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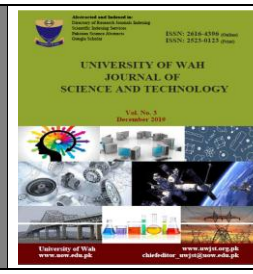

A Study of Properties of Wheat Straw Ash as a Partial Cement Replacement in the Production of Green Concrete

Muhammad Shoaib Khan, Farhan Ali and Muhammad Aamir Zaib

***Abstract*—Burning of wheat crop residue each year after harvesting is causing serious environmental degradation and severely effecting the quality of air. In proposed research properties of Wheat Straw Ash (WSA) and utilization of WSA as an environmentally friendly material is presented. Tests such as Blaine Air Permeability, X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) shows that WSA contain amorphous silica and has the potential to be used as a pozzolanic material, which is capable to replace cement partially. To determine the optimum percentage of WSA as a partial replacement of cement, a series of tests are conducted on 10%, 20% and 30% replacement of WSA by weight of cement. Slump and compaction factor test show a decrease in workability as the content of ash is increased, it is due to the large water absorption capacity of ash. One of the major finding is the high-water absorption capacity of the WSA which helps on a long term to reduce the shrinkage of concrete. Results show that the strength of concrete is decreased as the percentage of WSA is increased. The 10% replacement was relatable with the conventional concrete. A decrease in strength is noted for 20% and 30% replacement of cement by WSA.**

***Index Terms*— Green Concrete, Mechanical Properties, Pozzolan, Water Absorption, Wheat Straw.**

I. Introduction

CONCRETE is an important and extensively used construction material because of its strength, durability and availability of its ingredients around the world. Day by day increasing usage of conventional concrete in the construction industry are causing depletion of natural resources such and the extraction process leads to damage of landscape, contamination of water and air [1]. On the other hand, during the manufacturing process of cement, emission of toxic gases occurs causing air pollution. Studies have shown that the production of 1 ton of cement leads to the emission of 0.8 ton of carbon dioxide [2]. The quantity of CO_2 emission is almost equal to the production of cement. Therefore, the production of greener concrete is necessary to preserve the environment. Many researchers have pointed out the utilization of waste materials and industrial bio-products as an appropriate option to produce greener concrete. These studies includes the use of crumb rubber [3], waste glass as an aggregate in concrete [4] and various other by-products such as rice husk ash [5], fly ash [6], bamboo leaf ash [7], corn cob [8], olive [9], sisal [10] and slag [11]. These by-products are used as supplementary cementitious materials throughout the world. The present study focusses on the utilization of wheat straw ash (WSA) as a partial replacement of cement in concrete.

Wheat straw obtained from wheat milling is generally burnt in open area, as shown in the *Fig. 1*, thus polluting the environment [13-14]. On the other hand, the controlled burning of wheat straw can lead to the production of amorphous silica [15]. Amorphous silica plays a vital role in numerous chemical compounds and materials [16]. Silica (SiO_2) is an important component which is responsible for the strength of cement. Wheat straw ash is a pozzolanic material [17], containing a handsome amount of silica. According to a study [18], the quantity of silica in WSA is 73%. On the other hand, another study concluded the content of silica in WSA as 52% [19]. However, this change in the amount of silica is due to various factors such as topography, soil chemistry and type of fertilizers used.

Studies have concluded that the use of different pozzolanic materials improve the properties of mortar/concrete [20-21]. The properties of fresh and hardened concrete are affected by the amount of supplementary materials added to the mix. Various researchers conducted experiments on different percent

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replacement of cement by WSA. There are 8%, 16% and 24% WSA is used as a replacement of cement in [22]. Decrease compressive strength was noted in the first 28 days, later on after 180 days, compressive strength for 8% replacement was enhanced as compared to the control concrete. On the other hand, strength of mortar was investigated in [23] which is enhanced by using 7.5% replacement as an optimum proportion. In a recent study, 12.5% studied mortar and an increase of 17% in the 28 days strength as opposed to control mixture was noticed. According to a study [25], the strength of autoclaved mortar is increased by using 10.9% of WSA as a replacement of cement. Furthermore, a concrete mix comprises of barite, colemanite and 2.5% replacement of cement by WSA was also improved the compressive strength as compared to the conventional concrete [26]. Silica plays a vital role in strength gaining and the greater amount of silica will lead to a higher strength concrete. However, the amount of silica in WSA and other supplementary materials varies as discussed earlier. In the present study locally available wheat straw ash is used as a partial replacement of cement. The chemical properties, structure of the ash, properties of the fresh and hardened WSA concrete are studied in detail.

II. Collection of Samples

Pakistan is an agricultural country where the production of wheat is found to be in huge quantity and contributing very much to the country's economy each year. Wheat waste after milling, as shown in the *Fig. 2*, was sometimes mixed with grass and used as a source of food for some animals but the remaining huge amount of waste is either burnt or buried, which cause serious environmental threats.

The physical and chemical properties of WSA were affected by geographic location, soil chemistry, change in temperature and fertilizers used. In this study samples were collected from Khyber Pakhtunkhwa Province of Pakistan.

III. Experimental Testing and Methodology

A. Controlled Burning of Sample

The controlled burning of wheat straw leads to the production of high content of silica. The burning of wheat straw can result in crystalline silica amorphous silica, and carbon residues depending on different burning temperatures. Different researchers investigated different burning temperatures. According to the study conducted [18], the burning temperature ranged from 570°C to 670°C. It was observed an appropriate burning temperature of wheat straw is 900°C in [27]. Higher the burning temperature, higher is the amount of silica produced. However, burning at extreme high temperature causes the formation of crystalline silica as a resulting in decreased reactivity of the agricultural waste.

B. Blaine Air Permeability

Fineness is one of the important property of cement on which the rate of hydration greatly depends. The hydration process starts at the surface of the cement particles, thus the material availability for hydration is represented by the total surface area of the cement.

Fig. 1. Open Burning of Wheat Straw [12].

Fig. 2. Wheat Straw after grinding.

Higher the fineness of cement, the rapid is the development of strength. However, increasing fineness also effect other properties such as workability of fresh concrete and long-term behavior. The larger surface area requires more water due to smaller particle size and as a result greater amount of water will be required to produce a given workability and increasing the surface area speeds up settling. The fineness of particles can be increased but its effect on other properties and the cost of grinding must be kept in mind. Therefore, various properties are associated with fineness. The specific surface of the WSA is determined through the method of Blaine air permeability method. The specific surface is calculated as 2569 cm^2/gm.

The specific surface area of other wastes including banana leaf ash and oyster shell ash determined by [28-29], is 14,000 cm^2/g and 14280 cm^2/g, respectively, which is much higher than WSA. Similarly, the specific surface area of Mussel shell ash is also higher than WSA, however, it is approximately half of banana leaf ash and oyster shell ash [29].

C. X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD)

Literature review revealed that material is pozzolanic if the sum of percent of SiO_2, Fe_2O_3 and Al_2O_3 is greater than 70% [30]. Chemical analysis are performed on WSA through XRF is shown in the Table I, concluded that WSA is a pozzolanic material as the sum of percentage of SiO_2, Fe_2O_3 and Al_2O_3 is greater than 70% (equals to 75.51%) and it has the potential to be used as a partial replacement of cement in the production of sustainable concrete. No crystal peaks are observed during XRD analysis as shown in the *Fig. 3*, indicating amorphous silica in the ash (peaks between 25 and 30°) as a result pozzolanic activity is expected. A comparison of oxide composition of several agricultural wastes available in the literature is also shown in the Table II.

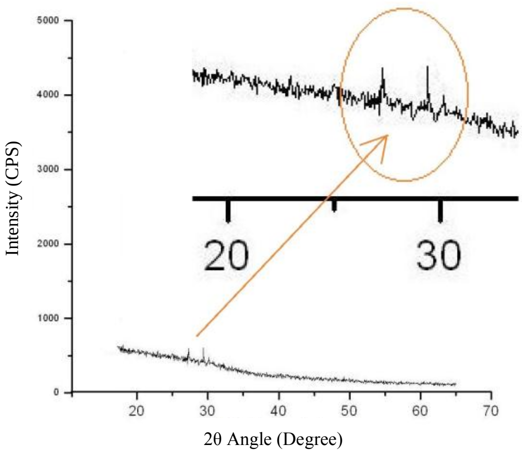


Fig. 3. X-ray diffraction analysis.

TABLE I
CHEMICAL COMPOSITION OF WSA

Compounds	Percent Values
Na_2O	1.67
Al_2O_3	0.94
CaO	3.23
MgO	1.85
SiO_2	73.4
K_2O	9.45
MnO	0.02
P_2O_5	1.28
TiO_2	1.90
Fe_2O_3	1.17

D. Scanning Electron Microscopy

The shape, size, and texture of WSA being important parameters are studied through scanning electron microscopy. SEM examine elongated and flat structure along the length, while honey comb structure is observed in the cross section of the WSA, as shown in the *Fig. 4 and Fig. 5*. The pores are of uniform size as shown in *Fig. 6*. These figures show the morphology of WSA powder in different scales. Results indicated porosity on the surface of ash. In terms of slump value and workability, the pores of WSA causes the mixing water to be absorbed and as a result reducing the workability of the mix. On the other hand, high water absorption helps in shrinkage of concrete. Therefore, different factors are associated with the shape of WSA grains.

TABLE II
CHEMICAL COMPOSITION OF VARIOUS AGRICULTURAL WASTES

Ref	Type of Waste	Oxide Composition (%) SiO_2, CaO, Al_2O_3, Fe_2O_3, Na_2O, MgO, K_2O
[31] [32] [33] [34] [35]	Bamboo Leaf Ash	73.1-81.1, 4.1-7.9, 1.0-4.0, 0.6-2.1, 0.2-0.3, 1.1 1.9, 1.2-5.7
[36] [37] [38]	Corn Cob Ash	37.0-66.4, 11.6-13, 2.4-7.5, 1.2-4.4, 0.3-0.4, 2.1-7.4, 4.9-15.0
[28]	Banana Leaf Ash	48.7, ---, 2.6, 1.4, 0.2, ---, ---
[39] [40]	Rice Husk Ash	86.98, 1.40, 0.84, 0.73, 2.46, 0.57, --- 88.32, 0.67, 0.46, 0.67, 0.12, 0.44, 2.91

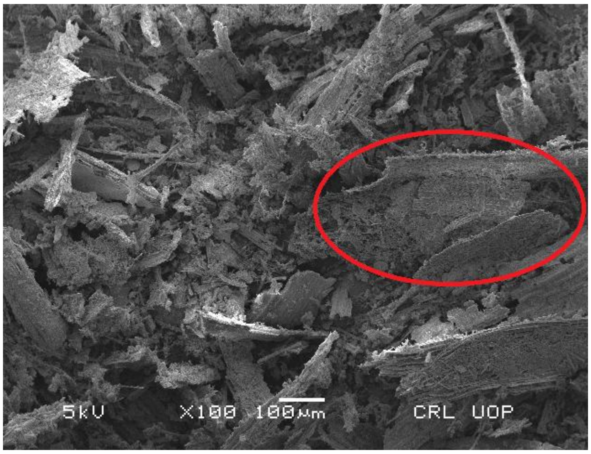


Fig. 4. Flat and Elongated Long Section.

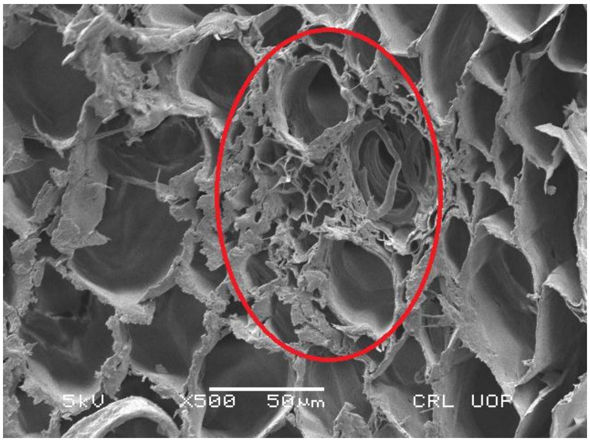


Fig. 5. Honey comb cross section.

In comparison with WSA, the SEM of various wastes including barley straw ash [41], bamboo leaf ash [31], banana leaf ash [28], elephant grass fibre [42] and rice husk ash [40] are shown in the *Fig. 7 (a), Fig. 7 (b1), Fig. 7 (b2), Fig. 7 (c), Fig. 7 (d)* and *Fig. 7 (e).*

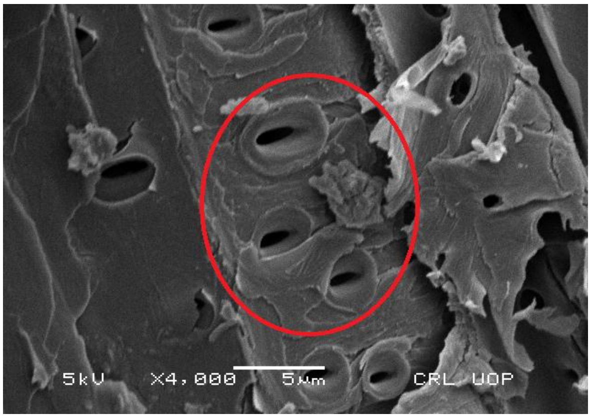
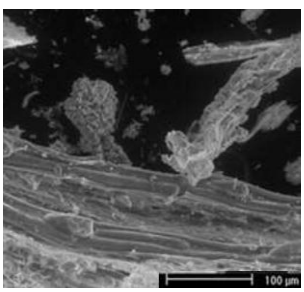
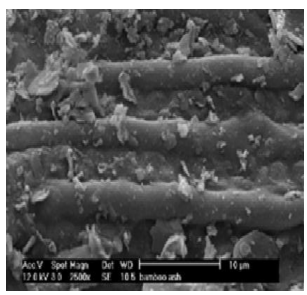


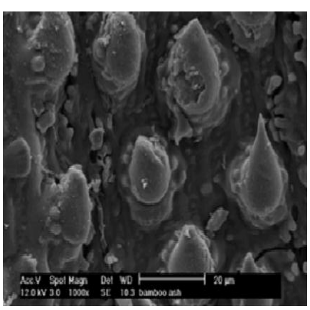
Fig. 6. Uniform size Pores.



(a)



(b1)



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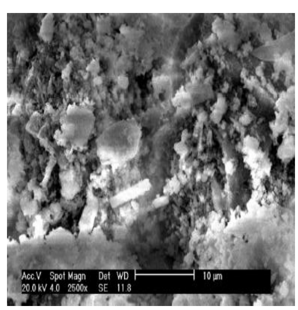
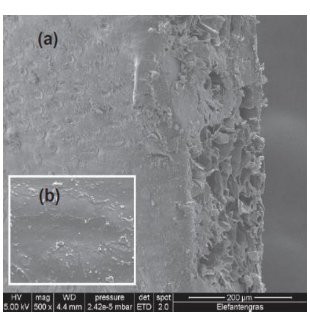
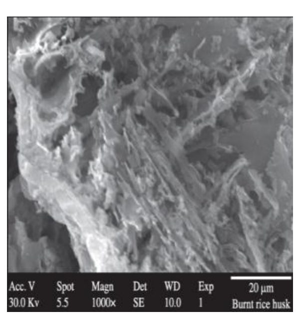


(c)



(d)



(e)

Fig. 7. SEM of various wastes: a) Barley Straw Ash [41], b) Bamboo Leaf Ash [31], c) Banana Leaf Ash [28], d) Elephant Grass Fibre [42], e) Rice Husk Ash [40].

E. *Mix Design Proportion*

Mix design of concrete is carried out according to the american concrete institute (ACI) method of mix design. A fixed water to cement ratio (to conduct an accurate comparative study) of 0.5 is kept for 0%, 10%, 20% and 30% replacement of WSA by weight of cement as shown in the Table III.

TABLE III
PROPORTIONS OF MIX DESIGN FOR CONCRETE MIX

Concrete	Cement (Kg)	WSA (Kg)	Water (Kg)	Fine Aggregates (Kg)	Coarse Aggregates (Kg)
0% WSA	10.76	---	5.38	41.5	30.8
10%WSA	9.68	1.07	5.38	41.5	30.8
20%WSA	8.60	2.15	5.38	41.5	30.8
30%WSA	7.53	3.22	5.38	41.5	30.8

F. *Tests on Fresh and Hardened Concrete*

Various types of tests were conducted on conventional concrete and on a mix containing different percent of WSA, in fresh and hardened state, such as slump, compaction factor, density, water absorption and compressive strength. A total number of six samples were tested for the determination of each property and then the average of these results was used for a comparative study between conventional and WSA concrete. The results of these tests are discussed in the next section.

IV. Results and Discussion

The results of various types of tests carried out are discussed in forthcoming subsections.

A. *Slump Test*

Slump test is carried out according to American Society for Testing and Materials standard ASTM-C143-05 and their values are presented in *Fig. 8*. A decrease in slump is noted as the ash content is increased. This is due to the high-water absorption capacity of ash.

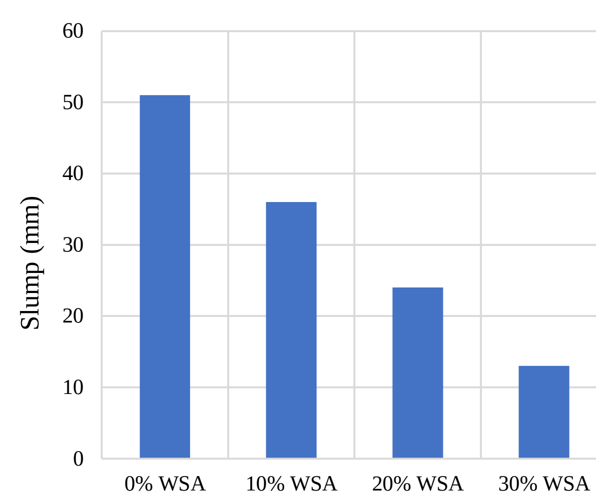


Fig.8. Variation of Slump with different ash content.

B. *Compaction Factor Test*

The workability of WSA for different percentages is evaluated using compaction factor test. A decrease in workability is calculated as the ash content is increased. The results are presented in *Fig. 9*.

The workability of wastes has been addressed by many researchers and replaced 5%, 10% and 15% of cement by olive and reported a reduction in workability [43]. A similar kind of study is conducted and replaced 5% to 30% amount of olive by weight of cement, however, it is concluded that there is an increase in workability [44]. Corn (maize farming waste) as a partial replacement of cement (2-25%) is used and decrease in workability was noted [38]. Like WSA, some of the other waste products also decrease workability of the paste [32, 45-48].

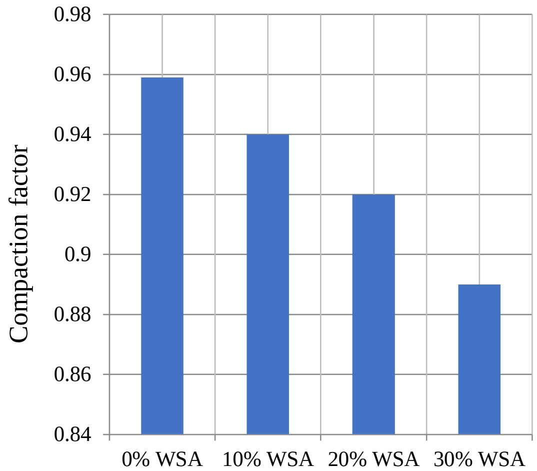


Fig. 9. Decrease in workability as WSA is increased.

C. Density

WSA is a lightweight material and its density decreases as the content of ash is increased. The density for each percent replacement is presented in *Fig. 10*.

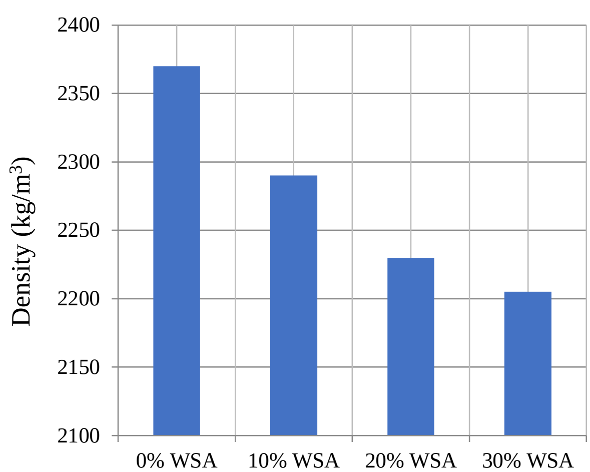


Fig. 10. Comparison of density of WSA Concrete

Similarly, other wastes such as corn [37], bamboo [49], date palm [50] and periwinkle [48, 51] are also lightweight materials. One of the advantages of using such materials is that they reduce the dead weight of the structure.

D. Water Absorption

Water absorption test is carried out on concrete cubes casted for each mix. Water absorption is increased as the percentage of WSA is increased. It is in earlier days and reduces with time because of the pores that get filled earlier as compared to conventional concrete. *Fig. 11* shows the summary of water absorption capacity of WSA.

The properties of concrete containing bamboo leaves ash was proposed and reported an increase in water absorption as compared to conventional concrete [49]. Similarly, olive waste ash [9], sisal fibres [52] and oyster shell [53] also have a higher water absorption capacity. However, few wastes such as elephant grass ash has approximately the same water absorption capacity as the normal concrete [54].

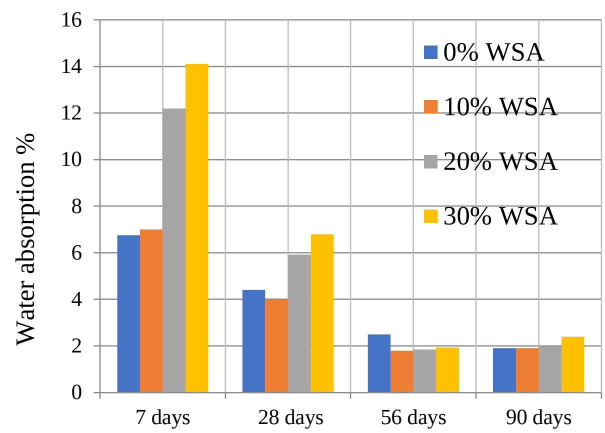


Fig. 11. Variation of Water Absorption of WSA Concrete with Age.

E. Compressive Strength

To determine the compressive strength, six cubes are tested after each 7, 28, 56 and 90 days of test curing as shown in *Fig. 12*. Results displayed in *Fig. 13*, show that 10% WSA replacement closely follows conventional concrete strength at 7, 28, 56 and 90 days, respectively. A decrease in strength is observed as the content of the ash is increased.

In terms of compressive strength of WSA, various waste products such as bamboo leaves ash [49], barley straw ash [55], corn cob ash [36] and banana leaves ash [28] also showed better compressive strength of mortar/concrete as compared to normal mortar/concrete when used instead of cement and aggregates. However, a slight decrease in the early day's compressive strength of bamboo leaves ash iss noted when used as a partial replacement of cement [54]. Similarly, olive waste ash also reduces the compressive strength [43]. On the other hand, Cordeiro and Sales [54] studied elephant grass ash as a partial replacement of cement and found no effect on the compressive strength. The strength of concrete greatly depends on the content of silica in a binder. However, the content of silica is varying in various agricultural wastes and this is due to the chemical composition of wastes which changes with topography, soil chemistry and type of fertilizers used.

Agricultural by-products are a suitable option to control the degradation and protect the environment, more importantly in a region where these wastes can be found in abundance. It requires approximately four giga-joules of energy to produce a ton of Portland cement [56]. However, the use of supplementary material reduces the demand of cement production. Furthermore, the utilization of these wastes not only reduces the emission of CO_2 but on the other hand also provides strength and durability to concrete, as investigated by several other researchers. Moreover, in an agricultural country like Pakistan, these wastes are found in abundance and the preparation of these wastes will ensure a handsome amount of profit to industries. Similarly, the construction of green buildings will also allow owners and developers to collect higher rents from the tenants. For example, in New York city, tenants pay higher rents for green buildings because of the benefits associated with these buildings such as reduced life cycle costs and durability [57]. Therefore, multiple benefits are associated with the utilization of waste materials in concrete.

Fig. 12. Testing of WSA Modified Concrete Cube.

V. Conclusions

Proposed paper summarizes the potential usage of an agricultural waste (wheat straw) as a sustainable material in the production of green concrete. Wheat straw ash contains handsome amount of amorphous silica and can be used to partially replace ordinary Portland cement in concrete. The compressive strength evaluated for different ash content indicated 10% replacement as an optimum percentage. However, this optimum content of WSA can be increased depending upon the chemical composition of the ash, which changes with topography, soil chemistry and type of fertilizers used. Moreover, the water absorption capacity of WSA is very immensely posed. On a long term, this absorbed water helps to reduce the shrinkage of concrete. The other important property of WSA is its density. Since it is a lightweight material and significantly reduces the dead weight of content where the total load of the structure is of prime importance.

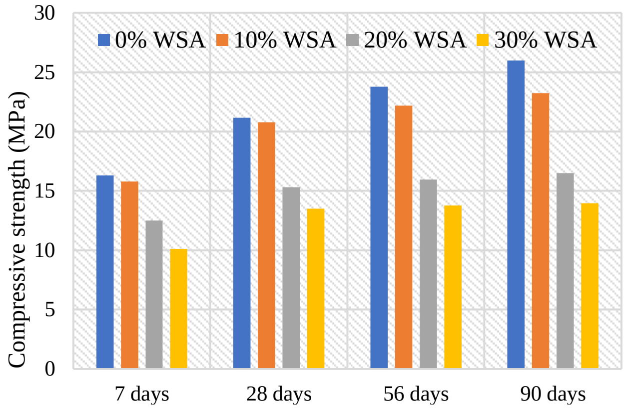


Fig. 13. Comparison of Compressive Strength.

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