

Performance Exploration of M25 Grade Concrete by Fractional Replacement of Ordinary Portland Cement by means of Glass Fiber using WASPAS Method



Subhasri Panda, Gopal Charan Behera, Dilip Kumar Bagal, Priyaranjan Dash

Abstract: The combination of one kind of fibers with another kind of fibers or one length with another length of fiber is termed as hybrid fiber. Mixing of different lengths of fiber in concrete is known as graded fiber. According to different research articles short fibers are unable to transfer force due to insufficient grip length, fibers more than critical length fail in snapping of fiber. Short length Fibers up to certain range increase toughness and bridge the micro cracks. Long fibers arrest macro cracks, resistance to post peak deformation. The M25 grade of concrete was chosen with a continual w/c ratio 0.43 where fractional replacement of Ordinary Portland Cement with glass fiber is done in different proportion. After preparing the samples according to Taguchi's method orthogonal array, the mechanical characterizations are performed. Hardened concrete tests have been piloted to evaluate the mechanical properties of M25 grade of concrete. Weighted Aggregated Sum Product Assessment (WASPAS) method is utilized for optimization of input variables. In order to outline comparative consequence of measured criteria a pairwise comparison matrix was used. The results of all tests were analyzed, comparison has done among concrete mixes and the conclusion is drawn.

Keywords: M25 Concrete, Material Replacement, Mechanical Strength, WASPAS method.

I. INTRODUCTION

"Concrete" is a manmade material which is mixture of cement, aggregates and water with or without admixture. Concrete made with these materials is quite brittle because of less tensile strength. To overcome the development of surface cracks, fibers are put in the mix. Toughness will be increased due to fiber addition. The problem of low tensile strength of concrete plays a critical role to encounter the torsional loads. To researchers this problem one may have to determine for reinforced concrete or pre-stressed concrete or composite concrete alike

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Fiber reinforced concrete (FRC) or ferrocement materials. [1-17]. Based on the test results from some pervious experiments, the present research work is done to find the optimal percentage of replacement of cement with combined application of glass fiber in M25 grade of concrete. Multi-response optimization was done with Weighted Aggregated Sum Product Assessment (WASPAS) method. Hardened concrete tests such as split tensile strength, compressive strength and flexural strength test has been conducted on the samples after 28 days to evaluate the mechanical properties of concrete with the addition of various proportions of glass fiber. Finally, the confirmation test was examined to confirm the attained results and the models are validated using Analysis of Variance (ANOVA).

II. MATERIAL AND THEIR PROPERTIES

A. Cement

53 graded ordinary Portland cement (OPC) conforming to IS:12269-1987 standard was used throughout this investigation with specific gravity of 3.1 [16], [17].

B. Fine Aggregate

Fine aggregate used in the present project work with specific gravity 2.61 and bulk density 1600 kg/m³. [16], [17].

C. Coarse Aggregate

Coarse aggregate having the maximum size of 20mm was utilized in this work having specific gravity 2.7 and bulk density 1460 Kg/m³ [16], [17].

D. Water

Fresh, colorless, odourless potable water is used.

E. Glass Fiber

Glass fibers with tensile strength of about 1700 MPa, modulus of elasticity of about 73 GPa, specific gravity of about 2.6, and filament diameter of 14 mm were used in the present investigation. The design mix was prepared a ratio 1:1.54:2.95 with the water-cement ratio of 0.43 [16], [17].

III. MIXING AND CASTING

M25 grade of concrete was designed as per the IS 10262 (2009). All the materials such as OPC, NCA, NFA, MP and FA of particular quantity are added in the concrete mixture machine. All the materials mixed properly in dry condition. Required amount of water has been added slowly it forms a homogenous mixture.



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specimens were casted for 28 days for each concrete mix based on L9 orthogonal array. The size details of test specimen are shown in Table I. Table II represents the input parameters.

Table- I: Test Specimen size details

Tests	Sample size	Nos.
For cube's compressive strength	150mm X 150mm X 150mm	9
Cylinder's split tensile strength	100mm diameter X 200mm height	9
Beam's flexural strength	10mm X 100mm X 50mm	9

Table- II: Input constraints

Factors	Symbol	Level-1	Level-2	Level-3
Cement	A	320 kg/m ³	340 kg/m ³	360 kg/m ³
Glass fiber	B	2 %	3 %	4 %

IV. CURING

Mould has been removed after 24 hours of casting period. Specimens are marked clearly after removed from the mould. All specimens are kept in curing tank and place there safely for 28 days which provide adequate moisture and temperature to cement hydration for adequate period of time.

V. HARDENED CONCRETE TEST

- Compressive Strength Test: Structural design codes are based on compressive strength. Tests have been conducted of the test specimen for 28 days. Cube specimens (150X150X150 mm³) cured in water has taken out. It has been tested immediately after drying. Compressive strength (MPa) was found out using the expression [16], [17]:

$$F_{compressive} = P/A \quad (1)$$

Where, P = Load in kN and A = Surface area of the cube

- Split Tensile Strength Test: Wet cylinder specimen (200 mm height X 100 mm diameter) has been taken from water after 28 days of curing. It has been tested immediately after drying. Split tensile strength (MPa) was found out using the expression:

$$F_{split\ tensile} = 2P/\pi DL \quad (2)$$

Where, P = Load in kN, D = diameter in mm and L = length in mm.

- Flexural Strength Test: Wet beam specimen (10X100X50 mm³) has been taken from water after 28 days of curing. It has been tested immediately after drying.

$$\sigma_f = 3FL/2bd^2 \quad (3)$$

Where F = maximum load, L = space amongst the supports, also "b" and "d" are breadth and wideness of specimen respectively.

VI. DETERMINATION OF WEIGHTS BY PAIR-WISE COMPARISON

By means of geometric mean of Analytic Hierarchy Process (AHP) method, relative consequence of output responses was calculated as shown in Table III. [17-20]-

$$GM_i = (\prod_{j=1}^n b_{ij})^{1/n} \quad (4)$$

$$w_j = GM_i / \sum_{j=1}^n GM_i \quad (5)$$

Table- III: Pair-wise comparison table of responses

Properties	Compressive strength	Split tensile strength	Flexural strength
Compressive strength	1	3	3
Split tensile strength	0.3	1	0.3
Flexural strength	0.3	3	1

Utilizing above-mentioned equations criteria weights were determined as w = [0.60, 0.13, 0.28] after the consistency check.

VII. WEIGHTED AGGREGATED SUM PRODUCT ASSESSMENT METHOD

The main approach of Weighted Aggregated Sum Product Assessment (WASPAS) method for answering Multi-Criteria Decision Making (MCDM) problems are [19].

- Step 1. Firstly, set the initial decision matrix.
- Step 2. Normalizing the Decision matrix utilizing following equations (6) and (7) for maximization and minimization criteria, respectively:

$$\bar{x}_{ij} = x_{ij} / \max_i x_{ij} \quad (6)$$

$$\bar{x}_{ij} = \min_i x_{ij} / x_{ij} \quad (7)$$

where x_{ij} is the assessment value of i^{th} alternate with respect to j^{th} measure.

- Step 3. Calculation of total comparative significance of i^{th} alternate, based on weighted sum method (WSM) using equation (8):

$$Q_i^{(1)} = \sum_{j=1}^n \bar{x}_{ij} \cdot w_j \quad (8)$$

- Step 4. Determination of total comparative significance of i^{th} alternate, based on weighted product method (WPM) using equation (9):

$$Q_i^{(2)} = \prod_{j=1}^n \bar{x}_{ij}^{w_j} \quad (9)$$

- Step 5: Computation of total comparative significance of alternatives is done using equation (10) and accordingly ranked from higher value to lower value [19]:

$$Q_i = \lambda \cdot Q_i^{(1)} + (1 - \lambda) \cdot Q_i^{(2)} \quad (10)$$

VIII. RESULTS AND DISCUSSION

The experimental analysis was conducted according to different operating parameter conditions prepared by using L9 orthogonal array design for experimental shown in table IV. The experimental results for split tensile strength, compressive strength and flexural strength were calculated and recorded in Table IV.



Table- IV: L₉ Orthogonal Array Design for Experimental Runs and Results

Run No.	A	B	Compressive strength (MPa)	Split tensile strength (MPa)	Flexural Strength (MPa)
1	320	2	36.25	3.57	4.31
2	320	3	37.98	3.80	4.75
3	320	4	37.89	3.68	4.55
4	340	2	35.18	3.50	4.23
5	340	3	36.91	3.73	4.66
6	340	4	36.82	3.61	4.46
7	360	2	35.93	3.51	4.43
8	360	3	37.65	3.75	4.86
9	360	4	37.57	3.63	4.67

Since semantic terms, employed to express the responses, have already been converted into crisp (real) values, the application of the WASPAS method starts with normalization of the decision matrix by applying equation (4) since the output has to be maximized. Consequently, total relative significance of alternatives based on WSM and WPM are designed by using equations (6) and (7), respectively. Lastly, combined condition of optimality of WASPAS method was designed by using equation (8). Table 7 shows the computational particulars of all alternatives using WASPAS method for λ value of 0.5.

Table- V: Computational details of the WASPAS method

Run No.	$Q_i^{(1)}$	$Q_i^{(2)}$	Q_i	Rank
1	0.9343	0.9339	0.9341	7
2	0.9937	0.9937	0.9937	1
3	0.9774	0.9770	0.9772	3
4	0.9102	0.9099	0.9100	9
5	0.9696	0.9696	0.9696	5
6	0.9532	0.9530	0.9531	6
7	0.9337	0.9336	0.9336	8
8	0.9931	0.9931	0.9931	2
9	0.9767	0.9766	0.9767	4

From total relative significance values of alternatives, it was detected that investigational results obtained in experiment no. 2 is the best result according to the ranking. Similarly, experiment no. 4 gave the worst result based on ranking. The highest and lowest value of Q_i obtained as 0.9937 and 0.9100 respectively. The combination of A1 and B2 of experimental run of 2 of Table no. IV indicates the largest value among all 9 tests. Similarly, the combination of A2 and B1 of experimental run 4 showed worst scenario among all runs. Now, figuring out the main effect plot with factors for total comparative significance i.e. Q_i with respect to all experimental runs using MINITAB software.

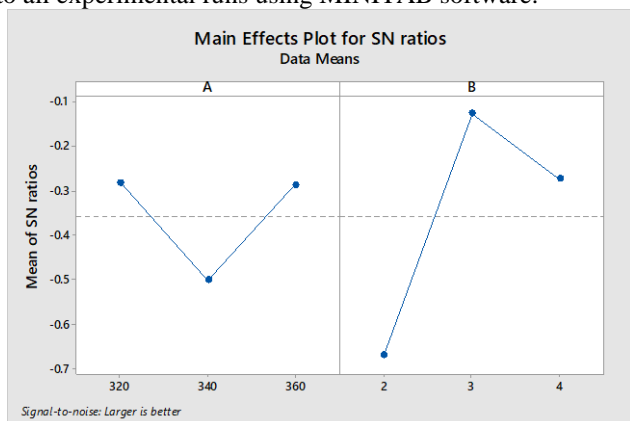


Fig. 1. Main effect plot with factors for total comparative significance (Q_i)

Now the total relative importance of responses was used to plot main effect. Based on this study, one can select a mixture of the levels that provide the larger average response. In Figure 1, the combination of A1 and B2 indicates the highest value of main effect plot for factors (Cement) A and (Glass fiber) B respectively. For that reason, A1B2 i.e. M25 concrete of cement with 320 kg/m³ and glass fiber with 3 % is the optimum parameter combination.

Table VI gives the Analysis of Variance (ANOVA) results for the calculated values of total relative importance of split tensile strength, compressive strength and flexural strength. According to Table VI, factor B, the percentage of glass fiber content with 83.37 % contribution is the best controlled parameters for M25 concrete followed by cement content i.e. factor A with 16.63 %.

$$S = 0.0042, R-Sq = 99.99 \%, R-Sq(adj) = 99.98 \%$$

Table- VI: Analysis of Variance(ANOVA)

Factor	DF	Adj SS	Adj MS	F-test	P-test	% Influence
A	2	0.0937	0.0937	0.0468	2714.54	16.63
B	2	0.4705	0.4705	0.2352	13619.75	83.37
Error	4	0.0000	0.0000	0.0000		0.01
Total	8	0.5643				

A. Confirmation experiment

It is performed for confirmation of augmentation of output superiority structures after outcome of best level of input limits using the formulae given in equation (11) [19-21].

$$\mu_{predicted} = a_{2m} + b_{1m} - 3\mu_{mean} \tag{11}$$

Here a_{2m} , b_{1m} are definite mean values of Q_i and μ_{mean} is total mean of overall Q_i of choices [19] from Table 7, it can be concluded that the predicted value and experimental value are in predicted ideal range.

Table- VII: Predictions

Optimal setting	Predicted value	Experimental value
A1B2	0.993645	0.9802

IX. CONCLUSION

The present work explores the development of concrete by replacing of OPC with different percentages of glass fiber. To find an optimum concrete mixture, recent multi-criteria decision-making optimization methods have been employed. Compressive, flexural and split tensile strengths were evaluated for different replacement of glass fiber-based concrete. The results of all tests were optimized using WASPAS method and the conclusions were found out. After the experimental and statistical approaches, the following assumptions can be made from this study.

- From the 28 days compressive, flexural and split tensile strength results, it is found that with 3% replacement of glass fiber with OPC getting high strength as comparing to the control specimen.
- The foretelling values determined using WASPAS and Taguchi coupled WASPAS method is almost similar to each other.
- Optimum setting for creation of concrete specimen by replacing of OPC with glass fiber using two optimization tactics are listed in table VIII.



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Table- VIII: Optimum settings

	Cement	Glass fiber
WASPAS	320 kg/m ³	3 %
Taguchi-WASPAS	320 kg/m ³	3 %

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