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An Experimental Investigation on Strength Characteristics of Concrete Using Wastepaper Sludge Ash (WPSA)

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Abstract

This study explores an experimental investigation in finding the strength characteristics of the concrete made with the addition of (WPSA) as a cementious material. The WPSA has some sort of pozzolanic properties and is high in silica, magnesium and low in calcium. Due to silica and magnesium content, it behaves like cement, and they also increase its setting time. The properties of concrete investigated where compressive strength, flexural strength, split tensile strength, slump test and water absorption test while WPSA was added in different percentages from 0 % to 40 %. The maximum coarse aggregate size used is 20mm.The M30 grade of concrete is designed using British Standard of mix design. The cubes of 150x150x150 mm were casted for the compressive strength test, cylinders of 150x300 mm were casted for split tensile strength test and beams of 100x100x500 mm were casted for the flexural strength test. All the specimens were placed in the water and then tested in the 7, 14 and 28 days. The WPSA concrete has some better mechanical and durability properties as compared to normal concrete. The compressive strength of the concrete was increased by adding 30 % of WPSA. The results further indicates that the split tensile strength and flexural strength of the same samples don't increase. Overall, the addition of WPSA to a minimum of 30 % as a replacement of cement is helpful in increasing the strength value which is helpful in reducing the CO2 emission from the construction industry.

Keywords

Cement, Concrete, WPSA, Compressive strength, Construction Industry.

1. Introduction

The most broadly utilized construction products in the world is concrete (Umar et al., 2020). It is the blend of cement, coarse aggregate, fine aggregate, sand, and water. On one side it is the backbone of the construction industry, but on the other side is the biggest polluter of the environment. The production and use of cement are having many harmful environmental impacts (Akan et al., 2017). The manufacturing of one ton of cement results in the emission of roughly one ton of CO2 and also emits SO2 (Umar et al., 2021). One ton of cement production consume approximately 90-150 KWT energy (Ahmad et al., 2013). Thus, the cost of the construction materials becomes very much expensive (Umar, 2020). All these factors contribute to the idea of replacement of waste supplementary materials which can be mixed with the concrete either fully or partially and increase the quality and strength of concrete while reducing the cost. This will help to save the resources and to avoid the environmental degradation.

The developed nations are already implementing the precautions and procedures to eliminate or to minimize the sources which are degrading the environment and are taking steps to use the sustainable energy sources. But in some developing countries this problem is having a huge impact and still they are not doing enough to solve the problem (Umar et al., 2020). China and India are already the world's leading producer of cement and are expected to increase their production within few decades and are the leading environmental polluter in the world (Statista, 2021).

As the world's cement demand is increasing it is estimated to be double in the next 30 years (Umar et al., 2021). By using SCM (supplementary cementitious materials) in place of a fractional replacement with the cement in concrete (Bai et al., 2003; Senthamarai and Manoharan, 2005). We can easily meet our required cement demand and there will be the reduction of energy, CO2 emissions, resource consumption having no harmful environmental impacts and no emission of the greenhouse gases. An additional environmental benefit is that the most used SCM e.g., hypo sludge, fly ash, silica fume are waste products which would otherwise dump in landfills (Umar 2021).

The production of paper generates enormous amount of solid waste which is also known as wastepaper sludge. This paper sludge is then dumped in landfills every year and is a major contributor to air pollution and is a health hazard (Simpson and Zimmie, 2005) It also poses a serious economic and environmental threat to the paper manufacturing companies (Solanki and Pitroda, 2012). Basically, it is a byproduct of the re-pulping and de-inking of the paper, and this waste is dumped because it has no use. It is also used as a land-spreading as agricultural fertilizer, burned in the Combined Heat and Power (CHP) plants at the paper mills. But the most common method is disposal to landfill. It consists of calcium carbonate, China clay and cellulose fibers and contains maximum of 40% moisture content- (Sobol et al., 2020). Physically the material is viscous, sticky and its texture ranges from hard to dry, viscosity to lumpiness. Paper sludge is classified as Class 2 liquid alternative fuels (CEMBUREAU, 2021; Ahmad et al., 2013). It is burned at about 800°C and the remaining fly ash which consists of the same properties of the Portland cement e.g., reactive silica and alumina (in the form of Metakoline) as well as lime (CaO). By utilizing these industrial wastes, we can develop a low-cost concrete and also the pollution problems will also be reduced. The inclusion of SCM in the concrete comes with additional benefits such as the energy consumed in the cement production will be saved, low cost, development in the engineering properties of the cement and the preservation of the environment. Every materials resilience is interconnected with the chemical, physical, and mineralogical and penetrability properties of materials thus the enhancement in these properties is expected to increase the strength characteristics of the materials.

The pozzolanic materials are those siliceous and aluminous materials which chemically reacts with the lime (calcium hydroxide) in the presence of water at the usual temperature to form composites which consists of cementitious properties. Consequently, the addition of pozzolanic materials to the concrete results in the additional improvement of the concrete quality and in its durability **(**Dunster, 2007). The WPSA is very high in calcium chloride and also contains minimum amounts of silica and some other pozzolanic materials. The blending of WPSA with the cement in the presence of the water results in the chemical reaction between Calcium Hydroxide (Ca (OH)2) with the hydrated Portland cement which in results produce Calcium Silicate Hydrate (C-S-H) (Garcés et al., 2008).

Paper sludge ash is in this manner possibly appropriate as a fixing ingredient in the cement kiln feed contributing calcium, silica and alumina. The next section explains the research approach adopted in this research project.

2. Methodology

This research aims to use WPSA powder in concrete and to see its performance (compressive strength) at 7,14 and 28 days. The concrete mix used in this research was M 30 which was made with different percentage of paper waste (0%, 10%, 20%, 30% and 40%). The description of materials used in this work is given as under:

2.1. Ordinary Portland cement (OPC)

The Portland cement (PC) which has been manufactured by the Lafarge Cement UK in accordance with BS EN 197-1, 2000, is used in the following investigation. The used cement is 53 grade OPC, the specific gravity is 3.15 and the initial setting time is 30 min (BS EN 197-1:2000, 2000).

2.2. WPSA

The Hypo sludge used in the experiment was obtained from University of South Wales Laboratory. The specific gravity of hypo sludge is found to be 2.17. The chemical composition of cement and hypo sludge is shown in Table.1.

Table: 1 Chemical Composition of hypo sludge and cement

No	Chemical composition	Cement (in %)	Hypo Sludge (in %)
1	Lime (Ca O)	62	46.2
2	Silica (SiO2)	22	9
3	Alumina	5	3.6
4	Magnesium	1	3.33
5	Calcium sulphate	4	4.05

2.3 Coarse Aggregates

In this experiment the coarse aggregate of crushed granite of 20 mm has been used and having specific gravity of 2. 82. All the physical properties e.g., specific gravity, gradation and fineness modulus are tested in accordance with British standard.

2.4. Fine Aggregates

In this experiment we have used manufactured sand having specific gravity of 2.62. All the physical properties e.g., specific gravity, gradation and fineness modulus are tested in accordance with British standard.

2.5. Water

The normal drinking water is used for the experimentation purpose especially for making of the concrete and curing procedure. The water which is clean and free from harmful Impurities e.g., acid, alkali, oil etc. should be used.
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3. Laboratory Experiment

The experimental program consisted of casting and testing of 50 cubes, 10 cylinders and 5 beams. The aim was to determine the mechanical properties like compressive strength, split tensile strength, flexural strength, and water absorption test respectively for M30/ C 25/30 grade of concrete at different replacement level of cement. The details of the specimens casted are shown in table 2.

Table 2. Details of specimens cast

Sr. No.	Grade of Concrete	Type of Concrete	% Of WPSA	No. of cubes cast 150x150x150mm	No. of cylinders cast 150x300mm	No. of beams cast 150x500mm
1	M30	without WPSA	0%	14	2	1
		with WPSA	10%	9	2	1
			20%	9	2	1
			30%	9	2	1

	40%	9	2	1
Total		50	10	5

The cement used in this experimentation is OPC. The water cement ratio is 0.6. All the specimens are prepared accordingly with BS EN 12350-2:2009 (2009) and BS EN 12350-4:2009 (2009). For the compressive strength test we have casted 45 cubes of 150x150x150mm dimensions (BS 1881-116:1983, 1983). For the split tensile strength test 10 cylinders of 150x300mm dimensions were casted. 5 beams of the 150x500mm dimensions were casted for checking the flexural strength. Finally, 5 more cubes were casted for the water absorption test. After casting and molding all specimens are then placed in water tank for curing for 7, 14 and 28 days respectively at a temperature of 27±2°C. After 7 days the 15 cubes specimens were removed from the water and tested for their compressive strength. The next cubes were tested on 14 days and then finally on 28 days all the remaining cubes, cylinders and beams were tested for their compressive, tensile and flexural strength properties. The specimens were also placed in the oven for 24 hours at 110°C to check the water absorption of the cubes.
A mix of M30 grade was prepared in accordance with the British standard (BS EN 206:2013+A2:2021 (2021). The mix proportion design is shown in below table (table 3).

Table 3. Mix Proportions

Paper Sludge Ash %	w/c ratio	Water (Kg/m3)	Cement (Kg/m3)	Fine Aggregate (Kg/m3)	Paper Sludge Ash (Kg/m3)	Coarse Aggregate (Kg/m3)	Slump (mm)
0	0.6	4.2	7	14	0.00	28	135
10	0.6	4.2	6.3	14	0.7	28	80
20	0.6	4.2	5.6	14	1.4	28	60
30	0.6	4.2	4.9	14	2.1	28	25
40	0.6	4.2	4.2	14	2.8	28	15

4. Test Results and Discussion

4.1 Compressive strength test

The compressive strength test results for the 7th, 14th and 28th days are presented in table 4. The average compressive strength value for the normal conventional concrete without any replacement of WPSA is 17.52 N/mm2, for the 7th day 21.30 N/mm2 for the 14th day and 27.55 N/mm2 for the final 28 days. For the second mix, with 10 % replacement with WPSA the values for the 7, 14, 28 days are 21.50, 24.44, 32.06 N/mm2 respectively.

Table 4. Compressive strength test results

S.NO.	% ADDITION OF WPSA	Average Compressive Strength (fck) N/mm2		
		7th day	14th day	28th day
1	0	17.52	21.30	27.55
2	10	21.50	24.44	32.06
3	20	23.80	25.32	35.20
4	30	24.90	28.50	36.90
5	40	17.15	22.10	25.80

The 3rd mix having 20 % WPSA replacement, its value comes out to be 23.80, 25.32, and 35.20 showing increase in the value from the previous one. For the 4th mix the average compressive values are very high as compared with all other mixtures and are 24.90, 28.50, 36.90 N/mm2 Finally for the 5th mix having 40 % replacement of WPSA the average compressive strength values starts decreasing and becomes 17.15, 22.10 and 25.80 N/mm2 respectively. The compressive strength increases when the percentage of WPSA is increased up to 30 percent (fig. 1). Further addition of WPSA results in the decreasing compressive strength values.

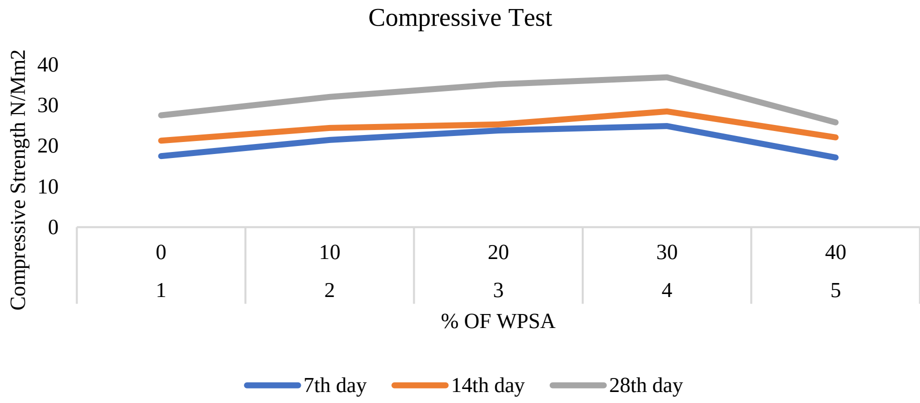

Fig. 1. Compressive Strength Test

4.2. Split Tensile Strength Test

The split tensile strength test results for various replacements of the WPSA are shown in fig. 2. The split tensile strength test was done on the cylinders. For each mix we had made two cylinders. The average value for the 1st cylinder having 0 percent replacement of WPSA is 3.117 (N/mm2), for the 2nd mix which contains 10 percent replacement of WPSA the value decreases and becomes 3.43 (N/mm2). similarly for the 3rd 4th and 5th mixes the values are constantly decreasing. All the tests were carried out for 28 days. From the above table it is noted that there is a continuous decrease in the values of the split tensile test as the WPSA replacement increases and also this decrease is also affected by the number of days in the water. Thus, we can't use WPSA for the tensile strength.

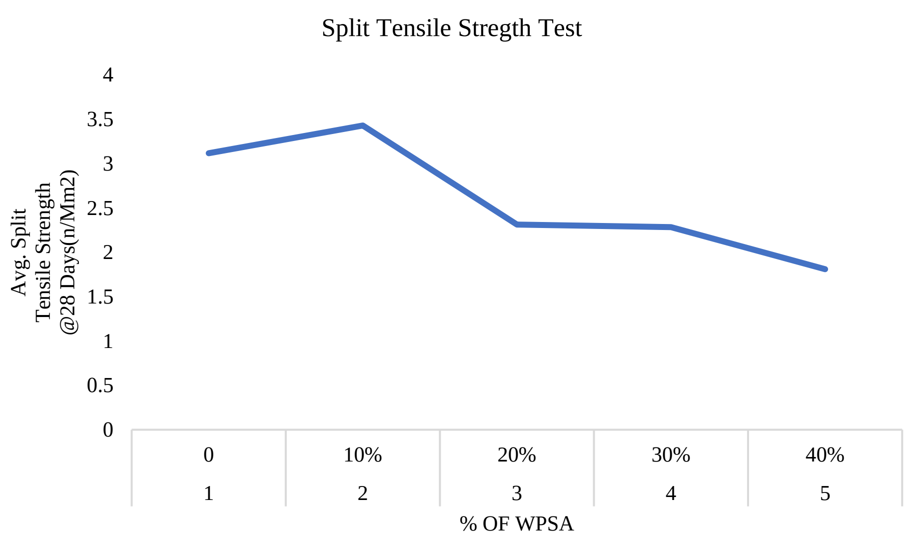

Fig. 2. Split Tensile Strength Test

4.3 Flexural Strength Test

The flexural strength test for different replacement level of WPSA is shown in fig. 3. From the results of flexural test, it is clearly shown that the strength for the 28 days is decreasing as the quantity of WPSA is increased. For the 0 percent WPSA replacement the strength is 3.62 (N/mm2), similarly for all other replacements of 10, 20, 30 and 40 % WPSA the values decrease as 3.27, 2.80, 2.57 and 2.38 (N/mm2) respectively.

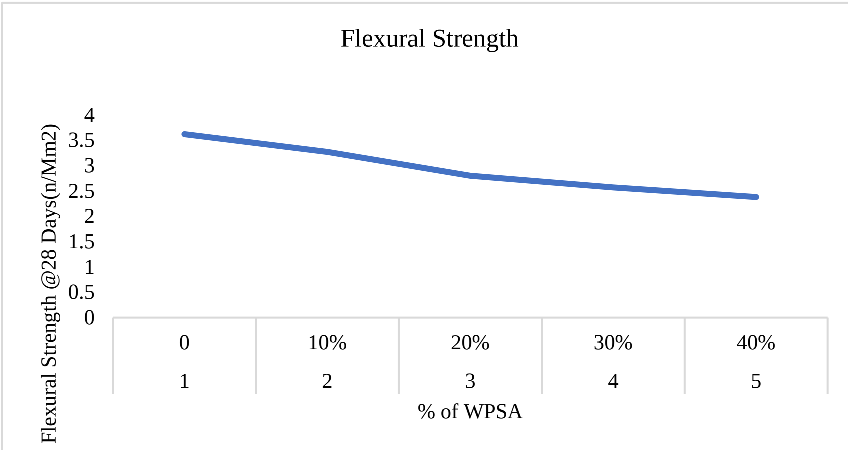

Fig. 3. Flexural Strength

4.4. Water absorption test

The water absorption test is done as per BS 1881-122. The cube specimens, after 28 days curing was evaluated and then are placed in the oven, dried for 24 hours at the temperature of 110°C. Then on the next day they were taken outside the oven and again weighed for the dry weight. Water Absorption Test results for cube specimens of size 150mm x 150mm x 150mm was shown in table 5.

Table 5. Water Absorption Test

Sr. No.	Paper Sludge Ash %	Dry weight of cube (gm)	Wet weight of cube (gm)	Water absorbed (gm)
1	0	2348	2475	127
2	10%	2334	2469	135
3	20%	2319	2457	138
4	30%	2209	2370	161
5	40%	2326	2462	136

The water absorption test shows that the more water is absorbed by increasing the percentage of paper sludge ash. For the 1st mix with 0 percent paper ash the water absorbed is 127 gm. For the 2nd mix having 10 % WPSA replacement the water absorbed is 137 gm. For the 3rd mix which consists of 20 % of WPSA replacement the absorb water is 138 gm. The 4th mix is having water absorption of 161 gm and the last mix have absorption of 136 gm which contains 30 and 40 percent paper ash respectively. From this result we can assume that as the paper ash percentage increases the water absorption also increases this is due to the fact that paper ash is very good in absorbing water at a faster rate and in huge quantities as compared with ordinary Portland cement. But one more thing to notice is that after 30 % paper ash replacement the specimens are unable to absorb more water so we can easily replace up to 30 percent wastepaper ash.

5. Conclusions

The main objective of this study was the utilization of WPSA as a supplementary cementious material (SCM) and to find out the strength characteristics of the materials. The present study is on the effect of the WPSA on the mechanical properties of the normal concrete. For the experimental investigation and analysis, we have conducted series of laboratory tests by adding different replacement levels of WPSA with concrete mixes to study and analysis the strength characteristics of paper pulp concrete. Based on our limited experiments the following conclusions are therefore drawn from this research:

1. The increase in WPSA content results in the decrease of slump values and the workability of the concrete mix decreases. The percentage of water absorption is also increased due to the absorbing capacity of Wastepaper sludge ash at a faster and quicker rate as compared with the normal ordinary Portland cement (OPC). Also, the slump flow diameter decreases due to water absorption.
2. The replacement of WPSA is done from 0% to 40% and it is concluded that with an increase in the percentage of the WPSA there is an increase in the compressive strength value for up to 30 % and after that if we go on increasing to 40%and 50% then the compressive strength suddenly started to decrease. The maximum compressive strength which is achieved at 30 % replacement for the 28 days is 36.90 $N/mm^{2.}$
3. The strength of concrete is unexpectedly decreased in the case with split tensile strength with all percentages of WPSA. Instead of increasing they are decreasing.
4. It is also observed that as the value of split tensile strength doesn't increase for any percentage of the replacement similarly following the trend the strength of the concrete even doesn't increase for the flexural strength but are continuously decreasing.
5. The presence of low silica content in the chemical composition of the WPSA is mainly responsible for decrease in the compressive, tensile and flexural strengths results.
6. The implementation of WPSA in the concrete is very economical because it will help in making low-cost concrete, cost of cement will also be reduced and also the waste sludge is a useless material having no use and is freely available at very enormous quantitites.it will also help the paper industries disposal costs.
7. The utilization of wastepaper sludge ash in the concrete will help a lot to totally eliminate the disposal problem of wastepaper sludge ash which is then dumped into landfills and pollute the environment.it can also protect the environment from the harmful pollutants and emission from the cement manufacturing industry. Thus, it proves to be very eco-friendly. The natural resources will also be saved by the usage of wastepaper sludge ash which would otherwise use into cement manufacturing.
8. As the cost of cement is decreasing the drawback is that at the same time the strength of concrete also decreases.
9. The average weight of the concrete decreases with an increase in wastepaper sludge ash content which results in making concrete very lightweight so it can be used for economic feasibility projects e.g., temporary shelters for people struck by natural disasters.
10. This research concludes that the wastepaper sludge ash can be used as an alternative supplementary cementious material, but engineers have to take very precise judgmental based decisions.

5.1. Recommendations for Future Work

Based on the limiting experimentation the following recommendations are drawn for future and further work:

1. The experimental procedure can be done by mixing WPSA with some silica admixtures, POFA (palm oil fuel ash) or any other pozzolanic materials.
2. The use of gypsum, lime and other materials at the place of cement.
3. The effect of other supplementary cementious materials like Metakaolin, blast furnace slag, ground granulated blast furnace slag, etc., on the strength and durability of paper waste concrete.
4. The specimens should also be placed in the acid (H_2SO_4 & HCL) to study acid durability factors.
5. The specimens to be tested for a greater number of days instead of 7, 14 and 28 days they can tested for 56 and 90 days.

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