Grenze International Journal of Engineering and Technology, June Issue

Study of Sustainable Pervious Concrete using Agro-Industrial Waste

S.G. Kalamkar[1], S.P. Raut[2], Vedant Kale[3], Vedant Daf[4], Tanmay Rahate[5] and Yash Barange[6]
[1]Research Scholer, Assistant Professor, Yeshwantrao Chavan College of Engineering, Nagpur, India
Email: sanketgk1@gmail.com
[2]Professor, Yeshwantrao Chavan College of Engineering, Nagpur, India
Email: sprce22@gmail.com
[3-6]Students, Yeshwantrao Chavan College of Engineering, Nagpur, India
Email: vedantkale86@gmail.com

***Abstract*— For the effective synthesis of sustainable pervious concrete, the polycarboxylate ether-based superplasticizer is blended together with agro-industrial waste materials, in which iron slag and rice husk-activated carbon are specifically utilized as partial replacement materials in order to provide workability at lower water/cement ratios. The aim and objective of this research are the enhancement and development of improved mechanical and durable qualities and reducing the environmental concern related to concrete production by synthesizing and implementing waste-produced components. Comprehensive analysis (specific gravity, abrasion resistance, crushing strength, XRF analysis, SEM-EDS, and XRD analysis) confirmed that iron slag is useful as a strong and angular aggregate that could hold reactive mineral constituents such as gehlenite and akermanite. High pozzolanic activity is also evident in RHAC, which contains high silica proportions and is known as an amorphous material that is macroscopically very porous. Based on these characteristics, mix designs are conducted in order to evaluate effective improvements in structural density development, strength, and permeability. The experimental findings confirmed that proper mix proportions of iron slag and RHAC could allow effective improvements in load transfer efficiency and afford greater development in the amount of C-S-H, which could afford reduced waste disposal problems and could also reduce dependence on natural aggregates. Based on these experimental findings, the research illustrates that agro-industrial wastes are an effective solution that could afford the development of environmentally compatible pervious concrete incorporating advanced chemical admixtures that could afford more functional qualities.**

***Index Terms*— Pervious concrete; Agro-industrial waste; Iron slag; Rice husk activated carbon (RHAC); Polycarboxylate ether superplasticizer; Pozzolanic activity; Sustainable construction; Mechanical properties; Durability; Permeability.**

I. Introduction

The construction sector worldwide is among the largest users of natural resources, in addition to being among the major sources of greenhouse gas emissions, waste, and destruction of the environment. For example, conventional concrete production contributes almost 8% of global CO_2 emissions, which is mainly attributed to cement production and extraction of virgin aggregates [1].

Grenze ID: 01.GIJET.12.2.204_22

As the world becomes more urbanized, there is a corresponding rise in material demands, thereby emphasizing the need for sustainable alternatives to these construction materials that have lower environmental footprints. Such alternatives can now be found through the use of agro-industrial wastes, including rice husk ash, rice husk activated carbon, bagasse ash, iron slag, and many others, partly in place of cement, fine aggregates, or coarse aggregates.

The agro-industrial waste is widely available in an agricultural economy and is also commonly linked with the possibility of occupation because of air and soil pollution if not managed properly [2]. The application of the waste for building material production is in accordance with the principles applied in the circular economy concept. There are several researches that have established that the application of agro-industrial waste can contribute towards reducing dependence on natural resources and improving the mechanical and permeability strengths of concrete [3]. Iron slag can improve the compressive and durability strengths of concrete, and rice husk ash can improve chemical resistance strength.

II. MATERIALS

Cement- Ordinary Portland Cement (OPC) of 53 grades, according to IS 12269:2013, was used as one of the main binding materials for this study. OPC of 53 grades is mostly used instead of other grades and other forms of cement for their structural applications due to their higher early strengths and their compatibility with supplementary cementitious materials. The chemical composition of ordinary Portland Cement, mainly comprising C_3S, C_2S, C_3A, and C_4AF, influences the rate of hydration and microscopic formations of concrete [1].

Coarse Aggregate-Crushed angular coarse aggregates of size 10-20 mm has been utilized for preparation of concrete samples. Crushed aggregates possess a renowned ability of good interlocking, which allows better load transfer and structural efficiency of concrete. Prior to their application, inter alia, they have been subjected to tests of impact value, crushing value, flakiness index, and water absorption, which had to comply with IS: 2386. particularly when mixed with admixtures of iron slag and rice-husk-based additive materials [4].

Rice Husk Activated Carbon (RHAC)- The partial substitution material used was Rice Husk Activated Carbon (RHAC) produced from controlled carbonization and activation of rice husk. The rice husk contains high amount of silicon, and RHAC offers a micro porous material with high porosity and possess pozallanic reactivity. The micro porous particles of RHAC promote better particle packing, and additionally, it generates calcium-silicate-hydrate gel when it comes into contact with calcium hydroxide produced during cement hydration [5].

Figure 1. Rice husk activated carbon

Iron slag granulated Blast Furnace Slag (GBFS) extracted from a Steel Mill was utilized as a replacement for fine or coarse aggregates. Iron Slag: An industrial waste material, which has not much metallic luster. It has large amounts of CaO, SiO_2, Al_2O_3, & MgO. As powder or aggregates, it has latent cementitious & pozzolanic action, which helps in increasing strength & durability of concrete [3]. In this study, characterization of the particle size distribution, specific gravity, & chemical analysis of the iron slag through XRF was done. The use of iron slag instead of aggregates has many advantages, which include reducing Natural Resource Depletion & helping in sustainable development of the construction industry [6].

Figure 2. Iron slag

Portable water free from oils, acids, organic impurities, and excess salts was used. IS:456:2000 code specifications had to be followed in order for the water to remain clean, which was essential in preventing the inhibition of hydration and strength processes. The water was very important in the process, especially for those mixtures that used chemically reactive wastes. This was because the inhibition of initial setting was required.
Chemical Admixture (Superplasticizer) in this investigation, a high-range water-reducing chemical admixture, specific to a polycarboxylate ether (PCE) superplasticizer, known by the name Auramix 300, was used to increase the workability and performance properties of concrete mixtures containing agro-industrial wastes. It has been reported that PCE superplasticizers are known to effectively reduce the demand for water by a range of 20-30% and can help to improve the workability under the distinct dispersion action, depending upon steric hindrance and electrostatic attraction, to separate the cement particles [7]. The use of the PCE superplasticizer admixture to the concrete mix not only increased the workability but also helped to improve the mechanical strength and durability of the concrete, considering that the reduced water-cement ratio was achieved by this addition, which was not feasible along with workability [8].

III. METHODOLOGY

The iron-slag material was thoroughly investigated from both physical and chemical analyses in order to determine its suitability as a substitute for aggregate material. From the physical analysis, drying and sieving methods were used to resize samples for sieve analysis as a means of evaluating aggregate material sizing suitable for classification purposes among natural aggregate materials (method IS 2386 sieve analysis). Bulk density, specific gravity, and absorption tests for materials were also used to determine material porosity and material content in mix proportions for aggregate material. Aggregate crushing value and aggregate impact value tests were used to determine aggregate material resistance to mechanical wear (method IS 2386). The overall shape and material texture was determined using macroscopy methods using microscopic examination as a supplementary means for evaluation with respect to angularity and surface roughness. Chemically, the oxide analysis of the iron-slag material was conducted through X-ray Fluorescence to evaluate percentage composition of calcium, Silicon Dioxide, Aluminum Oxide, Magnesia, and Iron oxides, important in assessing late reacting material, while Loss on Ignition was also assessed to evaluate possible carbon residue unburnt in manufacture. Mineralogy of the iron-slag material was evaluated through X-ray diffraction to evaluate calcium silicate formation, while scanning electron microscopy with EDS analysis linked material morphology to its chemistry and potential reactions to obtain iron-slag material suitable as aggregate replacement materials in concrete technology construction processes [3], [6]
Rice Husk Activated Carbon (RHAC) was also tested in an integrated package of physical and chemical analyses relevant to fine admixes. Fineness and surface area (Blaine or BET if available) were assessed to assess fining and reachability, with particle size distribution data provided for mix design purposes and hydration interaction modeling. Specific gravity and density measurement are also necessary due to the low density of carbonaceous materials. Compatibility with Portland cements was assessed using standard compatibility tests for cements – initial and final setting times and standard consistency – for hydration rate effects assessment. By contrast, the Strength Activity Index (compressive strength of mortars/cement mixtures at 7 and 28 days) was employed for the quantitative estimation of the pozzolanic contribution [5]. For chemical analyses, oxide composition data (notably the silica content and presence of oxide impurities) were supplied using XRF. Fixed carbon and unconsumed volatiles were determined using Loss on Ignition. Crystallinity was further ascertained using XRD with RHAC typically having an amorphous structure for silica. SEM-ED images supplied information on pore structure and surface morphology with elemental composition data provided using EDS analysis for Carbon, Silica, Potassium, and other constituent elements. Alternatively, Thermogravimetric analysis or Differential Scanning Calorimetry is employed if available for thermal stability and organics residues analysis [5], [6].

IV. RESULTS

The iron slag, which was used in the study, has been put to test to check its feasibility to be used as partial replacement materials within the concrete mixture These tests involve physical properties like specific gravity, absorption capacity, abrasion resistant values, and compression strength. More technical analysis involving SEM, EDS, and XRD analysis has also been done for the evaluation of structure and material composition. These sets of tests will enable us to determine the strength, durability, and composition of iron slag, as well as its viability for usage in concrete.

The specific gravity values for iron slag were obtained using the pycnometer method. While studying the values obtained W_1 to W_4, it was noticed that the specific gravity value, 2.85, indicates the density of the material, and the density of iron slag is higher than that of natural aggregates, meaning that iron slag is denser and hence iron slag can act as a replacement for concrete due to its higher density, and hence it will be stronger.

TABLE I. SPECIFIC GRAVITY OF IRON SLAG

Test Parameter	W1 (wt. of empty pycnometer) (gm)	W2 (wt. of empty pycnometer + iron slag) (gm)	W3 (wt. of empty pycnometer + iron slag + water) (gm)	W4 (wt. of pycnometer with water only) (gm)	Value
Specific Gravity	550	750	1560	1430	2.85

A. Water Absorption

The specific gravity was found to be 2.85. The bulk specific gravity was found to be 1.85. This clearly shows that it has pores in it, as well as being lighter. The water absorption capacity of 5.4% is moderate. This can significantly impact the workability and durability properties of the concrete as a possible aggregate.

TABLE II. WATER ABSORPTION OF IRON SLAG

Test Parameter	Specific Gravity	Bulk specific Gravity	Value
Water Absorption (%)	2.85	1.85	5.4%

The Los Angeles abrasion test was used to determine the resistance to wear of iron slag. The abrasion value was determined using the weights obtained from the test, and a result of 18.1% shows that the material has low abrasion loss. The toughness of iron slag is, therefore, suitable for its application in concrete and pavement work, which requires high abrasion resistance.

TABLE III. LOS ANGELES ABRASION TEST OF IRON SLAG

Test Parameter	W1 (wt. of iron slag) (gm)	W2 (wt. of iron slag retained on 1.7mm sieve) (gm)	W3 (W1 – W2) (gm)	Value
L.A. Abrasion Value (%)	5000	4095	905	18.1%

To determine the strength of iron slag against the compressive force, the crushing value test was conducted. By the recorded weight, the calculated crushing value of 17.57% shows that it has good strength and resistance to crushing. The result shows that iron slag has a very low crushing value, which proves that iron slag can be used as a coarse aggregate.

TABLE IV: AGGREGATE CRUSHING VALUE OF IRON SLAG

Test Parameter	W1 (wt. of iron slag) (gm)	W2 (wt. of iron slag passing 2.36mm sieve) (gm)	Value
Crushing Value (%)	3500	615	17.57%

SEM Analysis of Iron slag particles have a rough and angular surface topography, which assists, to some extent, in the development of mechanical interlocking properties against the cement paste matrix. There are moderate micro-voids, which show controlled porosity, which assists paste penetration. There is irregular particle shape, which provides assistance to bonding, leading to higher concrete strength.

TABLE V: SEM OBSERVATIONS OF IRON SLAG

Feature	Observation
Surface Texture	Rough, angular particles
Porosity	Moderate micro-voids observed
Particle Shape	Irregular, enhancing bonding

In EDS Analysis the chemical constituents of iron slag reflect a high concentration of CaO (34.8%) and SiO_2 (28.5%), which are signs that iron slag has a high possibility of being cementitious in nature. The presence of Fe_2O_3 (14.2%) and Al_2O_3 (8.7%) in the iron slag makes this a strong material too. The trace presence of MgO, together with other oxides, has a substantial effect on the stability of the iron slag in concrete works.
In XRD analysis, gehlenite (38%) and akermanite (26%) confirm the calcium alumino silicate system present in iron slag. This shows that calcium silicate phases (18%) can provide cementitious material activity, although iron oxide (10%) gives strength to iron slag. The balance is composed of minor crystalline phases that do not affect iron slag much.

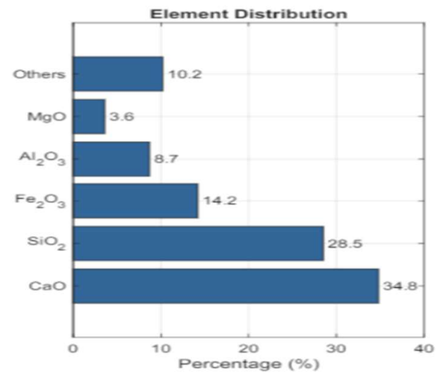

Figure 3. EDS Elemental Composition of Iron Slag

TABLE VI. XRD PHASES IDENTIFIED IN IRON SLAG

Crystalline Phase	Intensity (%)
Gehlenite ($Ca_2Al_2SiO_7$)	38
Akermanite ($Ca_2MgSi_2O_7$)	26
Calcium Silicate (C_2S/C_3S traces)	18
Iron Oxide (Fe_2O_3)	10
Others (minor crystalline forms)	8

Rice Husk Activated Carbon (RHAC) was analyzed using different physical and microstructural techniques to explore the possibility of using it as an additive for cement. RHAC is lightweight, porous, and rich in silica content. Since it is lightweight, porous, and rich in silica content, it is an excellent material with immense potential that can be used as a pozzolanic additive in the production of concrete. Different analysis techniques like Chemical Composition, SEM analysis, EDS analysis, and XRD tests have been used.

The oxide chemical composition is dominated by a high percentage of SiO_2, which amounts to 62.4%, reflecting the high silica and amorphous nature of the material. The low percentage levels of other oxides, such as CaO, Al_2O_3, and Fe_2O_3, make them reactive for showing high cementitious properties. The high ignition loss (LOI), which amounts to 21.7%, further indicates the presence of high carbonaceous material in the composition.

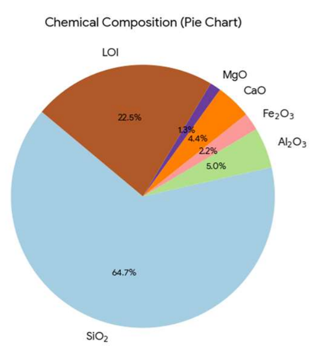

Figure 4. Chemical Composition of RHAC

In SEM Analysis morphology is highly porous with micro-voids, which is an indication that its surface area is highly effective. Its irregular flakes also ensure better bonding with the cement matrix that surrounds it. Looking at all these aspects, the potential for the reactive properties to be realized is high; thus, the material is eligible to function as a reactive/supplementary material in concrete.

TABLE VII: SEM OBSERVATIONS OF RHAC

Feature	Observation
Surface Texture	Highly porous, micro-voids abundant
Particle Shape	Irregular and flaky
Reactivity Potential	High due to large surface area

In EDS Analysis the elemental analysis reveals that the composition is mostly dominated by the presence of silicon (58.9%) and carbon (24.5%). This analysis confirms the composition's predominantly silica and carbon-rich properties. Also present is the oxide composition with the presence of oxygen (12.6%). Smaller quantities of calcium and iron might be the cause of the composition's binding properties. These elements comprise the smaller percentage with minimal effects on the composition.

TABLE VIII: EDS ELEMENTAL COMPOSITION OF RHAC

Element	Percentage (%)
Si	58.9
C	24.5
O	12.6
Ca	1.8
Fe	0.9
Others	1.3

In XRD analysist the amorphous silica content is high, as seen in the broad hump in the range of 20° to 30°, which implies a good quantity of the material with high pozzolanic activity. The moderate peaks of quartz are an indicator of the presence of the crystal form of SiO_2, and the low carbon residues as well as the presence of trace quantities of the other minor crystal oxides are not.

TABLE IX. XRD PHASES IDENTIFIED IN RHAC

Phase	Intensity
Amorphous Silica (broad hump 20°–30°)	High
Quartz (SiO_2)	Moderate
Carbon Residues	Low
Minor Crystalline Oxides	Trace

IV. CONCLUSIONS

In RHAC, the crystalline and amorphous components are detected by an XRD. The importance of having an amorphous silica component is that it reacts as a pozzolana when mixed with cement. This research shows that the incorporation of rice husk activated carbon (RHAC) and iron slag into previous concrete is an efficient approach to the enhancement of sustainability. Even though RHAC contributed to the improvement of the microstructure and encouraged the formation of C-S-H, the addition of iron slag enhanced strength and resistance. However, the combination of the two industrial waste materials minimized the requirement for natural materials, thereby assisting in the development of a stronger, longer lasting, and environmentally friendly pervious concrete. Overall, the combination of modern admixtures and agro-industrial waste has the potential for environmentally sustainable construction.

REFERENCES

[1] K. Scrivener et al., "Impacting factors and properties of limestone calcined clay cements (LC 3)," Green Mater, vol. 7, no. 1, pp. 3–14, Mar. 2019, doi: 10.1680/jgrma.18.00029.

[2] S. K. Singh and others, "Utilization of blast furnace slag in low-carbon concrete," Constr Build Mater, vol. 254, p. 119296, 2020.

[3] P. O. Awoyera and A. Adesina, "Plastic wastes to construction products: Status, limitations and future perspective," Case Studies in Construction Materials, vol. 12, p. e00330, Jun. 2020, doi: 10.1016/j.cscm.2020.e00330.

[4] 2020 Bhunia et al., "Performance evaluation of concrete using OPC and blended cements"".

[5] K. Ganesan, K. Rajagopal, and K. Thangavel, "Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete," Constr Build Mater, vol. 22, no. 8, pp. 1675–1683, Aug. 2008, doi: 10.1016/j.conbuildmat.2007.06.011.

[6] G. Habert et al., "Environmental impacts and decarbonization strategies in the cement and concrete industries," Nat Rev Earth Environ, vol. 1, no. 11, pp. 559–573, Sep. 2020, doi: 10.1038/s43017-020-0093-3.

[7] J. Plank and B. Sachsenhauser, "Experimental determination of the effective anionic charge density of polycarboxylate superplasticizers in cement pore solution," Cem Concr Res, vol. 39, no. 1, pp. 1–5, Jan. 2009, doi: 10.1016/j.cemconres.2008.09.001.

[8] C., H. D., & L. Z. (2020). Yu, "'Effect of Nano-SiO_2 Admixture on Hydration and Microstructure of Cement-based Materials.,'" 2020.