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5. An Effective Self Compacting Concrete Mix Selection Approach for the Structural Buildings

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ABSTRACT

This research aims to develop the optimal mix selection for self-compacting Concrete (SCC) depending on the experimental results. For this scenario, SCC mix design was considered as an optimization problem. So, a novel Redfox-based Concrete Mix Selection (RbCMS) technique was proposed for the optimal mix selection to improve the SCC compressive strength. Initially, the materials were selected such as cement, river sand as fine aggregate and fly ash and silica fume as coarse aggregate. Then, the materials were mixed into suitable proportions. The selected mix proportions of M45 grade are prepared with 0 to 30% mix percentage. Furthermore, the European Federation of National Associations Representing for Concretes (EFNARC) standards was used to mix the fresh Concrete using several tests such as Orimet, U box, L-box. Additionally, optimal mix was tested with several chemical attack tests like chloride and Carbonation in Concrete. Finally, the mix selection was optimized based on the fitness of RbCMS. In contrast, the proposed model was executed in the MATLAB tool with several performance measurements, including compressive strength (CS), split tensile strength and flexural strength. The suggested technique generated outstanding outcomes compared with the existing studies by providing approximate results for the optimal mix selection phenomena.

KEYWORDS:

Fly Ash, Cement, Redfox Optimization, Flexural Strength, Compressive Strength, Silica Fume.

1. Introduction:

New eco-friendly materials are widely available for modern structural buildings with optimal parameters. The excellent selection of materials provides a greater lifetime for building structure and quality on the environmental conditions and climatic changes [1, 2]. Concrete is the most necessary construction material used in many countries and regions of the globe. It is less expensive, and the production is a straightforward process. In addition, the concrete is source of civil works in structural buildings. Usually, the concrete has high compressive strength and low tensile strength. Due to the lower tensile strength, concrete is vulnerable to break. Hence, the tensile strength is improved by adding the reinforcement. Moreover, Concrete is formed by natural sources in the form of aggregates. It creates a burden on the environmental sources. Sometimes, lack of resources makes the constructor replace the natural aggregates with other recycled materials like slag, ceramics etc. [4, 5]. Also, a large amount of waste emitted from the construction site creates a risk to the environmental conditions. The most critical challenge in Concrete is shrinkage. It is the process of decrease of the concrete volume and length, which decreases the dimensions [6]. The shrinkage results from changes in water content and chemical features. Self-compacting Concrete (SCC) mostly experiences excess shrinkage [9]. This mixture may lead to undesirable effects on the mixed material. In Concrete, if the shrinkage crosses the tensile strength then cracks happen that will reduce the building strength [10]. Although minimizing the shrinkage is challenging, efficient approaches can reduce the shrinkage level. In this present research, the mix with the SCC is considered for testing [11].

Cement replacement gathers greater attention in the numerous types of research for achieving sustainable Concrete. Concrete containing recycled materials, such as fly ash instead of cement, was used to increase the compressive strength, making it suitable for low-strength applications [12, 13]. Recycled concrete aggregate has been widely employed to make numerous construction materials, including high-strength or performance Concrete, due to preserving natural resources, preventing environmental contamination, and cost-saving considerations of construction projects [14, 15]. The decision-makers built the best optimum design for the cementitious and bituminous materials. The decision maker selects the accurate proportion of the mix based on the critical and strength analysis. However, this process is complex and vulnerable to risk. So to remove this gap, an optimization process is included for adequately selecting the concrete mix with a promising strength and a more effective method [16-18].

The optimizing method initially creates the functions and applies optimization for the correct mix selection. In addition, various ML models have been utilized to learn the materials' properties to estimate optimal mix proportions [19, 20]. The widely used models were propagation, supporting vector, and tree-based approaches. However, the overfitting ratio is higher in the supporting vector model [21]. Also, inaccurate predictions might occur. The multi-objective functions must often be optimized simultaneously [22]. Therefore, a new model is presented in this research focusing on selecting an optimal concrete mix for the buildings. The critical contribution of this research was described as follows:

- Initially, a novel RbCMS technique was used to collect the material for the optimal mix selection.
- Consequently, the materials selected included cement, river sand as the fine aggregate and a mixture of fly ash and silica fume as the coarse aggregate. The testing process was also performed for various mix percentages ranging from 0% to 30%.
- Furthermore, the workability of the fresh Concrete was assessed, and the Concrete was placed in moulds.
- Several chemical attack tests, such as chloride and Carbonation in Concrete tested the durability of mix specimen.

- Moreover, the selection of the optimal mix was optimized using the fitness of the RbCMS technique.
- Finally, the performance metrics regarding CS, split tensile strength and flexural strength were validated.

The remaining part of this research was described as follows: In section 2, a literature review was stated. Section 3 provides the system model with its problems. A comprehensive process of the developed model was determined in Section 4. Section 5 presented the details of the experimental study. Section 6 concluded with the conclusion of future work.

2. Related Works:

A few associated works of the literature review were described as follows:

The higher-performance Concrete (HPC) can easily crack by the drying shrinkage, which diminishes the entire strength and concrete mix durability. The core parameter of the HPC is creeping behaviour. Therefore, Afroughsabet et al. [23] validated the creeping and shrinkage attitude of the HPC. Here the testing mix was created by the combined fibre-reinforced Concrete. It includes fibre and reduces the shrinkage rate. However, further increasing the fibre reduces the Concrete's overall strength and durability.

Sandanayake et al. [24] designed an optimized decision framework for selecting green material optimally to replace cement in Concrete. The framework's design aims to adopt the nature of the green material in the concrete mix. The green material chosen is fly ash geopolymer. The benefit of concrete mix with Melbourne results is higher performance in Green House Gas (GHG) emission and cost degradation. Also, attaining a globally optimized solution is complicated, and the cost is increased if the material is unavailable locally.

The optimized mix proportions with multi-objective constraints avail the best concrete mix. So Zhang et al. [25] introduced the ML-based optimization process such as backpropagation neural network, support vector regression, regression tree, k-nearest neighbour, random forest, and logistic regression to get the correct concrete mix proportions.

The ML function learns the characteristics of the different used materials based on discrete data and helps to get the concrete mix in optimal ratios. Also, it results in a higher accuracy rate in proportion prediction before construction. The disadvantage is that it faces a low convergence rate problem, whereas an insignificant decrease in root mean square error (RMSE) was observed.

Kurda et al. [26] discussed a new approach named the Multi-criteria decision method for concrete optimization which was suitable for various applications on the construction site. The suggested method optimizes the mixes by the global requirement layout that is in increased demand. The additional time and resources were not mandatory; the system mainly concentrated on the final optimal mix selection. The users can directly use the output mixes. However, this method is limited to optimizing the technical performance, such as mechanical and durability characteristics, based on the threshold level.

In concrete technology, mixing additives and their proportions is more challenging. Therefore, Bahrami et al. [27] studied the self-compacting component's (SCC) mechanical, rheological, and microstructural properties.

The mix included coarse and fine recycled aggregates. A part of added cement and micro silica has increased the mechanical properties and structural strength. According to the usage of maximum micro-silica content, the performance of the recycled aggregate mixed samples is more excellent for using high micro-silica than the normal concrete mix. However, the increased amount of micro silica reduces the self-compacting feature of SCC.

3. Materials and Mix Proportions:

Materials that are used for the current article is cement, river sand as fine aggregate, consider coarse aggregate as fly ash and silica fume. Here, the cement mix ratio is attained as per the EFNARC standard**.** Here, M45 grade is taken for the concrete mix. The ratios with the aggregate mixes are represented in Table 1.

The OPC is partially used with river sand, silica fume and fly ash aggregates with varying rates such as 0%, 10%, 20% and 30%. The correct ratio for the optimal concrete mix should be selected.

The fine aggregate (kg/m^3) of mix A1, A2, A3, A4 are 707, 507, 610, and 652, whereas the coarse aggregate (kg/m^3) for the four mixes such that 993, 1035, 1024, and 900. Furthermore, the mixing level for cement and water in the four mixes are 7 kg/m^3 and 147 kg/m^3.

Table 1: Mixing level of ratio for the aggregate mixes

Grade	**Mix. no**	**Mix (%)**	**Cement (kg/m^3)**	**Water (kg/m^3)**	**Fine aggregate (kg/m^3)**	**Coarse aggregate (kg/ m^3)**
M45	A1	0-fly ash 0- silica fume	7	147	707	993
	A2	10- fly ash 10- silica fume	7	147	507	1035
	A3	20- fly ash 20- silica fume	7	147	610	1024
	A4	30- fly ash 30- silica fume	7	147	652	900

4. Proposed RbCMS for Optimal Mix Selection:

A novel Redfox-based concrete mix selection (RbCMS) was introduced to select the optimal concrete mix for the structured buildings. Initially, the material was collected for the optimal mix selection, such as cement and river sand as fine aggregate.

Then, mixing material, included with fly ash and silica fume as coarse aggregate, was used for the mixing process. Finally, the optimized mix selection was made based on the fitness of the proposed RbCMS technique.

The Redfox algorithm is considered for optimal mix selection and shrinkage reduction. The architecture of the developed approach is shown in Fig. 1.

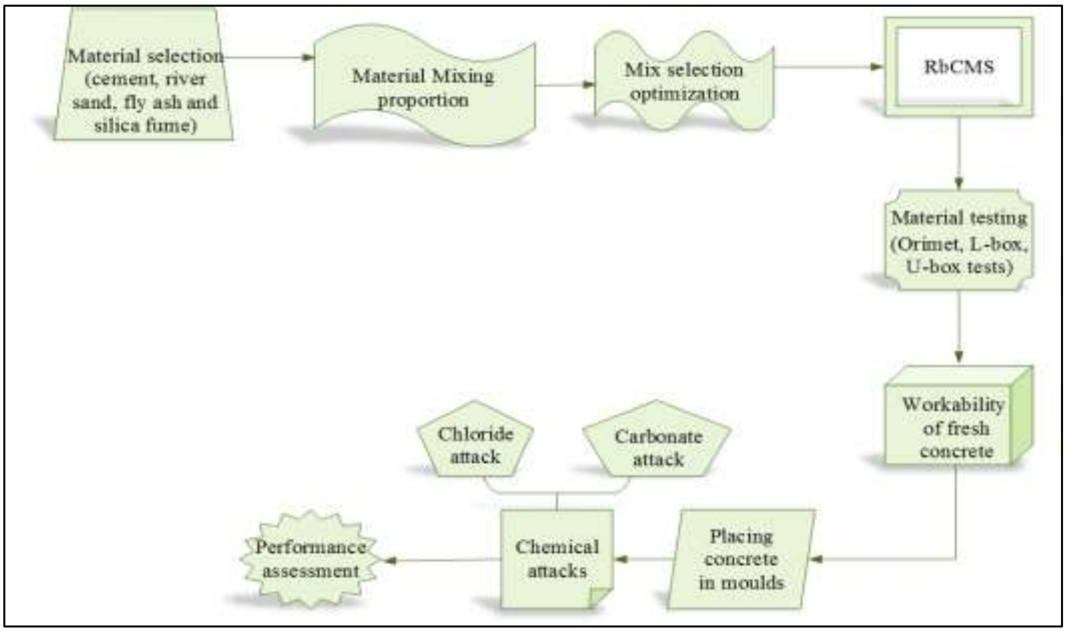

Figure 1: The schematic diagram for the proposed RbCMS model

The materials taken for the present research are silica fume and fly ash. It was used in Ordinary Portland Cement (OPC) to reduce shrinkage and maximize CS.

Reducing the shrinkage rate is essential to increase the strength and avoid cracks in the building. It can be minimized by selecting the optimal solution from different concentration mixes.

4.1 Testing process:

The Concrete was mixed in the traditional mixing of standard Concrete with chosen quantities such as 0%, 10%, 20%, and 30% to determine the optimal mix selection of Concrete.

4.1.1 Workability Criteria of Fresh Concrete:

After performing the concrete mixing process, the filling and passing test was measured through several tests. Here, EFNARC standards were used to mix the fresh Concrete by various tests, namely Orimet, U box, L-box tests. The properties of SCC play a necessary task in performing the mechanical and workability process. The Orimet test is used as a rapid field test to measure the Concrete's workability.

The H2/H1 is calculated using L-box test. Also, the U-box test estimated the passing ability of the Concrete of (H2-H1) value, and vertical part (H1) and horizontal part (H2) concrete heights were measured. The standard test results for these tests were the L-box test was 0.8-1.0, the U-box test was 0-30, Orimet test was 0-5s, respectively.

The placing of Concrete with various mixing levels in cubes, cylinders and beams, the specimens standard size used for placing the Concrete was $15cm \times 15cm \times 15cm$ cubes, $10cm \times 10cm \times 50cm$ beams, $15cm \times 30cm$ cylinder. After, the Concrete was kept in moulds, placed in moist air and pretreated at $20^{\circ}C$ 98% humidity for 7 and 28 days. After curing the specimen, take the Concrete from the moulds. Then, the excessive water was eradicated the surface area. Furthermore, the flexural strength, CS and split tensile strength were calculated. The pseudocode of the designed model is represented in algorithm 1.

4.2 Mix Selection Optimization:

This research used the Redfox algorithm to optimize the mix selection in the optimal Concrete's mix chemical attacks. This phenomenon depends on the concrete strength, and new concrete strength was measured using Eqn. (1).

$$R_n = R_0 + R_s \alpha (R_{best} - R_0) \tag{1}$$

Where, R_n represented the concrete cube, R_0 denoted as the attained concrete strength after cured with chemicals, R_{best} indicated as the maximum compressive strength and α was the randomly selected scaling hyper-parameter set. The new strength of the Concrete for the mix selection optimization was estimated in Eqn. (2).

$$R_s = \begin{cases} if\,(R_n \geq 55 & best \\ \quad else & \min imum \end{cases} \tag{2}$$

Where, R_s indicated as the optimal compressive strength of mix selection process compliance with IS 516:1959 standard whereas compressive strength (C) values greater than 55, the optimal mix was selected for SCC. Eqn. (2) was substituted in Eqn. (1); the new strength was calculated based on the compressive strength of the mix estimation scenario for the optimal mix selection of the SCC.

Algorithm 1: RbCMS

```
Start

{
      Material selection ()

      Material testing process

          Material mixing process

  Analyzing the concrete mix workability

          If the Concrete's workability was good

          then

          Concrete was placed

          Concrete was cured with normal water

          Cured concrete testing

               Fresh concrete properties

               // optimum Concrete mixing from M45 grade

               The mixed concrete was cured optimally in normal water with carbonate
               and chloride attack

                    Develop Redfox algorithm

                    // optimize the strength and mix selection of Concrete

     Process of RbCMS()

      Estimation of new concrete strength
               int $R_N, R_S, R_0, R_{best}, \alpha$;

               //Initialize the concrete strength parameters

               Compute the new strength of Concrete using Eqn. (1)and Eqn. (2)

               Here $R_s$ is the optimal compressive strength function of RbCMS
               //Optimized mix selection process was performed
}
Stop
```

Fig. 2 and Algorithm 1 clearly illustrate the steps for the designed technique. The MATLAB code was executed, and the outcomes were verified using the processing steps. In the pseudocode format, the algorithm was written by incorporating entire parameters of the mathematical function.

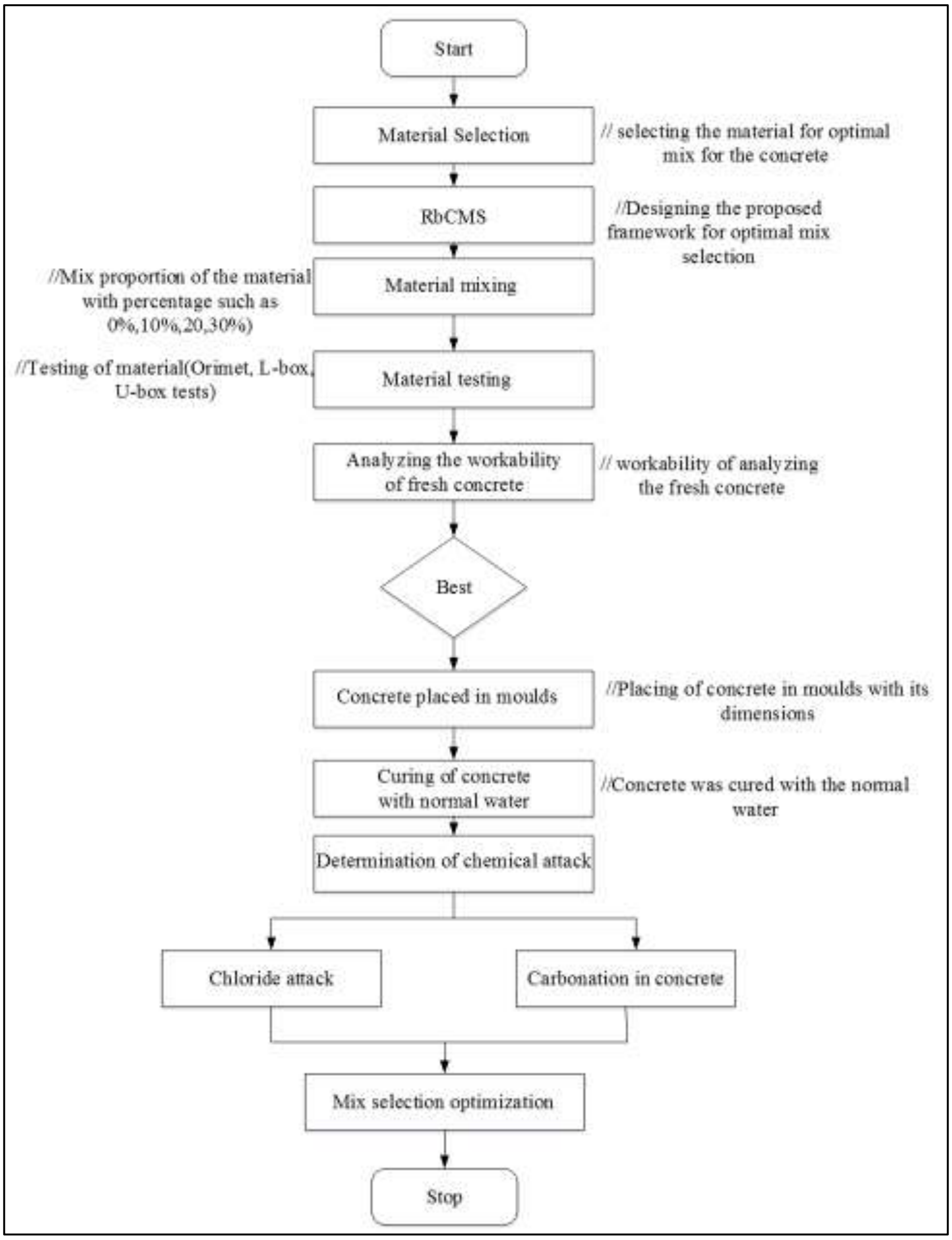

Figure 2: Flowchart of RbCMS model

5. Result and Discussion:

The developed mechanism was implemented in the MATLAB platform. This implementation process was processed on the Windows 10 platform. Moreover, the parameter specification used in this process was tabulated in Table 2. This work was used to implement the novel optimized technique for the optimal mix selection for the structural building.

Table 2: Parameter used in the proposed model

Operating system	Windows 10
Programming platform	MATLAB
Version	R2021a

5.1 Case study:

This research developed a novel technique for the optimal mix selection process: red fox optimizer. Initially, the proposed RbCMS was used to collect the material for selecting the optimal concrete mix phenomena. It verified that the developed design used mixing variables for the structural building.

5.1.1 Determination of chemical attack:

According to the presence of alkaline material in Concrete, place the chemical attacks in the SCC structure in compliance with IS: 456-1978 standards.

This could be defined by conducting the chemical attack test such as chloride attack, and Carbonation in Concrete. The flexural, compressive and split tensile strength is found out by testing the concrete specimens after the drying period.

a) Chloride attack:

Chloride attack was the vital characteristic of concrete durability. The concrete reinforcement corrosion is mainly affected Concrete by this attack.

The chlorides could be permitted in admixtures before construction which provides calcium chloride, and the water was mixed with contaminating with salt water or washed marine aggregates improperly.

After construction, the reinforcement corrosion was caused by the chlorides in salt or seawater that may damage or attack the Concrete.

Finally, the chloride present in water and oxygen, reacted with the protective layer of alkali around the concrete specimen and reinforcement was removed within 7 and 28 days as the outcome.

b) Carbonation in Concrete:

From the atmosphere, the carbon dioxide entered into concrete and calcium carbonate was generated by reacting with the calcium hydroxide, which is said to be Carbonation.

Generally, Concrete provides maximum alkaline content from the protected layer from the reinforcement. Yet, the carbondioxide turns into diluted carbonic acid, so the mix selection for SCC to diminish the alkalinity resulting in reinforcement corrosion takes place.

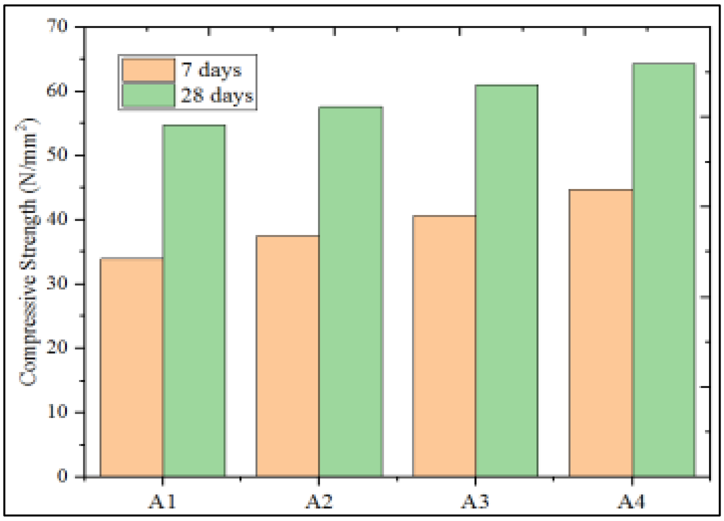

Figure 3: Analysis of Compressive strength for 7 and 28 days cured samples

The maximum and minimum CS (N/mm^2) gained for the 7 days cured samples is 44.73 and which is performed for A5 mix and A1 mix. Also, the highest compressive strength for 28 days cured sample of A4 mix is 64.29 (N/mm^2) and its lowest CS for 28 days is 54.81 N/mm^2, that is obtained for the A1 mix. The CS result for 7 and 28 days was illustrated in Fig. 3.

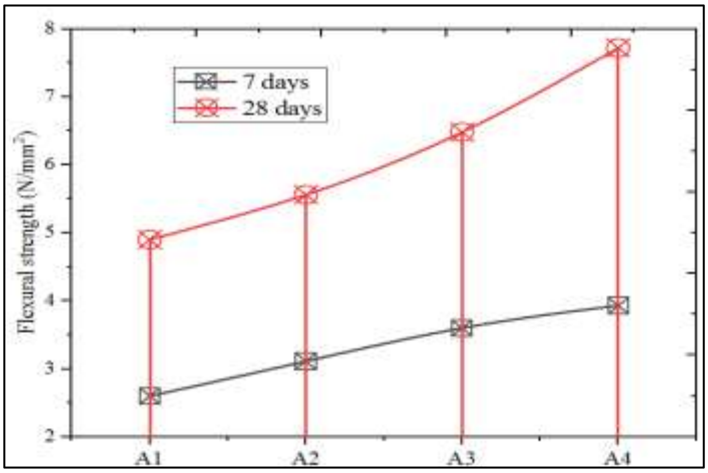

Figure 4: Flexural strength for 7 and 28 days of cured samples

The metrics of flexural strength were measured for 7 and 28 days. Here, the flexural strength (N/mm^2) of four mixes A1, A2, A3, and A4, for 7 days are 2.60, 3.11, 3.60, and 3.93. Additionally, the flexural strength for 28 days of four mixes is 4.90, 5.56, 6.48, and 7.72. Here, A5 attains good flexural strength for 7 and 28 days. The graphical representation of flexural strength is depicted in Fig. 4.

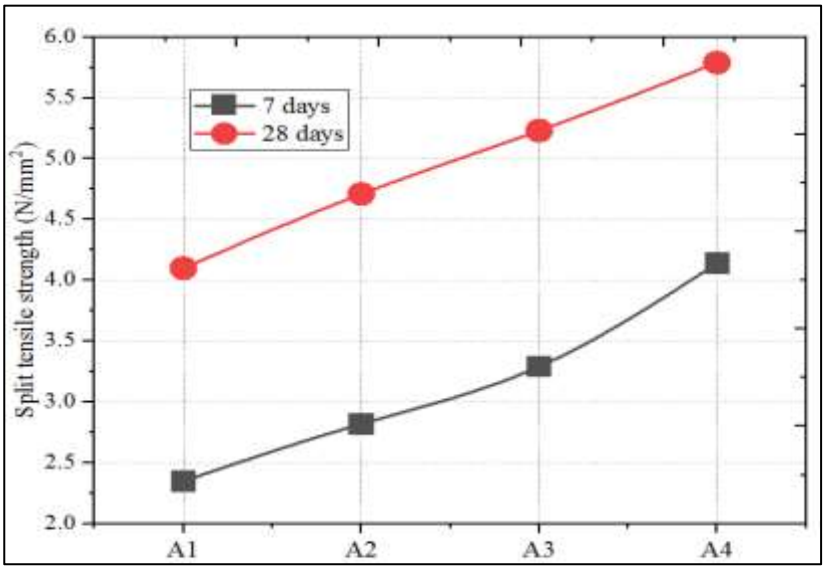

Figure 5: Split tensile strength for cured samples in 7 and 28 days

The split tensile strength (STS) (N/mm^2) had recorded for the 7 days cured samples of A1, A2, A3, and A4 mix were 2.35, 2.82, 3.29, and 4.14, whereas A4-mix gained the highest split tensile strength for 7 days. Moreover, the STS for 28 days of four mixes included 4.10, 4.71, 5.23, and 5.79. Here, the lowest and highest tensile strength recorded for 28 days were A1 and A4. The validation result of split tensile strength is represented in Fig. 5. The overall metrics result is determined in Table 3.

Table 3: Validation result

	Compressive strength (N/mm^2)		**Flexural strength (N/mm^2)**		**Split tensile strength (N/mm^2)**	
	7 days	**28 days**	**7 days**	**28 days**	**7 days**	**28 days**
A1	33.9	54.81	2.60	4.90	2.35	4.10
A2	37.47	57.62	3.11	5.56	2.82	4.71
A3	40.73	61.03	3.60	6.48	3.29	5.23
A4	44.73	64.29	3.93	7.72	4.14	5.79

5.2 Comparative Analysis:

In the proposed RbCMS model, the accurate performance of the optimal mix selection for structural building with various performance metrics such as CS, STS and flexural strength. Meanwhile, the developed mechanism was compared with several existing methods, such as the Self-compacting Concrete (SCC) approach [28], Basalt fibre technique (BFR) [29], Waterborne epoxy resin (WER) [30], Optimum mix design (OMD) [31].

5.2.1 Compressive strength:

The CS helped to know the overall stability. By performing this test, the concrete strength could be determined easily, and the concrete quality could be generated. The characteristic strength of Concrete was the casted concrete specimen's strength and tested for 28 days. It usually measured on the universal testing machine. Therefore, the specific test method affected the compressive strength metrics and reported to the explicit technical format.

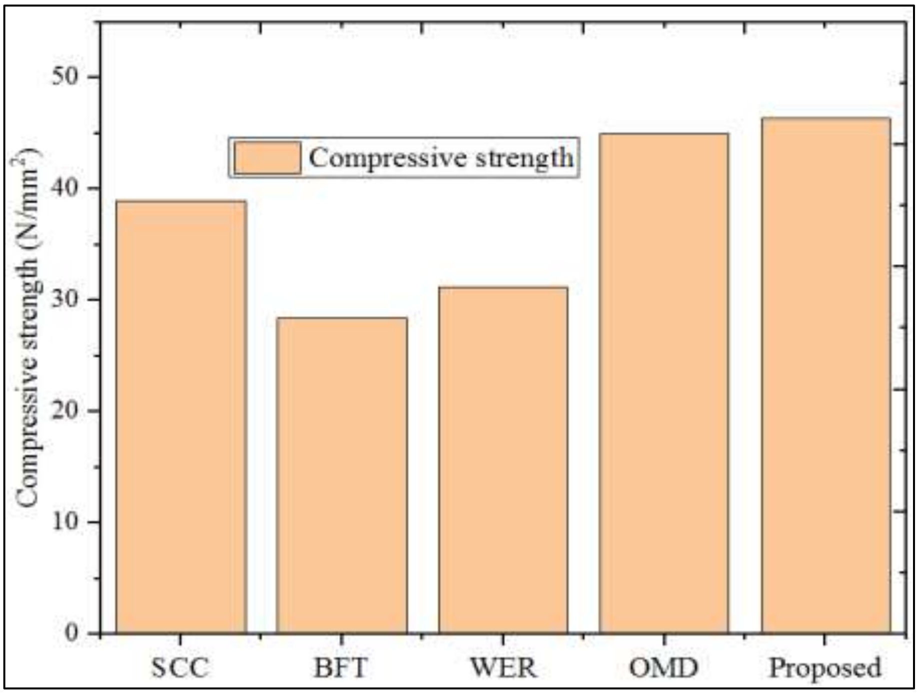

Figure 6: Comparison of compressive strength for 28 days

The CS for the SCC framework was reported at 38.99 N/mm^2, BFT gained at 28.4 N/mm^2, the method WER was registered at 31.2 N/mm^2 and the OMD technique scored 45 N/mm^2. Considering all these mechanisms, the designed model reported high compressive strength of 46.4 N/mm^2. These comparison statistics are described in Fig. 6.

5.2.2 Split tensile strength:

The STS was not the direct process of computing the Concrete's tensile test. Here, the standard cylindrical specimen was laid horizontally and applied the force on the cylinder on the surface, causing the formation of a vertical crack in the model with its diameter.

Henceforth, it is also defined as the point where the failure was based on the compression load and induced pure tensile stress with the specimen diameter.

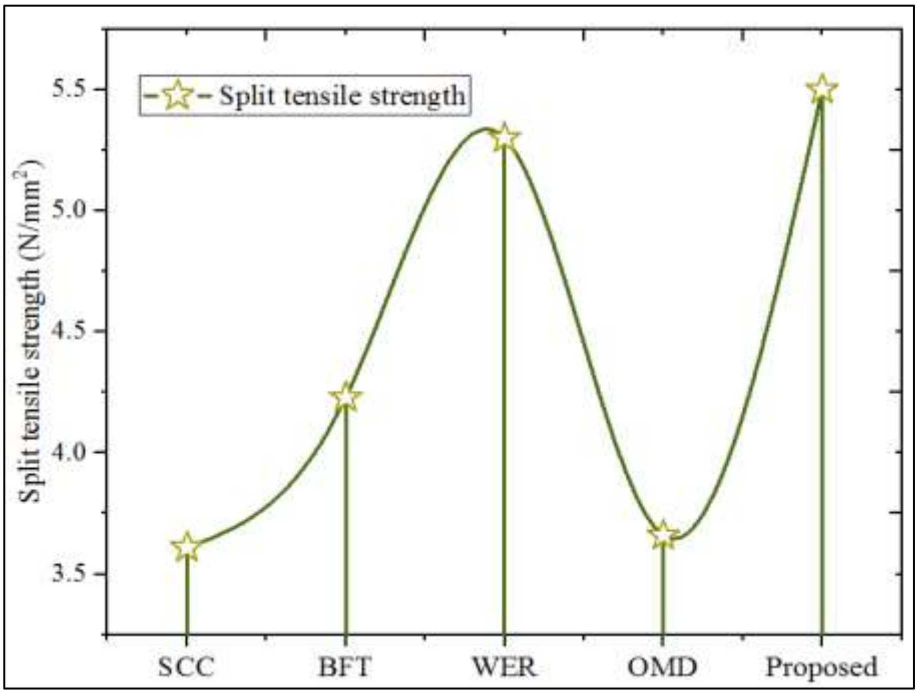

Figure 7: Comparison of split tensile strength for 28 days

The SSC model reported a 3.61 N/mm^2 split tensile strength (STS), the BFT model said a 4.23 N/mm^2 STS, WER model recorded 5.3 N/mm^2, and the model OMD gained 3.66 N/mm^2. The proposed model scored 5.5 N/mm^2 STS, better than the compared models. Comparison statistics are defined in Fig. 7.

5.2.3 Flexural strength:

The flexural strength was measured through the failure because of bending stress which considered the compressive and tensile stress at the failure part. Hence, if a similar material is subjected to tensile forces, the stress is uniformly distributed across all the fibers in the material.

Failure occurs when the tensile stress reaches the weakest fiber in the material. Thus, it is typical for the flexural strength to be greater than the tensile strength for a similar material.

The existing model's flexural strength, including SCC, had provided 3.9 N/mm^2, WER was 1.05 N/mm^2, and OMD scored 5.63 N/mm^2.

In contrast, compared with the other approaches, the developed mechanism provides the reliable result of flexural strength of 6.8 N/mm^2. Fig. 8 provides an overview of the flexural strength of various existing systems. The overall performance assessment of the proposed mechanism is tabulated in Table 4.

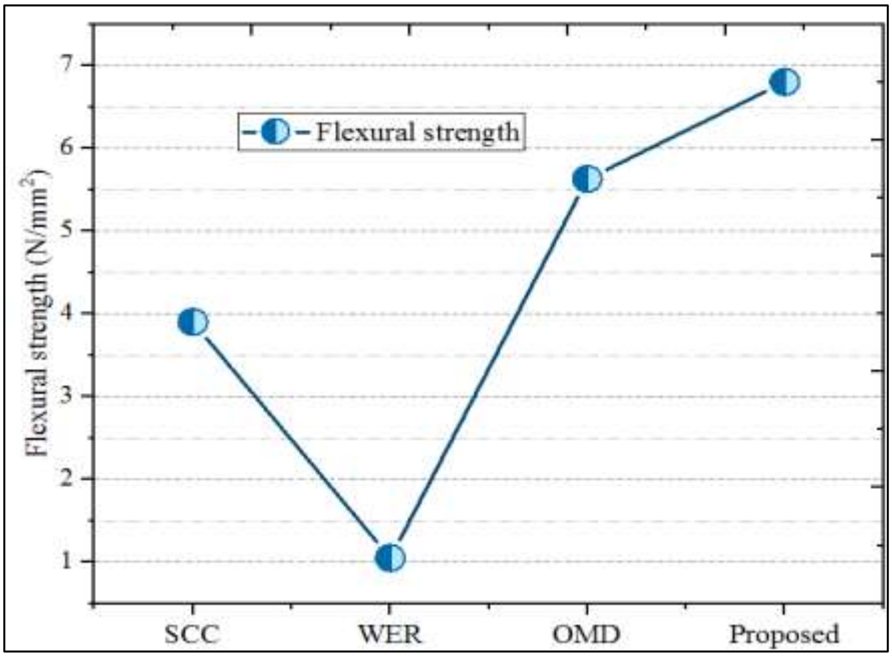

Figure 8: Comparison of flexural strength for 28 days

The developed model, superior to the prior studies, produced the optimal concrete mix selection for the effective building by measuring the performance metrics. Therefore, it would be possible to confirm this performance assessment by conducting a performance analysis in the final part. The proposed technique collected the material, mixing parameters of fly ash and silica fume phenomena, and optimal mix selection.

Table 4: Performance assessment of the developed model

Method	**Metrics**		
	Compressive Strength (N/mm^2)	**Split tensile strength** (N/mm^2)	**Flexural strength** (N/mm^2)
SCC [28]	38.99	3.61	3.9
BFT [29]	28.4	4.23	-
WER [30]	31.2	5.3	1.05
OMD [31]	45	3.66	5.63
Proposed	46.4	5.5	6.8

6. Conclusion:

This paper described a proposed RbCMS system of optimal mix selection for Structural building construction. The proposed model had several components: material collection, silica fume, fly ash mix and mix selection optimization.

The introduced novel RbCMS gained the finest outcome from all the metric performance evaluations. The implementation carried out for this process was performed in the MATLAB tool. Therefore, the overall performance statistics with the performance metrics included CS, STS and flexural strength of the developed mechanism, included with 46.4 N/mm^2, 5.5 N/mm^2, and 6.8 N/mm^2. Henceforth, the proposed model gained a high compressive strength associated with the existing tools. So, the mixing process for this developed mechanism was very effective. However, this study does not discuss the environmental impact against the proposed design. In future, designing the environmental impact analysis system will accurately define the significance of the proposed model.

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