Strength of Cement Mortar Containing Partial Addition and Replacement of Wood Waste Ash

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Abstract— Wood waste ash is generated as a by-product of combustion in wood-fired power plants, paper mills, and other wood burning industries. The present investigation is mainly aimed to use wood waste ash (WA) in cement mortar as partial replacement and addition to cement at different levels. The compressive strength of mortar mixes (1:3 and 1:6) was determined at different curing periods. It is concluded that the increase in the addition of WA decreased the mechanical properties. Whereas the mechanical properties of wood waste ash mortars have increased with 10% of replacement of cement by wood ash. Further increase in replacement level decreased the mechanical properties significantly. It is observed that for both the mortar mix proportions, the compressive strength values have increased with the addition or replacement of WA from 0% to 10%. Beyond 10%, the compressive strength values have decreased. Also, the present research carries out X-ray diffraction analysis (XRD) and scanning electron microscopic analysis (SEM) to examine the microstructural properties of mortar mixes.

Key words: Wood Waste Ash, Compressive Strength, X-Ray Diffraction, Scanning Electron Microscopic Analysis

I. Introduction

The rapid development of construction industry increased the demand of cement consumption. But the production of cement involves the depletion of natural resources and greenhouse gas emissions. Thus, there is the need to search for alternative materials to cement in the construction. Continuous generation of wastes arising from industrial by-products and agricultural residue, create acute environmental problems both in terms of their treatment and disposal. The construction industry has been identified as the one that absorbs the majority of such materials as fillers in concrete [1]. Some industrial wastes have been studied for use as supplementary cementing materials such as Fly ash [2-4], Silica fume [5 & 6], Pulverized fuel ash [7], Volcanic ash [8], Rice husk ash [9] and Corn cob ash (CCA) [10]. Wood waste ash is generated as a by-product of combustion in wood-fired power plants, paper mills, and other wood burning facilities. Abdullahi (2006) [11] determined the properties of wood ash to be used as partial replacement of cement. Naik et al. (2002) [12] investigated the compressive strength, splitting tensile strength and flexural strength of concrete mixtures made with wood ash up to the age of 365 days. Elinwa et al. (2008) [13] reported that incorporation of wood waste ash as partial cement replacement material by 10% of total binder weight in self a compacting mortar mix resulted in improvement in compressive strength of mix relative to control the mortar mix containing neat OPC as binder.

Ramos et al. (2013) [14] carried out extensive experimental program on mortar containing WA as partial cement replacement (0%, 10% and 20%) and concluded that enhanced strength and durability results were obtained. Raheem et al. [15] studied the thermal conductivity of WA blended cement mortar and revealed that the thermal conductivity decreased as the WA percentage increased. Naik et al. [12] determined the physical and chemical properties of wood ashes derived from different mills. Scanning Electron Microscopy (SEM) was used to determine shape of wood ash particles. The SEM micrographs showed wood ashes as a heterogeneous mixture of particles of varying sizes, which were generally angular in shape. Siddique (2014) [16] concluded that strength properties of WA blended concrete decreases marginally with the increased percentage of WA content, whereas these properties increased with age due to pozollanic action of WA.

To know the appropriate percentage replacement and addition of wood waste ash (WA) in cement, the present investigation is aimed to study the effect of WA on the compressive strength of cement mortar mixes at different curing periods. XRD and SEM analysis is also carried out to study the micro structural properties.

II. Experimental study

This section describes the materials and test methods used in the present investigation. Experimental program has been discussed to carry out the present research.

A. *Materials*

Ordinary Portland cement 53 grade corresponding to IS 12269:1987 [17] was used. The specific gravity of cement was 3.05. Properties of wood waste ash obtained from the local hotels are tabulated below in Table 1 and chemical composition of wood waste ash in Table 2. Natural river sand was used as fine aggregate. The specific gravity and fineness modulus of fine aggregate were found to be 2.75 and 2.80 respectively. Wood waste ash (WA) was obtained from local hotels where the saw dust used as fuel for preparing food products.

Specific gravity	2.56
Fineness	6.0 %

Table 1: Properties of Wood Waste Ash

Silicon dioxide (SiO_2) %	31.00
Aluminum oxide (Al_2O_3)%	14.40
Iron oxide (Fe_2O_3) %	6.90
Calcium oxide (CaO) %	12.60
Magnesium oxide (MgO) %	0.69
Potassium Oxide (K_2O) %	1.57
Loss of Ignition (1000^0c)	34.30
Moisture content %	1.60
Alkalis %	0.89

Table 2: Chemical Composition of Wood Waste Ash

B. Test methods

Compressive strength tests were carried out on mortar mixes. Three cubes of size 70.5 mm x 70.5 mm x 70.5 mm were cast for all the mixes and curing periods. XRD and SEM analyses were carried out to examine the microlevel properties of cement mortar mixes.

C. Experimental Program

In this work, the compressive strength of cement mortar mixes (1:3 and 1:6) have been studied for different wood waste ash (WA) addition or replacement levels.

III. RESULTS AND DISCUSSIONS

This section discusses the effect of wood ash addition and replacement on the compressive strength of mortar mixes.

A. Compressive Strength

1) Effect of Wood Ash Addition

Compressive strength results of mortar (1:3) are presented in Table 3. From the compressive strength results, it is observed that mortar mix without wood waste ash content was achieved a strength of 32 N/mm^2, 42 N/mm^2, 61 N/mm^2 and 67 N/mm^2 at 3, 7, 28 and 90 days respectively. The compressive strength values have increased with the addition of WA from 0% to 10%. The strength values at WA 10% were 33 N/mm^2, 46.5 N/mm^2, 70.5 N/mm^2 and 75.5 N/mm^2 at 3, 7, 28 and 90 days respectively. Further addition of WA beyond 10% decreased the strength of the mortar mixes as shown in Table 3.

Compressive strength results of mortar (1:6) are presented in Table 4. From the compressive strength results, it is observed that mortar mix without wood waste ash content was achieved a strength of 2.5 N/mm^2, 5.5 N/mm^2, 15.5 N/mm^2 and 16 N/mm^2 at 3, 7, 28 and 90 days respectively. The compressive strength values have been increased with the addition of WA from 0% to 10%. The strength values at WA 10% were 2.9 N/mm2, 6.2 N/mm2, 16.3 N/mm^2 and 16.6 N/mm^2 at 3, 7, 28 and 90 days respectively. Further addition of WA beyond 10% decreased the strength of the mortar mixes as shown in Table 4. The decrease in compressive strength is due to increase of water demand. The increased content of WA acts as filler material instead of contributing to pozzolanic action. Hence it is concluded that, the compressive strength decreased with addition of wood ash to the concrete beyond optimum content. From the results it is revealed that 10% WA addition can be taken as optimum addition.

S. No	% of WA	3 days N/mm^2	7days N/mm^2	28 days N/mm^2	90 days N/mm^2
1	0	32	42	61	67
2	5	32	42	66	71.5
3	10	33	46.5	70.5	75.5
4	15	32	44	67.5	72.5
5	20	31.5	42.5	63.5	70
6	25	31	39	61.5	63
7	30	26.5	34.5	51.5	52.5
8	35	20.5	30.5	44	45
9	40	19	28.5	37	38
10	45	16.5	25.5	30	32
11	50	13	24	30.5	31.5

Table 3: Compressive strength of mortar with WA addition (1:3)

S. No	% of WA	3 days N/mm^2	7days N/mm^2	28 days N/mm^2	90 days N/mm^2
1	0	2.5	5.5	15.5	16
2	5	2.6	5.8	15.9	16.4
3	10	2.9	6.2	16.3	16.6
4	15	2.6	5.9	15.9	16.2
5	20	2.3	12	15.1	112
6	25	1.8	4.1	12.7	12.8

Table 4: Compressive strength of mortar with WA addition (1:6)

2) Effect of cement replacement by WA

Compressive strength results of mortar (1:3) are presented in Table 5. From the compressive strength results, it is observed that mortar mix without wood waste ash content has achieved a strength of 32 N/mm^2, 42 N/mm^2, 61 N/mm^2 and 67 N/mm^2 at 3, 7, 28 and 90 days respectively. The compressive strength values have been increased with the replacement of cement by WA from 0% to 10%. The strength values at WA 10% were 32.5 N/mm^2, 44 N/mm^2, 69 N/mm^2 and 74 N/mm^2 at 3, 7, 28 and 90 days respectively. Further replacement of cement by WA beyond 10% decreased the strength of the mortar mixes as shown in Table 5.

Compressive strength results of mortar (1:6) are presented in Table 6. From the compressive strength results, it is observed that mortar mix without wood waste ash content has achieved a strength of 2.5 N/mm^2, 5.5 N/mm^2, 15.5 N/mm^2 and 16 N/mm^2 at 3, 7, 28 and 90 days respectively. The compressive strength values have increased with the replacement of WA from 0% to 10%. The strength values at WA 10% were 2.8 N/mm^2, 6.0 N/mm^2, 16.0 N/mm^2 and 16.4 N/mm^2 at 3, 7, 28 and 90 days respectively. Further replacement beyond 10%, decreased the strength of the mortar mixes as shown in Table 6. The decrease in compressive strength is due to increase of wood ash. The increased content of WA acts as filler material instead of contributing to pozzolanic action. Hence it is concluded that, the compressive strength decreased with replacement of wood ash in the concrete beyond optimum content. From the results it is revealed that 10% WA replacement level can be taken as optimum replacement.

S. No	% of WA	3 days N/mm^2	7days N/mm^2	28 days N/mm^2	90 days N/mm^2
1	0	32	42	61	67
2	5	32	43.5	65	70
3	10	32.5	44	69	74
4	15	32	43	66	71
5	20	31	41	63	69
6	25	29	38	59	62
7	30	25	33	50	51
8	35	20	30	43	44
9	40	18	28	36	37
10	45	16	25	30	32
11	50	13	23	30	31

Table 5: Compressive strength of mortar with WA replacement (1:3)

S. No	% of WA	3 days N/mm^2	7days N/mm^2	28 days N/mm^2	90 days N/mm^2
1	0	2.5	5.5	15.5	16

2	5	2.5	14	15.8	16.2
3	10	2.8	6	16	16.4
4	15	2.6	5.8	15.8	16.0
5	20	2.1	5.0	15	15.1
6	25	1.7	4.0	12.5	12.6

Table 6: Compressive strength of mortar with WA replacement (1:6)

B. X-ray Diffraction Analysis

X-ray diffraction analysis (XRD) of the cement mortar was performed using XRD Diffract meter, Siemens D500 with K radiations. This analysis was performed to analyse the mineralogical phases (amorphous or crystalline) of the cement mortar using WA replacement or addition. XRD technique was conducted to analyse the components of the mixes and the results are shown in Figures 1-5. The X-ray diffraction pattern and analysis of the mixes i.e. reference mix and WA mixes (1:3 and 1:6) was carried out at age of 28 days. The XRD patterns of 28 day age reference and test samples are shown in Figures 1-5. From the results, it can be seen that XRD patterns are almost the same. Compounds in Reference sample in Figure 1 and in test samples in Figures 2-5 identified are C_2S, C_3S, CH, C_2S, C_3S, CSH, CH, at 18.003^0 , 20.846^0, 26.616^0, 34.067^0, 36.55^0, 47.107^0, 59.957^0 respectively. The intensity of a compound CH at 26.6160 in the reference sample in Figure 1 is higher than that of the test sample in Figure 2 and in Figure 2 is higher than that of the test sample in Figure 3. CSH, at 47.1070 in the test sample in Figure 3 is shorter than that of the reference sample in Figure 1 and in Figure 1 is shorter than that of the test sample in Figure 2.

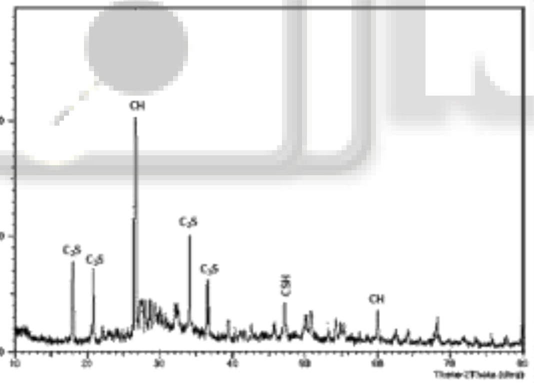

Fig. 1: XRD pattern of cement mortar (1:3) at 28 days

The above observations reveal that Silica oxide (SiO_2) in WA reacts with mainly calcium hydroxide ($CaOH_2$) liberated by the hydration of the silicates in cement give extra quantity of CSH which contributes additional compressive strength to cement mortar. The intensity of a compound CH at 26.616^0 in the reference sample in Figure 1 is higher than that of the test sample in Figure 10 and in Figure 10 is higher than test sample in Figure5.CSH, at 47.107^0 in the test sample in Figure 5 is shorter than that of the reference sample in Figure 1 and in Figure 1 is shorter than that of the test sample in Figure4.The above observations reveal that Silica oxide (SiO_2) in wood ash reacts with calcium hydroxide ($CaOH_2$) liberated by the hydration of the silicates in cement give extra quantity of CSH. However, additionally generated CSH in quantity in addition of WA in cement is little larger than that of the wood ash replacing cement.

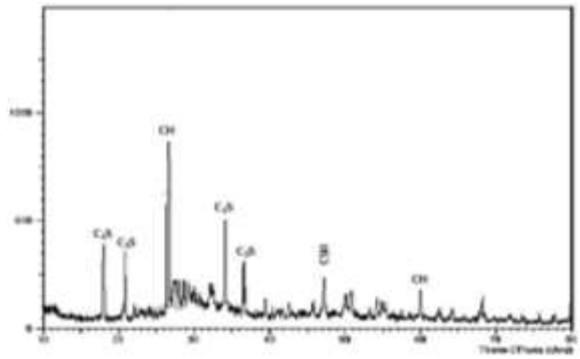

Fig. 2: XRD pattern of cement mortar (1:3) with 10% WA replacement at 28 days

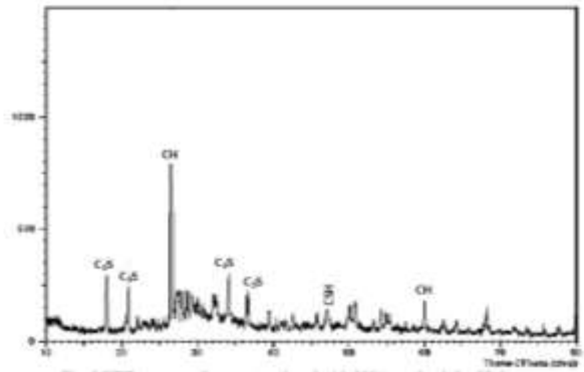

Fig. 3: XRD pattern of cement mortar (1:3) with 30% WA replacement at 28 days

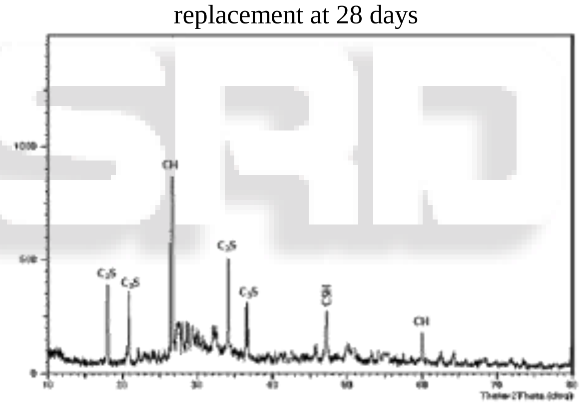

Fig. 4: XRD pattern of cement mortar (1:3) with 10% WA addition at 28 days

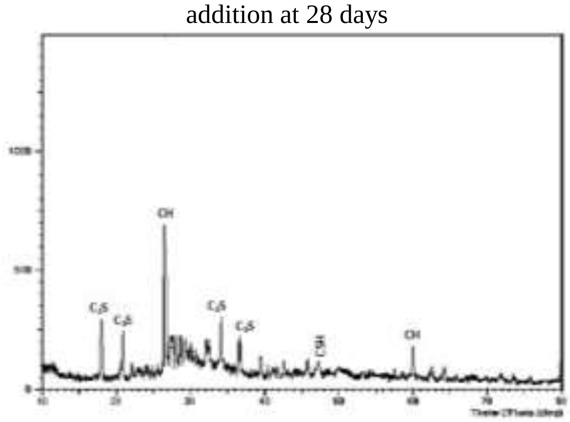

Fig. 5: XRD pattern of cement mortar (1:3) with 30% WA addition at 28 days

The XRD patterns of 28 day age reference and test samples are shown in Fig. s 6-10. In all Fig. s, it can be seen that XRD patterns are almost the same. Compounds in reference sample in Fig. 6 and in test samples Fig. s 7-10 identified are C_2S, C_3S, CH, C_2S, C_3S, CSH, CH and CSH at

26.616^0, 27.907^0, 29.54^0, 34.28^0, 39.567^0, 42.605^0,47.006^0, 53.107^0 respectively. The intensity of a compound CH at 29.54^0 in the reference sample in Fig. 6 is higher than that of the test sample in Fig. 7 and in Fig. 7 is higher than that of the test sample in Fig. 8. CSH, at 42.605^0 in the test sample in Fig. 8 is shorter than that of the reference sample in Fig. 6 and in Fig. 6 is shorter than that of the test sample in Fig. 7.

The above observations reveal that Silica oxide (SiO_2) in wood ash reacts with mainly calcium hydroxide ($CaOH_2$) liberated by the hydration of the silicates in cement give extra quantity of CSH. However, in experimental result, a little quantity of CSH is increased in 1: 6 cement mortar when wood ash replacing in cement and same is reflected in XRD Fig. s. The intensity of a compound CH at 29.54^0 in the reference sample in Fig. 6 is higher than that of the test sample in Fig. 9 and in Fig. 9 is higher than that of the test sample in Fig. 10. CSH, at 42.605^0 in the test sample in Fig. 10 is shorter than that of the reference sample in Fig. 6 and in Fig. 6 is shorter than that of the test sample in Fig. 9.

The above observations reveal that Silica oxide (SiO_2) in wood ash reacts with calcium hydroxide ($CaOH_2$) liberated by the hydration of the silicates in cement give extra quantity of CSH. However, additionally generated CSH in quantity in 1: 6 cement mortar in addition of wood ash in cement is a little larger than that of the wood ash replacing in cement and same is reflected in XRD Fig. s.

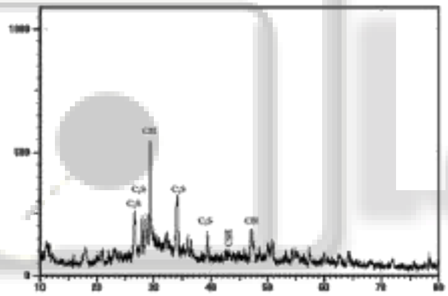
Fig. 6: XRD pattern of cement mortar (1:6) at 28 days

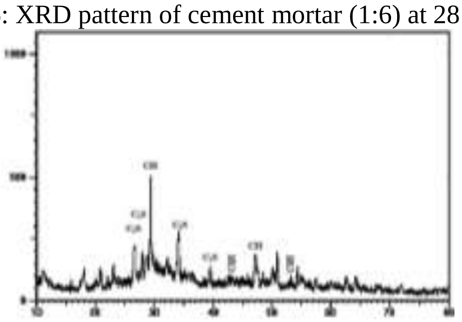
Fig. 7: XRD pattern of cement mortar (1:6) with 10% WA replacement at 28 days

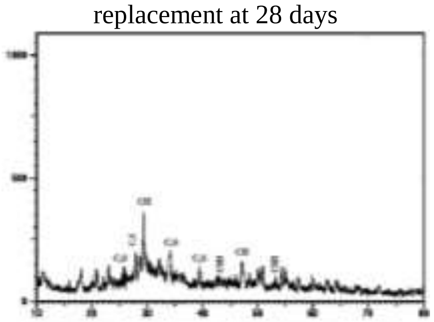
Fig. 8: XRD pattern of cement mortar (1:6) with 25% WA replacement at 28 days

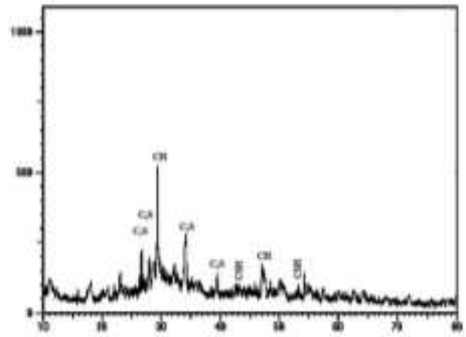
Fig. 9: XRD pattern of cement mortar (1:6) with 10% WA addition at 28 days

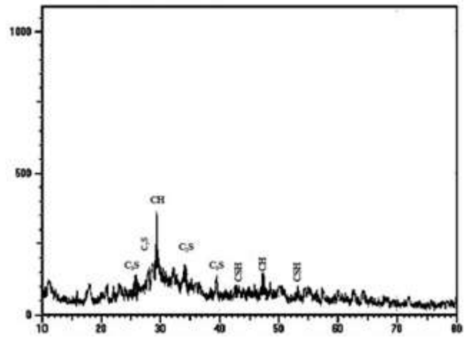
Fig. 10: XRD pattern of cement mortar (1:6) with 30% WA addition at 28 days

C. Scanning Electron Microscopy

SEM pictures of concrete mixes were obtained to understand the microstructure of wood ash blended mortar. In this study, SEM was carried out for the mortar mixes with WA replacement and addition levels of 0%, 10% and 30% after 28 and 90 days of curing. The SEM images of these mixes are shown in Fig. s 11-20. From the Fig. s 11 and 12, it is observed that the microstructure of conventional concrete (reference) mix contains partially hydrated, unhydrated and hydrated compounds of calcium. It is clearly seen from Fig. s 13 and 14 for WA at 10% replacement level, as age increases the microstructure of the concrete mixes have attained dense due to pozollanic action of WA. It is well known that, the calcium–silica–hydrate (C–S–H) is major component that influences both micro level and mechanical properties of concrete. The 10% WA addition refines the pore structure slightly better than the 10% WA replacement as shown in Fig. s 15 and 16. Whereas, the 30% WA replacement or addition is not able develop C-S-H gel, as excess WA particles will not completely contribute to pozzolanic action as shown in Fig. s 17-20. Hence, it can be concluded that optimum level of WA (10%) refines the pore structure and develops the microstructure of concrete and thus leads to the enhancement of mechanical properties.

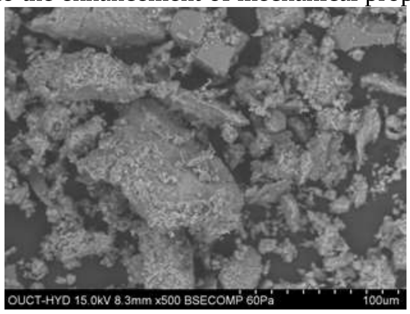

Fig. 11: SEM image of CC with WA 0% at 28 days

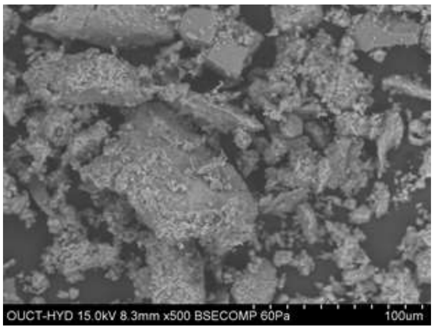

Fig. 12: SEM image of CC with WA 0% at 90 days

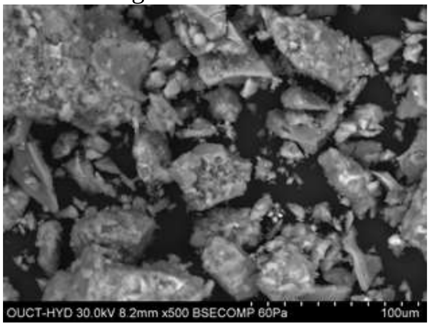

Fig. 13: SEM image of concrete with WA 10% replacement at 28 days

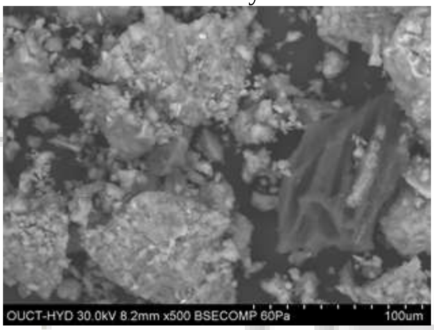

Fig. 14: SEM image of concrete with WA 10% replacement at 90 days

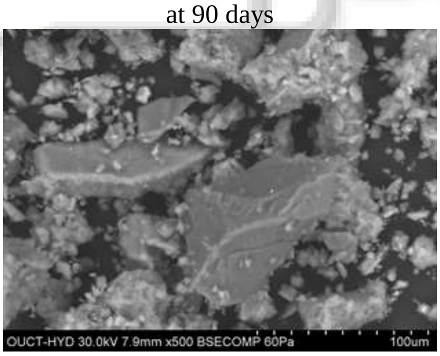

Fig. 15: SEM image of concrete with WA 10% addition at 28 days

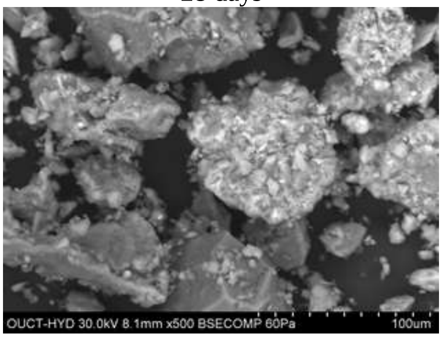

Fig. 16: SEM image of concrete with WA 10% addition at 90 days

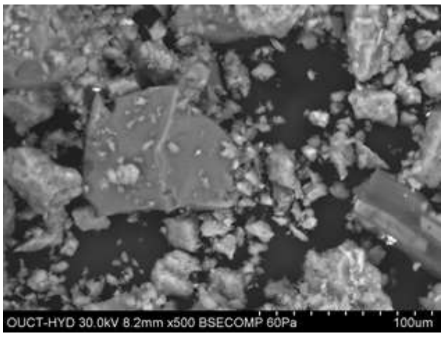

Fig. 17: SEM image of concrete with WA 30% replacement at 28 days

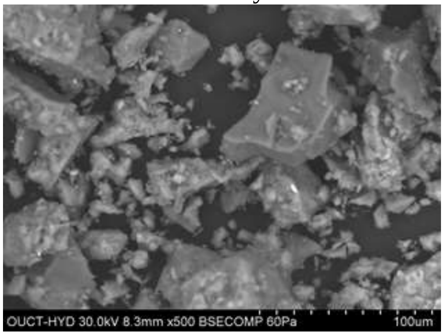

Fig. 18: SEM image of concrete with WA 30% replacement at 90 days

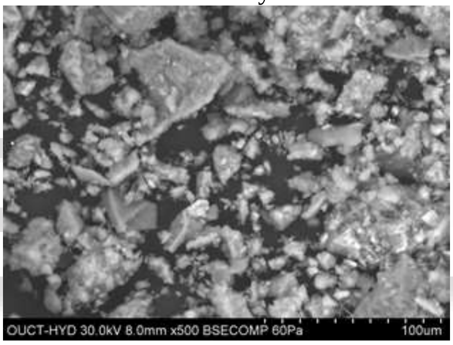

Fig. 19: SEM image of concrete with WA 30% addition at 28 days

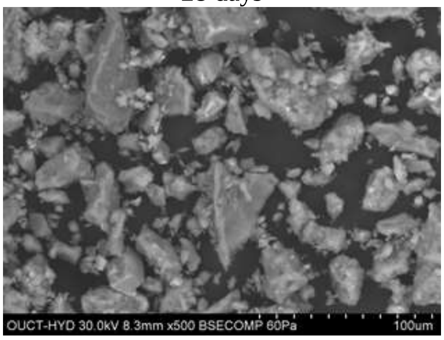

Fig. 20: SEM image of concrete with WA 30% addition at 90 days

IV. Conclusions

This section describes the conclusion drawn from the research.

1) It is observed that for both the mortar mix proportions, the compressive strength values have increased with the addition or replacement of cement by WA from 0% to 10%.
2) Beyond 10%, the compressive strength values have decreased.

3) From SEM analyses, it is revealed that 10% WA addition refines the pore structure slightly better than the 10% replacement

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