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EFFECT OF SULPHATE ON MORTAR WITH SUGARCANE BAGASSE ASH AND CALCIUM CARBIDE WASTE

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ABSTRACT

The demand for green and sustainable materials to replace conventional Portland cement have been grown extensively in recent years; this has facilitated the innovation of sustainable concrete materials. The accumulation of agricultural and industrial wastes had contributed to environmental pollution. This research focuses on the investigation of the effect of sodium sulphate on compressive strength and hardened density of mortar made from sugarcane bagasse ash (SCBA) and calcium carbide waste (CCW) as binder. The chemical composition of SCBA and CCW were determined. The mortar mix was prepared using the blend of 70/30, 60/40 and 50/50 mix ratios of SCBA and CCW. To study the effect of sulphate resistance, Mortar of 50 mm cube with different mix ratios containing SCBA and CCW were prepared and cured in water. The cubes were later immersed into sodium sulphate at a concentration of 10%. The compressive strength of concrete at 3, 7, 21, 28 and 56 days of water curing were determined. Mass loss and strength reduction due to sulphate effect were evaluated at 14, 28 and 56 days. The result obtained from chemical analysis of the sugarcane bagasse ash indicated that the combined percentage of Al_2O_3, Fe_2O_3, and SiO_2 is 78.76%, while chemical analysis of calcium carbide waste showed that the CaO is 87.0%. The compressive strength at 56 days shows that the control specimen has the highest value of 25.36 MPa while that of the formulated binder proportions were 6.93, 5.19 and 4.64 MPa for 70/30, 60/40 and 50/50 mix ratios, respectively. These shows that the 50/50 combination has the lowest strength development while 70/30 combination shows a better strength development compared to the control sample. This indicates that the compressive strength of the mortar decreases with increase in the proportion of CCW. The results of the sulphate resistance test shows that the control specimens and 70/30 mix combination showed a better performance in respect to visual appearance, weight and strength loss respectively. Hence, the mortars formulated from the various binder combinations satisfied the basic requirements for class N, P and O mortars as specified by BS EN 998 – 2.

***Keywords:** Calcium Carbide Waste (CCW); sodium sulphate; Mortar; Strength; Sugarcane Bagasse Ash (SCBA).*

INTRODUCTION

The modern lifestyle and advancement in technology has led to the increase in the amount and type of waste generated which has resulted into waste disposal crises. It has thus, become an issue to reduce or remove the so called waste generated. Agricultural waste like Sugarcane Bagasse Ash and Calcium Carbide were disposed on open fields and has negative impact on environment. It pollutes the surroundings and increasingly demanding for more landfill areas to cater its escalating disposal. This can be disastrous if left unattended and handled properly at the early stage. Therefore, it is crucial that a study is performed to put forth an alternative solution to this problem.

The utilisation of agro and industrial waste to replace cement as an alternative binder will not only enhance environmental performance but also reduce the carbon dioxide (CO_2) emission and energy consumption generated by cement industry.

Previous studies have been carried out on ashes and wastes obtained directly from the industries to study their pozzolanic activity and their suitability as binders. Generally, ASTM C 618 (2015) specified the combined percentage of SiO_2, Al_2O_3 and Fe_2O_3 of at least 70-75% as requirement for classifying materials as pozzolanic.

ASTM C 618 – 12a (2015) describes Pozzolan as a siliceous, aluminous material which in itself possesses little or no cementations value but will, in finely divided form and in presence of moisture, chemically react with lime at normal temperatures to form compounds possessing cementations properties of C-S-H. Pozzolan is a powdery form of essentially silica that, when partially substituted for cement, usually adds to the quality of concrete or mortar products (Neville & Brooks, 2010). These cements normally gain strength slowly and therefore require curing over a comparatively longer period, but the long-term strength is high.

Sugarcane bagasse ash and calcium carbide waste has been used as different entity by various researchers to study the performance of concrete or mortar. Nattapong et *al* (2011) combined calcium carbide residue and fly ash as binder to assess the strength performance of the concrete. They described calcium carbide waste (CCW) as a by-product obtained from the production process of acetylene gas (C_2H_2), as shown in equation 1.

$$CaC_2 + 2H_2O \longrightarrow C_2H_2 + Ca(OH)_2 \quad \text{(Eq.1)}$$

Acetylene (C_2H_2) gas is widely used for ripping fruits and welding while the by-product CCW is often discard as waste in landfill and thus poses a threat to the environment. CCW is mainly composed of calcium hydroxide [$Ca(OH)_2$] with a mass fraction of above 92% and is highly alkaline (pH > 12). It has been found that mixing CCW with certain pozzolans, which have high

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silicon dioxide (SiO_2) or aluminium oxide (Al_2O_3) content could yield pozzolanic reactions, resulting in final product that are similar to those obtained from the cement hydration process (Nattapong et *al* (2011).

The research of Nattapong et *al* (2011) shows that the addition of 3% $CaCl_2$ by weight of binder to the mixture of ground calcium carbide residue (CR) and fly ash (FA) yielded concrete that exhibited high workability and accelerated the compressive strength at early ages. Their research also indicated that the 450 kg/m^3 of CR-FA binder content with 3% $CaCl_2$ at a W/B of 0.35 yielded a compressive strength 24.3 MPa at 90 days without addition of Portland cement.

Chai and Roongreung (2003) observed a pozzolanic reaction between calcium carbide residue and rice husk ash and reported that the highest compressive strength of mortar was 15.6 MPa at 28 days. Their research has revealed that the calcium carbide waste can participate in a pozzolanic reaction.

Krammart and Tangtermsirikul (2004), reported that $Ca(OH)_2$ calcium carbide waste react with silica, alumina, and ferric oxides in fly ash through the pozzolanic reaction to form C-S-H, similar to those obtained from the cement hydration process. They also showed that the optimal ratio of calcium carbide residue to fly ash mortar mixture to achieve the highest compressive strength of 20.9 MPa at 90days was 30:70 by weight.

Sugarcane bagasse ash (SCBA) is one of the main by-products that can be used as mineral admixture. The ash is obtained from calcining the fibre after the extraction of the juice in sugarcane.

Several research have shown that when sugarcane bagasse is calcined at 700 ^{0}C and crushed to a finely grain particles and used as partially replacement of cement, it will yield an increase in initial setting time, final setting time and consistency. However, the flexural strength, split tensile strength, density and compressive strength were decreases with the increase in the percentage of sugarcane bagasse ash (Jayminkumar and Raijiwala, 2015).

Abdulkadir, Oyejobi and Lawal, (2014) evaluates the suitability of SCBA as a partial replacement for cement in concrete productions. Total weight of 34.7kg of sugarcane bagasse (SCB) were burnt at 700°C to calcined and weight of 2.71kg of SCBA were obtained after sieving through 45μm sieve. They observed that the replacement of OPC with 10% and 20% by SCBA has compressive strengths of 22.3N/mm^2 and 20.1N/mm^2 respectively, which satisfied the ASTM-595 (1985) specification for Pozzolanic activity index and recommended for the use of reinforced concrete structure.

Nuntachai, Napongsatorn and Chai (2009) shows that when bagasse ash is used as cement replacement material, there is improvement on the properties of mortar. The mortar containing ground bagasse ash at 40% replacement showed that the compressive strength was higher than the control mortar, while those that are not grounded have lower compressive strength than the control specimen. This shows that fineness of bagasse ash is important factor affecting the compressive strength of mortar. The research also concluded that mortar containing the ungrounded ash had a higher water requirement than mortar containing ground ash, which could be due to the large particle size and high porosity of the original ash.

This study aimed at investigating the fresh and sulphate resistance of mortar containing sugarcane bagasse ash and calcium carbide waste as cement replacement.

Experimental Program

Materials

The materials used in this study are sugarcane bagasse ash, calcium carbide waste, natural river sand, water and superplasticizer confirming to ASTM C494 (2013).

The sugarcane bagasse was collected from Sugarcane factory located behind Morize fertilizer factory Minna, Niger state. The bagasse ash was produced by open air burning for 4 hours and the ash was grinded to a finely surface and sieved through 75μm BS sieve. The Specific gravity SCBA obtained was 2.56.

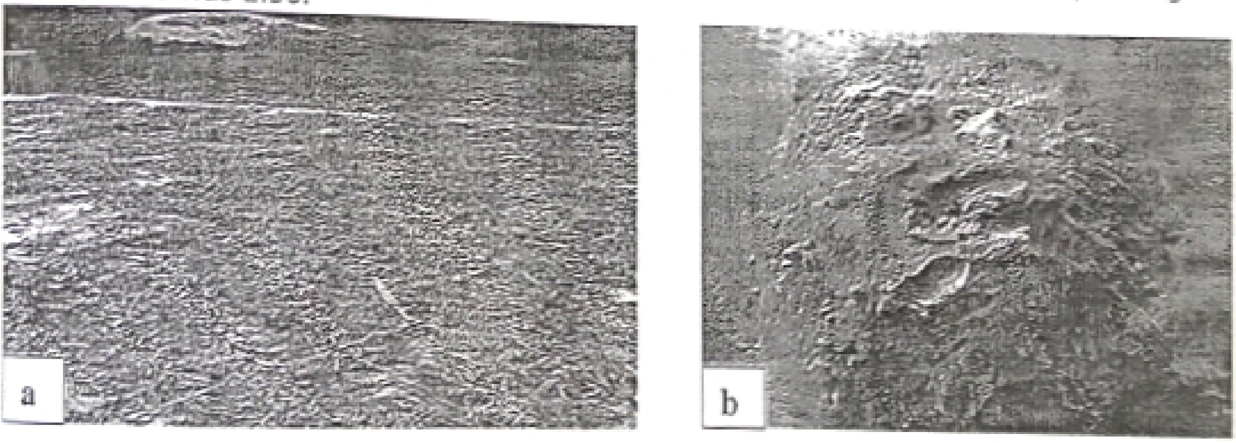

Fig. 1: (a) Image of the exposed sugarcane bagasse to dry for calcining (b) Sugarcane bagasse ash

The calcium carbide waste use for this research was obtained from a road side "panel beater" workshop in Minna, Niger state and was grinded to a finely with a BS sieve of 75μm. The Specific gravity of CCW = 2.27.

The cement used for this research study was ordinary Portland cement CEM I with strength of 42.5 MPa, conforming to BS EN 196-1 (2016) was locally purchase in the market. The Specific gravity of the cement was 3.1.

The sand used in this study was natural river sand obtained from the stream bed and was tested for sieve analysis, specific gravity on saturated surface-dry basis, oven-dry basis bulk density and moisture content in conformity to BS EN 13139 (2013). The result of sieve analysis shows that the fineness modules is 2.66, specific gravity = 2.54, bulk density = 0.78 g/cm^3 and moisture content was 5.76%.

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Mix proportion of mortar

The BS EN 998 (2016) method of mix design was adopted for this research work. The mortar mix was designed to 25 MPa minimum strength with a water/cement ratio of 0.34. The proportionality of the binder used for cement replacement for the mortar were 70:30, 60:40 and 50:50 for SCBA:CCW ratio and designated as M7030, M6040 and M5050, respectively. The mortar specimens for control was designated as M100. The designed water was added and mixed thoroughly up to homogeneous mortar paste for about 5 minutes.
Superplasticizer of 0.5 weight of the binder was used to avoid any addition of water and improve the setting time. Fifty four (54) cubes of 50 x 50 x 50 mm were casted for the compressive strength while thirty six (36) cubes of 50 x 50 x 50 mm were casted for the sulphate resistance test with the mix designed. Another eighteen (18) cubes were casted for control specimens. After casting, the cubes were kept in a laboratory for 3 days to set and harden due to the long setting time of the SCBA/CCW paste and then cured for the period of 3, 7, 21 and 28 and 56 days for compressive strength test. The cubes for sulphate resistance test were immersed into the mixture of 10% sodium sulphate solution with a concentration of 6.34 pH after the samples were cured for 28 days in water. The sulphate resistance test were conducted at 14, 28 and 56 days. The Mix proportion for the control and SCBA/CCW mortar specimens are shown in Table 1.

Table 1: Mix proportion for the control and SCBA/CCW mortar specimens

Mix Nomenclature	Proportion blend (%)	Fine aggregate (g)	Cement (g)	SCBA (g)	CCW (g)	Superplasticizer of 0.5 litres (g)	Required water (g)
M00	100	4290	1744	-----	----	-----	593
M7030	70/30	4290	-----	1008	378	6.93	915
M6040	60/40	4290	-----	864	504	6.84	955
M5050	50/50	4290	-----	720	648	6.84	981

RESULTS AND DISCUSSION

The test results include, the physical properties of the materials, chemical composition of the binders, compressive strength and sulphate resistance were discussed and analysed.

Physical properties of the materials

The physical properties of sand, SCBA, CCW and cement are summarize in Table 2, while figure 2 shows the particle size distribution of the sand used. From the sieve analysis carried out, the result shows that the fine aggregate (sand) used has a fineness modulus of 2.66, which is finely graded conforming to BS EN 13139 (2013), as stipulated for fineness modulus to be within the range of 2.3 - 3.0.

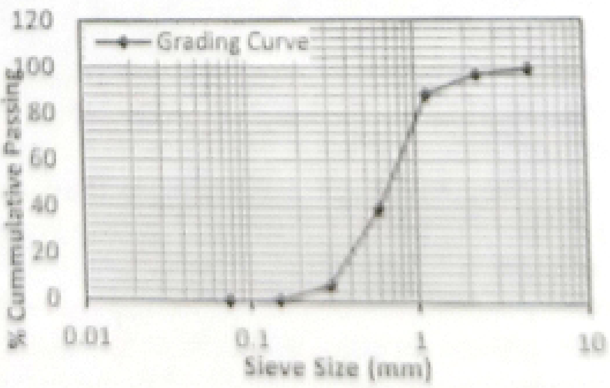

Fig 2 Particle size distribution for fine aggregate (sharp sand)

The moisture content test carried out observed that the average moisture content of the fine aggregate used was 5.76 % and was in conformity with BS EN 13139 (2013). The results of bulk density of fine aggregate for compacted and un-compacted (loose) were determined to be 1532.08 kg/m^3 and 1200.76 kg/m^3 respectively.
The ratio of un-compacted to compacted of fine aggregate was 0.78, which complied the standard specification of BS EN 13139 (2013), that was ranged between $0.87^{3.55}$ - $0.96^{3.55}$ and simplified as 0.61 - 0.87 by Neville (2011).
The result of the specific gravity of fine aggregate was 2.54 and confirmed with the range of 2.1 to 3.2 specified by BS EN 13139 (2013). The specific gravity of cement is 3.1 which was within the ranged of 3.2 specified by BS EN 196 (2016). While that of sugarcane bagasse ash (SCBA) and calcium carbide waste (CCW) were 2.56 and 2.27 respectively. It was observed that the specific gravity of CCW was slightly higher than those reported by Chai and Roongreung (2003) and Krammart and Tangtermsirikul (2004) which were 2.21 and 2.26, respectively. Osere (2016) also reported lower specific gravity of the SCBA compared to the current research work.

Table 3: Summary of physical property of materials

Materials	Sand	Cement	SCBA	CCW
Sieve Analysis	3.69	----	----	----
Specific Gravity	2.54	3.10	2.56	2.27
Bulk-Density (Kg/m3)	1532.08	----	----	----
Moisture Content (%)	5.76	----	----	----

Chemical composition of materials

The chemical composition of sugarcane bagasse ash (SCBA) and calcium carbide waste (CCW) used for this study was presented in Table 4. The results illustrated that the combined percentage of Al_2O_3, Fe_2O_3 and SiO_2 for SCBA is 78.76% which satisfied the 70% ASTM C618 – 12a (2013) requirement of pozzolanic materials. The silicon dioxide also conformed to BS EN 197 which stated that for any pozzolanic materials should not be less than 25% in silicon dioxide. The CaO SCBA is within the required 10% ASTM C618 – 12a (2013). This indicate that the chemical reaction with calcium hydroxide compounds exhibit cementitious properties. Similarly, the chemical analysis of CCW shows that Cao was 87.0%, which was above the required limit of 10% ASTM C618 – 12a (2013), however, other compositions were within the limit. From this aforementioned the chemical analysis of the constituent materials (SCBA and CCW) used were in accordance with the requirements of ASTM C618 – 12a (2013) and the materials shows pozzolanic properties.

Table 4: Chemical composition of (SCBA and CCW)

Chemical composition	% Concentration of SCBA	% Concentration of CCW
SiO_2	64.7	8.2
Al_2O_3	8.5	2.4
Fe_2O_3	5.6	1.0
CaO	6.7	87.2
MgO	2.8	0
Ka_2O	4.0	0.1
Na_2O	0.7	0
LOI	22.0	25.2

Compressive strength of mortar

Table 5 shows the average compressive strength values of the four mortar specimens at various testing age. The results showed that the compressive strength of SCBA/CCW mortar increased slightly with the curing age compare to the cement mortar specimens. The compressive strength of the SCBA/CCW mortar specimens at 56 days ranged from 4.16 to 6.93 MPa, depending on the binder content of SCBA/CCW in the mortar. Although the compressive strength of Portland cement mortar Portland cement increased up to 25.36 MPa at 56 days. This result indicated that there was a slight breakdown in the hydration of SCBA/CCW mortar. It is observed that the compressive strength of SCBA/CCW mortar were increased due the pozzolanic reaction between $Ca(OH)_2$ in CCW and SiO_2, Al_2O_3, and Fe_2O_3 in SCBA, which developed during curing. This behaviour is similar to that of control specimen with Portland cement used as a binder (Neville & Brooks, 2010; Shetty, 2006).

Table 5: Result of Compressive Strength test

Mix ratio (%)	Compressive strength (MPa)				
	3 days	7 days	21 days	28 days	56 days
M100	8.55	12.28	16.27	21.00	25.36
M70/30	2.20	3.55	4.71	5.79	6.93
M60/40	1.68	2.45	4.36	4.64	5.19
M50/50	1.73	2.75	3.20	3.83	4.16

Results of Sulphate Resistance test

The Sulphate Resistance test entails physical deterioration, differential weight and strength resistance of the mortar at different immersion period. The Fig. 3 shows the pictorial view of 56 day of the mortar immersed in sulphate solution. From the physical view it was observed that there was no apparent affection of the sulphate on the cement mortar of M100 and the SCBA/CCW mortar of 70/30% (M7030). But the SCBA/CCW mortar of 60/40% and 50/50% gradually developed wears and tears with the curing age.

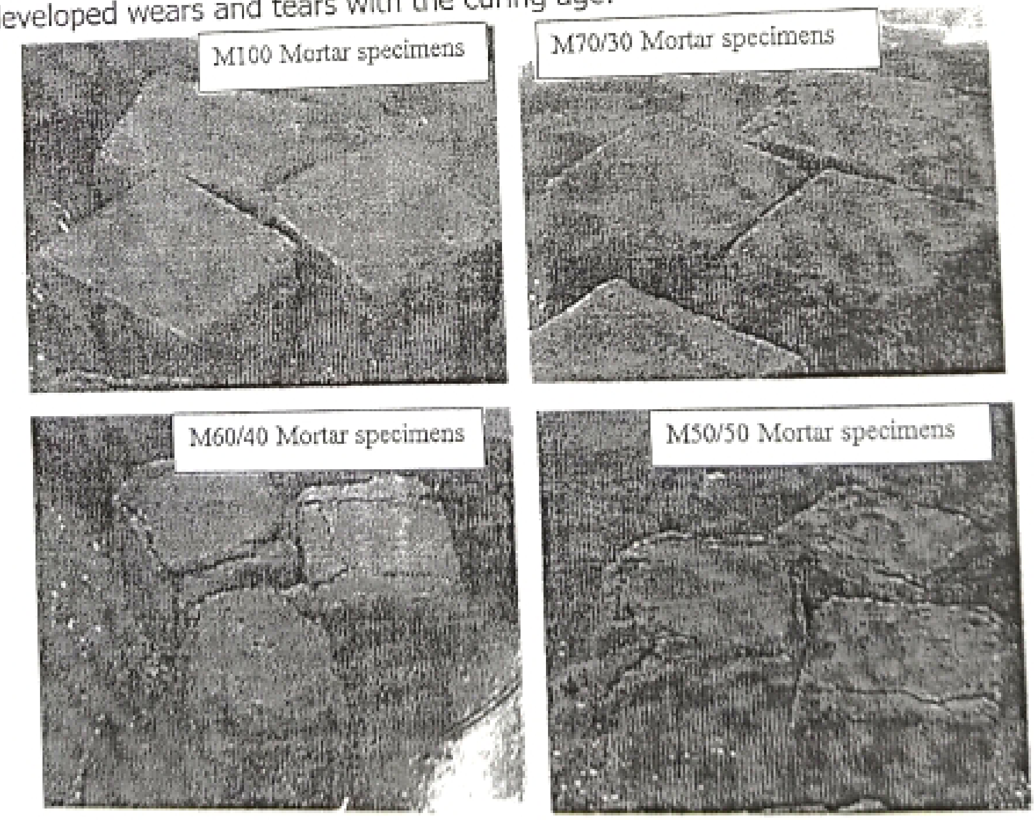

Fig. 3: Image of 56 day visual deterioration of respective mortar specimens

Table 6 and figure 4 below graph present the detail average results of the differential weight. The differential test was obtained with the average differential test on sulphate resistance of the mortar specimen's shows that the cement mortar maintain its stability and absorbed at appreciate level as the curing age increases. The SCBA/CCW mortar of 70/30% also maintain it state and absorbed at minimal level. While the 60/40% of SCBA/CCW loses weight and wearing as the curing ages increases. The 50/50% of the SCBA/CCW mortar absorbed excessively and soften at 56 days the curing.

Table 6: Result of Differential weight (Dif. W) g

Mix ratio (%)	Curing ages 14 days Dif. W (g)	28 days Dif. W (g)	56 days Dif. W (g)
M100	11	9.67	10
M70/30	4.67	6.67	4
M60/40	-13	5.33	-15.67
M50/50	14	14	7

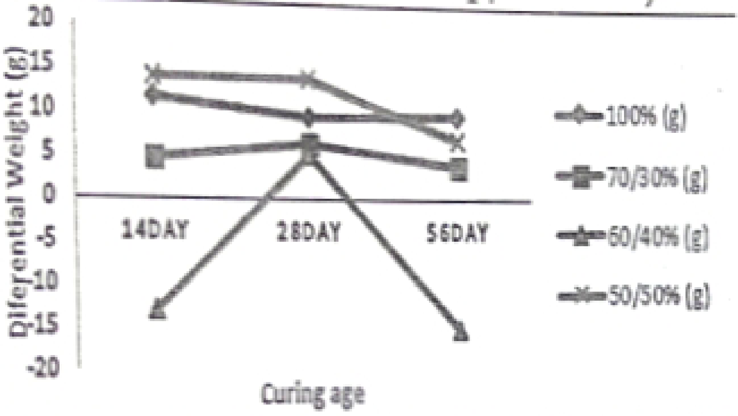

Figure 4: Summary of differential test on Sulphate Resistance

Table 7 showed the summary of average results of density and strength resistance of specimens immersed in sulphate for 14, 28 and 56 days at various percentage replacements. The results indicates that control specimen (M100) has strength of 25.57 MPa at 56 days. Similarly the SCBA/CCW mortar sample with 70/30%, 60/40% and 50/50% mix at 56 days were 6.17 MPa, 1.13 MPa and 1.45 MPa respectively. These results indicates that the compressive strength of the mortar decreases when the percentage of CCW was increased. This could be attributed to the high calcium oxide which decreases the strength of concrete as observed in section 3.2. It is also observed that the compressive strength of control samples (M100%) and SCBA/CCW samples at 70/30% increases with increased in immersion period and maintain it stability throughout the sulphate immersion. While the compressive strength of SCBA/CCW samples of 60/40% and 50/50% mortar specimens decreases with increase in curing age and loose it stability in the sulphate immersion. The density of mortar samples throughout the period of immersion is adequate compared to the loss of compressive strength. This could be attributed to smaller particles of SCBA and CCW occupied the micro pore of mortar specimens.

Table 7: Result of Density (Den) and Compressive Strength (CS) of the mortar immersed in sulphate solution.

Mix ratio (%)	Curing ages 14 days Den (kg/m^3)	14 days CS (MPa)	28 days Den (kg/m^3)	28 days CS (MPa)	56 days Den (kg/m^3)	56 days CS (MPa)
M100	2402	18.61	2356	22.16	2400	25.57
M70/30	2200	3.99	2221	5.73	2221	6.17
M60/40	2139	2.41	2030	2.72	2190	1.13
M50/50	2176	2.00	2147	1.88	2163	1.45

4. Conclusion

From the results of the experiment the following findings were deduced:

1. The result presented revealed that the control specimen developed more strength than that of the SCBA/CCW specimens due to the slight breakdown in the hydration of SCBA/CCW mortar.
2. Generally, the average densities and the average compressive strength of the mortar containing control specimen is higher compare to those containing SCBA/CCW.
3. The density and compressive strength of the mortar containing SCBA/CCW decreases with increase in percentage of CCW. Therefore it can be concluded that optimum percentage replacement was 70/30% of SCBA.
4. The result on sulphate resistance shows that control specimen and 70/30% of SCBA/CCW specimens resist sulphate attack.
5. The differential in weight and strength of 60/40% and 50/50% of SCBA/CCW specimens develop wear and tear during hydration period.
6. The 70/30% of SCBA/CCW specimens could be used for jointing of bricks, blocks and masonry work. It can also be used for plastering and rendering work having satisfied the requirements of strength class II for mortar by BS EN 998 (2016).

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