influential factor for both the 14-day and 28-day compressive strength of the concrete. On the other hand, the combination of kenaf and jute fibers emerged as the significant factor affecting the Split tensile strength.
- The Pareto chart analysis and ANOVA revealed that the developed models for fck_{14}, fck_{28} fts_{14} and fts_{28} are extremely substantial. The models exhibited high precision, as indicated by the p-values being less than 0.005.
- The design variables that led to the optimal responses for fck_{14}, fck_{28} fts_{14} and fts_{28} were achieved, signifying their significant importance in concrete design.
- The combination of jute fibres, kenaf fibres, and silica fumes can potentially lead to higher concrete strength due to enhanced bonding, fibre reinforcement and pozzolanic reaction as silica fumes react with calcium hydroxide in the presence of water to form additional calcium silicate hydrates (C-S-H).
- The limitations of the research include a limited number of concrete specimens used for experimentation. Response Surface Methodology (DOE) relies on the assumption that relationships between variables are linear. If the actual relationships in the concrete mixtures are nonlinear, the model's predictions may be less accurate.
- Future research in the prediction of strength properties of concrete with jute fibres, kenaf fibres, and silica fumes using a Response Surface Methodology (DOE) approach can explore various avenues like durability studies, Influence of fibre characteristics, effects of fibre dispersion, sustainability assessment.

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