Furnace temperature of coffee grounds as organic waste-based cementitious material in concrete

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Abstract. Organic waste results as a high impact as inorganic material to our environment which rise the alert to manage them seriously. Accordingly, this paper discusses the significance of organic waste-based material from the coffee powder utilized as the 5% cement replacement in concrete. Ultimately, the temperature variation of the muffle furnace to derive into coffee grounds husk ash is investigated chemically and mechanically to the compressive strength of concrete. Furnace temperature variation was set from 600°C up to 750°C for 2 hours which disclosed dominant potassium oxide. Else, some chemical components as found in cement was present except silicon oxide which predominantly appears in cement to increase concrete strength. However, the chemical reaction between coffee grounds ash, cement and other matrices in concrete mixture generated better compressive performance in accordance with the furnace temperature of 750°C climb reaching over 40 MPa which was above the targeted control sample. Even though the reactivity of the mixture was not detail observed, the coffee grounds ash obtained from 750°C furnace process was eligible as cement replacement in the concrete mixture for normal concrete design.

1. Introduction
Utilization of waste for several applications has been widely investigated as the effort for optimizing the principal of recycle and reuse of waste. Construction sector actively contributes for decreasing organic and inorganic waste to be further taken advantage as the replacement of certain construction material used in common. Closely, it will be economical and environmentally friendly by doing so.

Indonesia as one of the countries that produce coffee is surely familiar with it as one of the popular beverages so that prominently face the problem of the coffee grounds as a waste. Coffee grounds are one of the organic wastes that create problems for the environment obtained from the coffee bean processing and further consumption that generates 30% to 50% of agricultural waste from the total production of coffee [1]. Domestic agriculture material such as coffee grounds is widely known for fertilizer or landfill leachate absorbent due to high level of nitrogen [2,3]. However, the research about coffee grounds in concrete done before by Kua T was limited to the drying the coffee grounds at the temperature of 50°C which could not be categorized as ash due to the fineness and granularity size compared to cement.

Coffee grounds can be applicable for limited use in construction as non-structural application due to its low shear strength and high compressibility [2]. In geotechnical, we take the benefit of coffee grounds
as the agent for soil improvement, however muffle furnace is introduced for crystallization chemical process to observe the presence of chemical components to be the cement replacement in concrete. The process of altering coffee grounds into coffee grounds husk ash (CGHA) using muffle furnace used 4 heating temperatures starting from 600°C, 650°C, 700°C and 750°C for two hours which was expected to reach the fineness as cement. The employment of CGHA as 5% replacement of cement in concrete is further observed for each temperature.

2. Materials and methods
The replacement of cement with the CGHA was possible due to the result of the Scanning Electron Microscopy (SEM) test conducted. Hence, coffee grounds ash was cementitious so that the characteristic of the concrete due to 5% replacement of cement by CGHA is still possible for the normal concrete design.

2.1. Coffee grounds husk ash (CGHA)
In creating CHA from coffee grounds got from some coffee stalls started from sun-bathing the coffee grounds for 3 days continued by burning in the oven for 24 hours in the temperature of 200°C. Later, the muffle furnace was conducted for 120 minutes. Microwave muffle furnace keeps the incinerated material contained and isolate it from its excess such as contaminants, substances and contaminants. It implies that the samples to be incinerated are activated by microwave energy, but this is not the case since the procedure used with this device is furnace-in-a-furnace approach [5]. The temperature of muffle can furnace can hold until 1800°C which contributes to relatively poor overall performance among many laboratories that analyze silica compare to plasma furnace in creating ash [6].

Figure 1. Scanning Electron Microscopy of CGHA at 600°C until 750°C.
After the incineration, all the CGHA samples were tested to find out its chemical substances inside using SEM test as shown in figure 1. Table 1 provides the result of the chemical components of CGHA compared to Kua T which treated of 5-7 days of drying by using standard oven in the temperature of 50°C. As seen, the higher temperature of furnace resulted more chemical component and vanish another component. Silica and alumina are distinct for its inexistence even after higher furnace temperature, so that the contribution in increasing the strength of concrete will be impossible.

Interestingly, the presence of potassium oxide and calcium oxide are rising the possibility of using CGHA for cement replacement. Both components are beneficial for the hardening process of concrete after meeting water as the proportion of calcium oxide is lower. However, the higher temperature of furnace will lose more chemical components needed as the cement replacement. In addition, the fineness of the CGHA is almost the same as cement, but the specific gravity is half lower than cement about 1.37 gr/cm³ [2]. Unfortunately detail specific gravity for each temperature was missed to be detail checked.

The augment and/or replacement of cementitious material or mineral addition to the cement must present adequate fineness and granule size, and their chemical and physical characteristics must be well known [8]. The process of making CGHA introduced muffle furnace is one of the proposed methods of creating ash besides plasma furnace, however the availability of the silica content could be extremely lower than predicted.

### Table 1. SEM result of CGHA for various furnace temperature.

| Chemical composition (%) | 600°C | 650°C | 700°C | 750°C | CG [4] |
|--------------------------|-------|-------|-------|-------|--------|
| MgO                      | 5.40  | 3.96  | 5.68  | 2.95  | ND     |
| P₂O₅                     | 7.79  | 5.28  | 8.22  | 4.00  | ND     |
| SO₃                      | 5.92  | 3.50  | 5.60  | 2.74  | ND     |
| K₂O                      | 18.40 | 12.19 | 20.95 | 8.59  | 43.10  |
| CaO                      | 3.65  | 2.32  | 4.03  | 1.60  | 33.99  |
| ZnO                      | 7.26  | 3.81  | 7.49  | 2.84  | ND     |
| Fe₂O₃                    | ND    | 0.67  | ND    | ND    | 3.61   |
| SiO₂                     | ND    | ND    | ND    | ND    | ND     |
| Al₂O₃                    | ND    | ND    | ND    | ND    | ND     |
| TiO₂                     | ND    | ND    | ND    | ND    | 16.50  |

Note: ND = Not Detected

2.2. Experimental procedure

Samples consist of 3 samples for each temperature variation for compression test. The target compressive strength of concrete was 20 MPa which was molded in cylinder with the dimension of diameter and height of 150 mm and 300 mm respectively so that the compressive strength calculation do not need any correlation estimation [9]. Several tests were conducted in this paper such as slump, dry concrete density and compressive strength of concrete at the age of 28 days. Besides, the preliminary test of aggregate was also performed to make sure the quality of reaching the target compressive strength.

The 5% cement replacement by CGHA was measured based on the weight of cement. During mixing, the wet mixing was applied starting from coarse aggregate, one-third of water, fine aggregate and the rest of water. At last, did the dry mixing of remaining cement and CGHA before finally inserted into the concrete mixer. After all the components were well mixed, then continued with the slump test and molded the concrete. The standard operation for mixing and curing were done in Torsina Redicon laboratory.
3. Results and discussion
This section will discuss the result of the slump, density and compressive strength of concrete samples by explaining the average value from each temperature variation. All the results are served in table 2 and figure 2, therefore the detail discussion will refer from them.

Table 2. Slump, density and compressive strength.

| Temperature Variation | Slump (mm) | Density (kg/m$^3$) | Compressive strength (MPa) |
|-----------------------|------------|--------------------|---------------------------|
| 600°C                 | 100        | 2363.52            | 31.27                     |
| 650°C                 | 94         | 2346.37            | 34.17                     |
| 700°C                 | 100        | 2350.31            | 35.71                     |
| 750°C                 | 100        | 2364.15            | 40.57                     |
| Control sample        | 100        | 2377.36            | 39.83                     |

Slump value describes the workability of the fresh concrete before it is molded and compacted. Concern to the result, all the slump values were excellent without any significant deviation among all variations so that CGHA did not worsen the fresh concrete condition. Same results implied from the density of concrete samples after 28 days even though we noticed that the specific gravity of CGHA was almost half of cement, yet it did not shift the density into lightweight concrete category. All the replacement still indicated good result of normal concrete characteristics in both slump and density values.

Compression performance was satisfied as the target strength was only 20 MPa. Thus, all the concrete components were well chosen, and the mixing procedure was convincingly matched the standard so that the distribution of all components were uniform. Closely discussed about the replacement of cement by CGHA, the highest furnace temperature resulted highest compressive strength. Since we noticed that all variations reached the target compressive strength but the replacement of cement with CGHA had decreased starting from the 600°C until 700°C variations. Based on [10], the addition of cementitious or pozzolanic material as much as 20% such as fly ash will turn down the strength until 35%, so that the result from table 2 had proven it.

Figure 2. Relationship among slump, density and compressive strength.

Mentioning figure 2 for detail discussion about the effect of furnace temperature to the increment of the slump, density, and compressive strength can be clearly understood. Furnace temperature deal with the specific gravity of CGHA so that it does not create much problem to the value of slump and density. In terms of compression performance, the furnace temperature does big job in increasing the compressive strength. As the temperature increases, the proportion of potassium oxide and calcium oxide decrease
so that the durability of the concrete becomes higher. Those two chemical components work better since the proportion of them are also limited in cement. Simply, replacement of cement until 5% will be allowable for gaining normal strength concrete.

Wholly, the furnace temperature helps to reduce some chemical substances significantly so that the performance of the concrete due to the replacement of cement is possible to be done. The replacement of CGHA to the cement can be inert or reactive, such as chemical reaction of the CaO with cement-water blending into Ca(OH)$_2$ to produce C-S-H. It can increase the mechanical strength of the cementitious products through the filling of capillary spaces [8]. Next, the higher furnace temperature will also appear another important oxide which also present in cement such as sulfur trioxide and magnesium oxide which is also beneficial during concrete mixing and setting time. The reactivity of the chemical components in CGHA is the same as the component presents in cement. Nonetheless, the absence of silica even after quite high temperature has indicated the contribution of C-S-H production as the replacement of cement is not significant.

4. Conclusion
From the result and discussion, we may conclude the following:

- Furnace temperature for getting CGHA could be considered high energy by-product so that it needs further consideration for using it as supplementary or replacement of cement.
- Furnace temperature of 750°C is the starting temperature point for getting better compression performance of concrete since the proportion of potassium oxide and calcium oxide are lower down significantly.
- Utilization of CGHA as cementitious material for the 5% replacement of cement in normal concrete is slightly significant. Once the percentage higher, the durability will probably sag. Also, it is not recommended for using CGHA as the cement replacement for the high strength concrete as the compression performance target will be believed to be unreachable.

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