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The Properties of Self-Compacting Concrete (SCC) by Replacing Fly-Ash with Surkhi Brick Powder

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ABSTRACT

Surkhi is a fine powdered substance extracted from ashes of burnt clay in which remnants of burnt bricks or clay are found. Because of the pozzolanic character of Surkhi it can be thought to be an environmentally friendly supplement to other SCM such as Fly Ash (FA) and slag. This research work examines the characteristics of Self-Compacting Concrete (SCC) with Surkhi brick powder as a replacement material for FA. The experimental methodology involves mixing various proportions of Surkhi brick powder with SCC constituent materials, where after subjecting the mixed materials to standard tests focusing on the fresh and hardened properties, such as durability, Flexural Strength (FS), Split Tensile Strength (STS) and Compressive Strength (CS). According to the Okamura method five mix proportions were proposed. The flowability tests used in this research include the slump flow, J-Ring test, V-funnel, U-tube filling height, and L-box which were used to assess passing ability of SCC. The first was the control mix with 0% surkhi and the other four mixes contained surkhi in partial replacement of FA at 20%, 40%, 60% and 80%. The control SCC had a CS of 34.3MPa for 90 days and after using surkhi by the replacement of 60% FA the CS increased to 37.52MPa at the same age level of 90 days but for 40% as well as 80% replacement level, the average loss was 35.81MPa and 32.05MP.

KEYWORDS: *Self-Compacting Concrete (SCC), Fly Ash, Surkhi, Okamura method*

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1. INTRODUCTION

Concrete is an important building material that is widely used across the globe. It is made up of cement, sand, and coarse aggregate mixed with a proper quantity of water [1-3]. Conventional concrete is used for constructing massive walls or piers without vibrations, but Self-Compacting Concrete (SCC) has considerable fluidity in reinforcing and settles under its own weight [4, 5]. One of the most notable inventions in the construction industry in recent years is self-compacting concrete, which goes by many names than just "self-compacting concrete" (SCC) or "high-performance concrete." Another name for it is "self-consolidating concrete" [6, 7]. This form of concrete does not need vibration or compaction methods during the casting process to adequately occupy the areas between reinforcements and the corners of molds [8-10]. It may be used in both precast applications and for in-situ concrete placement [11].

SCC offers multiple advantages and applications as seen in Figure 1 [12]. SCC is a form of concrete that inherently levels and compacts under its own weight, therefore negating the need for external or internal compaction [13]. The development of SCC completely revolutionized the concrete industry. The desirable property of SCC is to match the speed of pumping with the rate of placing, making it an ideal material for effective pumping-based concrete placement. This concrete type is great for using with ready-mixed concrete because transit mixers don't have to wait long for it to set [14].

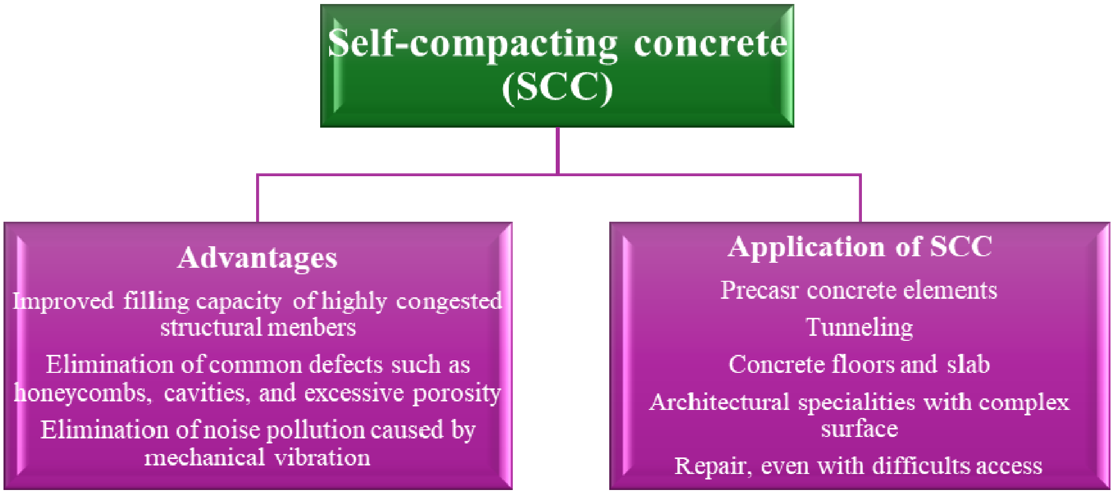

Figure 1: Advantages and Application of SCC [15].

Extensive study has shown that adding fibers to concrete significantly improves its structural qualities, including compressive, tensile, flexure, impact strength, and ductility [16-18]. The use of SCC in concrete manufacturing seems to be more efficient on a daily basis [19]. The study investigates the possibility for improvement of SCC by using Surkhi brick powder instead of the FA which is the major component of SCC. Surkhi, a by-product of waste brick, is examined as a sustainable substitute for FA, which is commonly used to improve the workability and durability of concrete. The inclusion of Surkhi in SCC can positively influence its fresh and hardened properties. The use of Surkhi Brick Powder as a replacement of FA will make the construction industry more environmentally friendly because Surkhi is a locally available cheaper material. Studies have shown that Surkhi can enhance the CS and durability of SCC, making it a promising alternative for sustainable construction practices. But the percentage of Surkhi in replacing FA for the preparation of the SCC needs further research to get the best result for the SCC in different structural construction. Here are the potential research objectives for the studies:

1. To evaluate the compatibility of surkhi brick powder as a partial or full replacement for FA in SCC mixtures, focusing on its chemical and physical properties.
2. To design and optimize mix proportions for SCC using the Okamura method, incorporating surkhi brick powder as a supplementary cementitious material.
3. To study the effect of replacing FA with surkhi brick powder on the workability of SCC, including slump flow, L-box test, and V-funnel tests.
4. To evaluate the mechanical properties of SCC with surkhi brick powder, including CS, STS, and FS, durability.

2. Literature Review

In this section, the authors provide previous work based on the properties of SCC by replacing fly-ash with surkhi brick powder with CS, FS, and SPS. Some of the investigations conducted in SCC and mortar have focused on interaction of different waste materials as partial replacement of normal materials. Singh et al. (2019) [20] investigated the mechanical properties of SCC and Normal Concrete where FA and brick dust have been utilized in the fine aggregate for the concrete mix and more specifically higher CS of about 37 % on 7th day 15% at 28th day and 8% at 56th day was observed.

Similarly, Mohd et al. (2022) [21] also pointed out enhanced CS when using FA and brick dust to replace fine aggregate where there was an enhancement of 37%, at 7 days, 15%, at 28 days, and 8% at 56 days. Aadi et al. (2024) [22] studied the possibility of including Cement Kiln Dust (CKD) and reported that as the proportions of CKD increased the slump flow diameter reduced and V-Funnel flow time increased with workability being affected by CKD.

On the other hand, Tuyan et al. (2022) [23] investigated the fresh state performance of SCC when waste clay brick powder and FA were used as cement replacements and reported lower values of both properties and CS than those of the top FA containing mixtures. Iqbal et al. (2022) [24] investigated the effects of brick powder and stone dust in SCC concrete where cement and sand are replaced and concluded that these improvements in the property of CS, FS, and STS are 12.7% 11% and 9%, respectively.

Lastly, Zhao et al. (2021) [25] investigated the performance of waste brick powder in self-compacting mortar and observed slight reduction of CS when compared to mortar with 100% cement; the reduction of the CS was 5.6%, 9.3% at 50%, 100 % of waste brick powder replacement, respectively. Collectively, these studies have shown that there is hope in using industrial waste material such as FA, brick dust, CKD, and brick powder to improve the mechanical properties of SCC and mortar though workability and strength responses differ.

3. Problem Statement

The increasing value of sustainable and high-performance construction materials has expanded the desire to enhance concrete showing properties but with less negative effects on the environment. SCC, which has excellent workability and high durability generally uses FA as a cementitious material. However, FA is not easily available, and the extraction also harms the environment, therefore the need to look at other options. Surkhi, a fine powder waste essentially derived from waste bricks, may serve as a substitute because of its pozzolanic characteristics. This particular issue revolves around the effects of applying Surkhi brick powder as a substitute for FA for SCC, with respect to its mechanical, physical and durability characteristics, keeping into view the practical aspects of the material in terms of its construction applications, structural performance, and overall sustainability objectives. With an objective to fill this gap, the present study has been planned to systematically investigate the physico-mechanical properties of SCC replacing FA partially or fully by Surkhi brick powder.

4. Methods and Material

Figure 2 shows the systematic way of conducting properties of SCC by FA substitution with surkhi brick powder. First, the research problem is identified and then the literature review is done in order to review the current state of knowledge on specific research objectives. After that, the objectives are set and the common materials required for producing SCC are identified. The material includes cement, fine aggregates, coarse aggregates of 10mm & 20mm, fly ash, water, and surkhi brick powder used as a substitute for the FA in the present study. The following step concerns the determination of the proportions of the mix for SCC using Okamura method while controlling the consistency and flow characteristics. Once, the proportions of concrete are fixed, concrete samples are prepared, and several tests are performed to know its mechanical and durability characteristics. They are the CS, STS, and FS tests to evaluate the ability of concrete to perform mechanically and durability tests to find whether concrete withstands a certain condition or not.

Lastly the test results are used to determine the impact of FA substitution by the surkhi brick powder on SCCs characteristics. This paper gives information about the possibility and effectiveness of utilizing surkhi brick powder as a sustainable material to replace some portion of cement in the production of SCC. Utilizing the totality of the above approach, the study activities yield credible results that also apply to practice.

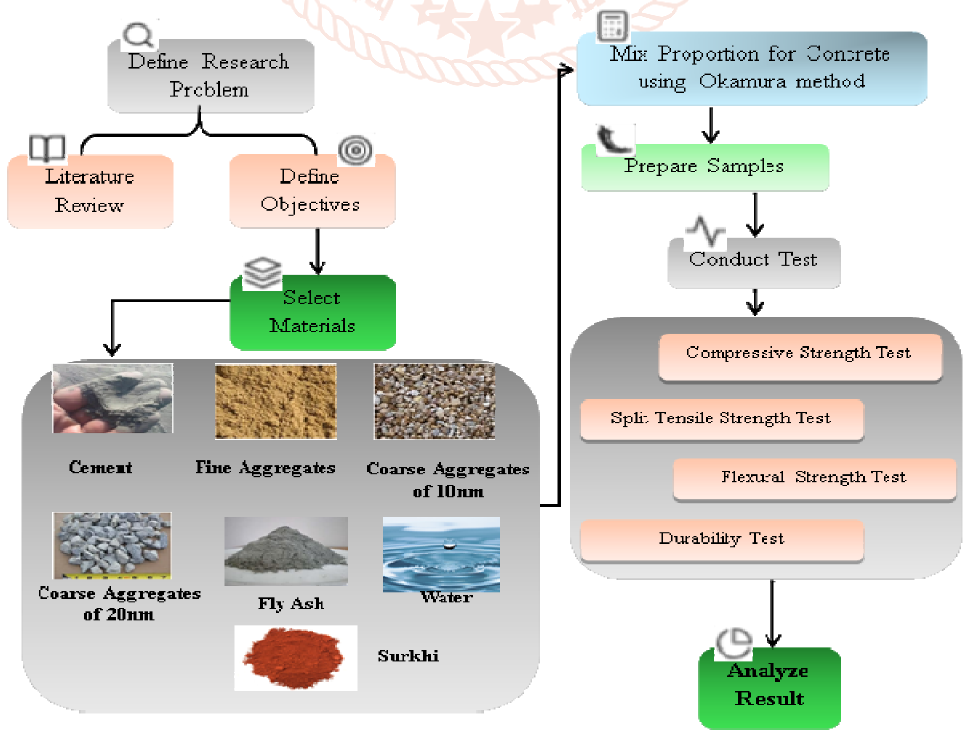

Figure 2: Flowchart of proposed work

- **Cement:** The whole experiment was conducted using Ordinary Portland Cement (OPC) of Grade 43. A range of tests were carried out on the cement in compliance with IS:269-2015 [26]. The cement's physical qualities are listed in Table 1. Figure 3 shows all material used in the study.
- **Fine Aggregate (FA):** The size was determined using local Kanahan River sand supplied by Nagpur, in compliance with grading zone II. The sand was passed through a 4.82 mm screen to get rid of any bigger particles. In accordance with IS: 383-2016, FA is physically evaluated and characterized using deposition.
- **Coarse Aggregate (CA):** The CA was made by mixing crushed stone of two different sizes, 10mm and 20mm. To keep the CA's massive size to a minimum, they determined to keep an 80:20 proportion. For physical attributes and sieve analysis, the CA met the standards set forth by IS: 383-2016.
- **Fly Ash (FA):** An additive accord was used with Class F fly ash that was manufactured by NTPC Unchahar. Cementitious materials are required to have 30% FA by weight in order to comply with IS: 456-2000 [27]. Table 1 provides the physical characteristics of FA.
- **Surkhi:** Surkhi is a pozollanic substance made by brick powder. In this study, FA was replaced in cement with 1st class brick dust at varying levels (0, 20, 40, 60, and 80%). The authors can find the physical parameters of Surkhi in Table 1.
- **Water and Super plasticizer (SP):** The concrete specimens were mixed and cured using potable water. Sika Viscocrete 20-HE is a brand name for Sika's modified poly-carboxylates of the SP type. At 30°C, the relative density of SP was 1.08.

Figure 3: Materials Used a) Cement b) Fine Aggregate c) Fly Ash d) Surkhi

Table 1: Physical Properties of Material Used

Physical Properties	Coarse Aggregate	Fine Aggregate	Fly Ash	Surkhi
Color	Grey	_	Grey (blackish)	Reddish orange
Specific gravity	3.53	3.51	3.25	3.62
Fitness modulus	0.74	0.66	0.89	0.75

4.1. Mixture Proportioning

The mix design of the SCC was done using the Okamura technique. Assuming a generic supply from ready-mixed concrete facilities, Okamura, and Ozawa (1995) have suggested a simple mix proportioning technique. The contents of course and fine aggregates are predetermined to facilitate self-compactability just by modifying the water-to-powder ratio and the dose of SP. The calcium concentration in concrete is established at 50% of the solid material. A set percentage of FA in the mortar is 40%. The powder's characteristics determine an expected water-to-powder ratio in volume, which ranges from 0.9 to 1.0. To make sure it compacts itself, researchers calculate out the SP dose and the final water-power ratio. The Okamura technique generates a highly efficient mix, optimally using local materials while conserving time and resources by reducing the variety of concrete mixes required. The mix design for SCC is shown in Table 2.

Table 2: SCC mix proportions for various mixes

Material	Cement (kg)	Fly ash (kg)	CA (kg)	FA (kg)	SP (kg)	Water (kg/m^3)
Quantity per cubic meter	524	165	708	800	274	3.8
	2	0.37	2.1	1.43	0.019	0.68

4.2. The Mechanical Properties of the Material

Cubes of $150\ mm \times 150\ mm \times 150\ mm$ were examined for CS, FS, durability, and STS tests at various time intervals beginning at 7 days, continuing for 14 days, 28 days, 56 days, and 90 days of age. In accordance with IS:516-2021, they completed testing [28-32].

5. Result and Discussion

The test findings derived from the experimental studies are provided as follows:

5.1. Workability

The workability of SCC is characterized by three properties: filing ability, passing ability, and fluidity. The workability of SCC refers to its ability to flow and consolidate under its own weight. Table 3 demonstrates the workability of SCC by substituting FA with varying percentages of surkhi. Figure 4 shows the images of testing methods.

Table 3: Workability of SSC by replacing FA with different % of surkhi

Methods	Different dose of SP with different % of FA replacing with surkhi				
	SCC	SCC-20	SCC-40	SCC-60	SCC-80
	SP-1.6%	SP-1.8%	SP-1.9%	SP-2.1%	SP-2.4%
Slump flow by Abram cone (mm)	730	720	715	693	673
V-funnel (sec)	6	7	9	11	12
L-box test (H1/H2)	1	1	0.8	0.9	0.9
U-tube filling height (H1-H2) mm	21	16	10	6	3
J-Ring (mm)	9	7	5	2	0

According to Table 6, the workability improves as the fraction of surkhi increases, as the dosage of super plasticizers must also be increased when the dose of surkhi is increased at partial replacement of FA. The greater water absorption of surkhi compared to FA results in increased water absorption, thus decreasing workability.


(a)


(b)


(c)


(d)


(e)

Figure 4: Testing for (a) Slump flow (b) V-funnel (c) L-box test (d) U-tube filling (e) J-Ring

FA consists of spherical particles that need less lubrication, while surkhi has angular particles, leading to increased water requirements for lubrication. The specific gravity of surkhi exceeds that of fine aggregate, resulting in a lower volume of surkhi for an equivalent weight, which can cause more spaces in concrete. Water designated for lubrication could be confined inside spaces, leading to diminished workability.

5.2. The Mechanical Properties of the Material

5.2.1. Compressive Strength

The outcomes of the analysis of the CS property of SCC mixes in which FA has been replaced by Surkhi brick powder show anemphatic variation in both the early and longer periods of time (Table 4). The control mix (SCC) for this investigation without Surkhi brick powder displayed increasing strength and reached 34.3MPa in 90 days. In the Surkhi mixes, the SCC-60 mix, which replaces 60% of FA showed better results and had the highest value of CS of 37.52MPa at 90 days. In SCC-20 and SCC-40 the strength development was moderate and closely matched with the control after 28 days and was higher than control at the later ages. On the other hand, the early and the 27 days strengths of SCC-80 were lower, and this could mean that high levels of replacement might water down the binder. These outcomes demonstrate that Surkhi brick powder can be used effectively in concrete as a substitute for FA with the best outcome obtained at 60% replacement. Figures 5 shown are bar graph of CS.

Table 4: CS (MPa) of concrete mixtures on different Mix ID at several days

Mix ID	CS for 7 days (MPa)	CS at 14 days (MPa)	CS for 28 days (MPa)	CS for 56 days (MPa)	CS at 90 days (MPa)
SCC	18.41	20.64	22.57	32.9	34.3
SCC-20	16.44	18.45	24.18	33.24	36.2
SCC-40	17.35	19.31	24.18	34.6	35.81
SCC-60	18.43	20.67	26.01	36.05	37.52
SCC-80	16.37	18.51	24.15	30.47	32.50

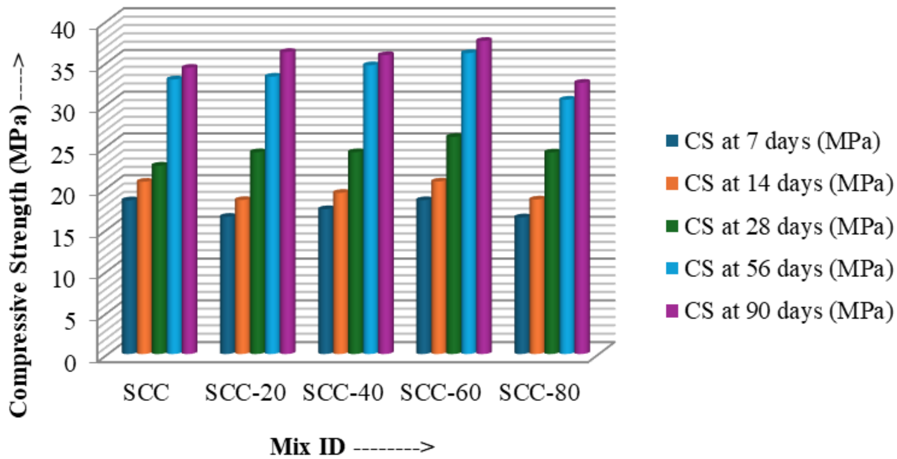

Figure 5: Compressive Strength

5.2.2. Flexural Strength

Test on replacements of FA by Surkhi brick powder shows that SCC mixes with moderate level of FA has high FS (Table 5). The control mix (SCC) archives constant rise in the FS which attained 4.71MPa at the age of 90 days. The SCC-40 mix, where 40% FA is replaced, presents the maximum value of FS at all curing ages analyzed, being 4.83MPa at 90 days, indicating that this increment in FA leads to optimized properties of the material. However, SCC-60 and SCC-80 mixes with higher Surkhi content have lower early-age and long-term strength compared with the others, particularly SCC-80 the sample that recorded the lowest strength in every point of time not surpassing 4.56MPa at 90 days. These results confirm the opportunity to improve the FS of SCC by using Surkhi additive but also illustrate potential deterioration of the overall performance when using a high percentage of the additive. Figures 6 shown are bar graph of FS.

Table 5: FS (MPa) of concrete mixtures on different Mix ID at several days

Mix ID	FS at 7 days (MPa)	FS at 14 days (MPa)	FS at 28 days (MPa)	FS at 56 days (MPa)	FS at 90 days (MPa)
SCC	4.15	4.20	4.38	4.52	4.71
SCC-20	4.17	4.26	4.48	4.68	4.85
SCC-40	4.21	4.32	4.65	4.73	4.83
SCC-60	3.82	4.12	4.30	4.57	4.74
SCC-80	3.51	3.84	4.03	4.23	4.56

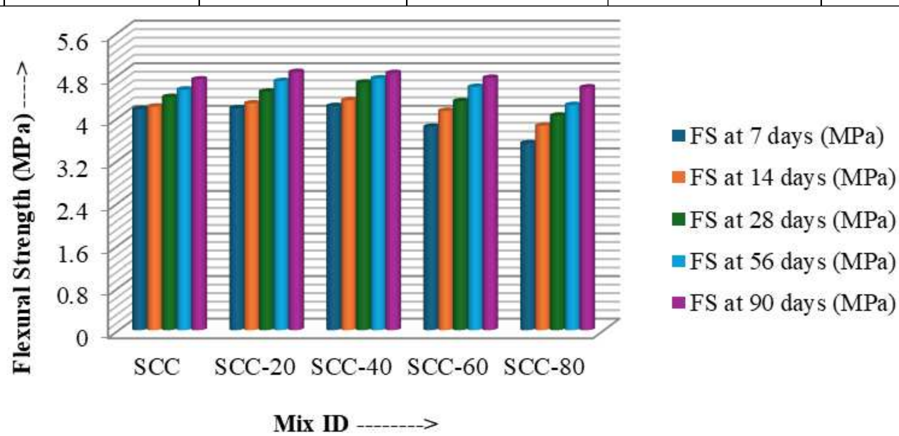

Figure 6: Flexural Strength

5.2.3. Split Tensile Strength

STS results for SCC mixes with varying levels of FA replaced by Surkhi brick powder reveal notable trends in performance (Table 6). The control mix (SCC) shows steady increases in STS, reaching 4.32 MPa at 90 days. The SCC-20 mix, with 20% FA replaced by Surkhi, exhibits the highest STS at all ages, achieving 4.81 MPa at 90 days, indicating that this replacement level optimizes the concrete's tensile properties. The SCC-40 mix, with 40% replacement, shows a decrease in STS on 7 and 14 days but recovers at later ages, reaching 4.71 MPa at 90 days. The SCC-60 mix performs similarly, with 4.82 MPa at 90 days, showing that higher levels of Surkhi replacement can maintain or even enhance tensile strength. The SCC-80 mix, however, shows consistent improvement in STS across all ages, reaching 4.80 MPa at 90 days, suggesting that even with higher replacement; Surkhi does not significantly hinder tensile strength. These results highlight that the partial replacement of FA with Surkhi brick powder can effectively enhance the STS of SCC, with moderate to high replacement levels offering superior performance. Figure 7 shows the bar graph of STS.

Table 6: STS (MPa) of concrete mixtures on different Mix ID at several days

Mix ID	STS at 7 days (MPa)	STS at 14 days (MPa)	STS at 28 days (MPa)	STS at 56 days (MPa)	STS at 90 days (MPa)
SCC	3.24	3.75	4.00	4.17	4.32
SCC-20	4.11	4.36	4.54	4.73	4.81
SCC-40	3.06	3.48	4.35	4.58	4.71
SCC-60	3.83	4.06	4.31	4.53	4.82
SCC-80	4.25	4.48	4.57	4.78	4.80

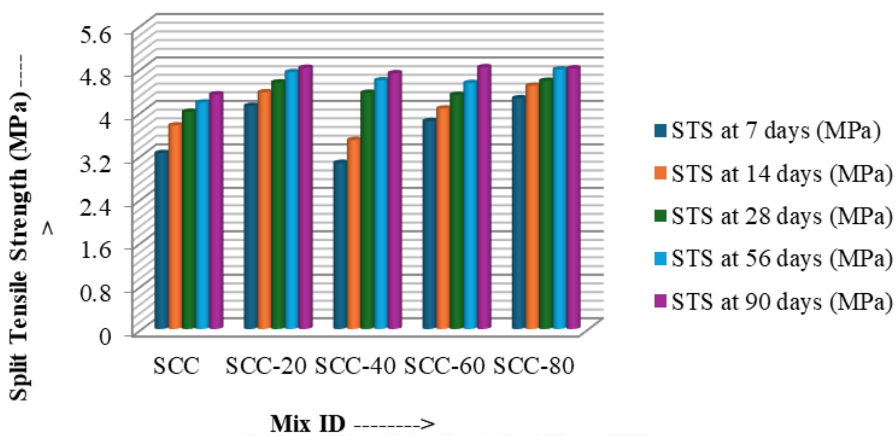

Figure 7: Split Tensile Strength

5.2.4. Durability

The durability results of the SCC mixes with FA partially replaced by Surkhi brick powder is indicating that the control mix (SCC) has the highest durability at all age groups and has largest durability value of 4.87MPa at 90 days (Table 7). Durability of concrete with SCC-20, which has 20 percent of FA replaced by Surkhi, is less than that of control concrete at early curing period and reaches 4.62 MPa at 90 days curing period. SCC-40 has achieved a high CS of 4.83 MPa at 90 days for moderate replacement of cement through Surkhi which does not affect durability in this case. Only the 60% Surkhi in the SCC-60 mix keeps the control mix's durability, reaching 4.73 MPa at 90 days. SCC-80 mix does achieve like SCC-20 mix at the early curing age but has a better 90 days' durability of 4.87 MPa equal to the control mix. The positive trends depicted in the above results indicate that a moderate to high level of Surkhi replacement could serve as a way of preserving, or even improving SCC's durability, even though they commissioned a slightly lower efficiency at the early stages as compared to the control group . Figure 8 shows the bar graph of durability.

Table 7: Durability (MPa) of concrete mixtures on different Mix ID at several days

Mix ID	Durability at 7 days (MPa)	Durability at 14 days (MPa)	Durability at 28 days (MPa)	Durability at 56 days (MPa)	Durability at 90 days (MPa)
SCC	4.23	4.35	4.52	4.76	4.87
SCC-20	3.14	3.31	4.13	4.24	4.62
SCC-40	3.23	3.47	4.46	4.63	4.83
SCC-60	4.12	4.24	4.52	4.65	4.73
SCC-80	3.67	3.72	4.57	4.63	4.87

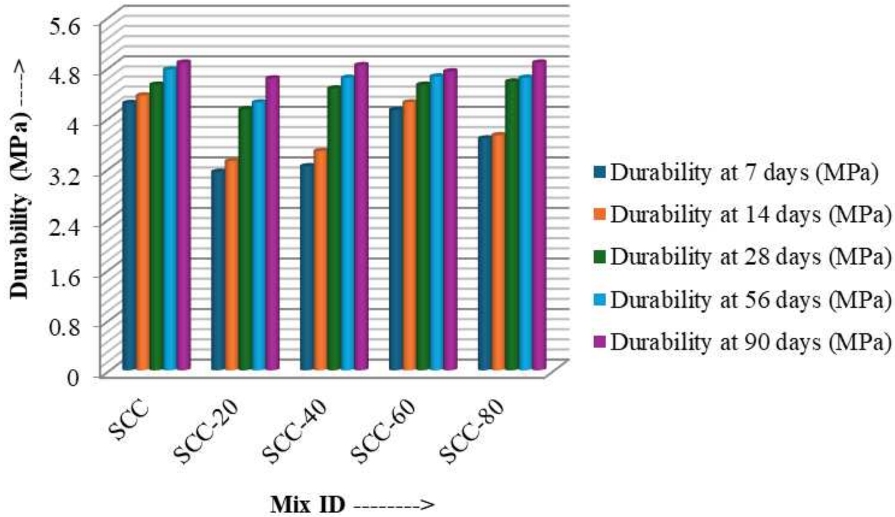

Figure 8: Durability

6. Conclusion

This work examines the characteristics of SCC when Surkhi brick powder a locally available material is used in place of the FA. The provided study concerned the evaluation of several characteristics of SCC, consisting of its properties on the fresh condition and CS, FS, and STS. From the experimental data the following conclusions are possible:

- The overall average CS of the control scc worked out to be 34.3MPa at the age of 90days and when 60% of FA was replaced with surkhi the CS went up to 37.52MPa at 90 days while for 40 and 80 % replacement of FA with surkhi the CS came down to 35.81 and 32.05MPa, respectively.
- The control SCC with an average FS of 4.71 MPa at the age of 90 days was further improved by 4.83 MPa when 40% FA was replaced with surkhi of the required weight but when the same repetition was done with 60% and 80% of surkhi the FS diminished to 4.74 and 4.56 MPa respectively.
- For the control SCC, the average STS is calculated to be 4.32MPa at the time of 90 days and when 60% FA replaced by surkhi, then increase in STS measured at 4.82MPa at the age of 90 days, where for 40% and 80% replace by surkhi the STS has been reduced to 4.71 and 4.80MPa.
- The average control SCC obtained for the study was 4.87MPa at 90days while upon replacement of 80% FA with surkhi the increase in durability was noted 4.87MPa by 90-day age of concrete while in case of 20% and 60 % replacement the durability relates decreased by 4.62MPa and 4.73MPa, respectively.

In conclusion, this study forms the basis for the development of sustainable concrete technology and high-performance concrete technology in subsequent studies.

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