Modeling of compressive and flexural strength for incremental replacement of natural sand with artificial sand in concrete

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Concrete is mixture of cement, sand and aggregate. We cannot imagine civil engineering structures without concrete. Concrete is backbone of infrastructural development of whole world. The strength of aggregate will affect the strength of concrete. Concrete plays the key role and a large quantum of concrete is being utilized in every construction practices. Due to scarcity of natural sand, it is necessary to find suitable substitute for this valuable material. Artificial sand is arising with appropriate replacement for natural sand. Artificial sand is produced from quires stone crusher. Hence the authors initiated to use, this imperative material for preparing concrete.

This paper presents experimental results based analysis of compressive and flexural strength of concrete acquired with combination of artificial sand and natural sand, utilizing indigenously prepared concrete mixture in the laboratory. The experimental plan has been organized based on L25 orthogonal array design. Parametric analysis has made based on Taguchi methodology.

The mathematical models have also been developed to correlate compressive strength (6c) and average flexural strength (6fs) with different three parameters. The parameters considered for research are grade of concrete, percentage of artificial sand and natural sand. The developed mathematical models for 6c and 6fs is adequate to represent the relationship and useful to predict these strengths for 28 days. Adequacy of developed mathematical model has also been tested by conducting different verification experiments. It is observed that difference between predicted and observed value of 6c and 6fs is lying within 5% and 9% respectively.

1. INTRODUCTION

Concrete is backbone of infrastructural development of whole world. Concrete plays the key role and a large quantum of concrete is being utilized in every construction practices. Natural river sand is one of the key ingredients of concrete, is becoming expensive due to excessive cost of transportation from sources. The scarcity of suitable river sand for use as fine aggregate, in construction applications, and the recent construction boom has led to a dramatic increase in the price. Also large scale depletion of sources creates environmental problems. Additionally various government agencies have put restrictions on sand quarrying to conserve this diminishing natural resources. This has prompted many engineers to look for alternate materials that are cheaper while possessing similar characteristics. To overcome these problems there is a need of cost effective alternative and innovative materials.

Concrete has capacity to enhance its properties with the help of other suitable material. Maximum volume of concrete is made of aggregate. The aggregate characteristics influence the workability, segregation and durability of concrete. Fine aggregates may be Natural sand, crushing natural gravels, crushing hard stones (artificial sand). Since from last twenty years we find that the availability of good quality of natural sand is decreasing. The natural sand deposits are drying up and hence there is an acute need to find suitable substitute that matches the properties of natural sand. The natural sand deposits are being emptied by construction industries. The quarry stone crushers are situated in the nearby areas from which it is possible to get artificial sand. By using artificial sand we can overcome environmental problems and protect river bed against erosion also remain as filter for ground water. Thus for preserving area of beauty, recreational value and biodiversity, most of local government agencies now a days granting permissions to aggregate-producers across the world. These are the facts in construction industry today and definitely it will not change dramatically. The rigorous study is necessary for use of artificial sand in place of natural sand. This paper presents experimental results based analysis of average compressive and average flexural strength of concrete acquired with combination of artificial sand and natural sand, utilizing indigenously prepared concrete mixture in the laboratory. The experimental plan has been organized based on L25 orthogonal array design. Parametric analysis has made based on Taguchi methodology. The mathematical model has also been developed to correlate compressive strength (6c) and average flexural strength (6fs) with grade of concrete, % artificial sand and % natural sand.

2. LITERATURE REVIEW

S. S. Fate [1] presented review about the application of crushed sand in concrete. He concluded that concrete with crushed sand performed better, since strength, durability and flexural strength was improved when concrete mix was prepared with natural sand. It is also concluded that workability of concrete manufactured with crushed sand was lesser because manufactured sand particles are angular in shape and their rough surface texture improves the internal friction in the mix which reduces workability of concrete. It is also pointed out that manufactured sand contains no organic impurities; hence it gives increased strength of Concrete with same cement content.

The hardened properties of concrete using quarry dust were investigated by sudhir et. al. [2]. Design mix of M25grade concrete with replacement of 0%, 20%, 25%, 30%, and 35% of quarry dust organized as M1, M2, M3,M4 and M5 respectively was considered for laboratory analysis viz. slump test, compaction factor test, compressive strength, split tensile strength and flexural strength of hardened concrete. It was observed that the measured slump values of quarry dust concrete with constant water cement ratio 0.44 were found to be 45, 50, 53, 57 and 60 mm for different mixes such as M1 (0% quarry dust), M2 (20% quarry dust), M3 (25% quarry dust) , M4 (30% quarry dust) and M5 (35% quarry dust) respectively. It was concluded that, the slump value increases with increase in percentage replacement of sand with quarry dust. The above slump value corresponds to low degree of workability, suitable for construction of tiles and bricks.

Ta-Peng et. al. [3] studied the effects of various fineness moduli (FM) of fine aggregate on the engineering properties of high-performance concrete (HPC). Two kinds of coarse aggregates (stiff and soft) and three kinds of fine aggregates (FM=3.24, 2.73 and 2.18) were used. It was observed that by using finer fine aggregates, the HPC with crushed porous brick pieces had a larger slump loss of fresh concrete in two hours than that using coarser fine aggregate. For concrete with dense crushed sandstone the slump loss is the same regardless of the different fineness moduli of fine aggregates in HPC. It was concluded that, no additional gain was achieved in the splitting tensile strength in HPC using coarser fine aggregate. To achieve similar workability in fresh concrete, HPC using smaller fineness modulus of fine aggregates required a bigger amount of super plasticizer in the concrete mixing.

An attempt was made by Dr. Pofale et. al. [4] to replace the natural sand in concrete control mixes of M25 and M30 grades designed for 100 to 120 mm slump at replacement levels of 30%, 40%, 50% and 60% using Portland Pozzolana Cement There were in all 5 mixes in each grade of concrete including control mix and four mixes with crusher dust as a partial replacement of natural sand. It was observed that with use of crusher dust at all replacement levels, the workability of concrete was reduced from 1-6%. From the test results, it was observed that the replacement of natural sand by crusher dust increased the compressive strength of concrete by 5-22%. It was also found that amongst all the mixes, the highest compressive strength was obtained for 40% replacement of sand by crusher dust. Hence it was finally concluded and recommended that crusher dust could be effectively used in concrete of above grades for replacement levels of sand by 30-60% economically leading to sustainable development.

V. Bhikshma et. al [5] studied performance of stone dust which can be used as partial or full replacement of river sand as fine aggregate without altering the strength, workability or setting characteristics of concrete. The results of tests on cubes (150×150×150 mm) and under reinforced concrete beams (150×230×1500 mm) were presented in order to obtain the flexural behaviour of under reinforced RC beams. A total of 24 cubes and 10 beams were tested for direct compression and flexure at 28 days.

Akshay et. al [6] presented a review of the different alternatives to natural sand in preparation of mortar and concrete. The paper highlighted on the physical and mechanical properties and strength aspect on mortar and concrete and considered possible alternatives available in place of natural sand in mortar and concrete. Importance of various materials which are recognized as domestic or industrial waste was also presented for use in the construction industry.

Priyanka et. al [7] investigated the effect of water cement ratio on fresh and hardened properties of concrete with partial replacement of natural sand by manufactured sand. Concrete mix design of M20 (2900 psi) grade was done according to Indian Standard code (IS 10262). Concrete cube, beam and cylindrical specimens were tested for evaluation of compressive, flexural and split tensile strength respectively. Workability was measured in terms of slump and compacting factor. The concrete exhibits excellent strength with 60% replacement of natural sand, so it can be used in concrete as viable alternative to natural sand. This paper puts forward the applications of manufactured sand as an attempt towards sustainable development in India.

V.S. Babu et. al. [8] studied the effects of repeated processing of recycled aggregate (RA) in rotating Loss Angeles abrasion drum (containing iron ball) , which reduces the old adhesive mortar, for application in high strength concrete. The various properties of fresh and hardened concrete were examined for both partial and full replacement of natural coarse aggregates by processed coarse recycled aggregate (PRA) in high strength concrete. The experimental results highlighted that (i) the lower the recycled aggregate substitution, the higher performance and lower risk, (ii) the processed recycled aggregate showed better results than unprocessed recycled aggregates. Authors claimed that, new recycled aggregate processing technique yields better results and this method is simple, suitable and opens new era in the production of high strength concrete for sustainable constructions and wider application of recycled aggregate.

A. K. Sahu et. al in January 2003 study showed that there is increase in compressive strength modulus of rupture and split strength by replacing natural sand with stone crusher waste with 20 and 40 percent as fine aggregate [9]. Mixes with artificial sand as fine aggregate observed consistently higher strength than the mixes with natural sand. The sharp edges of the particles in artificial sand provide better bond with cement than the rounded particles of natural sand resulting in higher strength. The excessive bleeding of concrete is reduced by using artificial sand [10].

Research of Ilangovana et. al presented that the Physical and chemical properties of quarry rock dust was satisfied the requirements of code provision in property studies. Natural river sand, if replaced by hundred percent quarry rock dust from quarries, may sometimes give equal or better than the reference concrete made with natural sand, in terms of compressive and flexural strength [11,12,13]. Jadhava et. al. presented the effect of partial replacement of natural sand by manufactured sand on the compressive strength of cement mortar of proportion 1:2, 1:3 and 1:6 with water cement ratio as 0.5 and 0.55. Results were compared with reference mix of 0% replacement of natural sand by manufactured sand. The compressive strength of cement mortar with 50% replacement of natural sand by manufactured sand revealed higher strength as compared to reference mix. The overall strength of mortar linearly increases for 0%, 50% replacement of natural sand by manufactured sand as compared with reference mix (Mix 1). Manufactured sand has a potential to provide alternative to natural sand and helps in maintaining the environment as well as economical balance [14].

Rajendra P. Mogre et. al. research showed that there is possibility of replacement of natural sand by artificial sand and feasibility ranges from 60% to 80%. It was seen from above research that there are variations in strength improvement of concrete made from artificial sand. It was also commented that there is need to find suitable optimum percentage replacement in the concrete [15,16]. Authors extended their research and observed that optimum replacement of natural sand by artificial sand was up to 65 % to increase strength of concrete. It was also observed that the percentage increase in strength was found maximum for M20 grade and gradually reduced for M40 grade [17, 18]. Authors also developed regression model for split tensile strength during incremental replacement of natural sand with artificial sand in concrete. It was found that, developed mathematical model was significant to represent the relationship and useful to predict the values split tensile strength of the concrete [19].

3. EXPERIMENTAL PROGRAMME

3.1 Material

3.1.1 Cement

Ordinary Portland cement of 53 grades confirming to IS 12269:1987 was used. The physical properties are tabulated as shown below (Table 1).

Table 1. Physical properties of cement (53 grade) [20, 21]

Property	Specific gravity	Soundness	Initial setting time	Final setting time	Normal consistency	Fineness m3/ Kg	28 days compressive strength
Value	3.12	1.20 mm	167 minute	255 minute	31%	320	58.25 MPa

3.1.2 Fine aggregate

Natural sand obtained from the river and available in the local market was used. The artificial sand obtained from the crusher was used. The physical properties and sieve analysis details of natural and artificial sand are given in Tables 2 and 3 respectively.

3.1.3 Coarse aggregate

Locally available rock stone aggregate of nominal size 10 mm and 20 mm mixed aggregate are used. The physical properties of these coarse aggregates are as below (Tables 4 and 5).

3.2 Workability of concrete

The properties of green concrete are measured in terms of workability. It is observed that Artificial Sand Concrete (ASC) was more homogeneous with uniform color and free from bleeding and segregation as compared to Natural Sand Concrete (NSC). The workability of concrete is measured by slump cone test and compaction factor test. The average values of these are reported in Table 6. It is observed that, the slump is reducing with increased in the % of artificial sand. To impart additional workability to green concrete a super plasticizer (AC-PLAST-BV-M4) was used. It was concrete admixture with less than 0.05% chloride content and conforms to IS 9103:1999. The super plasticizer was added 0.6% by weight of cement to all mixes.

Table 2. Properties of natural and artificial sand

Property	Specific gravity	Fineness modulus	Bulk gensity kg/m3
Natural Sand	2.6	2.78	15.60
Artificial Sand	2.90	2.97	17.62

Table 3. Sieve analysis details of natural and artificial sand

IS sieve	Percentage passing	
	Natural sand	Artificial sand
4.75 mm	96.2	95
2.36 mm	88.4	79
1.18 mm	65.8	55
600 µ	47.1	41
300 µ	19.6	20
150 µ	5	13

Table 4. Properties of coarse aggregate

Sr.no.	Property	Value
1	Specific Gravity	2.96
2	Bulk density kn/m3	16.10
3	Fineness Modules 20 mm	7.35
4	Fineness Modules 10 mm	6.54
5	Fineness Modules(20& 10) mm	6.95

Table 5. Quantity of material (for mix) [22, 23, 24, 25]

Sr. no	Grade of concrete	M 20	M 25	M 30	M 35	M 40
1	Cement kg/m3	315	350	380	420	445
2	Fine aggregate kg/m3	615	600	592	570	560
3	Coarse aggregate (10 mm and 20 mm) kg/m^3	1300	1261	1259	1250	1200
4	Aggregate cement ratio	6.07	5.31	4.87	4.33	3.95
5	Water litter /m3	156	162	175	182	180
6	Water cement ratio	0.49	0.46	0.46	0.43	0.41

Table 6. Workability of fresh concrete

Sr. no	Artificial sand (%)	Natural sand (%)	Concrete grade	Water cement ratio	Workability Of fresh concrete	
					Slump (mm)	CF
			M20	0.49	105	0.90
			M 25	0.46	97	0.88
1	00	100	M 30	0.46	96	0.88
			M 35	0.43	86	0.86
			M 40	0.41	80	0.85
			M 20	0.49	100	0.89
			M 25	0.46	94	0.88
2	40	60	M 30	0.46	93	0.87
			M 35	0.43	80	0.86
			M 40	0.41	74	0.85
			M 20	0.49	97	0.88
			M 25	0.46	92	0.88
3	60	40	M 30	0.46	90	0.87
			M 35	0.43	76	0.85
			M 40	0.41	71	0.84
			M 20	0.49	85	0.86
			M 25	0.46	78	0.85
4	80	20	M 30	0.46	74	0.85
			M 35	0.43	65	0.83
			M 40	0.41	58	0.82
			M 20	0.49	76	0.86
			M 25	0.46	69	0.84
5	100	00	M 30	0.46	63	0.83
			M 35	0.43	54	0.82
			M 40	0.41	50	0.81

3.3 Experimentation

Based on literature review and preliminary investigation three factors namely grade of concrete, percentage of artificial sand and percentage of natural sand are considered for investigation. A preliminary design of experiments using the orthogonal array (OA) [26,27] was carried out in order to assess the relative effect of these three parameters. Five levels of each factor were used in the experimental design through an L25 orthogonal array. Table 7 shows the parameters and their values used at different five levels.

Table 7. Factors and their levels

Sr. no	Parameters	Level 1	Level 2	Level 3	Level 4	Level 5
1	Grade of concrete, (M)	20	25	30	35	40
2	Percentage of artificial sand, (%)	0	40	60	80	100
3	Percentage of natural sand, (%)	100	60	40	20	0

Table 8. The matrix of levels used in the experimentation and experimental results

Expt. no	Grade M (X_1)	As (X_2 %)	Ns (X_3 %)	Experimental value (6c), N/mm^2	Experimental value (6fs) N/mm^2
1	20	0	100	27.5	3.30
2	20	40	60	33.3	3.70
3	20	60	40	39.1	4.90
4	20	80	20	42.2	5.30
5	20	100	0	49.1	5.75
6	25	0	100	28.82	3.53
7	25	40	60	35.93	4.02
8	25	60	40	41.84	5.43
9	25	80	20	45.03	5.83
10	25	100	0	52.29	6.30
11	30	0	100	30.03	3.63
12	30	40	60	36.36	4.11
13	30	60	40	42.37	5.45
14	30	80	20	45.79	5.86
15	30	100	0	53	6.32
16	35	0	100	28.7	3.50
17	35	40	60	34.3	3.85
18	35	60	40	41.3	5.05
19	35	80	20	43.2	5.55
20	35	100	0	50.01	5.90
21	40	0	100	27.4	3.28
22	40	40	60	33.1	3.65
23	40	60	40	39	4.85
24	40	80	20	41.8	5.25
25	40	100	0	48.9	5.71

6c =Average compressive strength in N/mm^2

M = Concrete Grade

As = Artificial sand in %

Ns = Natural Sand in %

6fs = Average Flexural strength in N/mm^2

The physical Characteristics of material used that is cement natural sand, artificial sand and coarse aggregate are tested initially. The exact amount of concrete ingredients (Table 5) were weighed and mixed thoroughly by using superplasticiser in laboratory concrete mixer till the consistent mix was achieved. The standard cube of 150 mm size steel mould and prism of size 100 x 100 x 500 were tested over a span of 400 mm. compacted on vibrating table. Cubes and prisms with varying percentage of natural and artificial sand were cast for testing. The average strength was calculated as per acceptance criteria using IS 456:2000. Table 8 shows the matrix of conditions used in the 25 experiments.

4. DEVELOPMENT OF MATHEMATICAL MODELS

The mathematical models to represent the relationship among average compressive, flexural strength (6c and 6fs)) and input parameters have been developed by regression analysis on the basis of L25 orthogonal array of robust design. The response equation have been developed, considering only liner and quadratic effects of grade of concrete, percentage of artificial sand and natural sand. The appropriate equation has been decided and coefficients have been determined using MATLAB software.

The developed mathematical model for compressive strength (6c) is

$$6c=3.3249+1.30752X_1+0.115088X_2-0.016772X_3-0.004032X_1^2-0.0012128X_2^2+0.00014384X_3^2 \quad (1)$$

where

6c =Average compressive strength in N/mm^2

X_1=Concrete Grade (M)

X_2=Artificial sand in % (As)

X_3=Natural Sand in % (Ns)

The developed mathematical model for flexural strength (6fs) is

$$6fs=0.54874+0.149564X_1+0.017384X_2-0.005052*X_3-0.0002364X_1^2-0.00018576X_2^2+0.000048X_3^3 \quad (2)$$

where,

6fs =Average Flexural strength in N/mm^2

X_1=Concrete Grade (M)

X_2=Artificial sand in % (As)

X_3=Natural Sand in % (Ns)

Table 9. Results of verification experimentation for average compressive strength

Sr. no	Grade X_1	AS X_2 (%)	NS X_3 (%)	6c Value from developed Model Equation	6c Value from Experimentation	Difference in values	Variation in %
1	20	20	80	29.26	28.09	-1.17	-4.16
2	25	20	80	34.89	35.13	0.24	0.69
3	30	20	80	40.32	41.05	0.73	1.78
4	35	20	80	45.55	44.27	-1.28	-2.88
5	40	20	80	50.57	51.46	0.89	1.73
6	20	65	35	29.81	30.38	0.57	1.88
7	25	65	35	35.44	36.49	1.05	2.88
8	30	65	35	40.87	42.58	1.71	4.02
9	35	65	35	46.10	45.78	-0.32	-0.69
10	40	65	35	51.12	53.1	1.98	3.73
11	20	70	30	29.60	30.25	0.65	2.14
12	25	70	30	35.23	36.29	1.06	2.91
13	30	70	30	40.66	42.5	1.84	4.32
14	35	70	30	45.89	45.51	-0.38	-0.83
15	40	70	30	50.92	52.78	1.86	3.53
16	20	75	25	29.34	29.9	0.56	1.86
17	25	75	25	34.97	35.8	0.83	2.31
18	30	75	25	40.40	42	1.60	3.80

Table 10. Results of verification experimentation for average flexural strength

Sr. no	Grade X_1	AS X_2 (%)	NSX_3 (%)	6fs Value from developed Model Equation	Experimental value (6fs)	Difference	Variation in %
1	20	20	80	3.62	3.35	-0.27	-8.12
2	25	20	80	4.32	4.02	-0.30	-7.38
3	30	20	80	5.00	5.30	0.30	5.67
4	35	20	80	5.67	5.69	0.02	0.35
5	40	20	80	6.33	6.15	-0.18	-2.92
6	20	65	35	3.67	3.77	0.10	2.58
7	25	65	35	4.37	4.18	-0.19	-4.48
8	30	65	35	5.05	5.48	0.43	7.85
9	35	65	35	5.72	5.88	0.16	2.70
10	40	65	35	6.38	6.41	0.03	0.47
11	20	70	30	3.64	3.72	0.08	2.05
12	25	70	30	4.34	4.10	-0.24	-5.81
13	30	70	30	5.02	5.43	0.41	7.53
14	35	70	30	5.69	5.84	0.15	2.53
15	40	70	30	6.35	6.30	-0.05	-0.82
16	20	75	25	3.61	3.65	0.04	1.15
17	25	75	25	4.30	4.00	-0.30	-7.57
18	30	75	25	4.99	5.35	0.36	6.81

5. VERIFICATION EXPERIMENTS

Adequacy of developed mathematical model of Average compressive strength has been tested by conducting different twenty verification experiments. The results of various verification experiments are shown in the Table 9. Results of eighteen verification experiments and its comparison with value obtained by model equations are also shown in the Table 9.

It is observed that difference between predicted and observed value of compression strength is lying within 5%.

Adequacy of developed mathematical model of Average flexural strength has also been tested by conducting different verification experiments. The results of verification experiments are shown in the Table 10. Results of eighteen verification experiments and its comparison with value obtained by model equations are shown in the Table 10.

It is observed that difference between predicted and observed value of flexural strength is lying within 9%.

6. CONCLUSION

The influence of various parameters such as grade of concrete, percentage of artificial sand and percentage of natural sand on compression and flexural strength has been examined.

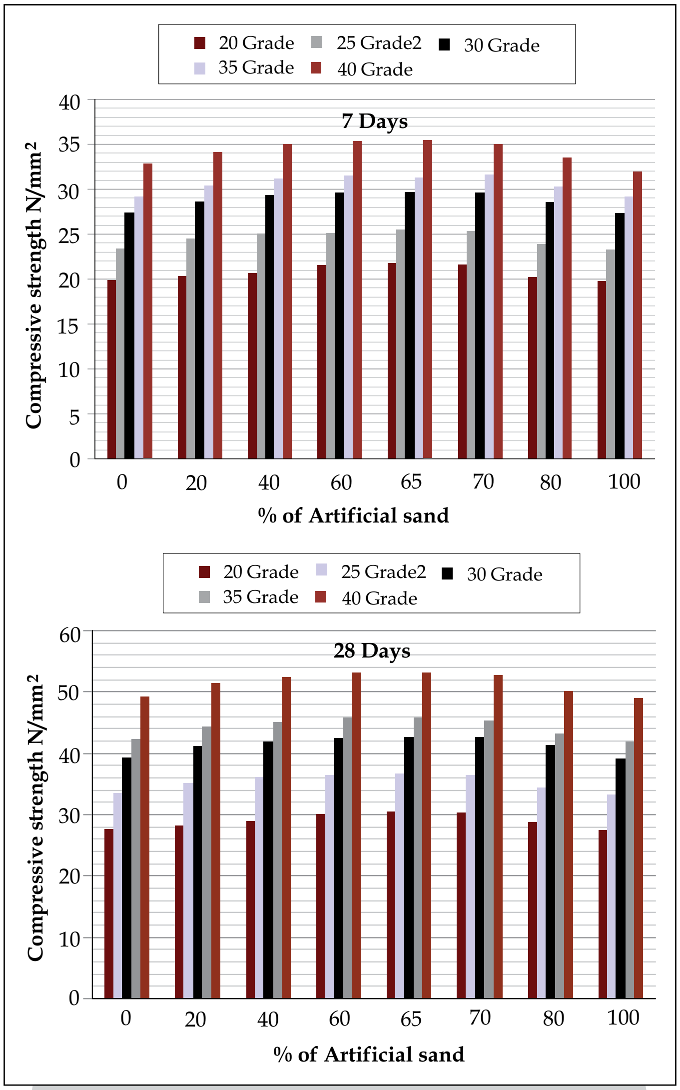

Figure 1. Graph of optimum replacement of artificial sand for maximum compressive strength (6c) for 7 and 28 days strength

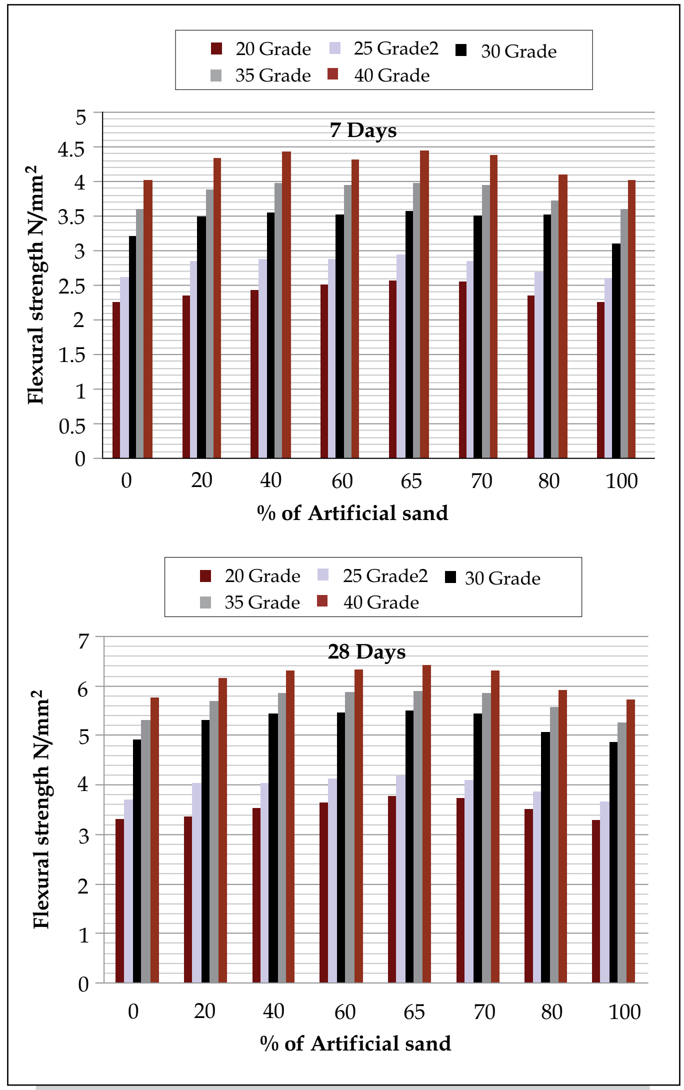

Figure 2. Graph of optimum replacement of artificial sand for maximum flexural strength (6fs) for 7 and 28 days strength.

From the set of experimental investigation, the following outcomes are observed.

1. There is consistent increase in strength of concrete by replacing natural sand with artificial sand up to 65 %.(Figures 1 and 2).
2. Percentage increase in strength is maximum for M20 grade and gradually reducing for M40 grade (Figure 3).
3. The developed mathematical model is significant to represent the relationship and useful to predict the values for compression and flexural strength of the concrete (Figures 4 and 5).
4. Adequacy of developed mathematical model has also been tested by conducting different verification experiments and it is observed that difference between predicted and observed value of compression and flexural strength are lying within 5% and 9% respectively.

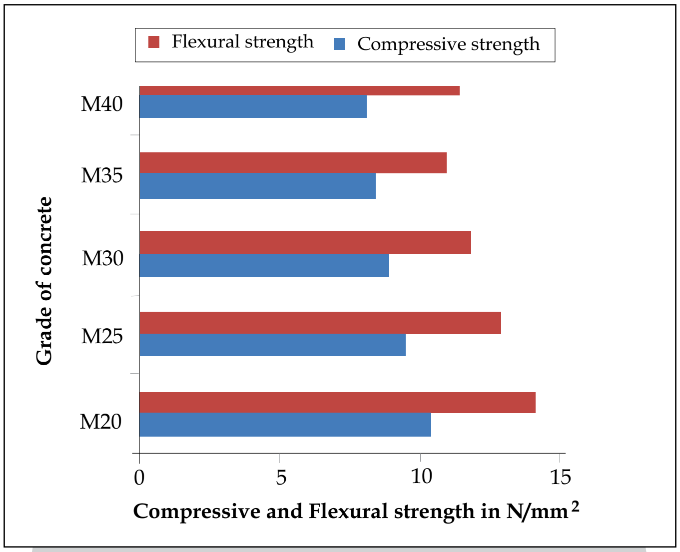

Figure 3. Percentage increase in compressive & flexural strength (6c & 6fs) for M20 to M40 grade of concrete

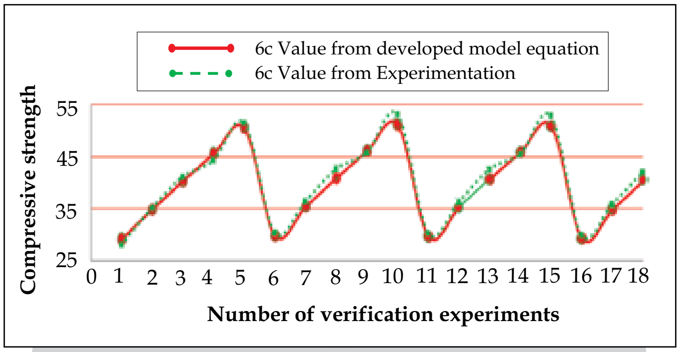

Figure 4. Comparision of experimentation and model values of compressive strength

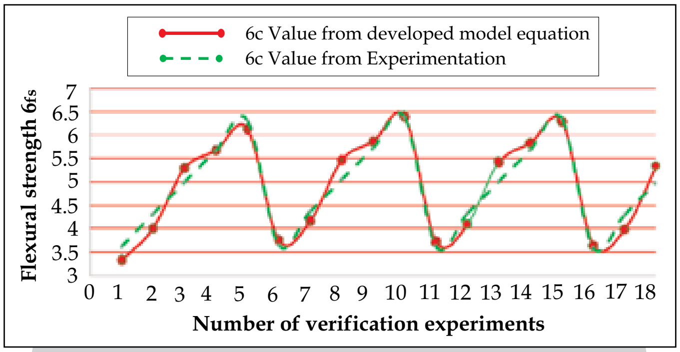

Figure 5. Comparision of experimentation and model values of flexural strength

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