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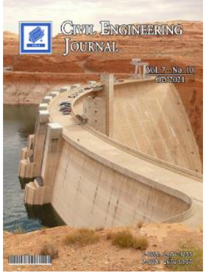

Mechanical Properties of Coarse Aggregate Electric Arc Furnace Slag in Cement Concrete

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Abstract

The feasibility of using EAF slag aggregate, fly ash, and silica fume in pavement Electric Arc Furnace Slag Concrete (CEAFS) is the focus of this research. EAF slag aggregate is volume stable and suitable for use in concrete, according to the findings of the testing. EAF slag was utilized to replace natural coarse aggregates in the CEAFS mixes. CEAFS was created by blending 50% crushed stone with 50% EAF slag in coarse aggregates, with fly ash (FA) and silica fume (SF) partially replacing cement at content levels (i.e. FA: 0, 20, 30, and 40%; SF: 0, 5, and 10%). The soil compaction approach was used to evaluate the optimal moisture level for CEAFS mixes containing EAF slag aggregate fly ash and silica fume. A testing program was used to investigate the weight of CEAFS units and their mechanical qualities (compressive strength, flexural strength, and elastic modulus). As a result, the fresh and hardened unit weights in the CEAFS are comparable. Moreover, variations in the concentration of mineral additives FA and SF in adhesives, as well as the CEAFS mixed aggregate ratio, have an impact on compressive strength, flexural strength, and elastic modulus at all ages. However, combining EAF slag aggregate with (FA0% +SF10%; FA10% +SF0%; FA10% +SF10%; and FA20% +SF10%) the CEAFS mixtures have improved mechanical characteristics over time. According to this study, CEAFS pavements can be made with EAF slag aggregate fly ash and silica fume. In addition, a formula correlation was suggested to compute CEAFS (i.e. compressive strength with elastic modulus and compressive strength with flexural strength).

Keywords: Electric Arc Furnace Slag Concrete (CEAFS); Fly Ash (FA); Silica Fume (SF); Elastic Modulus; Compressive Strength; Flexural Strength.

1. Introduction

The huge volume of natural aggregates used in building and civil engineering forces us to look for substitute materials. Furthermore, recycling aggregates in construction and building applications reduces waste disposal costs. This circular economy and industrial symbiosis concept aligns with European Union rules in the building sector that encourage sustainability and environmental evaluation [1, 2]. In a range of construction applications, recycled aggregates have lately been used as an alternative for natural aggregate [3, 4], and emphasizing the use of various types of metallurgical slags in industrial manufacturing [5-7]. The steelmaking business in Europe has changed dramatically in recent decades, with Electric Arc Furnace (EAF) steelmaking equipment largely replacing antiquated blast furnace Linz-Donawitz (LD) converters. EAF technology is used in the production of approximately 30% of European carbon and low alloy steels. EAF produces around 70% of all steel in Spain (10 million tons per year), accounting for about 15% of total EAF steel output (67 million tons per year) [8, 9]. Electric furnaces are used in steelmaking at two stages: melting-oxidizing

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procedures and secondary-reducing procedures. An Electric Arc Furnace will produce slag (EAFS) in proportions of 150–180 kg per ton of steel, while a Ladle Furnace will produce slag (LES) in proportions of 60–80 kg per ton of steel.

Several studies have been conducted to describe both EAFS [10-12], structural and reinforced concrete [13, 14], and self-compacting concrete [15, 16]. EAFS a byproduct of steel manufacturing, has been shown to be beneficial in the creation of concrete [15-17]. Due to its physical structure, it appears that the management of this waste can help to the efficient administration of the steel industry. EAFS is a repurposed material that offers a feasible alternative to natural aggregates that are rapidly depleting. EAFS has been explored as a concrete aggregate for a variety of concrete kinds. At 3, 7, and 28 days, the compressive and split-cylinder strengths were assessed. When 15% of the cement was replaced with EAF oxidizing slag, the strength development of the EAF slag concretes was slower than that of the OPC at early ages, but there was no noticeable drop in strength by 28 days [18]. When concrete is exposed to elevated temperatures, this study analyzes the behavior of employing EAFS as a partial or full coarse aggregate replacement by weight with varied percentages of 0, 15, 30, 50, and 100% [19]. The use of steel slag (SS) to replace natural aggregate (NA) in pervious concretes (PCs) was examined in this study. SS replacement levels were 25, 50, 75, and 100%. The compressive strength, splitting tensile strength, and flexural strength of the PCs were investigated, as well as the bulk density, connected porosity, and water permeability coefficient [20].

A previous study on fiber reinforced concrete made from electric arc furnace slag (CEAFS) and used in industrial pavement slabs was recently published by some of the authors of this study [21], which may be regarded directly linked to the current paper. They investigated its compositions and performance, focusing on the engineering aspects of the problem, and discovered that CEAFS reinforced with around 0.5% by volume of metallic or synthetic fibers had good mechanical properties in terms of strength, toughness, and post-cracking behavior; it also has enough abrasion resistance for use in pavements and concrete ground slabs that are subjected to abrasion. However, questions about the physical and chemical durability of these concretes were not addressed in that study, and these issues are now the subject of the current study, which investigates the presence of steelmaking slags and their effects.

In general, studies in the literature (including those of the present authors) describe CEAFS (without fibers) durability as satisfactory, but somewhat lower than conventional concrete durability, particularly in terms of carbonation and sulfate attack [22, 23], and freezing/thawing tests [24] results that are attributed to the high porosity of CEAFS and, in consequence, the higher permeability of the CEAFS. Researchers in Italy [25] tested the endurance of CEAFS in terms of freezing and thawing, wetting and drying, and accelerated aging in hot water. They came to the conclusion that it was comparable to standard concrete. However, the CEAFS resistance to chloride-ion penetration was improved, with reduced diffusion coefficients and improved durability in chloride settings. The quality of the slag is most likely the major factor causing variations in the findings of different study groups throughout the world.

In Vietnam, due to the severe environmental impact of steel slag and the fact that a large volume of excess steel slag has limited employment, e.g., only Ba Ria-Vung Tau province in Southern Vietnam receives roughly 3.75 million tons of billet yearly from steel production facilities, and annual steel slag output has nearly doubled to 412,000–562,000 tons [26]. This has piqued the concern of government officials since a vast amount of steel slag, which is rising year after year, might pose an environmental threat. Roller-compacted concrete pavement proportions of mixture (RCCP) to make RCCP, three different coarse aggregate combinations were used: 100% crushed stone (group A), 50% crushed stone plus 50% EAF slag (group B), and 100% EAF slag (group C). The weight of cement in this investigation was set at 12% of the total weight of cement and oven-dried aggregates. Fly ash (Class F) was used as a three-percentage replacement for cement in each aggregate category (i.e. 0, 20, and 40%) [27].

The study is findings are intended to provide answers to the problems raised above. This aids in a better understanding of the mechanical characteristics of CEAFS, as well as ensuring safe building progress and correct engineering design employing CEAFS. The ultimate goal of this study is to expand the applications of steel slag, which is used in such large quantities. The following are the specific objectives: CEAFS characteristics that have been documented include compressive strength, flexural strength, elastic modulus, and durability. The specimens were evaluated for compressive and flexural strengths at 3, 7, 28, and 56 days after curing, as well as Elastic modulus at 28, and 56 days. Finally, various correlations and experimental coefficients among the acquired data were offered based on the given results, which were generated from this study. The findings of this study are intended to clarify how CEAFS may be successfully generated from waste industry EAF slag waste, and assisting in the successful manufacturing of CESFS. Furthermore while also helping to environmental protection. The outcomes of this study will help to clarify how CEAFS may be effectively created from waste industrial EAF slag trash, as well as aiding in CESFS production. Additionally, while also contributing to environmental conservation.

2. Testing Program

2.1. Materials Used

Portland Cement Blended (PCB 40), Fly Ash (FA) and Silica Fume (SF)

The physical characteristics and chemical compositions of the PCB 40 used in this study, which was produced in Vietnam, following ASTM C150/C150M [28], the specific gravity of PCB 40 is 3.14. SF was provided by a local commercial company, and the chemical composition is reported in Table 1, following ASTM C1240-04 [29], the specific gravity of SF is 2.20. SF is an amorphous and highly reactive pozzolan are listed in Table 1 respectively. Cement was replaced with fly ash from Southern Vietnam. Table 1 shows the chemical composition and physical properties of PCB 40, Silica Fume, and Fly Ash. The specific gravity of FA is 2.40 because the total SAF ($SiO_2 + Al_2O_3 + Fe_2O_3$) = 91.3%> 70%. ASTM C618-05 [30] classifies fly ash as low-calcium (Class F) fly ash.

Table 1. PCB 40, FA, and SF were employed in this study because of their chemical makeup and physical qualities

Chemical composition (%)	**PCB 40**	**FA**	**SF**
Silica (SiO_2)	21.65	52.3	95.38
Alumina (Al_2O_3)	5.25	24.9	0.20
Ferric oxide (Fe_2O_3)	3.42	14.1	0.0063
Calcium oxide (CaO)	65.13	-	0.13
Magnesium oxide (MgO)	0.06	-	0.37
Sodium oxide (Na_2O)	0.10	0.67	0.28
Potassium oxide (K_2O)	0.72	-	0.007
Sulphuric anhydride (SO_3)	0.18	0.47	0.45
Loss on ignition (LOI)	2.8	0.15	0.859
Physical characteristics			
Fineness (Blaine) (m^2/kg)	380	289	16.000
Specific gravity	3.14	2.40	2.20
Initial setting time (min)	120	NA	NA
Final setting time (min)	180	NA	NA
Particle composition		-	
Retaining on 45 mm sieve (%)	NA	7.92	5.93
Compressive strength (N/mm^2)			
1 day	14.5	-	-
3 days	26.5	-	-
7 days	33.0	-	-
28 days	44.0	-	-

Note: NA means not available.

Fine Aggregate and coarse Aggregate

** Fine Aggregate*

River Sand is replaced with fine aggregate in this investigation. Tables 2 and 3, and Figures 1 and 2, detail the physical characteristics and sieve analysis, respectively, following ASTM C33 [31] and ASTM C29 [32] was used to assess the particle size distribution.

Figure 1. Testing of sand and rock aggregate

Table 2. Vietnam is Dong Nai river sand properties

Physical Properties of River Sand				
Fineness Modulus	**Water Absorption (%)**	**Specific Gravity (g/cm^3)**	**Bulk dry specific gravity (g/cm^3)**	**Moisture Content (%)**
2.51	0.45	2.64	2.63	2.5

Table 3. Fine aggregate grain size distribution

Percentage Passes of Fine Aggregates						
Sieve sizes	**4.75 mm**	**2.36 mm**	**1.18 mm**	**600 μm**	**300 μm**	**150 μm**
Percentage passing (ASTM C33 Standard)	95–100	80–100	50–85	25–60	5–30	0–10
Cumulative (%) passed	100	91.95	81.75	57.89	12.07	5.25

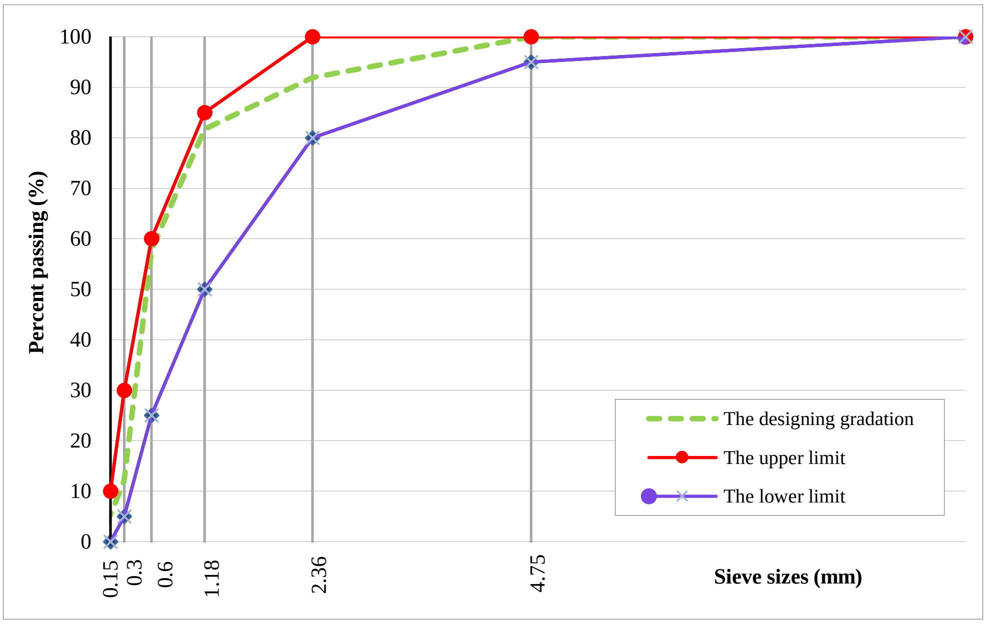


Figure 2. The size distribution of Sand particles

** Coarse Aggregate*

The coarse aggregate was a crushed stone that was collected from a local quarry and was originally made of basalt stone. The physical properties of coarse aggregate are presented in Table 4. The grain size distribution of coarse aggregate with a maximum dominant of 19 mm was presented in Table 5 and Figure 3.

Table 4. Vietnam Tan Dong Hiep is Dong Nai coarse aggregate property

D_{max} (mm)	**Water absorption (%)**	**Specific gravity (g/cm^3)**	**Bulk unit weight (g/cm^3)**	**Los Angeles abrasion value (%)**	**Moisture content (%)**
19	0.87	2.78	1.613	24.8	0.48

Table 5. Grain size distribution of coarse Aggregate

Percentage passes of coarse aggregate					
Sieve size	**25 mm**	**19 mm**	**9.5 mm**	**4.75 mm**	**2.36 mm**
Percentage passing (ASTM C33)	100	85-100	10-30	0-10	0-5
Cumulative (%) passed	100	93.5	15	8.0	0

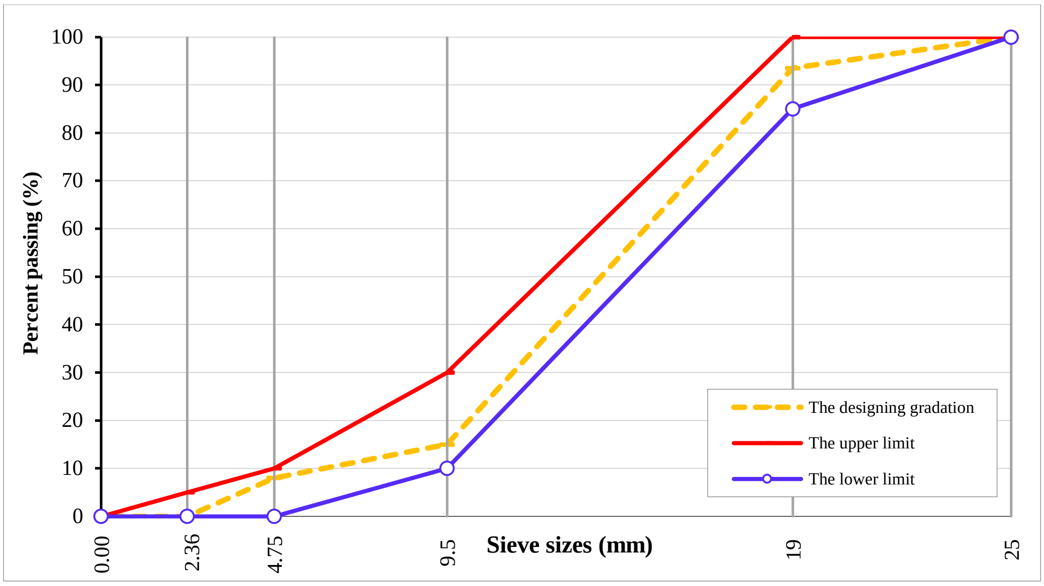


Figure 3. The size distribution of Coarse Aggregate particles

**** Coarse Steel Slag***

Green Material Co., Ltd, Phu My 1 Industrial Park, Tan Thanh District, Ba Ria-Vung Tau, Vietnam, sampling steel slag Table 6 summarizes the physical characteristics of coarse aggregate. (Table 7, and Figures 4 to 5.) depicted the coarse aggregate grain size distribution with a maximum predominance of Coarse aggregate (19, 4.75, and 4.75) mm, and (Table 8 and Figure 6.), show the chemical make-up of coarse steel slag, to limit the risk of expansion, EAF slag was aged in outdoor settings for at least 90 days and treated with water every day. Following the treatment operation, the physical and chemical properties of EAF slag aggregate were studied. The volume stability of EAF slag aggregate was determined using expansion experiments. The alkali reactivity of EAF slag aggregate was tested in accordance with ASTM D4792 [33].

Figure 4. The coarse Steel EAF slag aggregate employed in this study was tested

Table 6. The property of coarse steel slag

D_{max} (mm)	Water Absorption (%)	Specific Gravity (g/cm^3)	Bulk unit weight (g/cm^3)	Los Angeles abrasion value (%)	Expansion average (ASTM D4792) (%)
19	2.24	3.50	1.64	19.64	0.25

Table 7. Coarse aggregate EAF slag grain size dispersion

Percentage Passes of coarse Steel Slag					
Sieve size	**25 mm**	**19 mm**	**9.5 mm**	**4.75 mm**	**2.36 mm**
Percentage passing (ASTM C33)	100	85-100	10-30	0-10	0-5
Cumulative (%) passed	100	93.0	15	7.2	0.0

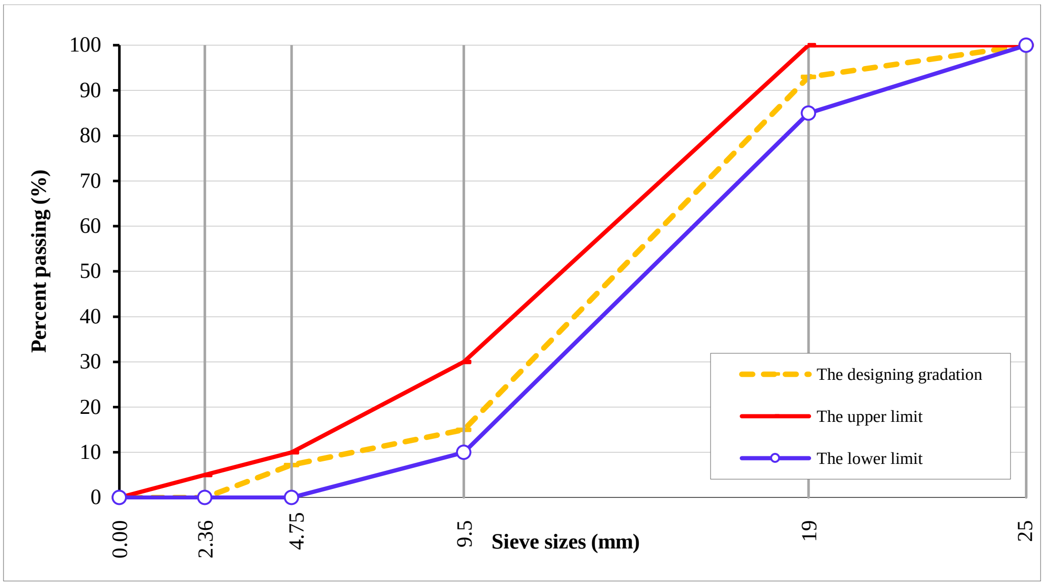
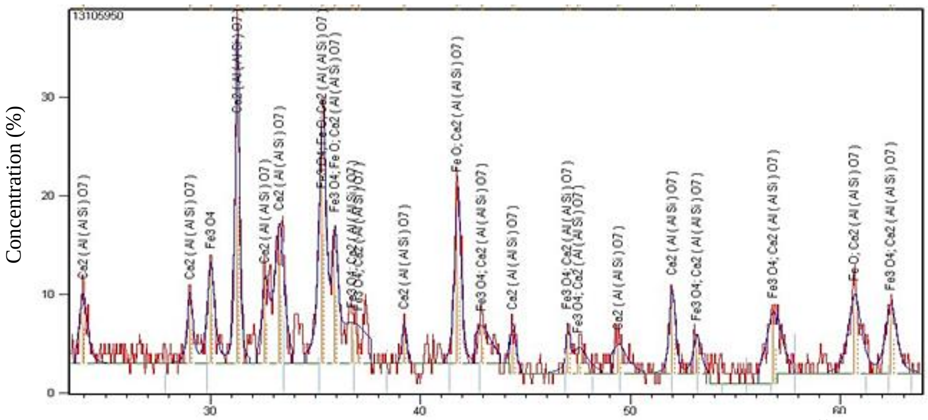


Figure 5. The size distribution of EAF slag aggregate particles

Table 8. Composition of Coarse Steel Slag's Chemical Configuration (%)

Oxide composition (wt. %)	CaO	SiO_2	Iron oxides Total	MgO	Al_2O_3	M_nO	TiO_2	Na_2O_3	K_2O	P_2O_5	Free CaO
In this study	25.49	14.60	40.36	6.62	7.25	3.70	0.40	0.30	0.10	0.40	<0.1%
Manso et al. [23]	23.90	15.3	42.50	5.10	7.40	4.50	-	-	-	-	0.45
Arribas et al. [12]	25.72	17.88	27.54	3.82	11.62	4.15	0.71	0.10	-	0.46	-
Faleschini et al. [34]	30.30	14.56	33.28	14.56	2.97	10.2	4.34	-	-	-	-
Monosi et al. [35]	26.00	14.00	35.00	5.00	12.00	6.00	0.41	0.20	0.10	-	-



EAF slag is X-ray diffractogram

Figure 6. Steel slag diffractogram

Remarks**:** The research was conducted out at the Ho Chi Minh City, Vietnam is Southern Sub-Institute of Building Materials. The slag is composition was determined using X-ray diffraction. The main chemicals discovered were periclase (magnesium oxide), quartz (silicate), lime (calcium oxide), alkalies (potassium and sodium), dolomite ($CaCO_3.MgCO_3$), and calcite ($CaCO_3$), as evidenced by the diffractogram in (Figure 6). An X-ray fluorescence spectrometer was used to evaluate the chemical composition of the slag in Table 8, and According to Ministry of Construction, Ha Noi, Viet Nam Decision No: 430/Q-BXD "Guideline on iron and steel slag for use as building materials" [36], Table 7-8 indicates its apparent (bulk) density and volumetric instability. As you can see, the slag did not expand.

**** Water***

In line with TCVN 4506:2012 [37], the water used to manufacture cement concrete does not include grease or other organic contaminants.

**** Superperplasticzer***

Sika Viscocrete 3000-20 shines because to its exceptionally high water reduction capacity, which allows for good fluidity while retaining the mixture is optimal adhesion. According to TCVN 8826:2011 [38] this admixture complies with the established criteria for chemical additions for concrete. Sika Viscocrete 3000-20, a 3rd generation polymer-based high-tech superplasticizer with excellent porosity and simple pumpability of concrete, was utilized in the experiment.

3. Mix Proportions and Sample Preparation

In principle, ensuring that the essential parameters, such as concrete strength, mix flexibility, and material, are satisfied while producing CEAFS components utilizing EAF slag is critical.

3.1. Design Standards and Techniques

To develop the CEAFS component, the researchers employed the ACI 211.1-97 [39] technique. The ACI method: The component-designing steps of CEAFS using EAF slag were completed in accordance with the manufacturer's instructions. To get the required slump, the concrete mixture is slump was adjusted.

3.2. Mix Proportions

The ACI specification was used to calculate and design the concrete composition with a specific strength of 30 MPa (C30); SF+FA was used in concrete to improve the strength and reduce the cement content. CEAFS was made by combining 50% crushed stone with 50% EAF slag in coarse aggregates. The original binder was made of 100% cement. Cement content is replaced by FA+SF, including 0, 10, 20, 30, and 40%, of the total quantity of the binder, FA for the control mix, referring to previous studies. Then, SF was utilized in various ratios in the gradation components, including 0, 5, and 10%, of the total quantity of the binder, SF for the control mixthe water to binder ratio was fixed at 0.44. Table 9 shows the mix proportions of six different mixes. The superplasticizer (SP) was gradually added to keep the slump value of the mixtures at 4±1 cm.

Table 9. Mix proportions and quantities for CEAFS

Mix code		In this study		C	S	FA	SF	CA+EAFS	SP	W/B
		FA (%)	SF (%)	(kg)	(kg)	(kg)	(kg)	(%)	(kg)	
C30	FA0-SF0	-	-	420	959	-	-	1046	5.04	0.44
	FA10-SF0	10	-	378	948	42	-	1046	5.46	
	FA20-SF0	20	-	336	938	84	-	1046	5.88	
	FA30-SF0	30	-	294	928	126	-	1046	6.51	
	FA40-SF0	40	-	252	917	168	-	1046	6.72	
	FA0-SF5	-	5	399	951	-	21	1046	4.62	
	FA0-SF10	-	10	378	945	-	42	1046	5.25	
	FA10-SF5	10	5	357	941	42	21	1046	6.09	
	FA20-SF5	20	5	315	931	84	21	1046	6.30	
	FA30-SF5	30	5	273	920	126	21	1046	6.72	
	FA40-SF5	40	5	231	910	168	21	1046	6.93	
	FA10-SF10	10	10	336	934	42	42	1046	6.22	
	FA20-SF10	20	10	294	924	84	42	1046	6.51	
	FA30-SF10	30	10	252	913	126	42	1046	7.14	
	FA40-SF10	40	10	210	903	168	42	1046	7.77	

Note: C-Cement; S-Sand; FA- Fly Ash; SF-Silica Fume; CA+EAFS-Coarse aggregates+Electric Arc Furnace slag; SP-Superplasticizer; W/B-Water/Binder (Cement+SF+FA).

3.3. Specimen Preparation and Testing Procedures

SF has a high surface area and Microsilica particle size, and is difficult to disperse in concrete mixes. The following steps are experimental mixing procedures for making homogeneous, stable concrete, as presented in Figures 7 to 8. There are seven steps to mixing the sample, including:

Figure 7. Material testing samples

Step 1: SF was mixed with 50% water and aggressively agitated to ensure that the SF particles were equally distributed for two minutes;

Step 2: For three minutes, a mixture of sand, coarse aggregates, EAF slag, cement, and FA was mixed;

Step 3: To the sand, EAF slag, Coarse aggregates, and cement mixture, a total of 25% water was added and well mixed for one minute;

Step 4: The SF and 50% water combination from step 1 was added to the Step 3 mixture and stirred for two minutes;

Step 5: Add the remaining 25% water to the solution and mix well for one minutes;

Step 6: The mixer was turned off for two minutes to allow the superplastic component to react, which improved the outcome;

Step 7: The mixture was continually agitated for another 3 minutes to avoid slumps and guarantee homogeneity.

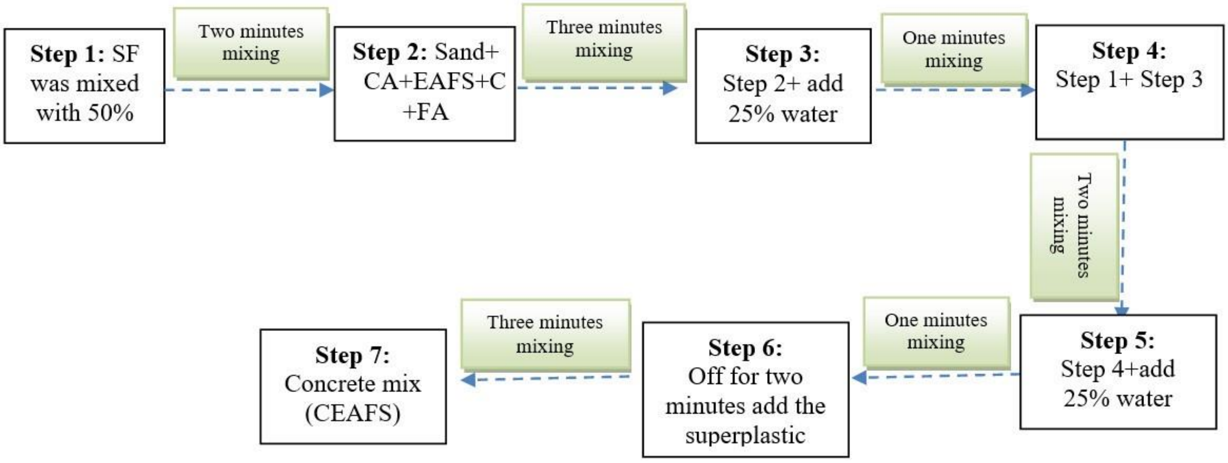


Figure 8. Flowchart depicting the seven stages involved in mixing the sample

***Remarks*:** Testing for hardening properties of CEAFS. The mixture was mixed in a 60-liter mixer. A compressive strength test on a cylindrical specimen with dimensions of 150×300 mm (d × h), a bending test on a beam of 150 mm 150 mm 600 mm, and Elastic modulus imensions of 150×300 mm (d × h) are among the available test specimens. Before sampling, the interior surface of the mold should be smooth, clean, and lubricated. A vibrator with a frequency of 2800-3000 rpm and an amplitude of 0.35÷0.5 mm compressed the samples. Then, they were cured in a room at (25 ± 2) ^{0}C for a minimum of 24h. Finally, the molds were removed and soaked in water. The compressive and flexural strengths were tested at 3, 7, 28, and 56 days. The elastic modulus was conducted at 28 and 56 days. All the tests were conducted in triplicate with specimens.

3.4. Compressive and Flexural Strength Tests

Experiments were conducted at the LAS – XD 498 Construction Testing Laboratory of the Union of Geosciences – Foundation Testing – Construction – Saigon, Vietnam. Compressive strength and flexural tensile strength tests are performed according to ASTM C39 [40], ASTM C78 [41], and elastic modulus ASTM C469 [42] respectively, after molding and curing. The load incensement speed is 0.3 MPa/s, and the testing instrument is a San 3000 electronic compressor with a maximum load of 3000 kN, as shown in Figure 9.

Figure 9. Compressive and flexural strength tests

4. Results and Discussion

4.1. The Properties of the EAF Slag

As demonstrated in Tables 6 to 7, the physical characteristics of EAF slag aggregate qualify it for use as a substitute for crushed stone aggregate. Table 8 summarizes the chemical makeup of aged EAF slag. The amount of free CaO in the sample (0.1%) was determined to be insufficient to cause cracking or instability. According to Luxán et al. [43], EAF black basic slag is a product of cold loading scrap that contains less than 40% calcium oxide (CaO). The CaO content of the EAF slag employed in this investigation is 25.49 percent. As a result, it is possible to identify EAF black basic slag. Table 8 summarizes the oxide compositions of EAF slag as reported by several studies [12, 23, 35]. EAF black basic slag has a very high density, water absorption, and porosity Mombelli et al. [44], if the MgO and Al_2O_3 concentrations are in the range of 5–7% and 7–10% by weight, respectively. In addition, the CaO concentration should not exceed 30% by weight. According to chemical composition data, EAF slag from the province of Ba Ria - Vung Tau in Vietnam possesses stable and nonleachable properties, making it suitable for recycling.

4.2. Mechanical Properties CEAFS

The compressive strength, flexural strength, and elastic modulus of CEAFS mixes were tested at various ages, as indicated in Table 12. With the proportion combinations FA and SF utilized, CEAFS durability met the objective level C30 at 3, 7, 28, and 56 days, in compared to FA0+SF0. The FA0+SF10 mixture has the greatest values in all ages (Figures 10 to 12.). This might be due to a variety of factors. To begin with, the water-cement ratio in the FA+SF combination is lower than in the FA0+SF0 mixes. Furthermore, Adegoloye et al. [45] discovered that the breadth of the Interfacial Transition Zone is greater in high water-cement ratio concretes than in low water-cement ratio concretes. Finally, Palankar et al. [46] found that a lack of binding strength between the cement paste and aggregates could be the cause of the concrete's loss of strength when employing EAF slag aggregate. This problem was created by the formation of a calcite layer during the weathering treatment of EAF slag aggregate. When CAFS does not use FA and SF additions, the strength suffers as a result of all of these factors.

Table 12. Results of CEAFS experiments on compressive strength, flexural strength, and elastic modulus

Mix code	In this study		Compressive strength (MPa)				Flexural strength (MPa)				Elastic modulus (MPa)	
	FA (%)	SF (%)	3 days	7 days	28 days	56 days	3 days	7 days	28 days	56 days	28 days	56 days
FA0-SF0	0	0	8.26	27.22	35.39	37.59	1.24	4.08	5.30	5.64	33300	34500
FA10-SF0	10	0	9.24	29.22	38.28	41.58	1.37	4.38	5.74	6.24	33500	35500
FA20-SF0	20	0	8.64	24.24	34.38	39.54	1.30	3.64	5.16	5.93	32100	34200
FA30-SF0	30	0	7.92	24.30	31.68	35.70	1.19	3.65	4.85	5.36	32000	32800
FA40-SF0	40	0	7.62	21.54	31.38	34.92	1.14	3.23	4.71	5.24	31500	32200
FA0-SF5	0	5	9.90	33.36	42.24	45.18	1.49	5.00	6.34	6.78	34800	36400
FA0-SF10	0	10	10.38	35.88	45.48	47.40	1.56	5.38	6.82	7.11	37100	38400
FA10-SF5	10	5	9.12	29.82	35.04	38.46	1.37	4.47	5.26	5.77	32800	33800
FA20-SF5	20	5	8.16	19.86	34.32	37.08	1.22	2.98	5.15	5.56	32000	33500
FA30-SF5	30	5	7.98	16.08	32.94	36.36	1.20	2.41	4.94	5.45	32800	33500
FA40-SF5	40	5	6.48	15.48	32.10	35.70	0.97	2.32	4.82	5.36	31900	32900
FA10-SF10	10	10	9.42	25.26	37.26	42.90	1.41	3.79	5.79	6.44	33400	36100
FA20-SF10	20	10	8.82	23.88	36.42	40.32	1.32	3.58	5.46	6.05	32900	34100
FA30-SF10	30	10	8.04	18.48	33.60	36.54	1.20	2.77	5.04	5.48	32000	33100
FA40-SF10	40	10	7.08	18.42	31.50	33.30	1.06	2.63	4.85	5.00	32100	32900

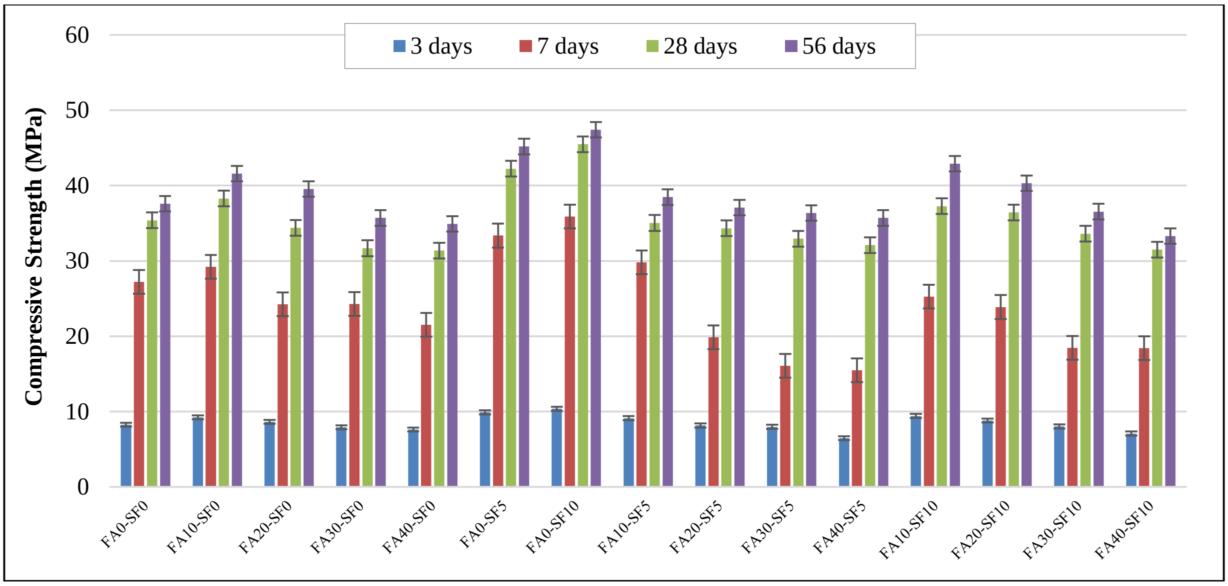


Figure 10. Compressive strength of CEAFS with FA+SF

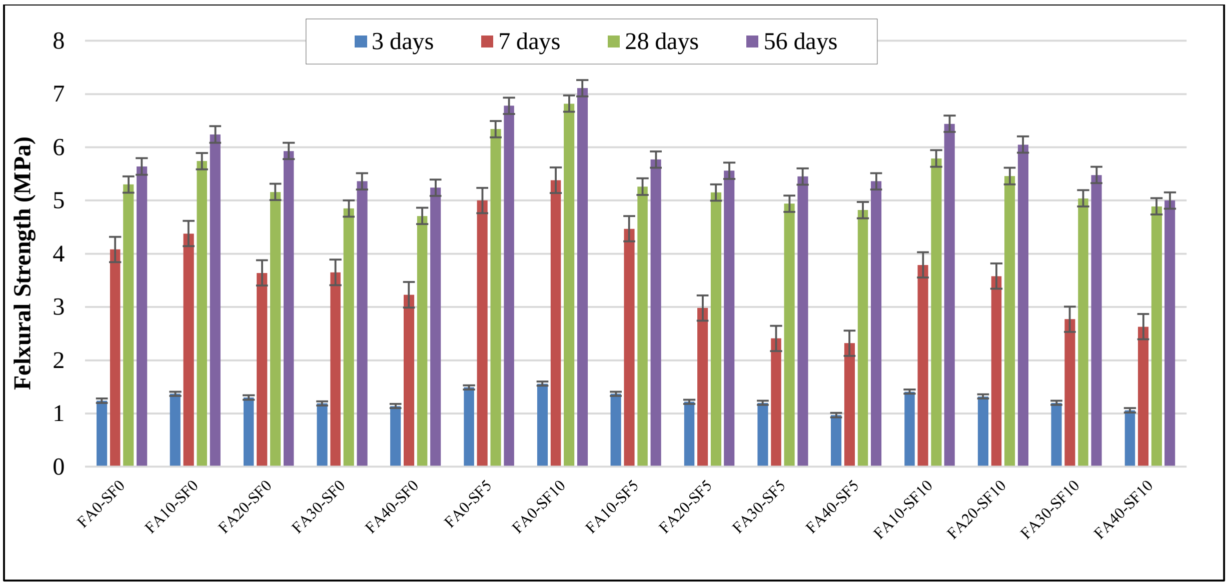


Figure 11. Flexural strength of CEAFS with FA+SF

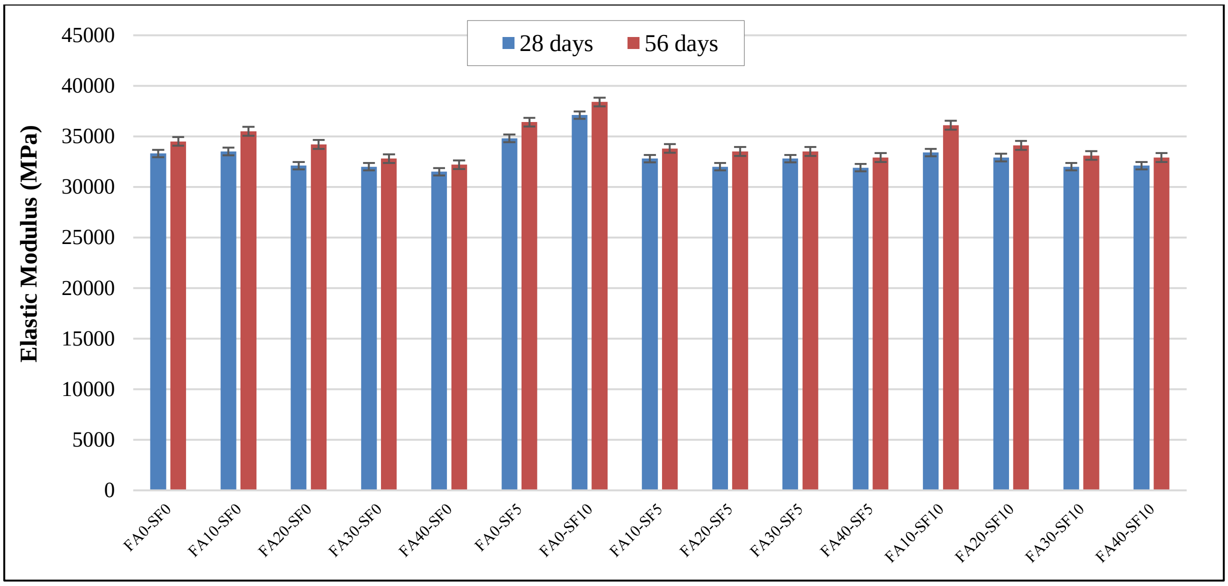


Figure 12. Elastic modulus of CEAFS with FA+SF

Remarks**:** These findings are consistent with earlier research on concrete [47, 48, 49]. However, the pozzolanic interaction of Fly Ash and Silica Fume increased the long-term strength. EAF slag aggregate, it may be claimed, holds water and inhibits the development of strength at an early age. At 28 days, and 56 days, as follows:

- The compressive strength in FA0+SF10 of CEAFS mixes was 45.48 and 47.40 MPa; in FA10+SF0 of CEAFS mixes was 38.28 and 41.58 MPa; in FA10+SF10 of CEAFS mixes was 37.26 and 42.90 MPa; and in FA20+SF10 of CEAFS mixes was 36.42 and 40.32 MPa.
- The Flexural strength in FA0+SF10 of CEAFS mixes was 6.82 and 7.11 MPa; in FA10+SF0 of CEAFS mixes was 5.74 and 6.24 MPa; and in FA10+SF10 of CEAFS mixes was 5.79 and 6.44 MPa; and in FA20+SF10 of CEAFS mixes was 5.46 and 6.05 MPa.
- The Elastic modulus in FA0+SF10 of CEAFS mixes was 37100 and 38400 MPa; in FA10+SF0 of CEAFS mixes was 33500 and 35500 MPa; and in FA10+SF10 of CEAFS mixes was 33400 and 36100 MPa; and in FA20+SF10 of CEAFS mixes was 32900 and 34100 MPa.
- These mixes might be used to build sub-bases.

4.3. Formulation of Strength using Analytic Methods

ACI "Committee, A.C.I., Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures" previously constructed a predicted-strength model using Ordinary Portland Cement. As shown in Equation 1, the anticipated model used compressive strength as a variable to determine the elastic modulus of concrete.

$$E = 4730(f_c')^{0.5} \tag{1}$$

Where: E: is elastic modulus (MPa); f_c': is compressive strength (MPa).

Based on the experimental results, Equation 1, which was generated using the Gauss–Newton technique using an exponential function and an independent variable, can be used to compute the correlation between elastic modulus and compressive strength of concrete containing FA and with or without SF. The expected elastic modulus based on compressive strength at 28 days is shown in Figure 13. Finally, the projected equations for CEAFS with FA and SF are provided in Equations 2 as follows:

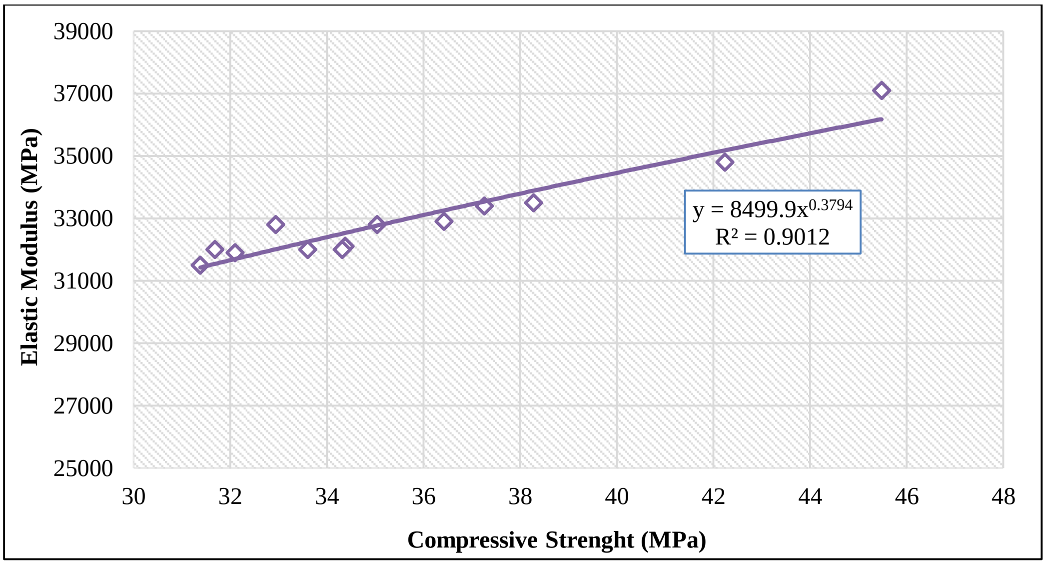


Figure 13. Elastic modulus in relation to compreesive strength of CEAFS with FA+SF

$$E = 8499.9(f_c')^{0.3794} \qquad R^2 = 0.9012 \tag{2}$$

Where: E: is elastic modulus of CEAFS (MPa); f_c': is compressive strength of CEAFS (MPa).

In addition, Technical report [50] demonstrated the relationship between flexural and compressive strength of Portland cement concrete in general f_r Equation 3;

$$f_r = 0.393(f_c')^{0.66} \tag{3}$$

Where: f_r: is flexural strength (MPa); f_r': is compressive strength (MPa).

The data from this study were used to propose a link between flexural strength and compressive strength at 28 days, similar to elastic modulus. As demonstrated in Figure 14, the Technical Repot algorithm was used to describe flexural strength based on compressive strength. Finally, Equations 4 relate CEAFS to FA and SF in the following way:

$$f_r = 0.1659(f_c')^{0.9737} \qquad R^2 = 0.9865 \tag{4}$$

Where: f_r: is flexural strength CEAFS (MPa); f_r': is compressive strength CEAFS (MPa).

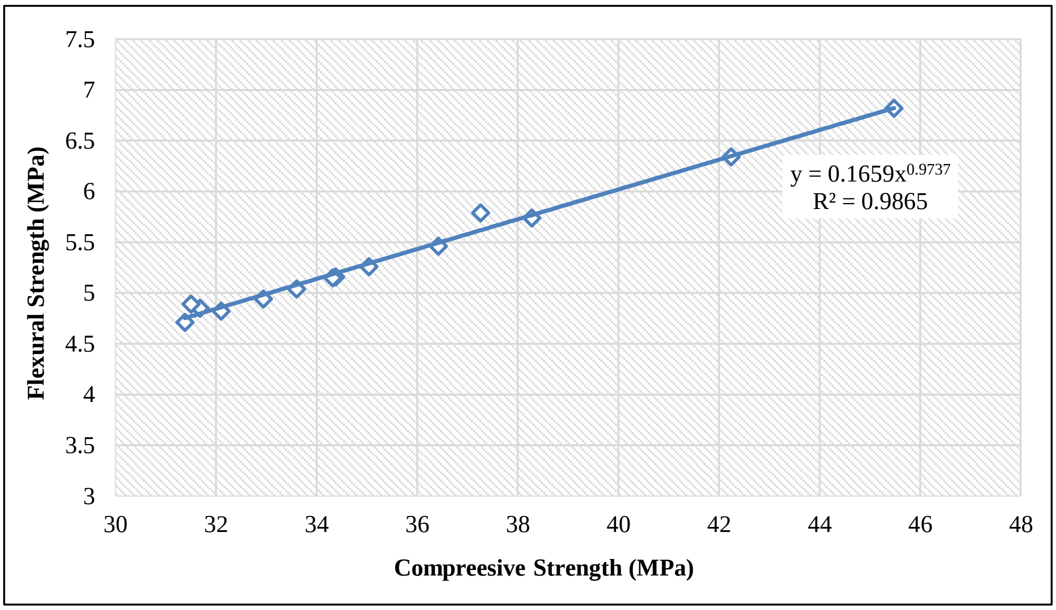


Figure 14. Flexural strength to compressive strength of CEAFS with FA+SF

5. Conclusions

Some potentially essential elements of the engineering qualities have been concluded based on a thorough testing program of CEAFS using Portland cement replacement with FA and SF:

- Based on the physical and chemical features of EAF slag in Ba Ria-Vung Tau Province, Vietnam, EAF slag aggregate is eligible to replace natural aggregates. The volume stability of the EAF slag aggregate was demonstrated by the expansion values obtained following the treatment process. As a result, the EAF slag employed in this research might be used in CEAFS.
- When EAF slag was used to replace crushed stone aggregate, there was a minor reduction in compressive strength, flexural strength, and elastic modulus. This is because rough-textured EAF slag improves only little in low Water/Binder (Cement+FA+SF) ratio concretes, resulting in a poor interfacial transition zone between the EAF slag aggregate and the cementitious matrix. In CEAFS, however, EAF slag can be used to replace 50% of crushed stone in coarse aggregates with 50% EAF slag, resulting in pavements that meet all construction engineering standards.
- Furthermore, when cement was partially substituted with fly ash, the strength of the concrete was reduced. Nonetheless, CEAFS, which contains EAF slag aggregate fly ash, and silica fume, provides good concrete that may be utilized for pavements. As a result, the mixture of EAF slag aggregate and (FA0%+SF10%, FA10%+SF0%, FA10%+SF10%, and FA20%+SF10%) is the best for recycling a huge amount of waste materials.
- The Gauss–Newton approach was used to find some best-fit equations for defining the elastic modulus and flexural strength of CEAFS using FA and SF, as follows:

  Elastic modulus in relation to compreesive strength:

  $$E = 8499.9(f_c')^{0.3794} \qquad R^2 = 0.9012$$

  Flexural strength to compreesive strength:

  $$f_r = 0.1659(f_c')^{0.9737} \qquad R^2 = 0.9865$$

6. Declarations

6.1. Data Availability Statement

The data presented in this study are available in article.

6.2. Funding

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6.3. Acknowledgements

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6.4. Conflicts of Interest

The author declare no conflict of interest.

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