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Research Paper

Experimental Study of Physical, Fresh-State and Strength Parameters of Concrete incorporating Wood Waste Ash as a Cementitious Material

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ABSTRACT

The increasing demand and production of cement have caused a huge environmental burden and thus researchers are involved in discovering waste materials having cementitious properties to reduce the production and usage of cement in order to contribute towards the development of a sustainable environment. The present study, therefore, sought to quantify the influence of wood waste ash (WWA) as a cementitious resource on the fresh-state, physical, and strength parameters of concrete. The water absorption, workability, density, compression strength, tensile strength, and flexural strength of concrete was checked at various replacement levels i.e. 0%, 5%, 10%, 15%, and 20% by weight fraction of cement. The density and water absorption were checked on the 28th day of curing while the strength parameters were tested at 7, 28, 56, and 90 days of curing period. The water absorption, density, and workability of concrete reduced with an increase in wood waste ash content while the strength values were increased up to 10% replacement level. Hence, this study suggests that 10% WWA can be used instead of cement for concrete structures.

1 Introduction

Concrete comprises a binder (cement or lime), aggregates (coarse and fine), and water. For many years, it is being utilized in construction as a mandatory material due to its durability, versatility, and availability [1]. Apart from these merits, concrete also possesses some negative properties such as less resistance to tensile forces and quasi-brittle failure, etc. [2]. These deficiencies quest for an optimum solution and hence, steel is embedded in concrete to improve its tensile strength conventionally up to an extent [2]. Moreover, the cement, which is used as a binder, adversely affects the environment. The production of cement causes a burden on the environment due to its carbon footprint. It has been forecasted that half of the overall carbon emissions will be resulting from the manufacturing of cement in the year 2020 [3]. Globally, a huge amount of waste is ejected by different industries which quest for an efficient framework of debris management in cities. Recycling of such waste materials into novel building materials can be a feasible solution to address the problems of pollution and the

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high cost of conventional building materials [4]. Hence, many researchers studied the feasibility of replacing cement by some recyclable, eco-friendly and efficient construction materials [5] such as sugarcane bagasse ash, palm oil fuel ash, rice husk ash, sewage sludge ash, furnace slag, coal ash, silica fume, waste glass, etc. [6]. In a study intended to inspect the mechanical characteristics of concrete by replacing cement with 10% rice husk ash keeping water-binder ratio at 0.45, 0.50 and 0.60. The results revealed that the compression and tension resistance forces increased by 14.51% and 10.71%, respectively, at 0.45 w/b ratio with a curing time of 56 days [7]. The tensile and compressive strength of concrete mixes with Lakhra Fly Ash used as a cement replacement material increased by 16% and 15% respectively at 25% replacement level [1]. An experimental study conducted on traditional concrete by replacing cement with eggshell powder ash (ESPA) at 5%, 10%, and 15% by weight of cement concluded that 10% replacement level is optimum and yields enhanced strength. The slump value decreased consistently with the addition of eggshell powder ash in concrete. This indicates that there occurs a reduction in the workability of concrete by the inclusion of ESPA in concrete [8]. Another research study conducted on the use of sugarcane bagasse ash (SBA) as a cementitious material concluded that 5% SBA in the concrete matrix increased its compressive strength up to 12% [9]. In another experimental program, the tile powder was incorporated at 0%, 10%, 20%, 30%, and 40% levels of replacement by weight of binder at 0.5 water-cement ratios. The results depicted that at 10% replacement level, the compression and tension resistance forces of concrete increased by 7.50% and 10.20% which is quite acceptable [10].

One such industrial waste product that can be utilized as a pozzolanic material is wood waste which is abundant and economical [11]. An enormous amount of wood waste is generated by cutting, milling, and drilling of wood. This waste wood is fine in shape and texture and hence contains some pozzolanic and cementitious properties [12]. About 6-10% of ash is obtained from the burning of wood waste [13]. This integration of waste wood ash in cement can have an established significance in many ways as it aims to boost the strength of concrete, reduce the environmental burden, help in efficient waste management and economical construction. Authors in [14] reported that higher magnitudes of wood waste ash result in a reduction of the strength of concrete. Marthong studied the behaviour of concrete blended with woody ash for grade 33, grade 43 and grade 53 cements and found that the inclusion of WWA results in low workability and compression resistance of concrete [12]. The concrete units produced with the inclusion of WWA are lighter in weight and can withstand high temperatures as reported by [15]. Moreover, concrete blended with WWA can resist freezing and thawing actions [16] but will be less workable as argued by [4] and [17]. The WWA content also reduces the bulk density of concrete structural elements because of its lower specific gravity than that of OPC [18]. Hence, it can be concluded that the wood waste ash can be utilized as a cementitious resource but in light-weight concrete structures. This study, therefore, aims to find out the optimum percentage of WWA that can be used for the preparation of structural grade concrete. Further objectives include evaluation of fresh-state, physical and hardened properties viz. water absorption, density, workability and strength values of concrete.

2 Materials, Mix Design and Methods

2.1 Materials

The materials utilized in this experiment were Ordinary Portland Cement (OPC), fine and coarse aggregates, water and wood waste ash.

2.1.1 Wood Waste Ash (WWA)

The timber waste is the waste of cutting and crushing of wood and it carries pozzolanic properties. The timber waste content was burned at 500-degree Celsius to obtain its ash having specific gravity 2.29 and a bulk density of 765 kg/m^3. The chemical properties of WWA and OPC utilized in this study are as under in Table. 1

Table 1- Chemical Composition of Wood Waste Ash and OPC

Oxide	SiO_2	CaO	MgO	Na_2O	Al_2O_3	Fe_2O_3	SO_3	K_2O	LOI
WWA	65.77%	2.07%	4.10%	0.07%	5.26%	9.60%	1.08%	2.47%	4.33%
OPC	20.67%	59.63%	3.66%	0.12%	6.03%	3.2%	2.49%	0.67%	8.44%

2.1.2 Water

Drinkable water with pH value of 7.6, complying with the prescriptions set in [19] and free from all impurities, was used in this research.

2.1.3 Cement

In concrete, cement is used as a binding material that sets and solidifies other materials to bind them together. The Ordinary Portland cement (OPC) of Grade 43 conforming to prescriptions set in [20] was used for the conduct of this research. Further physical and fundamental properties of cement are tabulated in Table. 2.

Table 2- Physical and Mechanical Properties of Cement

Characteristics	**Results**	**Limits** [20]
Manufacturer	Lucky Cement Factory, Karachi.	-
Normal Consistency	32%	-
Initial Setting Time	50 minutes	≥45 minutes
Final Setting Time	215 minutes	≤375 minutes
Fineness	7.2	-
Compressive Strength		
2 days	28.62 MPa	-
7 days	40.89 MPa	-
28 days	49.63 MPa	≥19MPa

- = Not Available/Not Applicable

2.1.4 Fine Aggregates

The natural sand or crushed stone passing through 4.75mm sieve is considered as fine aggregate and is used to fill the voids to ensure adequate bonding of concrete ingredients. The fine aggregates should be subjected to sieve analysis before utilization to ensure the complete filling of voids. Hence, it can be deduced that the strength of concrete grounds a lot on quality and density of fine aggregates. For this experimental investigation, Zone-II fine aggregates, free from all impurities, were obtained from Bolari, a renowned sand quarry of Sindh, Pakistan. The aggregates conformed to specifications set by [21]. The physical attributes of aggregates are tabulated as under in Table. 3 while the gradation curve of fine aggregates is shown in Figure. 1.

Table 3- Physical Properties of Fine Aggregates

Property	**Value**	**Limits** [21]
Fineness Modulus	2.76	2.3-3.1
Water Absorption	1.25%	0-4%
Specific Gravity	2.6	2.4-2.9
Density	1755 Kg/m^3	-
Silt Quantity	4.39%	≤5%

-= Not Available/Not Applicable

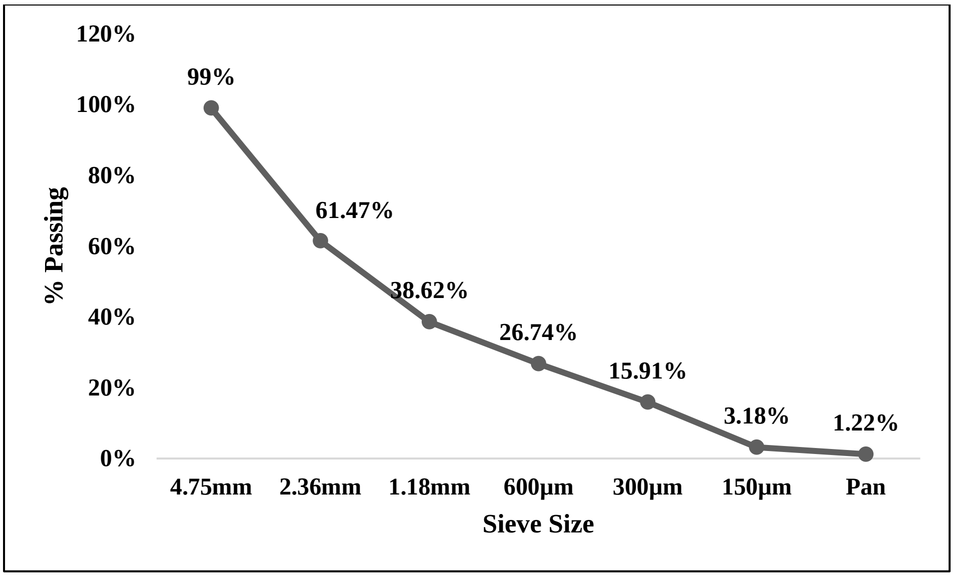

Figure 1- Gradation Curve of Fine Aggregates

2.1.5 Coarse Aggregates

Coarse Aggregates of size not more than 20mm obtained from Nooriabad were used. The aggregates conformed to specifications set by [21]. The properties of coarse aggregates are listed in Table. 3 while the gradation of CA is expressed in Figure. 2.

Table 3- Physical Properties of Coarse Aggregates

Property	**Value**	**Limits** [21]
Fineness Modulus (FM)	-	-
Water Absorption	2.7%	0-4%
Specific Gravity	2.69	2.4-2.9
Density (Kg/m^3)	1359	1200-1750

-= Not Available/Not Applicable

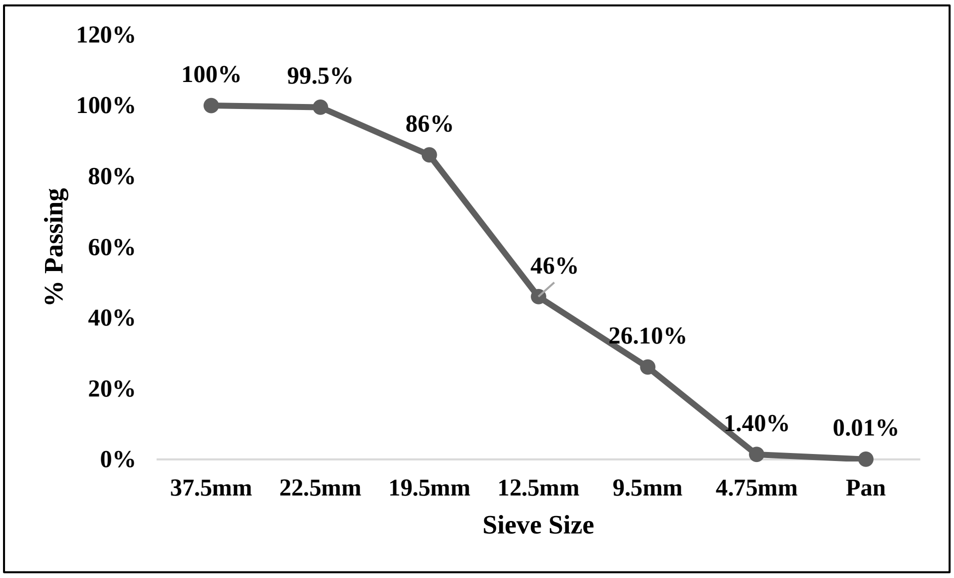

Figure 2- Gradation Curve of Coarse Aggregates

2.2 Detailing of Concrete Mixes

2.2.1 Control Concrete Matrices

In this research, a mix design with targeted strength of 30 MPa at 28 curing days with w/b ratio of 0.56 was prepared, conforming to specifications set in [19]. These mixtures consisted of 0% of WWA and were tested for benchmarking of strength values of concrete. The mix design ratio of 1: 1.52: 2.63 was adopted.

2.2.2 Wood Waste Ash Concrete Mixes

Concrete Mixes were prepared containing 5%, 10%, 15% and 20% WWA instead of cement by weight. The mixes were kept under curing conditions for 7, 28, 56 and 90 days.

2.3 Specimens

In this study, 60 number of cubes of size (150x150x150mm) were cast for compressive strength test, 40 cylinders of size (150x300mm) were cast for splitting tensile strength and 60 concrete beams of size (150x150x500mm) were cast for flexural strength test with constant w/b ratio of 0.56.

2.3.1 Preparation of Specimens

The specimens were cast in well-lubricated cylinders, beams and cubes and were compacted, demolded and cured for 7, 28, 56 and 90 days. This complete process was completed in compliance with the standards of [22].

2.3.2 Testing of Specimens

All specimens were subjected to tests conducted in order to investigate the physical, fresh-state, and strength parameters of concrete. The workability or flowability of concrete mixes was recorded using a slump cone achieved in line with specifications set in [23]. The values of density and water absorption of cubes were recorded in accordance with protocols set in [24]. For the water absorption test, concrete specimens were kept fully soaked in water for 24 hours at 25ºC temperature. The concrete specimens were then dried for 24 hours in an oven at a controlled temperature of 110ºC. During this procedure, the increase occurred in the weights of blocks determined the value of water absorption [25]. The densities of blocks were recorded after drying the blocks in an oven. The concrete blocks were weighed with electronic balance and the dimensions were recorded using Vernier caliper. The oven-dry weight (kg) was divided by dry volume (m^3) of blocks to obtain the density values (kg/m^3) [25]. Furthermore, Universal Testing Machine (UTM) was used to record compression strength of concrete cubes as prescribed by [26], the flexural strength of beams as per [27] and [28] while the splitting indirect tensile strength of concrete cylinders was recorded in accordance with the specifications set in [29]. The specimen subjected to compression resistance test, tension strength test, and flexural strength test are shown as under in Figure. 3.

Figure 3- Specimen subjected to Compressive Strength Test, Flexural Strength Test and Tensile Strength Test

3 Results and Discussions

The present study sought to check the effect of wood waste ash on fresh-state, physical, and hardened properties of concrete. The results obtained by performing various tests on WWA Concrete are explained as under:

3.1 Density and Water Absorption

Among physical properties, water absorption and density of concrete units are of high importance. The water absorption of concrete mixes is the fundamental and important property which depicts the state of the pore size distribution of concrete and is a measure of its durability [30]. The density of concrete is mainly dependent on its unit weight hence, both the terms are often mixed and are used in the same meanings. Most of the standards set for concrete adopt 2400 kg/m^3 as a value for the density of concrete. Both the properties i.e. density and water absorption were checked at a curing period of 28 days. It was observed in the results as presented below in Table. 4, that the density and water absorption values kept on decreasing with the increase in WWA percentage. The results align with the findings of [15]. As per [31], the water absorption of concrete less than 3% is regarded as good and 3% to 5% is considered as average. Hence, the water absorption of control mixes concrete specimens, and specimens containing 5% wood waste ash can be labelled as average while that of concrete specimens containing 10%, 15%, and 20% WWA can be termed as good.

Table 4- Physical Properties of WWA Concrete

S. No.	WWA (%)	Density (Kg/m^3)	Variation (%)	Water Absorption (%)	Variation (%)
1.	0%	2379	-	3.61	-
2.	5%	2345	-1.43%	3.22	-10.80%
3.	10%	2308	-2.98%	2.79	-22.71%
4.	15%	2292	-3.65%	2.42	-32.96%
5.	20%	2261	-4.96%	1.98	-45.15%

3.2 Workability

Workability is the most significant fresh-state property of concrete. It determines the ease with which concrete flows and can be used. The workability of concrete mixes was recorded with the help of slump cone and it was observed that with the inclusion of WWA, the workability was reduced due to high water demand of WWA as quoted in the Table. 5.

Table 5- Slump Values (Workability in mm) of WWA Concrete

S. No.	WWA (%)	Slump Value (mm)	Variation (%)
1.	0%	73	-
2.	5%	66	-9.59%
3.	10%	63	-13.67%
4.	15%	15	-79.45%
5.	20%	02	-97.26%

3.3 Compressive Strength

The compressive strength of concrete is of extreme importance. The compressive strength trend is shown in Figure. 4. It was noted that the use of WWA in concrete improved the compression strength up to 10% replacement level and then it decreased gradually. The same value of compression strength i.e. 32.61 MPa was obtained for 5% and 10% replacement of cement on the 28th day of curing and the compressive strength was recorded approximately 35 MPa for 90 days of curing.

Moreover, in comparison to control mix strength, the strength of concrete containing 15% and 20% WWA exhibited lesser strength.

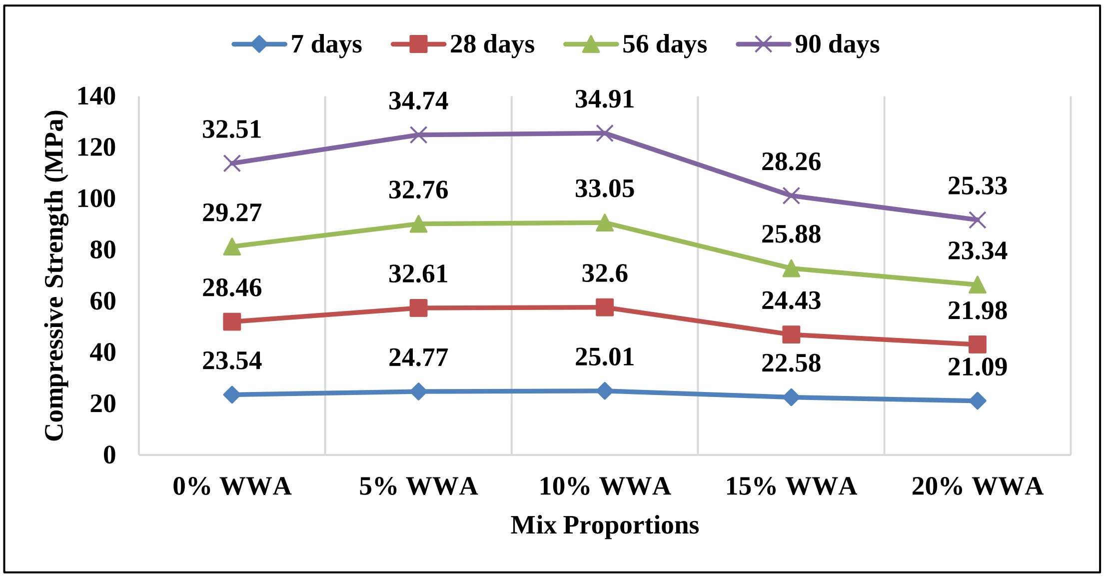

Figure 4- Compressive Strength of WWA Concrete

3.4 Tensile Strength

The tensile strength of concrete is considered very important as it is the property in which concrete lacks and numerous endeavours are considered to overcome this drawback; steel reinforcement being the most adopted and conventional method. The use of wood waste ash also increased the tensile strength of concrete up to 10% replacement level of cement but after 10% replacement, the tension strength reduced gradually. This is related with decrease in compressive strength due to increase in surface area of filler material. The trend of tensile strength is presented in Figure. 5 as under:

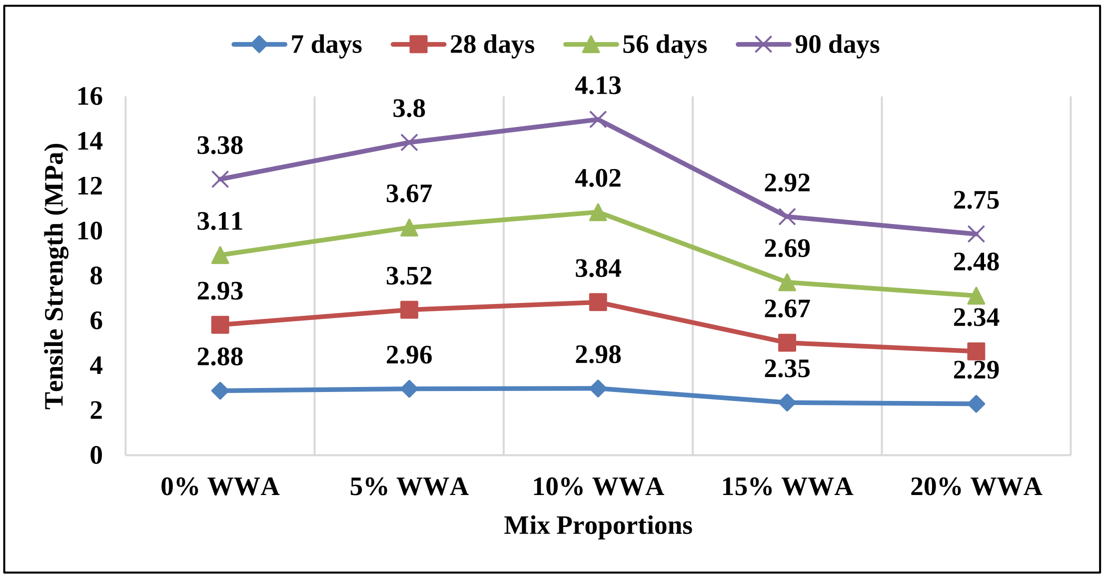

Figure 5- Split Tensile Strength of WWA Concrete

3.5 Flexural Strength

Flexural strength determines the tension resistance capability of un-reinforced concrete beams [32]. The flexural strength of WWA Concrete was recorded at 7, 28, 56, and 90 days of curing and it was observed that flexural strength values followed the same curve as that of tensile strength. Figure. 6 shows that the flexural strength of 10% WWA concrete beams is greater than that of control mix concrete beams and is within limits prescribed for structural grade concrete. The decrease in strength after 10% replacement interval is justified as the excess silica worked as a filler rather than binder resulting gradual decrease in strength of concrete.

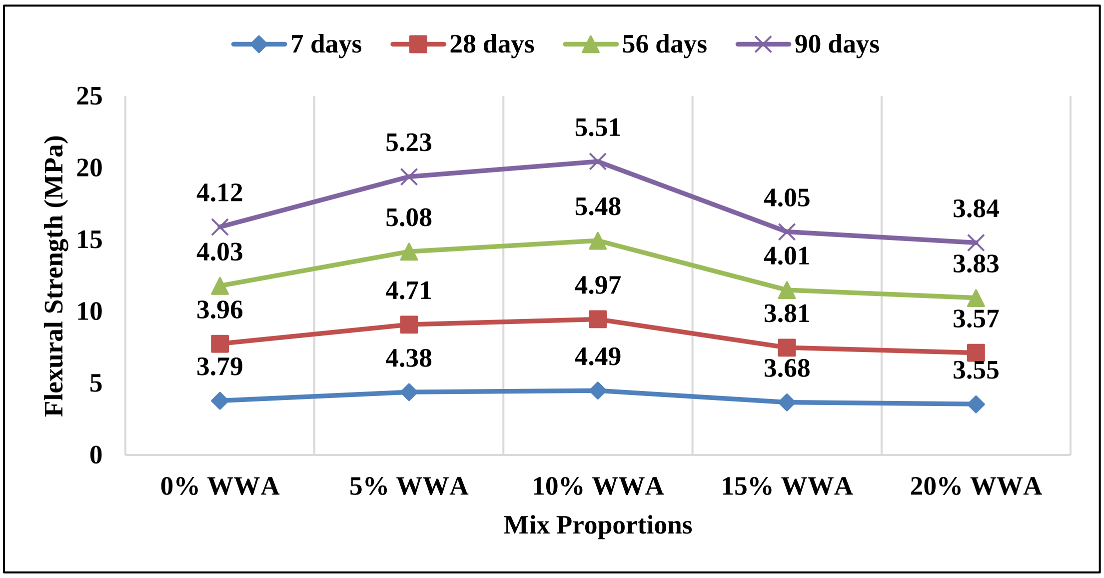

Figure 6- Flexural Strength of WWA Concrete

4 Conclusions

The study focused on checking the effect of WWA as a pozzolanic ingredient on the engineering properties of unreinforced concrete. The results reported that both the water absorption and density of concrete decreased with the increase in wood waste ash content. This implies that WWA concrete is strong and light-weight concrete. The WWA content also adversely affected the consistency and workability of concrete as with the increase of WWA content, the workability of concrete kept on decreasing. The increase in water demand of cement matrix due to the higher water affinity of WWA can be held responsible for a decrease in the workability of concrete as argued by [25] and [33]. The compression, tension and flexural strength of concrete increased by the addition of WWA content up to 5% and 10% weight fraction of cement. It can thus be concluded that 10% of timber waste ash instead of cement is optimum as it not only gives the highest strength values but also gives good workability test results. Such an improvement in strength values of concrete is because of pozzolanic and cementitious characteristics of Silicon Dioxide (SiO_2) present in wood waste ash. The reduction of strength values above 10% replacement level occurred because the excess silica worked as a filler material rather than a binding material resulting in greater surface area of filler to be bonded by cement.

5 Future Directions

Although, the capability of timber waste in concrete is evident there is more need for in-depth study and analysis to capture its complete structural response. This research aimed to quantify the effect of waste wood ash in normal strength concrete but there remains a need for similar study for high-strength concrete. The recommended future research studies also include a study of fire-resistant behavior, bending behavior, freezing and thawing resistance, cracking, stiffness, shrinkage, strength-strain relationship, acid attack resistance, and bond characteristics, etc. of the WWA concrete.

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