Developing ultra-high-performance White Portland cement with a low environmental effect using silica-rich white sand

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ABSTRACT
Hydration of White Sand (WS) blended White Portland Cement (WPC) has been studied by employing a number of experimental techniques.40% WPC has been replaced by WS. We examined setting time and liquid phase analysis of Blended WPC. After hydration of 28 days, we calculated free lime Percentage and compressive strength at different time intervals. It is found that in presence of WS, setting times of WPC are increased. Liquid phase analysis also shows the decrease in concentrations of calcium ions and hydroxide ions in blended WPC with respect to control WPC. Scanning electron microscopy (SEM) also shows the behavior of WPC and blended WPC. X-ray Diffraction (XRD) showed the formation of Calcium Silicate Hydrate (C-H-S) after 28 days of hydration. The formation of C-H-S gives strength to our blended cement. 40% replacement of WPC with WS, not only increase its whiteness but also increase the compressive strength value which is higher than the control WPC. From these results, it's clear that cement made of 60% WPC + 40% WS is better than control WPC. It also reduces the production and cost of WPC and it is also very helpful for environmental conservation.

Keywords WPC, WS, Blended cement, XRD, SEM

1. INTRODUCTION

India is a developing country and also India is the second most populated country in the world. Due to this making of buildings, expressways, highways, and bridges increase rapidly therefore demand for cement increase day by day. White Portland cement (WPC) is an important component for any construction, architecture, and also for decoration [1]. White colour has aesthetic benefits. It makes places appear more radiant and draws attention to architectural details [2]. The production of WPC is a very high energy consumption process and it also releases huge amounts of CO_2 while production of WPC. Approx. 1 ton CO_2 released on production of 1 ton WPC [3]. Production of WPC required more temperature than OPC. Therefore, the production of WPC required more energy than OPC [4].
So, we need to decrease the production of WPC to save our environment. Hence, we need to replace some proportion of WPC with some waste materials that behave like cement in presence of cement.

These waste materials are called pozzolanic materials. These pozzolanic materials show cementitious properties when they react with calciumhydroxide (CH) in presence of water [5].

Many waste materials are used to blend WPC like fly ash, rice husk, blast furnace slag, etc. but these waste materials are dark in color. These waste materials increase the strength of WPC but the colour of WPC is modified due to the dark colour of waste materials, therefore, it is very less useful for decorative purposes. So here I am using white sand (WS) to blend WPC. WS is white so it matches with WPC easily. XRD of WS shows it is very rich in silica.

The blending of WPC with WS enhances the quality of cement. It increases its setting time. Compressive strength also increases after hydration for 28 days. The colour of blended cement does not change much; therefore, it is also very useful for decorative purposes. XRD and SEM analysis of blended WPC and control WPC has been studied in this paper. Liquid phase analysis and the free lime percentage have been calculated. A detailed analysis of the above aspects is mentioned below in the research paper**.**

2. Experimental

We study the hydration of White sand (WS) blended White Portland cement.WS collected from a place called Ghurpur. Ghurpur is 20km away from Prayagraj, Utter Pradesh, India. In Ghurpur, this sand is found in the form of rocks. We collected these rocks and crush them then after filtration we get this white sand. The chemical composition of WPC and WS gave in the Table below.

Table 1 Chemical composition of WPC and WS

	Sio_2	Al_2o_3	CaO	MgO	K_2O	Na_2O	SO_3	Fe_2O_3
WPC	21.40	2.74	68.58	0.33	0.24	0.47	2.95	0.19
GWS	92.21	0.17	2.69	1.83	0.38	0.34	0.07	0.93

2.1 SAMPLE PREPARATION

We replace a different proportion of WPC with WS like we replace 10 %, 20 %, 30%, 40%, and 50%. So, we have 5 samples of different proportions of WPC and WS. All the samples contain 300 gm WPC and WS combined. Water Consistency (W/S) has been mentioned in the table below.

Table 2 Replacement of WPC by WS on different proportions.

	% Replacement	**WPC (in gm)**	**GWS (in gm)**	**Water (in ml)**	**W/S**
		270	30	92	0.30
		240	60	85	0.28
		210	90	80	0.26
		180	120	73	0.24
		150	150	68	0.22

2.2 SETTING TIME

Setting time is measured by Vicat apparatus. The initial and final setting time of all the samples is measured. We draw a graph that shows which sample has the highest setting time. The sample that has the highest setting time gives us the best result.

2.3 LIQUID PHASE ANALYSIS

In liquid phase analysis, we determine the concentrations of Hydroxyl ions (OH^-)and calcium ions (Ca^{2+}) at different time intervals.

2.4 FREE LIME PERCENTAGE

Free lime percentage of hydrated control WPC and blended WPC determine by Franke extraction method.

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According to the Franke extraction method, we take 1gm of hydrated sample and put it in the round bottom flask. Add 40 ml of an isopropyl alcohol and acetoacetic ester mixture of a ratio of 20:3. The mixture was reflexed for one hour using an air condenser to a silica tube. Cool it for half an hour. Now the solution is filtered quickly by G4 sintered glass crucible and washed with isopropyl alcohol. The filtrate was then titrated with 0.1N HCL using Bromophenol blue as an indicator. Colour changes from blue to yellow at the endpoint. Percentage of free lime calculated from flowing equation.

$$\% \text{ FREE LIME} = 0.2804 \times V/W$$

Here V = Volume of 0.1 N HCL

W= Weight of sample.

2.5 X-RAY DIFFRACTION ANALYSIS

XRD of my hydrated control WPC and blended WPC are taken from IIT Kanpur. I send 7 days and 28 days of hydrated samples of control WPC and blended WPC. They send me data of XRD, and from the given data we plot a graph between intensity and angle. The graph shows the excellence of Blended WPC. The phase identification of the powders was carried out using X-ray diffraction (XRD) in PANalytical Xpert using Cu Kα radiation (wavelength =0.15406nm)

2.4 SCANNING ELECTRON MICROSCOPY

Scanning electron microscopy (SEM) of 28 days hydrated control WPC and blended WPC taken from IIT, Kanpur. Surface morphology of control and blended cement analyzed by SEM. The morphology and particle size of the powders were observed under Tungsten (W) scanning electron microscope (CARL ZEISS EVO 50) at 20 kV voltage.

2.7 COMPRESSIVE STRENGTH

Compressive strength is the most important aspect of any cement, which shows the strength of the cement. The moulds of blended and control WPC were put in water for hydration. We break these moulds on different days with the help of a compressive strength machine. We make a bar graph to make a comparison between the strength of control WPC and blended WPC

3. Results and discussion

3.1 SETTING TIME

Setting time determined with the help of Vicat apparatus. There are two results of setting time, one is the initial and another is the final Setting time. We measured the initial and final setting time of each sample that we prepared. The Mixing proportion of WPC + WS gives maximum initial and final setting time considered as the best sample and further experiments proceed on this sample. The result of the initial and final setting time is given in figure 1

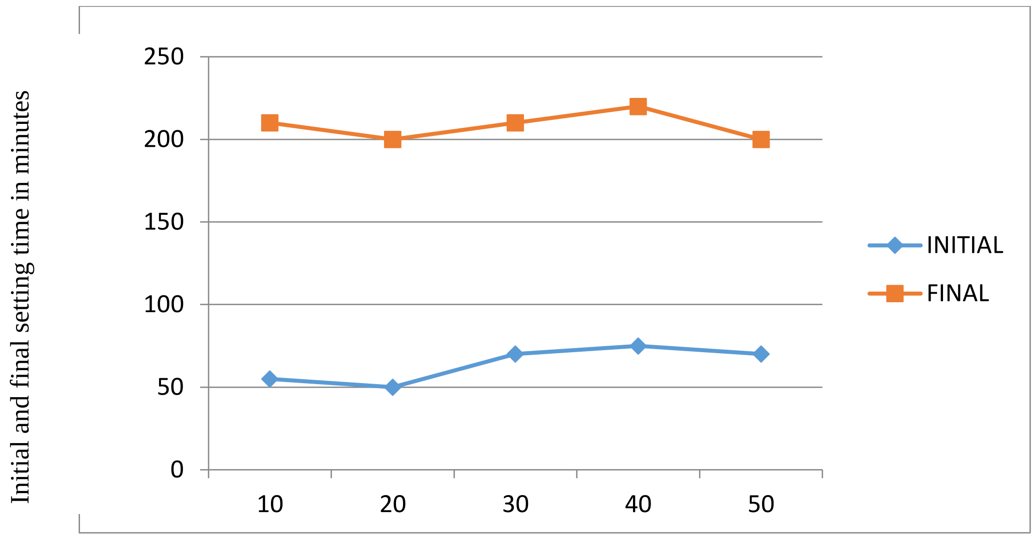

Figure 1 shows the initial and final setting time

In the above graph, we saw that at 40% of replacement of WPC with WS the initial and final setting time is maximum. W/S at 40% replacement is 0.26. The Initial and final setting time both increases hence we can say that WS acts as a retarder [6].

3.2 LIQUID PHASE ANALYSIS

Liquid phase analysis is a method to determine the concentration of Hydroxyl ions (OH^-) and Calcium ions (Ca^{2+}) at different intervals of time.

To determine OH^- concentration, we make a sample of 40% blended cement of W/S =5 ratio, which means 25 ml water in 5gm Blended cement. Then we filtered the solution at different intervals of time and titrated them with 0.1N HCL by using Phenolphthalein as an indicator.

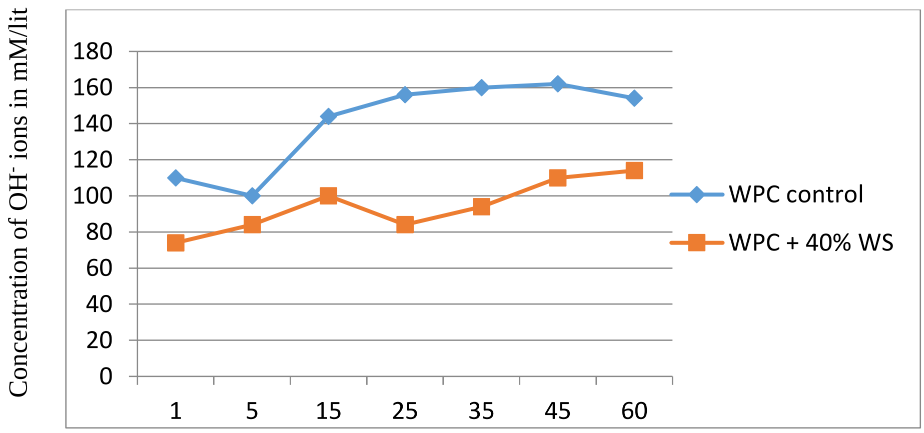

Figure 2 Liquid phase analysis of Hydroxyl ions

In **Figure 2,** the graph shows that the Concentration of OH^- ion first increases after 15 min its decreases.Then after 25 min its further increases and after 45 min it further decreases. In Blended cement, the Concentration of OH^- is lower than the control WPC.

The value is always lower in presence of WS because less cement is present per unit area due to the 40% replacement of WS and also some part of OH^- ions combined with WS [7].

For determination of the concentration of $Ca2^{+}$, we make a sample of 40% blended cement of 5 W/S ratios, which means 25 ml water in 5gm Blended cement. Then we filtered the solution at different intervals of time and titrated them with 0.1N EDTA solution by using Bromo Phenol Blue as an indicator

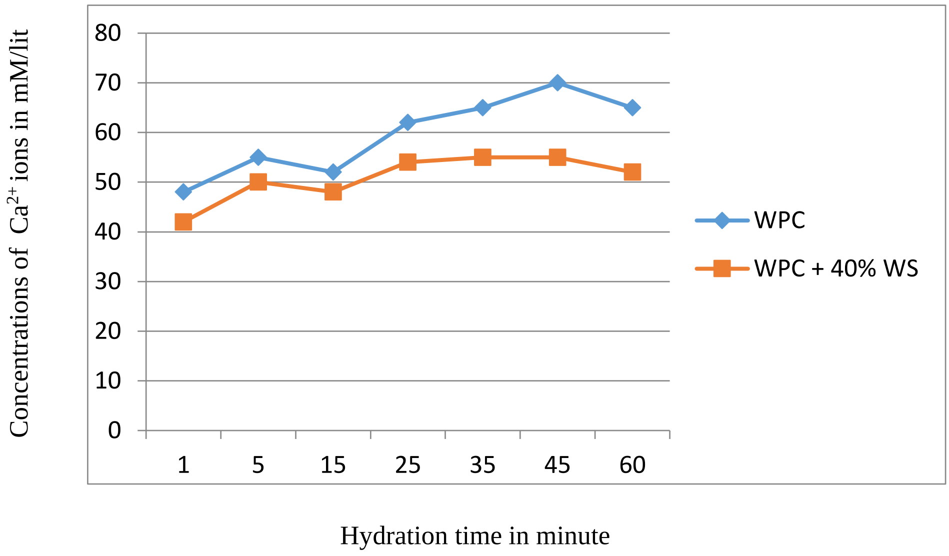

Figure 3 Liquid phase analysis of calcium ions.

Graph of Figure 3 shows Blended cement Concentration of Ca^{2+} ions first increase after 5 min it decreases to the minimum level but after 15 min concentration increase again but after 25 min it increases very slowly up to 50 min that it little bit decreases. A similar trend is shown in control WPC but Blended WPC has a lower value than control WPC because on the blending of WPC the Ca^{2+} ions of WPC are used to form calcium silicate hydrate (C-S-H) [8]. The lower concentration of $Ca2^{+}$ shows that blended WPC has lower cement content than control WPC [9].

3.3 FREE LIME

The free lime percentage is measured from the Franke method. [10] we calculate the free lime percentage of1 day, 3 days, 7 days, 14 days, and 28 days hydrated sample of control WPC and 40% WS blended WPC.

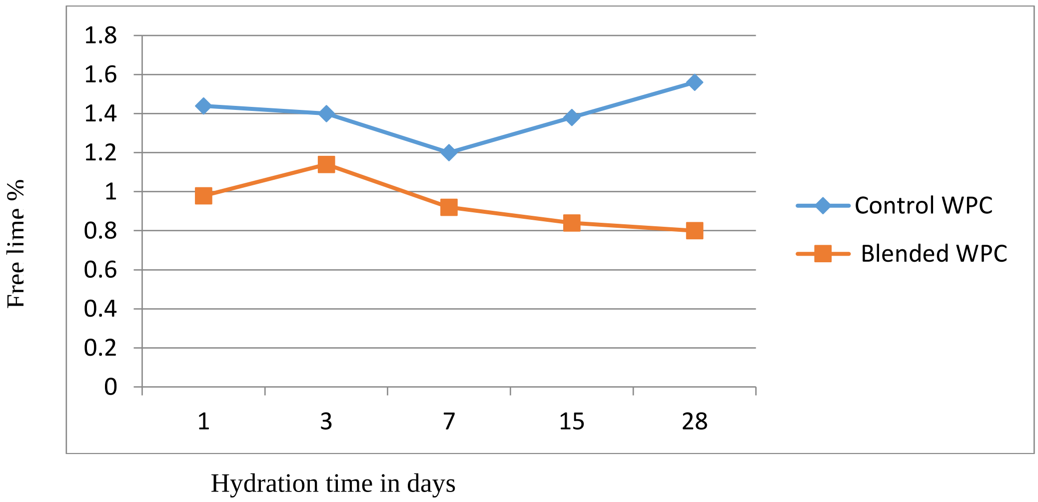

Figure 4 Free lime percentage at different intervals of time (Days)

The graph of Figure 4shows that the Free lime % of control WPC first decreased but after 7 days it increases. Free lime % of blended WPC is lower than control WPC. This is due to the dilution effect and also because of the reaction between calcium hydroxide and WS. When hydration days increase the action of WS also increases therefore Lime combined with WS, therefore free lime % decreases. Hence free lime % of blended WPC increases up to 3 days and then decreases up to 28 days [11].

3.4 XRD:

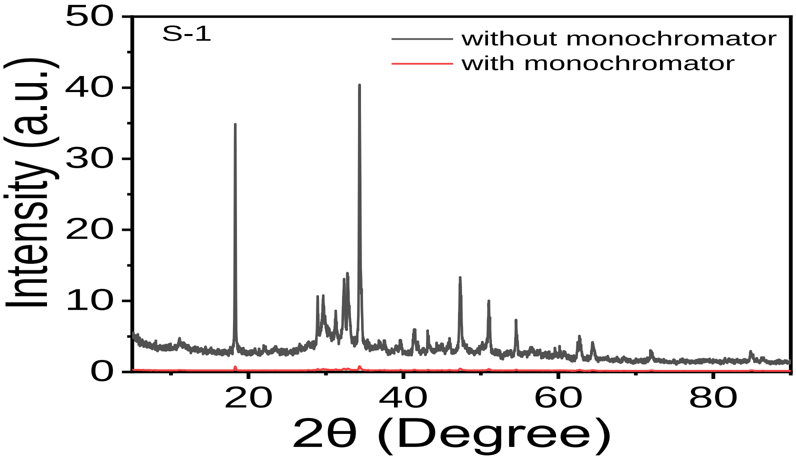

Figure 5 XRD of 7 days hydrated control WPC

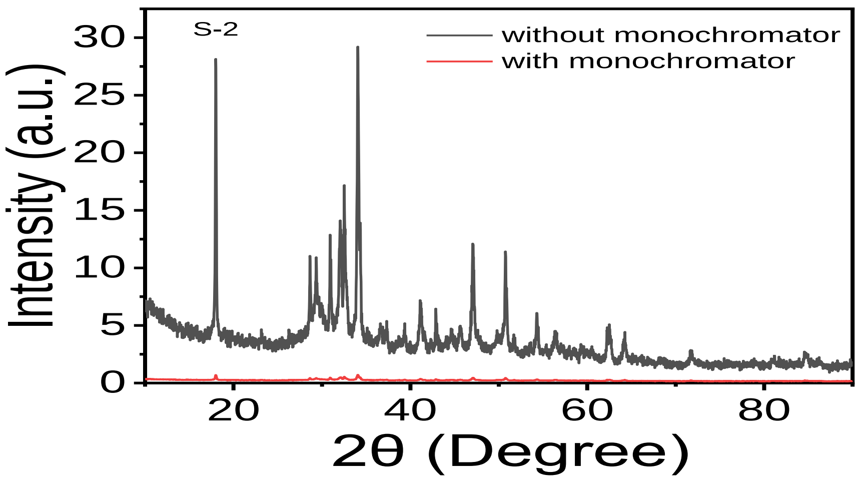

Figure 6 XRD of 28 days hydrated control WPC

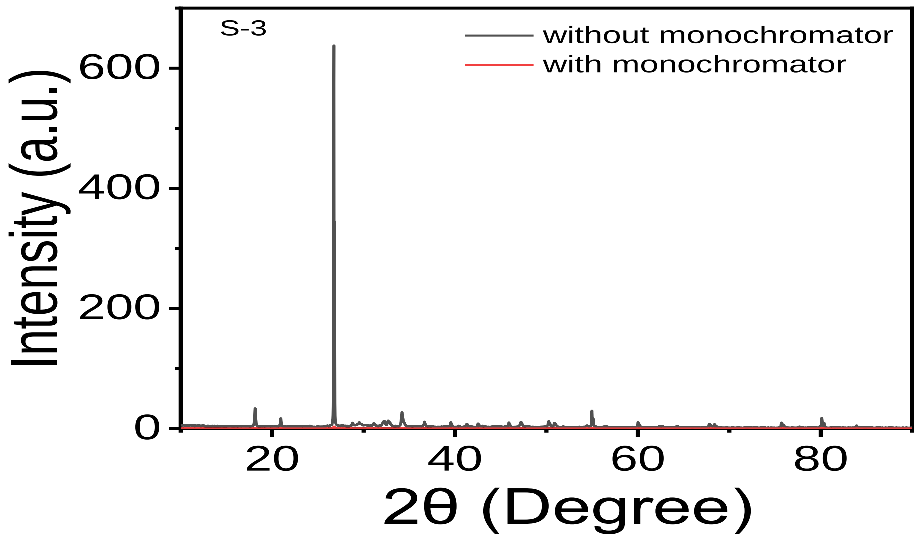

Figure 7. XRD of 7 days hydrated Blended cement

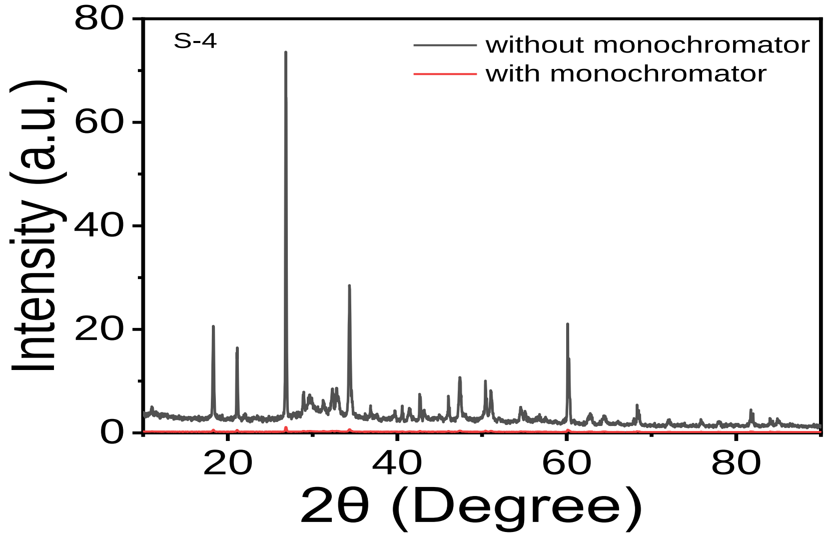

Figure 8. XRD of 28 days hydrated Blended cement

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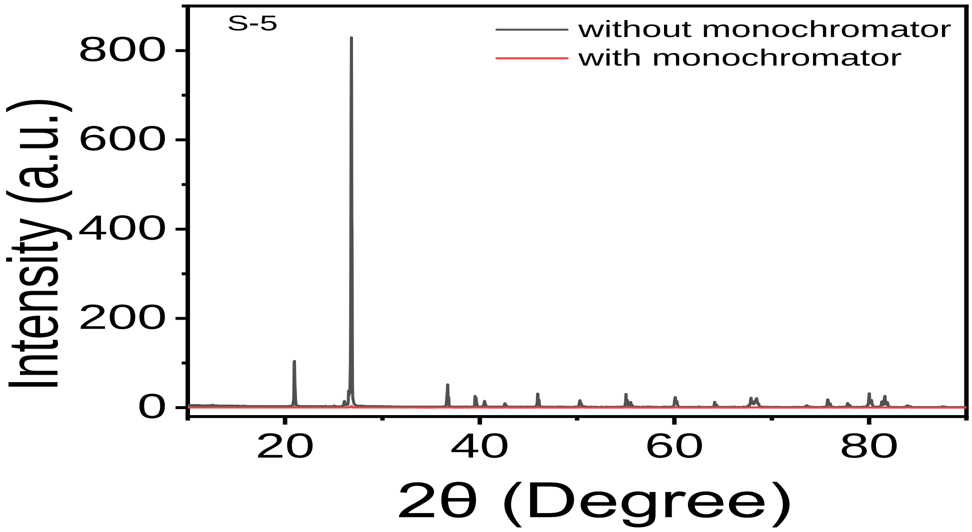

Figure 9.XRD of WS

Figure 5and Figure 6 show XRD of 7 days and 28 days hydrated control WPC respectively. In both Figure 5 and Figure 6, the peak of silica and peak of C-H-S are almost similar which means that a very a smallernumber of C-H-S forms after hydration of 28 days. It shows the strength of control WPC has not increased much after 28 days of hydration.

Figure 7 and Figure 8 show XRD of 7 days hydrated and 28 days hydrated blended WPC respectively. In Figure 7, the peak of silica is approx. 600 a.u (θ= 28^0)and the peak of C-H-S is negligible but in Figure 8, the peak of silica reduces to 70 ≈ 75 a.u but the peak of C-H-S increases up to 10 ≈ 20 a.u. so we can easily say that peak of C-S-H increases due to the pozzolanic reaction of WS and WPC [12-13]. Therefore, the strength of Blended WPC increases rapidly on the hydration of 28 days.

Figure 9 is the XRD of WS, in which the peak of silica is approx. 800 a.u. This shows that WS is very rich in silica.

3.5 SEM

Figure 10shows the scanning electron micrograph of 28 days hydrated control WPC and SEM of 28 days hydrated blended WPC shown in Figure 11, given below.

The SEM picture of the control WPC in Figure 10 confirms that it is a less dense structure with high porosity. The hydrated crystals are widely dispersed. But the SEM picture of blended WPC in Figure 11 shows that the structure is very dense with less porosity. Hydrated crystals are well dispersed within the picture. The pozzolanic reaction of WS is the main reason behind this. This pozzolanic reaction forms an additional hydrated product C-H-S and this C-H-S is well arranged and more compact in Figure 11. This formation of C-H-S is the main reason behind the strength of cement [14-15]

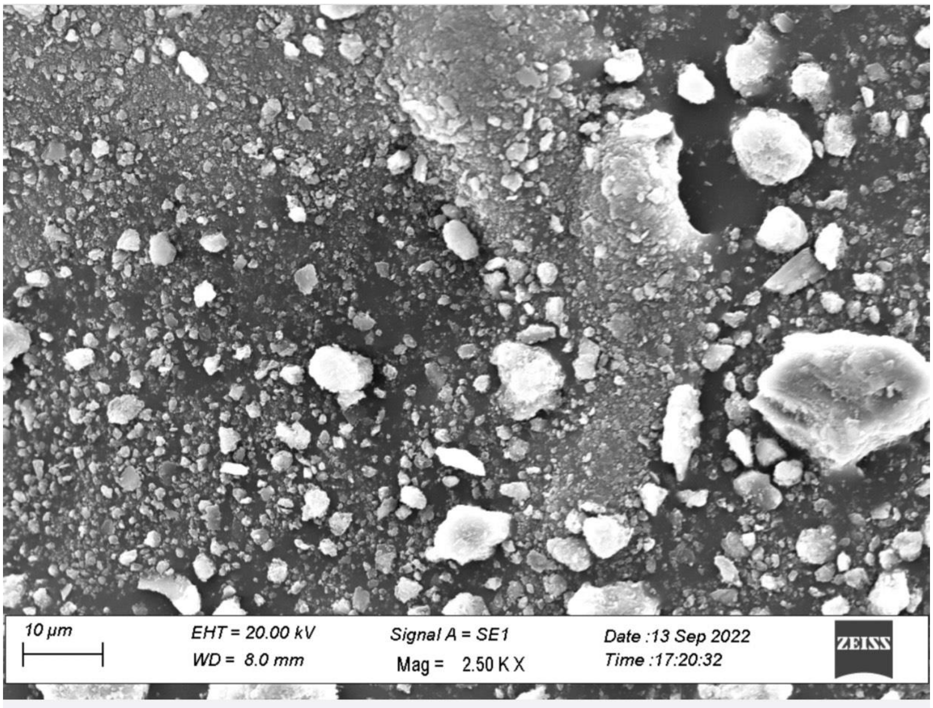

Figure 10. SEM image of 28 days hydrated control WPC

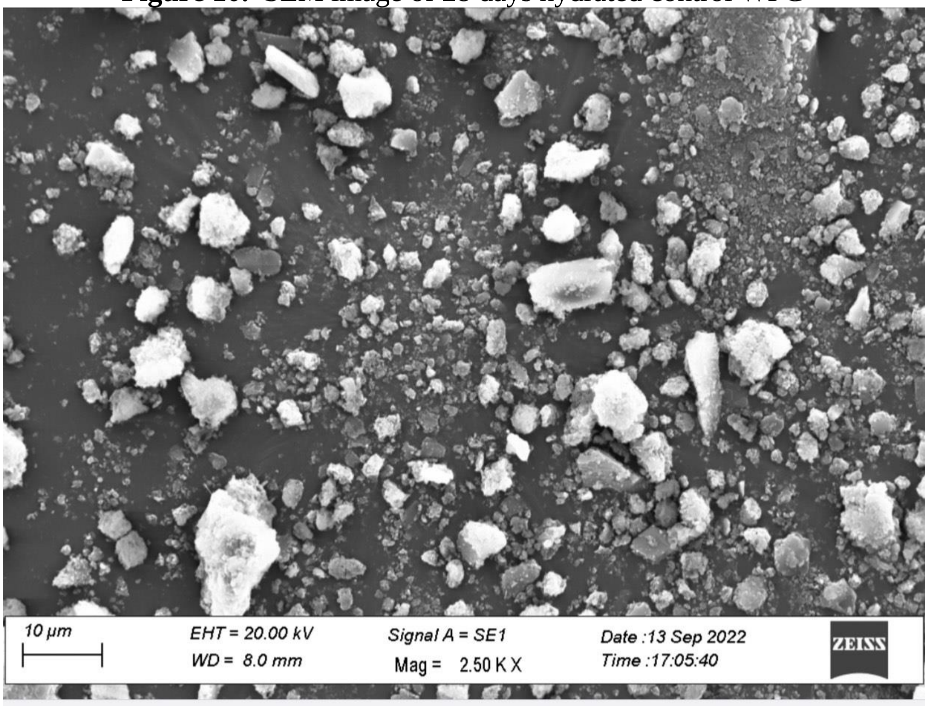

Figure 11.SEMimageof 28 days hydrated blended WPC

3.6 COMPRESSIVE STRENGTH

The strength of blended cement determines by the help of compressive strength. Compressive strength is determined by a compressive strength machine. We make a mould (5cm×5cm×5cm). Put these Moulds in water for hydration after different intervals of time ex. 1 day, 3 days,7 days,14 days, and 28 days, we break mould with the help of a compressive strength machine.

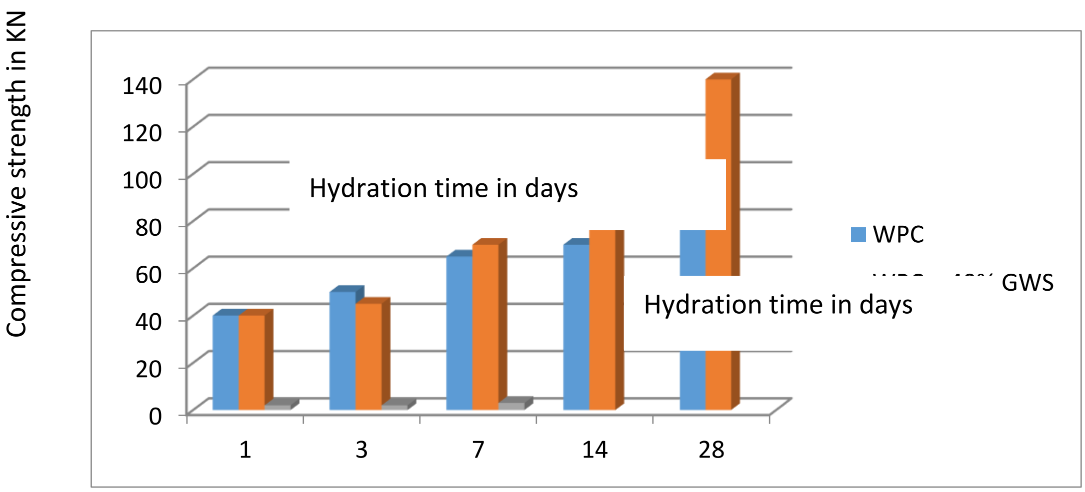

Figure 12. compressive strength of blended WPC with respect to control WPC

Figure 12 shows how the compressive strength of Blended cement increases. Up to 3 days the strength of the control WPC is higher than the Blended WPC but after 7 to 14 days the strength of the Blended WPC increases more than the control WPC. After 14 days the strength of Blended WPC increases rapidly. At 28 days the strength of blended WPC became 130KN (kilonewton) whereas the strength of control WPC is 75KN.

This increase in strength is due to the formation of Tricalciumsilicahydrate(C_3HS) due to the reaction between the silica of WS and calcium hydroxide Ca $(OH)_2$ present in the WPC. This is a double reaction as C-S-H is already formed in the hydration of cement which is a characteristic of pozzolanic materials [16-17].

5. Conclusions

In this paper, we investigate the effect of WS on WPC. WS is white and highly silica-rich material. When we replace 40% of WPC with WS, it increases its setting time and also increases its compressive strength after hydration of 28 days. After 28 days of hydration blended WPC gives approx 55KN more strength than control WPC. The increase in compressive strength is due to the formation of C-H-S by the reaction of WS. The formation of C-H-S in blended WPC is more than in control WPC as shown by Liquid phase analysis, in which the concentration of Ca^{2+} ions decrease in blended WPC because it forms C-H-S. The formation of C-H-S is also investigated with the help of XRD and SEM. XRD shows that after hydration of 28 days, the C-H-S peak of blended WPC increased. The free lime percentage is also calculated, which shows the decrease of free lime in blended WPC.

From all the results, we easily understand that WS blended WPC (40% WS + 60% WPC) is far better than control WPC. With the help of blending, we can also reduce the price of WPC. Production of WPC will also reduce by 40 %. This will help us to conserve energy and also there will be a significant reduction in the emission of CO_2. This will prevent our earth from the greenhouse effect. So that we can say WS not only improves the quality of WPC but also conserve our environment.

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