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# Partial Replacement of Wood Ash with Ordinary Portland Cement and Foundry Sand as Fine Aggregate

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**Abstract**

Wood ash is generated as residual/waste from combustion done in boilers at pulp and paper mills, steam power plants, and other thermal power generating facilities. Since wood is a renewable resource for energy and an environmentally friendly material, there is an increased requirement of using waste wood for the purpose of energy production thus leading to formation of more wood ash waste. The study focuses on incorporation of wood ash in combination with ordinary Portland cement while using it for various structural works. A critical review study in sieve analysis, consistency, and water absorption, setting time and slump tests of wood ash added to OPC will produce significant results to emphasize the detailed study process. Uncontrolled burning of saw dust to form wood ash is used as a partial replacement of cement, thereby changing its physical and chemical properties. These properties are found somewhat similar to fly ash. The concrete mixes are replaced with the amorphous wood ash as an admixture of cement having grain size less than 75 microns in proportions of 5%, 10%, 15%, 20%, 25% and 30% by weight of cement. In this Study, a research work is conducted for determining the change in workability or consistency of concrete mix, compressive strength, split tensile strength, flexural strength, etc., along with review of some durability properties. Foundry Sand is used as fine aggregate to obtain efficient results.

**Keywords:** Compressive strength; Wood ash; Carbonation; ASTM

## Introduction

Apart from historical evidences about demand of renewable energy in the present modernising world, in the era of urbanisation now the demand for renewable energy resources have further increased. A part of these resources is made by biomass resources including forestry and agricultural wastes. Forestry and agricultural biomasses are considered as efficient and favourable sources of fuel for energy production as their availability is in abundance and are cheap [1]. In the current period of energy production, power plants which run from biomass have low operational cost and have continuous supply of renewable fuel. The wastes generated from the biomass industries like sawdust, woodchips, wood bark, and hard chips) can be used as fuel offer a better way for their safe and efficient disposal [2]. The true residual solid wastes of these agricultural components are produced by thermal incineration which is environmentally safe and much economic. These wood ash wastes can be obtained in abundance from industries which require wood as their fuel for operating their boiler units [3]. The technologies available for production of wood ash in bulk are the fluidized bed and grate furnaces [4]. In grate furnaces biomass wastes are incinerated under high temperatures resulting in vitalization of organic complex compounds [5,6]

The wood ash incorporated as partial replacement of cement helps avoiding insignificant and bulk consumption of pure cement. Besides this the production of cement material all alone results in increased emission of certain greenhouse gases and much more pollutants. Hence replacing with wood ash leads to less production of cement, thus proving environmentally safe. Apart from this, this replacing technique reduces the cost also. The characteristic of ashes will be different for different types of agricultural wastes, timber, etc. These characteristics depend upon the (1) biomass characteristics (2) Incinerating technology (3) & location from where wood ash is obtained.

At present most of the biomass ash produced from power plants and timber factories is disposed using landfilling technique which accounts for 70% [5] ash generated and some part remains uncontrolled i.e., 20% [4]. Besides this the costs for disposal keep increasing day by day. So it is better to include that waste in certain manufacturing process. But before utilizing it needs to be treated well as it contains certain contaminants and compounds of C and N. Due to presence of higher contaminants these need not to be treated in an open environment.

A detailed study or research is being done to obtain different replacement materials for cement. As the cement industry at present is on a booming rise, the demand for cement is increasing but the cost should remain normal. So utilizing the wood ash by efficient means solves a twofold problem of their disposal as well as providing an efficient replacer for cement. A number of tests are carried by researchers which show positive effects of wood ash in cement. Hence using these wastes will be beneficial economically and environmentally.

The ultimate aim of this study is to analyze the effect of wood ash on different major properties of concrete.

## Objectives

The study focuses on the characteristics of wood ash/ saw dust and the properties incurred due to replacement of cement with wood ash. The objectives are:

1. To study the mechanical strength (compressive and tensile strength) of concrete along with the wood ash as partial replacement for cement.

2. To study the carbonation and drying shrinkage.

3. To study the effect on bulk density.

## Physical properties of wood ash

Wood ash particles are of different sizes and shapes. To obtain the

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fineness for replacement with cement sieve analysis is carried. Udeyou et al. [7] observed the physical properties of wood ash as of varying shapes. The average loss on ignition was found out to be equal to 10.46.

### Chemical composition

Some of the major components of wood ash are lime, $(ca(OH)_2)$, $CaCO_3$ and calcium silicate [6,8]. Nike et al. [9] proposed some of the chemical characteristics wood ash with different types of wood. The % age loss on ignition was between 6.5% to 58.1% and moisture content of 0.5% to 3.3%. The chemical properties of five sources of wood are in Table 1.

## Materials and Methods

### Materials

**Cement:** Ordinary Portland cement was used having particle size of 3.9 µm, specific gravity of 3.01. The physical and chemical analysis properties are provided in Table 2.

**Wood ash:** wood ash was made available from wood furnishing factory Phagwara Punjab. The wood ash was obtained by incineration of carpentry waste and other agricultural wastes like rotten wood.

**Aggregates:** Foundry sand having grain size of 4.75 mm along with specific gravity as 2.6. The coarse aggregates used were crushed gravel of size about 10 mm and specific gravity of 2.6. The grain size or particle size distribution was according to ASTM C33/ C33M-08 (Figure 1).

| Particulates (%) | Type 1 | Type 2 | Type 3 | Type 4 | Type 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 31.4 | 13.1 | 50.7 | 30.0 | 8.1 |
| $Al_2O_3$ | 17.3 | 7.8 | 8.2 | 12.3 | 7.5 |
| $Fe_2O_3$ | 9.7 | 2.6 | 2.1 | 14.2 | 3.0 |
| CaO | 3.6 | 13.7 | 19.6 | 2.2 | 25.3 |
| MgO | 0.7 | 2.6 | 6.5 | 0.7 | 4.5 |
| $K_2O$ | 1.1 | 0.4 | 2.8 | 2.0 | 2.7 |
| $Na_2O$ | 0.8 | 0.6 | 2.1 | 0.5 | 3.3 |
| Moisture | 2.3 | 0.5 | 0.2 | 0.4 | 3.3 |
| LOI | 30.6 | 58.1 | 6.7 | 35.3 | 32.8 |

**Table 1:** Chemical composition of wood ash [12].

| Constituents (% Age) | Values |
|---|---|
| **Chemical properties** | |
| $SiO_2$ | 21.25 |
| $Al_2O_3$ | 5.04 |
| $Fe_2O_3$ | 3.24 |
| CaO | 63.61 |
| MgO | 4.56 |
| Losson Ignition | 3.26 |
| **Physical properties** | |
| Specific Gravity | 3.1 |
| Mean Size | 23 µm |

**Table 2:** Constituents in OPC.

**Figure 1:** Typical foundry sand.

| % age of wood ash added | 7 days | 28 days | 56 days |
|---|---|---|---|
| 0 | 18.39 | 32.41 | 36.05 |
| 5% | 16.16 | 25.25 | 30.00 |
| 10% | 16.69 | 26.32 | 31.12 |
| 15% | 17.32 | 28.14 | 34.62 |
| 20% | 16.34 | 27.14 | 32.71 |

**Table 3:** Compressive strength ($N/mm^2$) test result (wood ash as partial replacement of cement).

### Methods

**Selection of mix proportion:** The target compressive strength for M20 mix was calculated according to IS: 10262 2009 [9] as 27.8 $N/mm^2$ for 28 days. The water-cement ratio, fine aggregate content and coarse aggregate content was accordingly then carried as per the mentioned IS code [ 9]. Thus mix proportion obtained was:

Cement content = 409.9 $kg/m^3$

Fine Aggregate Content = 545 $kg/m^3$

Coarse Aggregate Content = 1163 $kg/m^3$

**Preparation of mix:** Preparation of control mix (M20 Design mix Considered) was done first for which the trial mix having water-cement ratio of 0.47 was prepared. Mix was checked for workability (to obtain consistent mix) and Slump Cone Tests to validate the results. Control specimen was casted for 7 days, 28 days and 56 days having foundry sand were casted.

Secondly the preparation of mix for same 0.47 water cement ratio was done along with wood ash in different proportions of 5%, 10%, 15%, 20% and 25% by weight of OPC. The specimens were casted for 7days, 28 days and 56 days.

Cubes of 150 mm × 150 mm × 150 mm were casted to check compressive strength. Cylindrical Specimens were casted to check Split Tensile strength and Beams of dimensions 300 mm × 10 mm were casted to check flexural strength.

A minimum of 3 specimens were casted for a single test to analyse. Whole procedure was carried at room temperature. Compacting of concrete was carried with the help of vibrating machine.

**Curing of blocks:** Curing of all specimens was done after 2 days.

**Tests carried:** Tests were carried for compressive strength, split tensile strength, flexural strength, workability, water absorption, carbonation, drying shrinkage and for acid attacks like $H_2SO_4$ and HCL.

## Results and Discussion

### Compressive strength

The replacement percentage was 5%, 10%, 15% & 20% by weight of cement. Tests were conducted on 7 days, 28 days and 56 days using the digitalized CTM (compression Testing Machine), so the accumulation of errors can be said to be minimum in this research. The results are provided in Table 3.

The conclusions drawn based on the results are:

1. The compressive strength for the control mixes for 7 days, 28 days and 56 days obtained were 18 $N/mm^2$, 32 $N/mm^2$ and 36 $N/mm^2$ respectively.

2. With the use of wood ash there was an increase in the compressive strength but that increase was not up to the control specimens. The compressive strengths obtained for respective days are given in Table 3:

3. The Optimum results were obtained at 15% replacement.

4. There was increase in the ductile behavior of concrete for wood ash replacement when tested under CTM. The time required to break the wood ash specimen was long enough as compared to break the control specimen, as the development of cracks started increasing slowly under same rate of loading (Figures 2 and 3).

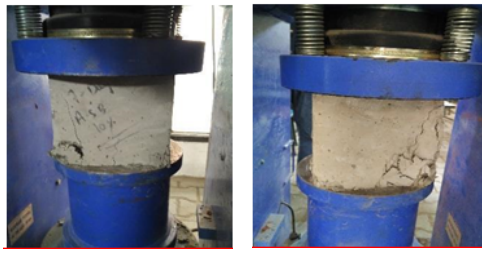
Rajamma et al. [1] observed the effects of wood ash on the compressive strength of concrete blocks. Wood ash was used to replace cement in percentages 10%, 20% and 30% by weight of cement, the optimum and significant results were shown on 10% of replacement exhibited higher 28 days strength. But with the replacement of 20% and 30% of by weight of cement, the 28days strength was insignificant and much reduced.

Udoeyo et al. [10] observed the compressive strength of concrete with replacements of 5%, 10%, 15% up to 30% and 30 by weight of cement).

Abdullia et al. [11] observed the compressive strength for 10%, 15%, 20% and 25%. The optimum results were observed at 15%. But the curing was done for 7 days, 14 days and 21 days. This showed the variation in results.

## Split tensile strength

The procedure was carried according to IS: 5816-199 [12]. The split tensile strength of the concrete with wood ash increased. The enhancement in split tensile strength was because of proper binding and insignificant surface area of binding particles (Table 4). But the increase was not higher than the control mix. We can say almost same results were obtained for 15% as the control specimen (Figures 4 and 5).



(a) (b)

**Figure 2:** Compressive strength testing.

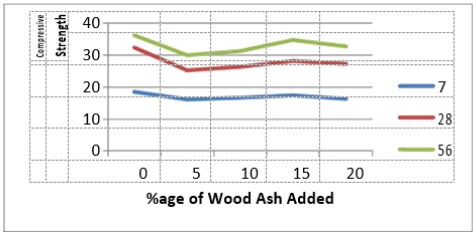



**Figure 3:** Comparison of compressive strength along wood ash percentage.

| % Age of wood ash | Split tensile strength at 7 days (N/mm²) | Split tensile strength at 28 days (N/mm²) | Split tensile strength at 56 days (N/mm²) |
|---|---|---|---|
| 0 | 2.32 | 3.64 | 4.16 |
| 5 | 1.37 | 2.47 | 3.14 |
| 10 | 1.82 | 2.85 | 3.79 |
| 15 | 2.19 | 3.29 | 4.02 |
| 20 | 1.92 | 2.77 | 3.96 |

**Table 4:** Split tensile strength test (wood ash as partial replacement of cement).

**Figure 4:** Failure of control specimen.

**Figure 5:** Failure of specimen along with wood ash.

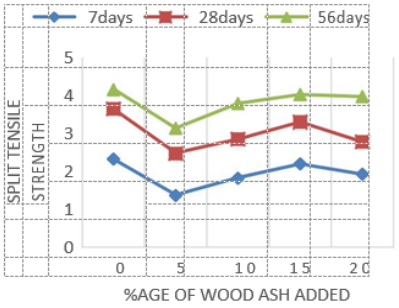



**Figure 6:** Comparison of split tensile strength along wood ash percentage.

(1) The average split tensile strength achieved by the control specimens for 7 days, 28 days and 56 days were 2.32 N/mm², 3.64 N/mm²and 4.16 N/mm² respectively.

(2) The strength of concrete along with the wood ash varied accordingly given in Table 4. The Optimum results were obtained on 15% replacement.

(3) Increase in the split tensile strength is because of the enhanced quality of cement paste due to addition of wood ash.

The failure for control specimen was brittle which resulted its splitting in two equal halves whereas when wood ash was incorporated the failure observed was not sudden but quite uniform upon load condition as given in Figure 6.

## Flexural strength

Beams were casted having dimensions of 300 mm × 10 mm × 10 mm to check flexural strength as per IS: 516 – 1959 [13]. Vibration of mix was done on vibrating machine according to IS recommendations. A system of 2 point loading was used with CTM to test the specimens. It was observed that there was an increase in the flexural strength

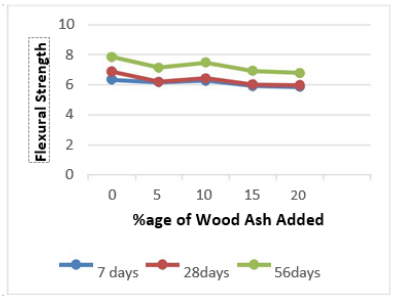



**Figure 7:** Comparison of flexural strength along wood ash percentage.

| % Age of wood ash | Flexural strength at 7 days (N/mm$^2$) | Flexural strength at 28 days (N/mm$^2$) | Flexural strength at 56 days (N/mm$^2$) |
|---|---|---|---|
| 0 | 6.34 | 6.87 | 7.84 |
| 5 | 6.17 | 6.19 | 7.13 |
| 10 | 6.26 | 6.43 | 7.47 |
| 15 | 5.91 | 6.01 | 6.91 |
| 20 | 5.84 | 5.96 | 6.77 |

**Table 5:** Flexural strength test.

specimens with wood ash but not greater than control specimens. Optimum results were obtained at 10% replacement (Figure 7). The results are given in Table 5.

## Water absorption

An increase in water absorption was observed maximum for 15% at 28 days which indicates that rate of pozzolonic reaction is much higher at 15% replacement. Beyond 15% replacement the water absorption significantly decreased.

Udoey et al. [7,10] According to this study the t-test carried showed certain results using wood ash as replacement of cement in the level of 5%, 10% and 25%, there was increase in water absorption for 28 days which was observed as significant. But the water absorption values uptill 10% were observed significant which produced positive results both with a without wood ash.

## Soundness

The soundness of concrete mix was studied and observed to be increase while increasing the wood ash % age. Similar results were obtained from other studies when the replacements were done from 5% to 30%. At 30% concrete obtained produced much soundness. Thus in short soundness increases in direct proportions of increased wood ash incorporation [14,15].

## Carbonation

The carbonation results along with the wood ash as partial replacement when water cement ratio of 0.50 was observed to decrease, providing optimum results at 5% of replacement. From other researches similar results were observed. The tests for carbonation showed that with 5% incorporation of wood ash in cement resulted in reduction in depth of carbonation. With the 10%, 15% and 25% the reduction in depth was insignificant [16].

## Bulk density

According to a study [17-19] bulk density was observed to decrease with increasing % age of wood ash as replacement for cement. Much more significant results were obtained at 40% replacement.

Reduction in bulk density at 40% was 2281 kg per cub. Meter and at 0% was 2482 kg per cub meter. This shows that wood ash observed is of low specific gravity.

## Drying shrinkage

Naike et al. [8] observed the shrinkage in concrete with wood ash. Replacement was done for 5%, 8% & 10% by weight of cement as a binder. The following results were obtained:

1. Shrinkage of concrete cube was 0.0092% at 7 days and 0.052% at 232 days.

2. At 5% replacement of cement with wood ash shrinkage was 0.012% at 7 days and 0.027% at 232 days.

3. At 8% replacement of cement with wood ash shrinkage was 0.014% at 7 days and 0.014% at 232 days.

4. At 12% replacement of cement with wood ash shrinkage was 0.0051% at 7 days and 0.044% at 232 days.

## Conclusions

Following are some of the investigated conclusions from the above study:

1. Wood ash may vary in quantity and quality because of many factors like temperature, type of wood or biomass, combustion type, etc. So it is quite necessary to analyze the wood ash before using.

2. The strength parameters obtained were quite better than the attaining target of M20**.** The results for compressive strength were much significant. The optimum level of replacement with wood ash produced positive results.

3. The incorporation of wood ash resulted in increase in the water absorption

4. Bulk density of concrete was observed to decrease with the increasing % age of wood ash.

5. Incorporation of wood ash concrete resulted in increase in mass at initial stages when immersed in acids.

6. Incorporation of wood ash made concrete ductile enough. It means that concrete was able to bear loads for longer time as the failure was not sudden.

7. Incorporation of wood ash enhanced the quality of paste, thereby increasing both split tensile strength and flexural strength of concrete.

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