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Research Article

Study on Fresh and Mechanical Properties of Polyblend Self-Compacting Concrete with Metakaolin, Lightweight Expanded Clay Aggregate, and SAP as Alternative Resources

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This paper discusses the possibility of developing a lightweight self-compacting concrete (SCC) with self-curing capabilities. In this regard, a supplementary cementitious material metakaolin, a presoaked lightweight expanded clay aggregate (LECA), and a chemical agent, superabsorbent polymer (SAP), were incorporated in developing a self-compacting self-curing concrete possessing a target strength of 60 MPa through experimental investigations, and the results are reported. The research includes an analysis of basic material properties of constituent materials including fresh properties of concrete and mechanical properties such as compressive and splitting tensile strength. It was inferred from the experimental results that utilization of self-curing agents in SCC has enhanced the mechanical properties when compared with conventional SCC mix. In particular, a combination of 0.3% SAP and 15% LECA gave the optimum strength values. The optimum usage limit of both the materials is presented in this study, and the results prove that SCC can be used as an alternate resource without disturbing the natural resources.

1. Introduction

Self-compacting concrete (SCC) is a special concrete having notable advantages such as high flowability and self-compaction with less segregation and is preferred in places of congested reinforcements. In spite of the advantages that SCC possesses, the cost involved in preparing it is higher than conventional concrete as the quantity of cement used is larger and also due to the usage of chemical admixtures to maintain the flowability [1]. In this section, a thorough literature review has been presented in three broad subcategories, namely (i) use of supplementary cementitious materials in SCC, (ii) significance of lightweight aggregate in SCC, and (iii) advantages of initiating self-curing process in SCC.

1.1. Use of Supplementary Cementitious Materials in SCC. SCC can be prepared economically by replacing partially cement with industrial wastes, namely fly ash (FA), ground granulated blast furnace (GGBS) slag, and limestone powder. Not only the supplementary cementitious materials will make the concrete preparation economical but will also help in reducing the autogenous shrinkage and higher heat hydration developed due to higher usage of cement in SCC [2–4].

Mineral admixtures in addition to reducing the total economy when used as an alternative cementitious material in SCC also enhance the workability and help in reducing the segregation of concrete [5]. Metakaolin, silica fume, GGBS, limestone powder, and fly ash are the usual supplementary cementitious materials that are used in conventional as well as SCC mixes. Among the various mineral admixtures available, metakaolin is preferred by many researchers due to the benefits it possesses such as less economic than micro-silica, having a higher alumina and silica content than FA and GGBS that results in the development of additional C-S-H gel [6].

Metakaolin has been used in the preparation of SCC, and various researchers have reported the fresh and hardened properties of concrete made using SCC [7–10]. Özcan and Kaymak [11] in their research on SCC reported that incorporating metakaolin along with calcite improved the long-term compressive strength and also enhanced the durability properties. Ashish and Verma [12] have performed an optimal metakaolin-based SCC mix design using particle packing, efficiency, and compressive strength methods by varying W/C ratios and reported that it was possible to produce the target strength up to 120 MPa when tested at early ages. Also, in another report, the same authors worked using waste foundry sand and metakaolin to prepare an economical and environmentally friendly SCC and revealed the advantages of using both in SCC [13]. In the present investigation also, a suitable SCC is prepared using metakaolin as an alternative cementitious material for cement. Investigations of earlier researchers state that the performance of concrete is indeed improved when metakaolin is used as a substitute for cement in normal and high-strength conventional concrete [14, 15]. Ashish et al. [16] have compared the cementing efficiencies of flash and rotary calcined metakaolin in concrete and reported that the MK can be replaced up to 30%, and flash calcined metakaolin showed enhanced strength properties compared with rotary calcined metakaolin. Kavitha et al. [17, 18] reported that the incorporation of metakaolin in SCC improves micro and macro properties and enhances durability. Vivek et al. [19–22] researched SCC using various mineral admixtures, namely silica fume, metakaolin, and GGBS in the binary mix and ternary combinations and also with natural and artificial fibers, and concluded that mineral admixtures had shown better performance when compared with control specimen.

1.2. Significance of Lightweight Aggregate in SCC. Though the cement content is reduced with mineral admixtures, the total cementitious quantity is maintained, and due to this high powder content, the viscosity is also sustained. The presence of high powder content used for modifying the viscosity may affect its density making it higher than the density of conventional concrete [23]. Replacement of fine or coarse aggregate with a suitable material can make the mix economical and also environmentally friendly as the natural resources can be preserved. Qasrawi [4] has tried replacing coarse aggregate with steel slag, and it was reported that a green sustainable SCC can be produced using industrial wastes. But the self-weight of concrete is also significant while designing reinforced concrete structures and executing multistorey frames. Hence, the use of lightweight aggregate in SCC can be a suitable solution for this problem, and in addition to reducing the self-weight, they possess further advantages such as reducing size in structural members, reducing heat absorption, labour requirement, and more importantly leading to reduced construction time [24].

Experimental results of earlier research works reveal that lightweight aggregate in SCC provides a suitable filling effect with less segregation in concrete [25]; this was confirmed by Kim et al. [26] who investigated the characteristics of semilightweight SCC using two different artificial lightweight aggregates and found that the flowability increased and segregation decreased. Adhikary et al. [27, 28] presented detailed reviews on using various materials such as expanded clay as a lightweight aggregate and aerogel in SCC. Juradin et al. [29] have researched SCC using silica fume, fly ash, and filler material to understand the effect on self-compacting lightweight concrete. The authors reported that the silica fume has enhanced SCC fresh properties, and the compressive strength was influenced by the expanded clay and the crushed aggregate. Ofuyatan et al. [30] implemented waste utilization in lightweight SCC with palm ash and reported that using 20% palm ash as partial substitution yielded optimum results. Nepamuceno et al. [31] proposed a grading curve of the lightweight aggregates based on the flow property of mortar. Li et al. [32] proposed a simple design mix method for using lightweight aggregates in SCC using ceramsite, a shale-type and spherical-shaped mineral whose particle size values were satisfactory for being used as a coarse aggregate. Afzali Naniz and Mazloom [33] discussed the effect of using lightweight mineral admixtures such as micro-silica, colloidal nano-silica, and their combinations in SCC and inferred that 10% silica fume and 3% colloidal nano-silica showed better fresh and strength properties. In the present work, lightweight expanded clay aggregate (LECA) was used as the lightweight aggregate.

1.3. Advantages of Initiating Self-Curing Process in SCC. Next to the large cement usage and self-weight, the other problem that the construction industry faces frequently is requiring sufficient water for curing. Improper curing may result in strength loss and stability and may also affect the performance of the reinforced concrete structures. The internal curing process could be an appropriate alternative for conventional curing techniques as it will increase the retention of water within self-compacting concretes with satisfactory fresh and hardened state concrete properties. Curing agents escalate the water retaining capability of SCC by dwindling water evaporation from SCC and help them possess sufficient hardened concrete properties. By employing a proper curing agent for concrete, defensibility and saving in water can be achieved in places of water scarcity. Azari Jafari et al. [34] reported that the use of presoaked superabsorbent polymers SAP in nonvibrated LWC mixtures enhanced the flowability of concrete up to a certain extent. Ali and Marzieh [35] have researched SCC using acrylic polymer and micro-SiO_2 to investigate the fresh properties, compressive strength, and water absorption test. It was inferred that the workability properties were improved and the high quality of SCC was produced using acrylic polymer of about 1–2% and 10% of micro-SiO_2.

Kamal et al. [36] studied the chances of developing a self-curing SCC possessing normal and high strength. The authors indicated in their results that it is possible to develop both normal and high-strength self-curing SCC and both perform well as structural elements. Chaitanya et al. [37] tried lightweight clay aggregate as self-curing agents for water detention and stated that the internal-curing agent LECA in concrete considerably gave better mechanical properties to concrete. Doha et al. [38] indicated in their report that the internal curing of concrete developed a denser hydrated cement paste and the interfacial transition zone (ITZ) had undergone suitable changes by becoming closer and dense, thereby upgrading the strength of concrete.

1.4. Research Gap. Although SCC with metakaolin, lightweight aggregates, and self-curing agents have been studied by earlier researchers, from the literature survey, it is clear that most of the mineral admixtures and lightweight components were added individually, and the research works focused on the effect of each mineral admixture in SCC. Very limited works were done implementing all the components together to prepare an SCC. So, as an upgrade to the earlier researches, here, a novel mix is proportioned using metakaolin, LECA, and a self-curing agent, namely superabsorbent polymer (SAP), and the physical and mechanical properties are discussed in this paper.

1.5. Research Significance. The novelty of this research is to prepare self-curing SCC with LECA as a partial substitute for fine aggregate to reduce the self-weight along with SAP as an internal curing agent and partially replace cement at a constant level of 10% metakaolin to develop a polyblend combination. LECA acts as an internal storing source in concrete and increases the water reattaining capability of SCC. Lightweight aggregates act as water retainers inside the concrete and ensure sufficient water is available for cement hydration in concrete. Along with the reduction in self-weight aspects, self-curing is also attributed to the current research. Hence, the modern method in today's construction process does not need to provide further moisture within concrete for more efficacious cement hydration along with lightweight aggregates for weight reduction and does not need to use conventional curing methods.

2. Material Proportions, Methodology, and Mix Design

2.1. Materials. OPC 53 grade cement and metakaolin were the basic cementitious materials used. Coarse aggregate of 12.5 mm downgraded size and fine aggregate M-sand (zone II) confirmed to IS 383-1970 [39] were the natural aggregates utilized for the current work. Table 1 shows the chemical composition of cement and metakaolin obtained from the x-ray fluorescent method. Figure 1 shows the XRD pattern of the metakaolin used from which it is understood that the sample possesses amorphous nature mostly though some narrow peaks are obtained at a certain angle due to the presence of silica. The microstructure of the MK used is also shown in Figure 2. Superabsorbent polymer (SAP) is a copolymer added as an additive in SCC as it acts as an internal curing agent in concrete.

Table 1: Chemical composition of cementitious materials used.

Formula	Concentration in percentage	
	Cement	Metakaolin
SiO_2	25.91	53.67
Al_2O_3	5.85	43.34
CaO	68.05	0.37
Fe_2O_3	0.12	0.46
MgO	0.07	0.09
TiO_2	—	1.19
SO_3	—	0.27
K_2O	—	0.17
Na_2O	—	0.12
P_2O_5	—	0.12
PbO	—	0.04
CeO_2	—	0.04
V_2O_5	—	0.04
Cl	—	0.02
Cr_2O_3	—	0.02
ZrO_2	—	0.01
Pd	—	96 ppm
NiO	—	95 ppm
ZnO	—	60 ppm
CuO	—	56 ppm
SrO	—	53 ppm

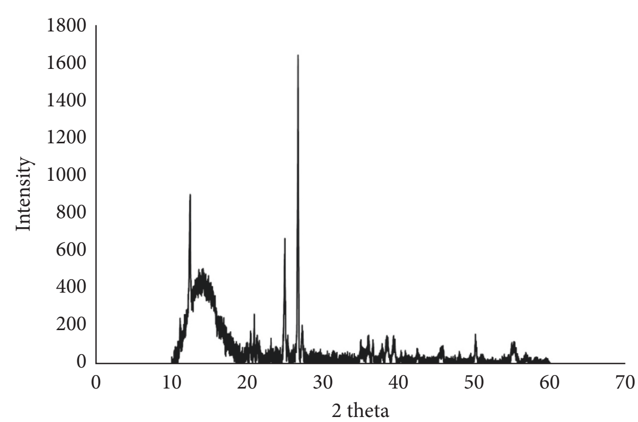

Figure 1: XRD image of Metakaolin.

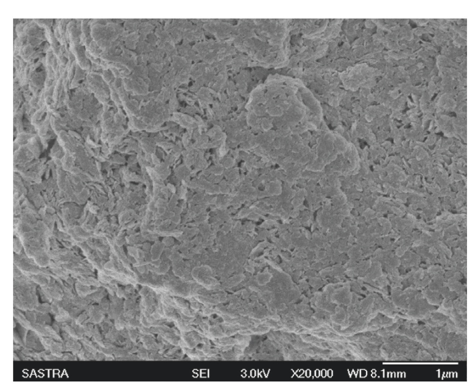

Figure 2: Microstructure of Metakaolin.

Lightweight expanded clay aggregate (LECA), which is porous, having less bulk density than the normal aggregate and size less than 5 mm as indicated by the supplier, was used as a partial substitute for fine aggregate. TEC MIX 640 a polycarboxylic ethers type superplasticizer (SP) and Glenium-2, a viscosity modifying agent, were the chemical agents used for maintaining the workability and flowability. The relevant initial tests required were conducted on the constituent materials of SCC, and Table 2 presents these.

2.2. Methodology. The methodology involves preparing SCC using constant 10% MK as a partial substitute for cement and using LECA as a partial replacement for river sand in various proportions along with an additive SAP. As a preliminary research study, the physical and chemical properties of the materials were examined, and their results were reported. After conducting the basic tests on constituents used in SCC, trial design mixes were prepared in the laboratory until the desired flowability of the SCC mix was met as per EFNARC guidelines. While examining fresh properties the mix proportions, W/C ratio and superplasticizer dosages were adjusted, and the slump flow trial tests were repeated. The cube and cylinder specimen moulds were made ready, and the prepared SCC mixes were cast, cured, and tested at the age of 7 days and 28 days to study the hardened state properties. Since the lightweight SCC mixes were prepared and tested, it is significant to compare the weight of all SCC mixes with respect to the control SCC mix. The microstructure studies were performed for the MK and the optimum SAP and LECA mixes. The flow chart on the research methodology adopted is illustrated in Figure 3.

2.3. SCC Mix Design and Material Proportion. Two series of SCC mixes were developed. In the first series, SAP was added as an additive in 0.1%, 0.3%, 0.5%, and 0.7% of cement content, and in the second series, LECA was replaced by fine aggregate from 0% to 25% in an increment of 5%, and totally 10 mixes were made including the control mix. The mix design was done according to IS 10262–2019 [40], and trial mixes were also conducted in the laboratory by slump flow test trials. In SCC, the binder content usually ranges between 400 and 600 kg/m^3. Here, 600 kg/m^3 is used for better flow and to maintain homogeneity in SCC mixes. W/C ratios have been adopted from the IS 10262-2019 and are kept as 0.35, and the target strength for the present mix is 68.25 N/mm^2. The fresh properties tests and mechanical properties tests were conducted. The mix proportion is shown in Table 3.

2.4. Trial Mixes. Among the two trial mixes specified in Table 4, the T2 ratio has been considered for casting specimens as it satisfied the requirements of the fresh properties of SCC.

3. Fresh Property Tests

SCC fresh properties tests were performed as per the European Federation of National Associations Representing for Concrete (EFNARC) specifications 2002 and 2005 [41, 42]. The test of the slump was akin to a conventional slump test, but instead of slump height, the diameter of the flow was measured to check whether the slump flow spread diameter is in the range between 650 mm and 800 mm. V-funnel and J-ring tests were used to find the fresh properties of SCC, while the former is used to test the ability to fill and the latter is used to appraise the passing capacity of SCC that tends to flow in critical reinforcements and other hindrances without any separation or blocking. Figures 4–6 illustrate the details.

After performing the fresh properties tests on SCC mixes, the obtained results were compared with the satisfactory limits laid by EFNARC guidelines shown in Tables 5 and 6.

3.1. Specimen Details. After conducting a fresh property test, cube specimens of size 100 mm × 100 mm × 100 mm and cylinder specimens of size 100 mm diameter × 200 mm height were cast to test the compressive and split tensile strength. The specimens were water-cured for the period of 7 days and 28 days to determine the mechanical properties as per IS 516 [43]. Hence, a total of 10 SCC mixes were cast after conducting a fresh properties test.

4. Results and Discussion

4.1. Fresh Properties of LECA, SAP, and Combined SCC Mixes

4.1.1. Flowability. As per EFNARC guidelines, the slump flow values shall be between 650 mm and 800 mm and also subclassified based on the slump flow (SF) class.

From Figure 7, it is apparent that all SCC mixes except 0.7% SAP have obtained the range specified in EFNARC guidelines as the slump values of the mixes are between 550 mm and 650 mm. The reason for the reduction in slump flow value in the 0.7% SAP mix was due to water demand that had affected the higher viscosity characteristics affecting the flowability properties of SCC. On comparing SAP-based SCC mixes slump flow values with SCC control mixes, it was inferred that the increase in the percentage of SAP has shown a reduction in slump flow values. The reason could be the influence of shear stress and plastic viscosity in the SAP-based SCC mixes. Among all SAP-based SCC mixes, the mix containing 0.1% of SAP performed better but the reduction in slump flow spread diameter values by 1.167%. It was inferred from Figure 6 that the slump flow spread diameter values had reduction by the increment of SAP percentages, which was analogous to the results reported by Azari Jafari et al. [34]. The reason for maintaining the flowability of SCC mixes in the presence of SAP (by varying percentages) was governed by the metakaolin of 10% (maintained constant) for all SCC mixes, which was similar to the research performed by Kavitha et al. [17, 18]. This was due to the presence of a higher surface area of MK caused better flowability of SCC mixes.

In LECA-based SCC mixes, a gradual increase in slump flow can be observed values when LECA is increased up to 10% in SCC beyond which, a reduction in slump flow values has occurred. The highest slump flow value was

Table 2: Material characteristics.

S. no.	Materials	Size	Water absorption (%)	Specific gravity
1	Cement	—	—	3.15
2	M-sand (fine)	4.75 mm	0.9	2.36
3	Coarse aggregate	12 mm	1.275	2.75
4	Metakaolin	1.5–2.5 microns	—	2.6
5	LECA	Below 10 mm	25	1.07
6	SAP	230–100 mesh	350–500 g/cc	—

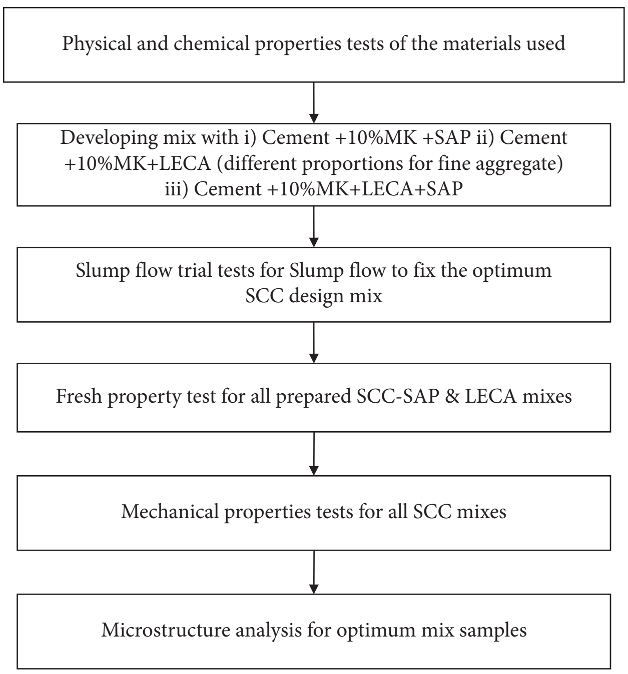

Figure 3: Methodology adopted.

obtained for a 10% LECA-based SCC mix when compared with SAP, and it had a flow spread diameter of about 3.357% when compared with the control SCC mix. The reason could be the size effect (less than 10 mm), and the specific gravity of LECA material used in the SCC mix has influenced the flowability property. As the range of slump flow values of LECA-based SCC mixes was between 660 mm and 750 mm, it is categorized as slump flow SF2 class and can be used for concreting of walls and columns. Hence, in LECA based SCC mixes, it is obvious that an increase in aggregate content will hinder the flowing property of SCC slightly as it causes a resistance to the flow because of very tiny holes inside aggregates, which takes over the mixing water and the lower density of light aggregates that creates the particle withstand against fluidity than the control mix. In contrast, LECA SCC mixes had the highest flowability compared to SAP that was inferred from the fresh properties results. The reason could be the presence of an internal curing agent in SAP-based SCC mixes that had the enhanced fluidity, which was similar to the results reported by Kim et al. [26].

The SAP and LECA blend SCC combinations have obtained the slump flow value of 680 mm, which is slightly less than the control SCC mix of about 0.73% but higher than SAP-based SCC mixes of about 0.44%. This small reduction in slump flow was mainly due to 0.3% SAP, but the homogeneity of SCC flow was enhanced by the presence of MK and LECA as discussed earlier.

4.1.2. T-500 Test. EFNARC guidelines mention that the time taken for T-500 shall be in the range of 2 to 5 seconds. T-500 test measures the flowability rate or viscosity of SCC since the flow time has been measured.

From Figure 8, it is clear that for all SCC mixes, the T-500 time was well within 5 s, whereas for 0.7% of SAP-based SCC mixes, an increase in time by 5.5 s is observed. Among all SAP-based SCC mixes, 0.1% SAP had performed better with the increase in time taken as 4.65% concerning the control SCC mix. Among all LECA-based SCC mixes, 15% of LECA had performed better than the control SCC mix of about 20.93% in terms of flow time gain.

From Figures 7 and 8, a similarity could be observed between obtained slump flow values and flow rates. An increase in flow rate is noted in SAP-based SCC mixes, whereas the flow rate has got decreased in LECA-based SCC mixes. From EFNARC guidelines, the viscosity class has been categorized based on the measured time taken in "seconds." If the time taken is less than or equal to 2 s, then it belonged to VS1 class, and the value is more than 2 s is referred to as VS2 class. Based on the obtained results, all SCC mixes belonged to VS2 class. Hence, viscosity of SCC mixes increased, and the time delay occurred. For the optimum combinations of LECA and SAP-based SCC mixes, the flow rate has got increased in the mix with the reduction in viscosity.

4.1.3. V-Funnel Test. The V-funnel test measures the flow time in SCC mixes. As per EFNARC guidelines, the flow time ranges between 6 and 12 seconds. The V-funnel test is also used to assess the viscosity and filling ability of SCC mixes. From the obtained results shown in Figure 9, all values are well within the EFNARC specifications.

About 0.7% of SAP-based SCC mixes possessed higher viscosity that increased the flow time by 25.93% compared with the control SCC mix, whereas 15% of LECA-based SCC mix has shown a time gain of about 7.41%. All SCC mixes belonged to the VF2 class whose flow time is more than 8 seconds and between 9 and 25 seconds. Hence, the viscosity is more pronounced in SAP-based SCC mixes when compared to other SCC mixes.

Table 3: Mix proportions.

Sl. no	Mix ID	C (kg/m^3)	MK (kg/m^3)	FA (kg/m^3)	LECA (kg/m^3)	SAP (kg/m^3)	CA (kg/m^3)	SP (l/m^3)	VMA (l/m^3)
1	Control SCC	600	—	930	—	—	804	7.2	0.6
2	0.1% SAP	540	60	930	—	0.6	804	7.2	0.6
3	0.3% SAP	540	60	930	—	1.8	804	7.2	0.6
4	0.5% SAP	540	60	930	—	3	804	7.2	0.6
5	0.7% SAP	540	60	930	—	4.2	804	7.2	0.6
6	5% LECA	540	60	883.5	46.5	—	804	7.2	0.6
7	10% LECA	540	60	837	93	—	804	7.2	0.6
8	15% LECA	540	60	790.5	139.5	—	804	7.2	0.6
9	20% LECA	540	60	744	186	—	804	7.2	0.6
10	0.3% SAP + 15% LECA	540	60	790.5	139.5	1.8	804	7.2	0.6

Table 4: Trail mix proportions as per IS 10262-2019 code of practice.

Mix ID	Cement	Metakaolin	Coarse aggregate	Fine aggregate	W/P	SP (%)	VMA (%)	Remarks
T1	0.85	0.15	1.34	1.55	0.35	0.9	0.1	Flow is not satisfied <650 mm
T2	0.85	0.15	1.34	1.55	0.33	1.2	0.1	Flow is satisfactory >650 mm

Figure 4: Slump flow test.

Figure 5: J-ring test.

4.2. Compressive Strength of LECA, SAP, and Combined SCC Mixes. Figure 10 illustrates the compressive strength for SAP, LECA, and their combinations along with the control SCC mix. About 0.3% SAP has obtained the highest compressive strength of about 33.65 MPa and 64.92 MPa when tested at the age of 7 days and 28 days with a strength gain of about 2.59% and 1.23% more than the control SCC mix. The reason could be the internal curing process namely copolymerization exhibited because of the addition of superabsorbent polymer in the SCC mix. Among all SCC mixes, SAP-based SCC mixes performed better than the LECA and control SCC mixes. From Figure 10, it is clear that beyond the addition of 0.3%, SAP has shown a gradual decrease in compressive strength, which was similar to the results reported by Afzali Naniz and Mazloom [33]. The reason was due to the SAP reduced shrinkage that had resulted in the strength loss, which was attributed analogous to the research reported by Chaitanya et al. [37]. In SCC, the polymer blended with mineral admixture had shown a high strength

Figure 6: V-funnel test.

Table 5: SCC fresh properties tests: satisfactory Limits as per EFNARC 2005 guidelines.

Test methods	Unit	The typical range of values	
Slump flow test by Abrams cone	mm	650	800
J-ring test	mm	0	10
T50 cm slump flow	s	2	5
V-funnel test	s	6	12
L-box test	H_2/H_1 ratio	0.8	1.0
U-box test	$H_2–H_1$ (mm)	0	30

Table 6: SCC fresh properties tests: consistency class as per EFNARC 2005 guidelines.

Test methods	Unit	Consistency class	The typical range of values
Slump flow test	mm	Slump flow class:	
		SF1	550–650
		SF2	660–750
		SF3	760–850
T-500 test	s	Viscosity class:	
		VS1	≤2
		VS2	>2
V-funnel test	s	Viscosity class:	
		VF1	≤8
		VF2	9 to 25
L-box test	H_2/H_1 ratio	Passing ability class:	
		PA1	≥0.80 with 2 rebars
		PA2	≥0.80 with 3 rebars

Figure 7: Slump flow spread diameter of all SCC mixes.

and quality, which was similar to the results reported by Azari Jafari et al. [34].

In the second series of mixes consisting of LECA-based SCC, 15% LECA has attained the highest compressive strength among other LECA-based SCC mixes. But it has got a strength reduction of about 11.19% and 2.62% at the age of 7 days and 28 day concerning control SCC mix. The reason for the strength reduction was the fine aggregate replacement. In an SCC mix, the main constituents are the fine aggregates that induce flowability and strength also. The trend obtained here was similar to the results inferred by Chaitanya et al. [37].

Finally, the optimum percentages of 0.3% SAP and 15% LECA have been blended to study the mechanical properties. From Figure 7, it was inferred that there is a slight strength reduction of about 3.45% and 0.70% at 7 days and 28 days with respect to control SCC. Figures 11–13 show the microstructure of selected optimum mixes. Since much variation was not found in the compressive strengths, the microstructure also did not show much variation; the presence of

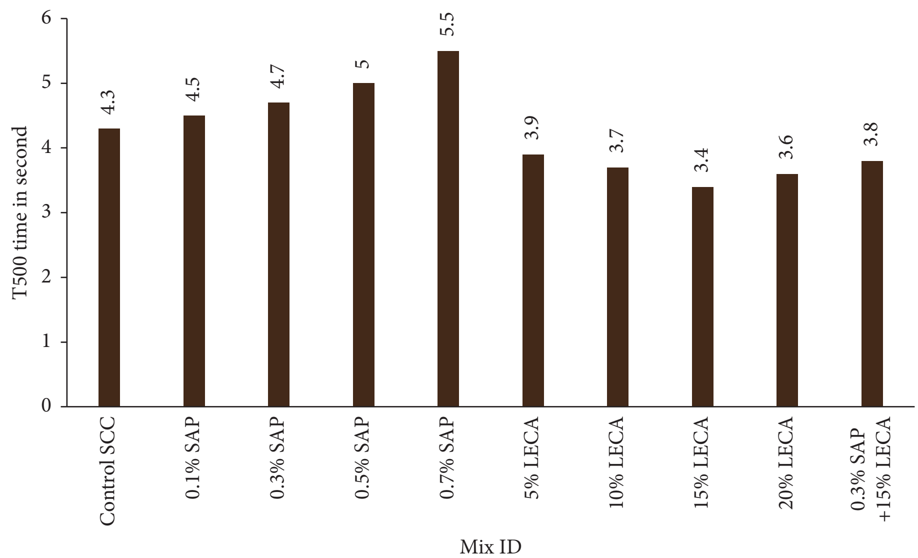

Figure 8: T-500 time of all SCC mixes.

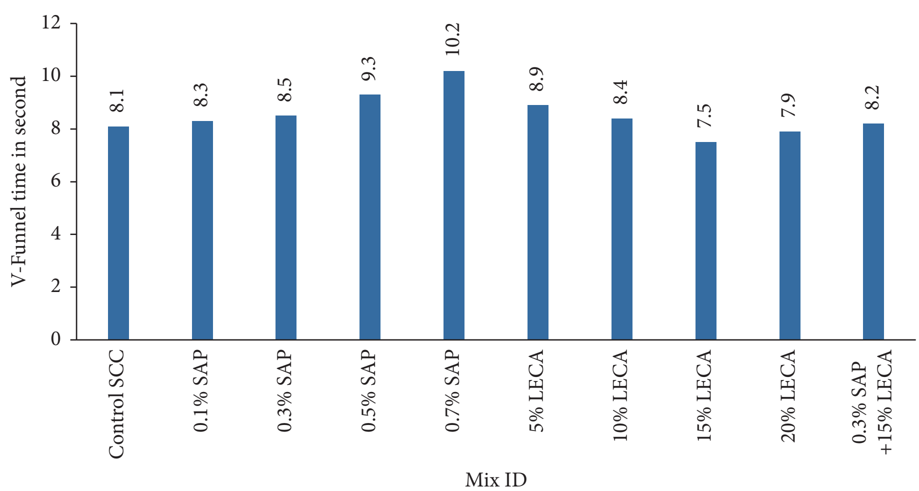

Figure 9: V-funnel time of all SCC mixes.

voids in 0.3% SAP and 15% LECA was less when compared with the control SCC specimen. Ettringite crystals were also not seen much in the mixes. From the results, it is understood that an equivalent concrete specimen can be made with target strength of about 60 MPa using SAP and LECA instead of normal aggregate in blended combinations along with MK.

4.3. Tensile Strength of LECA, SAP, and Combined SCC Mixes. Control SCC has obtained the highest tensile strength in concern to SAP, LECA, and their blended combinations, which is evident from Figure 14. Here also, much variation is not noted among the tensile strength values, and the same trend observed in compressive strength values followed here too. From Figures 10 and 14, it was inferred that for SAP and LECA SCC mixes, the average percentage ratio between the tensile strength and compressive strength ranges between 6.54 and 8.10 at the age of 28 days and 7 days, respectively. The obtained average compressive strength results for SAP and LECA SCC mixes were 12.4 and 15.4 times more than the respective average tensile strength at the age of 7 days and 28 days, respectively. Also, as the compressive strength increased in the series of mixes, the tensile strength would increase proportionately.

In SAP-based SCC mixes, 0.3% of SAP has the highest tensile strength among other SAP-based SCC mixes. But there is a strength reduction of 6.63% in 28 days compared with the control SCC mix. About 15% of LECA has the highest tensile strength among other LECA-based SCC mixes. A reduction in strength of about 14.86% from the control SCC mix in 28 days was observed. In SAP and LECA blended SCC mixes, at 28 days, the strength reduction noted was about 9.84% compared with the control SCC mix.

4.4. Unit Weight of SCC Mixes. The unit weight of normal weight concrete mixes lies between 2,400 and 2,500 kg/m^3, and that of other lightweight concrete mixes almost lies

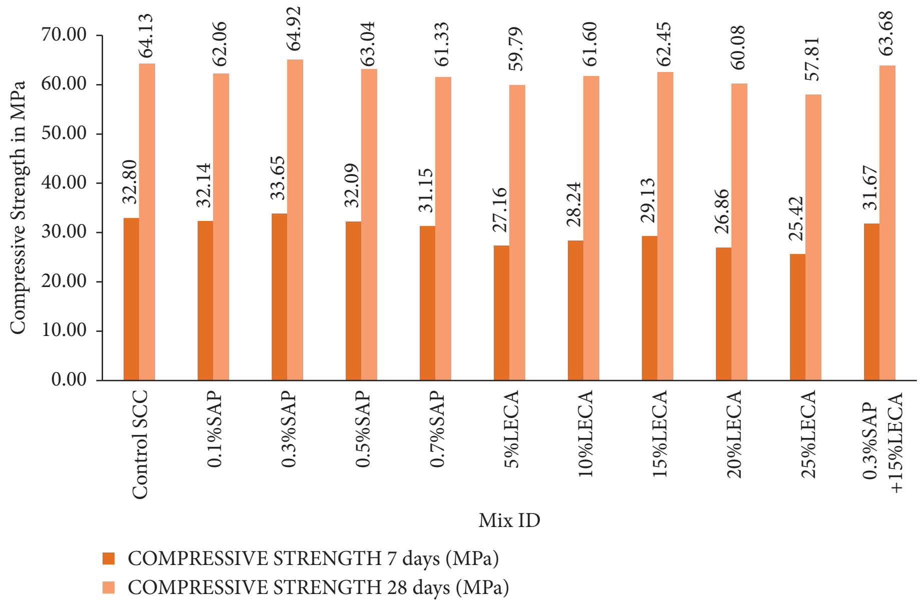

Figure 10: Compressive strength of all SCC mixes.

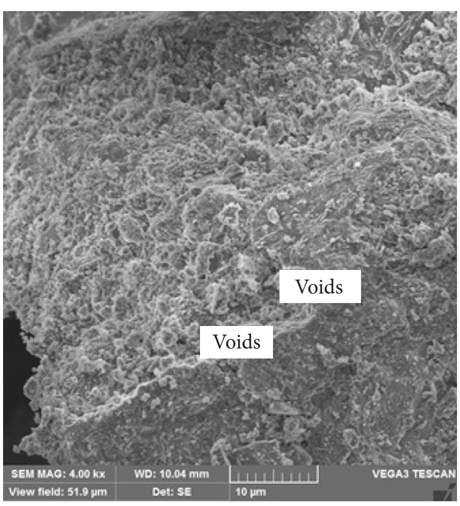

Figure 11: Microstructure of control SCC.

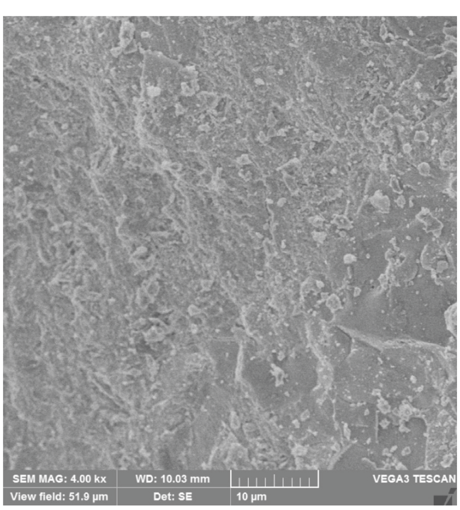

Figure 12: Microstructure of 0.3% SAP.

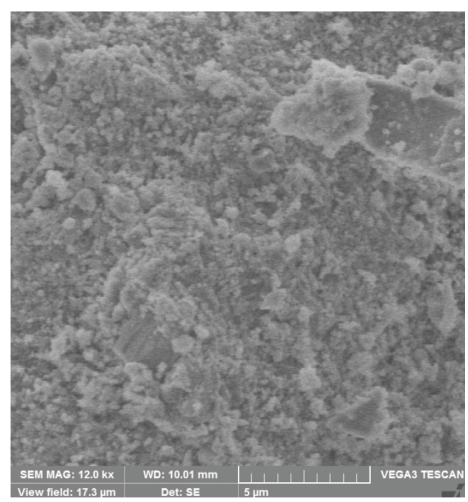

Figure 13: Microstructure of 15% LECA.

between 1,400 and 1,900 kg/m^3 as specified by the code ASTM C 330 [44] and ASTM C 567 [45–54].

Figure 15 shows the unit weight of all SCC mixes. The control SCC mix was analogous to the conventional concrete that obtained a unit weight of 2,562 kg/m^3. The first series of mixes containing SAP-based SCC mixes had the unit weight in the range between 2,444 kg/m^3 and 2,533 kg/m^3. Hence, a slight reduction of about 4.62% in unit weight was attained in SAP-based SCC mixes compared with the control SCC mix. It is also understood that as the percentage of SAP increased from 0.1% to 0.7% in SCC mixes, a gradual decrease in the unit weight took place. In the second series of SCC mixes, when the fine aggregate was substituted with LECA from 5% to 20%, the unit weight had the range between 1,891 kg/m^3 and 2,396 kg/m^3. The average unit weight of SAP and LECA SCC mixes were 2,293 kg/m^3 was 10.5% less than the unit weight of the control SCC mix, in which

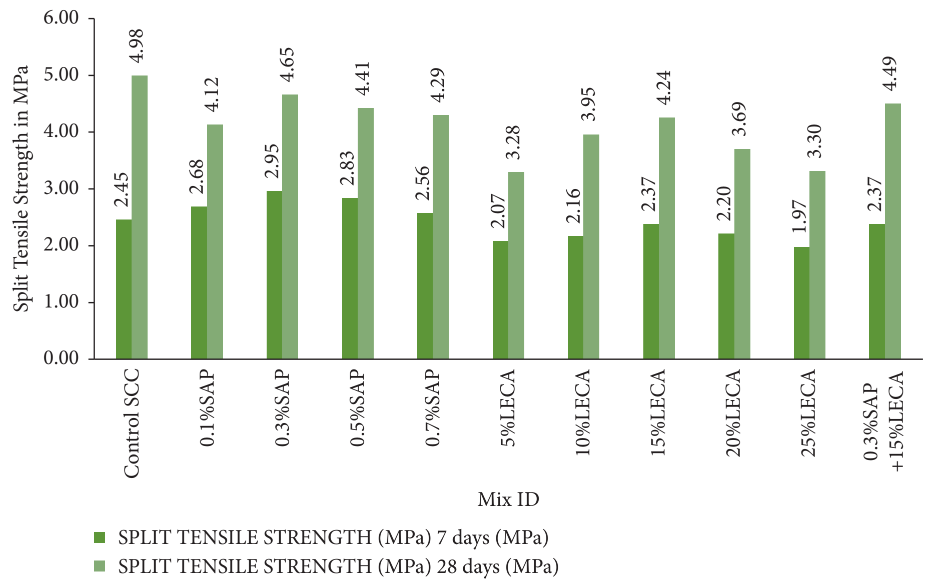

Figure 14: Tensile Strength of all SCC mixes.

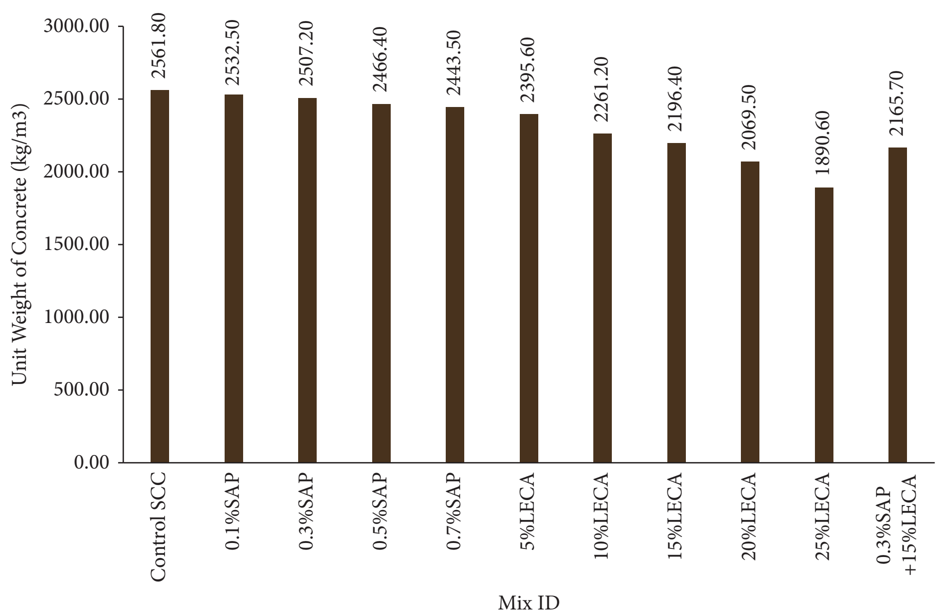

Figure 15: Unit weight of all SCC mixes.

the least unit weight was obtained by 0.3% SAP and 15% LECA concerning the control SCC mix. Thus, the unit weight of concrete was reduced by 26.2% when the fine aggregate was replaced by 25% of LECA in the SCC mix. In SAP and LECA blended SCC combinations, the unit weight was also reduced drastically by 15.46% concerning the control SCC mix.

5. Conclusions

The results obtained from the experimental investigations done on the SCC mixes with SAP and LECA individually and together are summarized below:

(i) The fresh properties test results of mixes made with all combinations indicate that the SCC mixes are well within the specifications of IS code guidelines. In general, it was noted that higher usage of LECA and SAP caused segregation and blocking effects in rheological properties.

(ii) Among the mixes made with SAP, 0.3% SAP registered the highest strength 28 days strength value with an increase in strength by 1.23% to the control specimen.

(iii) LECA-based mixes showed higher strength for 15% addition, which was less by 2.62% than the control mix.

(iv) The combined use of SAP and LECA in 0.3% and 15% showed a considerable reduction in weight, but the strength values were nearer to that of the specimens made with 0.3% SAP and 15% SAP separately, and the addition of SAP or LECA either individually or in combined form did not affect the strength.

(v) The split tensile strength of SAP mixes 0.3% SAP had the highest tensile strength that showed an increase in strength by 6.62%. About 15% of LECA mixes registered the highest tensile strength among the LECA-based mixes. But both values are less than the control specimen. The combined mix also registered a decrease in values compared to control by 9.84% after 28 days.

(vi) Also, though the differences in strength values of the SCC mixes prepared were less, it is to be noted that the strength values can be maintained even if part of the fine aggregate is replaced with a lightweight aggregate, and practically, it will be beneficial in saving the natural resources being depleted and in reducing the overall weight of the structure.

(vii) A considerable reduction in the unit weight of the specimens made with SAP and LECA was observed without affecting the strength properties. So, it is apparent that such a mix can be most preferred for multistorey structures.

(viii) The optimum blended mix (0.3% SAP and 15% LECA; lightweight) possessed better mechanical properties, and it is apparent from the results that SCC could be produced with both lightweight and self-curing properties.

(ix) Finally, it is understood SCC specimens can be made with a target strength of about 60 MPa using SAP and LECA instead of normal aggregate in blended combinations along with MK without much affecting the strength due to loss in weight.

Data Availability

All data used to support the findings of the study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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