Influence of superplasticizer on performance of cement – bottom ash concrete

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Abstract. The issue related to disposing waste material from industries has become one of the major environmental, economic and social problems. However, natural resources consumed worldwide, while at the same time increased amount and type of the waste material has resulted in waste disposal crisis with a growing consumer population. Therefore, the solution to this crisis is recycling waste into useful materials. In this project, Municipal Solid Waste Incineration (MSWI) by product which is bottom ash is used as partial replacement in cement. However, its properties as water absorbent become the issue for concrete strength. This research paper is to investigate the influence of superplasticizer on performance of cement-bottom ash concrete and designed for strength of 20 MPa at 28 days will be evaluated for its early stage properties. Superplasticizer is used to reduce water in cement while keeping up a consistent workability. The percentage of replacement in cement is by 0% (control), 10% and also 10%, 20% and 30% with addition of 0.30% by weight of cement of superplasticizer. In order to achieve the objective, few tests were carried out including slump test, density test, water absorption test and compression test. The result of this research indicates that 10% of replacement of bottom ash with superplasticizer shows highest compressive strength with 33.215 MPa with density 2417 kg/m³, water absorption of 1.41% and 122 mm for slump loss at 28 days. This study proved that the addition of superplasticizer can increase the workability and strength of concrete containing bottom ash as replacement for cement.

1. Introduction
Concrete is the most imperative material that utilized as a part of the development of different structural building structures. Concrete is composite material that has two noteworthy parts which is cement paste and aggregates [1]. However, at present, natural resources continue to be sustained continuously throughout the world, while waste generated from industry and municipalities increase significantly [2]. For instance, raw materials such as limestone used to produce cement are decreasing due to large-scale mining activities every day.

New alternative materials need to be found for sustainable development so as to substantially decrease the consumption of natural resources became vital to shield the interests of future generations [3]. High utilization of natural resources prompted to greater amount of industrial wastes and environmental degradation. Incineration process can reduce the quantity of waste quantities by 65% - 80% massively and 90% in volume and provide usable energy [4], it has been acknowledged as a successful strategy for managing Municipal Solid Waste (MSW). For Municipal Waste Solid Waste Incineration (MSWI), especially bottom ash and fly ash is produced.
Bottom ash has coarser dimensions (particles can achieve a few many millimeters in estimate), and the amount of chlorides and unsafe chemicals typically much lower than fly powder. Bottom ash is basically made out of silica (normally more than 50 % by weight, wt.%), alumina, iron oxide and calcium oxide, and is very comparative in structure to commonly used cement additions such as Ground-granulated blast-furnace slag (GGBFS) and pulverized coal fly ash (PFA). Several researchers have really demonstrated the pozzolonic activity of ground bottom ash showing their reactivity with the Portland cement or lime clinker and study the possibility of recycling of fly and ash in the manufacture of cement and concrete. Superplasticizer is used to reduce water in cement while keeping up a consistent workability. The results of investigations will reveal the complex nature of interactions between cement and superplasticizer in concrete.

2. Materials and methods

2.1. Raw materials
Bottom ash is from burning of Municipal Solid Waste (MSW) from incineration plants. Bottom ash has coarser size and contain other material, for example, glass, metal slag and other unburnt material. Therefore, bottom ash needs to be treated before replaced in cement. Firstly, raw bottom ash was sieved to remove large and unwanted particles. Then, bottom ash was grinded using dry grinder into smaller size. For the last stage, the grinded bottom ash was sieved passing through size 75μm manually to get similar size as cement.

Superplasticizer is a compound admixture that extra in concrete in little dose. It can fabricate the workability of mix, in diminishing of water/solid extent or even of bond sum. Execution of superplasticizer relies upon type of superplasticizer, the composition of concrete mixture, the time addition and the temperature conditions during mixing and concreting. In this research, only one type of superplasticizer was used, and the type of superplasticizer chose was Plastocerete-N. It is a concrete admixture in liquid form that acts as a highly efficient plasticizer and waterproofing agent, dark brown liquid form and the advisable dosage is 0.2% - 0.4% by weight of cement. A trial mixes have been carried to establish the exact dosage rate required and the most suitable dosage is 0.30% by weight of cement.

2.2. Concrete mix design and concrete testing
Concrete mix design for M20 Grade which mixture ratio is 1:2:4 as 1 for cement, fine aggregate and coarse aggregate as in standard. Cement was removed by weight and substituted up to 30% bottom ash by volume based on mix design. The water cement ratio also fixed to 0.6 for all mixed design and the addition of superplasticizer was 0.30% by weight of cement. The slump test was carried in order of assessing the consistency of the fresh concrete. Concrete were cast around 24 hours and put into water tank for 7 and 28 days curing period. Water absorption was used to determine the amount of water absorbed into the capillary pores of cement and bottom ash. After the concrete age was 28 days in a water tank, specimens were taken and weighed before being placed in the oven. Concrete cubes were left at a temperature of 115°C for 3 days in the oven. Then, dry specimens cool about 24 hours and the dry weight of the concrete is recorded. Subsequently, all the specimens were re-immersed in a water tank about an hour. Wet weight is recorded again. Compressive strength of concrete was tested using compression machine to measure its strength on 7 and 28 days. Image Scanning for binder properties was using cutting samples of prism. Then each prism surface according to the mix design is focused on using image scanning to get the effect of the surface.

3. Results and discussion

3.1. Raw materials characterization
Since bottom ash is from municipal solid waste, there are various contents and elements that cannot be seen by naked eyes. X-ray fluorescence (XRF) is used to test the chemical composition of raw cement
and bottom ash. Table 1 shows that untreated bottom ash has higher content of Al (5.18 %), Si (9.20%) and Fe (9.23%) compared to cement Al (2.1%), Si (8.39%) and Fe (5.36%). While cement has higher S (1.50%) and Ca (80.07%) compared to untreated bottom ash which is 0.825% and 57.77% respectively. The result indicates that there are similarities between bottom ash and cement.

The main component of cement is important as each play important role in cement. During hydration of calcium oxide (CaO) cement together with silicon dioxide (SiO₂), aluminum oxide (Al₂O₃), and iron oxide (Fe₂O₃) causes the hardening of Portland cement due to the formation of calcium aluminosilicates and hydrate aluminoferrite [5]. High calcium (Ca) content in cement can increase the strength of concrete and can delayed cement to set instantly while silica (Si) imparts the strength to cement. However, high content of aluminum (Al) and magnesium (Mg) can weaken the cement that will reduce the strength of cement.

| Compound (Oxide) | Cement (%) | Bottom Ash (%) |
|------------------|------------|----------------|
| Ca               | 80.07      | 57.77          |
| Si               | 8.39       | 9.20           |
| Fe               | 5.36       | 9.23           |
| Al               | 2.1        | 5.18           |
| K                | 1.52       | 4.57           |
| S                | 1.50       | 0.825          |
| Ti               | 0.37       | 2.37           |
| Mn               | 0.14       | 0.28           |
| Cu               | 0.059      | 0.251          |

The bottom ash MSWI contains elements that can be pozzolan or defined as silica and aluminous substances within which they have little or no value of a minute but will, in fine form and in humidity, react chemically with calcium hydroxide and normal temperature for forming a compound having cement properties. Thus, it can be possible as a bottom ash replacement in Portland cement production [6, 7, 8].

3.2. Workability

The workability test for bottom ash concrete was measured by performing slump test. Fixed amount of water (0.6 %) was added for all concrete mixes while the dosage of superplasticizer was the same for the mixture of 10%, 20% and 30% of bottom ash. The type of slump is shear slump as superplasticizer influence the workability of the mix. Superplasticizer used is a water redundant which means it has higher setting time than the normal mix without increasing water cement ratio. Table 2 shows the slump test for all mix designs. Concrete with the addition of MSWI bottom ash had remarkably reduced workability possibly because the bottom ash is a material with higher water absorptivity, higher natural air content, and a large portion of small particles, which would negatively affect the consistency of the concrete [9].

Referring the Table 2, 10 % of bottom ash with superplasticizer has highest slump loss because of the function of superplasticizer improved the concrete to retain in liquid state for a longer time. The mechanism of superplasticizer is by giving a very negative charge of cement so that they repel each other due to the same electrostatic charge and by suppressing cement particles, more water is available for concrete mixing [10]. Hence, it also supports the theory that slump can be increased by addition of chemical admixtures such as plasticizer or superplasticizer without changing the water-cement ratio [11].
Table 2. Result on slump test with different amount of bottom ash and superplasticizer.

| Mix design                      | Slump loss (mm) |
|---------------------------------|-----------------|
| Control                         | 60              |
| 10% bottom ash                  | 52              |
| 10% bottom ash + superplasticizer | 122            |
| 20% bottom ash + superplasticizer | 110            |
| 30% bottom ash + superplasticizer | 86             |

3.3. Density
Concrete density varies by aggregate volume and density, air content, cement concentration and maximum size of aggregate used. The strength of concrete material can be based on its density due to its high solid material providing higher strength. The easiest and specific way to determine the concrete density is to measure the amount and weigh it. Density can be defined as mass over volume. Figure 1 shows the average density for 7 and 28 days.

Figure 1. Density of concrete for 7 and 28 days.

Figure 1 shows on 28 days the 10% bottom ash with superplasticizer reach the peak of the graph as the average density is 2417 kg/m$^3$. It is because the use of superplasticizer increased compression strength by increasing the effectiveness of compaction to produce denser concrete [12] and also stated by manufacturer. 30% of bottom ash substitution with superplasticizer shows the lowest as 2280 kg/m. It is due to concrete with ash bottoms requires more water and excessive water presence forms internal voids inside hardened concrete [13].

3.4. Water absorption test
Water absorption is a test on determining the amount of water absorbed under specified conditions. Water absorption test is related to the durability of cube and also known as effective index to classify densification and quality of cube. The result was evaluated by calculating the percentage of weight of saturated sample to weight of dried sample (Figure 2).
Based on Figure 2, shows average of water absorption was increasing proportionally for both of 7 and 28 days and water absorption for 7 days is much higher than on 28 days as water absorption and porosity reduces with times. This happens because water still needed for curing process on 7 days. Another reason of this phenomenon is the structure and size of the pores decreases when the pores are filled with product hydration-calcium silica hydrates.). Due to the continuous hydration process as long as there is a reaction in the raw material, porosity reduction and water absorption is expected to be over 28 days [14]. Mixture contain 30 % of bottom ash with superplasticizer sample shows the highest which are 4.7 % and 2.20% on 7 and 28 days. Meanwhile 0%, 10% bottom ash and 10%,20% bottom ash with superplasticizer, the average of water absorbent is 1.04%,1.73%,2.39 % and 2.98% on 7 days while 0.61%, 1.87%, 1.41% and 2.03 % on 28 days. This means that high water absorption was affected by the size of the porous of the cube. It can be concluded that higher ash replacement under MSWI, the higher the porous size of the material. It can also be support because the bottom ash was porous material with high water resistance [15].

3.5 Compressive Strength
Compressive strength test was conducted to determine the capacity to withstand load or resist compression of bottom ash as partial replacement for cement substitution in concrete with superplasticizer as chemical admixture. Based on Figure 3, 0% bottom ash sample gained compressive strength of 24.055 MPa and 26.809 MPa at 7 and 28 days while 10% bottom ash without superplasticizer sample strength were 24.734 MPa and 32.873 MPa at 7 and 28 days respectively.
However, the compressive strength for 10% bottom ash with superplasticizer were 30.703 MPa and 33.215 MPa at 7 and 28 days. It shows that the strength of concrete increased rapidly on 7 days with the presence of superplasticizer as admixtures. This because the addition of superplasticizer provided more water for concrete mixing, so not only the hydration process would not be disturbed, but it is accelerated by additional water from cement particle deflocculation. Therefore, the increase in dose would increase the penetrated water and promote the hydration of the cement resulting in increased strength of concrete [16]. The use of superplasticizer also increases compression strength by increasing the effectiveness of compaction to produce denser concrete [12].

Bottom ash with 20% and 30% replacement with the addition of superplasticizer developed strength of 24.087 MPa and 21.940 MPa on 7 days whereas 31.759 MPa and 17.189 MPa on 28 days. It indicates that for 30% of bottom ash replacement for 28 days cannot achieved mix design 20MPa. This may be due to the large number of porosity in the cube. From the previous study, only the compressive strength of 10% bottom ash replacement was succeeded to achieve 20 MPa but this research found out the addition of superplasticizer can help to achieve strength above 20 MPa for other substitution of bottom ash up to 30%. Therefore, the addition of superplasticizer was improved and enhanced the strength of concrete at early stage properties.

3.6. Matrix binder characterization

Concrete cross section of concrete cut was observed using a microscope to analyse porosity and matrix binder paste. The concrete matrix binder characterization was based on cement and porous cement that occurs in concrete and to figure out the effect of superplasticizer on porosity. The bonding of the cement and aggregates and void in concrete would affect the strength of the concrete. Figure 4 shows the cross section for control mix, 10% bottom ash, 10% bottom with superplasticizer, 20% bottom ash with superplasticizer and 30% bottom ash with superplasticizer. Figure 4 (a) is from microscope while Figure 4 (b) is the picture of the cross section. The bright was considered as cement paste and the dark was considered as porous.
The content of cement paste at 0% bottom ash concrete surface was highest compared to other mixes so it supposedly has higher strength that other mixes. However, due to the number of void, the strength was less than expected which was supposedly higher than 10% bottom ash. With the substitution of 10% bottom ash in cement, the porosity of the concrete become higher but improved with the addition of superplasticizer parallel to the function of superplasticizer. Meanwhile, 30% bottom ash cross section has the lowest content of cement presenting the weak bonding between aggregates. It also shows that the porous at the concrete was more compared to other mixes. This indicates that more water absorption occurs between the porous in concrete. Hence, it concludes that the bonding with cement paste and the number of pores affect the strength of the concrete. The higher the bonding cement paste between aggregates, the stronger the strength of concrete. On the other hand, the bigger number porous present, the weaker the strength of concrete.

4. Conclusion
In this research the complex nature of interactions between cement and superplasticizer in concrete was investigate. Superplasticizer could increase the workability of mix of concrete and the strength of concrete. However, the dosage of superplasticizer also takes role for different percent of bottom ash replacement. Addition of superplasticizer to bottom ash concrete was increased the density of the concrete resulting development in strength. The higher the density, the higher the strength of concrete and the result of 10% bottom ash which was 2417 kg/m³ on 28 days. Water absorption affecting the strength of the concrete, the higher the rate of water absorption, the lower the strength of concrete. The percentage of water absorption at 30% bottom ash with superplasticizer indicated the highest which was 2.83% on 7 days and 2.03% on 28 days. Superplasticizer enhanced the strength of MSWI bottom ash concrete. Laboratory testing result showed that 10% bottom ash with 0.30 % superplasticizer by the weight of cement had the highest compressive strength for both 7 days and 28 days which were 30.703 MPa and 33.215 MPa. Meanwhile, the compressive strength for 20% bottom ash with superplasticizer can also achieved the strength design for both 7 days (24.087MPa) and 28 days (31.759MPa). Cross section of concrete used to characterise the matrix binder of concrete depends on the bonding between cement paste and aggregates. The stronger the bonding between cement paste and aggregates, the stronger the concrete. For the overall conclusion, this study will make the process environmental friendly and cleaner due to the recycling of incineration by product as raw material in the cement and also can minimize the landfill area. The product of this study also can produce sustainable product by adding MSWI bottom ash as partially replacement in cement as new alternative. In term of economical, this product from this research also can reduce cost as lower usage of cement in construction.
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