The Impact of Wheat Straw Ash as a Partial Cement Replacement Material on Concrete Properties

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Abstract

One of the main sources of generating carbon dioxide (a potent greenhouse gas) is cement industry. This research presents an attempt to replace cement with an eco-friendly material i.e., Wheat Straw Ash (WSA) an attempt in reducing the onsite waste. The leading source of food for 2.45 billion people in the world is wheat. For the marketing year 2021, the yearly worldwide wheat production was about 775.9 million tons and Pakistan with a share of 3.5% of the global production of wheat is ranked 7th. It has been observed that the standard straw gain is about 1300–1400 grams per 1000 grams of grain and when these straws are burnt, they produce about 20% of ash. This wheat straw is being used in this research by burning it in a temperature-managed furnace at 600 ^{o}C for continuous four hours. The ash obtained was then sieved from the #200 sieve with proper grinding. The workability, water absorption, compressive strength and unit weight are the tests performed at a variety of replacement proportions of these ashes (0%, 5%, 10%, 15% and 20%) of cement weight. The samples of water absorption test were examined at intervals of 1 and 28 days, while the specimens of compressive strength and unit weights were tested at the periods of 3, 7, 28 and 56 days. The findings of the study revealed that an optimum value of compressive strength occurs at 10% replacement of WSA, and unit weights decrease as the WSA content increases. Workability and water absorption of concrete increased because proportion of WSA increased. This study may be used as one of the reference points towards an eco-friendly approach in the construction industry as the WSA showed positive results over cement.

Keywords: *Cement replacement; wheat straw ash; compressive strength; workability; concrete*.

1. Introduction

The highly often employed artificial substance on the planet is concrete [1]. Every year, over 2.3 metric tons of concrete are utilized per person on the planet. Concrete's widespread use is mostly because of the readily available resources, its demonstrated flexibility, better mechanical and durability capabilities under harsh climatic conditions, and minimal maintenance throughout its life cycle, among other factors. Aside from playing a crucial part in the growth of our civilization, the concrete sector is also responsible for 10% of all industrialized carbon dioxide (CO_2) emissions into the air. Simply the manufacture of cement, the very essential component of concrete, accounts for 6% of world CO_2 emissions [2], [3]. Global CO_2 emissions have meaningful influence on the temperature of earth, resulting in climatic shifts and problems in relation with global warming [4].

Not only about CO_2 emissions, but the most cement-producing nations are concerned about rising energy costs, depletion of resources of nature, and a sufficient provision of materials of origin to manufacture cement of the desired grade. Concrete is required for the building of new and repaired existing facilities, and this need is predicted to grow in line with current urbanization trends. Many academics from all around the world are presently attempting to lessen the company's environmental impact. Concrete constructions are increasingly being designed using new materials that have a low carbon footprint, great strength, and longer design life. Aggregate’s lightweight usage in the lightweight or low-density concrete creation for structural applications, as well as the usage of reinforcement of fiber in concrete and mortar to minimize the structural components dimensions, is becoming increasingly popular [5]–[10].

The most efficient technique to reduce CO_2 emissions among the various technologies is to reduce the usage of clinker by partially substituting extra materials of cement [11]–[14]. Famous commercial materials including slag, silica fume, fly ash, natural pozzolans and calcined clays are commonly employed for this [15]–[20][21]. Limestone quarry dust,

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glass waste sludge electric arc furnace of slag, and the sludge of industrial granite have all lately been investigated as possible cement alternatives [22]–[24]. With the growing demand for concrete, there is a pressing need to research alternative feasible materials that can partially serve as cement replacement while providing at slightest similar or superior permanence and strength. In contemporary years, several scholars put their focus on the use of diverse wastes of industries in the development of sustainable concrete and the cement as well.

A significant amount of agricultural waste is generated, which leads to several environmental and landfill challenges. Various power plants used a large amount of these wastes as a fuel source. Dumping the ashes from their outdoor fires in open areas has serious environmental and health consequences. As a result, a large range of agricultural wastes has been brought to the existing building industry for prospective usage as a substitute for cement clinker, to encourage the use of green building materials and reduce air pollution. Several research studies on the possible exploit of agricultural waste that include ashes of rice husk and sugarcane bagasse in the building sector have been conducted in recent decades. Because they contain a great concentration of shapeless silica, several studies suggest these ashes are appropriate pozzolanic materials for the manufacture of concrete and sustainable cement. [25]–[27]. Wheat, including rice and sugarcane, is the most widely grown cereal crop on the planet and one of the world's principal food supplies for a population 2.5 billion people [29]. Between 2016 and 2017, worldwide wheat output was predicted to be 750 metric tons. Pakistan is also one of the world's top wheat-generating countries. From 2017 to 2018, Pakistan's yearly wheat output was predicted to be 26.6 million tons [30]. One kilogram of wheat grain yields around 1.3 to 1.4 kilograms straws of wheat. The majority of these straws of wheat is fed to cattle as a primary supply of nourishment [28]. Wheat straws burnt in an open field, on the other hand, have been observed to cause ecological health and pollution troubles for residents in the area in some cases. As observed in different Pakistani and Indian cities, this include, for example, road traffic accident and respiratory disorders among individuals[29], [30]

WSA has recently been investigated as an auxiliary cementitious element in cement and concrete by several scientists [35-37].

2. Materials and Methods

2.1. Cement

Concrete is created from a powdered mixture made from calcimine lime and clay called cement, which is combined with water, sand, gravel, and water. Cement is a binder or a substance that binds other materials together by setting, hardening, and setting. The chemical interaction between cement and water gives cement its strength. Hydration is the term for this procedure. WSA includes a significant quantity of SiO_2, which combines with Ca $(OH)_2$ to create CSH gel; and that since the pozzolanic process consumes lime, The Ca (OH)2 content of WSA-containing paste is lower than that of pure cement paste.

2.2. Wheat Straw Ash

Wheat straws are the outer most layers of grains or wheat seeds. They are constructed of inflexible components including the lignin and opaline silica to protect the seeds in growth season. When these straws are burned, they produce roughly 10% wheat straw ash by the weight of wheat straws. Wheat Straw Ash (WSA) is a carbon-neutral green product containing over 70% silica (SiO2), 10-40% carbon, and a few mineral components. Exploration of the use of WSA is becoming more appealing, and it has been a prominent topic of interest in current time due to its accessibility and low cost.

The wheat husk was obtained from a Floor Mill in Hyderabad for the study work outlined in this book, which was subsequently burned in a controlled environment at roughly 600°C for 4 hours in a Mirpurkhas Sindh industrial furnace. WSA was burned, then ground in a Los Angeles (LA) machine and sieved through a No. 200 sieve. X-ray Fluorescence (XRF) test was used to determine chemical composition of WSA.

2.3. Tests on Materials

Gradation, specific gravity, unit weights, and water absorption of coarse and fine aggregates are the exams used to evaluate the quality of materials. XRF test of WSA, slump flow test, and compressive strength tests for cylinders were also undertaken.

2.3.1. XRF of WSA

XRF is a non-destructive analytical technique for identifying and measuring element concentrations in solid, powdered, and liquid samples. It can detect elements ranging from sodium (Na) through uranium (U) and beyond at levels of trace as low as one part per million to 100%. XRF analysis is fast, accurate, and non-destructive, with minimum sample preparation required. Following are the steps to carryout the test.

- A controlled X-ray tube is used to irradiate a solid or liquid sample with high-energy X-rays.
- An electron from one of the atom's inner orbital shells is expelled when an atom in the sample is attacked with an X-ray of sufficient energy (higher than the atom's K or L shell binding energy).
- The atom regains stability when an electron from one of the atom's higher energy orbital shells fills the vacancy left in the inner orbital shell.
- By emitting a fluorescent X-ray, the electron falls to a lower energy state. The difference in energy between two quantum states of the electron is equal to the energy of this X-ray. The cornerstone of XRF analysis is the measurement of this energy.

2.4. Slump test

The workability or dependability of a concrete mix is tested by the concrete slump test which is either carried out on the job site or in the laboratory. To ensure that the concrete quality is reliable throughout the process of building, the concrete slump test is to be performed on each group. With low-costs and quick results, the concrete slump test is the most fundamental workability test. The ASTM C143 procedures are standard procedures to carryout slump test. In general, values of concrete slump are employed to assess the workability, that shows the ratio of water-cement, however a range of factors including dosage, mixing qualities, material qualities, and admixtures affect the concrete slump values highly.

2.5. Compressive Strength Test

The resistance of a substance to breaking under compression is known as compressive strength. The most significant of the different concrete tests is compressive strength because all the qualities of concrete are offered through this. This test is employed to check whether the concreting activity was done correctly or not. The several constraints, such as cement strength, ratio of water-cement, quality control and quality of concrete material govern the compressive strength of concrete throughout the manufacturing process. In a Universal Testing Machine or a Compression Machine, compressive strength is examined on cylinder or a cube. According to different standard codes, the standard specimens for this test are either cylinders or cubes. The standard test code for assessing the compressive strength of cylindrical concrete specimens is ASTM C39/C39M which is developed by the American Society for Testing Materials.

3. Results and Discussion

The outcome of tests performed on concrete are discussed here in this section.

3.1. XRF test results

The following table shows the XRF test results of WSA.

Table 1: XRF test of WSA

Compound	SiO2	K2O	MgO	Fe2O3	Al2O3	TiO2	CaO
Value (%)	73.95	11.51	1.83	1.15	0.91	1.92	5.21

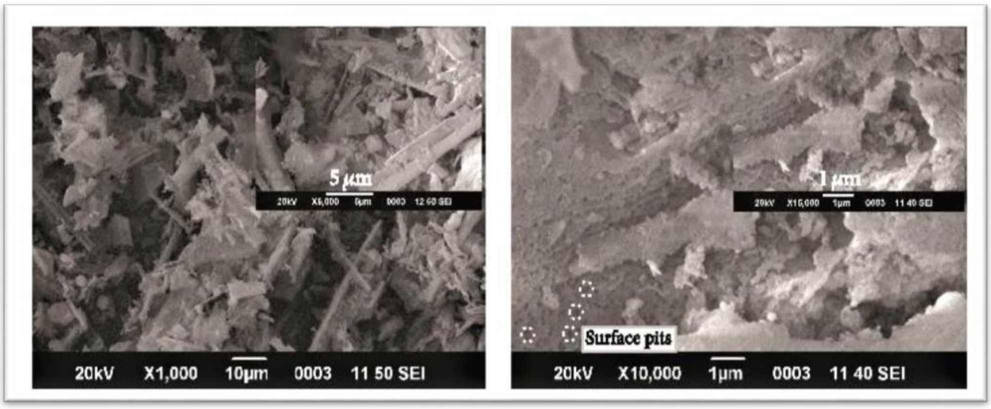

Fig.1 XRF of WSA

Table 1 & figure 1 are showing results of XRF of WSA. XRF is meant to indicate values of different contents present in WSA content. Results indicate that the WSA content contains highest value for silicon dioxide, which is a major source of binding materials. The 2nd highest value in WSA content is of potassium oxide. The 3rd highest content present in WSA is calcium oxide. A smaller proportion of magnesium oxide, ferric oxide & aluminum oxide is also present in WSA content.

3.2. Water Absorption

Water absorption is tested after a range of days of curing period. The following results show the water absorption after 1 day curing.

Table 2: Water absorption at 1 day

Mix Design	Specimen No.	W1 (Kg)	W2 (Kg)	W.A % $\left(\frac{W1-W2}{W1}\times 100\right)$	Average W.A%
M1	1	3.790	3.681	2.96	3.0 %
	2	3.785	3.673	3.04	
M2	1	3.780	3.687	2.52	2.6 %
	2	3.763	3.665	2.67	
M3	1	3.675	3.570	2.94	3.22 %
	2	3.685	3.560	3.5	
M4	1	3.732	3.613	3.30	2.67 %
	2	3.725	3.650	2.05	
M5	1	3.620	3.530	1.40	2.21 %
	2	3.595	3.588	3.03	

Table 2 shows the water absorption percentage of different concrete mixes at 1-day curing. The optimum value of water absorption occurs at 10% replacement of WSA i.e., 3.22% in the mix design labelled M3 and the minimum value of water absorption occurs at 20% replacement of WSA which is 2.21%, while for conventional concrete labelled M1 water absorption value is 3.0%.

Table 3: Water absorption of mix designs after 28 days of curing

Mix Design	Specimen No.	W1 (Kg)	W2 (Kg)	W.A % $\left(\frac{W1-W2}{W1}\times 100\right)$	Average W.A%
M1	1	3.805	3.690	3.11	3.32 %
	2	3.790	3.650	3.83	
M2	1	3.750	3.650	2.73	2.58 %
	2	3.780	3.690	2.43	
M3	1	3.685	3.570	3.22	3.47 %
	2	3.690	3.568	3.42	
M4	1	3.740	3.610	3.60	3.25 %
	2	3.735	3.630	2.89	
M5	1	3.622	3.510	3.19	2.65 %
	2	3.605	3.530	2.12	

Table 3 shows the water absorption percentage of different concrete mix design safter 28 days of curing. The maximum value of water absorption occurs at 10% replacement of WSA i.e., 3.47% and the minimum value of water absorption occurs at 20% replacement of WSA which is 2.65%, while for conventional concrete water absorption value is 3.32%.

3.2.1. Comparison Between 1 Day And 28 Days Water Absorption

The comparison between 1 day and 28 days of water absorption of different mixes is given in the following table.

Table 4: Comparison of water absorption

Mix Design	WSA %	1 Days' Curing	28 Days' Curing
M1	0%	3.0	3.47
M2	5%	2.6	2.58
M3	10%	3.22	3.32
M4	15%	2.67	3.25
M5	20%	2.21	2.65

Table 4 shows the comparison between 1 day and 28 days of water absorption. The water amalgamation of concrete decreases as the curing period increases, and the optimal value of water absorption occurs at 10% replacement of WSA on both 1 day and 28 days water absorption.

3.3. Workability

The workability is examined for each mix design. The slump values are given in the table below.

Table 5: Values of slump of various mix designs

Mix Design	Cement Content	WSA Content	Cement	Fine Aggregates	Coarse Aggregates	Water	Slump Value
	%	%	(Kg/ m^3)	(Kg/m^3)	(Kg/m^3)	(kg/m^3)	(mm)
M1	100%	0%	425	645	1055	204	41
M2	95%	5%	425	645	1055	204	52
M3	90%	10%	425	645	1055	204	72.5
M4	85%	15%	425	645	1055	204	77.5
M5	80%	20%	425	645	1055	204	87

Table 5 shows that workability of fresh concrete increases by increasing percentage of WSA, the maximum value of slump occurs at 20% replacement of WSA i.e., 87mm, the smallest value of slump occurs at 0% replacement of WSA i.e., 41mm.

3.4. Unit Weights

Unit weights of specimens were evaluated at different curing periods and their values are shown in tables.

Table 6: Unit weights values of different mixes

Mix Design	Specimen	WSA	Weight	Volume	Unit Weight	Average Unit Weight
		(%)	(Kg)	(m^3)	Kg/ m^3	
M1	1	0%	3.65	0.001647	2217.851	2214
	2	0%	3.63	0.001647	2209.107	
	3	0%	3.648	0.001647	2215.519	
M2	1	5%	3.643	0.001647	2212.022	2210
	2	5%	3.638	0.001647	2209.107	
	3	5%	3.638	0.001647	2209.107	
M3	1	10%	3.614	0.001647	2194.536	2199
	2	10%	3.629	0.001647	2203.279	
	3	10%	3.619	0.001647	2197.45	
	1	15%	3.595	0.001647	2182.878	2186
	2	15%	3.61	0.001647	2191.621	
	3	15%	3.6	0.001647	2185.792	
	1	20%	3.585	0.001647	2177.049	2174
	2	20%	3.576	0.001647	2171.22	
	3	20%	3.580	0.001647	2174.135	

Table 6 shows the density of concrete mixes at 3 days of curing. From the results it is obvious that maximum density occurs for conventional concrete i.e., 2214Kg/m^3 and it is seen that the density of concrete decrease as WSA increases.

Table 7: Unit weight of concrete mixes at 7 days

Mix Design	Specimen	WSA (%)	Weight (Kg)	Volume (m^3)	Unit Weight (Kg/ m$^{3)}$	Average Unit Weight
M1	1	0%	3.77	0.001647	2287.158	2283
	2	0%	3.752	0.001647	2278.142	
	3	0%	3.763	0.001647	2284.754	
M2	1	5%	3.757	0.001647	2281.148	2279
	2	5%	3.752	0.001647	2278.142	
	3	5%	3.752	0.001647	2278.142	
M3	1	10%	3.727	0.001647	2263.115	2267
	2	10%	3.742	0.001647	2272.131	
	3	10%	3.732	0.001647	2266.12	
M4	1	15%	3.707	0.001647	2251.093	2255
	2	15%	3.722	0.001647	2260.109	
	3	15%	3.712	0.001647	2254.098	
M5	1	20%	3.697	0.001647	2245.082	2242
	2	20%	3.687	0.001647	2239.071	
	3	20%	3.695	0.001647	2242.077	

Table 7 shows the density of concrete mixes at 7 days of curing. The maximum density occurs for conventional concrete i.e., 2283Kg/m^3 labelled M1 and it is worth noting that the density of concrete decreases as WSA increases.

Table 8: Density of concrete mixes at 28 days

Mix Design	Specimen	WSA (%)	Weight (Kg)	Volume (m^3)	Unit Weight (Kg/m^3)	Average Unit Weight
M1	1	0%	3.805	0.001647	2310.26	2306
	2	0%	3.790	0.001647	2301.15	
	3	0%	3.801	0.001647	2307.83	
M2	1	5%	3.795	0.001647	2304.2	2302
	2	5%	3.790	0.001647	2301.15	
	3	5%	3.790	0.001647	2301.15	
M3	1	10%	3.765	0.001647	2285.97	2290
	2	10%	3.780	0.001647	2295.08	
	3	10%	3.770	0.001647	2289.01	
M4	1	15%	3.745	0.001647	2273.83	2278
	2	15%	3.760	0.001647	2282.94	
	3	15%	3.750	0.001647	2276.87	
M5	1	20%	3.735	0.001647	2267.76	2265
	2	20%	3.725	0.001647	2261.70	
	3	20%	3.730	0.001647	2264.72	

Table 8 shows the density of concrete mixes at 28 days of curing. The maximum density occurs for conventional concrete i.e., 2306 Kg/m^3. The density of concrete decreases as WSA content in concrete increases.

Table 9: Density of mixes at 56 days

Mix Design	Specimen	WSA (%)	Weight (Kg)	Volume (m^3)	Unit Weight (Kg/m^3)	Average Unit Weight
M1	1	0%	3.815	0.001647	2316.33	2318
	2	0%	3.833	0.001647	2327.26	
	3	0%	3.804	0.001647	2309.65	
M2	1	5%	3.800	0.001647	2307.23	2309
	2	5%	3.817	0.001647	2317.55	
	3	5%	3.791	0.001647	2301.76	
M3	1	10%	3.813	0.001647	2315.12	2304
	2	10%	3.780	0.001647	2295.08	
	3	10%	3.793	0.001647	2302.98	
M4	1	15%	3.755	0.001647	2279.9	2286
	2	15%	3.776	0.001647	2292.65	
	3	15%	3.765	0.001647	2285.97	
M5	1	20%	3.750	0.001647	2276.87	2266
	2	20%	3.721	0.001647	2259.26	
	3	20%	3.725	0.001647	2261.69	

Table 9 shows the density of concrete mix designs after 56 days of curing. The maximum density occurs for conventional concrete i.e., 2318 Kg/m^3. It is noticed that the concrete density declines as WSA increases.

Table 10 Unit weights of mix designs after different days of curing

Mix Design	WSA (%)	3 days' curing	7 days' curing	28 days' Curing	56 days' Curing
M1	0%	2214	2283	2306	2318
M2	5%	2210	2279	2302	2309
M3	10%	2199	2267	2290	2304
M4	15%	2186	2255	2278	2286
M5	20%	2174	2242	2265	2266

The following figure shows the unit weight of various mixes of WSA concrete in graphical form.

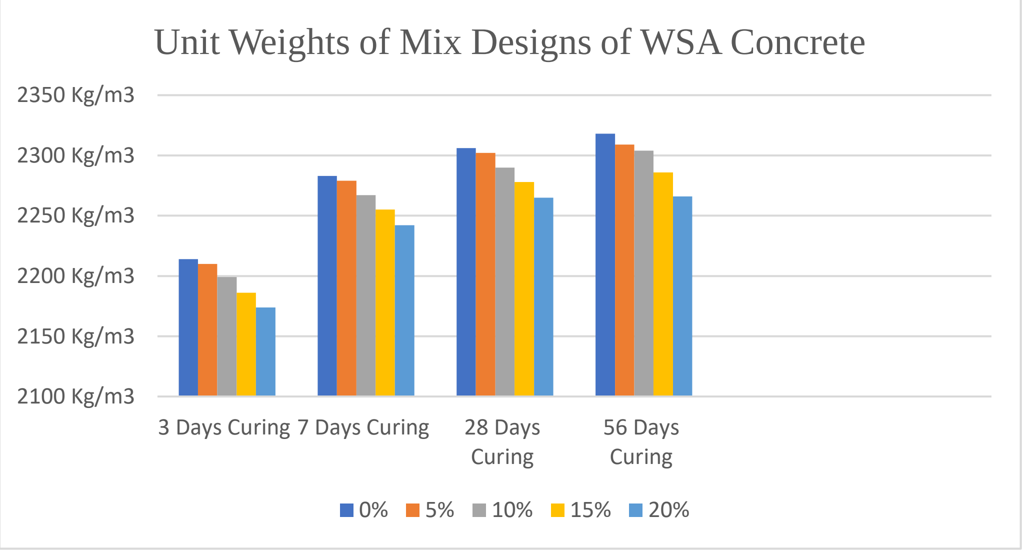

Fig.2: Comparison of unit weights of mix designs of concrete

Table 10 and Figure 2 indicate the density of concrete mixes at 3-, 7-, 28-and 56-days curing periods. Findings show that the density of concrete is decreasing when the WSA content is increasing.

3.5. Compressive strength of WSA Concrete

The compressive strength of WSA concrete after 3, 7, 28 and 56 days is given in the following table.

Table 11: Compressive strength of WSA concrete

Mix Design	WSA (%)	3 days' curing (MPa)	7 days' curing (MPa)	28 days' curing (MPa)	56 days' curing (MPa)
M1	0	17.80	21.83	32.56	33.92
M2	5	18.46	22.38	33.83	35.19
M3	10	19.31	24.45	35.10	35.89
M4	15	17.64	21.78	31.63	33.26
M5	20	16.32	20.49	29.72	27.01

The compressive strength of WSA concrete in graphical form is shown in following graph. Table 11 and Figure 3 show the compressive strength of WSA concrete mixes at 3-, 7-, 28- and 56-days curing period. The optimum increase in strength occurs at 10% replacement of WSA after all the days of curing.

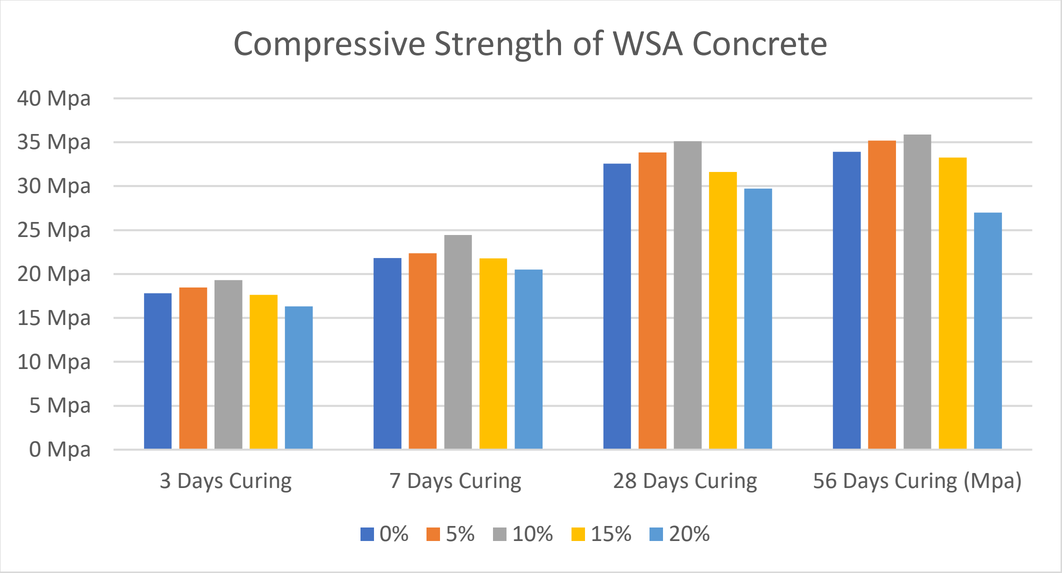

Fig.3: Compressive strength of concrete mixes

4. Conclusions & Suggestions

Concrete is one of the most important elements of construction industry, without it nowadays construction is nearly impossible. It possesses so many advantages including fast construction, durable, easily available, high strength and so on. Besides all this concrete also shares a considerable percentage of CO_2 emission in the atmosphere. The production of cement has increased energy crises and depletion of natural resources of the area. Therefore, it has become necessary to reduce the usage concrete or replace its constituent cement with any other recyclable and ecofriendly material. This study presented an attempt to replace cement with WSA in different portions. The findings of the study revealed that a maximum value of compressive strength was observed at 10% replacement and that the unit weight decreases as the proportion WSA is increased. It was observed that water absorption and workability increased as the WSA content in the concrete is increased. The extent of research was limited to fresh and hardened properties of concrete only and more work is still needed in order to have clarity between WSA concrete and conventional concrete. The following suggestions are recommended for future work under this domain.

- ✓ Determination of the additional features of fresh WSA concrete, such as setting, bleeding, segregation, hydration, air entrainment, and so on, in contrast to regular concrete.
- ✓ Assessment of the additional qualities of hardened WSA concrete, such as creep, shrinkage, crack development, water tightness (impermeability), and so on, in comparison to regular concrete.
- ✓ Relationship of the mechanical characteristics of WSA concrete to regular concrete, such as tensile strength, flexural strength, modulus of elasticity etc.
- ✓ Evaluation of the stress-strain behavior and structural behavior of WSA concrete in comparison to the ordinary concrete in reinforced concrete slabs, beams, and columns.

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