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Effectiveness of corn husk fibre on the compressive strength and water absorption of concrete containing cockle shells as coarse aggregate replacement materials

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Abstract. This study aimed to investigate the effectiveness of corn husk fibre (CHF) on concrete containing blood cockle shells (BCS) as coarse aggregate replacement materials in terms of compressive strength and water absorption. A total of 84 samples of concrete C30 with water-to cement ratio of 0.54 were prepared with curing period of 7, 14 and 28 days. Firstly, blood cockle shells (BCS) were utilised at 10%, 20% and 30% for coarse aggregate replacement by weight labelled as CS1, CS2 and CS3 respectively. CS1 has the highest compressive strength of 31.6 MPa, followed by CS3 and CS4. While CS3 has the highest water absorption at 3.55% in comparison to the control sample. Next, CHF were added to the concrete mixture containing the optimum content of BCS i.e. 10% (CS1) at 1%, 1.5% and 2% by volume labelled as CSH1, CSH2 and CHS3. Overall, there is significant reduction in the compressive strength where CSH2 exhibit the highest strength at 20.26 MPa. CSH3 has the highest water absorption at 3.07% in comparison to the control and CS1 sample.

1. Introduction

Coarse aggregate in concrete makes up 70 to 80% of its overall volume. The shape of aggregate is divided into the category of rounded, angular, elongated and flaky. While the aggregate surface texture is usually appraised using visual judgment based on smoothness and roughness influenced by the parent rock porosity as well as forces of attrition exposure [1].

Peninsular Malaysia is rich with blood cockle named *Anadara Granosa* as it spread across 100 km of coastal side. According to the statistic released by the Department of Fisheries Malaysia [2], the waste of cockle processing is estimated at 16,988.61 tonnes from the aquaculture system and the decay of cockle shells will take a long period of time [3]. Chilakala et al. [4] revealed that the illegal dumping of shells results in the occurrences of noxious odour and disease spread particularly concerning the area of open storage and various places. Furthermore, the multiple effects from the perspective of financial dimension, social, hygienic and environment reinforce the need of recycling the waste of blood cockle shells (BCS) from the early stage of production.

Corn husk fibre (CHF) is classified as the second largest source behind cotton and jute in the natural fibres categories [5]. A total of 9 million tonnes were produced yearly. In general, the constituents of corn husk fibre mainly are cellulose, lignin and hemicellulose. In the agricultural sector involving corn, produced abundant wastes from the process of harvesting and consumption resulting in nuisance to the environment due to improper disposal [6]. With the above, the main objective of this study is to evaluate the compressive strength and water absorption level of concrete mix that incorporates CHF. together with BCS as coarse aggregate replacement material.

2. Literature review

2.1. Blood cockle shell

Peninsular Malaysia is rich with blood cockles named *Anadara Granosa* as it spread across the length of 100 km coastal line. The smaller version of the blood cockle shell (BCS) usually has high water absorption, lower fineness modulus and high specific gravity (in terms of particle gravity) as opposed to the bigger version. The bulk density of BCS on the other hand is similar to the normal aggregate which ranges from 1280 to 1920 kg/m^3. However, some of the BCS shells classified to be having less specific gravity compared to normal aggregate and the classification of cockle cannot fall under lightweight aggregate as the value is higher than the recommended for lightweight aggregate [7]. Cockle shells hit almost the same value which is 2 % for most aggregate under normal weight class [7].

2.2. Corn husk fiber

Corn husk fibre (CHF) has been around in the fibre market for years and is produced around 9 million tonnes annually. In Malaysia, the produced corn was found to have 45.7 % of cellulose, 35.8 % of hemicellulose and 4.03 % of lignin with an ash content of 0.36 %. Technically, CHF have lower strength with greater elongation and its structure is similar to the cotton fibre. In comparison to other natural fibres such as cotton and jute, its crystallinity is much lower and due to this, the elongation of the fibre could be greater producing higher moisture absorption and areas for chemical reaction. The durability, pliability and softness, are based on the combination of moderate strength in conjunction with low modulus, higher toughness and taller elongation [8].

3. Materials and methods

In this research, the basic materials i.e. cement, fine aggregates, coarse aggregates and water were used. The introduction of BCS and CHF in the concrete mix serve as the partial replacement of coarse aggregates.

3.1. Materials

3.1.1. Cement

Ordinary Portland Cement (OPC) Type 1 manufactured in accordance with BS EN 197-1:2000 was utilized.

3.1.2. Fine aggregates

Natural river sand undergoes sieve analysis to determine the percentage passing 600 µm by weight in accordance with BS EN 12620:2002 +A1:2008. The fine aggregates were subjected to oven drying for 24 hours at 105˚C.

3.1.3. Coarse aggregates

Crushed gravel with nominal maximum size of 20 mm was used in accordance with BS 8500-1:2015+A2:2019. The coarse aggregates were subjected to oven drying for 24 hours at 105˚C.

3.1.4. Water

Tap water that is reasonably free from contamination in the laboratory was used.

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3.1.5. Blood Cockle Shells (BCS)

BCS were obtained from the fisheries market. The BCS were washed under constant tap water to eliminate sticking substances and soil. The BCS were then subjected to oven drying for 24 hours at 105˚C and undergone crushing process to obtain a nominal size of 20 mm by using sieving method.

3.1.6. Corn Husk Fibre (CHF)

CHF were obtained from the morning market. The CHF were washed under constant tap water to eliminate residual that stick at its surface and were then subjected to oven drying for 24 hours at 105˚C. The oven dried CHF where shredded and cut into 5 to 10 mm width and a maximum length of 20 mm.

3.2. Methods

3.2.1. Mix design proportion

The mix design proportion was prepared by using the design of normal concrete mixes (DOE method) with reference to BS EN 197-1:2000, BS EN 12620:2002 +A1:2008 and BS 8500 1:2015+A2:2019. The water-to-cement ratio will be kept at 0.54 throughout all batches. The target mean strength is 46 N/mm2 with a proportion defective of 2.5% while the slump ranges from 30 to 60 mm with a Vebe time of 3 to 6 seconds. Average relative density of aggregate taken is 2.65 with fine aggregate having a percentage passing of 40% at 600 µm. A total of 7 batches of concrete mixtures were prepared as shown in Table 1.

Table 1. Mix design proportion of concrete batches.

Batch	Percent of materials, %	Cement, kg/m^3	Water, kg/m^3	Fine aggregate, kg/m^3	Coarse aggregate, kg/m^3	Cockle shell, kg/m^3	Corn husk fibre, kg/m^3
Control	0	4.44	2.40	9.36	14.05	0	0
CS 1	10	4.44	2.40	9.36	12.64	1.41	0
CS 2	20	4.44	2.40	9.36	11.24	2.81	0
CS 3	30	4.44	2.40	9.36	9.83	4.22	0
CHS 1	1.0	4.44	2.40	9.36	12.64	1.41	0.126
CHS 2	1.5	4.44	2.40	9.36	12.64	1.41	0.189
CHS 3	2.0	4.44	2.40	9.36	12.64	1.41	0.252

CS – Concrete with BCS
CHS – Concrete containing optimum BCS with CHF

3.2.2. Sample preparation

84 samples using cube moulds of size 100 mm by 100 mm by 100 mm in accordance with BS EN 12390-1:2012. 63 samples were prepared for density and compressive strength test and 21 samples for water absorption test. Table 2 shows the distribution of the cube samples.

Table 2. Samples preparation.

Concrete batch	Curing periods (days)			Cumulative samples
	7	14	28	
Control	3	3	6	12
CS 1	3	3	6	12
CS 2	3	3	6	12
CS 3	3	3	6	12
CHS 1	3	3	6	12
CHS 2	3	3	6	12
CHS 3	3	3	6	12
Cumulative samples	21	21	42	84

3.2.3. Curing

The method of curing that was used in this research was water immersion. The curing period for the concrete samples were 7, 14 and 28 days. These samples were used for the determination of density and compressive strength while water absorption test was conducted only for 28 days concrete samples.

3.2.4. Concrete testing

Slump test was conducted on all fresh concrete mixtures in accordance with BS EN 12350-2:2029. Density test was carried out based on BS EN 12390-7:2029 while compressive strength test was conducted according to BS EN 12390-3:2029 for all the samples. Water absorption test was conducted on 28 days samples in accordance with BS 1881-122:2011.

(a) (b) (c) (d) (e) (f)

Figure 1. Methodology of research (a) Crushed and sieved BCS; (b) After-washed CHF; (c) Slump test; (d) Weighted concrete sample for density test; (e) Drying of concrete samples for water absorption test; (f) Compressive strength test.

4. Results and discussion

There are two important notes to be considered. Firstly, this research considered finding the optimum content of BCS to replace coarse aggregate by observing the highest compressive strength exhibited by CS1, CS2 and CS3. Secondly, the concrete containing optimum content of BCS will have an additional substance of CHF forming the mixtures of CSH1, CSH2 and CSH3.

4.1. Workability

Slump tests are conducted on all concrete batches as shown in figure 2 and 3. Figure 2 shows the slump readings for control and concrete containing cockle shell. With the addition of cockle shell, the slump reading increases with BCS content of 10 % and gradually reduced with BCS content of 20 % and 30 % as opposed to the control mixture.

The amount of BCS at 10 % has less surface area to be covered by cement paste compared to the control specimen. In comparison to 20 % and 30 % cockle shell mixtures, the cement paste has to cover a greater surface area which leads to the low slump results. This is based on the requirement of surface coating whereby more surface area needed more surface coating or cement paste available [9]. Hence, the concrete mixture of 10 % BCS was easily mixed and cast in moulds in comparison to other mixtures.

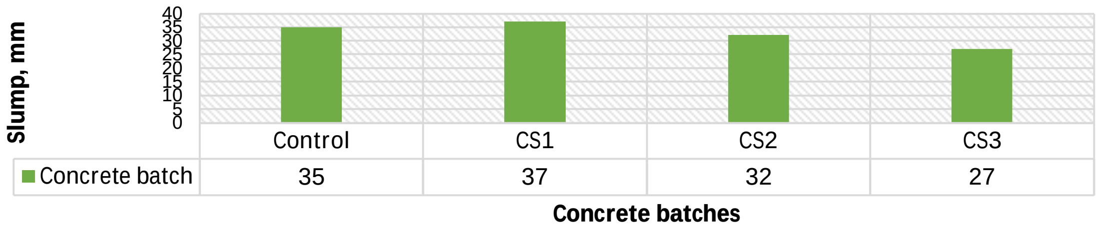

Figure 2. Slump of concrete mixtures containing BCS as coarse aggregates replacement material.

Figure 3 showcased the concrete slump test results containing CHF alongside optimum content of cockle shells of 10%. The mixtures of CSH1, CSH2 and CSH3 shown to have a declining pattern from

35, 32 to 29 mm. In terms of workability, CSH1, CHS2 and CSH3 has exhibit declining trend resulted in hard to mix and placed into moulds as addition of CHF increased.

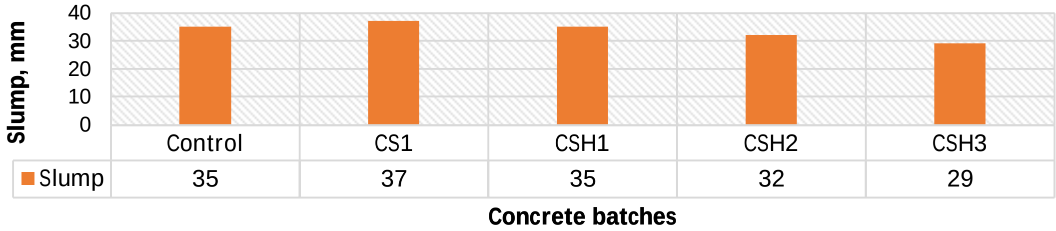

Figure 3. Slump of concrete mixtures containing CHF with optimum content of BCS of 10% as coarse aggregates replacement material.

The change in slump were due to the absorption of water by CHF. The pore structure characteristics of CHF enables water to penetrate inside causing the depletion of water. With the increment of CHF addition into CS1, the increased surface area of CHF resulted in more water to be absorbed [10]. Hence, the reduced workability of concrete mixtures was represented by the reduction of slump as CHF were added. Therefore, it can be justified that CSH1 has almost the same surface area as Control while CSH2 and CSH3 have higher surface area for water absorption and coating by cement paste compared to Control and CS1.

4.2. Density

Density test of concrete samples took place after curing periods of 7, 14 and 28 days. Figure 4 and 5 summarises the data of density for each concrete samples with respect to the curing periods.

Figure 4 indicates the pattern of density for concrete containing BCS at 10 %, 20 % and 30 %. The trend of concrete samples density was in declining pattern when compared to the control specimens. This becomes more significant when the concrete batches reaching 30 % coarse aggregate replacement, with density of 28 days concrete of just 2287 kg/m^3. Density is related to the porosity and permeability of concrete which mainly contributed by the cement paste coating to the substances in a mixture [11]. The formation of pores filled with air reduces the mass of concrete causing the reduction in density from 2400 kg/m^3 (CS1) to 2287 kg/m^3 (CS3).

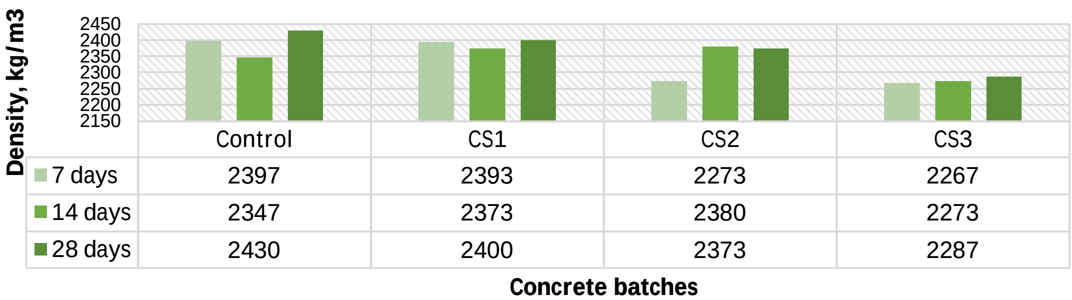

Figure 4. Density of concrete containing BCS as coarse aggregates replacement material

Figure 5 summarises the density of concrete containing CHF with optimum content of BCS of 10%. It can be seen the value of CHS1, CHS2 and CHS3 reduced to 2197, 2193 and 1947 kg/m^3 respectively in comparison to Control (2430 kg/m^3) and CS1 (2400 kg/m^3) samples. Chen et al. [10] mentioned that CHF undergoes cellulose swelling which allows for the element called polysaccharides to absorb water and enhance the size of it. This will increase the surface area which known as requiring more cement paste for coating [11].

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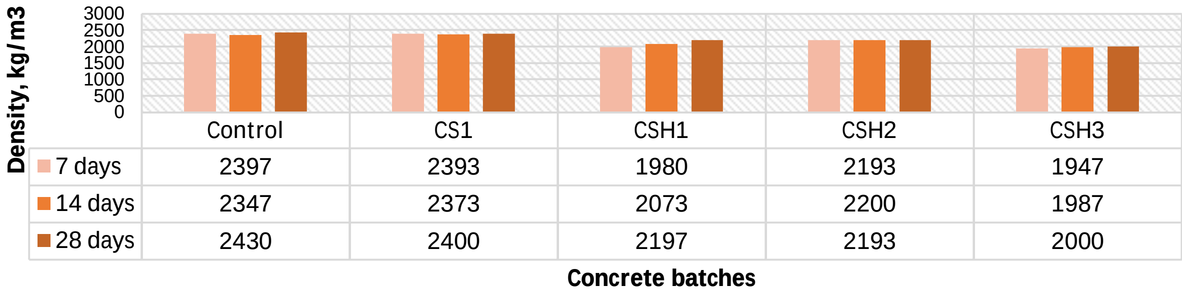


Figure 5. Density of concrete containing CHF with optimum content of BCS of 10%

4.3. Water absorption

The water absorption of concrete was conducted on the 28 days to assess the impermeability of concrete as well as to evaluate the porosity of concrete samples. The results are shown in figure 6 and 7.

Figure 6 summarised the water absorption of concrete with 10 %, 20 % and 30 % of coarse aggregates replacement by BCS. Control samples have the least absorption of water followed with CS1, CS2 and CS3 at 1.46 %, 2.46 %, 2.60 % and 3.55 % respectively. CS3 with 30% BSC replacement exhibits the highest water absorption. Water absorption is closely related to the voids and pore structure of concrete formed by the mixtures. As voids increased in concrete, this contributes to the increment towards permeability [12]. Hence, the voids allow for water to fill in when water absorption test were conducted on the concrete samples.

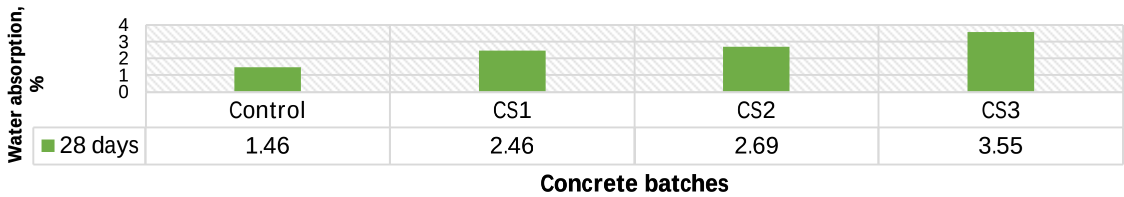


Figure 6. Water absorption of concrete containing BCS as coarse aggregates replacement material.

Figure 7 indicates the results of water absorption of concrete containing CHF with optimum content of BCS of 10%. The results show that there is an increase of absorption of water with the increment of CHF addition. CSH1 and CSH2 has less water absorption rate at 2.18 % and 2.34 % respectively compared to CS1 at 2.46 %. However, these exhibited values are larger than the Control which has the least water absorption at 1.46 %.

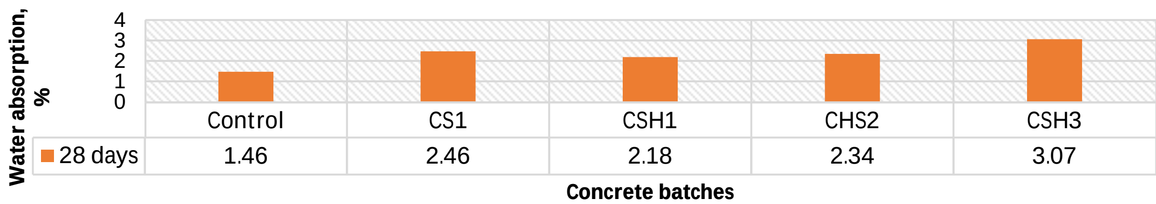


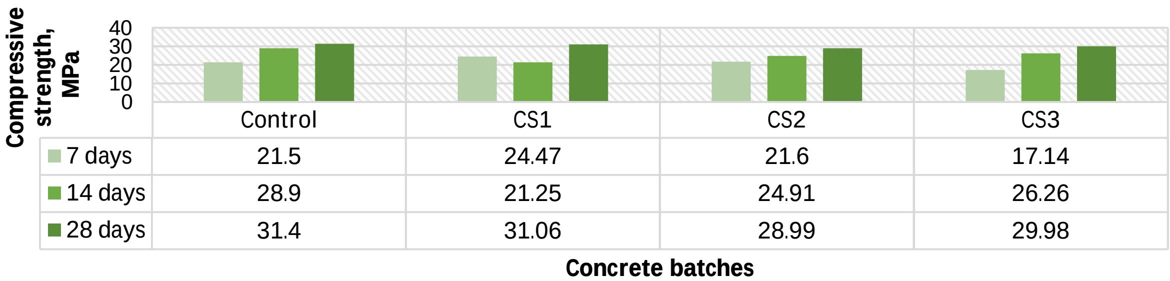
Figure 7. Water absorption of concrete containing CHF with optimum content of BCS of 10%.

From observation the CSH1, CSH2 and CSH3 in harden state has more cavity that allows water to flow through than voids. This indicates that CSH1, CSH2 and CSH3 has higher permeability but has low water absorption due to its capillary network that allow water to flow through rather than retaining it. In comparison to Control and CS1, the hardened concrete produced were more solid which may only consist of more voids or pores than networking capillary in the concrete structure. The formation of pore structure, cavity and capillary depends on the interfacial interlocking of concrete constituents. The cement paste coating does influence the formation of the characteristics mentioned which correspond to the surface area in concrete [11]. Control and CS1 has less substances in it which has less surface area provided, required less cement paste to coat compared to CSH1, CSH2 and CSH3 respectively. Hence, this justified the pattern of water absorption of concrete recorded in figure 7.

4.4. Compressive strength

The test of compressive strength was based on 7, 14 and 28 days of curing. Firstly, the average compressive strength value was used to determine the optimum content of BCS. From then on, CHF will be added in accordance with the design mix. Test results were shown in figure 8 and 9.

Figure 8 shows the compressive strength of concrete for Control, CS1, CS2 and CS3 which proportionated with 10 %, 20 % and 30 % of coarse aggregate replacement by BCS. The Control samples exhibited the highest compressive strength at 28 days with 31.4 MPa. The replaced coarse aggregate mixtures exhibit the value of 31.06 MPa (CS1), 28.99 MPa (CS2) and 29.98 MPa (CS3). Hence, the optimum content of BCS for the concrete mixtures is CS1 with 10 % of BCS as coarse aggregate replacement material.



	Control	CS1	CS2	CS3
7 days	21.5	24.47	21.6	17.14
14 days	28.9	21.25	24.91	26.26
28 days	31.4	31.06	28.99	29.98

Figure 8. Compressive strength of concrete containing BCS as coarse aggregates replacement material.

The difference in compressive strength is due to the coarse aggregate content that usually exceed more than half of the mixture ratio [12]. As more BCS incorporated into the mixture, more air voids formed thus inducing porosity trapped inside the mixture. Furthermore, the surface coating by cement paste become less available due to irregularities physical characteristics of BCS. Since the porosity of concrete induced were greater with the increment of BCS proportions, the bond of concrete through cement paste reduces which in turn effect the compressive strength of the concrete.

Figure 9 shows the pattern of compressive strength of the hardened concrete containing CHF alongside the optimum content of BCS. The 28 days results indicate the reduction of compressive strength when compared to Control and CS1 samples. The CSH2 samples obtained the highest compressive strength of only 20.26 MPa. While CHS1 and CSH3 exhibit much lower compressive strength value at 16.54 and 12.83 MPa. In comparison to the 28 days Control sample at 31.4 MPa, CSH1, CSH2 and CSH3 compressive strength show a reduction of 47.32%, 35.48 % and 59.14 % respectively. The results shows that the maximum compressive strength was achieved by the addition of 1.5 % CHF (CSH2) to the mixture of CS1.

The reduction of compressive strength is mainly due to the properties of CHF that enable absorption of water, disrupting the designed water to cement ratio, w/c of 0.54. Chen et al. [10] noted that CHF is under the category of high-water absorption around 0.0048 m3/kg. The high absorption of water by the CHF also induced fibres deterioration which promotes the holes and pores to form in the concrete matrix potentially reducing the overall strength of concrete [10].

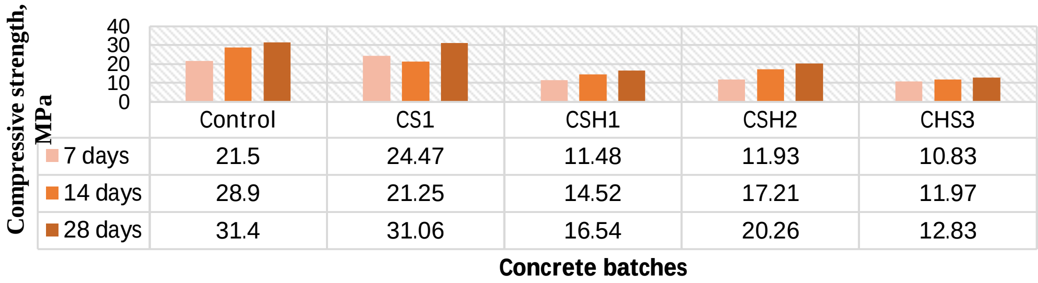


Figure 9. Compressive strength of concrete containing CHF with optimum content of BCS of 10%.

Generally, the fibre reinforced concrete has more porous structures which weakening the fibre-matrix connection [13]. With the increment of CHF addition, an inadequate binding of fibres may happen in which the natural fibres tend to cluster together causing strength degradation as the mixture become more complicated [14]. This can be seen from the initial incorporation of BCS added with CHF caused the mixture to become too complex. Furthermore, the addition of corn husk fibre reduced the compressive strength of concrete which may be contributed from the formation of cavities that reduces the interlayer areas between the components of concrete and fibre particles [15]. The size and shape of the fibre also play an important role in determining the compressive strength. This is due to the interfacial properties determined by the mechanical interlocking and chemical bonding between the cement elements and rough surface of the natural fibres [13]. Hence, the increment of corn husk fibre into concrete containing optimum content of BCS shells at 10 % resulted in the reduction of compressive strength when compared to both Control and CS1.

5. Conclusion

This research studied the effectiveness of corn husk fibre (CHF) on the compressive strength and water absorption of concrete containing blood cockle shells (BCS) as coarse aggregate replacement material. Below are the conclusions:

(i) The changes in density, compressive strength of concrete containing BCS correspond to the physical characteristics of BCS that induce cavity and leads to porosity due to insufficient of cement paste for surface coating thus causing the reduction in the concrete strength. The absorption of water depends on the porosity of concrete that allows for water to trap, which in this case formed by the introduction of BCS due to its physical characteristics. Thus, more BCS incorporated, the higher water content will be absorbed by concrete.

(ii) The differential in compressive strength performance by concrete with CHF alongside optimum content of BCS due to several factors such as the chosen width size is not compatible whereby fibre with low thickness may produce better result. Next, the increment of CHF tends to cluster together thus promotes inadequate binding and causing degradation in strength.

(iii) Other factors that affect the compressive strength is that the natural fibres promote water absorption which introduces more voids that leads to porosity and may increase permeability which results in further reduction of the concrete strength. The CHF fibres also does not undergo any pretreatment beforehand to eliminate any undesired properties, which reduce the interfacial interaction between concrete matrix that cause weakening of bonding.

(iv) The formation of pores and capillary is closely related to the coating of corn husk fibre surface area by cement paste that form voids contributing to porosity and permeability of concrete structures.

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