A Comparative Study on Strength of Concrete Using Wood Ash as Partial Replacement of Cement

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Abstract. The study here presents the conduct of wood ash as partial replacement by weight of cement in concrete. Portland cement as a binder in concrete is one of the fundamental development materials generally utilized particularly in creating nations. The expanding demand for cement can be met by partial replacement of cement. And also involves use of a waste product to create eco-friendly alternative supplement to binding in concrete. Two wood ashes from two different sources of woods were picked for the examination. The concrete mixes were blended with 0%, 10%, 15%, 20% and 25% from two sources of wood ash as a partial replacement by weight of cement and tested for compressive strength respectively. M25 grade of concrete was prepared for the examination. Concrete cubes were casted and cured for 7 and 28 days respectively, for test results. Shear slump was seen with the incorporation of wood ash in concrete which indicates the harshness of the mix because of less use of cement. Test outcome indicated that the wood ash is marginally pozzolanic, water demand increments as the wood ash increments in concrete mix consequently admixture was required to increase the workability of concrete mix. Just one type of wood ash indicated positive outcomes when compared with standard mix limits. Therefore 10% WA1 partial replacement showed highest value of strength however, our examination recommended wood ash as low potential to partial replacement of cement and composition of different types of wood ash may wary thus influencing the properties of concrete.

Keywords: Wood ash, Partial replacement, Compressive strength, M25, Concrete mix, Pozzolana;

1. Introduction
Concrete is a blended mix comprising essentially of binder cement, water, sand and coarse aggregate (gravel). Routinely utilized solder is the result of hydration of binder that is cement, which is the compound created among cement and water. Substitutions may moreover be included to concrete mixes to alter a part of its characteristics. Portland cement as a binder in concrete is one of the basic improvement materials generally utilized especially in making nations. The expanding need for the use of cement could be supplemented by partial replacement of cement. The quest for substitutive binder or replacement materials to cement prompted the finding the possibilities of utilizing industrial waste...
products, and horticultural leftovers as material binders. The utilization of industrial and agricultural waste in binder creation is an ecological amicable technique for removal of huge amounts of products that would somehow contaminate air, water and land. The wood ash used as partial replacement of binding cement aids maintaining strategic distance from significant and mass consumption of pure cement. Other than this the production of cement material all alone brings about expanded emanation of certain ozone depleting substances or greenhouse gases and substantially more contaminants. Subsequently supplanting with wood ash prompts litter utilization of cement that is binder, which is ecologically beneficial. Aside from this, supplanting strategy lessens the expenses. The properties of wood ashes will be diverse for various kinds of agricultural by-products, lumber, and so forth[2]. These attributes rely on the conformation, Burning technique and area.

In this study wood ash was used as a partial replacement to binder cement which is a pozzolana. Pozzolana is a compound which is abundant in calcium oxide, silica and alumina which themselves have no binding characteristics however in finely isolated structures and in the company of moisture, chemically responds with calcium hydroxide at normal temperature to form compound having binding characteristics. Wood ash can be related to fly ash since both are residue of wood however fly ash is a fossilized wood and wood ash is procured by just combustion of wood. Many waste materials having pozzolanic properties such as fly ash, rice husk and silica smoke have been studied and used as binder in blended cements.

In cement and wood ash the binding characteristic is due to the primary parts like lime (CaO), silica (SiO2), alumina (Al2O3), magnesia (MgO), iron oxide (Fe2O3), calcium sulfate (CaSO4), sulphur trioxide (SO3) and alkalines, however the proportion of elements in wood ash may differ because of the kind[1], procedure of combustion and occurrence of uncremated carbon and so forth[3,4,5]. In this way it marks it the primary explanation of variation of strength because of wood ash binding in the course of strength development and may proceed for a considerable length of time after the mix concrete has remained placed and cured. Strength development or hardening of concrete to a great extent is the result of the development of calcium silicate hydrate (C-S-H) as the cement keeps on hydrating. Upon the hydration of Portland cement (C-S-H) is the principle product and is chiefly accountable for the forte in cement based materials. (C-S-H) is byproduct of the reaction among the silicate stages of water and Portland cement. Following reaction depicts the interaction compound in cement and is communicated as:

\[ 2\text{Ca}_3\text{SiO}_5 + 7\text{H}_2\text{O} \rightarrow 3\text{CaO} \cdot 2\text{SiO}_2 \cdot 4\text{H}_2\text{O} + 3\text{Ca} (\text{OH})_2 + 173 \text{ kJ} \]

In inspection the crystal arrangement of C-S-H in cement paste has not been fully determined so far and there is still continuing examination over its nanostructure. SEM micrographs of (C-S-H) does not display any definite crystalline form. Crystalline form typically manifest as flakes or dendrites/fibrils.

2. Objective and Scope

In the contemporary times there is a significant increment in the accumulation of waste products, our scope in this examination traverses the attainment of cementitious characteristics on replacement of cement by a waste product which is wood ash. In order to shrink menaces instigated by wood ash and formulate non-toxic and proficient discarding, this study was performed. And also to check the effectiveness of partial replacement of cement by wood ash, thereby decreasing cement outlays.

The main objective for the performance of the study was to check the compressive strength of wood ash blended concrete and to analyse the results for variation in concrete characteristics due to wood ash. We also tried to find out the optimum replacement percentage for highest strength value and to decide the aptness of wood ash as cement replacement material.

3. Literature review

Our study of literature suggested wood ash as rather pozzolanic material with fine particles and greater surface areas[2]. Many studies from literature review were able to achieve target strength[1]. And also suggested types of wood ash may influence the binding properties of wood ash. Water absorption was also seen increasing in multiple studies. Throughout the literature study, higher replacement percentages that is higher than 20% by wood ash did not produce optimum results and was below standards[1,5].
4. Material components

4.1. Cement

In this study we used ordinary Portland cement of grade 43 was used throughout from ITC Company having constituent particle size of 3.9 μm. It was procured from a unit source. The cement was stowed and verified conforming to IS: 4031. The different physical properties of cement are organised in Table 1 below.

| Test          | Results     |
|---------------|-------------|
| Specific gravity | 3.144       |
| Consistency   | 31%         |
| Fineness      | 96%         |
| Initial setting time | 55 minutes   |
| Final setting time | 535 minutes |

4.2. Fine and coarse aggregate

In the study the fine aggregate (sand) and coarse aggregate (gravel) was procured from source locally available which were free from any chemical and biological contaminations conforming to IS: 383 – 1970 [Specification for Coarse and Fine Aggregates from Natural Sources for Concrete]. The gravel used in study were well graded and irregular in form. 20 mm was the highest size of gravel. The aggregates were waterless before use. Both the sand and gravel were verified for their physical necessities such as grading, fineness modulus, specific gravity and bulk density conforming to IS: 2386 – 1963 [Methods of test for aggregate for concrete]. The properties are shown in Table 2 below.

| Test                          | Sand | Coarse aggregate |
|-------------------------------|------|------------------|
| Specific gravity              | 2.34 | 2.18             |
| Fineness modulus              | 3.50 | N.A              |
| Zone                          | 2    | N.A              |
| Surface moisture content      | 0%   | 0%               |
| Water absorption              | 2.73%| 0.35%            |

4.3. Water

Water used for mixing and curing was potable, which was void of oils, acids, alkalis, sugars, salts and natural materials and different substances that might be detrimental to concrete or steel conforming to IS :3025 – 1964 part22, section 23 and IS : 456 – 2000 [code of training for plain and strengthened concrete]. The pH level estimation of water utilized was 7. In water the solids existing were within the allowable parameters conferring to section 5.4 of IS: 456 – 2000.

4.4. Wood ash

In the study two wood ashes were chosen from two different sources. Two wood ashes in the study are represented as WA1 and WA2. WA1 was procured from a restaurant oven in which firewood is used and WA2 was procured from combustion of wood byproducts from timber joinery mill. 150 micron sieve was used to strain the wood ash for usage as replacement in concrete mix. Our literature review suggested that the chief constituents of wood ash are Lime (calcium oxide, CaO), Silica (silicon dioxide, SiO₂), Alumina (aluminium oxide, Al₂O₃), Iron oxide (Fe₂O₃), Magnesia (magnesium oxide, MgO) [1,2,3,4,5]. These compounds in the existence of water react to create binding agents likewise cement. Cement also inhabit these constituent compounds. Which implies wood ash as a slight pozzolanic.
Occurrence of unburnt carbon in wood ash losses the pozzolanic constituent quantity in wood ash, which is why it is important to use the ash from well combusted wood[1,2].

4.5. Admixture
In the study Super plasticizer Commix-777 was used. The plasticizer in fluid structure, has been fashioned to increase workability by making a greasy concrete mix and also to improve water snugness by diminishing fissures. Properties: Integrating commix-777 concrete mix plasticizer in concrete mix lessens the water necessity for a similar constancy which in this manner allows the utilization of leaner blends. It also benefits the concrete mix by reducing the risk of cracking and fissures by entrapping minute air pockets in concrete mix. This plasticizer decreases rubbing in the damp constituents and air bubbles shaped, assimilate enlargement brought about by alterations of temperature in surrounding. In addition, there is a decrease in the water penetrability of the solidified mix by limiting formation of fissures. The mortar volume would increment from original by up to 20%.

5. Method

5.1. Mix proportion
Concrete mix of M25 was chosen and designed conforming to IS: 10262-2009 where the target strength came out to be as 31.4 N/mm² after 28 days of curing period. Water-cement ratio selected for the mix was 0.50. Therefore proportion mix ratio attained was (1: 1.57: 2.60).

5.2. Mix preparation
Firstly the 0% replacement mix (control mix) was prepared with attained mix ratio and selected water cement ratio of 0.50. Mix was checked for workability to confirm the results. Control mix specimen were casted for testing at 7 and 28 days.

Secondly we prepared the replacement mixes with wood ashes (WA1 & WA2) in various quantities of 10%, 15%, 20% and 25% by load of cement. Plasticizer was incorporated to achieve the desired workability of concrete mix. Concrete specimen cubes were casted for 7 and 28 days test results.

Concrete specimen cubes of dimension 150 mm × 150 mm × 150 mm were casted to analyze the compressive strength properties. At least 3 specimen cubes were casted for respective percentage of wood ashes (WA1 and WA2) to analyze the test results. The concrete in the cubes was compacted using vibrating machine. All the study, casting and curing was done at room temperature.
5.3. Curing of cubes
Concrete specimen cubes after casting were cured in potable water for 7 and 28 day test results.

5.4. Specimen testing
Concrete cubes were tested for compressive strength in digital CTM (compression testing machine).

6. Results and discussion

6.1. Workability

6.1.1. Slump cone test
After mixing of concrete the slump cone test was performed for all the mixes with and without replacement by wood ash and the slump value seen for wood ash blended mixes came out to be shear. This is a result of the harshness of the blend because of the lacking measure of cement and also the wood ash tends to absorb more water in concrete mix thus making the mix dry with the selected water cement ratio[4]. Admixture plasticizer conmix777 was utilized with replacement mixes to achieve desired workability of concrete at around 50 mm at various percentages as referenced in Table. 3 and 4 below. Our work proposed that the ideal workability can be achieved by adjusting the water concentration in concrete mix.

| Replacement of cement by wood ash (WA1) percentage | Percentage(%) of admixture | Slump |
|-----------------------------------------------------|-----------------------------|-------|
| Control mix 0%                                       | 0                           | 48    |
| WA1 10%                                              | 0.60% of cement             | 52    |
| WA1 15%                                              | 0.62% of cement             | 55    |
| WA1 20%                                              | 0.66% of cement             | 54    |
| WA1 25%                                              | 0.70% of cement             | 56    |

| Replacement of cement by wood ash (WA2) percentage | Percentage(%) of admixture | Slump |
|-----------------------------------------------------|-----------------------------|-------|
| Control mix 0%                                       | 0                           | 48    |
| WA2 10%                                              | 0.60% of cement             | 53    |
| WA2 15%                                              | 0.62% of cement             | 56    |
| WA2 20%                                              | 0.66% of cement             | 49    |
| WA2 25%                                              | 0.70% of cement             | 58    |
6.2. Compressive strength of cubes

After carrying out the compressive strength test after curing of concrete cube at 7 and 28 day respectively on digital compressive testing machine, results are tabulated above in Table. 5 and 6 of two wood ash (WA1 and WA2) substituted concrete cubes at different percentages of wood ash in concrete mix in terms of the compressive strength in N/mm². The results pointed to the fact that, there is variation in test results from the two types of wood ashes substituted concrete specimens. This can be mainly because of the difference in chemical composition of wood ashes, wood ashes which are rich in lime (CaO), Silica (silicon dioxide, SiO₂) and Alumina (aluminium oxide, Al₂O₃) contribute significantly in binding function in concrete mix as mention in section 1 above other than that there can be some small parameters which can also influence the binding properties such as unburnt carbon presence and water cement ratio. The mix was designed for characteristic strength of 25 N/mm² and the target strength obtained was 31.4 N/mm². On comparison with control mix (0% cement replacement), substituted concrete with wood ash (WA1) the results were somewhere around characteristic strength of M25 grade of concrete which can be used in construction however, the substituted concrete with wood ash (WA2) showed results way below the characteristic strength of M25 grade of concrete. Also the increasing percentage of cement replacement in the concrete mix showed decrease in the strength value of concrete specimens after testing in both cases as can also be seen in the Fig. 3 and Fig. 4 for 7 and 28 days compressive strength results respectively. Which implies the infeasibility of wood ash at higher percentages.

### Table 5. Compressive strength of wood ash concrete mix (WA1) cubes.

| Wood ash content by percentage (%) | Compressive strength after 7 days in N/mm² | Compressive strength after 28 days in N/mm² |
|-----------------------------------|------------------------------------------|------------------------------------------|
| Control mix 0%                    | 20.50                                    | 34.17                                    |
| WA1 10%                           | 21.46                                    | 24.71                                    |
| WA1 15%                           | 21.28                                    | 24.35                                    |
| WA1 20%                           | 20.32                                    | 23.17                                    |
| WA1 25%                           | 18.40                                    | 22                                        |

### Table 6. Compressive strength of wood ash concrete mix (WA2) cubes.

| Wood ash content by percentage (%) | Compressive strength after 7 days in N/mm² | Compressive strength after 28 days in N/mm² |
|-----------------------------------|------------------------------------------|------------------------------------------|
| Control mix 0%                    | 20.5                                     | 34.17                                    |
| WA2 10%                           | 16.40                                    | 19.91                                    |
| WA2 15%                           | 14.30                                    | 17.86                                    |
| WA2 20%                           | 13.60                                    | 16.53                                    |
| WA2 25%                           | 9.15                                     | 14.20                                    |
Fig 3. Compressive strength at 7 days in N/mm$^2$.

Fig 4. Compressive strength at 28 days in N/mm$^2$. 
7. Conclusions

1. Wood ash can be used to create M25 grade of concrete or any structural grade concrete however upon the increased use of wood ash in the concrete decreases the strength of concrete.
2. The wood ash might differ in quality as a result of several factors like temperature, style of wood or biomass, combustion sort, etc. thus it's quite necessary to study and analyze the wood ash before application.
3. Increasing water demand was seen with the increment in wood ash in concrete mix due to more water absorption by wood ash than cement.
4. Blending of wood ash in concrete mix tends to make harsh mix since cement is used in lesser content and it increases the water absorption thus gives shear slump almost at every replacement percentage therefore admixture is required to get the desirable workability of concrete mix.
5. The initial and final setting time of wood ash blended cement paste rises as the ash content increases. Recommended standards were satisfied for OPC paste at 10% and 20% replacement by wood ash blended cement paste.
6. Compressive strength of the cubes with 10% WA1 content improved appreciably after 7 and 28 days. Therefore ideal replacement percentage was 10% of WA1.
7. Wood ash use in concrete is not recommended at higher percentages as it tends to decrease the strength properties of concrete.
8. Pozzolanic material is reduced in the wood ash due to the existence of unburnt carbon because of irregular incineration of wood.
9. Our examination recommended wood ash as moderate potential to partial replacement of cement at higher replacement percentages and composition of different types of wood ash may vary thus influencing the properties of concrete.

8. References

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