International Journal of Early Childhood Special Education (INT-JECSE)
DOI:10.9756/INTJECSE/V14I5.907 ISSN: 1308-5581 Vol 14, Issue 05 2022

Flexural Strength of Waste Wood Ash Concrete at Elevated Temperatures

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ABSTRACT

This paper is aimed to present the properties of concrete by using waste wood ash (WWA) as a mineral admixture and partial substitute forOPC 53 grade Portland cement. The properties examined areflexural strength, and ultrasonic pulse velocity (UPV).Additionally, the concrete samples prepared are exposed to targeted temperatures of 200°C, 400°C, and 800^{0}C for measuring the residual properties.The partial substitution levels of wood ash are 0%-W0, 5%-W5, 10%-W10, 15%-W15, and 20%-W20. WWA concrete flexural strength results are compared with the results of M30 gradeconcrete flexural strength.WWA properties may vary in quality and magnitude by its production process like kind of wood and incineration technique. At 5% WWA (W5), a slight increase in the strength of WWA concrete is noticed. No significant resistance in the strength of WWA concrete is observed when subjected to targeted temperatures. In brief, the use of WWA in concrete benefits to convert environmental concern material to a sustainable resource in producing cementing materials.

Keywords: Pozzolanic, Sustainable concrete, Eco-friendly concrete, Wood ash,Filler material.

INTRODUCTION

In the present years, the increase in the energy demand and its insecurity augmented the utilization of renewable energy and its related resources. The most common energy resources are agricultural and forestry wastes or biomass resources are promising renewable energy resources with a continuous regeneration, economical and easy in handling nature. These resources are considered neutral energy resources by considering their consumption rate to growth rate. Further, the effective utilization of the by-products such as hard chips, sawmill scraps, wood bark, wood chips, and sawdust in the production of energy entrusts an effective method of handling these by-products. The combustion of these by-products reduces the volume and mass thus providing economically safe and environmentally friendly solid waste management. In most industries, the chief source of energy for maintaining small-scale boiler units is wood or wood waste [1-3].

Waste wood ash (WWA) is a waste fines/powder obtained by burning of waste wood particles (bark, sawdust, and chips). Wastes collected from wood related sources/industries are used as burning fuel in producing heat energy forsmall scale industries and household purposes. The physicochemical properties of WA primarily depend on the species of the wood, incineration temperature, supplementary fuels used, and the efficiency of the boiler. On average, the incineration of wood produces nearly 6% to 10% of ashes [3-5]. The viability of use of WA in concrete is governed by its chemical compounds.The major compounds found in WA are magnesium, carbon,manganese, potassium, calcium, sodium, and phosphorus. Some traces of molybdenum, copper, zinc, and boron are also found at per million levels.Typically, WA also consists of SiO_2, $CaCO_3$, and $K_2Ca(CO_3)_2$ which confirms the alkaline nature and will have a positive effect on the hydration process of cement [5].

In this study, an effort is made to experimentally study the viability of the use of WA as mineral admixture and partial substitute to cement for producing sustainable and eco-friendly concrete. The properties examined are flexural strength, and ultrasonic pulse velocity (UPV). Additionally, the concrete samples prepared are exposed to targeted temperatures of 200°C, 400°C, and 800^{0}C for measuring the residual properties. The experimentally obtained results are compared with the results of M30 grade concrete. For this aim, the locally available WWA is employed in the present research.

Materials and Methods

Table 1 shows the M30 grade concrete mix proportions.Portland cement (OPC 53 grade)in agreementwithIS 12269:2013 [6]having specific gravity of 3.15 is used. The potable water is used in mixing the concrete constituents, which is free from organic materials and suspended solids. Crushed aggregate with 20 mm maximum size is used in accordancewith IS 383: 2016 [7] with specific gravity and fineness modulus of 2.86 and 6.82. River sand is obtained from the local resources and is collected from the Krishna river. WWA is collected from a hotel central cooking system in Guntur city. M30 grade concrete is designed as per IS 10262: 2019 [8]. Figure 1 shows the locally available WA that is used for the experimental study.

The tests conducted on WWA concrete are shown in Table 2. The constituents of concrete are mixed homogeneously by an electrically operatedpan mixer and then the freshly mixed concrete is shifted into beams (50 x 10 x 10 cm). The fresh concrete samples are left undisturbed for 24 hours and are then transferred into the water for curing. A computerized universal testing machine is used for obtaining the strength tests results. The UPV tests equipment has two transducers with 54 kHz capacity is used for obtaining the UPV values. A set of concrete beam samples are shown in Fig. 2.Image showing the achievement of target temperatures are seen in Fig. 3. The concrete samples prepared are subjected to targeted temperatures of 200^{o}C, 400^{o}C, and 800^{0}C. The average heating rate maintained is 10^{o}C/min and the specimens are maintained for 2 hours at targeted temperatures. After removing the specimens from the electric arc furnace, the specimens are cooled naturally at room temperature. All the specimens are left undisturbed for 24 hours and then are examined for ultrasonic pulse velocity, visual inspection, flexural strength, and mass loss. Fig. 4 shows the setup of electric arc furnace.

Results and Discussion

Flexural Strength

Fig. 5 shows the average flexural strength resultsobtained at 28-days. For W0 concrete the average flexural strength is 4.6 MPa. With the addition of WA, for W5, W10, W15, and W20 the flexural strengths obtained are 4.7, 4.5, 4.3 and 4.1 MPa, respectively. At 28 days, for W5, W10, W15, and W20 concrete, the flexural strengths are 102.17%, 97.83%, 93.48%, and 89.13% of W0, respectively. The reduction in strength of WA concrete mixes may be by the poor bonding by WA in the cement matrix and also by the high surface area of WA. Furthermore, the decrease in the strength may be due to the increase in WA content that affects the chemical composition of the cement matrix.

Fig. 6 shows the variation of flexural strength of control and WWA concrete samples when subjected to targeted temperatures. At 200^{o}C, the reduction in strength is due to the reduction in cohesive forces in the hardened concrete that occurs with the evaporation of water. When the temperature reaches about 350^{o}C the aggregates get disrupted that leading to a further decrease in strength.Between 460 – 540^{o}C, decomposition of portlandite occurs and results in the leaching of CaO which is observed by whitish patches. At 573^{o}C, aggregates undergo physicochemical changes. Further, the second phase of C-S-H disintegrates which leads to further strength reduction.At 800^{o}C, the reduction in strength occurs by the desiccation of C-S-H, and calcium hydroxide alters to form calcium oxide. This results in weakening the interaction transition zone in concrete [12-14]. Fig. 7 shows a view of beam specimen subjected to 800^{o}C.

Ultrasonic Pulse Velocity

Fig. 8 presents the UPV results of control and WWAconcrete at ambient and targeted temperatures. These properties mainly depend upon the modulus of elasticity, density, soundness, curing, and aging of concrete. The setup of UPV testing is shown in figure 3. According to IS 13311 (Part 1): 1999b [9], UPV test results of above 4.5 km/s designate the excellent quality of concrete. All concrete mixes (W0, W5, W10, W15, and W20) exhibited excellent quality concrete. This signifies that the WWA concrete does not have any voids or cracks that may lead to damage tothe internal microstructure of the concrete.

The UPVvalues are reduced with the increase in targeted temperatures. The reduction in UPV values occurs due to the development of voids and capillary pores. At 200^{o}C, a minimal decrease in the UPV values is observed which could be by the loss of free water and dehydration of concrete. Between 400^{o}C – 600^{o}C, reduction in UPV values is observed which could be due to the transformation of the aggregate phase and dehydration of C-S-H gel. In short, the reduction in the UPV values of concrete might be due to the disintegration of the microstructure of concrete at targeted temperatures [14-15]. At 200^{o}C, the UPV values are good and above 3.5 km/s in accordance to IS 13311 (Part 1): 1999b [9]. At above 400^{o}C, the UPV values indicate doubtful concrete in accordance to IS 13311 (Part 1): 1999b [9].

Mass loss

Fig. 9 shows the variation of mass loss of control and WWAconcrete after being subjected to elevated temperatures. The mass loss of control and WWA concrete increases with the increase of targeted temperatures. The higher the targeted temperature more is the mass loss of concrete. Initially, between ambient temperature to 300^{o}C, mass loss is caused by the conversion of free water to vapors. Chemically bounded water would escape between 100^{o}C – 300^{o}C. The loss of structural water and crystal water would occur at above 300^{o}C resulting in the loss of hydroxyl (-OH). This creates deterioration of the mineral crystal lattice skeleton and enhances the defects in concrete. The deterioration of OH^- groups from Mg-hydroxide and Ca-hydroxide creates disintegration of the crystal lattice and consequent recrystallization occurs at between 300 – 600^{o}C. Between 500 – 650^{o}C, the carbonates in concrete convert into carbon dioxide and oxides. At above 800^{o}C, concrete undergoes physicochemical changes that lead to the generation of new recrystallization products resulting in expansion of concrete volume [14-16]. Additionally, the thermal incompatibility between the aggregates and cementing material results in the decomposition of the interaction transition zone which tends to strength reduction.

Visual Inspection

After natural cooling of the specimens, they are observed for physical visual inspection. The concrete specimens subjected to 200°C are observed with a little lighter grey color than at ambient temperature. At 400°C, the specimens are changed to light grey. No visible surface cracks are observed with the specimens when subjected to 400°C. At 800°C, the specimens are changed to ivory white with dark patches. Furthermore, extensive hairline and short capillary cracks are observed with the specimens. The visible changes observed with the specimens are by the decomposition of minerals and the loss of different forms of water in the pore solution. The free water bound in the pores evaporates at about 100°C. Between 100– 300°C, the chemically combined water evaporates. Above 200°C, the loss of structurally bounded water and crystal water may induce the loss of hydroxyl (-OH). Moreover, at above 300°C, carbonates/dolomite of gypsum in concrete are disintegrated into the water, calcium sulfate, carbon dioxide, and oxides. At above 100°C, crystal water in the gypsum of the cement matrix starts to evaporate. When the specimens are cooled, the properties of concrete may deteriorate. This happens when the specimens are cooled, they absorb the atmospheric moisture and that results in the expansion of concrete. Interim, at high temperatures the disintegrated product CaO, reacts with the moisture present in the air to form $Ca(OH)_2$ [15-17]. The steady expansion of the concrete volume leads to the formation of new cracks. From the discussion, it is evident that the crack dimension increases continuously together with the disintegration reactions.

Conclusions

Considering the findings obtained from the present experimental study, the conclusions are drawn are:

WWA concrete is prepared from the locally available WWA resources. At 5% WWA, a slight increase in the strength of WWA concrete is noticed. Reduction in the strength of WWA concrete is observed from 10% to 20%. The WWA may be used in the development of sustainable concrete as substitute for cement.

No visible surface cracks are observed with the specimens when subjected to 400°C. At 800°C, extensive hairline and short capillary cracks are observed with the specimens. At targeted temperatures, the reduction in the UPV values of reflects the damage caused in the internal microstructure of WWA concrete. No significant resistance in the strength of WWA concrete is observed when subjected to targeted temperatures. The UPV values are reduced with the increase in targeted temperatures. The reduction in UPV values occurs due to the development of voids and capillary pores. In brief, the use of WWA in concrete benefits to convert environmental concern material to a sustainable resource in producing cementing materials. In future, this experimental study may be extended to study the properties of WWAconcrete at different environmental conditions.

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Table 1: Concrete mix proportions

S.No.	Mix ID	Wood ash(%)	Wood ash	Cement	Natural Sand	Crushed Coarse aggregate	Water (lts)
1.	W0	0%	0.0	420.0	634.2	1184.4	168
2.	W5	5%	21.0	399.0	634.2	1184.4	168
3.	W10	10%	42.0	378.0	634.2	1184.4	168
4.	W15	15%	63.0	357.0	634.2	1184.4	168
5.	W20	20%	84.0	336.0	634.2	1184.4	168

*The constituents are in (kg/m^3)

Table 2: Tests conducted on WWA concrete

S.No.	Standard/Reference	Name of the test
1.	IS 516: 1959 [10]	Flexural strength
2.	IS 13311 (Part I): 1999 [9]	Ultrasonic pulse velocity
3.	ISO 834-10: 2014 [11]	Curve used to maintain the targeted temperatures

Figure 1: WWA used for experimental study

Figure 2: A set of concrete beam specimens

Figure 3: Image showing the achieved target temperatures.

Figure 4: Setup of electric arc furnace used

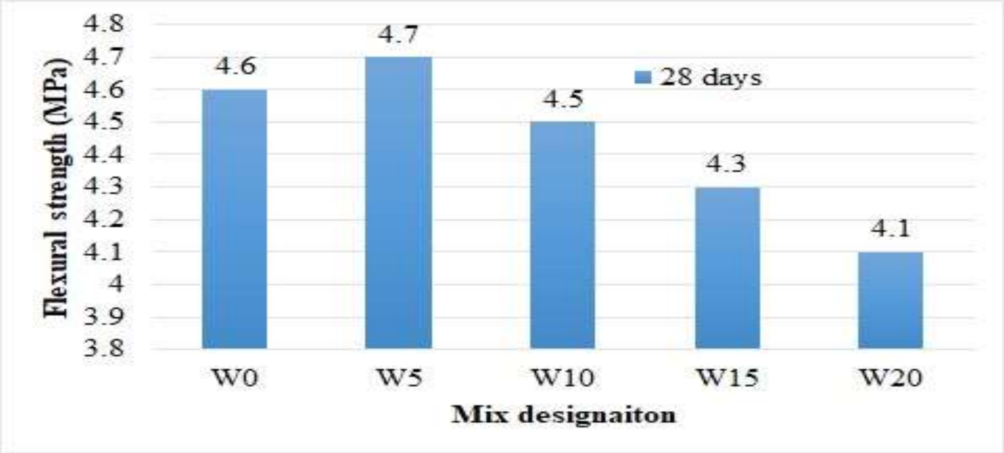
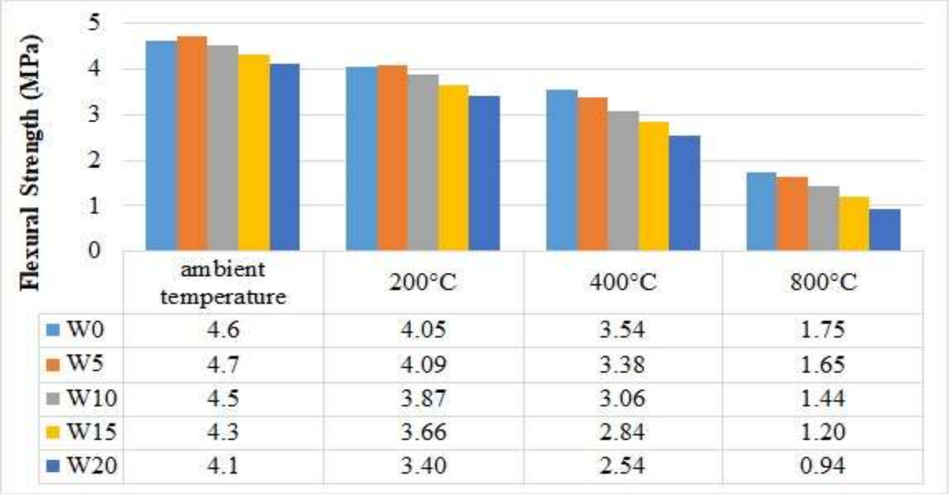


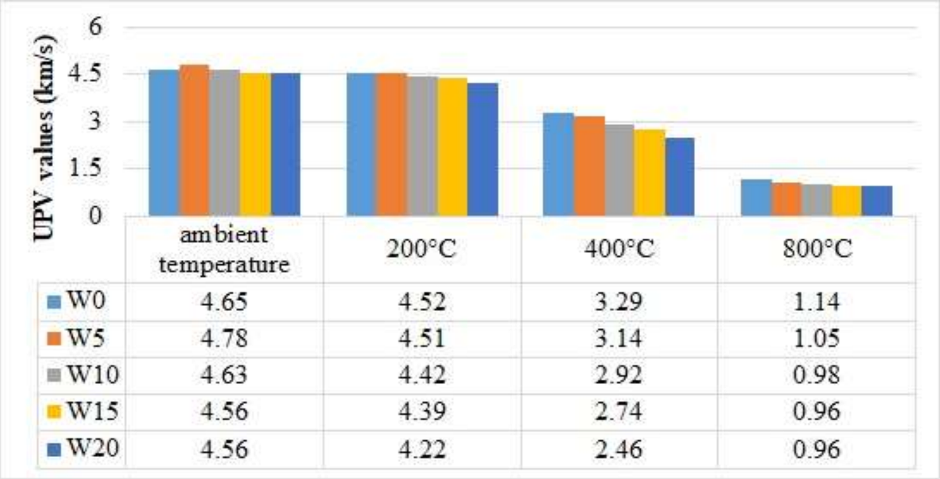
Figure 5: Variation of flexural strength of concrete at 28 days



	ambient temperature	200°C	400°C	800°C
W0	4.6	4.05	3.54	1.75
W5	4.7	4.09	3.38	1.65
W10	4.5	3.87	3.06	1.44
W15	4.3	3.66	2.84	1.20
W20	4.1	3.40	2.54	0.94

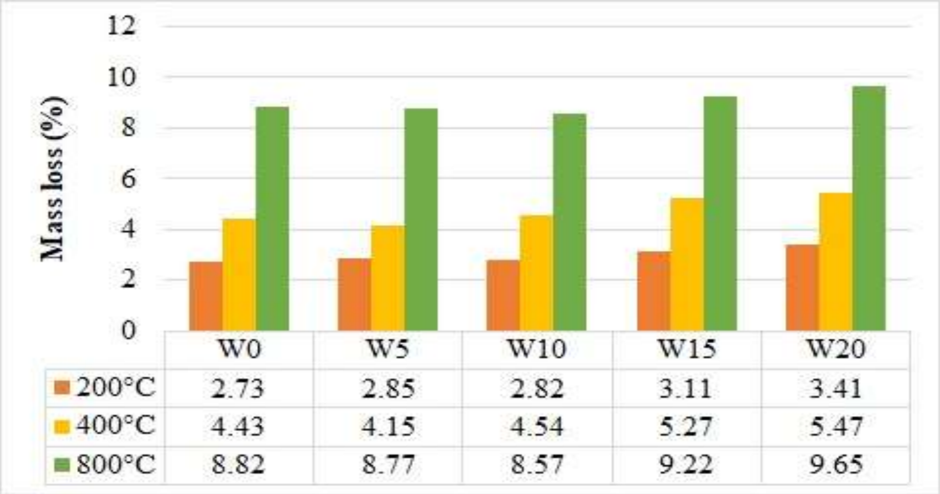
Figure 6: Variation of flexural strength at targeted temperatures

Figure 7: A view of beam specimen subjected to 800°C.



	ambient temperature	200°C	400°C	800°C
W0	4.65	4.52	3.29	1.14
W5	4.78	4.51	3.14	1.05
W10	4.63	4.42	2.92	0.98
W15	4.56	4.39	2.74	0.96
W20	4.56	4.22	2.46	0.96

Figure 8: Variation of UPV values with targeted temperatures



	W0	W5	W10	W15	W20
200°C	2.73	2.85	2.82	3.11	3.41
400°C	4.43	4.15	4.54	5.27	5.47
800°C	8.82	8.77	8.57	9.22	9.65

Figure 9: Variation of mass loss (%) of concrete with targeted temperatures