Effect of Rice Husk Ash and Silica Fume as Strength-Enhancing Materials on Properties of Modern Concrete—A Comprehensive Review

Shaswat Kumar Das, Saurabh Kumar Singh, Jyotirmoy Mishra and Syed Mohammed Mustakim

Abstract Achieving a concrete with good strength and durability using OPC is quite challenging in the present scenario as per the environmental exposures are concerned. Hence, Geopolymer concrete, concrete without cement, has proved to be a better alternative and qualifies to be a concrete for modern-age constructions. Modern concrete production should promote the idea of sustainable utilization of various industrial by-products such as fly ash, silica fume, Rice Husk Ash, ground-granulated blast-furnace slag (GGBS), and many more which are pozzolanic in nature. And the old conventional method of making concrete using OPC should be minimized gradually as cement production is a potential threat to environment due to huge carbon footprints leading to global warming. So the major challenge of concrete makers is to develop and implement newer construction materials which will enhance strength and durability of concrete. High-strength Geopolymer concrete and blended OPC-based concrete are the most important research areas which need to be encouraged at a higher scale for making durable high-rise structures utilizing strength-enhancing materials. In this review, the effects of incorporation of strength-enhancing materials, i.e., silica fume and Rice Husk Ash on Geopolymer concrete and OPC-based concrete, are discussed with necessary comparisons from various research studies around the world.

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K. Ganesh Babu et al. (eds.), *Emerging Trends in Civil Engineering*,
Lecture Notes in Civil Engineering 61,
https://doi.org/10.1007/978-981-15-1404-3_21

Keywords Geopolymer concrete · Pozzolanic · Strength-enhancing material · Rice Husk Ash

1 Introduction

From the 3800-year-old Great Pyramid of Giza to the modern architecture marvels like Burj Khalifa, human's love for high-rise buildings has never changed but as David Allan Coe said "It is not the beauty of a building you should look at; it's the construction of the foundation that will stand the test of time." With the ever-increasing rates of construction, now more than ever the use of cement has increased and is expected to reach the production rate of 4830 million metric tons by 2030 [1]. As of now cement is the second most widely used material worldwide with the first being water. The humongous use of ordinary Portland cement (OPC) gives rise to several problems. The major problems regarding OPC are sustainability, high CO_2 emissions (5–7% of the world's CO_2 emission is due to the use of OPC), and wastage of water in the curing process [2]. Geopolymer concrete (GPC) is a concrete without cement and is made up of industrial wastes containing high content of silicon and aluminum. It was first introduced by a French chemist named Joseph Davidovits. Apart from the aggregates, the major constituents of Geopolymer concrete are source material and alkaline liquids [3]. The major source materials used in Geopolymer concrete are fly ash and ground-granulated blast-furnace slag (GGBS). Furthermore to enhance the strength and durability properties of GPC, some strength-enhancing materials are also used, viz. silica fume, Rice Husk Ash, nano silica, etc. The markets have an ever-increasing demand for the strength-enhancing materials due to the significant increase in the quality and life of the modern concrete.

2 Geopolymer Concrete Versus OPC Concrete

Modern construction works require skilled laborers and good machinery which basically increase the cost of construction naturally. The cost of cement, its effect on environment due to carbon footprints, water requirements, and durability issues are now well known. On the other hand, Geopolymer concrete, the concrete without cement, will give a tough competition in near future to cement manufacturers as it reduces the dependence on cement and water for making concrete. Highly alkaline solutions, namely sodium/potassium hydroxide and sodium/potassium silicate along with industrial waste materials such as fly ash, GGBS, and Rice Husk Ash which are rich in silicon and aluminum combine to form the Geopolymer matrix which is very different from C-S-H gel mechanism in OPC-based concrete. Geopolymer concrete reduces water requirements for mixing and curing. On the other hand, conventional concrete needs sufficient water both for mixing and curing which increases problems with respect to water shortage. Extensive research findings from all over the world suggest that Geopolymer concrete is the third generation concrete. The first and the second are lime-based concrete and cement-based concrete. Researches established that Geopolymer concrete is superior to conventional concrete in terms of setting time, strength, workability, and durability. Though certain behavioral characteristics, proper mix design code has not been established till now. Hence, conventional concrete is preferred by most concrete makers and users.

3 Need for Strength-Enhancing Materials

Wind and seismic load conditions are now implemented in design of every high-rise structures. And particular emphasis should be given on quality and strength of concrete. Therefore, there is a need for strength-enhancing materials in making concrete as we know that a concrete with maximum strength has better mechanical properties too and also it can counter various load conditions. Numerous researches worldwide on the implementation of strength-enhancing materials like silica fume and Rice Husk Ash on making high-strength Geopolymer concrete and OPC-based concrete have proved to be encouraging. As the strength-enhancing materials are pozzolanic in nature, naturally they contribute to high strength and better durability in Geopolymer as well as conventional concrete. Geopolymer concrete needs rich source of silicon/aluminum which will make a high-strength Geopolymer matrix after reaction with alkaline solutions and conventional concrete requires C-S-H gel formation for strength which is enhanced by pozzolanic activity of these strength-enhancing materials such as silica fume and Rice Husk Ash.

4 Strength-Enhancing Materials—Silica Fume (SF) and Rice Husk Ash (RHA)

4.1 Silica Fume

Silica fume (SF) also known as micro-silica is a by-product of ferrosilicon industry. Silica fumes are very fine non-crystalline silica produced as a by-product during the production of elementary silicon or silicon-containing alloys in electric arc furnaces. The silica fumes have unbound potential to be used in conventional cement concrete and Geopolymer concrete due to the high amount of amorphous silica content present in it. ASTM has specified silica fume as pozzolanic material and developed a standard for its use in cementitious mixtures—ASTM C1240. The physical and chemical properties of silica fumes given by some scientists and researchers are given below in Table 1 and Table 2, respectively.

Table 1 Physical properties of silica fume

Physical properties	H. Y. Moon et al.	N. K. Amudhavalli
Specific gravity	2.20	2.20
Mean particle size (μm)	–	0.1
Specific surface area (m^2/Kg)	20,470	20,000
Bulk density (Kg/m^3)	–	576

4.2 Rice Husk Ash

India being the second largest producer of rice has enough resources to produce Rice Husk Ash (RHA) in humongous quantities. RHA is a by-product of the rice milling industries. It is produced by controlled combustion of rice husk in the steam boiler. The heat energy produced in the process is used in processing the rice [6]. Meanwhile, this process produces 55 kg of ash per 1000 kg of husk [7]. The RHA produced can be used as a supplementary cementitious material (SCM) in OPC concrete and as a strength-enhancing material in Geopolymer concrete because of the high percentage of nascent SiO_2 present in the ash. The physical and chemical properties of RHA proposed by some researchers are tabulated below (Tables 3 and 4).

5 Effects of Silica Fume on Concrete

5.1 Compressive Strength

Conventional Concrete. Karthikeyan and Arunkumar stated that the compressive strength of conventional concrete increases when silica fume is added although the change in compressive strength is not very significant. They found maximum compressive strength of 65.60 MPa with 10% of silica fume where the normal concrete compressive strength was 61.79 MPa [12]. The compressive strength results have been depicted in Fig. 1.

Geopolymer Concrete. F. N. Okoye et al. stated that the compressive strength of Geopolymer concrete significantly increases with an increase in silica fume content, and they observed the maximum compressive strength of the GPC having 40% of silica fume which was nearly twice of the GPC without the silica fume [5].

A Joshua Daniel et al. studied the behavior of Geopolymeric reactions with OPC as a precursor. They replaced OPC by silica fume in M25 grade concrete with 20, 40, and 60%. They found the maximum compressive strength of 30.1 MPa with 40% of silica fume, and there was a reduction in compressive strength of the mixtures

Table 2 Chemical properties of silica fume

Silica fume	SiO_2	CaO	MgO	Na_2O	K_2O	MnO	Al_2O_3	Fe_2O_3	SO_3	LOI
H. Y. Moon et al. [4]	91.20	0.70	0.30	–	–	–	1.30	0.8	–	2.30
F. N. Okoye et al. [5]	93.67	0.31	0.84	0.40	1.10	0.84	0.83	1.30	0.16	2.10

Table 3 Physical properties of RHA

Physical properties	Mehta et al. [7]	Nagrale et al. [8]
Mean particle size	–	63.8
Specific gravity	2.06	2.11 µm
Fineness passing 45 µm (%)	99	98

containing 20 and 60% silica fume by 30.37 and 19.45% with respect to conventional concrete [13].

5.2 Workability

Conventional Concrete. The workability of cement concrete with different percentage replacements of cement by silica fumes was investigated, and it was found that at increased percentage of silica fume enhanced the concrete workability marginally, the maximum compaction factor and slump were found as 87 and 42 mm at a replacement of 35% of OPC by silica fumes [14].

Geopolymer Concrete. The workability of Geopolymer concrete gradually decreases with the percentage increment of silica fumes. The workability of Geopolymer concrete containing silica fume was measured using slump cone, and it was observed that silica fume-containing mixtures were less workable than that of the mix containing only fly ash [5].

P. Chindaprasirt et al. stated that the Geopolymer mixes are more cohesive as compared to OPC concrete mixes due to the addition of viscous sodium silicate solutions in the fresh Geopolymer concrete [15].

5.3 Durability

5.3.1 Sulfate Attack

Conventional Concrete. The sulfate attack occurs in conventional concrete due to the presence of calcium compounds (free lime) when the silica fume is added to cement concrete mixes as a replacement of cement; it shows pozzolanic activity and utilizes the free lime content to form secondary C-S-H gel. In a 5% sodium sulfate solution, the resistance of mortar specimens with silica fumes showed a greater resistance than the conventional mortar specimens [4].

Geopolymer Concrete. The Geopolymer concrete containing silica fume displayed greater sulfate resistance in comparison to both OPC concrete and Geopolymer concrete without silica fume. The increment in sulfate resistance of silica

Table 4 Chemical properties of RHA

Constituents	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
Le et al. [9]	86.81	0.50	0.87	1.04	0.85	–	0.69	3.16	4.6
Lung [10]	91.00	0.35	0.41	–	0.81	1.21	0.08	3.21	8.5
Zerbino et al. [11]	95.04	0.30	0.44	1.25	0.45	0.01	0.09	1.04	0.51

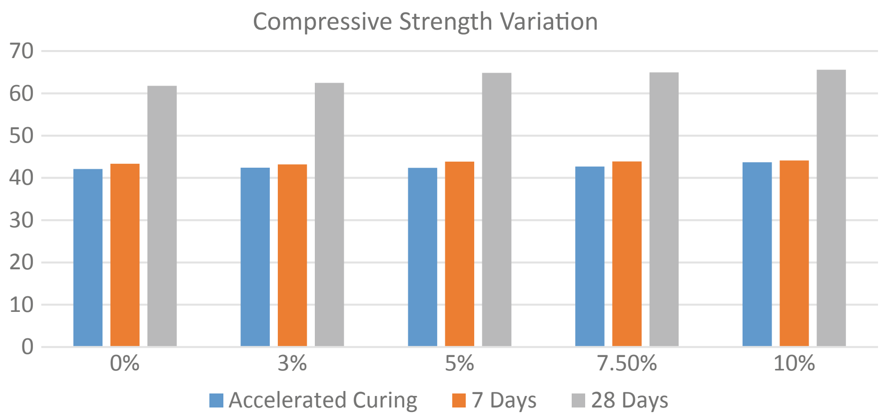

Fig. 1 Variation of compressive strength with % of silica Fume (Karthikeyan et al. [12])

fume incorporated Geopolymer concrete may be due to the denser microstructure development [16].

5.3.2 Chloride Attack

Conventional Concrete. Safwan A. Khedr investigated the performance of mortar specimens with and without silica fume in high concentration of HCl and found a greater resistance to chloride attack in mortar specimens containing silica fumes [17].

Geopolymer Concrete. The experiments by F. N. Okoye et al. on keeping Geopolymer concrete cubes with silica fumes in a chloride environment of 5% NaCl for 56 days depicted that the sample had good chloride resistance [5]. The micro-structural image of the specimens was analyzed by SEM analysis (Fig. 2).

6 Effect of Rice Husk Ash on Concrete

6.1 Compressive Strength

Conventional Concrete. P. Chandan Kumar investigated the effect of Rice Husk Ash in cement concrete by replacing the OPC in various percentages, and he found that the 7.5% replacement of OPC by RHA gives better compressive strength as compared to the conventional one [18].

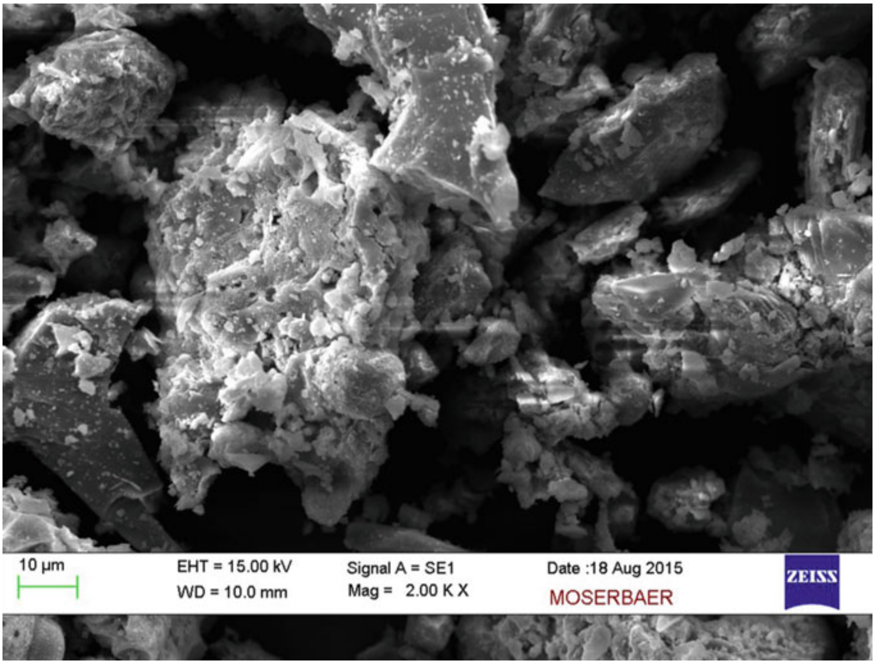

Fig. 2 SEM image of GPC specimen after chloride treatment (F. N. Okoye et al. [5])

Tests on compressive strength were conducted by M. S. Ismail and A. M. Waliuddin by varying percentages of RHA in cement concrete. They concluded that the replacement of 20% of the mixture with RHA gave the best results in compressive strength tests [19]. Furthermore Arvind Kumar et al. studied the effect of Rice Husk Ash in OPC concrete by replacing 20% of cement by RHA; initially, they found the early strength of RHA-based concrete was less but the final strength was slightly higher as compared to conventional concrete [20] (Fig. 3).

Geopolymer Concrete. Seyed Mahmoud Zabihi et al. conducted experimental investigations on OPC-RHA-based Geopolymer concrete. The results explicitly indicate that a significant enhancement in compressive strength occurs when the OPC is replaced up to 80% by RHA [21].

Howsoever, the results of experiments conducted by P. V. Ramani et al. imply that RHA is a strength-enhancing material when used in place of GGBS in quantities under 10%. Beyond that RHA tends to decrease the compressive strength. When GGBS is replaced by RHA in an optimum doge, compressive strength of 51 MPa was achieved in the span of 28 days [22].

The experiments conducted by D. R. Dara and A. C. Bhogayata on varying RHA percentages from 0 to 25% in fly ash-based Geopolymer concrete depict the increment of compressive strength by 5.40% compared to normal concrete samples at 25% of RHA [23].

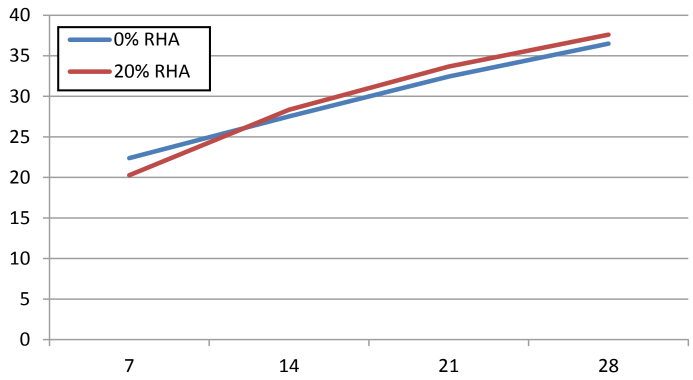

Fig. 3 Variation of compressive strength with time (Kumar et al. [20])

6.2 Workability

Conventional Concrete. RHA has a very large specific surface area due to highly porous nature of the material and fineness. This results in decreased workability of the concrete due to excessive water absorption [17].

Ramakrishnan S. et al. has conducted slump test (as per IS: 1199-1959) to measure workability, and they found a decreasing value of slump with the increment of RHA percentage in the concrete matrix [24]. The slump test results are shown in Table 5.

Geopolymer Concrete. In fly ash-based Geopolymer concrete, the workability gradually decreases with the percentage increase of RHA. At 25 and 30% of RHA content, the Geopolymer concrete shows very less workability [25].

RidhoBayuaji et al. performed an experiment to check the workability of RHA-fly ash-based Geopolymer concrete and found a cohesive and non-workable concrete mix. Thereafter, they added table sugar in a doge of 10.5 kg/m^3 in the Geopolymer concrete. This resulted in a longer setting period enabling the concrete to be workable for a longer time [26].

Table 5 Slump results with different % of RHA (Ramakrishnan et al. [24])

Mix	S. No.	RHA %	Slump value
M40	01	0	71
	02	5	33
	03	10	18
	04	15	5
	05	20	–
	06	25	–

6.3 Durability

6.3.1 Sulfate Attack

Conventional concrete. The sulfate resistance of RHA-based concrete is exceptionally higher as compared to normal concrete. When the RHA specimens were immersed in Na_2SO_4 and $MgSO_4$, the strength decoration of RHA-based concrete was negligible as compared to that of normal concrete specimens [27].

H. K. Venkatanarayanan et al. reported that the sulfate resistance of the RHA-based concrete cubes was greater than the control concrete cubes at 360 days [28].

Geopolymer Concrete. It is being reported that the Geopolymer concrete has greater sulfate resistance than the cement concretes as there is no free lime content. Geopolymer concrete shows greater sulfate resistance with increasing levels of RHA from 0 to 15% [29]. Yun YongKim et al. studied the behavior of Geopolymer mortar made up of RHA in sulfate environment and found the effective resistance of the specimens of RHA-based mortars toward sulfate attack [30].

6.3.2 Chloride Attack

Conventional Concrete. OPC concrete is comparatively porous in nature than RHA-based concrete; hence, it is more prone to the chloride attacks as the chloride ions tend to penetrate the concrete through these voids. RHA reduces the total volume of void ultimately making concrete impervious to chloride ion penetration.

The corrosion performance of concrete was studied with RHA content of 0, 5, 10, 15, 20, 25, and 30%, and it was notified that the concrete with 15, 20, 25, and 30% of RHA showed greater chloride resistance [31].

Geopolymer Concrete. The corrosion resistance of Geopolymer concrete improves when GGBS is replaced with RHA. P. V. Raman et al. conducted rapid chloride permeability tests (RCPTs) on Geopolymer concrete specimens containing 0, 10, 20, and 30% RHA [22]. The results of the experiment are charted below (Fig. 4).

7 Conclusions

Based on the studies and comparisons mentioned in the paper, we can reach on the conclusion that both Rice Husk Ash and silica fume enhance the properties of conventional as well as Geopolymer concrete. However, the impacts on strength and durability of these strength-enhancing materials are more significant in case of

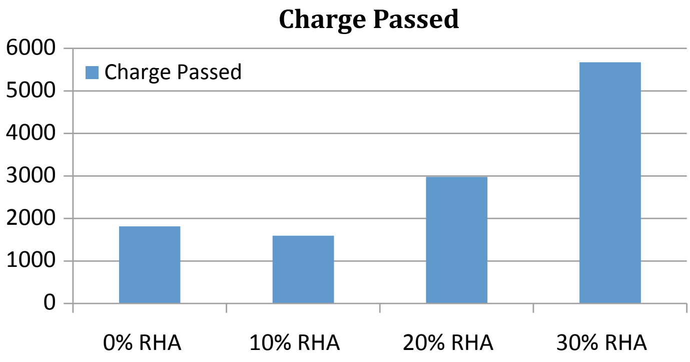

Fig. 4 Rapid chloride permeability test results with different % RHA (Ramani et al. [22])

Geopolymer concrete. These materials improve the properties of conventional concrete but it is not sustainable as concrete uses OPC as the primary binder. Hence, more efforts and extensive research are required to establish and implement Geopolymer concrete to promote sustainable development.

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