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Department of Civil Engineering
Capital University of Science and Technology, Islamabad Pakistan

FRESH, MECHANICAL AND DURABILITY PROPERTIES OF ECO-FRIENDLY CONCRETE CONTAINING SUGARCANE BAGASSE ASH AND WOOD SAW DUST

[a]Syed Muhammad Mudassir Zia, [b]Faheem Butt

a, b: Department of Civil Engineering, University of Engineering and Technology, Taxila
a: syedmudassirzia@gmail.com
b:faheem.butt@uettaxila.edu.pk

Abstract-In this study, sugarcane bagasse ash (SCBA) and wood sawdust (WSD) has been partly replaced with the binder and fine aggregates respectively to propose optimum percentages for producing an eco-friendly concrete. The SCBA and WSD were replaced as 0%, 7%, 14% and 21%, by weight with ordinary Portland cement (OPC) and by volume with the Lawrencepur sand respectively. A total of 16 mix types were prepared to determine fresh (using slump test), hardened (using compressive, split tensile and flexural strength tests) and durability (using water absorption and acid resistance tests) properties for deciding an optimum mix. Considering the fresh and mechanical properties, the optimum values of SCBA and WSD for replacement with the OPC and sand respectively were found to be 14% and 7% respectively. The samples of blended OPC mixes prepared with WSD and SCBA showed more water absorption but better acid resistance than the control specimen.

Keywords- Eco-friendly Concrete, Mechanical Properties, Sugarcane Bagasse Ash, Wood Saw Dust

1 INTRODUCTION

The rising production of ordinary Portland cement (OPC) has environmental issues. Researchers are looking for such kind of materials, as a partial or full replacement of OPC, which can provide ecofriendly solution. Many waste products (natural and artificial) for replacing the OPC have been investigated to produce concrete of required specifications. There is a continuous struggle and research to produce geopolymer concrete (GPC) by replacing OPC completely with other supplementary/waste binding materials. There are some natural materials, which are usually dumped as waste, have the potential to be used as a binding or fillers materials in concrete. The availability of such binding material in abundance is also posing a challenge for the researchers. The sugarcane bagasse ash (SCBA) and wood saw dust (WSD) are natural pozzolans and amongst those materials which are available in Pakistan in significant amounts and can be considered as a partial replacement of OPC and fine aggregates respectively, to produce an eco-friendly concrete.

Rajasekar et al. [1] used SCBA as a partial replacement of OPC and found 15% as an optimum value for high ultra-strength concrete. The SCBA, as a partial replacement of OPC, produced less heat during hydration and it gained additional strength[2]. The durability of concrete increased with increasing percentages of fly ash (FA) when it was replaced with OPC; however, its optimum replacement value was found to be 30% for compressive strength, after which strength decreased significantly[3]. The SCBA has also been investigated as a filler material to produce self-compacting concrete[4]. Ganesan et al. [5] concluded that 20% of SCBA replacement, burnt at 650ºC, was affective against attack of chlorides and achieved high early strength. Cordeiro et al. [6] found that finer SCBA was more significant to produce durable concrete than the coarser SCBA. Zareei et al.[7] replaced OPC with SCBA and found 5% as an optimum replacement value to produce lightweight and self-compacting concrete. According to Singh and Jain [8] workability was decreased and compressive strength increased for 10% replacement of SCBA with the OPC. Wood-crete members have been developed using WSD which can be used as a semi-structural member or as an insulating member [9]. Adebakin et al. [10] found that 10% of WSD was effective as a partial replacement of sand for light weight concrete. Ahmad et al.[11] concluded from their study that WSD is an effective natural byproduct to produce ecofriendly and lightweight concrete.
Pakistan, being an agricultural country, has a significant annual production of these waste/byproduct materials which can be utilized for construction. The purpose of this study is to use these natural waste/byproducts to produce an environment friendly concrete. The present study therefore, is focused on investigation for the suitability and if so, the optimum

replacement levels of SCBA and WSD with the OPC and sand respectively, to develop an equally good as the conventional concrete and an eco-friendly concrete. To achieve this, a series of mixes were prepared by varying the amount of SCBA and WSD to partially replace OPC and sand respectively in a blended OPC concrete as shown in

Table. A total of 16 mix types were designed (Table 3), comprising firstly the OPC concrete mix serving as the control mix, then the blended OPC concrete mix types with 0%, 7%, 14%, and 21% replacement levels of both SCBA and WSD, while keeping all the other ingredients the same in all the mix types. The tests are then conducted to find an optimum mix from fresh properties i.e. workability and mechanical properties viz. compressive, split tensile and flexural strengths and durability properties viz. water absorption and acid resistance tests.

2 EXPERIMENTAL PROGRAM

2.1 Materials:

The OPC of grade 43 from Fauji Cement Factory was used in the present study. It was made sure that cement was fresh and was stored in a secure environment to keep it safe against moisture penetration. The fineness of cement was determined through ASTMC204-18 [13]. The physical and chemical properties of the used OPC, SCBA and WSD are given in Table 1 and Table 2.

The Lawrencepur sand, passing sieve number 4, was used as fine aggregate. The fineness modulus and specific gravity of the sand as per ASTM C136 [15] and ASTM D854 [16] were determined to be 2.50 and 2.71 respectively. The Margallah crush was used as coarse aggregate, with the range of particle size from 19 mm to 9.5 mm. The water absorption of coarse aggregate was measured to be 2.5%.The SCBA utilized in this study was obtained from Layyah Sugar Mills, Layyah. The SCBA was burnt in the mill between 500ºC to 550ºC. It was then grinded in the grinding mill until 60% particles passed from Sieve No. 325. The WSD was obtained from the Timber Market, Layyah and the particles passing through 4.75 mm sieve were selected to be used in the study. The pictures of the materials used in the present study are shown in Figure 1.

Table 1: The physical properties of OPC, SCBA and WSD used in the study

Property	**Specific Gravity**	**Unit Weight (Kg/m^3)**	**Passing Sieve No. 325 (%)**	**Fineness by Blaine (cm^2/g)**
OPC	3.05	1470		3100
SCBA	2.12	610	>60	
WSD	2.15	305		

Table 2: The chemical properties of OPC and SCBA used in the study

Compound	**SiO_2**	**SO_3**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O+K_2O**	**P_2O_5**	**LOI**
OPC	19.31	2.17	0.30	5.36	3.42	0.04	2.40	62.04	1.08	0.87	2.48
SCBA	69.93	0.59		5.27	5.38			6.20	5.64	1.63	5.36

Mix ID	**CM**[1]	**BD-0.7**[2]	**BD-0.14**	**BD-0.21**	**BD-7.0**	**BD-7.7**	**BD-7.14**	**BD-7.21**	**BD-14.0**	**BD-`14.7**	**BD-14.14**	**BD-14.21**	**BD-21.0**	**BD-21.7**	**BD-21.14**	**BD-21.21**
SCBA	0%	0%	0%	0%	7%	7%	7%	7%	14%	14%	14%	14%	21%	21%	21%	21%
Saw Dust	0%	7%	14%	21%	0%	7%	14%	21%	0%	7%	14%	21%	0%	7%	14%	21%

[1] Control Mix
[2] Blended Cement Mix with 0% SCBA and 7% WSD; Here, B stands for "sugarcane bagasse ash", D for "wood saw dust", the first numeric for % replacement level of sugarcane bagasse ash and the second numeric for % replacement level of wood saw dust respectively.

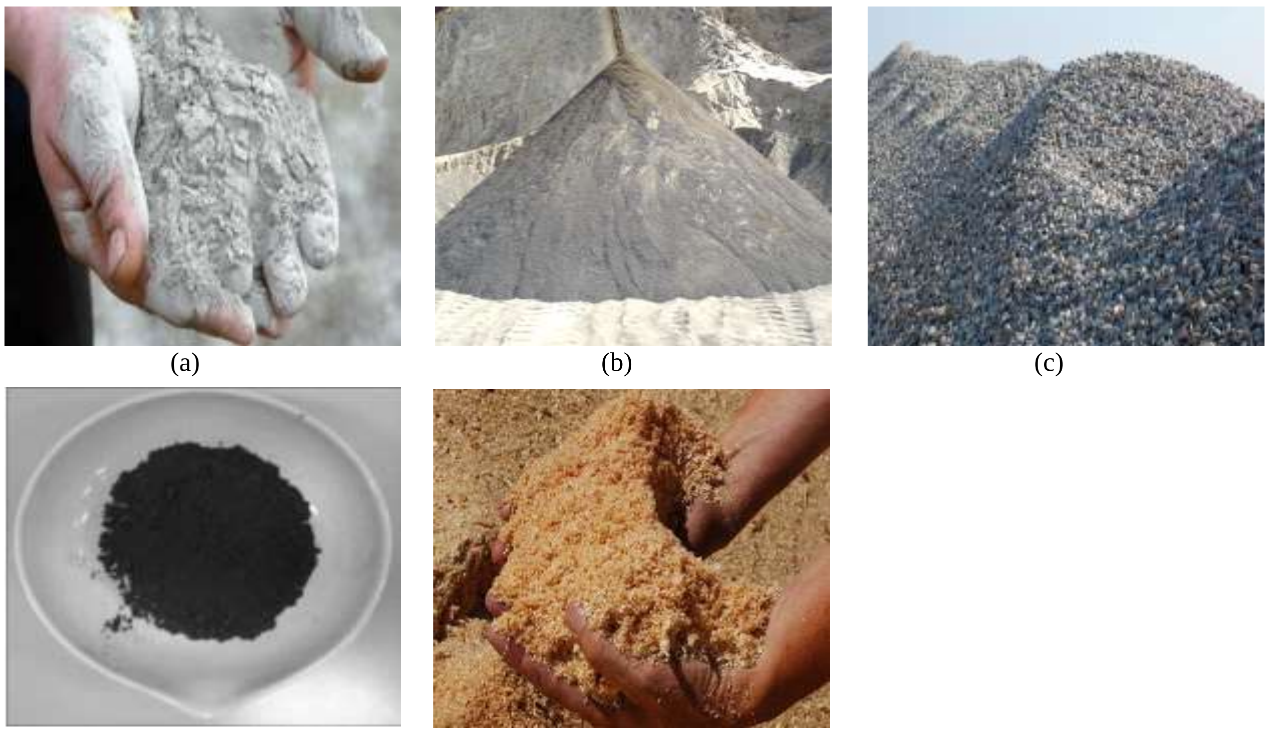
Table 3: The mix type ID's and proportions

2.2 Mix proportions and samples preparation:

A total of 16 mix types were prepared by partially replacing the OPC and sand with SCBA and WSD respectively, in four different percentages i.e.0%, 07%, 14%, and 21%. The water to binder (W/B) ratio was kept constant as 0.50 for all the mixes, with a fixed binder content of 340 kg/m^3. The fine aggregates were taken as half of coarse aggregate by volume.

The WSD was partially replaced with sand at 0%, 07%, 14%, and 21% by volume. Table 3 provides detail of mix types and their identities for varying percentages of SCBA and WSD.

A total of 320 samples were casted in the laboratory, comprising 96 cylinders, 96 cubes (150mm x 150mm x 150mm), 32 cubes (100mm x 100mm x 100mm), and 96 prisms. After thoroughly mixing the constituents of concrete, slump test was carried out to determine workability of fresh mix. After 24 hours of casting, samples were placed in a water tank for curing at 23°C temperature for the duration of curing. For determining compression, tensile and flexural strengths, compression test, split cylinder test and third point loading test were performed respectively. To check durability of the hardened mix specimens, water absorption and acid resistance tests were executed.



(a) (b) (c)

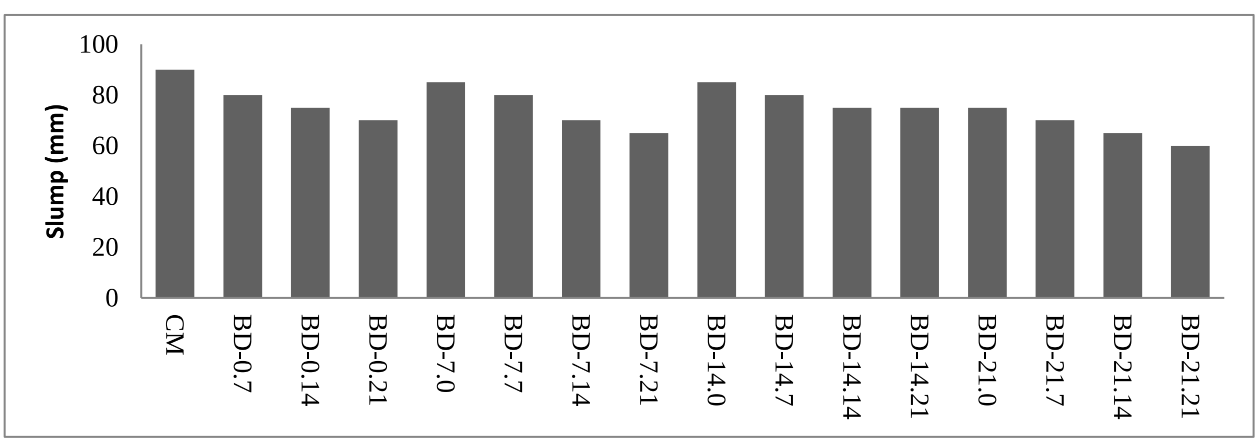
(d) €

Figure 1: The materials used in the study. (a) OPC, (b) Lawrencepur sand, (c) Coarse Aggregates, (d) SCBA, (e) WSD

3 RESULTS AND DISCUSSION

3.1 Workability:

The slump test on freshly mixed concrete was performed according to ASTM C143/C143M-05[17]. The slump test values are shown in Figure 2. It can be observed from the figure that SCBA increased slump values up to 14% replacement with OPC. The addition of WSD has been observed to decrease the slump values for all replacement levels. The maximum value of slump for the blended OPC mix was 85 mm by BD-7.0 and BD-14.0 both; whereas lowest slump value was 60



mm depicted by BD-21.21. The optimum values, after observing the slump value trends, are for 14% SCBA and 7% WSD replacement with a slump value of 80 mm measured on BD-14.7.

Figure 2: The slump test values of mixes

3.2 Compressive Strength:

The compressive strength of 96 concrete cubes of size 150 x150 x150mm after 7, 28, and 90 days of moist curing were determined according to BS1881:Part116:1983 [18]. The compression test was carried out in 3000kN capacity machine. The compressive strength values of all mixes are shown in Figure 3. It can be observed that the partial replacement of SCBA with OPC decreased the strength. Any increase in the strength is attributable to transformation of calcium hydrate (CH) into calcium silicate hydrate (CSH) due to the pozzolanic reaction [7]. The compressive strength in this case was found to decrease with increasing SCBA content due to low pozzolanic reaction. However, the 7 day strength was less affected than the 28 and 90 days. In the blended OPC mixes without WSD, the maximum 90 days strength was observed in BD-7.0 (15.91MPa); however a negligible decrease was observed for greater replacement levels of SCBA in BD-14.0 (15.62MPa), BD-21.0 (15.17MPa). On the other hand, the addition of WSD in the blended OPC mixes caused further decrease in the compressive strength; however, this decrease was considerably less for the blended OPC mixes with greater replacement levels of SCBA (7% and 14%) with the exception of blended OPC mixes of 21% replaced SCBA. When sand was replaced with WSD, the strength was observed to be reduced due to less formation of CSH. The optimum values, after observing the compressive strength trends, are for 14% SCBA and 7% WSD replacement with a compressive strength of 15MPa(≈2200*psi) measured on BD-14.7*.

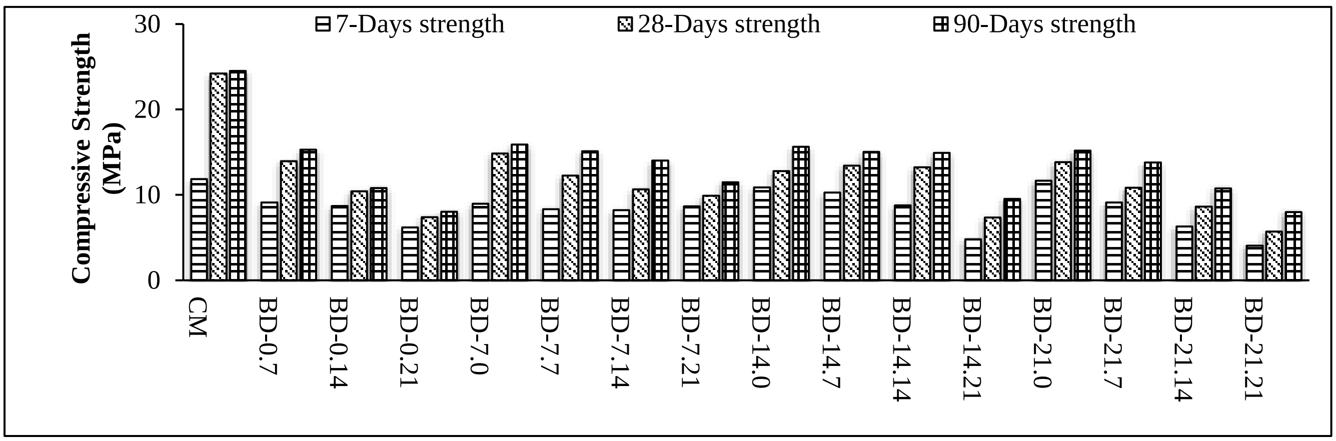
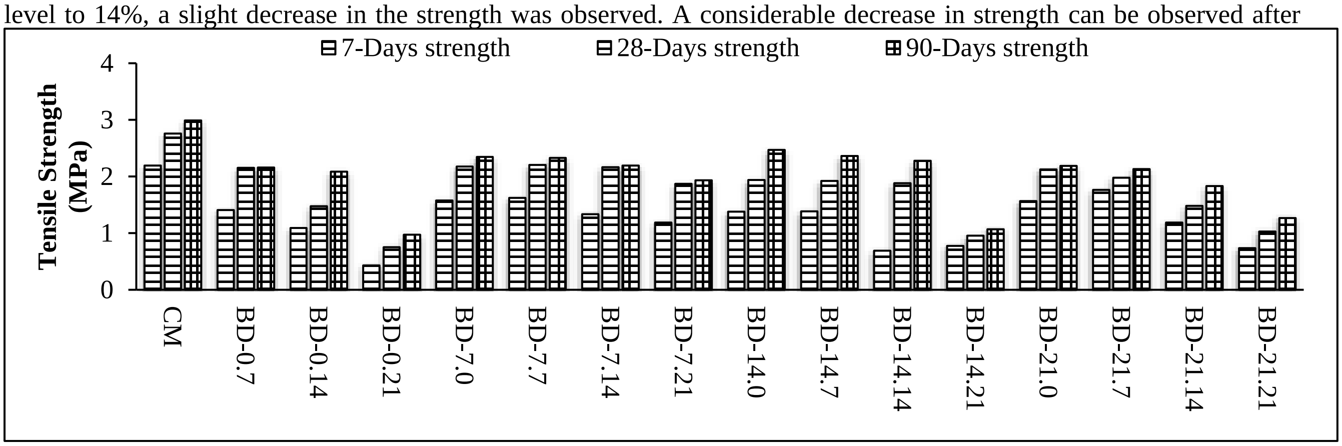


Figure 3: The result of Compressive Strength of mixes

3.3 Splitting tensile strength:

The splitting tensile strength was determined by testing cylinders of 150 mm diameter and 300 mm height, after 7, 28, and 90 days curing, according to ASTM C496/C496M–17[19]. Figure 4 shows the result of splitting tensile strength of all the mix types. It can be observed that the tensile strength increased for blended OPC mixes without WSD, for SCBA replacement levels upto 14% i.e. BD-14.0 (2.47MPa); whereas it decreased slightly with further increase in SCBA replacement to 21% i.e. BD-21.0 (2.19MPa). With the addition of WSD to the blended OPC mixes, splitting tensile strength remains nearly the same or has a negligible decrease for 7% replacement; whereas a further increase in the replacement level to 14%, a slight decrease in the strength was observed. A considerable decrease in strength can be observed after



further addition of WSD to 21% replacement level. The optimum values, after observing the split tensile strength trends, are for 14% SCBA and 7% WSD replacement with a strength of 2.37MPa (≈345*psi)*.

Figure 4: The result of splitting tensile strength of mixes

3.4 Flexural strength:

The flexural strength of 96 prisms of size 500 x 100 x 100 mm, after 7, 28, & 90 days of curing, were determined according to ASTM C78/C78M-18[20] using third point loading. Figure 5 shows the result of flexural strength tests. It can be observed that flexural strength of blended OPC mixes without WSD, increased with an increase in SCBA replacement level to 7% after which it shows a decreasing trend. With the addition of WSD to the blended OPC mixes, a decrease in strength was observed with the WSD replacement level, with the exception of BD-0.7 and BD-0.14 (both shows nearly same strength after 90 days). The optimum values, after observing the flexural strength trends, are for 7% SCBA and 7% WSD replacement with a strength of 2.94MPa (≈426*psi)*.

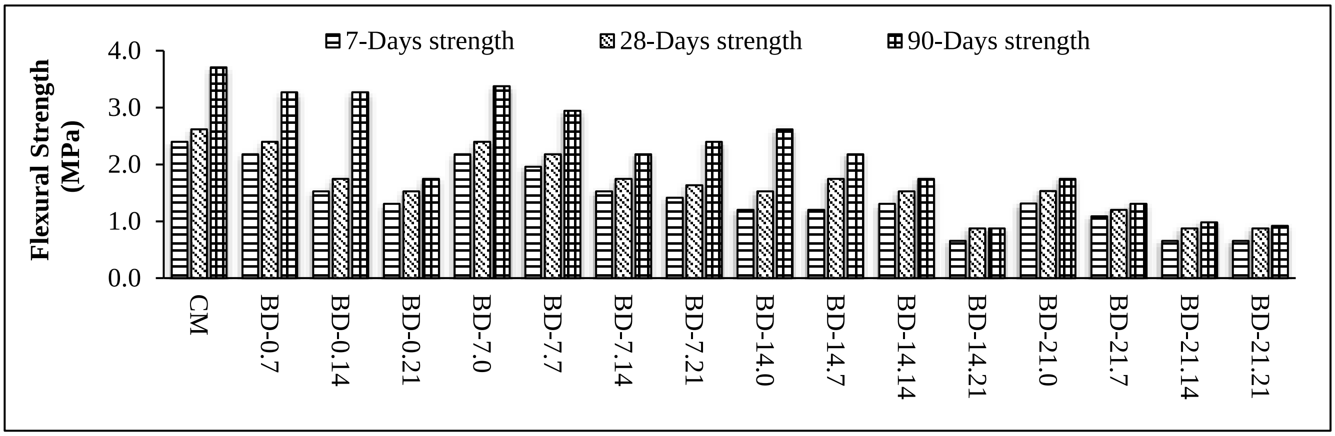


Figure 5: The result of flexural strength of mixes

3.5 Water Absorption:

The water absorption of a specimen was determined by immersing a cube of size 100 x 100 x 100 mm in water for 24 hours[12]. After 24 hours, the wet weight of the cubic specimen is measured and placed in an oven for 2 hours at a temperature of 120^{o}C. The dry weight is then measured and divided it by the wet weight to get percentage water absorption of the specimen. Figure 6 shows the result of water absorption of all the mix specimens.It can be observed that water absorption of blended (with SCBA) OPC mixes without WSD, increased with an increase in SCBA replacement level to 14% after which it decreased. With the addition of WSD to the blended OPC mixes, an increase in water absorption was observed for all the replacement levels. For the blended (with SCBA) OPC mixes with WSD, the least water absorption was observed in BD-14.7 (4.24%).

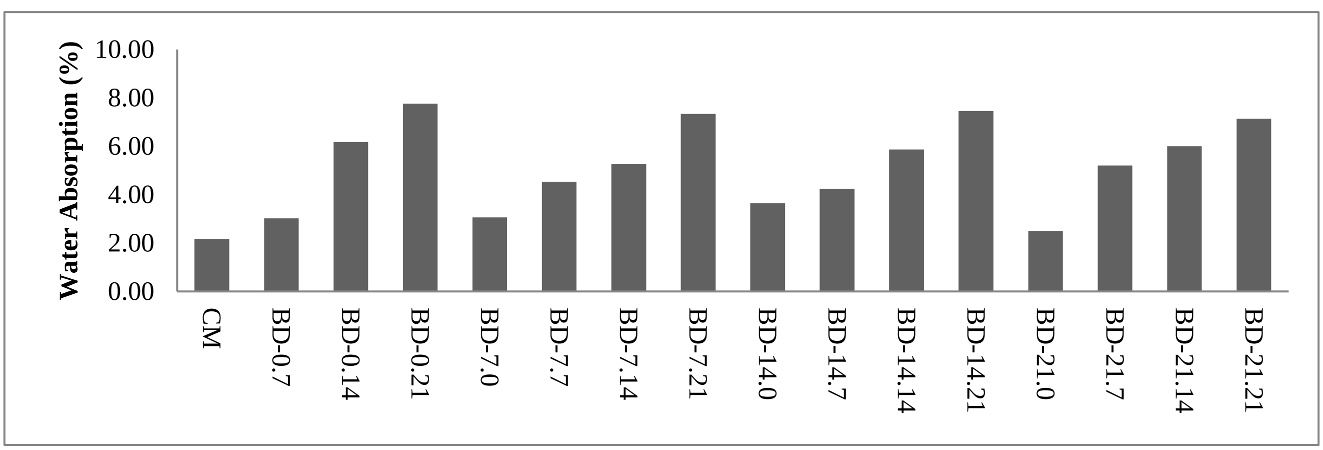
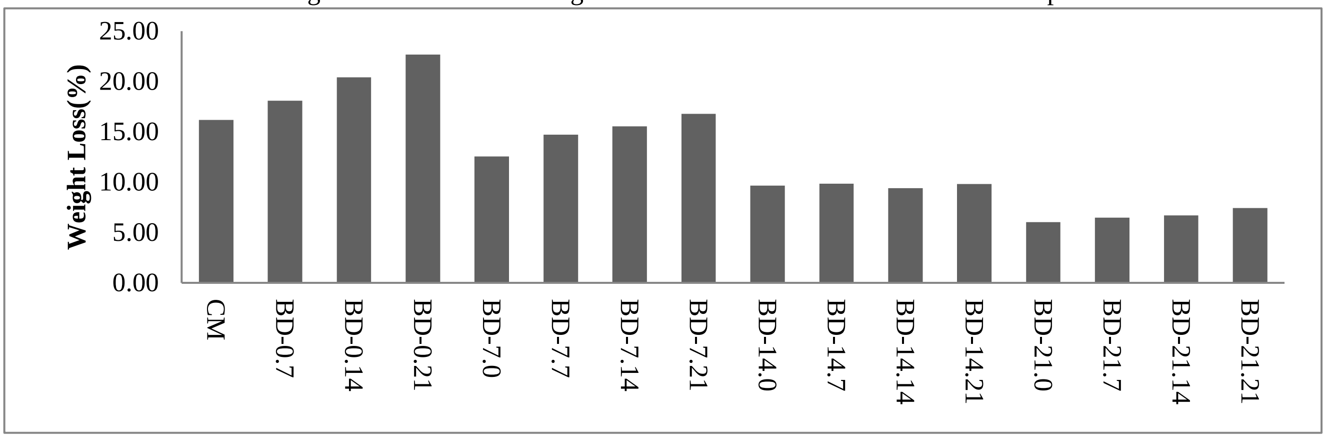


Figure 6: The result of water absorption test of mix specimens

3.6 Acid Resistance:

After completion of the curing period, a cubic specimen of size 100 x 100 x 100 mm was immersed for 60 days, in a 5% solution of sulphuric acid(H_2SO_4) [3]. The specimen was then washed with distilled water. The resistance against attack of acid was measured by finding the loss of weight. The pH value of the solution was kept constant to examine its effect on durability. Figure 7 shows the result of percent weight loss of specimen of all the mix types due to acid attack. It can be observed that replacement of both SCBA and WSD caused a noticeable decrease in the percent weight loss of specimen due to acid attack. It indicates better acid resistance of SCBA blended mixes than the OPC control mix. There is more ettringite formation and gypsum in the control mix as compared to the blended mix with SCBA and WSD, which are major source of loss of weight, due to reaction of sulphate with C_3A and $CA(OH)_2$. [14]

Figure 7: The result of weight loss due to acid attack for different mix specimens



4 PRACTICAL IMPLEMENTATION

The acidic environment causes the concrete and mortar surface to deteriorate, eventually resulting in structure deterioration which amounts to durability issues. The better acid resistance of SCBA and WSD blended OPC mixes has provided an option for their use in such harsh environments in the form of sewerage pipes for industrial wastes and lean concrete at foundations/footing. For both uses strength requirement is significantly less than required by the reinforced concrete structural members. From this study, the optimum values of replacement levels of SCBA and WSD are 14% and 7% respectively which yielded 80mm of slump, 15MPa of compressive strength, 2.37MPa of tensile strength, 4.2% of water absorption and 9.9% of weight loss in acid attack.

5 CONCLUSION

Following conclusions can be drawn from this study:

- The SCBA replacement upto 14% with OPC increased the workability whereas an increase from 14% caused a decrease. The addition of WSD caused a decrease in the slump values for all the replacement levels. The combined effect of SCBA and WSD on workability is found more prominent, as compared to their individual effect, where slump value decreased significantly with increasing percentages of both.
- The compressive and flexural strengths slightly increased for 7% SCBA replacement after which both decreased. The WSD caused a negligible decrease with 7% replacement in compressive and tensile strengths; whereas further increase in its replacement levels caused significant decrease in both strengths. The combined effect of SCBA and WSD also caused the mechanical strength to decrease significantly.
- It can be observed from strength test results that the combination of both materials is not useful due to significant strength reduction. However, considering the fresh and mechanical properties viz. slump, compressive strength and tensile strength values, the optimum values of replacement levels of SCBA and WSD are 14% and 7% respectively which yielded 80mm of slump, 15MPa of compressive strength and 2.37MPa of tensile strength.
- The results of water absorption indicated that the blended OPC mixes with SCBA and WSD absorbs more water; however addition of SCBA resulted in better acid resistance than the OPC control mix.

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