Comparative Mechanical Characterization of M30 Concrete Grade by Fractional Replacement of Portland Pozzolana Cement with Industrial Waste Using CoCoSo and CODAS Methods

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Abstract. Since last few years, marble has been deliberated as some of the utmost significant embellished constructing resources. Marble Powder (MP) and Fly Ash (FA) are nearly those materials, which creates health hazards and pollutes the environment. This present study targets to investigate the effect of marble powder and fly ash as fractional replacement of cement respectively in different concrete mixes. The M30 grade of concrete was chosen with a continual w/c ratio 0.43 where fractional replacement of Portland Pozzolana Cement with Marble Powder and Fly Ash is done in different proportion. After preparing the samples according to Taguchi’s method orthogonal array, the mechanical characterizations are performed. Hardened concrete tests such as compressive strength, split tensile strength and flexural strength test have been piloted to appraise the mechanical properties of concrete. Two current multi-response optimization techniques were used i.e. Combinative Distance-based Assessment (CODAS) and Combined Compromise Solution (CoCoSo) method for optimization of process parameters. 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.

1. Introduction

A new revolution took place in the construction industry when cement was invented in the 19th century. Concrete manufacturing is one of the technique related to building and construction industry have been developed after the invention of cement. Marble industry was one of the pristine industry related to building and construction. Nowadays deployment of marble remaining in many sectors advantages in regulating environmental hazards. Similarly, Fly Ash is used extensively as a fractional replacement of...
cement; however, its inclusion in concrete provides various aids, such important lessening in early strength due to moderately relaxed hydration of Fly Ash [1-13]. The present investigation work is done to find the optimal percentage of replacement of cement with combined application of fly ash and marble powder in M30 grade of concrete. Multi-response optimization was done by Combinative Distance-based Assessment (CODAS) and Combined Compromise Solution (CoCoSo) method. Hardened concrete tests such as compressive strength, split tensile strength and flexural strength test has been piloted to evaluate the mechanical properties of concrete with the addition of various proportions of fly ash and marble powder.

2. Experimental Analysis and Methodology

Materials used for fabrication of test specimen are as follows:
1. Portland Pozzolana Cement (PPC)
2. Marble Powder (MP)
3. Fly Ash (FA)
4. Coarse Aggregate
5. Fine Aggregate
6. Water

1. Portland Pozzolana Cement (PPC): It makes concrete extra resistant, thicker as related to Ordinary Portland Cement. PPC produces a smaller amount of warmness of hydration and deals better resistance to outbreak of antagonistic water.

2. Marble Powder (MP): It is formed from handling plants where marble blocks sawing and polishing is done.

3. Fly Ash (FA): It is formed from burning of anthracite coal and bituminous coal, which has roughly 7% lime.

4. Natural Fine Aggregate (NFA): Regionally accessible sand confirming to IS specifications turned into used as the satisfactory combination in the concrete coaching. The specific gravity of Natural Fine Aggregate is 2.66. The bulk density of Natural Fine Aggregate is 1415 Kg/m³. Water absorption of sand is 13.89%.

5. Natural Coarse Aggregate (NCA): The sieve analysis test has been carried out for the NCA and the procedures are followed as per the IS code. As a result, the aggregate has taken between sizes of 10 mm to 20 mm. The specific gravity of aggregate has found out which further used in the mix design procedure. Fineness modulus range of 10 mm to 20 mm size coarse aggregate is 6.0 to 6.9.

6. Water: 15% tap water was used for preparing the concrete mix.

| 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    |

2.1. Mixing and Casting

M30 grade of concrete was designed as per the Indian Standard code of practice (IS 10262 (2009)). All the materials such as PPC, 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. Specimens were casted for 90 days for each concrete mix based on L9 orthogonal array. The size details of test specimen are shown in Table 1. Table 2 shows the input parameters.
### Table 2. Input parameters

| Factors          | Symbol | Level 1       | Level 2       | Level 3       |
|------------------|--------|---------------|---------------|---------------|
| cement           | A      | 320 kg/m³     | 340 kg/m³     | 360 kg/m³     |
| Fly ash          | B      | 5 %           | 15 %          | 20 %          |
| Marble powder    | C      | 5 %           | 15 %          | 20 %          |

2.2. **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 90 days, which provide adequate moisture and temperature to cement hydration for adequate period.

2.3. **Hardened Concrete Test**
Prepared concrete specimens were tested using 600 KN universal testing machine and with a crosshead speed of 10mm/min.

1. **Compressive Strength Test:** Structural design codes are based on compressive strength. Tests have been conducted of the test specimen for 90 days. Cube specimens (150 X 150 X 150) mm cured in water has taken out. It has been tested immediately after drying. Compressive strength (MPa) was found out using the expression:

\[
F_{\text{compressive}} = \frac{P}{A} \tag{1}
\]

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

2. **Split Tensile Strength Test:** Wet cylinder specimen (200 mm height X 100 mm diameter) has been taken from water after 90 days of curing. It has been tested immediately after drying. Split tensile strength (MPa) was found out using the expression:

\[
F_{\text{Split tensile}} = \frac{2P}{\pi DL} \tag{2}
\]

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

3. **Flexural Strength Test:** Wet beam specimen (10 X 100 X 50) mm has been taken from water after 90 days of curing. It has been tested immediately after drying. The flexural stress in three-point bending test was found using formula:

\[
\sigma_f = \frac{3FL}{2bd^2} \tag{3}
\]

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

2.4. **Weight Calculation between Criteria by means of Pair-Wise Comparison**
For formulating the pair-wise comparison matrix, Saaty’s nine-point preference scale was used. Output response weights were premeditated by following equations [14]-

\[
GM_i = \left( \prod_{j=1}^{n} b_{ij} \right)^{1/n} \tag{4}
\]

\[
w_j = \frac{GM_i}{\sum_{j=1}^{n} GM_i} \tag{5}
\]

Output response weights were attained as 0.60, 0.13, 0.27, which will be used in CoCoSo method and CODAS method for optimization.

2.5. **Combined Compromise Solution Method**
The following steps are used to crack CoCoSo problem [15, 16]:

1. Determination of initial decision-making matrix using equation (6):
2. Via compromise normalisation equation, normalisation of norms values is prepared:

\[ r_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \]  

; for benefit  

\[ r_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \]  

; for cost  

3. Determination of \( S_i \) and \( P_i \) :  

\[ S_i = \sum_{j=1}^{n} (w_j r_{ij}) \]  

\[ P_i = \sum_{j=1}^{n} (r_{ij})^w_j \]  

4. Three appraisal score are used to generate relative weights of other options derived using equation (11), (12), (13):  

\[ k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)} \]  

\[ k_{ib} = \frac{S_i}{\min S_i} + \frac{P_i}{\min P_i} \]  

\[ k_{ic} = \frac{\lambda (S_i) + (1 - \lambda) (P_i)}{(\lambda \max S_i + (1 - \lambda) \max P_i)} \]  

5. The ranking of all the alternatives is found based on \( k_i \) values from higher to lower:  

\[ k_i = (k_{ia} k_{ib} k_{ic})^\frac{1}{3} + (k_{ia} + k_{ib} + k_{ic}) \]  

2.6. Combinative Distance-based Assessment (CODAS) Method  

The steps for CODAS method are as follows [17]:  

1. Determination of the initial decision-making matrix using equation (15):  

\[ X = [x_{ij}]_{n \times m} = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1m} \\ x_{21} & x_{22} & \ldots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \ldots & x_{nm} \end{bmatrix} \]  

Where \( x_{ij} (x_{ij} \geq 0) \) is performance value of \( i^{th} \) alternative on \( j^{th} \) criterion.  

2. The normalisation of criteria values using equation (16):  

\[ n_{ij} = \begin{cases} \frac{x_{ij}}{\max x_{ij}} & \text{if } j \in N_b \\ \frac{x_{ij}}{\min x_{ij}} & \text{if } j \in N_c \end{cases} \]  

Where \( N_b \) and \( N_c \) represent the benefit and cost criteria respectively.  

3. Weighted normalized matrix is premeditated using the following equation:  

\[ r_{ij} = w_j n_{ij} \]  

Where \( w_j \) (0<\( w_j <1 \)) is weight of \( j^{th} \) criterion, and \( \sum_{j=1}^{m} w_j = 1 \).  

4. Determination of the negative-ideal solution (point) using equation (18) and (19):  

\[ ns = [n s_j]_{1 \times m} \]
\[ n_s_j = \min r_{ij} \]  

5. Calculation of Euclidean distances and Taxicab distances for options using negative-ideal solution using equation (20) and (21) respectively:

\[ E_i = \sqrt{\sum_{j=1}^{m}(r_{ij} - n_s_j)^2} \]  
\[ T_i = \sum_{j=1}^{m}|r_{ij} - n_s_j| \]

6. Construction of relative assessment matrix using equation (22):

\[ R_a = [h_{ik}]_{n \times n} \]

\[ h_{ik} = (E_i + E_k) + (\psi(E_i - E_k))X(T_i - T_k) \]

Where \( k \in \{1,2,\ldots,n\} \) and \( \psi \) denotes threshold function defined as follows:

\[ \psi(x) = \begin{cases} 1 & \text{if } |x| \geq \tau \\ 0 & \text{if } |x| \leq \tau \end{cases} \]

7. Assessment score for respective alternative is calculated using equation (xxv) and their ranking is done according to the decreasing values of \( H_i \) and the alternative with highest value of \( H_i \) is best choice among all alternatives:

\[ H_i = \sum_{k=1}^{n} h_{ik} \]

3. Results and Discussion

Samples were made using L9 orthogonal array of Taguchi’s design shown in Table 3. The experimental results for compressive strength, flexural strength and split tensile strength are listed in Table 3.

| Run No. | A  | B  | C  | Compressive strength, MPa | Split tensile strength, MPa | Flexural Strength, MPa |
|---------|----|----|----|---------------------------|----------------------------|------------------------|
| 1       | 320| 5  | 5  | 49.24                     | 4.83                       | 4.700                  |
| 2       | 320| 15 | 15 | 49.03                     | 4.30                       | 4.732                  |
| 3       | 320| 20 | 20 | 39.55                     | 4.25                       | 3.904                  |
| 4       | 340| 5  | 15 | 40.36                     | 3.80                       | 4.442                  |
| 5       | 340| 15 | 20 | 39.51                     | 4.50                       | 4.290                  |
| 6       | 340| 20 | 5  | 40.21                     | 3.88                       | 4.108                  |
| 7       | 360| 5  | 20 | 45.68                     | 4.68                       | 4.382                  |
| 8       | 360| 15 | 5  | 45.27                     | 4.12                       | 4.394                  |
| 9       | 360| 20 | 15 | 48.96                     | 3.82                       | 4.026                  |

3.1. Optimization using CoCoSo Method

Normalised decision-making matrix was formed shown in Table 4. The comparability sequence matrix was formed using formulas (9) and (10), respectively. The values of \( k_a, k_b, \) and \( k_c \) are calculated using Equations (11), (12) and (13). Equation (14) produces the ranking score by \( k_i \) for finding final ranks for the options.
3.2. Optimization using CODAS Method

The normalized matrix was calculated using equation (16) as listed in Table 5. Weighted normalized performance values was evaluated using weights of different criteria, and then the negative-ideal solution is determined. Euclidean distances and Taxicab distances of every alternative were computed. The relative assessment matrix and assessment scores ($H_i$) of every alternative were calculated using Table 6 and equations (22) to (24). The results are presented in Table 6.

Table 4. Computational data of CoCoSo Method

| Expt. No. | Compressive strength | Split tensile strength | Flexural Strength | $k_{ia}$ | $k_{ib}$ | $k_{ic}$ | $k_i$ | Rank of $k_i$ |
|-----------|----------------------|------------------------|-------------------|--------|--------|--------|--------|----------------|
| 1         | 1.000                | 1.000                  | 0.964             | 0.173  | 12.836 | 1.000  | 5.974  | 1              |
| 2         | 0.978                | 0.485                  | 1.000             | 0.159  | 11.160 | 0.917  | 5.253  | 2              |
| 3         | 0.004                | 0.437                  | 0.005             | 0.063  | 2.387  | 0.365  | 1.319  | 8              |
| 4         | 0.087                | 0.000                  | 0.653             | 0.057  | 2.420  | 0.330  | 1.292  | 9              |
| 5         | 0.000                | 0.680                  | 0.470             | 0.089  | 4.064  | 0.514  | 2.126  | 6              |
| 6         | 0.072                | 0.078                  | 0.251             | 0.071  | 2.310  | 0.411  | 1.338  | 7              |
| 7         | 0.634                | 0.854                  | 0.581             | 0.145  | 9.352  | 0.836  | 4.486  | 3              |
| 8         | 0.592                | 0.311                  | 0.595             | 0.126  | 7.374  | 0.729  | 3.622  | 5              |
| 9         | 0.971                | 0.019                  | 0.152             | 0.0927 | 7.513  | 0.5546 | 3.1501 | 4              |

From $k_i$ values of alternatives, it was detected that investigational results obtained in experiment no. 1 is the best result according to the ranking.

Table 5. The normalized decision-making matrix

| Expt. No. | Compressive strength | Split tensile strength | Flexural Strength |
|-----------|----------------------|------------------------|-------------------|
| 1         | 0.8024               | 0.7867                 | 0.8298            |
| 2         | 0.8058               | 0.8837                 | 0.8242            |
| 3         | 0.9990               | 0.8941                 | 0.9990            |
| 4         | 0.9789               | 1.0000                 | 0.8780            |
| 5         | 1.0000               | 0.8444                 | 0.9091            |
| 6         | 0.9826               | 0.9794                 | 0.9494            |
| 7         | 0.8649               | 0.8120                 | 0.8900            |
| 8         | 0.8728               | 0.9223                 | 0.8876            |
| 9         | 0.8070               | 0.9948                 | 0.9687            |

Table 6. Computational results using CODAS Method

| Expt. No. | $E_i$ | $T_i$ | $H_i$ | Rank |
|-----------|-------|-------|-------|------|
| 1         | 0.0015 | 0.0016 | 0.6158 | 1    |
| 2         | 0.0128 | 0.0147 | 0.5145 | 2    |
| 3         | 0.1279 | 0.1792 | -0.5213 | 9    |
| 4         | 0.1105 | 0.1482 | -0.3655 | 6    |
| 5         | 0.1210 | 0.1490 | -0.4603 | 8    |
| 6         | 0.1161 | 0.1670 | -0.4153 | 7    |
| 7         | 0.0417 | 0.0586 | 0.2535 | 3    |
| 8         | 0.0489 | 0.0770 | 0.1886 | 5    |
| 9         | 0.0476 | 0.0689 | 0.2005 | 4    |
According to assessment scores, the ranking of alternatives is E1>E2>E7>E9>E8>E4>E6>E5>E9. Therefore, E1, i.e. concrete specimen no. 1 is the best concrete mixture with respect to the valuation of the CODAS method.

After applying two different optimization technique, Cement with 320 kg/m³, Marble Powder with 5% and Fly Ash with 5% content is the optimal parameter setting for fabrication of M30 concrete. Figure 1 shows the split tensile strength, compressive strength and flexural strength of all the experimental run where the values obtained in 1st experiment is optimal values attained using optimal parameter settings obtained using CoCoSo and CODAS method.

![Figure 1. Output responses obtained in L9 experimental run](image)

**4. Conclusions**

The present work explores the development of concrete by replacing of PPC with marble powder and fly ash. To find an optimum concrete mixture, recent multi-criteria decision-making optimization methods have been employed. Split tensile strength, compressive strength and flexural strength were evaluated for different replacement of marble powder and fly ash based concrete. The results of all tests were optimized using CoCoSo and CODAS method, compared and the following conclusions are made from this study.

From the split tensile strength, compressive strength and flexural strength results of 90 days, it was found that with 5% replacement of marble powder and fly ash respectively with PPC getting great strength as comparing to control specimen.

| Algorithm        | Optimal Setting | Cement    | Marble Powder | Fly Ash |
|------------------|-----------------|-----------|---------------|---------|
| CoCoSo Method    | A1 B1 C1        | 320 kg/m³ | 5 %           | 5 %     |
| CODAS Method     | A1 B1 C1        | 320 kg/m³ | 5 %           | 5 %     |

The predictive values found using CoCoSo and CODAS method is similar to each other. Optimal factor setting for concrete specimen fabrication by replacing of PPC with marble powder and fly ash using two different optimization methods are stated in Table 7. The optimum values will be convenient for industrial assortment of amalgamation of PPC, marble powder and fly ash for construction.
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