IOP Conf. Series: Earth and Environmental Science 1205 (2023) 012040 doi:10.1088/1755-1315/1205/1/012040

Thermo-voltage and strength performance of catalysed biomass concrete with Phosphomolybdic Acid and Ferric Chloride as renewable energy source

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Abstract. Catalyzed biomass concrete (CBC) is a cutting-edge technology that produces its own voltages when exposed to temperature changes. It is achieved by mixing catalyst and biomass in conventional concrete during fresh state, and the product generates electricity by oxidation. It helps in reducing cement consumption and minimizing environmental effect, yet to produce new renewable energy from concrete itself. Existing studies has proven the voltage effectiveness of CBC but still low in compressive strength, making it not suitable to serve as load carrying component. Hence in this study, a new chemical combination of catalyst in CBC is examined and reported in its voltage and compressive strength performance. Cubes and specimens with catalyst percentage ranging from 5% to 40% were prepared and tested its compressive strength up to 56 days and its voltage performance under three different exposing condition from 0ºC to 100ºC. The findings show that CBC specimens with such catalyst combination able to produce voltages, where specimens with 40% of catalyst had the highest voltage measurement of 0.443V. While for compressive strength, CBC cubes with 10% of catalyst performed higher than 40%, but the strength captured with new catalyst combination is better that existing study. It is evident that CBC with such catalyst suitable to serve as load bearing component, and at the same time, generating electricity with complete circuit, under temperature different.

1. Introduction

Carbon dioxide emissions to environment always get concern from various parties, especially when annual world cement production has reported grown from 1 billion tons to 1.7 billions tons since 1970 [4,23]. Researchers, especially in advanced concrete materials field, actively searching for innovative materials as cement replacement and at the same time, fulfilling the green building index's requirements. Many proven that by replacing part of cement with biomass can results in better compressive strength and durability, and is able to reduce the emission of CO_2 during production [2,3,6,7,15–21]. More, it helps in enhancing the durability, chemical resistance properties, low heat development and other mechanical properties comparing to conventional Portland cement concrete. However, the potential of biomass in concrete is yet fully discovered. Biomass, has been proven by chemistries and researchers, when incorporates with catalyst, on its capability in generating electricity under exposing criteria [5,8,12–14,22,24]. Many researches are conducted purely on biomass itself, and there are only researchers from INTI International University, Malaysia started the initiative in mixing various type of catalyzed biomass in concrete, and results show promising voltage generated, but the compressive strength obtained was lower than expected [10,11]. This combination named Catalyzed Biomass Concrete (CBC), and it is patented under patent id PI2018003068. Combination of catalyzed biomass and concrete constituents can re-character public impression towards concrete where it gives strength and integrity to building structures and able to generate electricity under thermal exposure. This is in line with National Renewable Energy Policy: Achieving 20% renewable energy capacity mix by 2025.

Through literatures and technical papers for CBC research, the results show that such concrete mix combination is feasible in generating electricity with a designed circuit that collects charges and stores it in battery, just like solar panel. An average voltage density of 120 V/m^2 is recorded. Such novel renewable energy source gives more environmental benefits which may also bring the construction industry one step ahead others. However, as mentioned the compressive strength was reported degraded up to 60-70% compared to control concrete cube [10,11]. Such degradation is suspected due to oxidation of biomass with catalyst for active charges, depleting the amount of biomass used in producing cementitious materials. The application of CBC with low compressive strength is not wide, and it is only suitable for non-load bearing components, such as wall plaster, wall mansory, architectures fitting, etc. Hence, in order to utilize the CBC concrete in load-bearing component, it is needed to figure out the best mix materials so sufficient compressive strength can be achieved, and at the same time, generate sufficient charges for electricity.

In this paper, a new catalyst mixture of Phosphomolybdic acid and Ferric Chloride is proposed to be used as catalyst in CBC, whereas the biomass used was palm oil fuel ash (POFA). Eight batches of CBC cubes and specimens were prepared with different proportion of catalyst, and examined with compressive strength test and conductivity test, respectively. Compressive strength tests were conducted in compliance with ASTM C39/C39M, and strengths were recorded for 7th, 28th and 56th day of moist curing. For Conductivity Test, CBC specimens were exposed to three different exposing condition, namely cold, normal and hot condition, with temperature ranging from 0^{o}C to 100^{o}C. Voltage readings were captured as per methodology proposed by existing study. The experimental rig of the proposed mixture is established in INTI International University, Malaysia. The methodology, compressive strength performance and voltage performance of CBC with such catalyst is presented and discussed in detail.

2. Experiment methods

This study aims to determine the performance of catalysed biomass concrete specimens with varying amounts of Phosphomolybdic acid and Ferric Chloride to generate electricity at exposing temperature up to 100^{o}C. Furthermore, compressive strength tests were performed to study the strength development of catalysed biomass concrete using POFA as a partial cementsubstitute with Phosphomolybdic acid and Ferric Chloride as a catalyst. The mix proportion, cube preparation and testing methodology are described in the following section.

2.1 Materials, proportion and specimen preparation

Eight batches of CBC cubes for compressive strength test (dimension 100 mm x 100 mm x 100 mm) and CBC specimens (50 mm x 50 mm x 20 mm) for conductivity test were prepared according to the mix proportion presented in Table 1. Other than common concrete constituents, palm oil fuel ash (POFA) was added as biomass and catalyst of Phosphomolybdic Acid and Ferric Chloride (POM-$FeCl_3$) were added in the mix for biomass oxidation process. Catalyst was added following increasing proportion of 5% up to 40% of cement replacement, while the rest of constituents maintain fixed throughout the study. DoE concrete mix design method of M30 was adopted in this study due to no available design code for CBC concrete. The design was done by assuming the wet density of CBC

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concrete is 2400 kg/m^3. To make it practical, the method of mixing was similar to the method in mixing conventional concrete, the catalyst was added slowly and evenly during mixing process. CBC cubes and specimens were cured in oven for 24 hours at 90^{o}C right after the wet mix is poured in mould. This aim to escalate the hydration and pozzolanic processes, as well as to liquefy the catalyst if a powdered form catalyst is used. The catalyst in CBC acts as photochemical and thermochemical catalyst which helps in biomass oxidation, and acts as charge carrier to receive electrons in catalyzed biomass [25]. This combination works under exposed temperature different. A electric circuit is needed to be installed to capture and store all charges like solar panel, but it is not the main objective of the study, hence only voltage performance is captured using multimeter.

Table 1. Mix proportion for CBC cubes and specimens with catalyst.

Materials	**Proportion (kg/m^3)**
Ordinary Portland Cement (OPC)	300
Palm Oil Fuel Ash (POFA) – 0.3mm size	75 (20% of cement tent)
Water	210
Fine Aggregates	544
Coarse Aggregate (max 20mm, SSD)	1268
POM-$FeCl_3$	5% - 40% of cement content

(a) (b)

Figure 1. Palm oil fuel ash (POFA): (a) phosphomolybdic acid (H3Mo12PO4012H2O) and (b) used in this study as biomass and catalyst, respectively.

After heat curing for 24 hours, all CBC cubes were brought for moist curing up to 56 days to complete its hydration and pozzolanic reaction. CBC cubes were compressively loaded after curing for 7, 28 and 56 days. Voltage test can be started after 24 hours of heat curing. An external circuit is needed to be set up before voltage test, as discussed in the following section.

2.2 CBC specimen's external circuit and voltage testing

External circuit was installed on CBC specimens (50mm x 50mm x 20mm) after heat curing at 90^{o}C for 24 hours if compressive strength is not priority, else prolonged curing is necessary for further hydration and pozzolanic process. Figure 2 shows the external circuit for CBC specimen. A carbon cloth was attached on the surface of specimen to create differential portal in electrochemical reaction, and the voltage generated can be measure by touching both specimen and carbon cloth by multimeter's probes [13,22]. It is necessary to make sure both probes are contacted with CBC specimen firmly. Loosen probes and uneven surface of specimen may affect the efficiency of the result generated.

Once the circuit is ready, voltage test under various exposing temperature can be conducted. Three range of temperatures were designed to ease the result discussion: cold, normal, and hot exposure. Temperature for cold exposure ranged from 0 ºC to 20 ºC, medium exposure ranged from 20 ºC to 40 ºC, while hot exposure ranged from 40 ºC to 100 ºC. The testing setup and procedure was following the proposed methodology by Lee [10,11]. The exposure setup for voltage test under three different exposing condition is illustrated in Figure 3. A thermometer is put in the middle of the testing medium to measure the exposing temperature towards CBC specimens. Once it reached the desired temperature, probes from multimeter were connected and reading was taken within 15 seconds. The maximum voltage generated within the period is reported as the highest voltage generated by CBC specimen. It is vital to make sure CBC specimen is always in dry condition during voltage testing so to maintain the confident level of the result. The voltage sensitivity is high when CBC specimen is wet or contain any acidic/alkaline solution as reported in existing research [10]. Repeat the measurement for 10 times per specimens so to achieve high confident level's result.

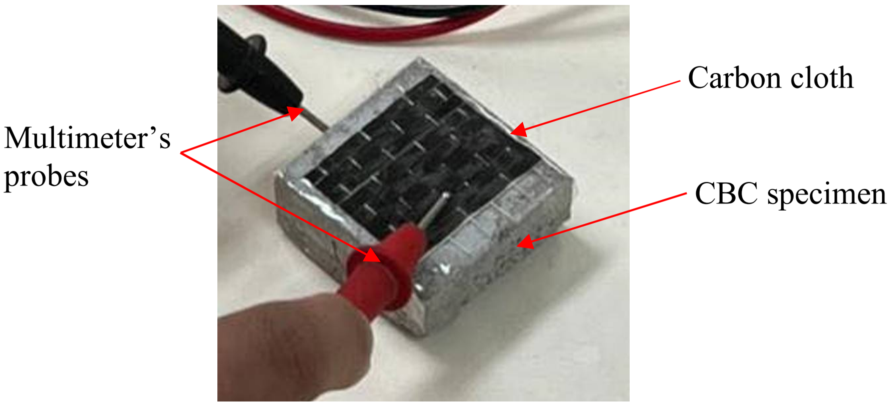
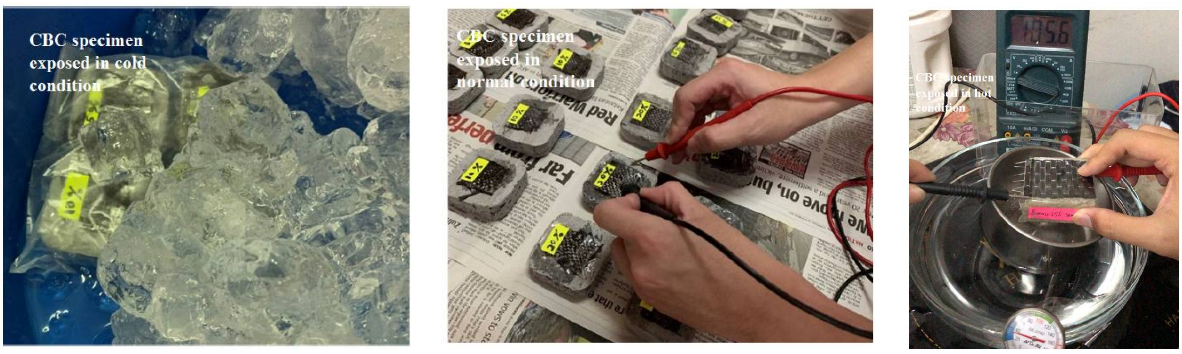


Figure 2. External circuit for CBC specimen.



(a) (b) (c)

Figure 3. Voltage test for CBC specimens under: (a) cold exposure, (b) normal exposure, and (c) hot exposure.

2.3 CBC cube and compressive strength test

Previous studies concluded that CBC cube has lower strength compared to control due to biomass oxidation but lesser pozzolanic reaction with active solution. The compressive strength of CBC with Phosphomolybdic Acid and Ferric Chloride is yet available in any compendex, hence it is important to produce CBC with satisfactory strength yet able to produce voltages. All CBC cube in this study was compressed after its prescribed curing duration, in according to ASTM C39/C39M [1] for 7th, 28th, and 56th day. Cubes were loaded until failure, cracking behaviour was observed throughout the test, ultimate compressive strength was recorded when it reached peak capacity.

3. Result and discussion

3.1 Conductivity test result

In general, it can be concluded that the voltage generation from CBC specimen is proportion to the increase in exposing temperature, as well as the percentage of mixing catalyst. Figure 4 plotted the graph of voltage (v) versus exposing temperature for CBC specimens in this study. The specimens with 40% of catalyst achieve the greatest voltagemeasurement for low temperature ranging from 0°C to 20°C with 0.345V and lowest voltage 0.076V with 5% of catalyst. The voltage reading trendline for all catalyst solution was noted to continuously increase as the temperature increased from 0°C to 20°C. Similar outcome can be observed for normal exposing temperature, where specimens with 40% catalyst captured highest voltage of 0.363V, where the lowest voltage capture is specimen with 5% catalyst, results in 0.133V.

One interesting phenomenon observed is the voltage measurement for specimens containing 10%, 15%, 25%, 30%, and 35% catalyst solution drops significantly as the temperature rises to 40°C, then climbs more as the temperature rises. When compared to 30°C and 40°C, the voltage values for all specimens show a gentle upward trend or flatten out pattern for all specimens.

While for hot exposing condition, the observation is identical like cold and normal condition, specimens with 40% catalyst stands at the highest voltage generation (0.4V) while specimens with 5% catalyst are comparatively lower, with voltage about 0.206V. Moreover, the specimen with 5%, 20%, 25% and 35% of catalyst solution achieved a flatten out trendline with fluctuating reading across all the temperature in hot condition. The specimens with a gradual decrease trendline are 10%, 15% and 40% which having a peak reading in the range of 50°C to 70°C and slowly decrease in voltage reading. Overall, the trendline of the voltage reading for all specimens was noted to beincreasing lesser leading to a gentle slope.

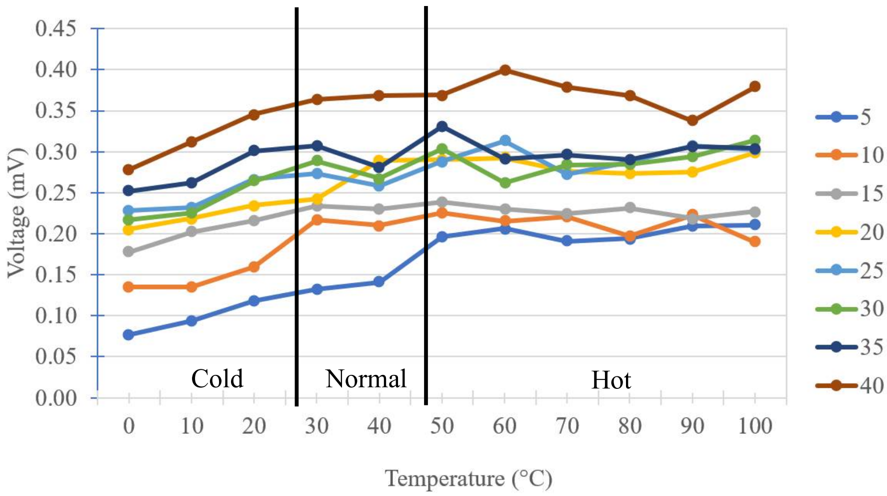


Figure 4. Graph of Voltage (V) versus exposing temperature for CBC specimens with different mixing proportion of catalyst.

3.2 Compressive strength test

In general, CBC cubes exhibit extremely low compressive strength at early stage (7^{th} day of curing), where strength degraded more than 85% to control specimens. All CBC cubes were weak in strength as the portion of conventional hydration reaction has been taken placed by pozzolanic and oxidation processes. Then, at 28^{th} day of curing, the phenomenon changes. CBC cubes gained strength up to 21.3 MPa for cube with 10% catalyst, 14.57 MPa for cube with 40% catalyst: strength degradation equivalent to 22.7% and 47.2% respectively. Figure 5 shows the average compressive strength performance of CBC cubes with different proportion of catalyst. These outcomes has against the existing researches on more than 60% of strength degradation [9], where by using the catalyst proposed in this study, it is able to improve the strength capacity. Similar observation can be concluded for concrete strength at 56th day, although compressive strength of CBC cubes has increased, it is still lower than control specimen in comparison. The gap different has become smaller: 12.5% degradation for cube with 10% catalyst. Whilst for cube with 40% catalyst, the compressive strength maintained at 14 MPa, indicates the negative effect of high dose of catalyst.

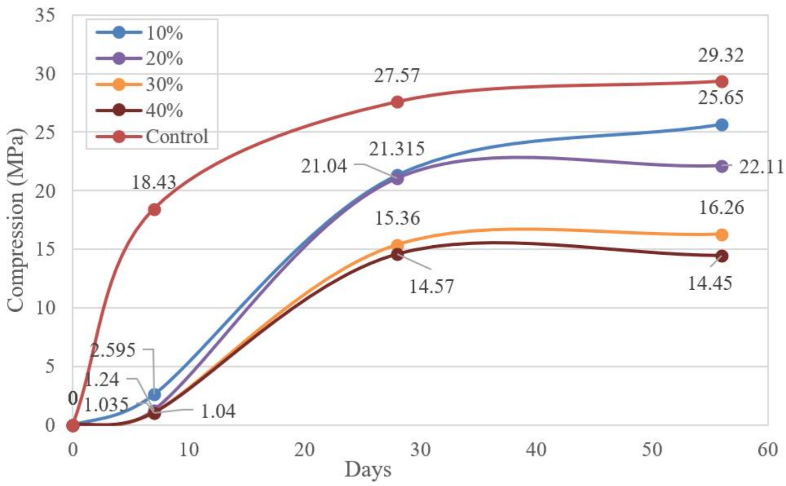


Figure 5. Average compressive strength development of CBC cubes with different proportion of catalyst.

In a nutshell, the more the dosage of catalyst in CBC cubes, the lesser the compressive strength can be achieved. But, when considering the voltage performance, the higher the dosage of catalyst, the better it is. When it is completed with a circuit, CBC can be served like solar panel to provide electricity sorely without need to carry a structure load. If CBC is designed to serve both electricity and structure loading, hence it needs to consider in lower dosage of catalyst, giving higher compressive strength, but medium rate in producing electricity.

4. Conclusion

In this study, eight series of cubes with different percentage of catalyst were prepared and examined for its voltage test and compressive strength test. The outcomes are presented in accordance with the aims, and the following conclusions can be made:

1. CBC specimens with varying concentrations of catalyst ranging from 5% to 40% successfully produced voltages. The voltage measurements raised as the temperature climbed. However, the CBC specimens tested in room temperature of 30ºC to 40ºC exhibits less abrupt in the raise of voltage reading, but it doesn't affect the use of CBC as thermoelectric component, provided with proper circuit.
2. Compare to existing study, the catalyst used in this study has successfully decreases the gap of degradation between control and CBC cubes. The compressive strength captured was higher than reported in existing study, however, it is still under strength comparing with control sample.

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Acknowledgement
The research described in this paper is supported by the FRGS 2020-1 under Vot FRGS/1/2020/TK0/INTI/02/1 and INTI Seeding Grant under Vot INTI-FEQS-15-03-2021. Laboratory testing of the specimens were performed in the Concrete Laboratory, INTI International University, Nilai. Assistance from the dutiful technicians was very much acknowledged.