Strength of concrete with wood ash and waste glass as partial replacement materials

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Abstract. This paper discusses a study on the use of wood ash as partial replacement of cement and waste glass as partial replacement of fine aggregate in concrete. Wood ash was used to replace cement at 5% and 10% and waste glass was used to replace fine aggregate at 10% and 15%. When wood ash was added to concrete, the compressive strength of concrete was found to reduce marginally with respect to the reference mix and the optimal value of compressive strength was obtained at 5% replacement. Addition of waste glass to replace fine aggregate resulted in marginal reduction of compressive strength of concrete at 10% replacement. However, a drastic reduction in compressive strength was observed at 15% replacement level of waste glass. Replacing 5% of cement with wood ash and 10% of fine aggregate with waste glass yielded satisfactory results and thereby at these replacement levels, wood ash and waste glass can be used as replacement materials in concrete. Incorporating the waste materials in concrete will be an efficient and effective way to dispose these materials and will result in lower consumption of natural materials in the manufacturing process of concrete thereby resulting in an environment friendly and cheaper concrete.

1. Introduction

Concrete is one of the most extensively used construction materials in the world. Concrete can be produced from locally available materials, can be cast into a wide variety of structural configurations and requires minimal maintenance during its service life. It has many advantages such as good durability, fire resistance, energy efficiency, low cost and aesthetics and can be moulded into any shape and fabricated on site. The versatility and mouldability of this material, its high compressive strength and discovery of reinforcing and prestressing techniques which helped to make up for its low tensile strength have contributed largely to its widespread use.

However, construction industry worldwide is now encountering a major problem of shortage of natural resources, especially those required in manufacturing concrete. The production of cement causes carbon dioxide emission at a massive scale. The increased cost and environmental degradation caused while manufacturing cement and the scarcity of naturally available aggregates establishes the need for investigating alternative materials for use in concrete. Several researchers have made attempts by investigating and ascertaining the usefulness of locally available materials. Some of these materials include waste glass, byproducts of agriculture, wood waste etc. As concrete is the main constituent in the construction of the building elements, reducing the cost of concrete production will reduce the overall cost of construction. Incorporating other materials in manufacturing concrete and reviewing the
strength properties of concrete with the new materials thus becomes relevant topic of research nowadays.

The incorporation of the waste wood ash (WWA) produced as a result of incineration of saw dust at elevated temperature and powdered glass in concrete could be a stepping stone to a greener environment. Saw dust is essentially a waste product from the mills and its effective disposal is a major concern. Along with that, waste glass from various industries is increasing day by day. When the waste glass is crushed, sand like particles sizes are obtained, similar to natural sand and it exhibits the properties of an aggregate. If these materials could be used in concrete for replacing fine aggregate and cement, it could reduce the utilization of cement in concrete and at the same time result in an effective and efficient method to manage these waste materials.

Various researchers have studied replacement of cement with wood ash and observed a reduction in strength of concrete with addition of wood ash [1-4]. However as the curing age increased, strength was found to increase. A study on partial replacement of fine aggregate with glass aggregate determined the optimum percentage of glass aggregate which gave maximum compressive and flexural strength as 20% [5]. The addition of waste glass in concrete showed high impermeability, enhanced flow properties and higher strength at elevated temperatures when used in low proportions as aggregate replacement[6]. Other studies reported that the workability of concrete decreased with addition of glass aggregates when used to replace fine aggregates in concrete [5, 7]. Glass aggregate can be a satisfactory substitute for natural fine aggregate at replacement levels up to 20% of the total aggregate [8].

Previous research have identified wood ash and waste glass a potential replacement materials for cement and aggregates in concrete. This study investigates the compressive strength of concrete produced by replacing cement and fine aggregate with waste wood ash and waste glass respectively. Wood ash has been used to replace cement at 5% and 10% levels and waste glass used to replace fine aggregate at 10% and 15% levels.

2. Materials and methods

2.1. Materials
Ordinary Portland Cement (OPC) of 53 grade was used in the present study. The saw dust required for production of wood ash was procured from a nearby wood mill. The saw dust was then incinerated in an induction furnace to obtain wood ash. The combustion temperature was 700°C which was maintained for 30 to 40 minutes. Around 2.5 kg of saw dust could be loaded at a time in the furnace and after incineration; it yielded only around 30 g of wood ash. The loss on ignition was found to be very high. Manufactured sand was used as fine aggregate and conformed to Zone 2 as per IS 383: 2016. Waste glass, used to replace fine aggregate, was procured from the construction waste yard in the premises. To convert it to fine aggregate, it was loaded into the Los Angel Abrasion testing machine along with cast iron balls and rotated for 1000 revolutions. The glass aggregate thus obtained was in the size ranging from 4.75 mm to 0.075 mm. Sieve analysis performed identified the glass aggregate as conforming to Zone 1 as per IS 383: 2016. Due to difficulty in obtaining sufficient quantities of wood ash, the sizes of specimens for testing compressive strength were reduced to 50 mm x 50 mm x 50 mm. Hence, coarse aggregate of size in range of 6.30 mm to 4.75 mm was used in the present study. Crushed natural stone was used as coarse aggregate. The aggregates retained in 4.75 mm sieve and passing through 6.3 mm was used for the preparing the specimens. The specific gravity of the materials are summarized in Table 1.
2.2. Methods
Nominal concrete mix of 1:1:2 was adopted in the present study. Specimens were cast by replacing 5% and 10% of cement with waste wood ash and 10% and 15% of fine aggregate by glass aggregate. In addition, specimens with only wood ash replacement at 5% and 10% and only glass replacement at 10% and 15% were cast. For each replacement percentage, three cubes were cast for 28 days and three cubes were cast for determining 56 days compressive strengths. The results obtained were compared with those for the reference mix (with no replacements). The test specimen were stored in a place free from vibrations and kept at a temperature of 27±2°C for 24 hours from the time of addition of water. After this period, specimens were marked and removed from moulds and immediately submerged in clean water and cured for 28 days and 56 days accordingly. Before testing, specimens were taken from water and allowed to air dry. Specimens were tested on a compression testing machine of capacity 2000 kN at a uniform rating of loading of 140 kg/cm² per minute. The maximum load at failure was noted and the compressive strength was calculated.

3. Results and discussion

3.1. X-ray diffraction analysis
The X-ray diffraction (XRD) technique can be used to identify the crystalline phases present in a material and thereby reveal information on mineralogical phases present in the material. In this study, X-ray diffraction analysis was used to investigate the wood ash sample obtained by burning saw dust. The burnt saw dust ash particles were crushed gently using a mortar and pestle. The powdered sample passing through 75 μm was then taken for the testing. The XRD analysis was performed using an X’Pert Pro PANalytical diffractometer. The scanning range adopted was over the 2θ range from 5-65°. Cu-Kα radiation was used to generate X-rays with test settings of 45 kV voltage and a current of 30 mA. The identification of crystalline phases was carried out using the software, X’Pert HighScore Plus with ICSD database.

Figure 1 shows the XRD diffractogram pattern of the tested sample. The obtained pattern shows a mostly crystalline material with few traces of amorphous phases. The main phases present are cristobalite (minor trace quantity only), crystalline quartz, calcite and some amorphous silica (hump between 2θ 26-33°). The main peak of cristobalite is found at 2θ 21.56° (main peak) and 35.6°. Quartz peaks are identified at 23.7° (main peak), 29.5°, 41.6° and 42.8° 2θ. Calcite (calcium carbonate) peaks are at 29.62° (main peak), 36.2°, 39.7°, and 47.8° 2θ. Prominent minerals are calcite and crystalline quartz which are inert crystalline phases and does not contribute to the pozzolanic activity.
3.2. Compressive strength
Table 2 and figure 2 show the results of the compressive strength tests at 28 days and 56 days. In Table 2, the legend W represents the concrete with wood ash as a partial replacement of cement. The term G indicates the use of glass aggregates as a partial replacement of fine aggregate (M Sand). The results on compressive strength of concrete mixed with wood ash and waste glass as partial replacement for cement and fine aggregate respectively reveals that the strength achieved is comparable to that of the reference sample even after the incorporation of waste materials like wood ash and glass aggregate. The compressive strength of concrete mixed with wood ash as partial replacement of cement revealed a decrease in strength as the amount of wood ash increased, but the compressive strength was comparable to that of reference concrete at 5% replacement.

Table 2. Results of compressive strength test.

| Mix                          | 28 days compressive strength (MPa) | 56 days compressive strength (MPa) |
|------------------------------|-----------------------------------|------------------------------------|
| Reference                    | 42.7                              | 47.5                               |
| Wood ash 5% (W5)             | 41.3                              | 46.9                               |
| Wood ash 10% (W10)           | 36.3                              | 43.5                               |
| Glass 10% (G10)              | 40.0                              | 41.9                               |
| Glass 15% (G15)              | 28.8                              | 32.5                               |
| Wood ash 5%, glass 10% (W5G10)| 41.1                              | 46.7                               |
| Wood ash 5%, glass 15% (W5G15)| 32.5                              | 36.5                               |
| Wood ash 10%, glass 10% (W10G10)| 39.5                              | 42.7                               |
| Wood ash 10%, glass 15% (W10G15)| 24.5                              | 28.0                               |

For concrete mixed with waste glass as partial replacement of fine aggregate, a massive decrease in strength was observed as the amount of waste glass increased, but the compressive strength was comparable to that of reference concrete at 10% replacement. In mixes, with both wood ash and glass aggregate as replacement materials, the highest strength was achieved with 5% wood ash replacement.
and 10% waste glass replacement. When comparing the compressive strengths with conventional concrete, a decrease in strength was observed for concrete with wood ash and waste glass but the strength became more comparable as the curing age increased to 56 days. In the mix containing 5% wood ash and 10% waste glass, the strength was lower by 3.74% of the reference concrete at 28 days but at 56 days it was lower by only 1.68%. Similar results were obtained for concrete with wood ash replacement at 5% level.

Figure 2. Compressive strength comparison of various mixes.

4. Conclusions
In this study, the compressive strength of concrete produced by replacing cement and fine aggregate with waste wood ash and waste glass respectively is investigated. Wood ash has been used to replace cement at 5% and 10% levels and waste glass used to replace fine aggregate at 10% and 15% levels. The following conclusions can be made based on the results obtained in this study:

- Wood ash can be used for partial replacement of cement in concrete.
- Waste glass can be potentially used for partial replacement of fine aggregate in concrete.
- The addition of wood ash decreases the concrete strength marginally. Strength also decreased marginally when waste glass was added to the concrete.
- Replacement of cement by wood ash and fine aggregate by waste glass simultaneously showed only a marginal decrease in strength.
- The optimum value of compressive strength is obtained at 5% replacement of cement with wood ash and 10% replacement of fine aggregate with waste glass.
- The percentage of strength reduction with respect to that of reference decreased in the 56th day when compared to 28th day, implying that the strength of the mix increased with age.
- Using waste wood ash and waste glass in concrete can be looked upon as an effective method of disposing these waste materials with no damage to the environment. However, more research on the concrete durability using these materials is to be investigated.
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