PROPERTIES OF CONCRETE MADE OF FINE AGGREGATES PARTIALLY REPLACED BY INCINERATED MUNICIPAL SOLID WASTE BOTTOM ASH

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ABSTRACT

The objectives of this research is to investigate the influence of Municipal Solid Waste Incinerated Bottom Ashes (MSWI-BA) on engineering properties of specimens when part of fine aggregate is replaced with it. Disposal of municipal wastes is a major key issue which causes a problematic challenge in Lebanon as landfill space for the disposal of ash from Municipal Solid Waste Incineration (MSWI) becomes rare. It becomes smarter to reduce the volume of materials being disposed. Recycling is one approach, waste minimization is the second, and combustion for energy production is the third. Therefore, one of the possibilities that have a beneficial impact on the environment and consequently on the society is to use Municipal Solid Waste Incineration (MSWI) ashes in concrete production, as it is done with coal combustion products. The bottom ash features the most convenient composition for this purpose as it is available in highest amounts among the MSWI ashes. Bottom ash can be used as partial replacement of sand in concrete. This has the additional advantage of replacing sand and gravel, which must be mined sometimes from environmentally sensitive areas. The properties of concrete with partial substitution of sand by bottom ash up to 50% was investigated in terms of compressive strength, pulse velocity, capillary and total absorption. The bottom ash incorporated in the concrete behaves almost like ordinary sand. These results indicates that the use of waste in concrete constitutes a potential means of adding value and at the same time reduce greenhouse gases.

1. INTRODUCTION

Waste generation is one of the main problem facing the modern world. There are different waste stream coming from various industries including the coal power, steel and municipal solid waste industries. It is possible that many of these wastes can be used in the production of concrete (Baalbaki et al., 2018; Charbaji et al. 2018; El-Darwish *et al., 1997;* El-Kurdi *et al*., 2014; Hadjsadok *et al*., 2012; Herki and Khatib, 2013; Herki and Khatib, 2016; Khatib *et al*., 2008; Khatib *et al*., 2009; Khatib *et al.* 2013a; Khatib *et al.* 2013b; Khatib *et al.* 2014; Khatib *et al*., 2015; Khatib, 2016 ; Khatib *et al*., 2016; Mangat *et al*., 2006; Okeyinka *et al*., 2015; Sonebi *et al*., 2016; Wright and Khatib, 2016).

The Municipal Solid are originated from many sources such as houses, hospitals, and industries. These solid waste are harmful when disposed in landfill due to emission of dangerous gases such as methane. One of the most common solution of these Municipal Solid Waste is incineration and reuse it in construction products depending on the size of granules resulted from the incineration. These ashes could be potentially used in concrete, road pavements, embankments, ceramics, and glasses. MSWI bottom ash has no negative or harmful effect on humans or life beings. Thus using MSWI bottom ash in construction helps in one way to reduce pollution problem and in other way can help in saving materials and money for construction (Prabhudev et al. 2016).

1.1. Municipal Solid Waste Incineration bottom Ash.

Bottom ash is the main solid residue produced by municipal solid waste incineration facilities. Incineration is a thermal treatment technology used to reduce the waste volume up to 90% and is one of the widely-used technologies for treating municipal solid waste. This material is composed primarily of a mineral matrix and contains unburnt organic matter. Generally, incineration plants incorporate power generation facilities to recover the heat energy produced. Additionally, they include several process controls and exhaust gas cleaning measures to ensure that the gas emissions meet the standards imposed by regulatory bodies for public health and environmental protection. Figure 1 shows a schematic diagram of this process.

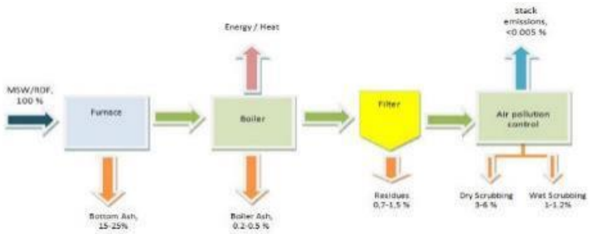

Fig. 1 – Production Process of Bottom Ash

1.2. Process of Incineration

The solid waste, which is continuously fed into the furnace by a crane, is combusted at temperatures above 850 °C for a period of time to ensure complete burning. The heat from the combustion is used by a boiler to generate steam that then drives a turbine to generate electricity. The exhaust gas from the boiler is cleaned by advanced pollution control systems to ensure compliance with the environmental standards. Once the solid waste has been completely burned out, the remaining residue is called bottom ash, which is ejected at the bottom of the combustion chamber. The bottom ash corresponds to about 15 to 20% by weight or 4-6% by volume of the original waste. After storage the bottom ash may be screened into fine and coarse fractions and the ferrous metals (iron or steel) in the ash will be extracted using large magnets. The metals represent 5-10% of the bottom ash and are sent to the steel works for recycling. The remaining bottom ash is non-hazardous and is typically used in other applications such as an aggregate in concrete or for road building. The ash residues from incineration include bottom ash from the furnace and fly ash from the exhaust gas cleaning systems. Both bottom and fly ashes are either used as a fertilizer, reused as construction material or disposed at landfills (Figure 2).

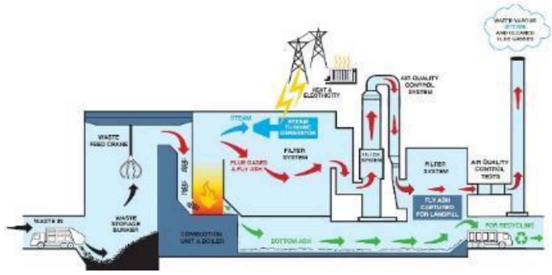

Fig. 2 – Incineration Process

1.3. Background

Dixit et al. (2016) showed that replacing of bottom ash as fine aggregate with a range which vary from 0 to 15% increases the compressive strength at age of 7 and 28 days. The compressive strength of bottom ash starts to decrease when the replacement level increased to 20% and above. The 10% and 15% replacement level showed that the water absorption rate of concrete is lower compared to control specimen. The water absorption rate starts to increase at 20% of replacement level. They concluded that that the pulse velocity of concrete mixes containing 10% and 15% achieve the higher. It was found that the water requirement increases with an increase in the level of sand replacement of BA (Kasemchaisiri and Tangtermsirikul, 2008). This was due to the increase of porosity in cellular concrete. Similar results have been reported on a study of concrete using bottom ash as sand in literature explained that this was due to the high porosity of BA which absorbed water and resulted in high water requirements. The density of concrete decreased with the increase in % replacement of bottom ash from 0% to 30%, due to the low specific gravity of bottom ash as compared to fine aggregate (Kadam and Patil 2013).

2. EXPERIMENTAL PROGRAM

The BA was investigated in partial substitution of sand to produce cubical concrete specimens of mortar of 100x100x100 mm dimensions. The fineness modulus of the BA used was 1.55. The absorption and specific gravity were respectively 10% and 2.3g/cm^3. The samples were prepared and cured in lab conditions in water up to the specified testing age. Different Mechanical and Physical testing methods was conducted on the concrete specimens. The percentage of substitution of BA was 0, 25 and 50 % by weight of sand. Table 1 presents the concrete mixture proportions.

Table 1 - Mixtures proportions

w/c ratio	% of BA	Cement (kg/m^3)	B.A kg/m^3	Water (kg/m^3)	Sand (kg/m^3)	Coarse agg. 1/2" kg/m^3	Coarse agg. 3/8" kg/m^3
	0%	460	0	278.5	785	447.5	618
0.55	25%	460	196.25	285.5	589.25	447.5	618
	50%	460	392.5	290	392.5	447.5	618

3. TEST RESULTS

3.1. Compressive Strength

The compressive strength was slightly increased at 7, 14 and 28 days at 25% but a significant drop was found at higher percentage of 50% (Figure 3).

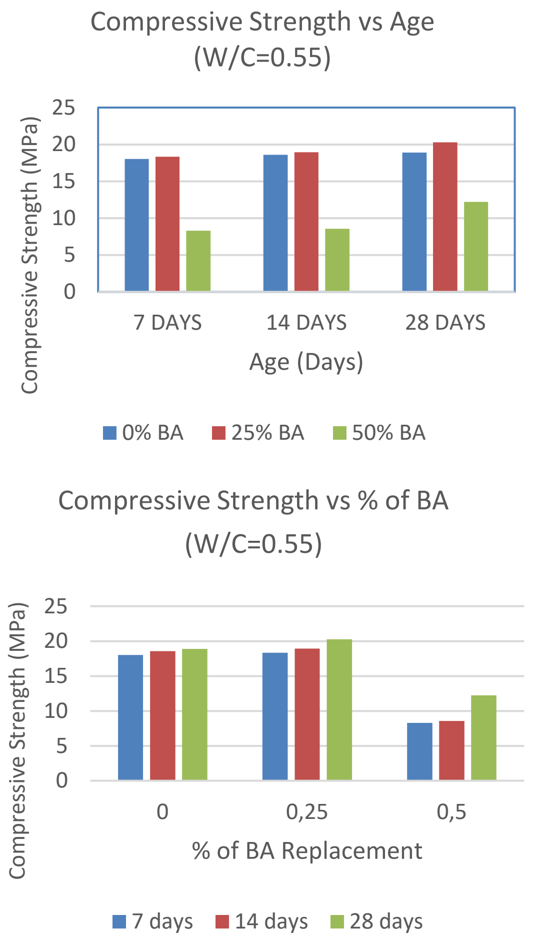

Fig 3 – Compressive Strength

3.2. **Ultra-sonic pulse velocity**

The pulse velocity of concrete mixes containing BA decreases as the percentage of BA increases. It was found that for the same percentage there is no difference in terms of pulse velocity between earlier and late ages. As the density of concrete decreases due to the low specific gravity of the BA. Therefore, the UPV decreases accordingly due to the increase in voids ratio (Figure 4).

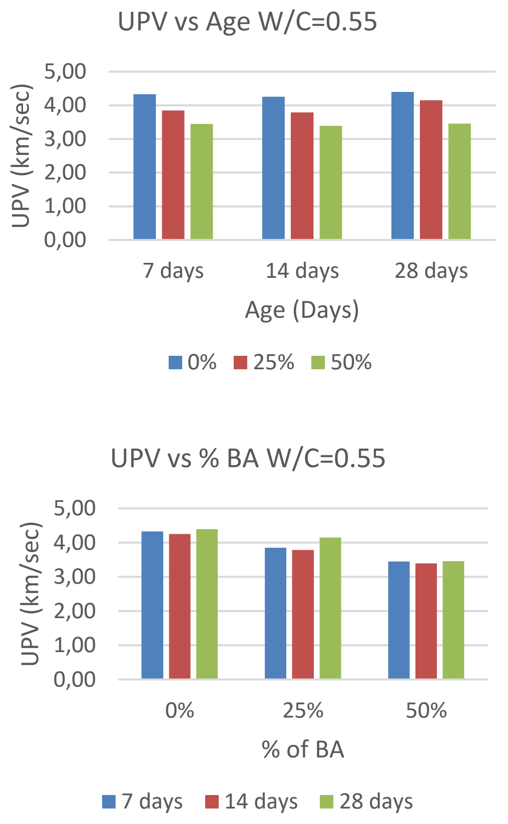

Fig 4 – Ultra Sonic Pulse Velocity

3.3. Capillary Absorption Test

The capillary absorption test was conducted as per ASTM C1585. The rate of absorption was measured on cubical concrete specimens containing BA. The samples are partially immersed in water (up to 5 mm from the bottom) after drying in oven. The dry surfaces of the specimens are covered by plastic sheets to minimize the evaporation. The specimens are weighted at different time intervals starting for 1minute up to two days. It was found that the porosity of the concrete increases with the increase in BA replacement due to its higher porosity which lead to higher capillary absorption (Figure 5). At longer age, the volume of pores in concrete decreases by the time due to the continuity of hydration process which iis followed by pores filling phenomenon (Figure 6).

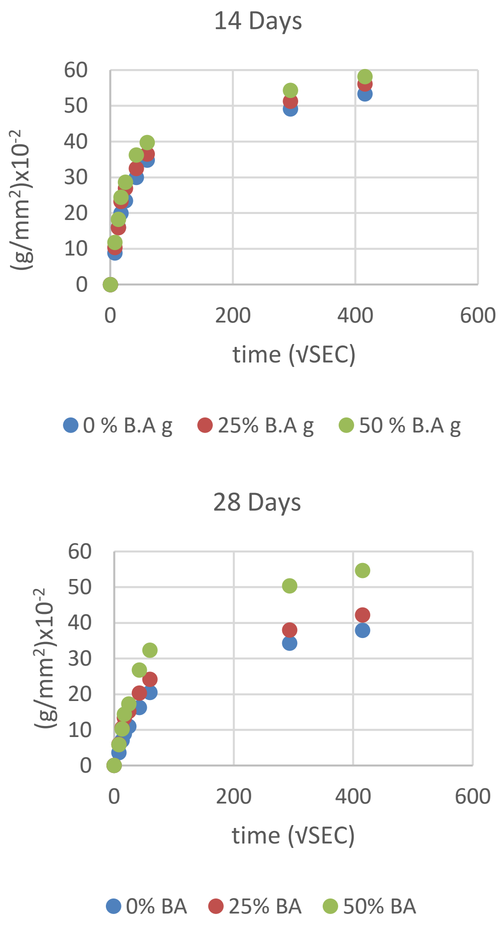

Fig 5 – Effect of BA percentage

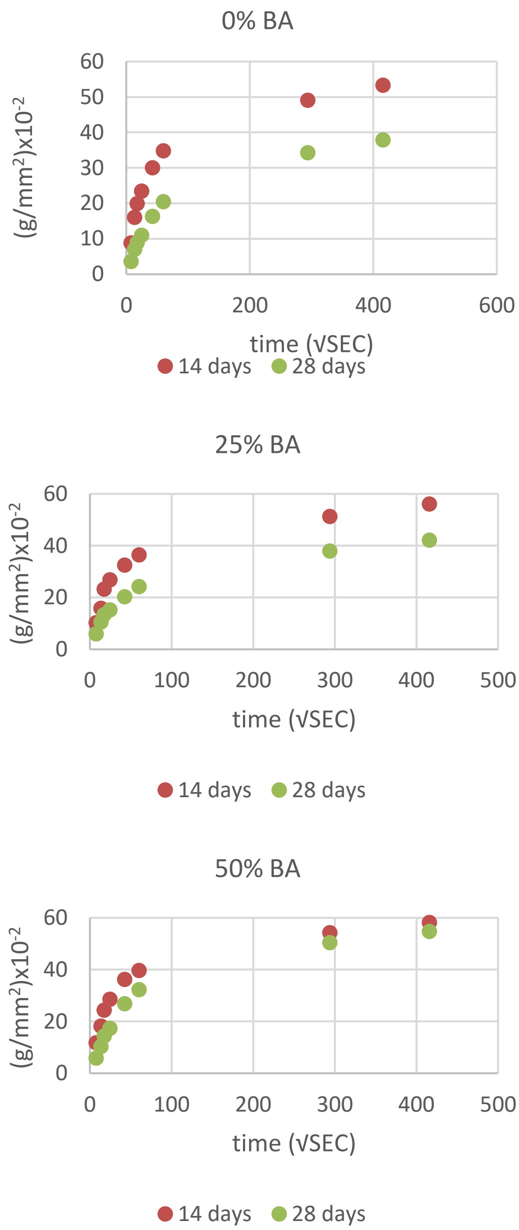

Fig 6 – Effect of Curing

3.4. Total absorption

The test procedure involves drying a specimen to a constant weight, weighing it, immersing it in water for specified amount of time, and weighing it again. The increase in weight as a percentage of the original weight is expressed as its absorption in percent. Following 14 and 28 days of curing, the mortar specimens are placed in oven at 80C for 48 hrs until a constant mass is reached. Afterwards, the cubes are totally immersed in water for 24 hrs and the total absorption is determined accordingly. Results are presented in Figures 7 and 8. The test results indicated that the total absorption increases as the % of MSWI-BA increases for mixtures containing 0%, 25% and 40% MSWI-BA respectively. As the MSWI-BA has a high amount of fine particles, this leads to a much higher surface area and therefore contributing to higher water absorption. Consequently, as the curing time increases, the absorption decreases accordingly.

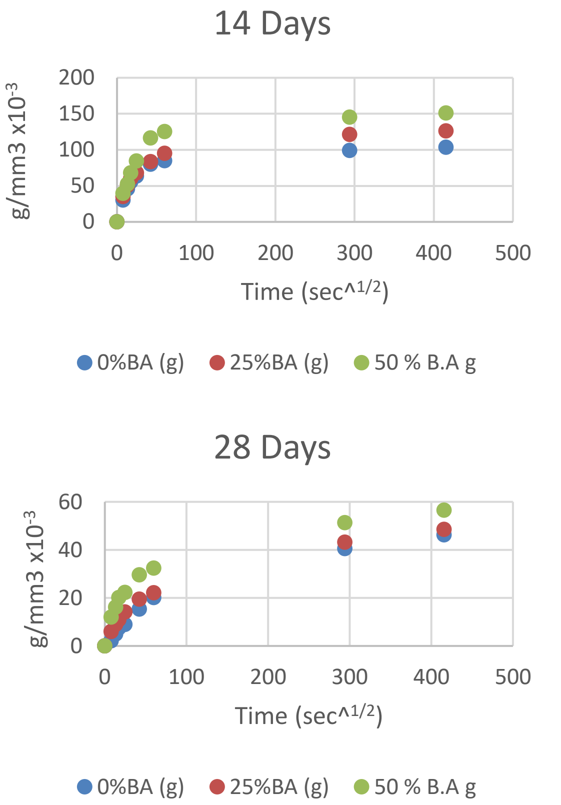

Fig. 7 - Effect of BA percentage

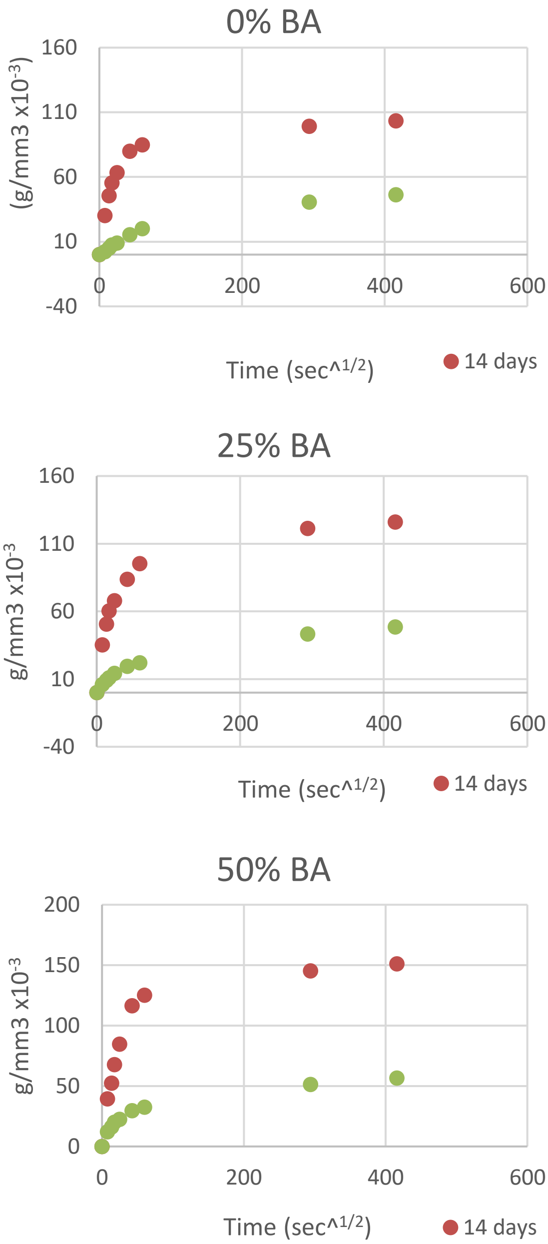

Fig. 8 - Effect of Curing

4. CONCLUSIONS

The potential MSWI-BA use as a partial replacement in mortar specimens was investigated through a testing program which include compressive strength, Ultrasonic pulse velocity, total and capillary water absorption. It is concluded that the compressive strength improves to a certain optimum percentage extent (20-25%) and a drastic decrease occur when exceeding this limit. The increase in strength might be attributed to moderate potential in pozzolanic activity. Regarding the physical properties of concrete in terms of UPV, total and capillary absorption tests, when sand is partially replaced by BA UPV, it was shown that the replacement of sand by BA raises the porosity as well as the voids in concrete. However, the cement matrix is densified and the porosity is decreased to the normal levels by the curing time which is important factor governing the concrete properties. The incorporation of BA in cement could not be limited to concrete uses but further utilization need to be investigated such as masonry blocks, tiles, pavement, etc. As a matter of fact, the utilization of MSWI-BA in construction materials has a good potential and can be considered as a reasonable solution for reducing landfill disposal and serving the concrete sustainability.

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