Retraction

Retraction: An Approach to Develop a Sustainable Preference Index for Self Compacting Concrete (IOP Conf. Ser.: Mater. Sci. Eng. 998 012058)

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This article has been retracted by IOP Publishing following an investigation in which the paper was found to be very similar to a previously published paper [1]. This investigation was conducted according to COPE guidelines and it is agreed the paper should be retracted on the basis of redundant publication. The author does not agree with this retraction.

[1] A. Suchith Reddy, P. Rathish Kumar, P. Anand Raj, Development of Sustainable Performance Index (SPI) for Self-Compacting Concretes, Journal of Building Engineering, Volume 27, 2020, 100974, ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2019.100974

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An Approach to Develop a Sustainable Preference Index for Self Compacting Concrete

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Abstract. In construction industry, selecting a right material from the various alternatives is a critical task in contributing to promote sustainability. For evaluating performance of the material different conflicting attributes are considered which is very complex to make a decision. Focusing on that point, there is a necessity to implement an effective MCDM (Multi-Criteria Decision Making) technique in the building construction which helps the decision makers to choose the feasible sustainable material from the alternatives. The present study explores about the application of Preference Selection Index Method to develop an approach in selecting the optimum Supplementary Cementitious Materials which is called as Sustainable Preference Index (SPI). The foremost concern in the study is to optimize the use of SCM’s as a substitute for cement in Self Compacting Concrete (SCC) to assess sustainable performance by considering technical, environment and ecological traits. To illustrate an approach to develop a Sustainable Preference Index a case study has been considered by varying mineral admixtures such as Fly Ash and GGBS by 10%, 20%, 30%, 40% replacement of the mass of cement in SCC. From different available SCC mixes, the possible alternate in Self Compacting Concrete can be identified based on Sustainable Preference Index value which indicates sustainable performance. Among the FA and GGBS based Self Compacting Concrete mixes, 40GGBS-SCC has attained the highest Sustainable Preference Index (SPI) value. For 40GGBS-SCC the SPI value obtained is 0.891 whereas for 100OPC-SCC it is 0.740. From the SPI values attained, it can be concluded that 40GGBS-SCC is 20.4% more sustainable than the 100OPC-SCC.

1. Introduction

In Engineering Design, one of the significant difficulties is to select the right material from various choices accessible. In present situation, the advancement of novel and inventive material is required to substitute the conventional materials and at the same time they either turn out to be vanished or causing an enormous problem in promoting sustainability. Choosing proper material is essential for design, functional use, practicability and performance [1]. Materials perform in a different way with regard to single criteria. To select perfect material and attain the preferred outcomes, mix must be strong enough to attain the necessary performance. In case of Self Compacting Concrete, apart from all the properties like workability, durability, strength, the material should be sustainable.

The utilization of concrete is not evaded owing to its distinctive characteristics and benefits, but the effects caused can be lessen by generating concrete mainly aiming on sustainable features like using materials with lowest embodied energy, technologies and methods [2]. Concrete is the highest expended material after the water and it is presumed that the concrete demand will increase by 2050 up to 18 billion tons per year [3].
The usage of Self Compacting Concrete has come to be more demanding because of its outstanding properties of self-positioning and self-consolidation. The growing demand is highly associated with a sustainable development, so the technology of self-compacting concrete becoming questionable because of its relatively high content of cement which increase the value of carbon footprint. To overcome this the utilization of industrial waste and low cement content is used which decreases the effects on social, economic and environmental traits to attain sustainability. Building Assessment tools like Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Assessment Methodology (BREEAM) awarded points to the construction industry for the execution of these sustainable aspects. These building sustainability assessment tools helps to evaluate the level of sustainability reached by construction [4].

1.1. Preference Selection Index (PSI) Method:

PSI method was developed for resolving the problems of multi-criteria decision making (MCDM). MCDM refers to taking judgements while several alternatives and contradictory attributes are considered. Methods which are available in assisting decision making considers several number of criteria as well as their interrelationship are also problematic to know whereas the weight of attributes plays a vital part in optimizing the material alternatives. Each and every attribute/criteria involved are important equally in evaluating performance of concrete towards sustainability. So, Preference Selection Index is one of the best method to meet the necessity of a decision problems. In this proposed technique, individual attribute that have high conflict in providing the relative weight of attribute is not necessary to consider. PSI method is suitable when there is a problem in determining the relative significance between criteria/attributes [5], [6].

1.2. Usage of SCM’s (Supplementary Cementitious Materials)

The utilization of dissimilar types of SCM’s or binder materials with varying proportion replacing cement is challenging to find the optimal material for the preferred application. Silica Fume (SF), Ground Granulated Blast Furnace Slag (GGBS), Metakaolin (M), Fly ash (FA), etc., are the various SCM’s which decreases consumption of cement and also lessens the carbon footprint and byproduct waste which lead in supporting sustainability. Fly ash production is about 210 MT in 2017 and estimated to rise up to 410 MT by 2025 in India and the yearly world manufacture of FA and GGBS are 430 MT and 525 MT respectively. To examine the overall behavior of FA and GGBS various research studies are done. Use of FA and GGBS reduces greenhouse gases in a typical concrete mix. Selecting appropriate material depends on various attributes like technical, environment and economical aspects. In order to assess the sustainable concrete performance, all the attributes have to be considered instead of a single attribute [7].

2. Need for the study

The prerequisite must be sufficient enough to assess the performance and select an optimum solution to attain the preferred outcomes. There will be a drop in the material and cost of labor with the varying replacement level of SCM’s and on the other side it will benefit ecology and environment. It can be noted that use of SCM’s not only benefits the environment but also diminishes the total LCC. According to [8] in a distinct concrete mix, mineral admixtures (Fly Ash and GGBS) are used to decrease the CO₂ emissions by 13% and 22%. Replacement of these admixtures may attain slow mechanical strength and show variation in the performance of concrete. The key concern is to prioritize the use of SCM’s (Fly Ash and Ground Granulated Blast-Furnace slag) in Self Compacting Concrete as a substitute for cement to assess concrete performance. Choosing an appropriate material for the design of structural components includes several attributes. Apart from the attribute associated with environment, economic and social aspects (Triple Bottom Line) attribute related to technical aspects are considered to evaluate the concrete sustainability. The data related to attributes are mentioned based on the conducted experiments. FA with low calcium is used. Binder content is considered as 475 kg/m³ and w/c ratio is 0.35 which is kept constant. SCM’s (FA and GGBS) are substituted with Ordinary Portland Cement for 10%, 20%, 30% and 40%. In order to select an optimize mix from the alternatives, seven influencing attributes are considered to evaluate the sustainable performance based on the application of PSI method and develop a Sustainable Preference Index (SPI)
approach. This SPI approach will fetch out the quantifiable method in optimizing as well as assessing the mixes based on the performance of concrete.

3. Materials and Methodology

Apart from the Triple Bottom Line (TBL) aspects, technical aspects play a key role for evaluating material performance. Experimental work is carried out to examine the physical properties and hardened properties of SCC by casting specimens of nine different combinations of FA and GGBS. Conventional Self Compacting Concrete designated as 100OPC-SCC, FA based SCC 10%, 20%, 30%, and 40% replacement of cement designated as 10FA-SCC, 20FA-SCC, 30FA-SCC, 40FA-SCC and GGBS based SCC 10%, 20%, 30% and 40% replacement of cement designated as 10GGBS-SCC, 20GGBS-SCC, 30GGBS-SCC, 40GGBS-SCC. In the present study nine mix proportions are considered to judge the performance of concrete.

3.1. Materials

Materials used in the present study were as follows:

3.1.1 Cement

53 grade Ordinary Portland Cement which is locally available was used in the present study for all the Self Compacting Concrete mixes. Table 1 shows the physical properties of cement thus obtained as per the requirement of IS12260-2013 [9]. Chemical composition details of cement are shown in Table 2.

| Properties                  | Test Results | Requirement as per IS:12269-2013 |
|-----------------------------|--------------|----------------------------------|
| Normal Consistency          | 30%          |                                  |
| Specific Gravity            | 3.1 kg/m³    |                                  |
| Initial Setting time        | 54 min       | Not less than 30 min.            |
| Final Setting time          | 568 min      | Not more than 600 min.           |
| Soundness (Le Chatelier)    | 3 mm         | Not more than 10 mm              |
| Fineness of Cement          | 4%           | Less than 10%                    |
| Compressive Strength        | 54.2 MPa     | 53 MPa                           |

3.1.2. Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS)

FA and GGBS were used as binder materials in the present study. Low calcium based FA was collected from Ramagundam Thermal Power Station, India. GGBS was obtained from JSW cements. GGBS is one of the green building material used for sustainable construction. Chemical composition details of FA and GGBS are shown in Table 2.

| Chemical Composition | SiO₂  | Al₂O₃ | Fe₂O₃ | CaO   | MgO   | SO₃  | K₂O  | Na₂O  | LOI  |
|----------------------|-------|-------|-------|-------|-------|------|------|-------|------|
| Cement               | 18.93 | 4.56  | 4.96  | 66.68 | 0.88  | 2.6  | 0.43 | 0.14  | 0.82 |
| FA                   | 61.13 | 27.53 | 4.25  | 4.07  | 1.70  | 0.38 | -    | 0.26  | 0.68 |
| GGBS                 | 34.06 | 23    | 0.8   | 32.6  | 7.89  | 0.9  | -    | -     | 0.75 |
3.1.3. Fine Aggregate and Coarse Aggregate

Fine aggregate confirming to Zone-2 is preferred. Coarse aggregate of different sizes was used in the study. 60% of aggregate between the range 12.5 mm-10mm size and 40% of aggregate between the range 10 mm-4.75 mm are used. Both aggregates confirmed to [10]. Table 3 shows physical properties of fine aggregate and coarse aggregate.

Table 3. Physical properties – Fine Aggregate and Coarse Aggregate

| Physical Properties | Fine aggregate | Coarse aggregate |
|---------------------|----------------|------------------|
| Bulk density (kg/m³) | 1.46           | 1.52             |
| Specific Gravity (kg/m³) | 2.42         | 2.86             |
| Water absorption (%) | 2              | 0.6              |

3.1.4. Water

For preparation of Self Compacting Concrete, potable water was used.

3.1.5. Super Plasticizer

In the present study Chryso Optima 100 is used as super plasticizer.

3.2. Selection of attributes for sustainable performance of concrete

For assessing the sustainable concrete performance seven influencing attributes are considered in the study. They are A₁ – Segregation Ratio, A₂ – Compressive Strength, A₃ – Binder Intensity, A₄ – Service Life, A₅ – Life Cycle Cost, A₆ – Carbonation, A₇ – Chloride Diffusion Coefficient. These attributes are interdependent on each other and represented as Aⱼ. Similar attributes are considered by [7].

3.2.1. Segregation ratio

Segregation Ratio is defined as the ratio of concrete quantity poured on 5 mm sieve (350 mm dia.) to the quantity of workable paste. This method is used to assess the strength of SCC under fresh properties [11]. As per ERNARC specifications, acceptable segregation resistance range should be between 5 and 15% [12].

3.2.2. Binder Intensity

BI is defined as the amount of binder essential to make strength of 1MPa at any age. This indicates the importance of binder in developing the strength of concrete for numerous replacement levels.

3.2.3. Compressive strength

Compressive strength refers to the ability of structural element or certain material to withstand the loads.

3.2.4. Service Life

Service life is defined as the duration of time after which all the essential properties of the structure go beyond the least possible acceptable values when retained in a regular manner. Durability aspects play a crucial role in sustainable performance of concrete. Life 365 software is used to estimate concrete service life [13].

3.2.5. Life Cycle Cost

LCC is an essential economic analysis which is required to select an alternative that influence both awaiting and forthcoming costs. LCC depends and varies on time and location. It is measured in terms of labor cost, material cost, transportation cost, manufacturing cost per cubic meter of concrete. LCC depend on several circumstances such as availability, demand and supply. This is one of the most important attribute in a decision problem to decide sustainable performance [14].
3.2.6. Carbonation Depth

Carbonation is the occurrence of the reaction of Ca(OH)$_2$ in the cement paste with CO$_2$ in the environment to produce CaCO$_3$ and decreases the pH value. Amount to which Ca(OH)$_2$ changes to CaCO$_3$ is measured by considering carbonation depth. Solution of phenolphthalein indicator is sprayed on the surface of concrete to find the carbonation depth. When there is no color change it indicates that the alkalinity of the specimen is decreased.

3.2.7. Chloride Diffusion Coefficient

CDC is the major factor to predict the chloride ingress in concrete. This is one of the major characteristic of concrete that influence durability and service life.

3.3. Procedure involved for computing Sustainable Preference Index (SPI)

Following are the steps suggested in developing SPI using application of PSI Method.

**Step 1. Outline the problem:** Define the objective, identify material alternatives ($M_i$), selection attributes ($A_j$) and ($P_{ij}$) is the performance measure of different alternatives with respect to attribute to create $N_{ij}$ Decision Matrix.

**Step 2. Frame the decision matrix considering alternatives and attributes:** It involves assembly of a matrix based on obtained data that detail about the attribute. Each row and each column of the decision matrix is assigned to one material alternatives ($M_i$) and one attribute/criteria ($A_j$). An element $P_{ij}$ of the matrix $N_{ij}$ provides the values of the $j^{th}$ attribute in real values i.e, a non-normalized form. $n$ is the number of alternatives and $m$ is the number of criteria/attributes, then the $N_{ij}$ decision matrix as an n*m matrix denoted as follows:

$$N_{ij} = [P_{ij}] = \begin{bmatrix} P_{11} & P_{12} & P_{13} & \cdots & P_{1m} \\ P_{21} & P_{22} & P_{23} & \cdots & P_{2m} \\ P_{31} & P_{32} & P_{33} & \cdots & P_{3m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ P_{n1} & P_{n2} & P_{n3} & \cdots & P_{nm} \end{bmatrix}$$

where $P_{ij}$ indicates performance quantity ($i = 1, 2, 3, \ldots n$ and $j = 1, 2, 3, \ldots m$).

**Step 3. Normalization of the Decision matrix ($N_{ij}$):** In MCDM approach it is necessary to convert the attribute values as dimensionless. Therefore, the decision matrix values are converted into 0 and 1. The process of converting the decision matrix values is called as normalization.

If the attributes are beneficial kind, then greater values are intended, which are normalized by using equation (i)

$$N_{ij} = \frac{P_{ij}}{P_{j,max}} \quad \text{-------- (i)}$$

If the attributes are non-beneficial kind, then lesser values are intended, which are normalized by using equation (ii)

$$N_{ij} = \frac{P_{j,min}}{P_{ij}} \quad \text{-------- (ii)}$$

**Step 4. Determine Mean Value of the normalized data ($N_j$):** Mean value of the normalized data for each attribute is determined using equation (iii)

$$N_j = \frac{1}{n} \sum_{i=1}^{n} N_{ij} \quad \text{-------- (iii)}$$
Step 5. Determine Preference Variation Value (\(V_j\)) for \(j^{th}\) attribute: Preference Variation Value amongst the values of each attribute is determined using equation (iv)

\[
V_j = \sum_{i=1}^{n} (N_{ij} - N_j)^2 \quad \text{ (iv)}
\]

Step 6. Compute the Deviation (\(\delta_j\)) in Preference Variation for \(j^{th}\) attribute: Using equation (v) Deviation in the \(V_j\) value is determined for each attribute

\[
\delta_j = (1 - V_j) \quad \text{ (v)}
\]

Step 7. Determine the Overall Preference Value (\(O_j\)) for \(j^{th}\) attribute: By using equation (vi) overall preference value is computed for each attribute

\[
O_j = \frac{\delta_j}{\sum_{j=1}^{m} \delta_j} \quad \text{ (vi)}
\]

Furthermore, \(\sum_{j=1}^{m} O_j = 1\) (Total \(O_j\) of all the attributes must be one)

Step 8. Compute SPI (Sustainable Preference Index) values and Assign Ranks: Sustainable Preference Index \(\text{SPI}_i\) for \(i^{th}\) alternative is calculated for every alternative using equation (vii)

\[
\text{SPI}_i = \sum_{j=1}^{m} N_{ij} \times O_j \quad \text{ (vii)}
\]

After computing \(\text{SPI}_i\) values, alternatives with the maximum value will be ranked first and so on.

4. Illustration of a case study (SPI for Self Compacting Concrete)

Selecting a best sustainable material among different options to achieve as preferred is a complex task to promote sustainability considering conflicting attributes. This problem can be determined by developing a Sustainable Preference Index or Sustainable Performance Index (SPI). Sustainable performance indicators such as social, environmental and economic aspects are considered in evaluating performance of the material in construction which is found immensely in the literatures. In the present study, technical aspects are also considered to assess the sustainability of concrete. Supplementary Cementitious Materials (FA and GGBS) replaced with cement in SCC with different percentages as 10\%, 20\%, 30\%, 40\%. Mix proportions of SCC using different combinations of FA and GGBS are shown in Table 4. Fresh properties of the SCC mixes are shown in Table 5. It is noticed from the results shown in Table 6. that for the same properties, GGBS mixes achieved better than FA based SCC mixes. Hence the durability attributes and sustainability attributes are connected with each other, it indicates that GGBS based SCC has good performance than FA based SCC towards sustainability.

Table 4. Mix Proportions of SCC for 1 m³

| Mix        | Binder Materials (kg) | Fine Aggregate (kg) | Coarse Aggregate (kg) | Super-Plasticizer dosage (ml) | Water (kg) |
|------------|------------------------|---------------------|-----------------------|-------------------------------|------------|
|            | OPC Fly Ash GGBS       |                     |                       |                               |            |
| 100OPC-SCC | 475 0 0                | 891 856             | 5.7 166.25            |                               |            |
| 10FA-SCC   | 427.5 47.5 0           | 891 856             | 5.7 166.25            |                               |            |
| 20FA-SCC   | 380 95 0               | 891 856             | 5.7 166.25            |                               |            |
| 30FA-SCC   | 332.5 142.5 0          | 891 856             | 5.7 166.25            |                               |            |
| 40FA-SCC   | 285 190 0              | 891 856             | 5.7 166.25            |                               |            |
| 10GGBS-SCC | 427.5 0 47.5           | 891 856             | 5.7 166.25            |                               |            |
| 20GGBS-SCC | 380 0 95               | 891 856             | 5.7 166.25            |                               |            |
| 30GGBS-SCC | 332.5 0 142.5          | 891 856             | 5.7 166.25            |                               |            |
Following are the steps elaborated in developing SPI (Sustainable Preference Index) value and decide the rank to optimize the sustainable material.

**Step 1.** The different material alternatives \( (M_i) \) and attributes \( (A_j) \) for the stated problem is defined. Nine alternative mixes and seven attributes are considered for optimizing the Self Compacting Concrete mix in the study.

**Step 2.** Calculation of each attribute of the Decision Matrix were taken at 28 days. Table 6. shows values indicating the different material alternatives \( (M_i) \) and attributes \( (A_j) \) to form decision matrix \( N_{ij} \).

### Table 5. Fresh properties of the alternative SCC mixes

| Mix          | Segregation Ratio | Slump Flow (mm) | V-funnel (sec) | L-Box Test Ratio | Time (sec) |
|--------------|-------------------|-----------------|----------------|------------------|------------|
| 100OPC-SCC   | 9.3               | 675             | 9.16           | 0.92             | 18.4       |
| 10FA-SCC     | 9.4               | 695             | 9.18           | 0.93             | 18.4       |
| 20FA-SCC     | 9.5               | 705             | 9.2            | 0.95             | 18.3       |
| 30FA-SCC     | 9.7               | 728             | 10.2           | 0.97             | 18.2       |
| 40FA-SCC     | 9.8               | 750             | 10.4           | 0.98             | 18.0       |
| 10GGBS-SCC   | 9.5               | 680             | 9.23           | 0.94             | 18.4       |
| 20GGBS-SCC   | 9.7               | 690             | 9.32           | 0.95             | 18.2       |
| 30GGBS-SCC   | 9.8               | 710             | 10.15          | 0.97             | 18.1       |
| 40GGBS-SCC   | 9.9               | 725             | 10.8           | 0.98             | 17.9       |

### Table 6. Decision Matrix

| Mix          | \( A_1 \) | \( A_2 \) | \( A_3 \) | \( A_4 \) | \( A_5 \) | \( A_6 \) | \( A_7 \) |
|--------------|----------|----------|----------|----------|----------|----------|----------|
| 100OPC-SCC   | 9.3      | 76.4     | 0        | 16.4     | 9870     | 1.25     | 5.2      |
| 10FA-SCC     | 9.4      | 75.6     | 0.63     | 38.7     | 8840     | 2.65     | 3.95     |
| 20FA-SCC     | 9.5      | 74.5     | 1.28     | 69.2     | 8460     | 3.85     | 3.47     |
| 30FA-SCC     | 9.7      | 72.8     | 1.96     | 61.1     | 8020     | 5.75     | 2.18     |
| 40FA-SCC     | 9.8      | 72.1     | 2.64     | 56.5     | 7950     | 7.25     | 1.42     |
| 10GGBS-SCC   | 9.5      | 78.7     | 0.60     | 35.8     | 8980     | 2.85     | 3.84     |
| 20GGBS-SCC   | 9.7      | 77.3     | 1.23     | 56.2     | 8650     | 3.65     | 3.1      |
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Step 3. Normalization of a Decision matrix ($N_j$) – In this step, Decision matrix is normalized to a non-dimensional form by using equations (i) and (ii). Decision matrix values are converted into 0 and 1. The corresponding values are shown in Table 7. First four attributes ($A_1, A_2, A_3, A_4$) are considered as beneficial type and next three attributes ($A_5, A_6, A_7$) are considered as cost type.

Table 7. Normalized Decision Matrix ($N_j$)

| Mix           | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ |
|---------------|-------|-------|-------|-------|-------|-------|-------|
| 100OPC-SCC    | 0.94  | 0.97  | 0     | 0.12  | 0.81  | 1.0   | 0.27  |
| 10FA-SCC      | 0.95  | 0.96  | 0.24  | 0.28  | 0.90  | 0.47  | 0.36  |
| 20FA-SCC      | 0.96  | 0.95  | 0.48  | 0.50  | 0.94  | 0.32  | 0.41  |
| 30FA-SCC      | 0.98  | 0.93  | 0.74  | 0.44  | 0.99  | 0.22  | 0.65  |
| 40FA-SCC      | 0.99  | 0.92  | 1.0   | 0.41  | 1.0   | 0.17  | 1.0   |
| 10GGBS-SCC    | 0.96  | 1.0   | 0.23  | 0.26  | 0.89  | 0.44  | 0.37  |
| 20GGBS-SCC    | 0.98  | 0.98  | 0.47  | 0.41  | 0.92  | 0.34  | 0.46  |
| 30GGBS-SCC    | 0.99  | 0.97  | 0.71  | 0.79  | 0.95  | 0.24  | 0.63  |
| 40GGBS-SCC    | 1.0   | 0.97  | 0.95  | 1.0   | 0.98  | 0.19  | 0.91  |

Step 4. Calculation of mean value ($N_j$) of the normalized numbers for $j^{th}$ attribute is determined by equation (iii). Mean values obtained are shown in Table 8.

Table 8. Mean value ($N_j$)

| $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ |
|-------|-------|-------|-------|-------|-------|-------|
| Mean Value | 0.97 | 0.96 | 0.54 | 0.47 | 0.93 | 0.38 | 0.56 |

Step 5. Calculation of Preference Variation ($V_j$) among the values for $j^{th}$ attribute is determined using equation (iv). The values obtained are shown in Table 9.

Table 9. Preference Variation Value ($V_j$) Matrix

| Mix       | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ |
|-----------|-------|-------|-------|-------|-------|-------|-------|
| 100OPC-SCC| 0.0009| 0.0001| 0.2916| 0.1225| 0.0144| 0.3844| 0.0841|
Step 6. Deviation ($\delta_j$) in the preference variation value for $j^{th}$ attribute is calculated by equation (v). Deviation values obtained are shown in Table 10.

| A1  | A2  | A3  | A4  | A5  | A6  | A7  |
|-----|-----|-----|-----|-----|-----|-----|
| 0.996 | 0.995 | 0.065 | 0.486 | 0.972 | 0.473 | 0.478 |

Table 10. Deviation Values of attributes ($\delta_j$)

Step 7. Overall preference value ($O_j$) for $j^{th}$ attribute is computed using the equation (vi). The values obtained are shown in Table 11.

| A1  | A2  | A3  | A4  | A5  | A6  | A7  |
|-----|-----|-----|-----|-----|-----|-----|
| 0.223 | 0.223 | 0.015 | 0.108 | 0.217 | 0.106 | 0.107 |

Table 11. Overall Preference Value ($O_j$)

Step 8. Sustainable Preference Index ($\text{SPI}_j$) – These values are computed for every alternative using equation (vii). SPI$_j$ values obtained are shown in Table 12. After computing SPI$_j$ values, alternatives having the highest value will be ranked first and so on. It can be noted that greater the value of SPI$_j$, better the sustainable performance of concrete.

| OPC-SCC | 10FA-SCC | 20FA-SCC | 30FA-SCC | 40FA-SCC | 10GGBS-SCC | 20GGBS-SCC | 30GGBS-SCC | 40GGBS-SCC |
|---------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|
| (SPI$_j$) | 0.740 | 0.744 | 0.769 | 0.792 | 0.828 | 0.748 | 0.773 | 0.832 | 0.891 |

Table 12. Sustainable Preference Index (SPI$_j$)

From Table 12, it is noticed that the performance of GGBS based Self Compacting Concrete is better than Fly Ash based SCC and normal SCC mix to promote sustainability. Among FA and GGBS based SCC,
40% GGBS based SCC (40GGBS-SCC) has ranked first with highest SPI value of 0.891 whereas SCC conventional mix (100OPC-SCC) has ranked last with SPI value of 0.740 which is 20.4% less sustainable. Table 6 shows the values of the various attributes considered to assess the sustainable performance ranking for the alternative mixes and the corresponding values are shown in figures below. Conventional Self Compacting Concrete designated as 100OPC-SCC, 20FA-SCC, 30FA-SCC, 40FA-SCC and GGBS based SCC 10%, 20%, 30% and 40% replacement of cement designated as 10GGBS-SCC, 20GGBS-SCC, 30GGBS-SCC, 40GGBS-SCC.

**Figure 1.** Segregation Ratio for the alternative SCC mixes

From Figure 1. it is observed that the segregation ratio is more for FA and GGBS based SCC mixes than conventional SCC mix. As per ERNARC specifications, acceptable segregation resistance range should be between 5 and 15%.

**Figure 2.** Compressive Strength for the alternative SCC mixes

From Figure 2. It shows that the strength decreased for FA based SCC and GGBS based SCC mixes but there is an increase in the durability. Sustainability Preference Index approach considers both the durability and strength aspects in optimizing the performance of concrete. 40GGBS-SCC has the maximum SPI value of 0.891 compared to various alternative SCC mixes.
From Figure 3, it is noticed that for FA based SCC and GGBS based SCC, the binder intensity increase linearly with higher cement replacement. Among FA based SCC series, BI is higher for 40FA-SCC but the overall value of SPI is less than 30GGBS-SCC and 40GGBS-SCC. This increase or change is because of other influencing attributes.

From Figure 4, it shows that with percentage increase in replacement there is a rise in service life for GGBS based SCC series but it is not linear in case of FA based SCC. 40GGBS-SCC has attained a higher service life of 137.9 and attained highest value of SPI.

From Figure 5, it shows that the life cycle cost for the alternative mixes.
From Figure 5, it shows that with rise in percentage replacement of cement there is a drop in LCC for FA and GGBS based SCC series compared to conventional SCC. Though 40GGBS-SCC has the least value of LCC, it has the highest SPI value.

![Figure 6. Carbonation depth for the alternative mixes](image)

From Figure 6, it shows that the CD value is increasing with the percentage replacement compared to conventional SCC which is not a decent indication for performance of concrete. This unexpected trend of CD and SPI values may be due to high porosity of concrete. It can be noted that even concrete prepared with SCM’s exhibit high carbonation [15].

![Figure 7. CDC for the alternative mixes](image)

From Figure 7, it shows that for FA and GGBS based SCC there is a reduction in CDC values with increase in percentage replacement compared to conventional SCC. 40FA-SCC has the least CDC value among all the alternatives which has a value of 0.828.

5. Conclusions

Based on the application of PSI method an approach Sustainable Preference Index is proposed for decision making in construction industry and this proposed method helps in choosing appropriate alternative among a pool of available alternatives. This paper highlights about the SPI method in developing and optimizing the concrete performance towards sustainability. Seven influencing attributes are considered for assessing sustainable performance of concrete.
The study contextualized the application of Preference Selection Index and developed Sustainable Preference Index approach in optimizing the different binder material for SCC mix varying FA and GGBS percentage with 10%, 20%, 30%, 40%.

Among FA and GGBS based SCC, 40% GGBS based SCC (M9) has ranked first with highest SPI value of 0.891 whereas SCC conventional mix has ranked last with SPI value of 0.740 which is 20.4% less sustainable.

Based on sustainable performance, (FA based SCC, GGBS based SCC) mixes are prioritized as 40GGBS-SCC > 30GGBS-SCC > 40FA-SCC > 30FA-SCC > 20GGBS-SCC > 20FA-SCC > 10GGBS-SCC > 10FA-SCC > 100OPC-SCC.

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