Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 1, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Comparative Evaluation of the Pozzolanic Activity of Artificial Pozzolans: Steel Slag, Fly Ash, and GGBFS

Sravan Chilukuri[1,*], Sanjeet Kumar[2], Ashwin Raut[3]

Abstract

Evaluating the pozzolanic activity of specific industrial waste is crucial given the growing demand for cementitious materials. This research aims to expand the possibilities of incorporating pozzolanic waste such as Steel Slag (SS) as additives to cement. SS is a byproduct of the steel production process. A byproduct of the steelmaking process, slags have long been used as aggregates in building materials like concrete and roads. A closed-loop structure and circular economy might be established within the metallurgical sectors through improved slag utilization, which could promote growth in the economy and sustainability for future generations. Evaluation of cement substitutes' pozzolanic activity is becoming more critical in light of the growing need for environmentally friendly cementitious products. The pozzolanic activity of SS was evaluated using three different methods: Frattini tests, strength activity index, and saturated lime. The results of the Frattini test and the strength of activity index test showed a significant association. However, there was no relationship found between these outcomes and the saturated lime test. The BET surface area analyzer, zeta analyzer, and Standard Le Chatelier flask were used in a number of analyses to characterize SS. The chemical composition of SS was evaluated using X-ray fluorescence (XRF), and mineralogical analysis was conducted using X-ray diffraction (XRD). A solubility curve was employed in the Frattini test to display the concentrations of hydroxyl (OH–) and calcium (Ca+2) ions. The Strength Activity Index (SAI) was determined by compressive strength tests using 10%, 20%, and 30% of the mortar cubes' weight as stainless steel (SS) in lieu of some of the cement. Seventy-eight days after SS mortar was let to cure, the SAI was measured and the results were compared. The ratios for the Frattini and Strength Activity Index tests are 1:1 and 0.15:1, respectively, for the saturated lime test. The saturation lime test removes more Ca (OH)2 than other methods, hence the results do not match those from other procedures.

Keywords: Steel Slag, Frattini, strength activity, saturated lime

INTRODUCTION

Pozzolan is any siliceous or siliceous aluminous substance. Natural cementing properties are low. Cementing requires moisture and normal temperature reactivity with calcium hydroxide to form a product with cementing properties. Now a days concrete as well as cement industries use these pozzolanic material for utilization I their products to reduce the number of raw materials that area induced in the production [1]. Many researches have stated that industrial and agriculture pozzolans are most suitable and best choices as binder in the sustainable development.

Furthermore fuel of Palm oil as (POFA) [2] Rice husk ash (RHA), coconut shell ash are more widely used agriculture end products all over the world. In industrial waste products research has been widely sticked with Glass powder, different types of slags,

***Author for Correspondence**
Sravan Chilukuri

[1]Research Scholar, Department of Civil Engineering, Koneru Lakshmiah Education Foundation, Andhra Pradesh, India
[2,3]Associate Professor, Department of Civil Engineering, Koneru Lakshmiah Education Foundation, Andhra Pradesh India

Received Date: July 19, 2024
Accepted Date: September 09, 2024
Published Date: October 10, 2024

Citation: Sravan Chilukuri, Sanjeet Kumar, Ashwin Raut. Comparative Evaluation of the Pozzolanic Activity of Artificial Pozzolans: Steel Slag, Fly Ash, and GGBFS. Journal of Polymer & Composites. 2025; 13(Special Issue 1): S341–S361p.

tailings, wood, plastic are most common. Due to the reactive silica and pozzolan's availability, this area of research has remained unbroken. Stocking this waste stuff caused considerable environmental issues. This made researches to work on industrial and agricultural waste material to find out the potential usage of waste materials which are naturally non bio degradable in the environment [3]. The key encounters in the building business are less availability of aggregates, economically high in prices, and excessive CO_2 emissions in the environment [4]. Research has been done on industrial wastes such as wood, plastic [5, 6], glass, and agriculture wastes such as RHA, POFA, Strawbales etc.

Recently, The research on waste end products from industries and agriculture has been widely spread [7]. The usage of agriculture and industrial waste end products produced during the manufacture process focused on reducing the wastes. Researches today are striving to develop new alternative binders.

Steel slag is known as one of the end goods from the steel making industry. The weight of the discharge can be approximately 15–20% of the total weight. At present the discharge is enormous in major steel producing countries like China, India but the rate of utilization is very nominal. The biggest problem with steel slag according to many researches is its stock piling, it consumes large space as well as pollutes the environment. Steel slag contains some amounts of cementitious properties some of them are C_2S, C_3S, C_2F, C_4AF [8]. Steel slag has the potential to partially replace cement, according to some studies. But when it comes to comparison with cement its activity is lesser than that of cement [9, 10]. Steel slag displays a different variation in chemical and mineralogical composition [11]. To address economic, environmental, and technological concerns, some studies have suggested using steel slag as a cement component, taking into account factors such cement-like characteristics. The results of numerous studies on steel slag have shown that it is a viable alternative material [9–15]. Iron and steel companies manufacture four types of slag: EAFS, BOFS, BFS, and LFS. Figure 1 indicates that slag type depends on the steel manufacturing process's destination (World Steel Association, 2010; Seetharaman, 2013).

Blast Furnace Slag (BFS) is formed in the first phase of the steel-making process when liquid iron is synthesized in a blast furnace that runs at extremely high temperatures—roughly 1600°C. It is a method for making iron from iron ore or iron oxides that makes use of coke as a limestone and fuel as a mixing agent. One method involves allowing BFS to cool naturally in the open air, which results in air-cooled slag; another involves rapidly cooling it outdoors with a large amount of water and high pressure, which results in water-quenched slag. Choosing either air cooling and quenching with water determines the exact physicochemical features of the final BFS. As a byproduct of the basic-oxygen furnace, which transforms molten iron into steel, steel-furnace slag (BOFS) is an integral part of the steelmaking process. Melted iron and scrap steel react chemically in a highly oxygenated steel-making vessel to produce the final product (Deo et al., 2013). To make slag and eliminate impurities, lime and dolomite have been added. After the reaction is finished, the slag is thrown onto regions where water sprays can cool it down (Seetharaman, 2013). The steel is then removed from the slag. Pouring the slag is an important processing step; to enable its utilization, extra processing is often used, like crushing the slag to form aggregates. High-power electric arcs are used in place of gaseous fuels in the Electric Arc Furnace (EAF) steel-making process (Yildirim and Prezzi, 2011). Within the EAF, where an electric arc serves as the primary energy source for melting the steel and fluxes, EAFS is produced. In addition, carbon and oxygen are injected into the furnace at designated cold locations to add chemical energy. Alloy iron is mixed into the steel during the melting process to give it the correct chemical makeup.

After further flux ingredients, such as metal alloys and lime, are added to the ladle incinerator to purge the steel of any remaining impurities, the result is known as Ladle Furnace Slag (LFS) (Ilyushechkin et al., 2012, Yang et al., 2018;). The process of purification involves the ladle furnace, which is used to remove hydrogen, nitrogen, and oxygen from steel. For ultra-low carbon steel purification, it performs the final desulphurization and decarbonization (Yildirim and Prezzi, 2011). Following these processes of purification, the steel is relocated from the furnace ladle to the caster, where it is eventually solidified into slabs, billets, and other building-related products (Yang et al., 2018). Figure 1 and Figure 2 shows the flow mechanism and slags formed at different places.

Steel scrap, occasionally paired with pig iron or straight reduced iron, is the main ingredient in EAF steel. Initial impurities such as phosphorus, sulfur, and aluminium are removed from the steel by adding flux elements including oxygen, lime, and iron alloy. According to Yang et al. (2018), the EAF is the first step in refining scrap steel by turning it into molten steel. Melted steel and EAFS are the end products of this procedure. According to Yang et al. (2018), the EAFS is thrown away and the melted steel is moved to the furnace ladle for further refinement.

One study [15] found that coarse aggerate steel slag improves asphalt concrete mixture mechanical strength. Steel slag conducts electricity better than lime stone [10] tested performance and fired cement clinker with slag. Steel slag improves concrete compressive and tensile strength, according to [14]. Numerous studies have shown that using steel slag in construction would reduce environmental impact and erase the impact of steelmaking. The steel slag is nevertheless connected to a few significant issues. First, its thermal history reduces cementitious activity compared to Portland cement [16]. Second, more f-CaO and f-MgO causes steel slag cement volume change to be unacceptable [17]. We use grinded steel slag to fix these difficulties. The factory outlet one is coarser. To develop blocks, steel slag is ground and sieved at 150 µ. This study pulverizes factory outlet steel slag using a laboratory pulverizer, which is inexpensive and readily available. Pulverized steel slag's pozzolanic activity is examined using various sizes of particles and weight replacement ratios.

Slag with little to no hydration activity is commonly referred to as basic oxygen furnace slag or steel slag. The chemical composition of C2S (di-calcium silicate), C2S (tri-calcium silicate), C4AF (tetra calcium alumino ferrite), and C2F (di-calcium ferrite) in the hydration phase is nearly equal to that of cement. These C3S and C2S exhibit poor activity since there was little cooling during processing. These inactive phases, which grow closer to the active sones and hinder the cementitious material throughout the hydration process, include FeOx and the solid RO phases, which were more than 25%. to enhance steel slag's hydration process. According to in his research has proved the finer the steels lag in the mixture the higher the activation and hydration. According to in his research has proved the finer the steels lag in the mixture the higher the activation and hydration. Using super fine blast furnace slag (SFBF) slag increases the cement hydration when added as supplementary cementitious material. And he described the hydration might be observed at early age. Grinding mill was used to grind the steel slag into finer aid. And ball was described to be best in manufacturing milling works. Because the SS served as a microfiller in the mix in the interface transition zone (ITZ), the finer particles' filling action accelerated the cementitious matrix's packing density and increased the mortar's pore structure. Therefore, using steel slag (SS) or super fine blast furnace slag (SSBF) as a complementary component in mineral mixtures can be a very efficient technique to reduce the amount of cement in concrete.

Fly ash is a by-product that is generated or left over as a product material during coal combustion and usually highly left over in thermal power plants. Fly ash is generally generated in very fine particles and is one of the maximum mutual types of manufacturing left-over product. Fly ash contains silica and alumina and possess properties of cement when reacted. Fly ash is collected from the bottom of the furnace. In global rankings India stands at fourth place in overall fly ash generation by coal combustion. The adverse disposal of fly ash contains serious harmful effects to the environment. Currently only 30 % is used in structural nd civil applications rest 70% is remained as a left-over waste which is dumped in the landfills. Recently the usage of fly ash has been increased as industries directly manufacturing Portland pozzolana cement. Many researchers have shown that the usage of fly ash in civil application generally advances the automatic and toughness possessions of cement and structural applications. So, the usage has increased due to its beneficial applications. SO, if these waste materials can be cleverly utilized to decrease the effect son environment and recycling can be increased.

This paper describes about the pozzolanic reaction of steel slag based upon the different fineness. It contrasts with GGBFS, regular Portland cement, and fly ash. The pozzolanic activity of all the materials are assesses through Frattini test. The activity index strength of all the materials were assessed through experimental procedure i.e., compressive strength of all the specific material cubes prepared and tested by replacing OPC with FA, SS, GGBFS. The SAI of all the materials cubes were cured for period for 7 and 28 days and established for strength compression. Previously works were related to only Frattini test and SAI test, here we have extensively tested materials with tests like Chappelle test, TGA analysis and lime saturation test.

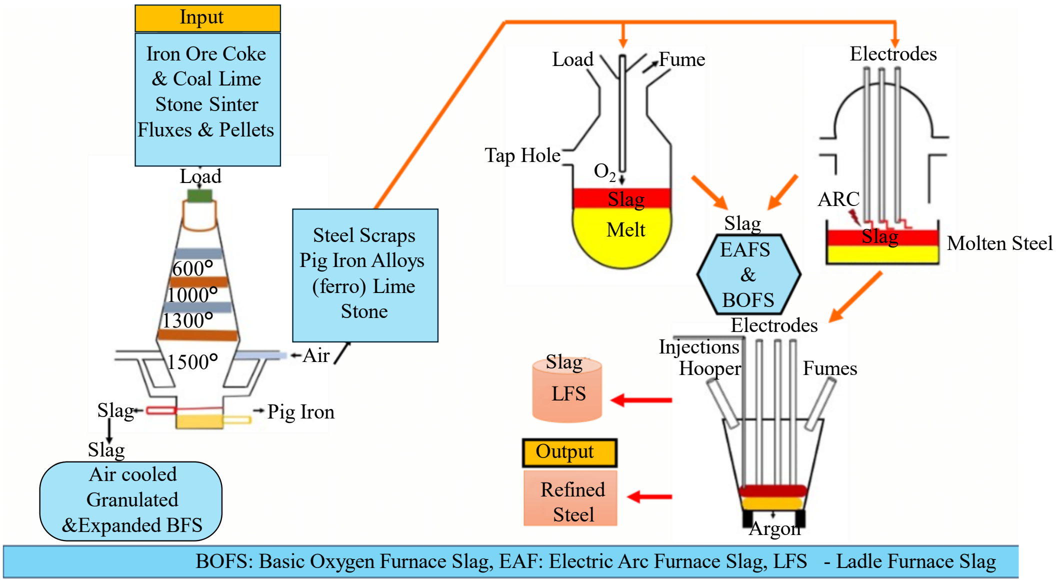


Figure 1. Steel Slag Production Flow Chart.

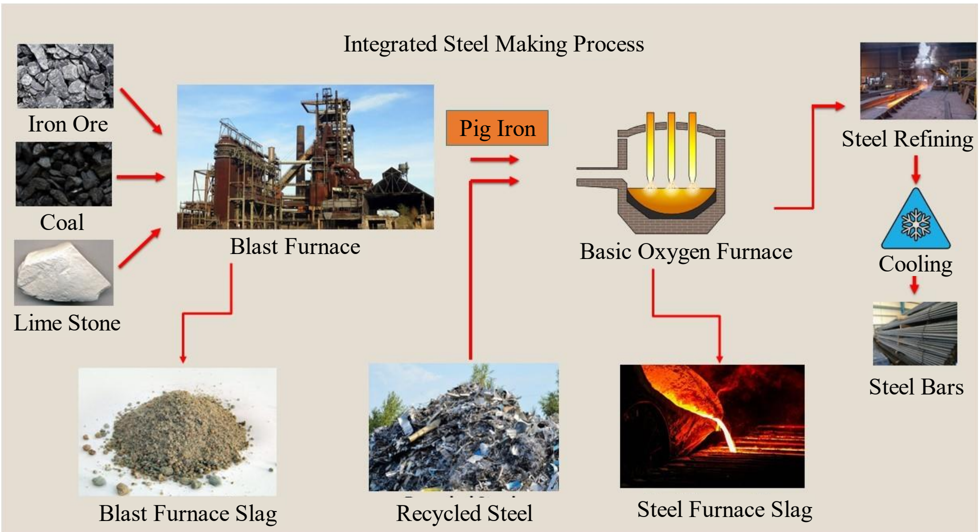


Figure 2. Integrated steels making process.

MATERIALS AND METHODOLOGY

Materials

Steel Slag

The steel slag was provided by Vishakhapatnam steel plant (RNIL). The texture of the slag is coarser and is present in greyish colour. After the grinding process the slag turns to whitish grey and resembles

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

cement. The slag that comes out from factory outlet is very coarser. Which was turned to finer particles by using ball mill. The Physical form of three different slags were presented in Figure 3. distribution of Particle size of three different fineness of steel slag as mentioned in Figure 4.

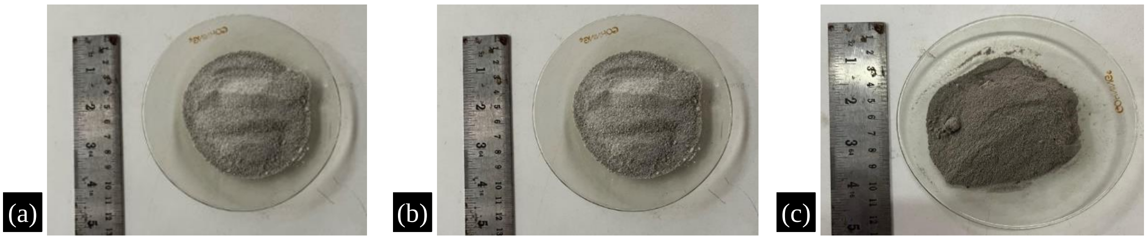


Figure 3. Different Grades of Steel Slag (a) Crude steel slag (S1) (b) 3’n Pulverized steel (c) 5’n Pulverized steel slag(S3) slag (S2)

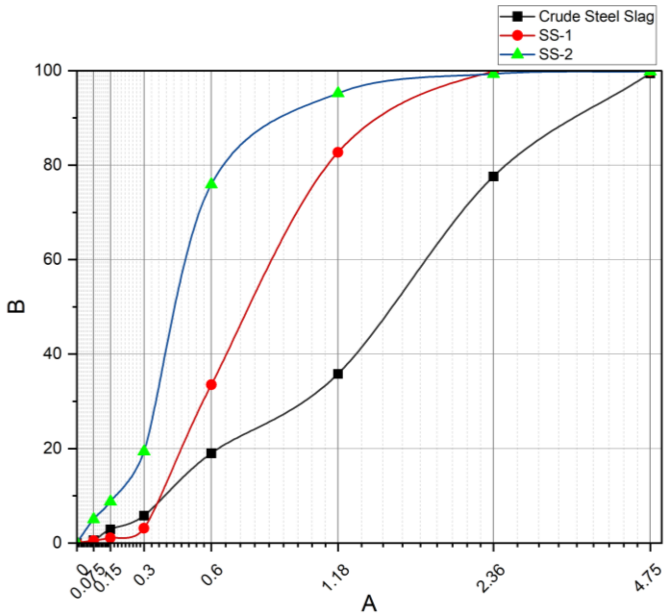


Figure 4. The distribution of particle sizes in steel slag.

Crusher Dust

The nearby RMC facility produces crusher dust, which is collected as garbage. Figure 5 depicts the physical representation of crusher dust. Figure 6 additionally displays the crusher dust particle size distribution.

Figure 5. Crusher dust.

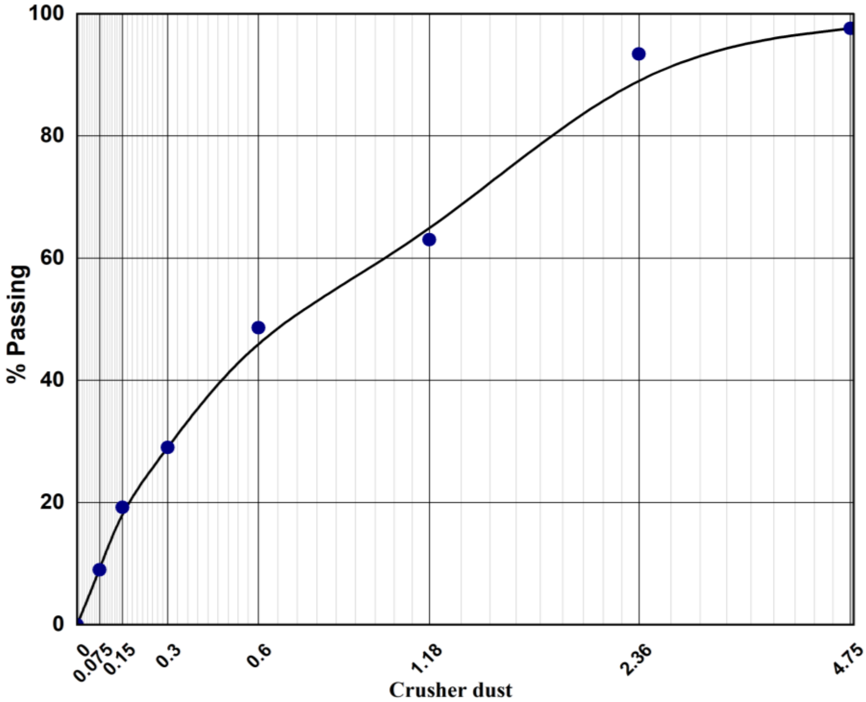


Figure 6. Distribution of Dust Particle Size Crusher.

Fly Ash

Fly ash is collected from Kondapalli thermal power plant which is in Krishna district of Andhra Pradesh, India. Ash is disposed near the pond which is 5 km away from the thermal power plant. The texture is very smooth and is in whitish grey colour. The physical form is presented in Figure 7. The particle size analysis was shown in Figure 8.

Journal of Polymer & Composites
Volume 13, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)


Figure 7. Fly ash.

GGBFS

GGBFs was procured from local vendor. It is whitish in colour and very smooth in texture. GGBFS as a cementitious material is widely used locally. In our study GGBFS is used as comparison material with steel slag ad fly ash. The physical form of GGBFS was shown in Figure 9.

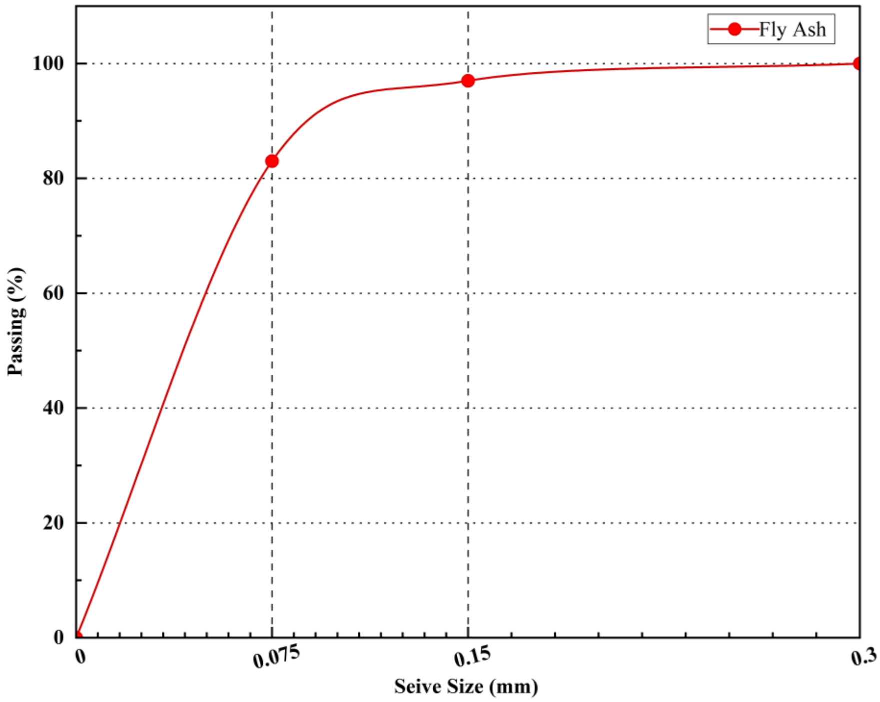


Figure 8. Analysis of Fly Ash Particle Sizes.

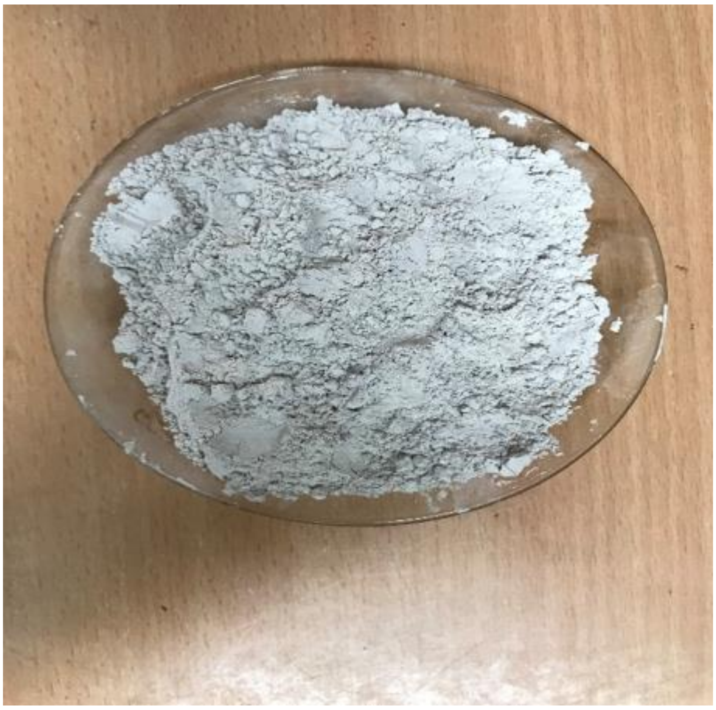


Figure 9. GGBFS.

Lime

Hydrated lime was used in our study as prime binder. Hydrated lime was procured from vendor locally. The physical form of lime powder is shown in Figure 10.

Loss of ignition (LOI) was determined by oven drying material (2-5 grams) at 105 degree and calcinating for 1 hour and again weight is taken. Ph was done in lab premises, Specific gravity, grain size analysis was also done.

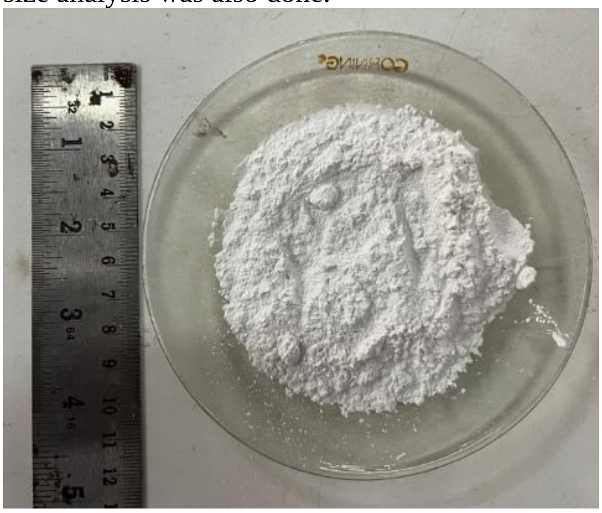


Figure 10. Lime powder.

METHODOLOGY

Physical Properties

Physical things like density, particle size, specific gravity, surface area was determined for all the particles i.e., SS, FA, GGBFS, OPC. Zeta size of SS, FA, GGBFS were analysed. The specific area and density were analysed using standard test procedure according to IS 1727:2004 (Table 1)

Journal of Polymer & Composites
Volume 13, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Table 1. Raw Material's Physical properties

Physical things	SS	FY	GGBFS
Explicit gravity	2.560	2.1 to 3	2.9
Drying shrinkage	1.620%	2.2	14.1
Setting time-initial	800 min	9 hours	
Soundness	3 mm		
Setting time-final	1210 min		

Mineralogical Analysis

The mineralogical analysis for steel slag, GGBFS, OPC, fly ash was done at Bruker make diffractometer (At KL University, Guntur, Andhra Pradesh) by suing The XRD patterns recorded on "PAN alytical EMPYREAN diffractometer" using Cu K α (λ=1.5405 Å) radiation.

Chemical Study

Bruker model S8 Tiger and S4 Pioneer sequential wavelength dispersive X-ray spectrometers were used to examine and perform chemical analyses of fly ash, ground-granulated blast-furnace slag, normal Portland cement, and steel slag.

Experimental Methods

X ray Diffraction Analysis

Through XRD examination, the steel slag's mineralogical constituents were ascertained. At KL University in Guntur, Andhra Pradesh, they used a Bruker made diffractometer to do the analysis. The results show the samples' and specimens' XRD patterns. According to #PDF 01-079-1455, the main constituents of fly ash are mullite ($Al_6Si_2O_{13}$) and quartz (SiO_2). Johannesenite ($CaMn_2$+Si_2O_6), dolomite, silica (SiO_2), and calcium carbonate ($CaCO_3$) were present in trace levels in the steel slag powder. Whereas the XRD pattern of fly ash displays its amorphous nature between 2θ 18-26°C, it is not as amorphous as steel slag. The phase structure could be determined using this method, which simplified pattern recognition and correlation. Some crucial information was uncovered by analyzing the steel slag powder's *XRD* pattern. Reference: Figure 11.

Table 2. Chemical characteristics of three test materials.

Sample	Steel slag	Fly Ash	GGBFS
SiO_2	69.00%	60.20%	36.80%
TiO_2	702 PPM	1.99%	0.76%
Al_2O_3	1.88%	27.90%	16.50%
MnO	66.1 PPM	370PPM	0.37%
Fe_2O_3	0.36%	4.66%	0.58%
CaO	8.18%	1.25%	35.10%
MgO	3.91%	0.53%	6.26%
Na_2O	14.80%	593PPM	0.26%
K2O	8.32%	1.47%	0.43%
P_2O_5	308 PPM	0.48%	367PPM

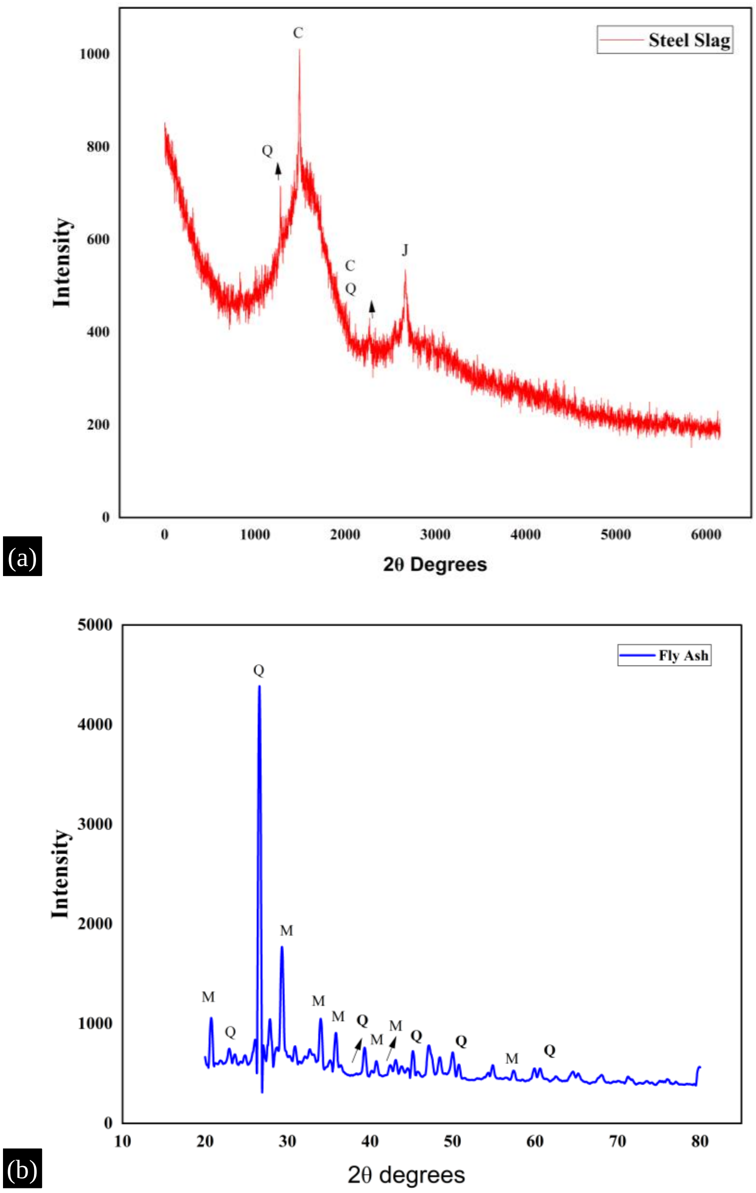


Figure 11. XRD analysis (a) XRD analysis for Steel Slag (b) XRD analysis for Fly Ash.

XRF Analysis

At the National Center of Earth Sciences in Thiruvananthapuram, the XRF analysis was performed. Also, the oxide composition of materials such as steel slag (SS), fly ash, and GGBFS was examined using Bruker model S8 Tiger and S4 Pioneer sequential wave length dispersive xray spectrometers. The above Table 2 shows the compositions of different materials. The requirements of Natural or natural pozzolanic materials that can be used in concrete are mentioned in IS3812 are also mentioned in the Table. The XRF analysis of GGBFS shows SiO_2, Al_2O_3, Cao, Mgo are the major constituents. And other elements like Mno, TiO_2, Na_2O are in trace amounts.

The XRF study of steel slag indicates high Cao and SiO_2 concentration. Chemical proportions of steel slag vary with smelting procedures, steel, and raw ingredients. The primary mineral compositions found in steel slags are free lime, calcium, magnesium peridotite, tricalcium silicate, and di-calcium silicate. Steel slag can be further separated into low and high basicity categories according to their level of basicity. Fly ash analysis indicates more Fe_2O_3, Al_2O_3, SiO_2. All of these exceed class N pozzolan minimums. Fly ash chemical properties are based on power plant coal kinds.

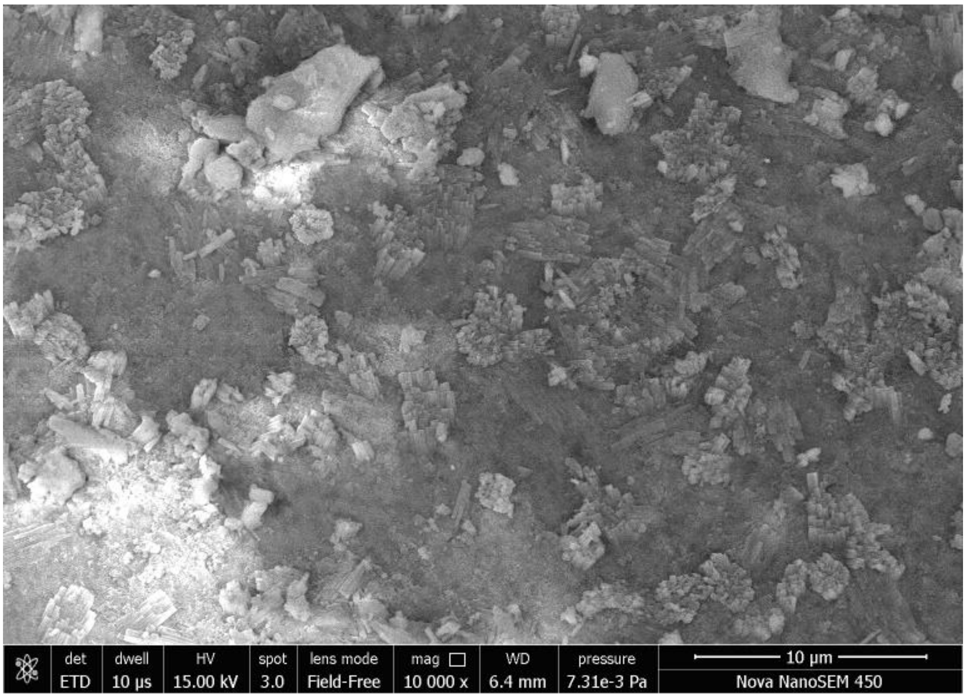
Microstructure Analysis

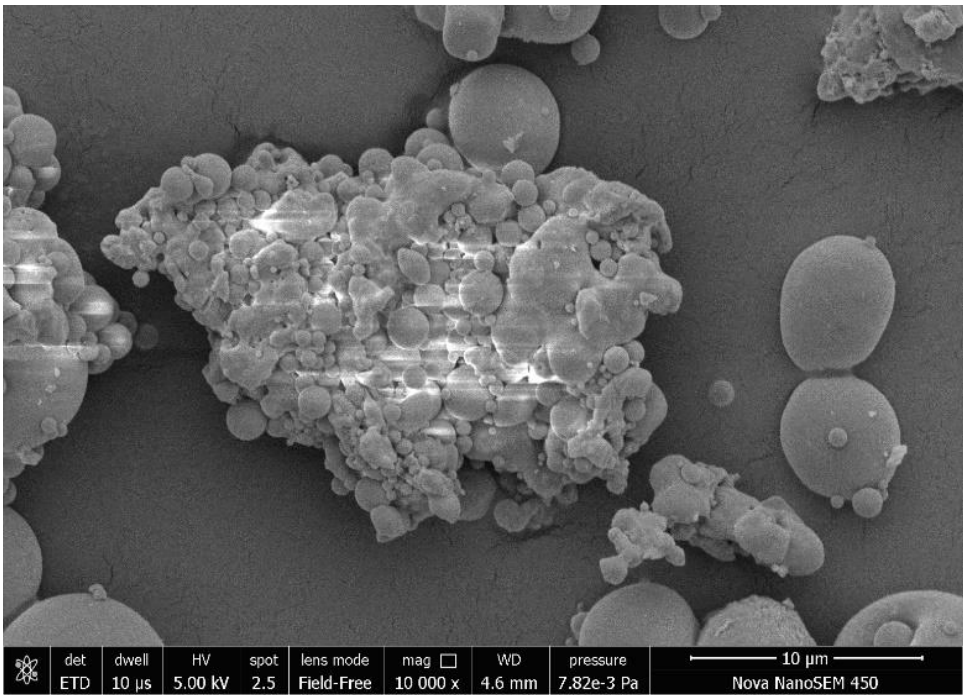
Both the raw material steel slag and the block made from it, which is lime, undergo microstructure examination. Steel slag, fly ash, and GGBFS were analyzed using a JEOL field-emitted scanning electron microscope (FESEM) to study their microstructure and morphology. The constant layout of aggregate throughout the specimens is demonstrated by FESEM pictures, which illustrate the uniform arrangement of aggregates within concrete blocks.The raw materials were coated with platinum before the test to improve visibility and allow for detailed topographic evaluation. This coating ensures smooth charge conductivity. Figure 12 shows the analysis of raw materials using FESEM. The electron image showed that the electrons are angular in shape and came in a wide range of sizes. The particles' structural features reveal that they are porous, with macro levels, micro levels, and meso pores all present.

Sample Preparation

The steel slag (SS[1]) was first heated at oven for eliminating the moisture content. Then pulverized at laboratory pulveriser to grind it into finer powder. As direct material is more coarser and reaction rate is very low.

(a)



(b)


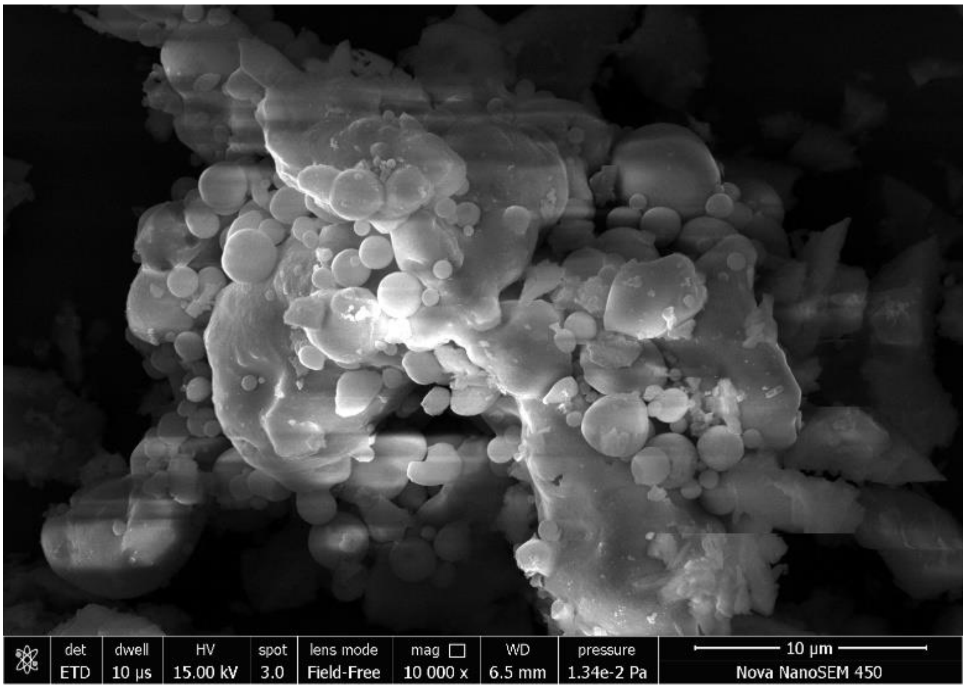
(c)


Figure 12. Sem Micrograph's of Raw Materials (a) Sem Micrograph of Steel Slag (b) Sem Micrograph of Fly Ash (c) Sem Micrograph of GGBFS.

By using the laboratory pulveriser for grinding the steel slag is most economical and widely available facility. These pulverisers use rotating plate and stationary plate moving in opposite direction to hold the material and uses compressive force to break the particles into fine ones. These plates are in rotation such that they yield more consistent size range. The movement is planetary in vertical direction which in turn assists the produce fine mesh by grinding the material. The slag that is collected from the pulveriser is taken and sieved and desired product which could satisfy our need is collected. The slag is heated before grinding so that the moisture is removed and lump forming is eradicated. Hence the factory outlet slag after heating is most eligible for pulverizing.

Physical and Mechanical Properties

(1) The ordinary Portland cement was substituted by steel slag (SS) at a replacement mass ratio of 10,20,20 % respectively. The requirements of Grain size analysis, normal consistency, specific gravity, setting time (initial and final), soundness was tested in accordance with Indian national standards IS 1727 and IS 2720:1985.
(2) Motors made of lime and steel slag were subjected to strength tests using blocks and the Indian national standard IS 516. A water-to-binder ratio of 0.35 was used to create the specimens, which had dimensions of 75×75×75. After an initial 28 curing days in sprinkle curing, the samples are allowed to dry completely for one day before testing. The specimens were evaluated at different ages: 7 and 28.

POZZOLANIC REACTIVITY TESTS

Saturated Lime Test

From $Ca(OH)_2$, portlandite is precipitated by OPC hydration. There is a reaction between the pozzolan and the Ca (OH)2. This event causes a shift in equilibrium, leading to more solid Ca (OH)2 dissolving. till the pozzolan or portlandite is dissolved. Hence, the saturated lime test is easier. Ca (OH)2 is present in the solution in a consistent amount. A saturated lime solution is created for the test by dissolving two grams of hydrated lime powder in one liter of distilled water. In polycarbonate bottles, one gram of pozzolanic material is added to 75 cc of saturated lime solution to create test samples. The bottles were filtered using filter paper after being heated at 40°C for seven and twenty-eight days. Samples were tested and filtered for $[OH^-]$ and $[Ca^{2+}]$. Ca^{2+} ions are properly measured before testing. Test pozzolan or water reacts with Ca^{2+} ions. We know how much lime the test materials fixed in this reaction. The percentage of total Cao fixed in each gram of pozzolanic test substance is given. First, steel slag was tested, then fly ash and GGBFS, which were mostly pozzolanic materials in the industry. Higher temperatures ensure precise pozzolan reaction.

Strength Activity Index (SAI)

Compressive strength tests on 50×50×50 cubes are used to determine the SAI of the material in accordance with BS 3892. To make the control samples, 1350 grams of suitably sieved river sand, 450 grams of cement, and 225 milliliters of water were combined, and 50×50×50 mm cubes were cast. In place of cement, steel slag, fly ash, and GGBFS were used to cast the cement mortar cure specimens. As a control, the sample that is only composed of cement and sand and does not contain any pozzolana (0%) will be used. Steel slag has SS-1, SS-2, and SS-3, fly ash has FA-1, FA-2, and FA-3, and GGBFS has G-1, G-2, and G-3, in that order. They were demolded and left to cure for a total of twenty-eight days after that. For our test samples same procedure is followed and 20 % of cement is replaced with Steel slag and cubes were casted. Same way fly ash, GGBFs were also used as test materials (Table 3).

Table 3. Strength activity Index Mix Composition.

S.N.	Sand (g)	Cement (g)	Water (ml)	Steel Slag (g)	Fly Ash(g)	GGBFS(g)
Control	1350	450	225	-	-	-
SS-1	1350	360	225	90	-	-
SS-2	1350	360	225	90	-	-
SS-3	1350	360	225	90	-	-
Fly Ash	1350	360	225	-	90	-
GGBFS	1350	360	225	-	-	90

Each sample was returned to curing for an additional 28 days following demoulding. After the curing time was over, they were taken out of the water, let to dry on the surface, and then tested for their compressive strength. The Figure 13 displayed the mean of three tests.

$$\text{SAI}=A \div B \times 100$$

Test specimen A's compressive strength (MPa) is known, and test specimen B's compressive strength (MPa) is known as well.

Frattini Test

Frattini test is a chemical type of test analysis in which the test method analysis the presence of calcium oxide in the sample. Hence it establishes the pozzolanic activity of the sample material. Where calcium Oxide I determined as active pozzolanic material. Here in the experimentation setup the materials like steel slag, fly ash, GGBFS were blending with OPC for checking for active pozzolanic activity. The control sample is taken by blending 20 grams of OPC with 100 ml of distilled water. This sample will act as control. And the remaining samples were taken by blending 5 grams of SS, FA, GGBFS with 15 grams of OPC. And each material is named separately as F1, F2, F3 respectively. These tests were widely reported in (ASTM C311 and BS 3892, EN 196-5)

All samples were wrapped and baked for 8–15 days at 40°C. Samples are empty or manually-filtered. The material is titrated to 0.1 mol/L HCL with methyl orange indicator. This measures Hydroxyl ion concentration. The sample is titrated repeatedly till it turns orange from yellow. Second, the solution pH should be 13. To find the calcium ion concentration, the sample should be titrated against a 0.0.3 m EDTA solution if the pH value is less than or greater than 13. On the solubility curve, with [OH-] (mmol/L) on the X-axis and [Cao] (mmol/L) on the Y-axis, were plotted the acquired data. The Cao concentration of the SS, FA, and GGBFS samples was then evaluated using the same approach, and a comparison was made with the standard curve. Highly pozzolanic substance has Cao concentrations below the curve. At concentrations above the curve, the substance is non-reacting and non-pozzolanic. If a non-pozzolanic substance is tested again in 15 days.

C(OH-) = (1000*0.1*HCL consumption[ml]*HCL-factor)/25 ml

C(CaO)= (1000*0.025 *EDTA consumption [ml]* EDTA factor)/25 ml

TGA-DTA

Weight loss can be measured using thermo gravimetric analysis (TGA), and ranges can be located using differential thermo gravimetric analysis (DTA) in relation to thermal decompositions. A distinct peak in DTA indicates a change in TGA. To investigate the reactions occurring during heat treatment of materials, TGA-DTA analyses were performed in this work. With the help of STA 6000 (Perkin Elmer), the analysis was conducted. The dosage range for this test is 5–50 mg, and the temperature is adjusted between 0 and 900 degrees.

Chapelle Test

The followed test is NFP 18-513. That measures the limitation of Ca $(OH)_2$ by mixture with siliceous and alumina silicates that are present in pozzolans. In our study 3 grams of Cao is mixed with 1 gr am of pozzolan (referred in NF P 18-513). For the experimentation study decarbonized or distilled water is used. 250 ml of water is taken in plastic container and is placed in water bath at 90 degrees for 16 hours' time period. For further study a control mixture is prepared with only distilled water and Cao. For eliminating free Ca $(OH)_2$ a mixture of sugar with water is prepared by dissolving 60 grams of sugar. The obtained solution was filter and titrated with 0.1 HCL solution.

$$mgCao = 2 \times \left((V2 - V1) \div V2\right) \times 74 \div 75 \times 1000$$

V_1= (Ca0+ Pozzolan) titration mixture

V_2= Titration volume of control mixture

RESULTS AND DISCUSSIONS

Strength Activity Index

The results shown were average of three repetitions. Firstly, the control developed block compressive strength was 25.6 Mpa at 28 days. The study is formulated by using the equation (1). Steel slag, fly ash, and GGBFS are the test pozzolans whose compressive strengths are displayed in Figure 13. In comparison to the control block, the outcomes indicate a decline in compressive strength. Whereby, when compared to the control block, all test pozzolans performed worse. Between developed tested pozzolans blocks and control blocks, there is a difference. Many factors, besides cement, are involved in this experiment when it comes to the materials' reduced strength. Permeability, porosity, material quality, and the kinetics of the hydration reaction are a few variables that affect strength. Since dilution occurs, if the specimens are inert, the strength will be reduced by 20%. Since there was no pozzolanic activity, the sand was taken as an inert control for this investigation. We may infer from this theory that there is significant pozzolanic activity in steel slag, fly ash, and GGBFS.

$$SAI= A/B\ 100 \tag{1}$$

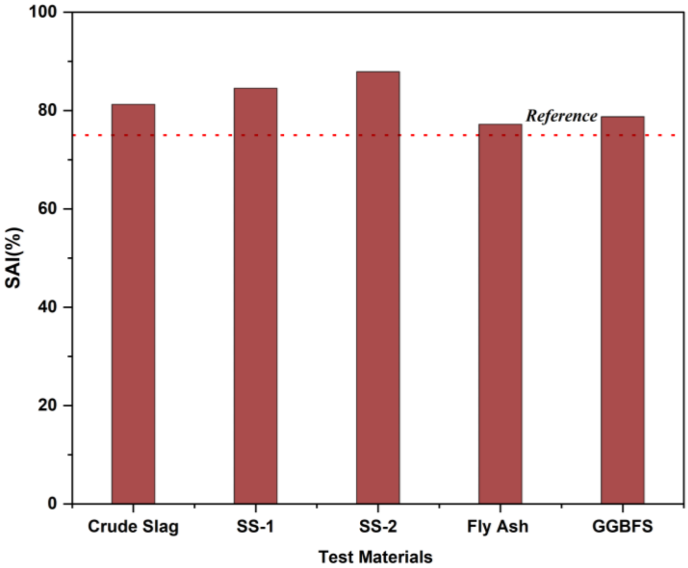


Figure 13. Five test material strength activity index.

Frattini Test

Figure 14 shows the concentrations set for [OH^-] and [Cao] for the sample's solutions after 8 and 15 days. Figures indicates the results of samples containing 80% OPC and 20 % test pozzolan material. This was done together with theoretical Cao maximum and Cao reduction. Figure 14 compares the obtained results with standard solubility curve. Here Steels slag, fly ash, GGBFS show pozzolanic activity. According to standard EN 196-5 for pozzolanic cements. Steel slag, fly ash and GGBFS showed clear pozzolanic reactions with alkalinity and Cao concentrations denoting under saturation with respect to portlandite. For GGBFS the value is slightly below the solubility curve. Conversely, for fly ash and steel slag, the value is marginally below the solubility curve. This indicates that the pozzolanas of the fly ash and steel slag are greater than those of GGBFS when compared to these substances. The elimination of Ca^{2+} ions is indicated by all pozzolans values below the solubility curve, and this phenomenon is known as pozzolanic activity. Additionally, after 15 days as opposed to 8 days of first trial, there may be a discernible increase in the pozzolanic activity. The formula below, which uses variables 2 and 3, can be used to find the theoretical maximum. (EN 196-5). This allows the calcium concentration (Cao) to be measured as the distinction between two measurements and compared to the theoretical maximum.

$$C(OH-) = (1000*0.1*HCL\ consumption[ml]*HCL\text{-}factor)/25\ ml \tag{2}$$

$$C(CaO)= (1000*0.025 *EDTA\ consumption\ [ml]* EDTA\ factor)/25\ ml \tag{3}$$

Saturated Lime Test

The simplified test process makes it easy to determine the saturated lime results. When the test is first started, a fixed amount of lime is added, and when it is finished, the amount of lime that remains is calculated. Since components on the paper filter and solid testing materials both fix lime, the variation in lime quantity can be explained. A null or zero value for fixed lime is expected from the control sample, which only contains saturation lime solutions and sand. The solubility limit for lime was unexpectedly exceeded by 0.3 g, or 3.0 mmol L^−1, by the amount of lime injected (2 g, or 20.45 mmol L^−1). Accordingly, after too much lime is removed from the control sample and other inactive materials. which forms when filter paper is used to filter lime. While the process is evident, several findings indicate that the precipitate is eliminated by an interaction with sand. As a result, it is essential to use the control sample as a basic baseline for zero activity. However, it is imperative to acknowledge the significant constraint of this technique stemming from the noted overabundance of lime addition. Considering the soluble content of Ca(OH)2 varies with temperature, it is essential to keep any stock solution free of CO_2 and maintained at a steady temperature for accurate and consistent results. Notably, the control's baseline value does not need to be subtracted when working with samples that exhibit a positive fixing of lime. This is because, after resolving first 3 mmol L^−1 of lime by the test specimen substantial, the originally lime solution saturated exhausts its reservoir of precipitate lime. Figure 15 displays the outcomes of the saturation lime tests.

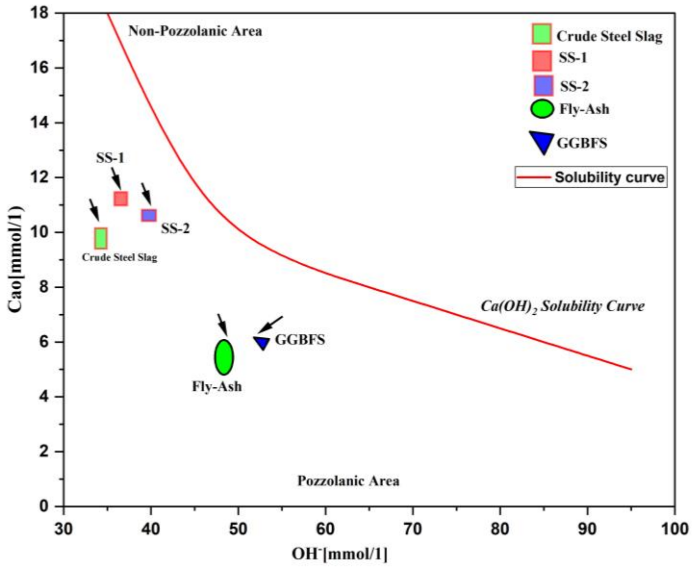


Figure 14. Results of the Frattini test for five sample pozzolans following eight days of curing at 40°C. The test mixes were made up of 16 g PC and 4 g pozzolan in 100 ml of distilled water inside of a plastic bottle that was sealed.

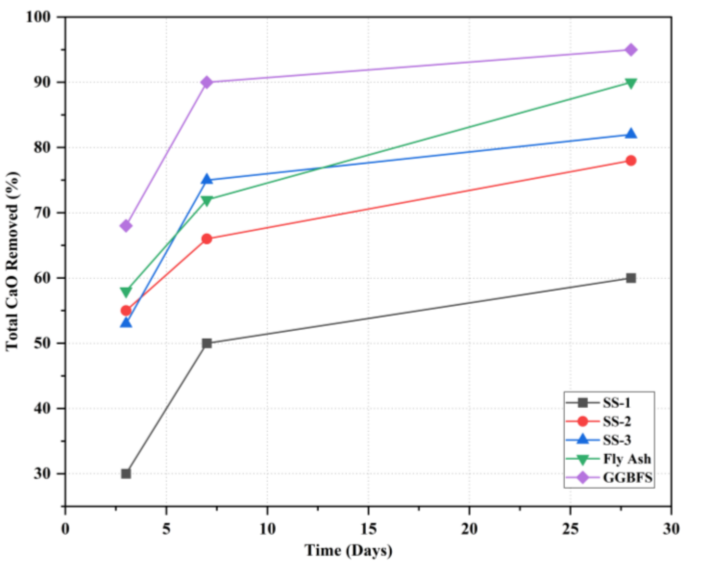


Figure 15. Saturated lime Results of Test materials.

Journal of Polymer & Composites
Volume 13, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Chappelle Test

Figure 16 shows the results obtained after performing Chappelle test. This study calculates the quantity of Cao taken in relation to NF P 18-513. To be classified as a pozzolanic material, the test material's Cao content must exceed 660 mg/g of pozzolan. Many researchers considered Chappelle test as fastest means of pozzolanic testing.

$$\text{mg CaO} = 2 \times ((v2-v1)/v2) \times 74/56 \times 1000 \tag{4}$$

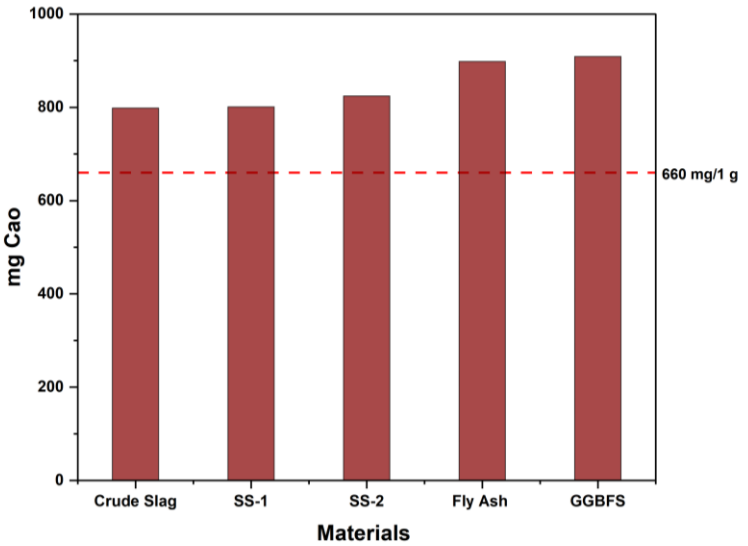


Figure 16. Five test material chappele test.

TGDTA

PerkinElmer TGA 4000 was used to characterize the sample, ramping at a rate of 10°C/min in a nitrogen atmosphere. Based on the graph, it can be deduced that around 1% of the mass was lost at 100°C, possibly as a result of the sample losing moisture. Following moisture loss, a gradual deterioration was noted in a temperature range of 150°C to 700°C, corresponding to a weight loss of about ~2%. The possible cause of this weight loss is the conversion of carbon forms found in slag from steel production into carbon oxide gasses. At 800°C, the remaining undegraded weight was around 97%, indicating the existence of metal oxides, which typically degrade at very high temperatures. TGA curves for several steel slag fine kinds are shown in Figure 17, which also shows how each curve behaves at different phases, such as the moisture measurement step, VM step, and ash determination step. The crucible is covered in the presence of nitrogen for the measurements of moisture and VM, then it is removed to reveal an oxygen atmosphere for the determination of ash. Two circles are depicted in the illustration along the central line, signifying the 850 °C temperature drop that occurs throughout the ash determination process.

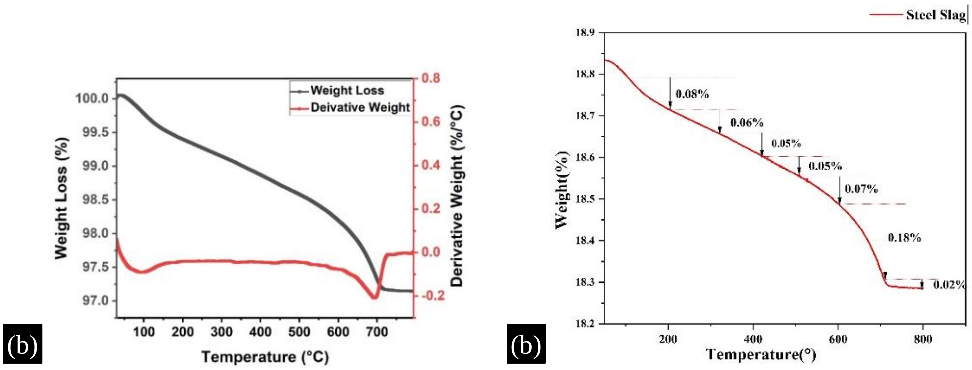


Figure 17. Thermo-Gravimetric Analysis of Steel Slag.

Correlation Between Different Test Methods

Figure 18 shows the correlation graphs that were made by comparing the Chappelle parameter to the Strength Activity Index and Frattini Test.

DISCUSSION

Any approach used for assessing a material's pozzolanic activity must be taken into consideration. When evaluating the pozzolanic nature of materials, it is usual practice to employ a variety of methodologies. Using a variety of test methods is justified by the possibility that at least one will be productive and reveal a inclination in the consumption of Ca (OH)2 in conjunction with lime. Two parameters—temperature and raw material curing—are taken into account while comparing various test techniques in this case. For instance, the Strength of Activity Index Test is conducted at 24 °C for 28 days. For eight days, the Frattini test is conducted at 40 °C. There is an exemption in this case with the saturated lime test process because there is no waiting period of days required for the cement to hydrate. The ratio of lime to pozzolan mass is possibly the most important parameter to take into account when comparing experiments. Precisely measuring the amount of Ca (OH)2 generated during Portland cement hydration is difficult. However, following complete hydration, roughly quarter of the initial mass cement normally remains as Ca (OH)2. Because of this, a mass ratio of 1:1 can be expected in the strength activities test and the Frattini test, where there was 8 grams of concrete for every 2 g of pozzolana.

By combining 1 gram of test pozzolan with 75 milliliters of saturated lime solution—which contains 0.15 grams of Ca (OH)2 altogether—one can get an even lower lime:pozzolan ratio of 0.15:1 in the saturated lime test.

When compared with other tests Saturated Lime test is known to show positive pozzolanic activities hence the saturated lime test is disposed compared with Frattini test. So, when it comes to our raw materials all the materials showed positive pozzolanic activity. It is to be noted that saturated lime showed higher positivity which is not the case with Frattini test. According to the steel slag test results, a small amount of lime can be quickly removed from the solution. However, it should be mentioned that this mechanism is only as strong as it can be. The Frattini test suggests that cement hydration produces a different super-saturated lime solution. This compares CEM-1 pore fluid with saturated Ca (OH)2 Solution. In this case, depending on alkali activity, calcium hydroxide's solubility in water is reduced by alkali metal ions (Na+ and K+) from 20 mmol l-1 to 1-4 mmol l-1. The pH of CEM-I solutions is raised over the natural equilibrium of pure portlandite (pH 12.4) by Na+ and K+ ions. Besides portlandite, alkali metal ions may also be involved in the pozzolanic reaction when using the Frattini approach. The initially present portlandite in blended cements dissolves again as the process of hydration moves on, contributing to the production of more C–S–H. Therefore, it is reasonable to assume a parallel mechanism here.

Evaluation of the Frattini as Compared to the Process of Saturated Lime (SL)

The outcomes show that the SL test reaches a steady balance within a week. This is because the pozzolanic activity was the same in all the materials tested (SS-1, SS-2, SS-2, Fly Ash, and GGBFS). Minimum to high levels of activity were seen in every sample. All of the materials produced positive test results for the Frattini and saturated lime tests. Through its ability to exchange Na+ and K+ ions, ISSA may have a cation exchange capacity large enough to remove a sizable amount of calcium from the solution. Reducing the pozzolan used for the SL test, which results in a lower pozzolan mass, could lead to the following possibility: The mass ratio of Ca(OH)2 was 1:1. In the SL trial, every test material showed appreciable pozzolanic activity within seven days. The Frattini test is used. Furthermore, a noteworthy distinction was seen between the pozzolanic activity of Fly Ash, SS-1, SS-2, SS-3, and GGBFS. There was therefore no association found in the SL and Frattini tests.

An analysis of the SAI and the Frattini Tests Comparing their Respective Strengths

Since the Frattini and Saturated Lime tests both require a certain amount of pozzolan to be mixed with Portland cement, it was purposefully decided to compare cement replacement levels that are

Journal of Polymer & Composites
Volume 13, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

equivalent—that is, a constant 20%. Strength Activity Index blocks' Frattini test findings indicate pore solution Ca (OH)2 concentration. Adding 20% of the test materials is sufficient to reduce the Ca (OH)2 concentration, according to the Frattini Test results. So, it's not surprising that the control samples made of benign sand had more strength than the SAI blocks containing 20% test samples. It is evident from the data that pozzolanic activity is higher in finer steel slag (SS-2) than in basic steel slag when associated to other materials. Therefore, the Frattini test's Ca (OH)2 extraction from the solution, particularly within 8 days, suggests that the SAI test will likely exhibit a comparable pattern after 28 days. SS-2 and Ca (OH)2 in the pore solution create strength-contributing C-S-H gel phases. Results from both of these investigations are significantly related. The analysis graph is represented in Figure 19.

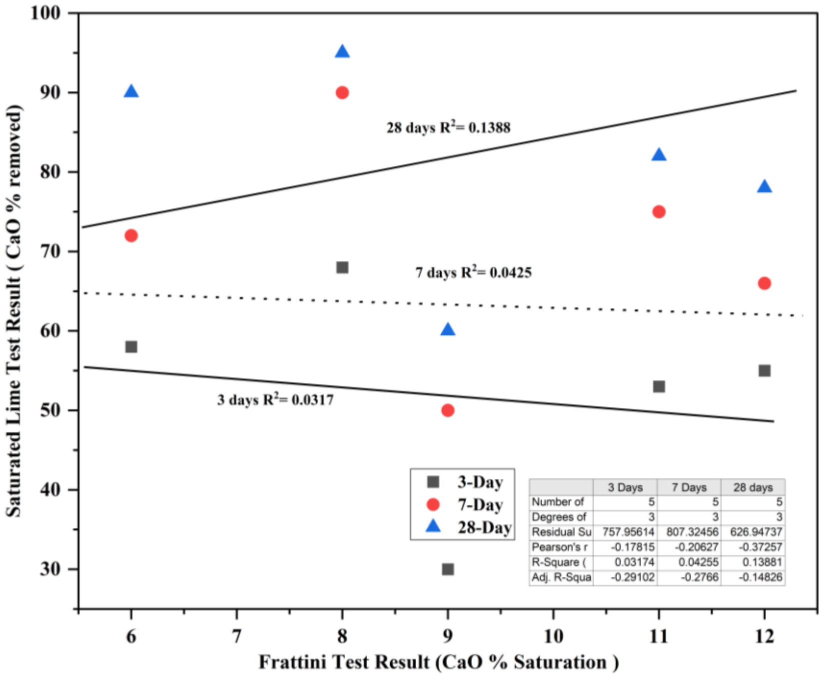


Figure 18. Correlation between different test methods.

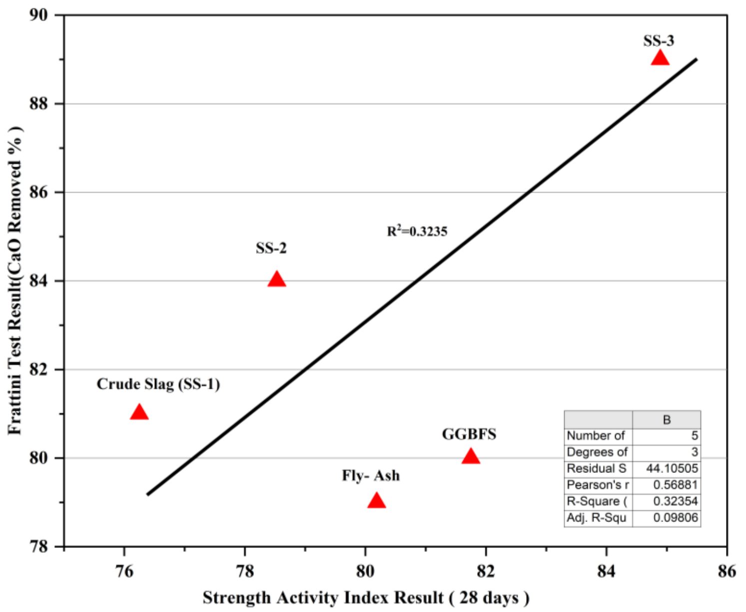


Figure 19. comparison of SAI and Frattini Test.

SAI and SL Trial Comparison

The SL trials demonstrate essentially equal activity of pozzolanic for the SS-1, SS-2, SS-3, Fly Ash, and GGBFS. In Which Strength activity index showed positive result for Fly Ash, GGBFS and high positive pozzolanic activity for three steel slag samples. In which SS-2 Showed very good result. Hence, the absence of correlation between the methods is to be expected. Variations are probably due to the different chemical system used during the SL test, which does not require cement and does not result in the production of the bulk solid phase like the SAI and Frattini experiments do. Furthermore, the mixture's water demand affects the SAI outcomes. Interestingly, the amount of water needed in SAI mixes to achieve standard uniformity varied significantly amongst test pozzolans.

According to hydration stoichiometry, 103.5 ml of water must be added in order for PC to fully hydrate at a water-to-cement (w/c) ratio of 0.23. But SF illustrations used 296 ml of water, whereas a control SAI mortar contained 225 ml. When there is too much water in the cement paste, the porosity increases and the matrix strength suffers. The extent of this effect resulting from water content compared to any pozzolanic reaction remains uncertain and warrants further investigation. The Graph has been represented in Figure 20.

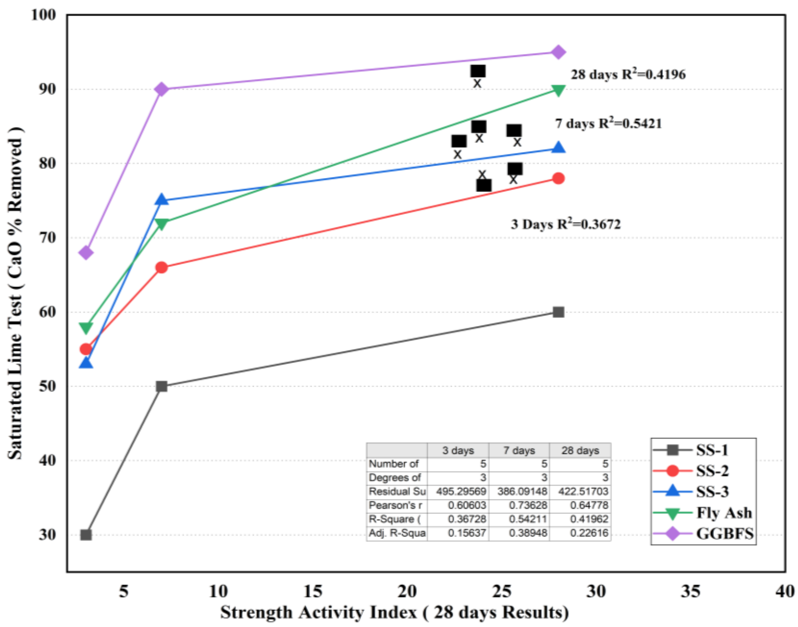


Figure 20. Comparison of SAI and SL.

CONCLUSIONS

Raising the lime: Pozzolan Ratio, when applied to saturated lime, may have the tendency to raise the correlation of test techniques; this may require additional research. One way to produce a mass ratio of 1:1 between pozzolan and Ca $(OH)_2$ is to combine one gram of pozzolan test with 500 cc of soaked solution of lime. While the particular SAI water effect outcomes is unknown, future study should use a super-plasticizer to achieve consistent findings with a fixed water-to-binder ratio.

- Steel Slag, Fly ash and GGBFS all three materials showed their pozzolanic activity in testing.
- Ultra-fine Steel Slag (SS-3) showed more reactivity when compared with remaining crude steel slag (SS-1) and fine steel slag (SS-2).
- SS-3 showed highest reactivity in day -1 lime test saturated.
- In the saturated seven-day lime test, all of the test materials displayed increased reactivity.
- Measurement of the Frattini test results is possible when the [OH-] is between 35 and 90 mmol 1^{-1}
- The SAI and the Frattini tests did not show any association with the SL test.

- There was a significant association found between the Frattini test findings and the SAI.
- It is not possible to use the SL test to determine the pozzolanic activities of GGBFS, Fly ash, and Steel Slag (SS-1, SS-2, and SS-3) in a 7-day period.

The SAI and the Frattini tests did not show any association with the SL test.There was a significant association found between the Frattini test findings and the SAI.It is not possible to use the SL test to determine the pozzolanic activities of GGBFS, Fly ash, and SS-1, SS-2, and SS-3 slag steels in a 7-day period. Its activator-to-pozzolan ratio is significantly lower than with other techniques, and errors may arise from being unaware of the exact amount of Ca (OH)2 in each sample. Using the Frattini and SAI procedures is recommended. By combining these tests with independent methods for determining Ca (OH)2 content, including thermal or diffraction analyses, a thorough assessment of the materials' pozzolanic activity can be achieved.

REFERENCES

1. Gadikota G, Fricker K, Jang SH, Park AH. Carbonation of silicate minerals and industrial wastes and their potential use as sustainable construction materials. InAdvances in CO2 Capture, Sequestration, and Conversion 2015 (pp. 295-322). American Chemical Society.
2. Raut AN, Gomez CP. Thermal and mechanical performance of oil palm fiber reinforced mortar utilizing palm oil fly ash as a complementary binder. Construction and Building Materials. 2016 Nov 15;126:476-83.
3. Scrivener KL, John VM, Gartner EM. Eco-efficient cements: Potential economically viable solutions for a low-CO2 cement-based materials industry. Cement and concrete Research. 2018 Dec 1;114:2-6.
4. Iswarya G, Beulah M. Use of zeolite and industrial waste materials in high strength concrete–A review. Materials Today: Proceedings. 2021 Jan 1;46:116-23.
5. Kishore K. Geopolymer concrete and its strength influencing variables. Materials Today: Proceedings. 2023 Jan 1;80:1434-41.
6. Almeshal I, Tayeh BA, Alyousef R, Alabduljabbar H, Mohamed AM. Eco-friendly concrete containing recycled plastic as partial replacement for sand. Journal of Materials Research and Technology. 2020 May 1;9(3):4631-43.
7. Aprianti E, Shafigh P, Bahri S, Farahani JN. Supplementary cementitious materials origin from agricultural wastes–A review. Construction and Building Materials. 2015 Jan 15;74:176-87.
8. Li Z, Zhao S, Zhao X, He T. Cementitious property modification of basic oxygen furnace steel slag. Construction and Building Materials. 2013 Nov 1;48:575-9.
9. Setién J, Hernández D, González JJ. Characterization of ladle furnace basic slag for use as a construction material. Construction and Building Materials. 2009 May 1;23(5):1788-94.
10. Tsakiridis PE, Papadimitriou GD, Tsivilis S, Koroneos C. Utilization of steel slag for Portland cement clinker production. Journal of hazardous materials. 2008 Apr 1;152(2):805-11.
11. Wang Q, Yan P. Hydration properties of basic oxygen furnace steel slag. Construction and Building Materials. 2010 Jul 1;24(7):1134-40.
12. Barišić I, Dimter S, Rukavina T. Strength properties of steel slag stabilized mixes. Composites Part B: Engineering. 2014 Mar 1;58:386-91.
13. Anastasiou E, Filikas KG, Stefanidou M. Utilization of fine recycled aggregates in concrete with fly ash and steel slag. Construction and Building Materials. 2014 Jan 15;50:154-61.
14. Qasrawi H, Shalabi F, Asi I. Use of low CaO unprocessed steel slag in concrete as fine aggregate. Construction and Building Materials. 2009 Feb 1;23(2):1118-25.
15. Ahmedzade P, Sengoz B. Evaluation of steel slag coarse aggregate in hot mix asphalt concrete. Journal of hazardous materials. 2009 Jun 15;165(1-3):300-5.
16. Hu S, Wang H, Zhang G, Ding Q. Bonding and abrasion resistance of geopolymeric repair material made with steel slag. Cement and concrete composites. 2008 Mar 1;30(3):239-44.
17. Wang G, Wang Y, Gao Z. Use of steel slag as a granular material: Volume expansion prediction and usability criteria. Journal of Hazardous Materials. 2010 Dec 15;184(1-3):555-60.

