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 ash is generated from biomass, it needs to be treated well as it contains certain contaminants. 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 saw dust, 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 fluid bed incineration. These technologies have solved 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.

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 saw dust, 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 fluid bed incineration. These technologies have solved 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.

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Physical properties of wood ash

Wood ash particles are of different sizes and shapes. To obtain the
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), CaCO3 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 2.

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).

Methods

Selection of mix proportion: The target compressive strength for M20 mix was calculated according to IS: 10262 2009 [9] as 27.8 N/mm2 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/m³
- Fine Aggregate Content = 545 kg/m³
- Coarse Aggregate Content = 1163 kg/m³

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 7 days, 28 days and 56 days.

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

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/mm², 32 N/mm² and 36 N/mm² 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 28 days 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).

(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/mm² and 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.

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.

(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...
incorporation [14,15]. Short soundness increases in direct proportions of increased wood ash to 30%. At 30% concrete obtained produced much soundness. Thus in increase while increasing the wood ash % age. Similar results were obtained at 40% replacement. Much more significant results were obtained at 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].

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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