



Compressive Strength of Concrete using Fly Ash and Rice Husk Ash: A Review

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Abstract

Decreasing our over-reliance on cement as an ingredient in the making of concrete due to its contribution to the CO₂ emissions has led to numerous researches been conducted to find suitable replacement for cement in concrete mixes. Materials like fly ash, ground granulated blast furnace slag, silica fume, rice husk ash and metakaolin among others have been identified as materials that can at the very least be used as a replacement for cement in concrete mix. These materials are referred to as supplementary cementitious materials (SCMs). This paper reviewed the work that has been done on the use of fly ash and rice husk ash as partial replacements for concrete, its chemical composition and its effect on the compressive strength of concrete. Charts, tables and figures were employed as tools to study the various chemical compounds of fly ash and rice husk ash. It was seen that depending on how the coal or rice husk was initially processed the percentage of some of the minor compounds like Sodium oxide (Na₂O), Titanium oxide (TiO₂) and Phosphorus pentoxide (P₂O₅) were sometimes very low or not recorded as part of the final product. The data on the compressive strength of concrete after fly ash and rice husk ash had been added in percentage increments of 0%, 10%, 20%, 30%, 40%, 50% and 0%, 5%, 7.5%, 10%, 12.5%, 15% respectively analysed over a minimum period of 7 days and a maximum period of 28 days found out that the optimal percentage partial replacement of fly ash and rice husk ash for a strong compressive concrete strength is 30% of fly ash and 7.5% of rice husk ash.

Keywords: Compressive Strength; Rice Husk Ash; Fly Ash; Concrete; Chemical Properties.

1. Introduction

Industrialization and urbanization, population growth, globalization of the economy market and consumerism and environmental pollution are the main factors which contribute to the social and economic changes in the society. These factors have caused another phenomenon; climate change. This is resulting in dangerous issues to humanity [1].

Negative environmental impacts associated with widespread use of cement has led researchers to take giant steps concerning the advancement of tools and materials with the aim of decreasing the over-reliance of cement in the production of concrete and masonry building materials [2].

Environmental protection and conservation are a big problem in a global context. The construction industry is increasing at an exponential rate and this has an impact on the demand for construction materials [3]. The rapid advancement of globalisation and the increase in population growth has caused an increase in building construction which has subsequently resulted in a greater demand for building materials [4]. Currently, sustainable development is one of the most interests around the world [5].

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Natural aggregates used in construction are gradually being depleted due to industrialisation and urbanisation. Therefore, the development of sustainable construction materials and recyclable construction resources is necessary [6]. There is a direct correlation between the construction industry, world resources, energy consumption and carbon dioxide emissions [7].

Concrete has been posing problems for architects, engineers, researchers and constructors for a long time [8]. Next to water, the second most used up material is concrete which accounts for about 5% of the CO₂ emissions in the world (Worrell, 2001 as cited by Gaurav and Amit, 2015) [9]. Eight to ten percent of the CO₂ emissions in the world comes from the production of cement [1]. Due to the 5% anthropogenic CO₂ that the cement industry contributes in the world, this makes it a crucial area when it comes to the mitigation strategies concerned with the reduction of CO₂ emissions (Ernst Worrell et al, 2001 as cited by Gupta and Wyal, 2015) [7].

The percentage replacement of cement with a suitable substitute is the best way in decreasing CO₂ emissions [10]. Fly ash (FA), silica fume (SF), ground granulated blast furnace slag (GGBS), metakaolin (MK) and rice husk ash (RHA) among others are some of the mineral admixtures used for cement replacement [11]. These are called supplementary cementitious materials (SCMs).

SCMs are materials that satisfies the requirement of improving strength, permeability, durability, unit weight, consistency and hydraulic factors of concrete [12]. The use of SCMs reduces waste materials and their impacts on the environment while also reducing its carbon footprint when it is used to replace cement in concrete. The mechanical properties of concrete can be enhanced by SCMs when used either in a fresh state or hardened mixtures (Lothenbach et al, 2011; Aprianti et al, 2015; Snellings et al, 2015 and Elahi et al, 2015 as cited by Zhi-hai et al, 2017) [13]. Using supplementary cementitious materials constitute a modern means of replacing Ordinary Portland Cement [2].

The problems associated with the protection of the environment makes using waste a necessary material in the construction and building industry. Waste can be used to produce building materials or to improve a lot of the different parts of the existing building materials [14]. A lot of developing countries have a problem regarding waste since it results in the rise in pollution. This problem could be solved through the recycling of these materials into new construction materials. This could also serve as a way of reducing the high cost of construction materials in these countries [8]. SCMs also reduces the cost associated with construction while providing “green” concrete with its comparable mechanical properties. They are thus generally used in concrete in a blended form or added into concrete mixtures [13].

Research has been intensified in the use of some locally available materials which can serve as partial replacement for cement in construction works due to the need to decrease to huge cost involved in using Ordinary Portland cement in concrete [15]. This paper reviews the research works done by other researchers by using tables, charts and figures to analyse the chemical compounds of fly ash and rice husk ash and its effect on the compressive strength of concrete after 7, 14 and 28 days after different percentages of fly ash and rice hush ash have been added to concrete as a partial replacement.

2. Fly Ash

Fly ash is a fine powder that is a by-product of burning pulverised coal in electric generation power plants. Fly ash is a pozzolan, that is; it is a substance containing aluminous and siliceous material that forms cement in the presence of water. When mixed with lime and water, fly ash forms a compound similar to Portland cement [16].

Fly ash can be a cost-effective substitute for Portland cement in many markets. Fly ash is also recognised as an environmentally friendly material because it is a by-product and has low embodied energy [16]. Most fly ash is pozzolanic, which means it is a siliceous or siliceous-and-aluminous material that reacts with calcium hydroxide to form cement [17].

As early as the 1914, fly ash was recognised as a pozzolanic material even though it was not until 1937 a significant research regarding its use was made [18]. Volcanic ash or pozzolana was used in the construction of some Roman buildings such as the aqueducts and the Pantheon [19].

Fly ash has been used as a partial replacement of fine aggregate and has been recommended for structural use [11]. Fly ash increases the strength of concrete and it also makes it easier to pump [16]. Fly ash improves concrete's workability, pumpability, cohesiveness, finish, ultimate strength and durability as well as solves many problems experienced with concrete today and all for less cost [17]. The biggest reason to use fly ash in concrete is the increased life cycle expectancy and increase in durability associated with its use [20].



Figure 1. Fly ash [21]

2.1. Chemical Properties of Fly Ash

Fly ash is a material that can vary significantly in composition. It is a residue that is left behind from the burning coal, which is collected on an electrostatic precipitator or in a baghouse [17]. Fly ash is classified into two classes according to the ASTM C618. These two classes are Class F Fly ash and Class C Fly ash [22]. The main difference between these classes is the quantity of chemical composition in the fly ash.

The quality of a fly ash is influenced by the fly characteristics (coal), co-firing of fuels, and various aspects of the combustion and flue gas cleaning/collection processes. The most important aspects of fly ash for use in concrete are Loss of Ignition (LOI), fineness, chemical composition and uniformity [21].

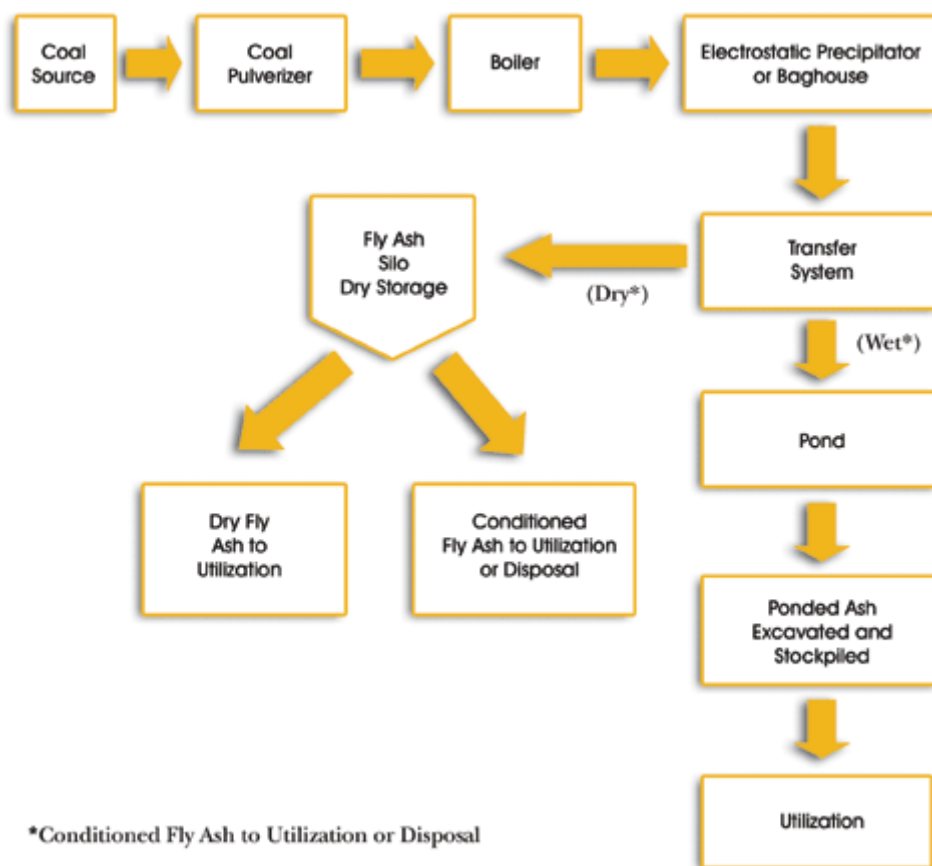


Figure 2. Flowchart showing the process of fly ash production [21]

The chemical composition of fly ash from previous studies by other authors is given in Table 1 and Figure 3.

Table 1. Chemical properties of fly ash in weight (%)

Chemical composition	Sources								
	[23]	[24]	[25]	[26]	[27]	[28]	[29]	[30]	[31]
SiO ₂	29.7	52.83	51.43	48.61	42.1	51.7	50.5	55.0	50.0
Al ₂ O ₃	10.65	21.50	30.93	23.79	21.0	31.9	28.9	24.5	32.85
Fe ₂ O ₃	6.18	10.49	2.29	7.91	7.12	3.48	4.7	7.1	4.21
CaO	32.92	6.44	6.75	3.06	14.8	1.21	5.0	4.2	4.91
P ₂ O ₅	ND	1.75	1.08	ND	ND	ND	0.76	ND	ND

MgO	5.93	0.89	1.95	2.07	2.0	0.81	1.8	1.95	1.58
SO ₃	9.98	ND	0.54	0.40	0.7	0.25	0.21	0.08	ND
Na ₂ O	0.74	0.82	0.54	ND	0-2	1.02	ND	0.30	1.42
K ₂ O	0.61	1.76	0.77	ND	0-5	1.02	0.8	3.88	1.35
TiO ₂	ND	1.60	1.74	ND	ND	ND	1.56	2.02	ND
LOI*	2.09	1.50	1.21	3.12	7.31	9.63	3.6	0.32	3.20

LOI – Loss on Ignition, ND – No Data

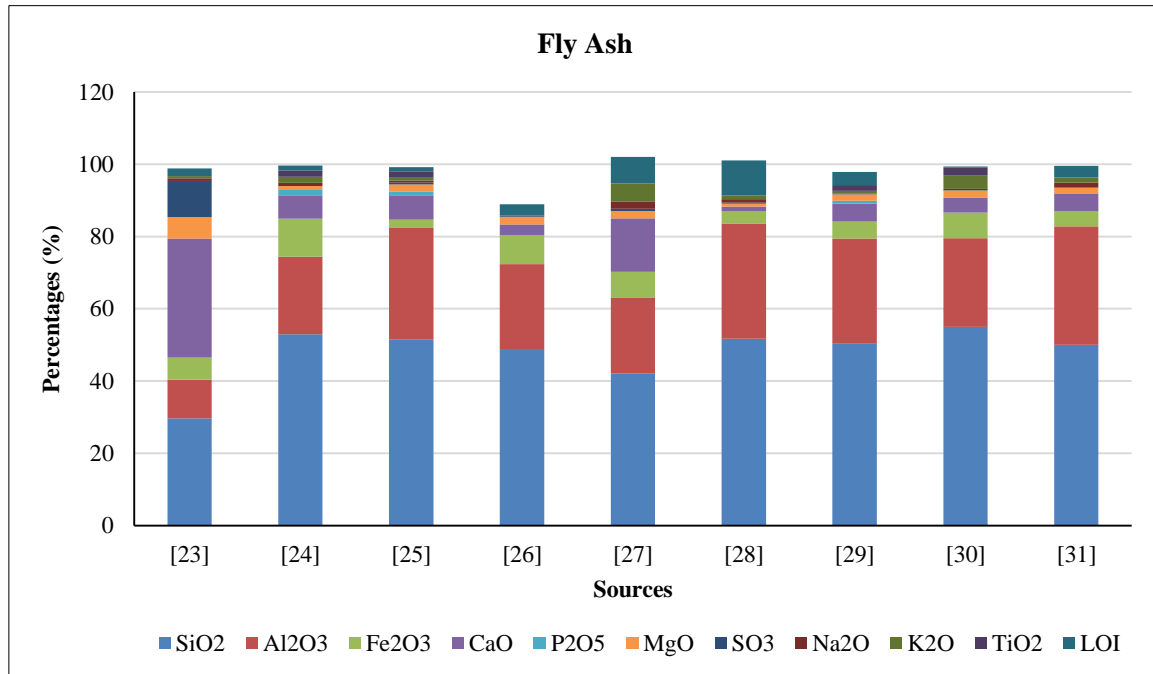


Figure 3. A stacked bar chart showing the various chemical compounds in a fly ash mixture

It can be seen from Table 1 and Figure 3 that depending on the process in which the coal is burnt and the source of the coal, the chemical compounds in the fly ash mixture will vary.

3. Rice Husk Ash

Rice husk ash (RHA) is a waste product from the cultivation of rice that is usually used for in the manufacturing of concrete. Rice husk is one of the agricultural wastes and by-products of rice which constitute about one-fifth of 751.9 million tons of rice produced annually in the world (FAO, 2017 as cited by Selvaraja et al. 2017) [32].

The milling of paddy in a rice mill is the way in which rice husk is made and rice husk ash is obtained after rice husk has been burnt the rice husk in boiler [33]. The covering of the rice is what is known as rice husk. A high level of silica dioxide (SiO₂) is obtained if the proper processes of burning the rice husk are followed. This can be used as a supplementary cementitious material and in addition to cement can be used to manufacture concrete materials [7].

Rice husk is seen as a pozzolana. A pozzolana is any material that can be considered as a siliceous/aluminous material with little or no cementitious value but can be used to make a stable and insoluble cementitious material when in the presence of calcium hydroxide which was liberated during the hydration of Portland cement (Sima, 1974 as cited by Dabai et al. 2009) [34].

Concrete made with Portland cement and rice husk ash has a high compressive strength due to the calcium silicate hydrate gel which forms around the cement particles. This becomes denser and less porous thereby increasing the strength of the concrete as far as cracking in concerned [8].



Figure 4. Rice husk ash [35]

3.1. Chemical Properties of Rice Husk Ash

Burning of rice husk into ash is a prerequisite by which the physical characteristics and chemical compounds a mixture admixture could be met [15]. To ensure a quality rice husk ash, the way in which the rice husk ash is made and the conditions under which it is made should be considered carefully in order to make the ash an active pozzolanic material [36].

Depending on the raw material which was used, the incineration method, time, duration and the temperature of the burning, the colour of the final rice husk ash product will range from white gray to black [37]. The burning temperature of RHA is extremely important to ensure pozzolanic behaviour. Rice husk ash is recommended to be burnt below 1440°C is its melting point (Sugita, 1993 as cited by Rumman et al. 2020) [38].

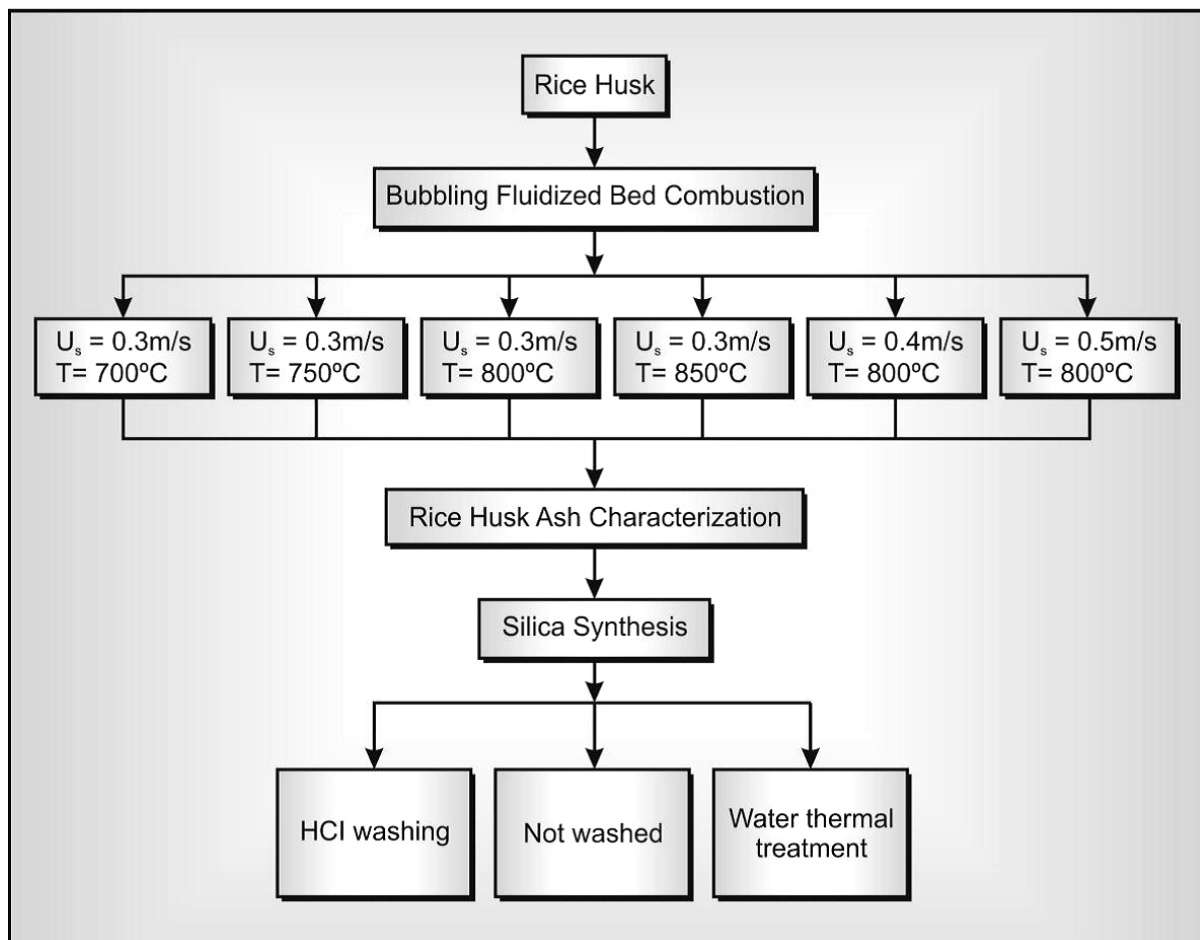


Figure 5. Flowchart showing the process of Rice Husk Ash production [39]

The chemical composition of rice husk ash from previous studies by other authors is given in Table 2 and Figure 6.

Table 2. Chemical properties of rice husk ash in weight (%)

Chemical composition	Sources								
	[40]	[39]	[41]	[42]	[43]	[44]	[45]	[46]	[47]
SiO ₂	96.7	86.0	89.61	87.4	85.58	97.5	93.4	90.0	96.7
Al ₂ O ₃	1.01	5.12	0.04	0.4	0.25	0.73	0.05	0.46	1.01
Fe ₂ O ₃	0.05	1.12	0.22	0.3	0.21	1.18	0.06	0.43	0.05
CaO	0.49	1.26	0.91	0.9	1.83	0.18	0.31	1.10	0.49
SO ₃	ND	2.79	ND	0.4	0.26	0.49	ND	ND	ND
P ₂ O ₅	ND	0.48	ND	ND	0.67	ND	0.8	2.43	ND
MgO	0.19	0.48	0.42	0.6	0.50	ND	0.35	0.77	0.19
TiO ₂	ND	0.17	ND	ND	ND	ND	ND	ND	0.16
Na ₂ O	0.16	0.05	0.07	0.04	ND	0.10	0.1	ND	0.26
K ₂ O	0.91	1.82	1.58	3.39	3.39	1.39	1.4	4.60	0.91
LOI*	4.81	ND	5.91	4.60	6.99	ND	ND	3.90	4.81

LOI – Loss on Ignition, ND – No Data

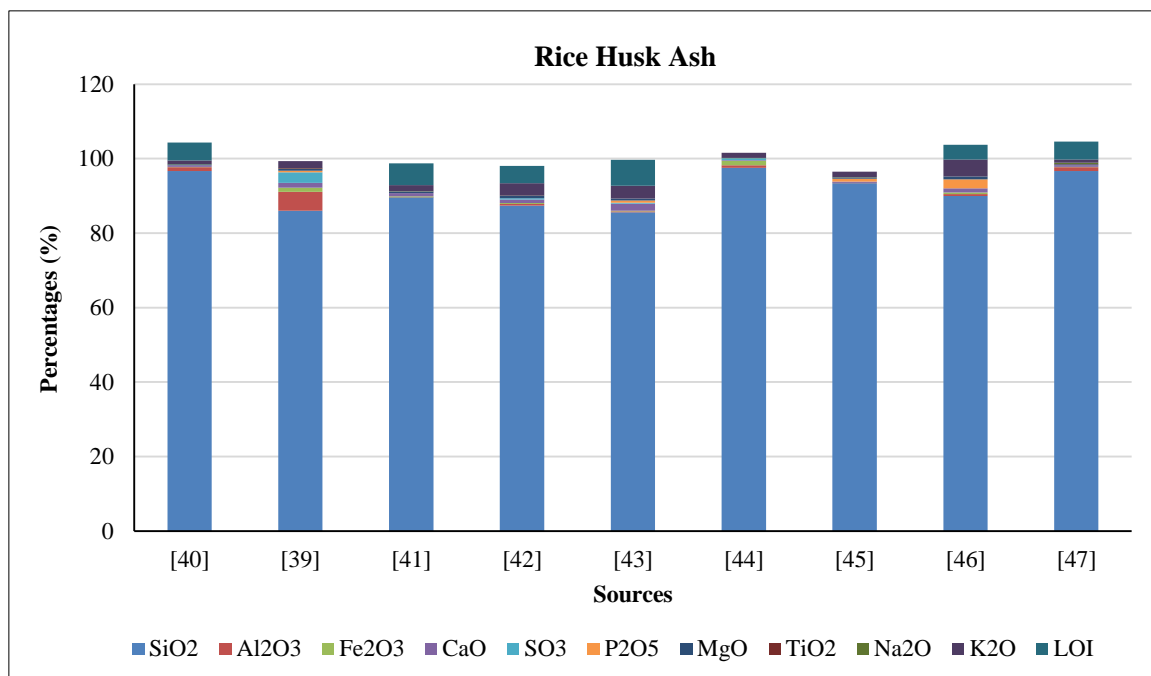


Figure 6. A stacked bar chart showing the various chemical compounds in a rice husk ash mixture

4. Compressive Strength

Compressive strength is defined and interpreted differently by various people. The following are some of its numerous definitions:

- The compressive strength of a material or a structure is the ability of a material or structure to withstand loads [48].
- The maximum compressive stress under which a given solid material can withstand without fracturing is known as its compressive stress [49].
- Compressive strength is measured on materials, components and structures [50].
- The most important aspect of building materials is its compressive strength [51].

One of the most crucial parts of concrete is its compressive [52]. The compressive strength of concrete varies depending on what it is being used for. The concrete compressive strength for residential concrete is 2500 psi to 4000 psi and more in commercial structures. A psi exceeding 10000 psi are used for certain constructions [49].

Compressive strength of a material is calculated as: $CS = F \div A$, where CS is the compressive strength, F is the force at point of failure and A is the initial cross-sectional area.

4.1. Compressive Strength of Fly Ash and Rice Husk Ash Concrete

It can be seen from Tables 3 and 4 and Figures 7 and 8 that for an optimum compressive strength of fly ash and rice husk ash a 30% replacement of fly ash and 7.5% replacement of rice husk ash are adequate.

Table 3. Compressive strength of fly ash concrete [53]

Fly Ash (%)	7 days	14 days	28 days
0	26.7	36.7	40.2
10	27.4	38.25	41.9
20	28.3	39.5	43.23
30	30.25	41.4	45.28
40	27.75	37.74	42.00
50	25.5	37.03	39.15

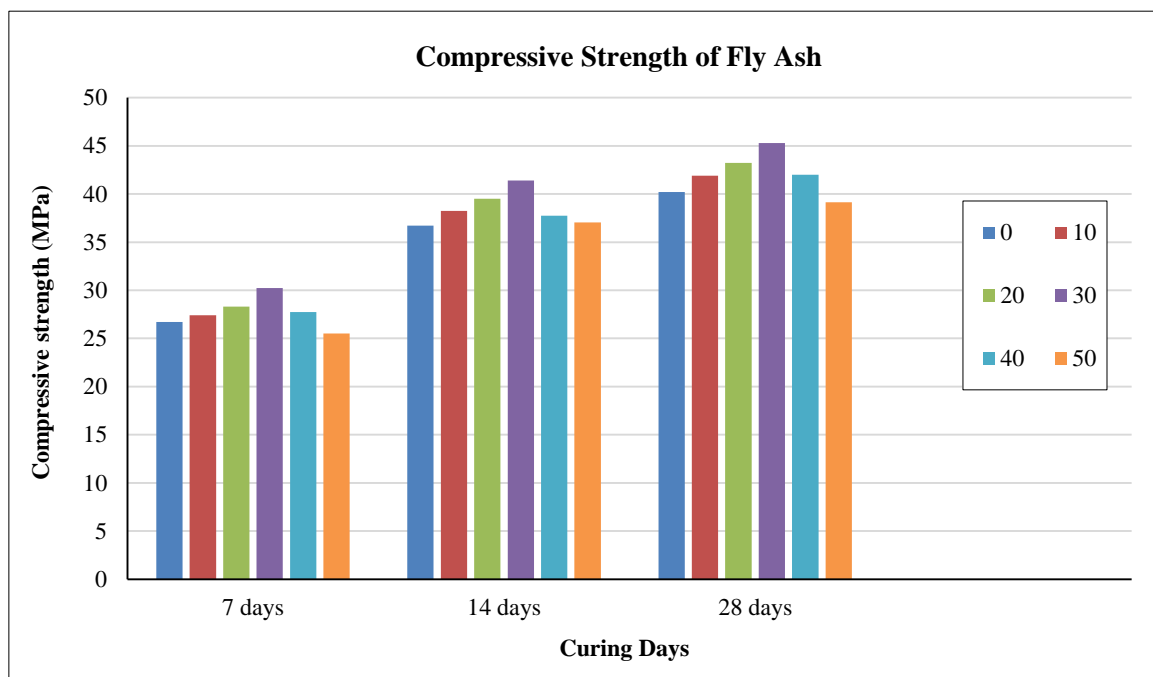


Figure 7. Bar chart depicting the compressive strength depending on the fly ash replacement

Table 4. Compressive strength of M-40 of rice husk ash concrete [33]

Rice Husk Ash (%)	7 days (MPa)	28 days (MPa)
0	27.8	41.70
5	26.6	39.90
7.5	28.3	42.45
10	27.3	40.95
12.5	26.2	39.30
15	25.9	38.85

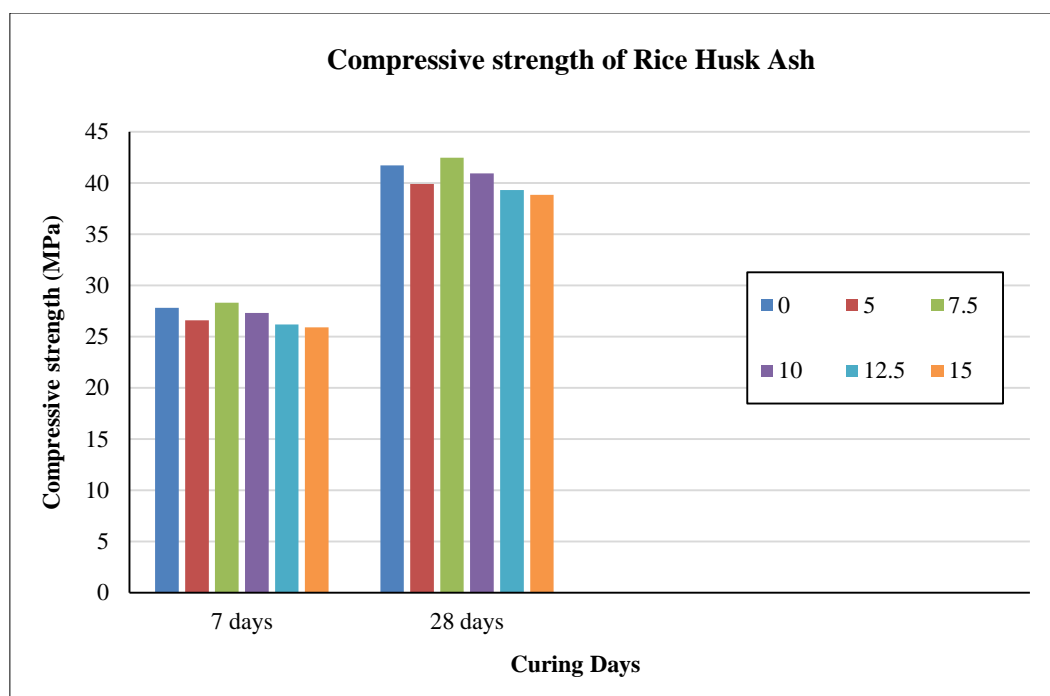


Figure 8. Bar chart depicting the compressive strength depending on the rice husk ash replacement

5. Conclusion

The need to create environmentally friendly materials which can serve as a partial replacement for cement in concrete mixes has gained a lot of attention due to cement's contribution to the CO₂ emissions. Charts, tables and figures were employed as tools to study the various chemical compounds of fly ash and rice husk ash. The use of these tools showed that the degree of relationship that exists between fly ash and rice husk ash in terms of its compressive strength and percentage replacement of cement with either fly ash or rice husk ash was established. The various chemical compounds derived after the burning of coal and rice husk were also studied. It can be seen from Tables 1 and 2 and Figures 3 and 6 that the method or process in which the raw material be it coal or rice husk is processed determined how much percentage some of the minor chemical compounds like Sodium Oxide (Na₂O), Titanium Oxide (TiO₂) and Phosphorus Pentoxide (P₂O₅) were recorded in the final products. Tests conducted by researchers in previous studies in concrete containing fly ash and rice husk ash as partial replacements were compared with concrete by varying the percentage replacement of fly ash and rice husk ash.

Fly ash and rice husk ash were added in percentage increments of 0%, 10%, 20%, 30%, 40%, 50% and 0%, 5%, 7.5%, 10%, 12.5%, 15% respectively as shown in Tables 3 and 4 and Figures 7 and 8. The compressive strength was analysed over a minimum period of 7 days and a maximum period of 28 days. It was found out that the optimal percentage partial replacement of fly ash and rice husk ash for a strong compressive concrete strength is 30% for fly ash and 7.5% for rice husk ash. It can be concluded that at the right percentage replacement of either fly ash or rice husk ash, there was an increase in the compressive strength of the concrete. This shows that fly ash and rice husk ash have the potential to be used as partial replacements in concrete production.

6. Conflicts of Interest

The authors declare no conflict of interest.

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