International Journal of Applied Science and Engineering

Optimization of mixture proportions for self-compacting concrete using TOPSIS method

Kesavamoorthi. R, Mohan Ganesh. G

School of Civil Engineering, Vellore Institute of technology, Vellore, India

ABSTRACT

The process of concrete mix design encompasses numerous parameters. Finding the ideal mix design may be quite challenging for self-compacting concrete (SCC). This research aims to identify the best optimum mix proportions for SCC using TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method. In this methodology, SCC mixtures with an extensive set of experimental data and performance measures are combined into a single value for optimizing. For this the required data sets of twenty-one SCC mixtures were developed utilizing the Nan-Su method with M50 grade of concrete and cast for finding fresh and mechanical properties. The slump flow was measured using EFNARC standards and compressive strength was measured. The input parameters for the TOPSIS method were slump flow, compressive strength, superplasticizer (SP), viscosity modifying agent (VMA), and the W/C ratio which were among the five criteria used to choose as alternatives among the twenty-one different mix proportions. Therefore, the experimental data set of SCC provides the essential data for the decision matrix. TOPSIS is a ranking algorithm for condensing the results of many different criteria into a single value. By evaluating and rating the various mixture proportions, the optimal one was identified which reduces the number of trail mixtures in future, as seen in the details given in this study. Further, the study will evaluate the effect of supplementary cementitious materials (SCMs) on the properties of SCC. The replacement of SCMs improves the fresh and mechanical properties compared to the control mix and SCMs promotes the sustainable and environmentally friendly construction practices.

Keywords: EFNARC, Nan-Su method, Self-compacting concrete, TOPSIS.

OPEN ACCESS

Received: August 31, 2024
Revised: March 01, 2025
Accepted: March 28, 2025

Corresponding Author:
Mohan Ganesh. G
gmohanganesh@vit.ac.in

Publisher:
Chaoyang University of Technology
ISSN: 1727-2394 (Print)
ISSN: 1727-7841 (Online)

1. INTRODUCTION

Self-compacting concrete (SCC) is a concrete that can fill the formwork with a congested reinforced zone without any external or mechanical vibration and instead uses its own weight. Self-compatibility can only be achieved by using the right components in the right proportions. The qualities of the elements make self-compacting concrete flowable and homogenous. The cement and aggregates flocculate spontaneously in mixing water (Okamura and Ouchi, 2003). Surface active admixtures and the increased specific surface area play an essential role in SCC development. SCC may be made using local materials, but the mix design is different. Around the globe, several mixture design models for SCC have been created. When optimizing SCC, the material is generally reduced. This minimal quantity depends on aggregate packing density, cement, and fine aggregate (Skarendahl and Billberg, 2006). A factor that determines self-compatibility includes the quantity of aggregate, binder, mixing water, type and dosage of Superplasticizer. Nan-Su stated that the proposed mix design might be considered the high-quality mix design for SCC. This design approach focused on the target strength; each material proportion is driven to its maximum strength at the appropriate stage. The significant benefit of this approach is that pastes of the binder fill into the voids of aggregates, and packing density plays a vital role. This method decreases the number of trail mixes, helping to find the desired mix (Su et al., 2001). The production of SCC that meets the demand of manufacturers requires the simultaneous evaluation of all essential components. The endurance of concrete is influenced by various components which are frequently found to be in contradiction with one another. Hence, considering all these quality standards, one might see it as a multi-objective optimization technique for identifying the optimal composition (Şimşek et al., 2013a; Şimşek et al., 2016b). To address this, utilization of a Multi-Criteria Decision Making (MCDM) optimization method is necessary to classify the optimal SCC mixture (Sharifi et al., 2020; Swathi and Vidjeapriya, 2024).

MCDM methods are used to assess, analyze, and ranking possibilities of alternatives for industrial application. Weighted sum method, weighted product method, TOPSIS and analytic hierarchy process are some of the MCDM methods that have been used in the real world to make decisions. This approach is well-suited for research assignments that require selecting the most optimal parameters from many variable alternatives. This approach is used when determining the variety of alternatives and multiple ranges of criteria, each with its own set of competing characteristics and the trade-offs (Revilla-Cuesta et al., 2021). Subsequently, MCDM methods support research efforts in identifying the most effective combination to achieve desired characteristics without compromising any optimization criteria. This method helps researchers to make the best choice for response and gives them the ability to choose the best option according to several variables (Praveenkumar et al., 2019). In MCDM, TOPSIS is widely employed in a variety of engineering applications because of its relative ease of computation. The TOPSIS approach was developed to address complex multi-criteria issues, with the core premise of picking alternatives that are closest to the best Positive Ideal Solution (PIS) and distant from the Negative Ideal Solution-worst (NIS). TOPSIS is a practical decision-making strategy that may be utilized when choosing choices from a list of present criteria. According to the MCDM technique, the decision table is split into four sections: (1) alternatives, (2) criteria, (3) relative significance of each criterion and (4) performance of criterion without trade-off among them (Praveenkumar and Sankarasubramanian, 2021). Response surface, Taguchi and Design of experiment approaches were employed in a few cases to determine the effect of attributes based on concrete quality. Several optimization approaches are used in the literature to estimate the ideal mix proportions of various types of concrete and TOPSIS is the easiest way to compute ideal solution (Türkmen et al., 2003; Athiyaman and Mohan Ganesh, 2018; Kunhanandan, 2006). Table 1 shows the pervious study on optimization by TOPSIS method. Based on the above literature the TOPSIS method is most suitable method to optimize the mix proportion of SCC.

In order to minimize the economic and environmental effects of cement manufacture, it is possible to use supplemental cementitious materials (SCMs) such fly ash, bottom ash, slag, silica fume, and natural pozzolans as replacements for cement to produce concrete (Bicer, 2018). Fly ash is a residual product generated by thermal power plants. The addition of fly ash to concrete enhances its freshness, mechanical strength, and the durability (Chindaprasirt et al., 2005; Murugan et al., 2012). The study conducted by Nili et al. (2010) investigated the effects of replacing cement with 8% silica fume. This enhanced the strength and adaptability of the SCC. Another study examined the properties of SCC by substituting 40% of the cement with SCMs, namely 30% fly ash and 10% silica fume (Athiyamaan and Mohan Ganesh, 2020a). The utilization of SCMs has improved the rheological and mechanical characteristics, while also decreasing the expenses associated with cement.

1.1 Aim of the Study

Self-compatibility can only be achieved by using the right components with the right proportions. SCC consists of many conflicting factors; it is critical to use a systematic method under a set of constraints. The main objective of this study is to identify the most suitable combination of materials for self-compacting concrete, considering aspects such as the ratio of water to cement, the amount of superplasticizer, the volume of VMA, the flowability of the concrete, and its compressive strength. In this connection, multi-response TOPSIS method used to optimize the mix proportion of SCC used in this study to rank the best mix proportions of the SCC. Additionally, the study will evaluate the effect of SCMs on the properties of self-compacting concrete.

2. EXPERIMENTAL PHASES

This study divides the experimental stages into two distinct phases. Phase I deals with determining the optimum mixture proportion for self-compacting concrete using the TOPSIS method. Phase II, deals with the fresh and mechanical properties of SCC using an optimized mix proportion, both with and without SCMs. Additionally, the cost analysis was done to determine the advantages of utilization of SCMs in SCC.

Table 1. Previous studies on optimization by TOPSIS method

Type of concrete	To optimize	Optimization method	References
High strength SCC	Mixture proportion	TOPSIS	Şimşek et al., 2013
Polymer blended concrete	Mixture proportion	TOPSIS	Şimşek et al., 2016
SCC	Mix design	TOPSIS	Sharifi et al., 2020
High strength concrete	Low carbon binders	TOPSIS	Swathi and Vidjeapriya, 2024
SCC	Optimal concrete composition	TOPSIS	Cuesta et al., 2021
High performance concrete	Mixture proportion	TOPSIS	Praveenkumar et al., 2019

2.1 Materials

In this study, Ordinary Portland Cement (OPC-53) grade, flyash, and silica fume was used in this study. Manufacture sand (M–Sand) used as a fine aggregate with a specific gravity of 2.64 and fineness modulus of 2.52, confirmed to IS 383-2016. Coarse aggregates are retained on a 10 mm sieve, confirming that IS 383-2016 was used in this study. Fig. 1 depicts particle size distribution of binders and fine aggregate.

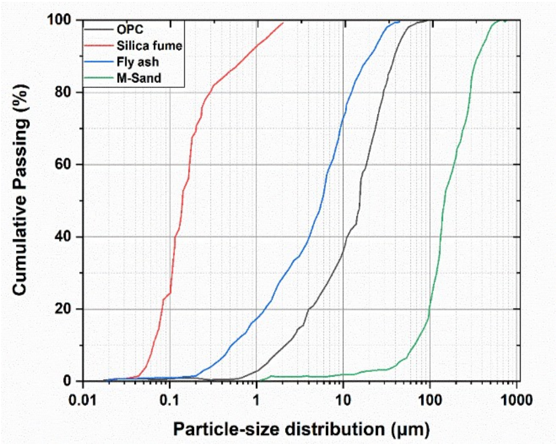

Fig. 1. Particle size distribution of binders and M-Sand

In this study, Superplasticizer-Polycarboxylate ether (PCE) based, specifically Master Glenium SKY 8233, and viscosity modifying agent (VMA), specifically Master Matrix VMA 358 with a specific gravity of 1.06 and pH greater than 6 was used. The chemical and physical characteristics of binders are shown in Table 2. All the trail mixes are prepared using these materials.

3. EXPERIMENTAL WORK PHASE – I

3.1 A TOPSIS Method of an Optimization for SCC Mixtures

The TOPSIS method's primary concept is that the selected choice should be the option that is the closest distance from the PIS and the furthest away from the NIS. Fig. 2 illustrates the TOPSIS approach. This approach is an easy to comprehend, observant and well-balanced technique. Furthermore, unlike other MCDM approaches, TOPSIS does not use regular assumptions to create common values (Sokolović et al., 2021). TOPSIS considers the criteria as having equal weightage among them and expressed as:

$$w = f\,(w_1, w_2, \cdots \cdots \cdots, w_n) \quad (1)$$

$$w = f\,(w_1, w_2, \cdots \cdots \cdots, w_n) \quad (2)$$

$$\sum W_{i=1}^{n} = 1$$

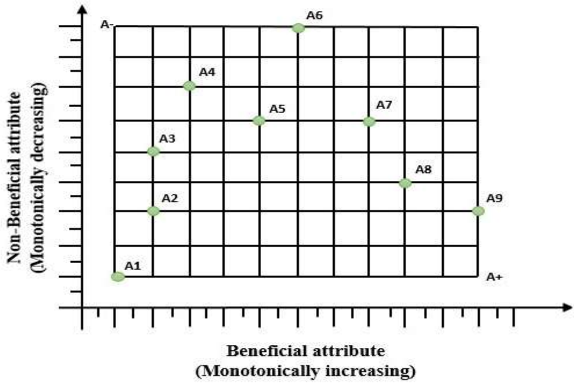

Fig. 2. Illustration of TOPSIS method (Praveenkumar and Sankarasubramanian, 2021)

The TOPSIS approach involves the following design of the study:

Step: 1 Constructing a decision matrix

$$D = \begin{array}{c c} & \begin{array}{cccccc} K_1 & K_2 & \ldots & K_j & \ldots & K_n \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{array} & \begin{bmatrix} K_{11} & K_{12} & \ldots & K_{1j} & \ldots & K_{1n} \\ K_{21} & K_{22} & \ldots & K_{2j} & \ldots & K_{2n} \\ \vdots & \vdots & \ldots & \vdots & \ldots & \vdots \\ K_{i1} & K_{i2} & \ldots & K_{ij} & \ldots & K_{in} \\ \vdots & \vdots & \ldots & \vdots & \ldots & \vdots \\ K_{m1} & K_{m2} & \ldots & K_{mj} & \ldots & K_{mn} \end{bmatrix} \end{array} \quad (3)$$

Where,

A_i = the i^{th} alternative considered

K_{ij} = the numerical outcome of the i^{th} alternative for the j^{th} criterion

Step: 2 Identification of normalized decision matrix

The TOPSIS approach uses vector normalization to normalize the attributes;

$$K_{ij} = \frac{K_{ij}}{\sqrt{\sum_{i=1}^{m} K_{ij}^2}};\ i = 1,2 \cdots m;\ j = 1,2 \cdots n \quad (4)$$

Different units of measurement are used to determine attributes having conflicting properties. As a result, to maintain a uniform scale of measurement, it is necessary to normalize attributes.

Table 2. Chemical and physical properties of cement

Compounds	Cao	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	K_2O	Loss on ignition	Insoluble material	Specific gravity
Cement	64.17	18.12	5.62	2.25	5.64	5.85	1	2.33	0.49	3.15
Flyash	3.68	53.2	26.1	9.69	1.21	1.19	-	4.69	-	2.32
Silica fume	< 1	93.1	-	-	-	-	-	2.78	-	2.20

Step: 3 To Construct the weighted normalized decision matrix

$$V = W_j K_{ij} \quad \text{Where } \sum_{j=1}^{n} W_j = 1 \tag{5}$$

Step: 4 Determine the PIS (B^+) and NIS (B^-)

$$B^+ = \{(\sum_i^{max} U_{ij} \,|j \in J), (\sum_i^{min} U_{ij} | j \in J | i = 1,2,\ldots,m)\} \tag{6}$$

$$B^+ = \{a_1^+, a_2^+, a_3^+, \cdots\cdots, a_n^+\}$$

$$B^- = \{(\sum_i^{min} U_{ij} \,|j \in J), (\sum_i^{max} U_{ij} | j \in J | i = 1,2,\ldots,m)\} \tag{7}$$

$$B^- = \{a_1^-, a_2^-, a_3^-, \cdots\cdots, a_n^-\}$$

Step: 5 Calculation of the separation measures between the ideal solutions of positive (Si^+) and negative (Si^-) signs

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_j^{\,+})^2}, i = 1, 2, \ldots \text{m} \tag{8}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_j^{\,-})^2}, i = 1, 2, \ldots \text{m} \tag{9}$$

Step: 6 Rank the preferred order (*Hi)* or choose the option closest to 1

$$H_i = \frac{S_i^-}{S_i^+ + S_i^-},\ 0 < H_i < 1 \tag{10}$$

The optimum option is selected based on the preference value closest to the perfect solution in terms of quality. Preferences are presented in decreasing order from most to least important. Fig. 3 shows the procedure for selection of optimum SCC mixture proportion.

3.2 Mix Proportions and Trail Mixes

The Nan-Su method was used to develop the SCC mix in this study (Su et al., 2001). Cement, fine and coarse aggregate were held constant while the W/C ratio (0.38, 0.4, 0.42) and SP dose were varied (1.4% to 1.7%). A total of 21 trail mixes were conducted that the mixes were designated as M1 to M21, as mentioned in Table 3.

The tests were conducted to examine the slump flow as per EFNARC standards (EFNARC, 2005) with different W/C ratios and SP dosages. After 24hrs of casting, the samples were removed from the moulds and cured in water for 28 days.

3.3 Determination of Optimization Condition for SCC

An optimization method used to choose the appropriate mixture fraction of input ingredients (cement, fine and coarse aggregate, water, superplasticizer, VMA) for standard characteristics concrete.

3.4 Identifying the Optimization Objectives for SCC Production

The primary objective of this investigation is as follows:

- To achieve optimum concrete quality with best mix proportions using experimental data.
- Similar weights (W/C ratio, SP dose, VMA, slump flow, and compressive strength) were used to assess the production of SCC. These factors have been given equal weightage to assess their impact on SCC.

3.5 Alternative's and Assessment Criteria

The decision-maker must consider various characteristics associated with different alternatives (mix proportions) to evaluate, prioritize, and ultimately select the most suitable alternative. The alternatives are designated as M_i (M = 1, 2, 3, …., 21). Five assessment criteria were determined for SCC. An initial performance criterion and workability properties are evaluated using slump flow for different W/C ratios, SP dosages and VMA. The second performance criterion is compressive strength at 28 days.

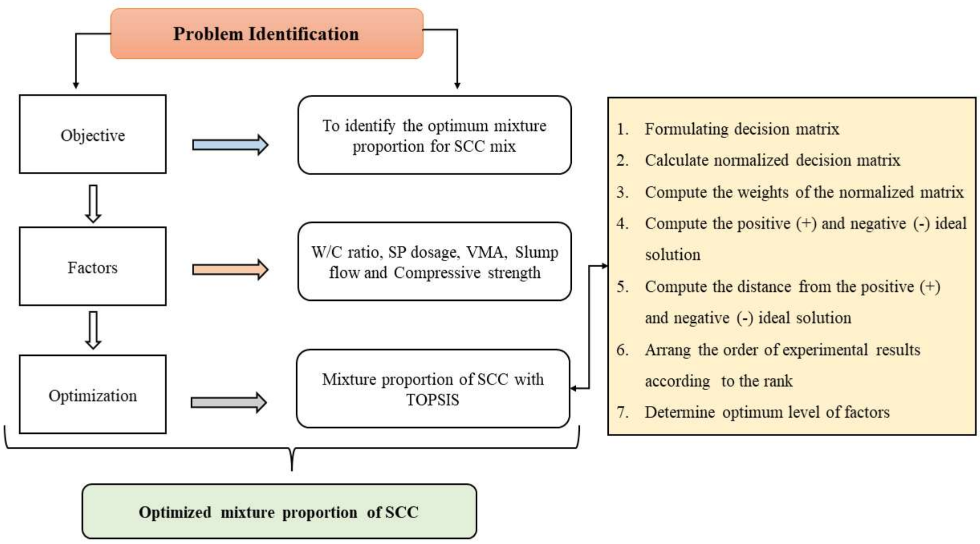

Fig. 3. Procedure for selection of optimum SCC mixture proportion

Table 3. Description of the materials needed for 1 m^3 of SCC

Mix	Cement	Fine aggregate	Coarse aggregate	Water		Superplasticizer		VMA	
ID	kg/m^3	kg/m^3	kg/m^3	Ratio	kg/m^3	%	kg/m^3	%	kg/m^3
M1	550	910	700	0.38	209	1.4	7.70	0.05	0.28
M2	550	910	700	0.38	209	1.45	7.98	0.05	0.28
M3	550	910	700	0.38	209	1.5	8.25	0.05	0.28
M4	550	910	700	0.38	209	1.55	8.53	0.05	0.28
M5	550	910	700	0.38	209	1.6	8.80	0.05	0.28
M6	550	910	700	0.38	209	1.65	9.08	0.05	0.28
M7	550	910	700	0.38	209	1.7	9.35	0.05	0.28
M8	550	910	700	0.40	220	1.4	7.70	0.05	0.28
M9	550	910	700	0.40	220	1.45	7.98	0.05	0.28
M10	550	910	700	0.40	220	1.5	8.25	0.05	0.28
M11	550	910	700	0.40	220	1.55	8.53	0.05	0.28
M12	550	910	700	0.40	220	1.6	8.80	0.05	0.28
M13	550	910	700	0.40	220	1.65	9.08	0.05	0.28
M14	550	910	700	0.40	220	1.7	9.35	0.05	0.28
M15	550	910	700	0.42	231	1.4	7.70	0.05	0.28
M16	550	910	700	0.42	231	1.45	7.98	0.05	0.28
M17	550	910	700	0.42	231	1.5	8.25	0.05	0.28
M18	550	910	700	0.42	231	1.55	8.53	0.05	0.28
M19	550	910	700	0.42	231	1.6	8.80	0.05	0.28
M20	550	910	700	0.42	231	1.65	9.08	0.05	0.28
M21	550	910	700	0.42	231	1.7	9.35	0.05	0.28

4. RESULTS AND DISCUSSION

4.1 Experimental Results

The workability of concrete was assessed at fresh stage and the mechanical characteristics were determined after 28 days of cube compressive strength. The dosage of superplasticiser with different W/C ratios influenced the result of slump flow and cube compressive strength are shown in Figs. 4a to 4d. The figures (4a, 4b, and 4c) shows the findings of trail mixes M1 to M21, in which slump flow and compressive strength are represented by three different W/C ratios of 0.38, 0.4, and 0.42 at varying SP dosage (1.4% to 1.7%). Fig. 4d displays all the combined findings from Figs. 4a, 4b, and 4c.

In Fig. 4a, with a W/C ratio of 0.38 and mixes M1 to M7, the M7 SCC mix outperforms the other mixes in slump flow (720 mm) and compressive strength (53.51 MPa). In Fig. 4b with a W/C ratio of 0.40, mixes M8 to M14 performs better in slump flow, although compressive strength steadily decreases as compared to Fig. 4a. In Fig. 4c, with a W/C ratio of 0.42, mixes M15 to M21 improves the slump flow performance but compressive strength gradually reduced like Fig. 4b. According to the experimental results, the trail mixes indicated as M1 to M8 showed better performance than the other trail mixes.

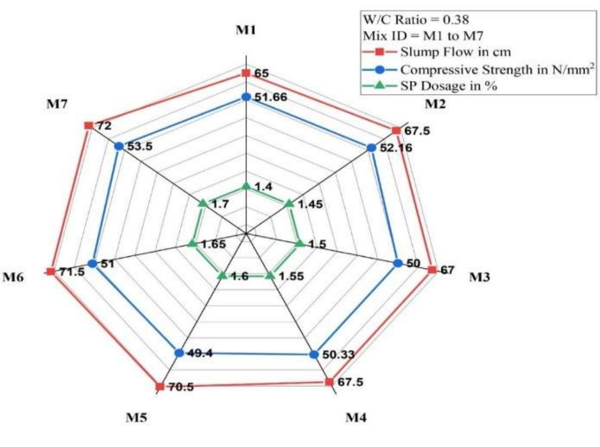

Fig. 4a. W/C ratio = 0.38 with SF, CS and SP dosage

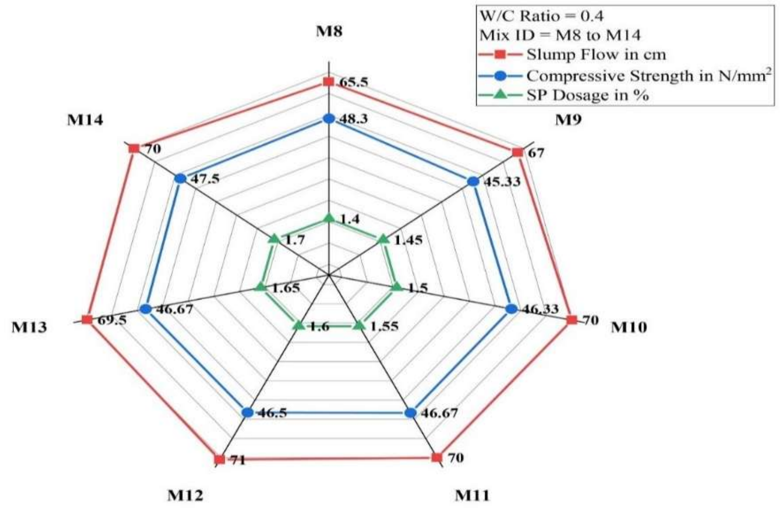

Fig. 4b. W/C ratio = 0.40 with SF, CS and SP dosage.

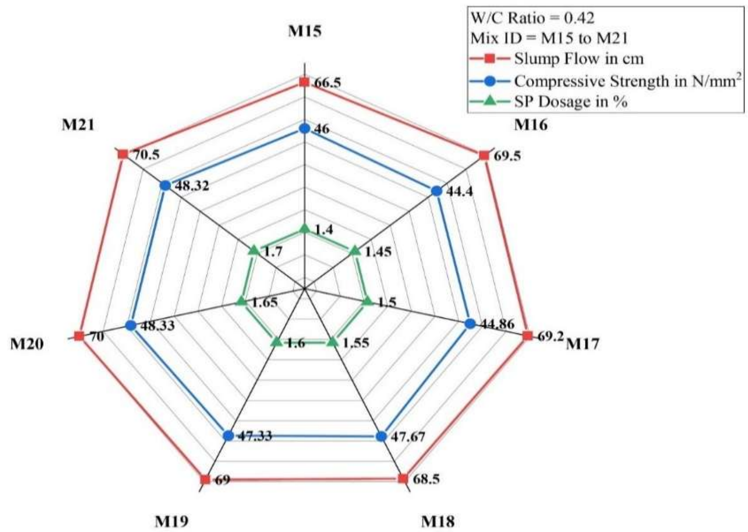

Fig. 4c. W/C ratio = 0.42 with SF, CS and SP dosage

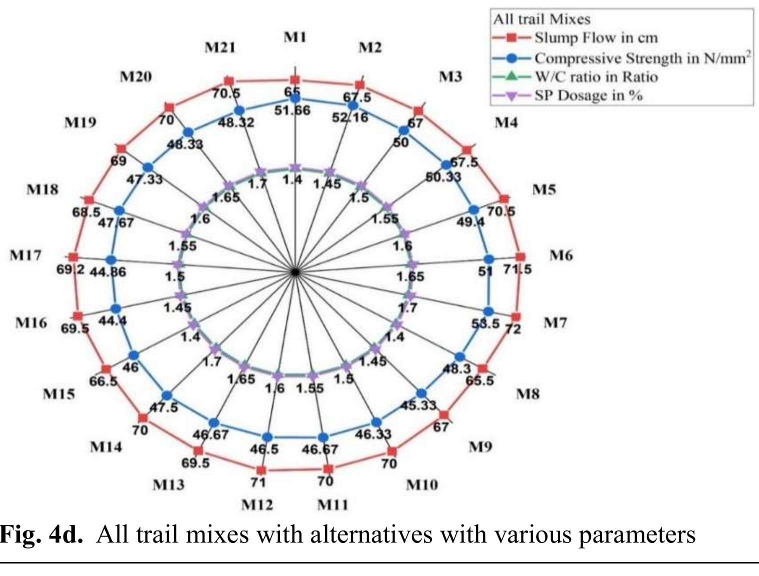

Fig. 4d. All trail mixes with alternatives with various parameters

4.2 The TOPSIS Approach for Optimization

The following are the stages involved in this approach of optimisation: There are three parts to this process: (a) Making a decision matrix (b) Estimating a weight-normalised decision matrix (c) Assessing the alternatives (PSI and NIS, separation matrix, relative closeness) and the (d) Raking the alternatives down (Abed et al., 2022).

4.2.1 Construction of Decision Matrix

To properly evaluate the interrelationships between the many alternatives of information that go into a MCDM process, it's necessary to organise data into a matrix structure. *m* x *n* matrix to represent our alternatives and criteria in the decision-making process. The element K_{ij} (i = 1, 2, …, m and j = 1, 2, …, n) indicates alternative i, when evaluated against a given criteria j. Otherwise, it might be illustrated as a narration of each choice concerning the criteria indicated by K_{ij} decision matrix (Şimşek and Uygunoğlu, 2016). Fig. 4d illustrates the formation of the decision matrix according to the alternatives and criteria.

4.2.2 Weighted Normalised Decision Matrix Estimation

In order to get the normalised decision matrix, Eq. (4) and the matrices values of K_{ij} are used. Traditionally, there are two types of criteria: benefit criterion (cumulative preference) and cost criteria (declining preference). Because the benefits criteria demand a larger value, it yields superior results than the cost, which requires lower values. Eq. (4) normalises all of the decision matrix's criterion values, resulting in the normalised decision matrix. Vector normalisation is used in this equation. Table 4 displays the normalised decision matrix.

Table 4. The normalized decision matrix

MIX ID	Normalized W/C ratio	Normalized SP	Normalized VMA	Normalized slump flow	Normalized compressive strength
M1	43681	59	0.078	422500	2659
M2	43681	64	0.078	455625	2721
M3	43681	68	0.078	448900	2500
M4	43681	73	0.078	455625	2533
M5	43681	77	0.078	497025	2440
M6	43681	82	0.078	511225	2601
M7	43681	87	0.078	518400	2862
M8	48400	59	0.078	429025	2333
M9	48400	64	0.078	448900	2055
M10	48400	68	0.078	490000	2147
M11	48400	73	0.078	490000	2178
M12	48400	77	0.078	504100	2162
M13	48400	82	0.078	483025	2178
M14	48400	87	0.078	490000	2256
M15	53361	59	0.078	442225	2116
M16	53361	64	0.078	483025	1971
M17	53361	68	0.078	478864	2013
M18	53361	73	0.078	469225	2272
M19	53361	77	0.078	476100	2240
M20	53361	82	0.078	490000	2336
M21	53361	87	0.078	497025	2335

It is created by multiplying the weight of a criterion (w_j) by each element of a normalised matrix, as indicated in Eq. (5). The weight of 1/5 is applied to each of the five criteria since they are all deemed of similar value. Table 5 displays the normalised matrix weight.

4.2.3 Assessment of Alternatives

The assessment strategy used by the TOPSIS technique is based on the discovery of near-ideal solutions. This proximity can be stated as a simple Euclidean distance between two points. Therefore, the optimal alternative should be near the positive-ideal solution while remaining far from the negative-ideal solution (Reddy et al., 2020). Using Eq. (6) and (7) the each criterion is justified as having the best and worst performance values, respectively, by justifying for the NIS (B^-) or the PIS (B^+). Table 6 displays both PIS and NIS for each criterion.

The Euclidean distance or separation values are afterwards calculated in order to assess the closeness of the alternatives to the ideal solution in an expanded space. (S_i^+) and (S_i^-) ideal solutions are separated by the separation values of each alternative in Eq. (8) and Eq. (9). Table 7 presents the estimated positive and negative separation values.

Table 5. The normalized weighted decision matrix

MIX ID	Normalized weighted W/C ratio	Normalized weighted SP	Normalized weighted VMA	Normalized weighted slump flow	Normalized weighted compressive strength
M1	0.0108	0.0257	0.0091	0.0117	0.1648
M2	0.0108	0.0266	0.0091	0.0122	0.1667
M3	0.0108	0.0275	0.0091	0.0121	0.1598
M4	0.0108	0.0284	0.0091	0.0122	0.1608
M5	0.0108	0.0293	0.0091	0.0127	0.1579
M6	0.0108	0.0302	0.0091	0.0129	0.163
M7	0.0108	0.0312	0.0091	0.013	0.1709
M8	0.0113	0.0257	0.0091	0.0118	0.1623
M9	0.0113	0.0266	0.0091	0.0121	0.1582
M10	0.0113	0.0275	0.0091	0.0126	0.1598
M11	0.0113	0.0284	0.0091	0.0126	0.1607
M12	0.0113	0.0293	0.0091	0.0128	0.163
M13	0.0113	0.0302	0.0091	0.0125	0.1566
M14	0.0113	0.0312	0.0091	0.0126	0.1531
M15	0.0119	0.0257	0.0091	0.012	0.1569
M16	0.0119	0.0266	0.0091	0.0125	0.1543
M17	0.0119	0.0275	0.0091	0.0125	0.1582
M18	0.0119	0.0284	0.0091	0.0124	0.1523
M19	0.0119	0.0293	0.0091	0.0124	0.1576
M20	0.0119	0.0302	0.0091	0.0126	0.1544
M21	0.0119	0.0312	0.0091	0.0127	0.1503

Table 6. Positive and negative ideal solution

Solution	W/C ratio	SP	VMA	Slump flow	Compressive strength
B^+	0.0119	0.0312	0.0091	0.0130	0.1709
B^-	0.0108	0.0257	0.0091	0.0117	0.1503

Table 7. The estimated separation values

MIX ID	S_j^+	S_j^-
M1	0.0140	0.0145
M2	0.0107	0.0177
M3	0.0168	0.0116
M4	0.0148	0.0137
M5	0.0163	0.0122
M6	0.0101	0.0184
M7	0.0011	0.0274
M8	0.0159	0.0126
M9	0.0188	0.0097
M10	0.0158	0.0127
M11	0.0140	0.0145
M12	0.0106	0.0179
M13	0.0164	0.0121
M14	0.0188	0.0097
M15	0.0205	0.008
M16	0.0217	0.0068
M17	0.0169	0.0116
M18	0.0220	0.0065
M19	0.0158	0.0127
M20	0.0179	0.0106
M21	0.0209	0.0076

4.2.4 Ranking of the Alternatives

Using the results of S_i^+ and S_i^- calculations, the preference value for each choice is determined. The preferance value (H_i) quantifies the solution's closeness to the ideal. To get the preference value for each choice, Eq. (10) is applied. A similarity index is a number between 0 and 1. When it comes to the best results, H_i near to 1 is measured the best, while H_i near to 0 is considered the worst. Table 8 presents the preference values associated with each alternative.

Table 8. Preference value (H_i)

MIX ID	H_i
M1	0.509
M2	0.623
M3	0.408
M4	0.481
M5	0.428
M6	0.646
M7	0.961
M8	0.442
M9	0.340
M10	0.446
M11	0.509
M12	0.628
M13	0.425
M14	0.340
M15	0.281
M16	0.239
M17	0.407
M18	0.228
M19	0.446
M20	0.372
M21	0.267

The values of the mix M7 is W/C ratio of 0.38 and the SP dose of 1.7% which are near to one. As a potential outcome of preference value, the concrete mixes are listed in Table 9.

Overall, the M7 mix outperforms all other 21 mixes in terms of slump flow and compressive strength. Further experimental work carried out with this optimized mixture proportions.

5. EXPERIMENTAL WORK PHASE – II

In this phase, the experimental work was conducted by utilizing the optimized mixture proportion of M7. SCC0FA0SF represents the control mix, which was made without SCMs, while SCC30FA10SF represents the mix that was made with SCMs. FA and SF represent the proportions of fly ash and silica fume that are used to replace a 40% amount of cement. The fresh properties that were evaluated included slump flow, T_{500}, V-funnel, and L-box tests. The results were cross-checked with the limitations set by EFNARC (EFNARC, 2005). The mechanical properties are assessed through compressive, split tensile, and flexural strength tests after 28 days. The tests were done in accordance with the specifications provided in IS 516 (Indian Standards.).

5.1 Result of Fresh Properties of SCC

Table 10 displays the fresh properties of SCC. The control mixes have a slump flow of 720 mm, which is within the EFNARC limits for the SF-2 class. The slump flow for the SCM mix is 752 mm, which is SF-3 class set by EFNARC limits that is a 4.4% increased slump flow, when compared to the control mix. The use of SCMs resulted in an increase in the slump flow. The flow ability was improved by the spherical shape and fineness of flyash particles (Murugan et al., 2012). Similarly, silica fume is very thin and very reactive. It effectively occupies the voids between the cement particles, resulting in less bleeding and segregation. The T_{500} values for both the control and SCMs mix are 4.8 and 4.2 s, respectively, within the EFNARC limits of the VS-2 class. The V-funnel test results show that the control mix requires 8 seconds, while the SCMs mix requires 3.4 s. Both of these values are within the EFNARC limits VF-1 class. SCMs decrease water demand and enhance the workability of concrete. This often leads to a reduction in V-Funnel flow time, indicating better flowability (Athiyamaan and Mohan Ganesh, 2018b). The L-box test values for the control mix and the SCMs mix are 0.88 and 0.81, respectively. These values are within the PA-2 class of EFNARC limits. The findings indicate that using SCMs improves the rheological characteristics of SCC in comparison to the control mix. Fig. 5 depicts a fresh test conducted on SCC.

(a) Slump Flow (b) V-Funnel Test (C) L-Box Test

Fig. 5. Fresh test on SCC

Table 9. Ranking of SCC mix proportion validated with TOPSIS method

MIX ID	Cement	Fine aggregate	Coarse aggregate	Water	SP	VMA	Slump flow	Compressive strength	H_i
	kg/m³	kg/m³	kg/m³	kg/m³	kg/m³	kg/m³	mm	N/mm²	Rank
M7	550	910	700	209	9.35	0.275	720	53.50	1
M6	550	910	700	209	9.075	0.275	715	51.00	2
M21	550	910	700	231	9.35	0.275	705	48.32	3
M14	550	910	700	220	9.35	0.275	700	47.50	4
M20	550	910	700	231	9.075	0.275	700	48.33	5
M5	550	910	700	209	8.8	0.275	705	49.40	6
M13	550	910	700	220	9.075	0.275	695	46.67	7
M19	550	910	700	231	8.8	0.275	690	47.33	8
M4	550	910	700	209	8.525	0.275	675	50.33	9
M12	550	910	700	220	8.8	0.275	710	46.50	10
M18	550	910	700	231	8.525	0.275	685	47.67	11
M11	550	910	700	220	8.525	0.275	700	46.67	12
M3	550	910	700	209	8.25	0.275	670	50.00	13
M2	550	910	700	209	7.975	0.275	675	52.17	14
M1	550	910	700	209	7.7	0.275	650	51.57	15
M10	550	910	700	220	8.25	0.275	700	46.33	16
M17	550	910	700	231	8.25	0.275	692	44.87	17
M8	550	910	700	220	7.7	0.275	655	48.30	18
M9	550	910	700	220	7.975	0.275	670	45.33	19
M16	550	910	700	231	7.975	0.275	695	44.40	20
M15	550	910	700	231	7.7	0.275	665	46.00	21

Table 10. Result of fresh properties of SCC with and without SCMs

MIX ID	Slump flow (mm)	EFNARC limits	T_{500} (s)	EFNARC limits	V-Funnel (s)	EFNARC limits	L-Box (H2/H1)	EFNARC limits
SCC0FA0SF	720	SF-2	4.8	VS-2	8	VF-1	0.88	PA-2
SCC30FA10SF	752	SF-3	4.2	VS-2	3.4	VF-1	0.81	PA-2

5.2 Result on Mechanical Properties of SCC

The mechanical properties of control and SCMs mixtures are shown in Table 11. The compression strength was measured with M50-grade concrete in this study. The compressive strength values for the control and SCMs mixtures are 52.32 and 53.6 MPa, respectively. The substitution of SCM enhances the compressive strength by 2.45%. Similarly, the split tensile strength and flexural strength showed an increase of 18.84% and 55.49%, respectively, when compared to the control mix. The use of SCMs enhanced the microstructure and decreased the porosity of the concrete. The combination of fly ash and silica fume can have a synergistic effect (Athiyamaan and Mohan Ganesh, 2020a). Fly ash improves workability and reduces water demand, while silica fume enhances early strength development and densifies the microstructure, which is observed in scaning electron microscope analysis. Fig. 6 displays the SEM images of SCC. The use of SCMs can result in the development of SCC that exhibit enhanced mechanical properties, including increased compressive, split tensile, and flexural strengths.

Table 11. Result of mechanical properties of SCC with and without SCMs at 28 days

MIX ID	Compressive strength in MPa	Split tensile strength in MPa	Flexural strength in Mpa
SCC0FA0SF	52.32	3.45	7.07
SCC30FA10SF	53.6	4.10	10.99

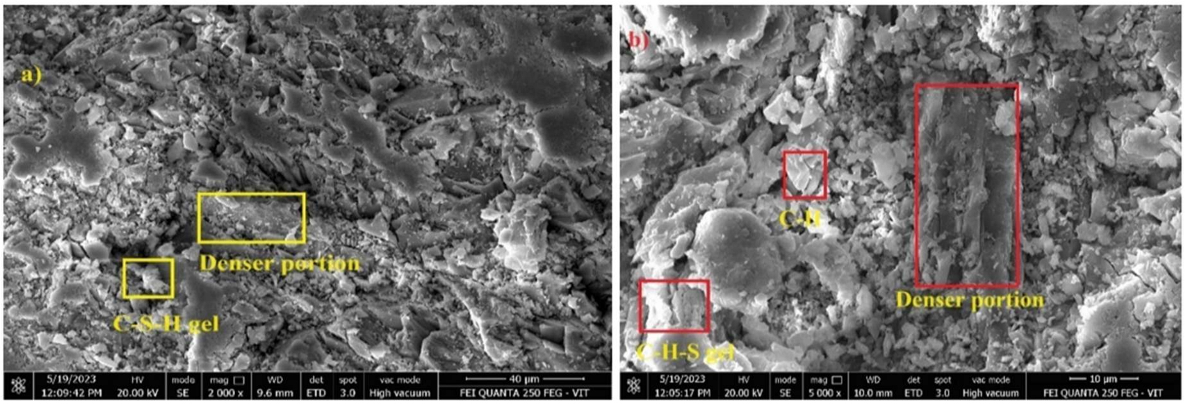

Fig. 6. SEM imges of SCC with SCMs (a) and (b) Denser protion, C-S-H gel and C-H of concrete matrix

5.3 Cost Analysis

As part of the worldwide movement towards sustainable and eco-friendly construction methods, it is possible to substitute certain amounts of cement with alternative pozzolanic materials like SCMs (Regalla and Senthil Kumar, 2024a). These SCMs are environmentally conscious and aim to reduce the carbon footprint . To summarize, this part will focus on determining the cost per cubic meter of the SCC mixes manufactured utilizing SCMs (Regalla and Senthil Kumar, 2024b). The cost of materials excludes energy-related expenses associated with manufacturing and transportation. The estimation is derived from the collective expenses linked to each individual concrete material. This is achieved by using data acquired from nearby suppliers. Please be aware that these prices do not incorporate the expense of water. Table 12 displays the cost analysis for SCC mixtures.

The data was subsequently utilized to compute the production expense of one cubic meter of concrete for both the control and SCMs mixes of SCC. It is important to mention that the process of determining material prices is relatively straightforward for the local market (Regalla and Senthil Kumar, 2024c). It is crucial to emphasize that these rates display substantial fluctuation and depend on several factors, such as the quantity needed, delivery location and time, and user categorization (individual or industrial) (Regalla and Senthil Kumar, 2023d). As a result, the material cost per cubic meter for the control mix is \$268.54 per m^3 and \$255.05 per m^3 for SCMs, respectively. However, replacing cement with SCMs saves \$13.49 per m^3. The cost analyse indicates that the SCC mix incorporating SCMs is less expensive than the control mix, leading to a 5% cost savings. The control mix costs \$5.37 per load, while the SCM mix costs \$4.97 per load. Nevertheless, the SCC30FA10SF mix, which includes SCMs (fly ash and silica fume), has a slightly lower total cost per cubic meter and higher strength compared to the SCC0FA0SF control mix. This results in a better economic index and a lower cost per 1 kN of strength. This analysis concluded that the substitution of SCMs in the SCC benefits both economic and sustainable construction practices.

Table 12. Coast analysis of SCC mixes

Materials	Rate per kg in USD (\$)	SCC0FA0SF (control mix) in kg/m^3/USD (\$)	SCC30FA10SF (SCMs mix) in kg/m^3/USD (\$)
Cement	0.11	62.57	37.54
Fine aggregate	0.11	98.08	98.08
Coarse aggregate	0.12	83.83	83.83
Fly ash	0.12	-	3.95
Silica fume	0.24	-	6.59
SP	2.51	23.51	23.51
VMA	1.92	0.54	0.54
Total cost per CUM in USD (\$) =		268.54	254.05
Strength MPa		52.32	53.6
Economy index (EI)		0.19483	0.21098
Cost per 1 KN		5.13	4.74

6. CONCLUSIONS

In this investigation, the TOPSIS method was used to identify optimal mixture proportions of self-compacting concrete. A conclusion was reached using the experimental and optimization methods.

- The dose of superplasticizer (SP), which ranges from 1.4% to 1.7%, and the various W/C ratios (0.38, 0.40, and 0.42) affect each mix percentage of SCC. Five major variables (multi-response) affect the mix proportions: compressive strength, slump flow, VMA, SP dosages, and W/C ratio. The TOPSIS optimization algorithm is used to twenty-one trail mix testing results.

- A single answer was created from the multi-response experimental data. The optimal mix percentage, as determined by the TOPSIS approach, is M7, with a preference value of 0.980.
- Among the twenty-one trail mixes, the M7 optimal mixture proportions had the highest compressive strength (53.50 MPa) and the largest slump flow (720 mm).
- Compared to the control mix, replacing SCMs improves the fresh properties of SCC. SCMs reduce water demand, boost fluidity, and enhance the workability of the SCC.
- The replacement of SCMs improves the mechanical properties contrary to the control mix. The SCM replacement increased the compressive strength by up to 2.45%. Likewise, the split tensile and flexural strengths increased by 18.84% and 55.49%, respectively.
- According to the cost analysis, replacing cement with SCMs saves \$13.49 per m^3. The substitution of SCMs in the SCC is beneficial to both economic and sustainable construction practices.

The results of this experiment indicate that the TOPSIS method is more effective at selecting the optimal SCC mixture proportions. It is recommended to use TOPSIS methodologies for the resolution of various multi-criteria engineering issues involving decision-making. It is possible to replace some quantities of cement with alternative pozzolanic materials, such as SCMs, to promote sustainable and environmentally friendly construction practices.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGMENTS

The authors feel highly indebted to chancellor of Vellore Institute of Technology, Vellore, Tamil Nadu, India for providing the opportunity to pursue our research.

REFERENCES

Abed, M., Fořt, J., Rashid, K. 2022. Multicriterial life cycle assessment of eco-efficient self-compacting concrete modified by waste perlite powder and recycled concrete aggregate. Construction and Building Materials, 348, 128696.

Athiyamaan, V., Mohan Ganesh, G. 2020a. Experimental, statistical and simulation analysis on impact of micro steel fibres in reinforced SCC containing admixtures. Construction and Building Materials, 246.

Athiyaman, V., Mohan Ganesh, G. 2018b. Optimization of SCC mix design using nan-su theory embodying DOE method. The Indian Concrete Journal, 92, 31-41.

Bicer, A. 2018. Effect of fly ash particle size on thermal and mechanical properties of fly ash-cement composites. Thermal Science and Engineering Progress, 8, 78–82.

Chindaprasirt, P., Jaturapitakkul, C., Sinsiri, T. 2005. Effect of fly ash fineness on compressive strength and pore size of blended cement paste. Cement and Concrete Composites, 27, 425–428.

EFNARC, 2005. The European guidelines for self-compacting concrete specification, production and use. The European guidelines for self - compacting concrete, 22, 563.

Kunhanandan, E.K., N.K.R. 2006. Models relating mixture composition to the density and strength of foam concrete using response surface methodology . Cement and Concrete Composites, 28, 752–760.

Murugan, S.B., Ganesh, G.M., Santhi, A.S. 2012. Regression models for prediction of compressive strength of high-volume fly ash (HVFA) concrete. Arabian Journal for Science and Engineering, 39, 1659–1669.

Nili, M., Afroughsabet, V. 2010. Combined effect of silica fume and steel fibers on the impact resistance and mechanical properties of concrete. International Journal of Impact Engineering, 37, 879–886.

Okamura, H., Ouchi, M. 2003. Self-Compacting Concrete. Journal of Advanced Concrete Technology, 1, 5–15.

Praveenkumar, S., Sankarasubramanian, G. 2021. Optimization of mix proportions for high performance concrete using TOPSIS method. Journal of Building Pathology and Rehabilitation, 6, 39.

Praveenkumar, S., Sankarasubramanian, G., Sindhu, S. 2019. Selecting optimized mix proportion of bagasse ash blended high performance concrete using analytical hierarchy process (AHP). Computers and Concrete, 23, 459–470.

Reddy, A.S., Kumar, P.R., Raj, P.A. 2020. Development of sustainable performance index (SPI) for self-compacting concretes. Journal of Building Engineering, 27, 100974.

Regalla, S.S., Senthil Kumar, N. 2024a. Effect of curing regimes on the rheological, mechanical, hydration and microstructure of ultra-high-performance concrete (UHPC) using indigenous resources: progress towards sustainable construction practices. Composite Interfaces, 31, 777–820.

Regalla, S.S., Senthil Kumar, N. 2024b. Investigation of hydration kinetics, microstructure and mechanical properties of multiwalled carbon nano tubes (MWCNT) based future emerging ecological economic ultra high-performance concrete (E3 UHPC). Results in Engineering, 23, 102432.

Regalla, S.S., Senthil Kumar, N. 2024c. Effect of nano SiO2 on rheology, nucleation seeding, hydration mechanism, mechanical properties and microstructure amelioration of ultra-high-performance concrete. Case Studies in Construction Materials, 20, e03147.

Regalla, S., Senthil Kumar, N. 2023d. Influence of graphene oxide in the hydration mechanism by reinforcing mechanical strength and microstructural characterization of ultra-high-performance concrete (UHPC). Journal of Dispersion Science and Technology, 46, 170–187.

Revilla-Cuesta, V., Skaf, M., Espinosa, A.B., Ortega-López, V. 2021. Multi-criteria feasibility of real use of self-compacting concrete with sustainable aggregate, binder and powder. Journal of Cleaner Production, 325, 129327.

Sharifi, E., Sadjadi, S.J., Aliha, M.R.M., Moniri, A. 2020. Optimization of high-strength self-consolidating concrete mix design using an improved Taguchi optimization method. Construction and Building Materials, 236, 117547.

Şimşek, B., Iç, Y.T., Şimşek, E.H. 2013a. A TOPSIS-based Taguchi optimization to determine optimal mixture proportions of the high strength self-compacting concrete. Chemometrics and Intelligent Laboratory Systems, 125, 18–32.

Şimşek, B., Uygunoğlu, T. 2016b. Multi-response optimization of polymer blended concrete: A TOPSIS based Taguchi application. Construction and Building Materials, 117, 251–262.

Skarendahl, A., Billberg, Peter. 2006. Casting of self-compacting concrete: Final report of RILEM TC 188-CSC. RILEM Publications.

Soković, J., Stanujkić, D., Štirbanović, Z. 2021. Selection of process for aluminium separation from waste cables by TOPSIS and WASPAS methods. Minerals Engineering, 173, 107186.

Su, N., Hsu, K.-C., Chai, H.-W. 2001. A simple mix design method for self-compacting concrete. Cement and Concrete Research, 31, 1799–1807.

Swathi, B., Vidjeapriya, R. 2024. A multi-criterial optimization of low-carbon binders for a sustainable high-strength concrete using TOPSIS. Construction and Building Materials, 425, 135992.

Türkmen, İ., Gül, R., Çelİk, C., Demİrboğa, R. 2003. Determination by the Taguchi method of optimum conditions for mechanical properties of high strength concrete with admixtures of silica fume and blast furnace slag. Civil Engineering and Environmental Systems, 20, 105–118.