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Research Article

Investigation of Fresh and Hardened Characteristics of Self-Compacting Concrete with the Incorporation of Ethylene Vinyl Acetate and Steel-Making Slag

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Advancement in the construction industry causes decline in the availability of natural resources, and this decline can be overcome by utilization of the available raw materials. This study is focused on the combined effects of ethylene vinyl acetate (EVA) and ladle furnace slag (LFS) on fresh and hardened characteristics of self-compacting concrete (SCC) by replacing some fraction of cement and sand. The characteristics of SCC in its fresh state are investigated by workability, while hardened characteristics are investigated by elastic modulus and compressive, tensile, and flexural strength. The findings showed that the workability is enhanced by the incorporation of EVA, while decreased with LFS. Furthermore, all the strength properties were enhanced at all the replacement levels of EVA and LFS except for the splitting tensile strength. The utmost gain in elastic modulus and compressive, tensile, and flexural strength was up to 18, 20, 10, and 15% more by increasing the dosage of LFS while keeping EVA constant.

1. Introduction

Concrete has a significant role in building nearly all the construction plans throughout the world. Aggregates, cement, and water are the primary ingredients of concrete. The volume covered by the aggregates is approximately 70% in concrete [1]. Sometimes, admixtures are added to concrete for a certain property in demand. Almost in all construction projects, cement is the basic binding element of concrete which holds the ingredients all together in a packed mass. The manufacturing of cement demands for a huge amount of energy which is then transmitted to the environment in the form of greenhouse gases and particulate matter [2].

From one point of view, humankind is facilitated with the advancement in engineering technology and industrialization, while it has severely stroked the environment from another point of view by the discharge of poisonous gases and yielding of a huge amount of solid wastes [3–8]. To avoid such problems, a lot of studies have been made till now by utilizing industrial wastes in concrete through the substitution of some portion of aggregates and binding materials for expecting better performance of concrete. For instance, one of the researchers concluded that adding recycled coarse aggregates and blast furnace as a replacement for coarse aggregates and cement, respectively, may decrease the mechanical properties [9]. Alternatively, 100% replacement of coarse aggregate by stainless steel-oxidized slag may raise the compressive strength up to 14% [10–13]. The incorporation of steel-making slag in concrete may yield to the enhanced compressive strength up to 35% [14] and other properties such as durability, bonding to steel rebars, and others [15–22]. Compressive strength of concrete may decrease when fly ash and steel-making slag are incorporated in combination with recycled aggregates [23]. By incorporating steel-making slag as a replacement for coarse aggregates, the mechanical properties may decrease up to 50% [24]. In a similar manner, some of the studies are showing a decreasing trend of 30% in compressive strength by the inclusion of steel-making slag [25, 26]. However, 100% enhancement in compressive strength takes place by the substitution of iron slag with sand [27]. Enhancement of compressive strength was found by replacing fine and coarse aggregates with cooled slag and air-cooled slag, respectively [28]. The substitution of steel-making slag with basalt aggregates may increase the mechanical properties; even so, the reduction in the workability was observed [29]. Mechanical behavior may be enhanced by replacing sand with blast furnace slag [30].

SCC is a sort of concrete representing the enhanced workability and nonsegregation properties. This kind of concrete needs little mechanical effort for the purpose of compaction as it could be pour out at ease and at any place [31]. To obtain better flow characteristics of SCC, the fine aggregate is often proportioned in greater amount compared to the coarse aggregate [32]. However, if cement is solely considered a binding material in concrete, it will make the construction more uneconomical and would lead to the hazardous impact on the environment. Because of such a rationale, the researchers started studying the effect of substituting cement by blast furnace slag, fly ash, silica fume, SBR (styrene-butadiene rubber), and EVA [33, 34]. The mentioned materials were used by researchers as a substitute for cement, and they concluded better performance concerning durability characteristics [35, 36]. Workability [37] and strength properties [38] of SCC might be enhanced by the inclusion of fly ash and blast furnace slag. Incorporating steel-making slag up to a dosage of 50% as a replacement for sand might decrease the workability of concrete [39], but other authors have obtained good results with electric arc furnace slag as coarse aggregates [40]. Strength and flow characteristics of SCC may be improved by the inclusion of marble powder and lime [41].

EVA may be utilized relatively flourishing in developing concrete in various supplemental applications [42]. Globally, a lot of waste is produced, which may affect the environment; for example, EVA after utilizing as a shoe sole on the user side is more critical concerning environmental issues. In the 70^{th} decennium, EVA was brought in as a substitution material for leather in the shoe industry [43]. Globally, the production of shoes is almost seventeen billion pairs, each year. Utilization of these shoe pairs leads to a tremendous quantity of waste which is then conveyed to the landfill sites for final disposal [44]. It would be more benefitting if such a kind of material is employed in developing concrete by such a practice, and the construction will be more economical and environmentally friendly. Polymers like EVA and SBR are used nowadays in many construction applications either in an emulsified or redistributed form [45, 46]. By the utilization of polymers in concrete, many desired characteristics may be acquired like increased elastic modulus [47], higher flexural strength [48], and improved compressive strength [49]. Nevertheless, few studies are depicting a decreasing trend in mechanical properties of concrete by the utilization of polymers [50]. However, because of the nature of experiments, former results cannot be correlated straight away [51].

The necessities of utilization of EVA in construction applications are increasing each day. As per the understanding of the authors, the findings concerning the combined influences of EVA and LFS in the development of SCC are limited. Consequently, efforts have been made in this study to conclude findings concerning combined influences of EVA and LFS on SCC in its fresh and hardened states.

2. Scope of the Study

Most often, compressive strength is compromised while improving the workability by adding extra water to the concrete mix, while in this research, it is determined adding EVA to concrete mix improves workability without compromising the compressive strength. According to few researchers, as mentioned in the literature, the mechanical properties may decrease up to 50% by incorporating steel-making slag as a replacement for coarse aggregates [24]. In a similar manner, some of the studies are showing a decreasing trend of 30% in compressive strength by the inclusion of steel-making slag [25, 26]. The compressive strength of the concrete in the present study is enhanced by the incorporation of LFS as a fine aggregate, which also improves concrete's mechanical properties. Cement is a basic binding element of concrete utilized almost in each construction which holds the ingredients all together in a packed mass, while the manufacturing of cement demands for a huge amount of energy which is then transmitted to the environment, leading to the formation of a tremendous amount of carbon dioxide [2]. For acquiring improved characteristics of SCC, the necessities for cement increase which could make the construction more expensive. So, this necessitates a substitution material to get over such issues in construction practices; therefore, an effort is made in this study for using EVA as a partial replacement for cement, and the workability and other mechanical properties are enhanced.

3. Properties of Materials

Locally available cement with a trade mark Askari was utilized in this study, whose properties are listed in Table 1. The surface area of the cement was found to be 337 m^2/kg. Materials like fine aggregates (locally named Lawrencepur sand) and coarse aggregates (locally named Margalla crush) were conveyed from nearby available sources. The nominal size of coarse aggregates was found to be 19 mm. A huge amount of LFS may be found near the regional steel manufactory plant as a waste material, so it was carried from the local steel manufactory plant. The large sizes of the LFS were ground to an average of 3 mm grains. The physical and chemical characteristics of LFS are tabulated

Table 1: Proportions of cement ingredients.

Compounds (%)									Mineral compounds (%)			
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LOI	C_2S	C_3S	C_3A	C_4AF
21.3	7.2	2.3	61.1	1.9	2.9	0.5	0.3	2.5	27.9	48.6	11.3	7.8

Table 2: Physical and chemical characteristics of LFS.

	Name of the compound	Oxide composition (%)
Chemical properties	CaO	43.41
	SiO_2	14.67
	Fe_2O_3	23.72
	Al_2O_3	3.84
	MgO	7.60
	MnO	2.93
	SO_3	0.29
	Cr_2O_3	0.46
	P_2O_5	0.91
	TiO_2	0.53
	K_2O	0.06
	CaO_{free}	—
	Loss on ignition	1.58
Physical properties	Average porosity (%)	7.62
	Specific gravity	3.10
	Specific weight (kg/m^3)	1858
	Water absorption (%)	1.08

in Table 2, whereas the characteristics of aggregates are tabulated in Table 3. EVA was acquired by chopping down the shoe soles to powdered form of sizes equal to or less than cement sizes. The physical characteristics of EVA are shown in Table 4, while its Vicat softening data are shown in Table 5. Heat resistance of polymers is a critical parameter in construction, and it can be evaluated based on the capability of polymers used to maintain their performances under elevated temperatures. Heat resistance of the polymers can be found out through Vicat softening temperature. Ultra plastic 470 is employed as a water-reducing admixture.

4. Proportioning of the Mixes

For mix proportioning, 10 mixes were prepared in accordance with ACI 237R-07. Of these 10 mixes, 9 were blended mixes which were prepared by the addition of EVA and LFS as a substitute for cement and fine aggregates, while the remaining mix was the reference mix which was prepared without the addition of EVA or LFS. The substitution level for EVA and LFS was kept up to 6, 12, and 18% and 40, 60, and 80%, respectively. The desired strength was targeted at the 28th day with a slump of 580 mm. The reference mix was decided on the basis of trails accompanied by the inclusion of EVA and LFS in different fractions. The symbols used for various blended mixes are shown in Table 6, while the details of mix proportioning are tabulated in Table 7. The fine aggregate used in this study was natural siliceous sand with some percentages of LFS, with the finer contents of siliceous sand lying in the range of 0.075 mm to 4.75 mm, while the crushed LFS ranged from 0 to 9.5 mm, and the gradation curves for component fractions are shown in Figure 1, whereas the gradation curves for all the mixes are shown in Figure 2.

5. Experimentation

For the purpose of intended functioning of SCC, various levels of replacements EVA and LFS were employed in concrete with cement and sand, respectively. SCC was studied in its fresh state as well as in the hardened state, and the details are given as follows.

5.1. Characteristics of Fresh SCC. Characteristics of fresh SCC were examined by a series of tests, involving the determination of air content, density, and workability. Air content and workability tests were investigated complying with ASTM C138. Workability tests were conducted by L-box, J-ring V-funnel, and slump flow tests complying with BS EN 12350-10:2010, BS EN 12350-12:2010, BS EN 12350-9:2010, and BS EN 12350-8:2010, respectively. The flow experiments are conducted in the laboratory, as depicted in Figure 3.

5.2. Characteristics of Hardened SCC. SCC in the hardened state was investigated by compressive, flexural, and splitting tensile strength tests. These tests were carried out using cylindrical moulds. The moulds used for the splitting tensile strength test were 200 mm in length and 100 mm in diameter. The flexural strength test was performed with the help of prismatic beams having $100 \times 100 \times 350$ mm dimensions. A four-point loading system was used for the flexural strength test. Immersed curing was followed for 28 days complying with ASTM C192. A total of ten mixes were prepared, in which one was the reference mix and the other nine were blended mixes. Out of these nine mixes, three mixes were prepared for each of the desired strength, for instance, three mixes for compressive strength, three mixes for tensile strength, and three mixes for flexural strength. The strengths were determined according to ASTM specifications; that is, compressive strength was determined according to ASTM C39, flexural strength according to ASTM C192, splitting tensile strength according to ASTM C496, and elastic modulus according to ASTM C469.

6. Results and Discussion

The findings of this study are presented as follows.

6.1. Findings of Fresh SCC. The findings associated with the SCC in its fresh state are shown in Table 8. The findings revealed that, by increasing the content of LFS at a fixed level of EVA, the air content is enhanced although the drift of density is nearly the same as the negligible increase

Table 3: Physical characteristics of fine and coarse aggregates.

Materials used	Characteristics					
	Size (mm)	Relative density	Specific weight (kg/m^3)	Percentage		
				Water absorption	Water content	Contaminants
Sand	4	2.29	1971	0.21	0.51	0.00
Gravel	19	2.67	1582	0.69	0.32	0.00

Table 4: Characteristics of EVA.

Materials	Appearance	pH (20°C)	Grain size (μm)	Transition temp. (°C)	Viscosity at 20°C (mPa·s)	Relative density (60°F)	Surface area (m^2/kg)
EVA	Half white	9.3	Less than 50	−9.1	2204	0.94–0.98	329

Table 5: Softening of EVA through the Vicat apparatus.

Sample	Rise of temperature at respective penetration (°C)			
	1 mm	2 mm	3 mm	4 mm
1	69.89	71.23	72.56	74.11
2	70.21	71.93	72.10	73.54
Average	70.05	71.58	72.33	73.82

Table 6: Notations used for various blended mixes.

Materials	E_0	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9
% of EVA	0	6	6	6	12	12	12	18	18	18
% of LFS	0	40	60	80	40	60	80	40	60	80

or reduction drift is seen. One of the reasons for enhancing the air content may be the porous nature of the LFS itself. While concerning the workability, Figure 4 depicts that all the flow properties were reduced except for the V-funnel flow test which showed enhancement in its flow properties with the increase of LFS at a fixed rate of EVA inclusion.

Since the relative density of the steel-making slag is more than that of sand, the prediction was to enhance the workability of SCC rather than to reduce by the inclusion of the steel-making slag [40]. The reduction in workability is possibly due to either the rough texture of LFS or the extra water absorption of LFS. The findings of the present study concerning fresh SCC show similarity to the past results [29, 31, 40, 45], where reduction in workability was concluded in SCC with the substitution of sand by steel-making slag.

From another point of view, the inclusion of EVA at a fixed level of LFS enhanced all the flow characteristics with the exception of the V-funnel test, which showed reduction in the flow characteristics, as shown in Figure 4. The results obtained in this study are in line with those of previous research [45], where same results were concluded by the inclusion of polymers in concrete at various levels.

6.2. Findings of Hardened SCC. All the mechanical testing results of SCC in its hardened state are listed in Table 9. For each value of mechanical testing, three samples were tested, and subsequently, an average or mean value was determined. The coefficient of variation (COV) for all results has also been found out as it is a significant indicator of the dataset dispersion. The COV is defined as the ratio of the standard deviation to the mean value. The percentage of COV is nearly similar for compressive, flexural, and splitting tensile strength, around 2.5%. However, the variability observed for elastic modulus is significantly lowered (between 0.7 and 1.2).

6.2.1. Compressive Strength. The findings concerning compressive strength revealed that increasing the dosage of both EVA and LFS enhanced the compressive strength. For instance, the compressive strength is enhanced when cement is substituted by EVA at a fixed level of LFS. Likewise, it is enhanced when sand is substituted by LFS at a fixed level of EVA, as listed in Table 9 and Figure 5.

The maximum compressive strength was 20% more than that of the reference mix while substituting 18% of cement and 80% of sand by EVA and LFS, respectively, at all replacement levels, as depicted in Figures 5(a) and 5(b), whereas the minimum compressive strength was 2.6% more than that of the reference mix while substituting 6% of cement and 40% of sand by EVA and LFS, respectively, at all the replacement levels. The results of the previous findings depict that when LFS is used up to a replacement level of 30% with fine aggregates, the compressive strength is enhanced [25, 27, 31]. Furthermore, according to one of the researchers [32], the compressive strength is enhanced by the inclusion of EVA in concrete which is in line with the present findings. The enhancement in the compressive strength behavior of SCC is possibly due to the fact that EVA has the property of reducing the water content as a result of which the hydrated cement particles create strong bonds with the aggregates [52]. The enhancement in compressive strength by the use of polymers may be either due to the creation of binding forces or due to the filling potentiality of the polymers [53]. One of the studies [48] concluded that the free radical on the boundaries of aggregates establishes hydrogen bonds with the polymers, thus developing the

Table 7: Mix design data.

Mix ID	W/B	Materials (kg/m^3)						
		Cement content	EVA content	Water content	Fine aggregates	LFS	Coarse aggregates	Superplasticizer
E_0	0.52	440.0	0.00	226	965	0.00	695	11
E_1	0.52	413.6	26.4	214	579	386	695	11
E_2	0.52	413.6	26.4	214	386	579	695	11
E_3	0.52	413.6	26.4	214	193	772	695	11
E_4	0.52	387.2	52.8	200	579	386	695	11
E_5	0.52	387.2	52.8	200	386	579	695	11
E_6	0.52	387.2	52.8	200	193	772	695	11
E_7	0.52	360.8	79.2	190	579	386	695	11
E_8	0.52	360.8	79.2	190	386	579	695	11
E_9	0.52	360.8	79.2	190	193	772	695	11

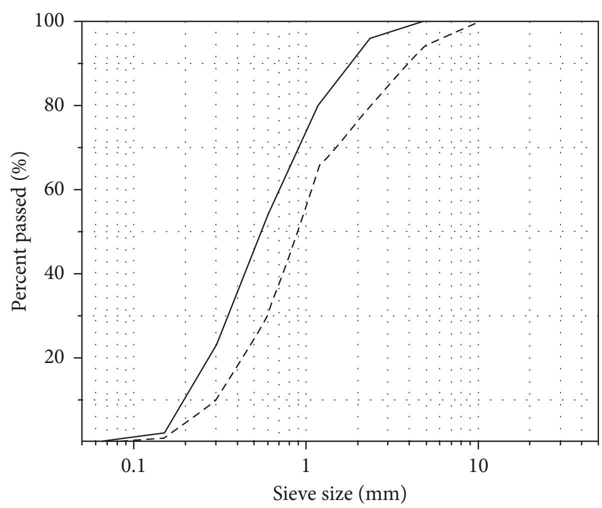


Figure 1: Gradation of aggregate fractions.

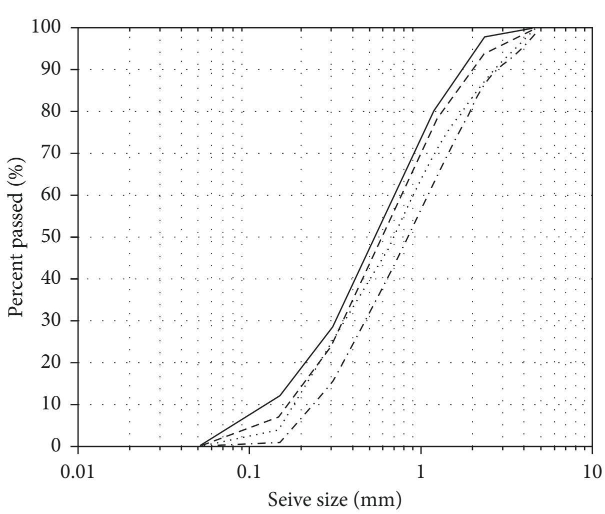


Figure 2: Aggregate gradation of mixtures.

concrete of enhanced compressive strength. The tremendous retention of water by the polymer led to the higher compressive strength of concrete [54].

6.2.2. Flexural Strength. The findings concerning flexural strength are shown in Table 9 and Figure 6. The data of flexural strength revealed that increasing the amount of both EVA and LFS enhanced the flexural strength at all substitution levels. Such a variation was also seen in case of compressive strength findings in a similar fashion.

The maximum flexural strength was 17.4% more than that of the reference mix, while substituting 12% of cement and 80% of sand by EVA and LFS, respectively, at all replacement levels, as depicted in Figures 6(a) and 6(b), whereas the minimum flexural strength was 2.7% more than that of the reference mix, while substituting 6% of cement and 40% of sand by EVA and LFS, respectively, at all the replacement levels.

According to one of the studies [55], by replacing sand up to 60% by steel-making slag, the maximum enhancement in the flexural strength is up to 9.3% which is indicating a similar trend as presented in this study. A similar increasing behavior of flexural strength was noted with the incorporation of polymers in concrete by another researcher [47]. Likewise, the flexural strength might increase up to 20% if polymers are blended in concrete at various replacement levels [45]. The flexural strength of concrete may be 3 times that of the controlled mix when polymers are incorporated in concrete [56].

6.2.3. Splitting Tensile Strength. The findings concerning splitting tensile strength are shown in Table 9 and depicted in Figure 7. The data revealed that splitting tensile strength of SCC is enhanced by increasing the dosage of LFS at the constant level of EVA content. In the meantime, it was reduced by increasing the dosage of EVA at the constant level of LFS. The maximum splitting tensile strength was 13.2% more than that of the reference mix, while substituting 6% of cement and 40% of sand by EVA and LFS, respectively, as depicted in Figures 7(a) and 7(b), whereas the minimum splitting tensile strength was 5.6% more than that of the reference mix, while substituting 18% of cement and 80% of sand by EVA and LFS, respectively.

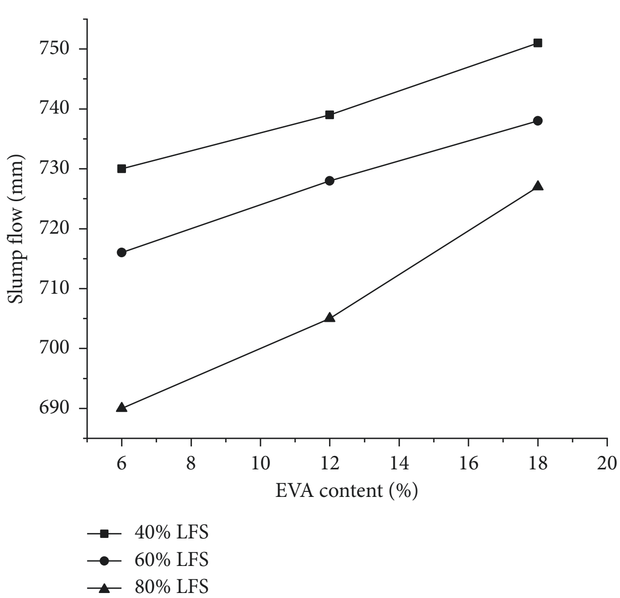
(a)

(b)

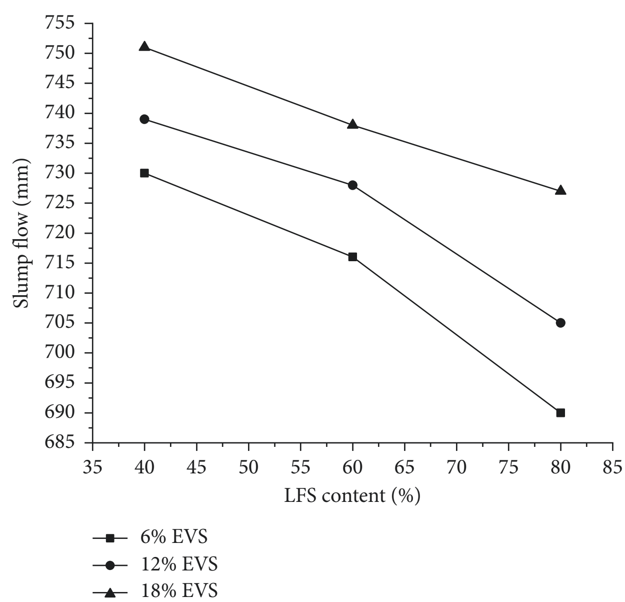
Figure 3: Laboratory testing of slump flow (a) and J-ring (b).

Table 8: Findings of SCC in its fresh state.

Mix ID	Fresh SCC characteristics					
	Slump flow (mm)	J-ring (mm)	L-box data	V-funnel (s)	Air content (%)	Relative density (kg/m^3)
E_0	741	721	1.20	8.6	3.45	2503
E_1	730	693	1.08	9.23	3.46	2513
E_2	716	679	1.04	10.13	3.47	2516
E_3	690	662	0.97	10.87	3.47	2517
E_4	739	715	1.20	9.52	3.47	2515
E_5	728	695	1.13	9.77	3.46	2513
E_6	705	673	1.03	9.86	3.46	2509
E_7	751	729	1.20	9.01	3.45	2506
E_8	738	717	1.20	9.31	3.44	2496
E_9	727	699	1.13	9.42	3.43	2489



(a)



(b)

Figure 4: Comparative analysis of slump flow at a fixed rate of (a) EVA inclusion and (b) LFS inclusion.

The decline in splitting tensile strength might be due to the fact that the particles of EVA promote hydration; consequently, the density of the cement grains decreased [54].

From another point of view, when sand is substituted by iron slag at a replacement level up to 40%, the splitting tensile strength may be enhanced [30]. Splitting tensile

Table 9: Hardened properties of SCC.

Concrete Mix	No. of samples tested	Strength (N/mm²) Compressive		Split tensile		Flexural		Elastic modulus	
		Mean	COV (%)	Mean	COV (%)	Mean	COV (%)	Mean	COV (%)
E_0	3	22.6	3.2	2.37	1.5	2.58	1.2	24012	0.9
E_1	3	23.2	2.8	2.43	1.9	2.65	1.8	24842	1.2
E_2	3	24.1	1.9	2.54	1.9	2.69	1.7	25356	0.7
E_3	3	24.5	2.7	2.60	2.3	2.71	2.3	25804	0.7
E_4	3	24.9	2.8	2.33	2.5	2.78	1.7	26112	0.8
E_5	3	25.3	1.4	2.46	1.8	2.81	1.6	26612	1.1
E_6	3	25.8	1.8	2.53	1.7	2.86	1.7	27109	0.9
E_7	3	26.6	1.3	2.14	1.7	2.89	1.4	27625	0.8
E_8	3	26.9	1.6	2.22	1.2	2.92	2.4	27980	1.1
E_9	3	27.1	2.1	2.31	1.1	2.96	1.1	28219	0.8

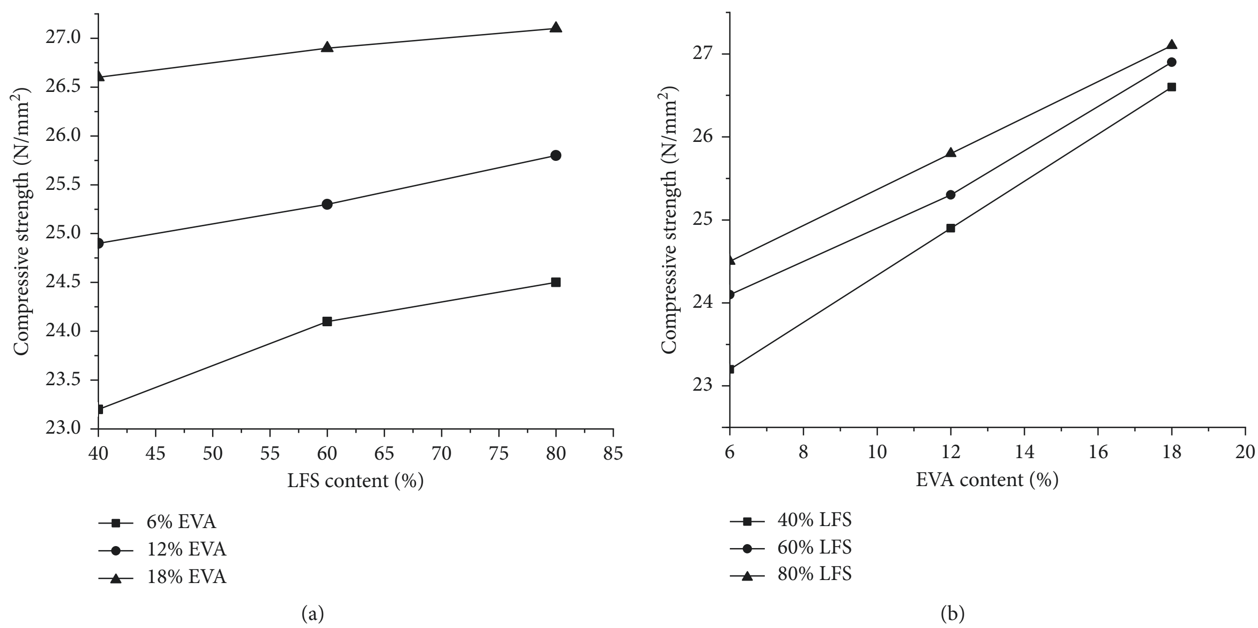


Figure 5: Comparative analysis of compressive strength at a fixed rate of (a) EVA inclusion and (b) LFS inclusion.

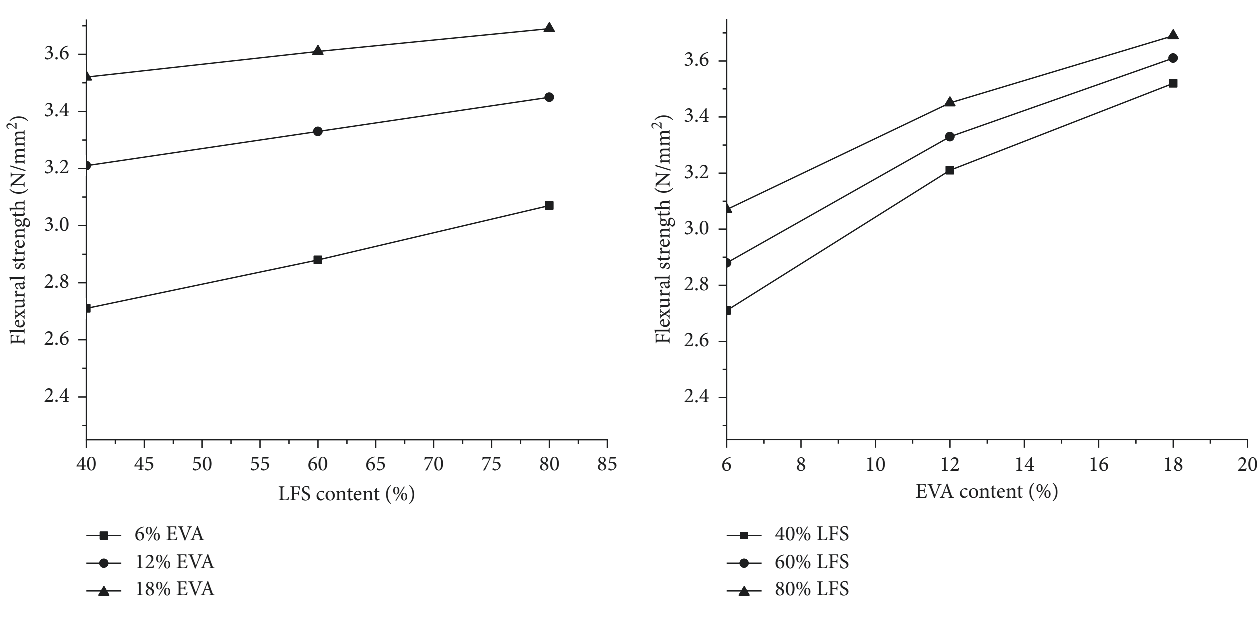


Figure 6: Comparative analysis of flexural strength at a fixed rate of (a) EVA inclusion and (b) LFS inclusion.

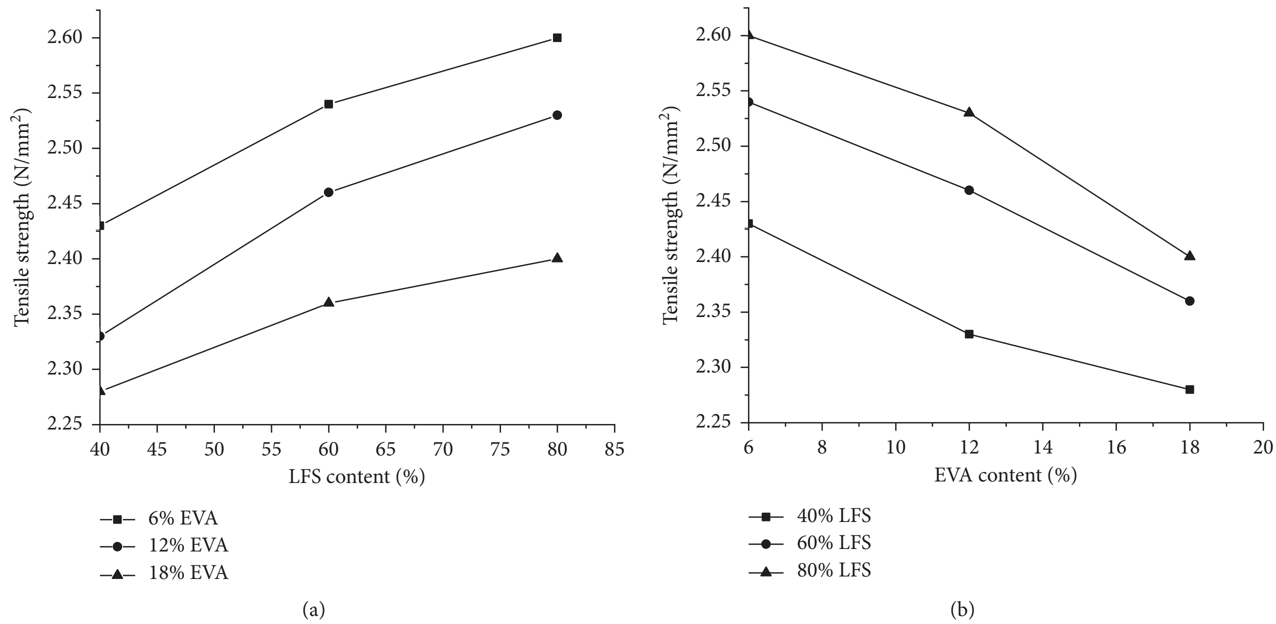


Figure 7: Comparative analysis of splitting tensile strength at a fixed rate of (a) EVA inclusion and (b) LFS inclusion.

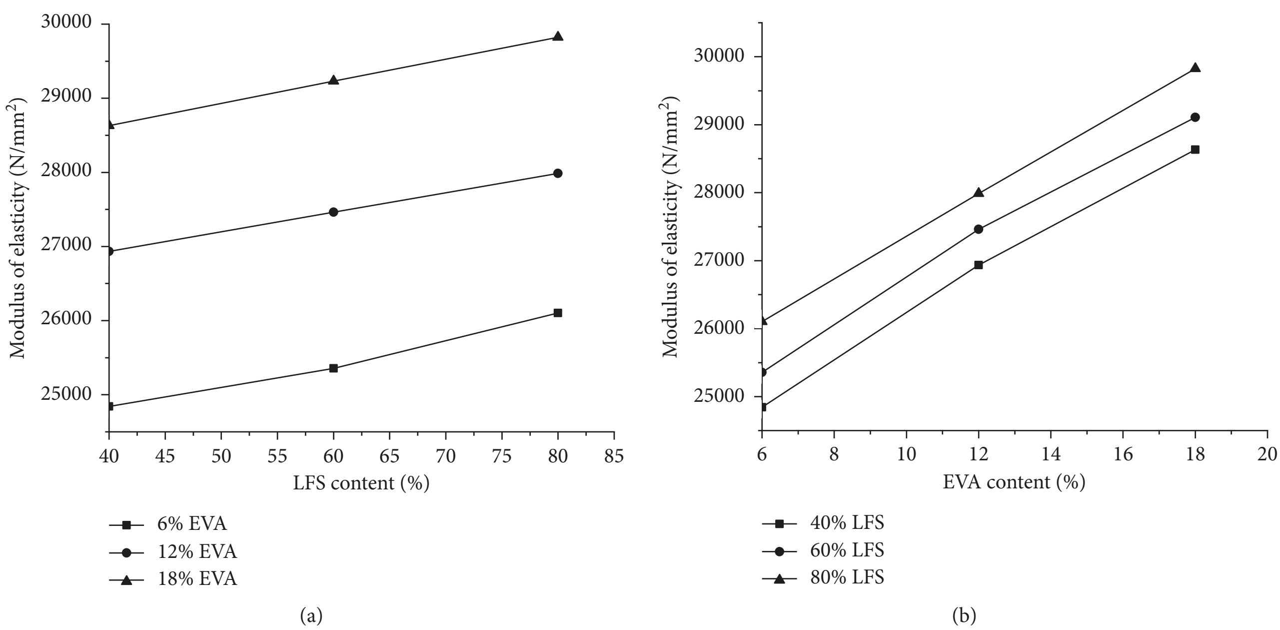


Figure 8: Comparative analysis of elastic modulus at a fixed rate of (a) EVA inclusion and (b) LFS inclusion.

strength may also increase if sand is replaced by granular blast furnace slag up to 60% [55]. Similar findings were ensued by utilizing blast furnace slag as a replacement for sand up to 30% [29].

6.2.4. Modulus of Elasticity. The findings concerning modulus of elasticity are shown in Table 9 and depicted in Figure 8. Elastic modulus is behaving in a same manner as compressive strength. The maximum rise in modulus of elasticity was up to 17.5% more than that of the reference mix, while substituting 12% of cement and 80% of sand by EVA and LFS, respectively, at all replacement levels, as depicted in Figures 8(a) and 8(b), whereas the minimum rise in modulus of elasticity was 3.5% more than that of the reference mix, while substituting 6% of cement and 40% of sand by EVA and LFS, respectively, at all the replacement levels. One of the researchers concluded that the inclusion of polymers in concrete enhanced the modulus of elasticity [48].

7. Conclusions

This study is presented to look into the combined influences of EVA and LFS on SCC by the partial substitutions with cement and sand, respectively. SCC in its fresh and hardened states was studied, and their findings are summarized as follows:

(i) The flow characteristics of SCC are improved with the inclusion of EVA itself. The improvement in workability is possibly due to the fact that EVA has enhanced the relative packing density of the particles.

(ii) By the addition of LFS, the workability characteristics are decreased. The reduction in workability is possibly due to either the rough texture of the slag or the extra water absorption of the LFS.

(iii) Furthermore, at a fixed level of EVA, the entire mechanical behavior is improved. The improvement may possibly due to either the pozzolanic processes or the variations in the stiffness of sand and LFS.

(iv) Meanwhile, at a fixed level of LFS, all the mechanical properties are improved except the splitting tensile strength which decreased. The reduction might be due to the fact that the particles of EVA promote untimely hydration on the boundaries of cement grains, which results in the decreased density of cement grains.

(v) The inclusion of EVA combined with LFS might be efficiently employed in construction concerning the manufacturing of cement that may be helpful in compensating the use of a huge quantity of cement by avoiding the utilization of natural resources. Following this, all the issues concerning the environment and landfill sites might be resolved. In constructions where moderate strength is demanded, using such concrete is more appropriate. Nevertheless, relevance of the findings by the authors encourages further investigations regarding the durability properties of SCC using EVA and LFS to clearly summarize it before its applications.

Data Availability

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

Conflicts of Interest

On behalf of all authors, the corresponding author states that there are no conflicts of interest.

References

[1] V. Subathra Devi and B. K. Gnanavel, "Properties of concrete manufactured using steel slag," *Procedia Engineering*, vol. 97, pp. 95–104, 2014.

[2] M. S. Imbabi, C. Carrigan, and S. Mckenna, "Trends and developments in green cement and concrete technology," *International Journal of Sustainable Built Environment*, vol. 1, no. 2, pp. 194–216, 2012.

[3] J. Xiao, L. Li, L. Shen, and C. S. Poon, "Compressive behaviour of recycled aggregate concrete under impact loading," *Cement and Concrete Research*, vol. 71, pp. 46–55, 2015.

[4] V. Malhotra, *SP-202: Third Canmet/ACI International Symposium: Sustainable Development of Cement and Concrete*, Vol. 202, ACI Special Publication, Los Angeles, CA, USA, 2001.

[5] P. K. Mehta, "Global concrete industry sustainability," *Concrete International*, vol. 31, no. 2, pp. 45–48, 2009.

[6] J. M. Manso, D. Hernández, M. M. Losáñez, and J. J. González, "Design and elaboration of concrete mixtures using steelmaking slags," *ACI Materials Journal*, vol. 108, no. 6, pp. 673–681, 2011.

[7] F. Faleschini, P. De Marzi, and C. Pellegrino, "Recycled concrete containing EAF slag: environmental assessment through LCA," *European Journal of Environmental and Civil Engineering*, vol. 18, no. 9, pp. 1009–1024, 2014.

[8] M. A. Zanini, "Structural reliability of bridges realized with reinforced concretes containing electric arc furnace slag aggregates," *Engineering Structures*, vol. 188, pp. 305–319, 2019.

[9] R. K. Majhi, A. N. Nayak, and B. B. Mukharjee, "Development of sustainable concrete using recycled coarse aggregate and ground granulated blast furnace slag," *Construction and Building Materials*, vol. 159, pp. 417–430, 2018.

[10] H. Motz and J. Geiseler, "Products of steel slags an opportunity to save natural resources," *Waste Management*, vol. 21, no. 3, pp. 285–293, 2001.

[11] P. J. Koros, "Dusts, scale, slags, sludges... not wastes, but sources of profits," *Metallurgical and Materials Transactions B*, vol. 34, no. 6, pp. 769–779, 2003.

[12] I. Z. Yildirim and M. Prezzi, "Chemical, mineralogical, and morphological properties of steel slag," *Advances in Civil Engineering*, vol. 2011, Article ID 463638, 13 pages, 2011.

[13] M. Frías, J. T. San-José, and I. Vegas, "Árido siderúrgico en hormigones: proceso de envejecimiento y su efecto en compuestos potencialmente expansivos," *Materiales de Construcción*, vol. 60, no. 297, pp. 33–46, 2010.

[14] J. T. San-José, I. Vegas, I. Arribas, and I. Marcos, "The performance of steel-making slag concretes in the hardened state," *Materials and Design*, vol. 60, pp. 612–619, 2014.

[15] J. M. Manso, J. A. Polanco, M. Losañez, and J. J. González, "Durability of concrete made with EAF slag as aggregate," *Cement and Concrete Composites*, vol. 28, no. 6, pp. 528–534, 2006.

[16] I. Arribas, I. Vegas, J. T. San-José, and J. M. Manso, "Durability studies on steelmaking slag concretes," *Materials and Design*, vol. 63, pp. 168–176, 2014.

[17] F. Faleschini, A. Santamaria, M. A. Zanini, J. T. San José, and C. Pellegrino, "Bond between steel reinforcement bars and electric arc furnace slag concrete," *Materials and Structures*, vol. 50, no. 3, 2017.

[18] A. Santamaria, F. Faleschini, G. Giacomello et al., "Dimensional stability of electric arc furnace slag in civil engineering applications," *Journal of Cleaner Production*, vol. 205, pp. 599–609, 2018.

[19] S.-W. Kim, Y.-J. Lee, and K.-H. Kim, "Flexural behavior of reinforced concrete beams with electric arc furnace slag aggregates," *Journal of Asian Architecture and Building Engineering*, vol. 11, no. 1, pp. 133–138, 2012.

[20] Y. J. Lee, H. G. Kim, J. H. Park, K. S. Lee, and K. H. Kim, "Flexural behaviour prediction for RC beams in consideration of compressive stress distribution of concrete with electric arc

furnace oxidising slag aggregates," *European Journal of Environmental and Civil Engineering*, pp. 1–20, 2017.

[21] C. Pellegrino, P. Cavagnis, F. Faleschini, and K. Brunelli, "Properties of concretes with black/oxidizing electric arc furnace slag aggregate," *Cement and Concrete Composites*, vol. 37, no. 1, pp. 232–240, 2013.

[22] A. Liapis, E. K. Anastasiou, M. Papachristoforou, and I. Papayianni, "Feasibility study and criteria for EAF slag utilization in concrete products," *Journal of Sustainable Metallurgy*, vol. 4, no. 1, pp. 68–76, 2018.

[23] E. Anastasiou, K. Georgiadis Filikas, and M. Stefanidou, "Utilization of fine recycled aggregates in concrete with fly ash and steel slag," *Construction and Building Materials*, vol. 50, pp. 154–161, 2014.

[24] G. I. Sezer and M. Gülderen, "Usage of steel slag in concrete as fine and/or coarse aggregate," *Indian Journal of Engineering and Materials Sciences*, vol. 22, pp. 339–344, 2015.

[25] A. John and E. John, "Study on the partial replacement of fine aggregate using induction furnace slag," *American Journal of Engineering Research*, vol. 4, pp. 1–5, 2013.

[26] M. S. Rajan, "Study on strength properties of concrete by partially replacement of sand by steel slag," *International Journal of Engineering, Science and Technology*, vol. 1, no. 6, pp. 96–99, 2014.

[27] C. Khajuria and R. Siddique, "Use of iron slag as partial replacement of sand to concrete," *International Journal of Science, Engineering and Technology Research*, vol. 3, no. 6, pp. 1877–1880, 2014.

[28] C. R. Panda, K. K. Mishra, K. C. Panda, B. D. Nayak, and B. B. Nayak, "Environmental and technical assessment of ferrochrome slag as concrete aggregate material," *Construction and Building Materials*, vol. 49, pp. 262–271, 2013.

[29] S. Saxena and A. R. Tembhurkar, "Impact of use of steel slag as coarse aggregate and wastewater on fresh and hardened properties of concrete," *Construction and Building Materials*, vol. 165, pp. 126–137, 2018.

[30] M. K. Dash, S. K. Patro, and A. K. Rath, "Sustainable use of industrial-waste as partial replacement of fine aggregate for preparation of concrete—a review," *International Journal of Sustainable Built Environment*, vol. 5, no. 2, pp. 484–516, 2016, In press.

[31] ACI Committee Report 237, *237R-07 Self-Consolidating Concrete*, American Concrete Institute, Farmington Hills, MI, USA, 2007.

[32] P. Diederich, M. Mouret, and F. Ponchon, "Simple tools for achieving self-compacting ability of concrete according to the nature of the limestone filler," *Construction and Building Materials*, vol. 48, pp. 840–852, 2013.

[33] M. Gesoğlu and E. Özbay, "Effects of mineral admixtures on fresh and hardened properties of self-compacting concretes: binary, ternary and quaternary systems," *Materials and Structures*, vol. 40, no. 9, pp. 913–926, 2007.

[34] K. A. Khan, I. Ahmad, and M. Alam, "Effect of ethylene vinyl acetate (EVA) on the setting time of cement at different temperatures as well as on the mechanical strength of concrete," *Arabian Journal for Science and Engineering*, vol. 44, no. 5, pp. 4075–4084, 2018.

[35] V. M. Malhotra and P. K. Mehta, *Pozzolanic and Cementitious Materials*, Taylor & Francis, Abingdon, UK, 1996.

[36] V. G. Papadakis and S. Tsimas, "Greek supplementary cementing materials and their incorporation in concrete," *Cement and Concrete Composites*, vol. 27, no. 2, pp. 223–230, 2005.

[37] M. Stratoura, D. R. Iaz, and E. Badogiannis, "Chloride penetration in lightweight aggregate mortars incorporating supplementary cementing materials," *Advances in Civil Engineering*, vol. 2018, Article ID 9759167, 8 pages, 2018.

[38] S. Iqbal, A. Ali, K. Holschemacher, Y. Ribakov, and T. A. Bier, "Effect of fly ash on properties of self-compacting high strength lightweight concrete," *Periodica Polytechnica Civil Engineering*, vol. 61, no. 1, pp. 81–87, 2016.

[39] H. Qasrawi, F. Shalabi, and I. Asi, "Use of low CaO unprocessed steel slag in concrete as fine aggregate," *Construction and Building Materials*, vol. 23, no. 2, pp. 1118–1125, 2009.

[40] A. Santamaría, A. Orbe, M. M. Losañez, M. Skaf, V. Ortega-Lopez, and J. J. González, "Self-compacting concrete incorporating electric arc-furnace steelmaking slag as aggregate," *Materials and Design*, vol. 115, pp. 179–193, 2017.

[41] H. E. Elyamany, A. E. M. Abd Elmoaty, and B. Mohamed, "Effect of filler types on physical, mechanical and microstructure of self compacting concrete and Flow-able concrete," *Alexandria Engineering Journal*, vol. 53, no. 2, pp. 295–307, 2014.

[42] R. Siddique, J. Khatib, and I. Kaur, "Use of recycled plastic in concrete: a review," *Waste Management*, vol. 28, no. 10, pp. 1835–1852, 2008.

[43] P. Panyakapo and M. Panyakapo, "Reuse of thermosetting plastic waste for lightweight concrete," *Waste Management*, vol. 28, no. 9, pp. 1581–1588, 2008.

[44] T. Staikos and S. Rahimifard, "Post-consumer waste management issues in the footwear industry," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 221, no. 2, pp. 363–368, 2007.

[45] Y. Ohama, "Polymer-based admixtures," *Cement and Concrete Composites*, vol. 20, no. 2-3, pp. 189–212, 1998.

[46] D. D. L. Chung, "Use of polymers for cement-based structural materials," *Journal of Materials Science*, vol. 39, no. 9, pp. 2973–2978, 2004.

[47] B. Chen, L. Guo, and W. Sun, "Fatigue performance and multiscale mechanisms of concrete toughened by polymers and waste rubber," *Advances in Materials Science and Engineering*, vol. 2014, Article ID 684207, 7 pages, 2014.

[48] X.-M. Kong, C.-C. Wu, Y.-R. Zhang, and J.-L. Li, "Polymer-modified mortar with a gradient polymer distribution: preparation, permeability, and mechanical behaviour," *Construction and Building Materials*, vol. 38, pp. 195–203, 2013.

[49] J. Schulze and O. Killermann, "Long-term performance of redispersible powders in mortars," *Cement and Concrete Research*, vol. 31, no. 3, pp. 357–362, 2001.

[50] M. Pei, W. Kim, W. Hyung, A. J. Ango, and Y. Soh, "Effects of emulsifiers on properties of poly(styrene-butyl acrylate) latex-modified mortars," *Cement and Concrete Research*, vol. 32, no. 6, pp. 837–841, 2002.

[51] G. Barluenga and F. Hernández-Olivares, "SBR latex modified mortar rheology and mechanical behaviour," *Cement and Concrete Research*, vol. 34, no. 3, pp. 527–535, 2004.

[52] M. Miller, *Polymers in Cementitious Materials*, Smithers Rapra Publishing, Shawbury, UK, 2005.

[53] R. J. Folic and V. S. Radonjanin, "Experimental research on polymer modified concrete," *ACI Materials Journal*, vol. 95, no. 4, pp. 463–469, 1998.

[54] A. G. Razaqpur, B. O. Isgor, S. Greenaway, and A. Selley, "Concrete contribution to the shear resistance of fiber reinforced polymer reinforced concrete members," *Journal of Composites for Construction*, vol. 8, no. 5, pp. 452–460, 2004.

[55] R. K. Patra and B. B. Mukharjee, "Influence of incorporation of granulated blast furnace slag as replacement of fine aggregate on properties of concrete," *Journal of Cleaner Production*, vol. 165, pp. 468–476, 2017.

[56] A. Noushini, K. Vessalas, G. Arabian, and B. Samali, "Drying shrinkage behaviour of fibre reinforced concrete incorporating polyvinyl alcohol fibres and fly ash," *Advances in Civil Engineering*, vol. 2014, Article ID 836173, 10 pages, 2014.