MICROSTRUCTURAL STUDY OF COCONUT SHELL CONCRETE

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Abstract- Rapid growth of the construction industry results in high demand for the aggregate. However, the aggressive consumption of aggregate significantly affects the environment when mining and quarry activities need to be carried out to supply the aggregate. This study was conducted to use agricultural waste, i.e., crushed coconut shells as an alternative to coarse aggregate in the concrete mix known as coconut shell concrete (CSC). A series of experiments were carried out to determine the compressive strength of CSC and to study the micro-morphologies of the CSC at 1, 7 and 28 days. The strength development of the CSC was observed and validated with the compressive strength of the samples at different ages. The use of crushed coconut shells as aggregates replacement does not change the micro-morphologies of normal concrete mix.

Keywords- Agricultural wastes, Coconut Shell Concrete, Lightweight Aggregate Concrete, Sustainability.

1 Introduction

Concrete is widely used in building construction due to its properties and strength. The main constituents of the concrete are cement, sand, and aggregate which are mixed with water. Concrete production requires a significant number of natural resources such as rocks and sand since approximately three-quarters of the concrete volume is occupied by aggregate. The aggregates have a significant effect on the structural performance and durability of the concrete [1]. The high demand for concrete due to the rapid growth of the construction industry and aggressive consumption of non-renewable sources caused a shortage of the aggregate [2]. Recent studies have been carried out to develop alternative materials to substitute the use of aggregate in the concrete mixture including the utilization of agricultural wastes such as palm kernel shells (PKS) and coconut shells (CS) [3]–[9].

The CS has great abrasion, high strength and toughness [10]. It is also can be classified as lightweight aggregate [11]. The physical characteristics of CS with smooth surface, angular shape and varies in size offer a good bond and workability for the concrete mix [12]. Table 1 shows physical properties of coconut shell and coarse aggregate [13]. Previous studies reported that the use of crushed coconut shells as aggregate replacement in conventional concrete reduced the density in the range of 1750 kg/m^3 to 1900 kg/m^3 [5], [14]. Comprehensive studies reported the potential of CSC as the alternative to aggregate substitution in the concrete mix with reliable mechanical properties and performance of the CSC as structural and non-structural application [5], [10], [15], [16]. Incorporation of pozzolana and fibres in the CSC also showed improvement in the ultimate moment capacity and flexural toughness up to 14% and 45% respectively [17] . However less reported on the micro-morphologies of the CSC.

Strength development and micro-morphology of concrete is studied by observing the interior microstructure characteristics of the concrete. It provides understanding on the interaction between the CSC constituents since the microstructure of concrete changes with time due to ongoing hydration and environmental factors. Various methods are used to investigate the microstructure such as Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD). The SEM is used to reveal vast cross-sectional regions while XRD is common to determine the quantity of components of the samples in different phases [18]. This study was carried out to examine the micro-morphologies of CSC at different ages of curing days. A comparison was made with the interior characteristics of normal concrete.

Table 1 Physical properties of coconut shell and coarse aggregate [13]

Properties	Coarse aggregate	Crushed coconut shell
Fineness modulus	4.2	6.5
Specific gravity	2.7	1.3
Loose bulk density (kg/m^3)	1480	510
Dense bulk density (kg/m^3)	1610	600
Water absorption (%)	1	6
Aggregate crushing value (%)	16.6	2.5
Aggregate impact value (%)	11.0	4.2

2 Experimental Procedures

2.1 Sample preparation

A total of 18 samples were prepared which consist of control samples (NC) and coconut shell concrete (CSC) with a design mix ratio of 1: 1.6: 0.7 (cement: sand: aggregate/CS). The cement contents and water-cement ratio were 480 kg/m^3 and 0.42 respectively. The design mix for 1 m^3 samples is shown in Table 2.

Table 2 Concrete mix design for 1 m^3 sample

Sample	Cement	Sand	Water	Coarse aggregate	Crushed coconut shell
NC	480	770	200	340	-
CSC	480	770	200	-	340

* All units in kg

The concrete mix batches were mixed using a concrete mixer approximately for 3 minutes to ensure the constituents were mixed well. The CS was purchased from the wider of east coast of Malaysia and available in a crush form. The range size of CS (see Figure 1a) and coarse aggregate approximately 10 mm – 13 mm. Prior to the CSC mixing, the crushed coconut shells were immersed in the water for 24 hours to confirm that the condition of the crushed coconut shells was in a saturated surface dry (SSD) state. In the SSD state, all the pores in the CS are full and the water absorption during concrete mixing can be controlled. All the 18 samples were cast in cube moulds with dimensions of 150 mm x 150 mm x 150 mm and demoulded after 24 hours. The samples were covered with plastic sheet for curing purposes (Figure 1b). The plastic cover was used to keep the moisture of the samples for the cement hydration process.

a)  b) 

Figure 1: (a) Crushed coconut shell (b) curing with plastic cover

2.2 Compression test setup

A compression test was conducted to determine the compressive strength of samples in accordance with [19]. The compressive strength of the cube samples was measured at ages 1, 7 and 28 days of the samples using the Universal Testing Machine (UTM) as shown in Figure 2a. Figure 2b shows the compression test setup of the cube samples. The compressive strength of the samples was calculated using equation (1) [19].

$$f_c = \frac{F}{A_c} \quad (1)$$

where f_c is the compressive strength (N/mm^2), F is the maximum load at failure (N) and A_c is the cross-sectional area of the specimen on which the compressive force acts (mm^2).

a)  b) 

Figure 2: (a) Universal testing machine (b) compression test setup

2.3 Scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDS) analysis

In this study, the surface morphology observations of samples were performed using a ZEISS Gemini SEM 500 (Figure 3) and EDS was used to determine composition of the samples which was measured in terms of weight percentage (wt. %). Prior to the SEM and EDS analysis, the samples from post compression test at age 1-, 7- and 28 days were taken at the middle of the broken samples. The samples were finely crushed into powder and those passing the 90µm sieve was utilized for SEM analysis and packed before the SEM analysis to terminate the hydration process. The SEM able to identify the microstructure of pore spaces and to study the microstructural characterization after hydration with greater magnification. Before the SEM analysis, the samples were kept in a dry temperature of 60°C for 2 or 3 hours. The powder was put onto an aluminium stub covered with conductive carbon tape for SEM analysis (Figure 4 (a)) to ensure the powder is dispersed evenly on the carbon tape's surface. A sputter coater (Quorum Q150R Thin- Film Coater) was used to apply a platinum mixture to the powder (Figure 4(b)).

Figure 3: Gemini SEM 500 instrument

a)  b) 

Figure 4: (a) Sample powder on aluminium stub (b) Sample coating with platinum

3 Results and Discussion

3.1 Compressive strength, f_c

Crushed coconut replacement with aggregate slightly reduced the compressive strength approximately 3.7% when compared to the NC. The compressive strength both type of the concrete samples increased with the increment of the curing age (see Figure 5). With the presence of water, the cement hydration process began when the silicates and luminates in cement produce hard mass called hardened cement paste [1]. Strength development of both concrete samples showed significant increment at the early age with the strength rate up to 180% when measured from day-1 to day-7 of the samples. However, at the later age, the increment rate showed slight reduction when the strength increment of the samples was only about 30% at the age of 28 days. At this phase the cement hydration process was almost complete, and the hard mass also occupied the concrete volume. The aggregate replacement with crushed coconut shell did not change the cement hydration process of the samples since the CSC also showed similar pattern with NC on the strength development from day-1 to day-28. Similar finding also reported by [10], [20]. Concrete samples with coconut shell coarse aggregate showed compressive strength up to 19.84 N/mm^2, which satisfies the use of the CSC mix for structural lightweight concrete [21].

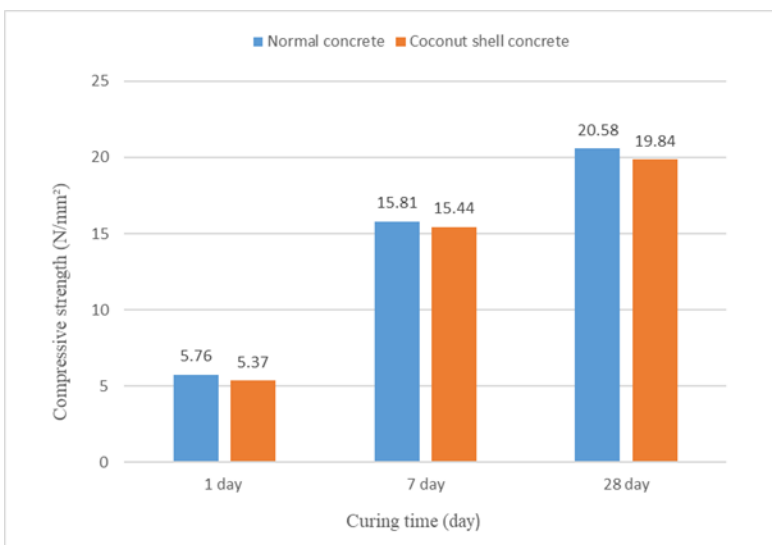


Figure 5: Compressive strength of the samples for 1-, 7-, and 28 days of curing

3.2 SEM observations

The micro-morphologies of the normal concrete and CSC for 1, 7 and 28 days are shown in Figure 6, Figure 7 and Figure 8, respectively. At early age of the samples, multiple ettringite fiber bundles were observed as the most hydration products occupied the samples. This agreed with the final product of cement hydration process where the first product to form in the process is ettringite [1]. The ettringite distribution was varied for both types of concrete samples. From the observation, the CSC sample showed high amount of ettringite at the age day -1 when compared to normal concrete (see Figure 6). The amount of ettringite started to decrease when the important product for the concrete strength (C-S-H) began to dominate the concrete volume at day-7 (see Figure 7) and significantly increased at the age 28 days (see Figure 8) for both normal concrete and CSC samples. At this age, the matrix became more denser [22], and the C-H was incorporated in the concrete samples and the strength of the samples already achieved up to 99% of the targeted strength [23]. The normal concrete sample showed C-S-H products filled the concrete volume with less pores were observed while CSC sample showed porous characteristics where larger and darker area was spotted (Figure 8 (b)). The SEM observations agreed with the finding of compressive strength where the CSC samples showed lower strength when compared to the NC samples as explained in section 3.1.

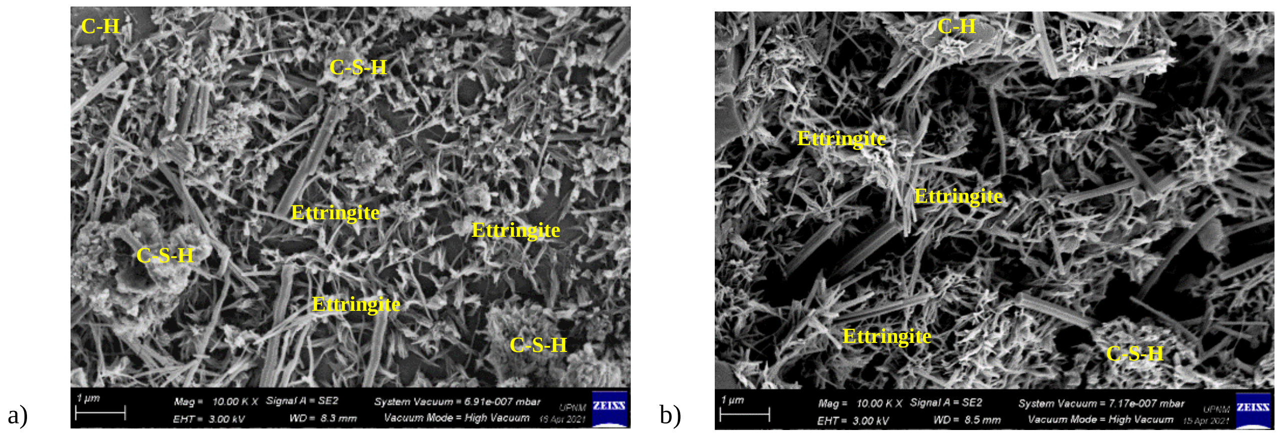


Figure 6: SEM images of (a) normal concrete (b) coconut shell concrete at age 1 day

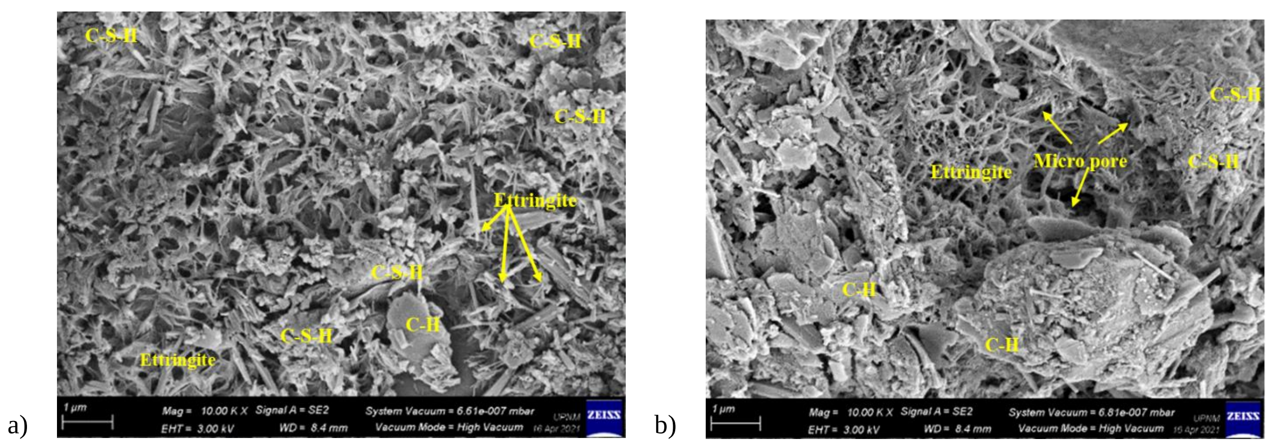
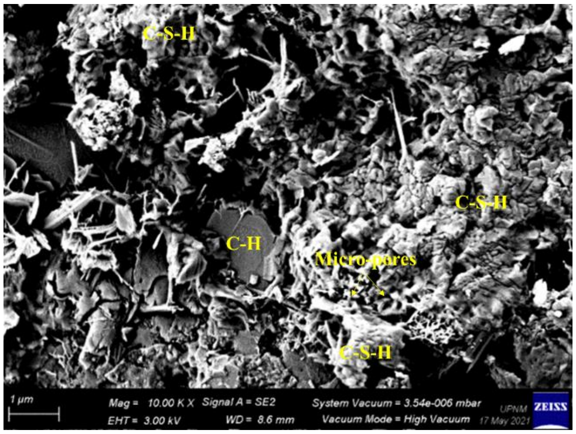


Figure 7: SEM images of (a) normal concrete (b) coconut shell concrete at age 7 days

a) 

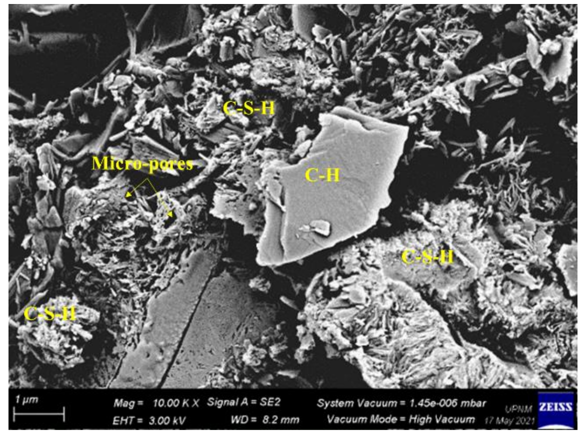
b) 

Figure 8: SEM images of (a) normal concrete (b) coconut shell concrete at age 28 days

4 Conclusion

The utilization of crushed coconut shells as aggregate replacement in concrete production promotes sustainability development goals. The development of CSC as lightweight concrete is encouraging yet the strength development of the CSC is less reported. This study was carried out to investigate the micro-morphologies of the CSC using SEM method. It can be concluded that:

a. The rate of strength increment between CSC and NC are similar where the early-age strength rates (180%) were higher than the later age strength rate (30%) of the concrete samples. The compressive strength of the CSC is slightly lower than NC approximately -3.6%.
b. The crushed coconut shell replacement in the concrete mix does not change the micro-morphologies of the concrete with C-S-H products occupied the volume of the matrix. However, the CSC samples showed porous characteristics when compared with the NC.

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