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Research Article

Treatment of Bottom Ash Medical Waste (BAMW) from Hospital Infectious Waste into Paving Block Products

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Abstract: Hospital solid waste is infectious waste, so it is included in the category of hazardous and toxic waste. One method of processing hospital solid waste is by burning it in an incinerator. The result of burning B3 waste at high temperatures is ash or known as bottom ash medical waste (BAMW), medical waste fly ash (MWFA), dangerous gases, compounds such as dioxins and furans, and toxic metals such as lead, cadmium, and mercury. Ash from hospital waste processing is included in hazardous and toxic materials, so it needs to be handled properly. This study aims to process BAMW using the solidification/stabilization method. Bottom ash as a research material is taken from the burning of hospital waste using an incinerator. The BAMW processing product is paving blocks. The study was conducted by varying the composition of paving blocks. The variations carried out were the percentage of BAMW and its particle size. In addition, a Total Organic Carbon (TOC) level test was carried out on the water used to soak the paving blocks after being stored for 28 days. The results of the study showed that the higher the percentage of BAMW, the lower the compressive strength of the paving blocks, while the ability to absorb water and wear increased. The size of the BAMW particles also affects the quality of the paving blocks. The smaller the particle size, the better the quality of the paving blocks. Higher compressive strength indicates better quality of the paving blocks. The results of the analysis of the water used to soak the paving blocks showed that the TOC concentration was higher if the compressive strength decreased. BAMW can be used as an additional material for making paving blocks, but the composition should not be large. Further research can be done using adhesive materials such as plastic to increase compressive strength.

Keywords: Solidification, bottom ash medical waste, particle size, paving block, incinerator.

Introduction

Hospitals, healthcare facilities, and research centers around the world produce large amounts of biomedical waste, which is hazardous to human health and natural habitats. The scale of biomedical waste production has increased rapidly in recent decades. According to the Indonesian Hospital Community, data shows an estimated 366 tons/day of medical waste from 2,813 hospitals throughout Indonesia [1]. Hospitals and public health institutions produce 15% of all radioactive, hazardous, and toxic waste. The Ministry of Health states that hospital waste in Indonesia is 290 tons/day. The production of medical waste in Surabaya every month is 163.9 tons, and only 29.8% is processed independently using incinerators by health facilities [2].

Hospital waste management using the incineration method produces solid residues, such as bottom ash and fly ash, as well as air pollution. The residue contains heavy metals, inorganic salts, and organic compounds. The BAMW problem is not only in Indonesia, but also in Europe with around 20 million tons. BAMW contributes around 25% of the total bottom ash [3]. BAMW needs special attention because it contains Si, Al, Ca, and Fe metals as well as heavy metals in low concentrations. The results of bottom ash analysis contain Al, Ca, Fe, K, Mg, Mn, Na, P and Si metals. In addition, it also contains metals in low concentrations, namely As, Ba, Cd, Cu, Cr, Mo, Ni, Pb, Se, Sn, Tl, V and Zn [4]. Medical waste must be processed using a special method because it can endanger human health and cause serious environmental problems [5]. Incineration is the most common medical waste treatment method and is used worldwide. Medical waste can be processed using incinerators, such as organs, body parts, and human tissue, which require special processing methods [6]. Incineration is an oxidation process at high temperatures so that the inorganic and organic compound content turns into ash.

Hospital medical waste incineration is the right method for integrated waste management. Incinerator can reduce waste weight by 70-90%. This method can also be used as an energy source. Infectious

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hospital waste is processed by incineration process aimed at destroying infectious organisms in waste. The operating temperature of the incinerator is between 1100 and 1200 °C [7]. Incineration is an ideal solution to reduce waste volume while destroying harmful microorganisms and minimizing uncontrolled heavy metal discharge. Incineration produces solid residue called biomedical waste ash. Biomedical waste that is burned can reduce environmental impacts [8]. In addition to bottom ash, the incinerator produces fly ash, toxic gases such as sulfur dioxide, nitrogen oxides, hydrogen chloride, mercury, carbon monoxide, hydrogen fluoride, dioxins and furans.

Among the various types of solid residues from waste incineration, bottom ash is produced in the largest amount and is considered the most suitable for use. Based on Indonesian government regulation number 22 of 2021 concerning the implementation of environmental protection and management, ash from incinerators is hazardous and toxic waste with waste code A303-5, category one. Category one means that the waste has an acute and direct impact on humans and will certainly have a negative impact on the environment. Bottom ash from incinerators contains heavy metals so special treatment is required so that it does not spread into the environment. Several techniques have been developed for incinerator ash processing so that it can be reused in various applications [8]. Processing incinerator ash waste and solid waste can be done by solidification/stabilization. Several studies have processed incineration waste with solidification using bottom ash materials [4]; solid waste from slaughterhouses [9]; textile waste processing sludge [10]; waste from combustion with furnace [11,12]; soil [13]; organic waste from rivers [14]; solid waste [15]; Nano-MgO [16]; sludge gasification ash [17] and sludge waste [18].

Solidification is a technology used to process industrial solid waste containing hazardous material components by preventing and/or reducing the potential hazards of waste, which then changes the contaminants into the least soluble, immobile and non-toxic form through the compaction process [19]. The solidification/stabilization method has advantages including efficiency, environmentally friendliness and is a low-cost method for processing various geomaterials. Solidification/stabilization technology is applied to make concrete, covering materials, bricks, paving blocks [20]. Paving blocks can be made using mud from groundwater processing [21,22], soil containing humic acid [23], and organic waste/rivers [24]. The use of incinerator ash waste as an additional material for making paving blocks is preferred because of its low organic content. Organic mud will inhibit cement binding [24]. Paving blocks according to SNI 03-0691-1996 [25] are a composition of building materials made from a mixture of Portland cement or hydraulic adhesive, water and fine aggregate with or without additional materials that do not reduce the quality of the paving block. Paving blocks with good quality are those that have high compressive strength and low absorption value. Based on the background described above, it is necessary to conduct research on the use of incinerator ash from infectious hospital waste into making paving block material. This research stage includes characterization of incinerator ash material and evaluating the effects of varying composition of incinerator ash mixture material on paving block quality. The purpose of this study is to treat BAMW into paving blocks through solidification/stabilization. Heavy metals in BAMW will be confined in paving blocks, preventing release into the environment.

Materials and Methods

Materials

The materials used in the study were BAMW from a hospital in Yogyakarta, Indonesia, Portland cement from the silo of the Merapi Volcanic Innovation Center, and fine aggregate (sand) from Merapi at the Merapi Volcanic Innovation Center, Islamic University of Indonesia.

Methods

Characterization of BAMW

BAMW was ground using a grinding machine, then sieved using sieves of sizes 10, 30, 60, 100 and 200 mesh. The arrangement of the sieves starts from the top largest size and the smallest size. Furthermore, the sizes trapped in the sieve are separated based on the size of the sieve. Incinerator bottom ash with a size of 200 mesh was characterized using a Scanning Electron Microscope-Energy Dispersive X-Ray (SEM-EDX) from Phenom-World to determine morphology and metal elements.

BAMW Treatment into Paving Block Products

Paving blocks are made with various ratios of sand, cement and incinerator bottom ash. The solidification/stabilization process is carried out with a fixed percentage of sand while cement and incinerator bottom ash are veried. The general research process is shown in Figure 1. The comparison of the composition between sand, cement and incinerator bottom ash is shown in Table 1. The effect of variations in BAMW particle size is shown in Table 2.

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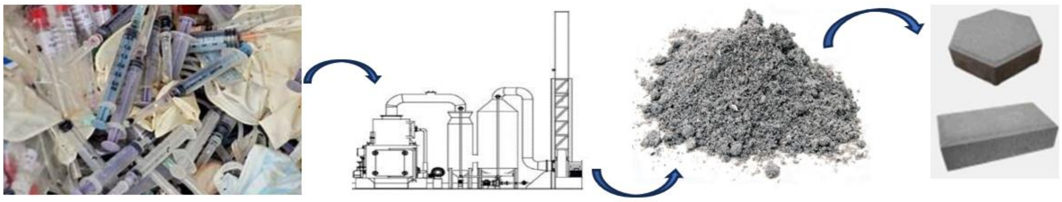

Figure 1. Processing of BAMW into paving block products

Table 1. Composition of paving blocks with variations of cement and BAMW

Sample code	Sand (%)	Cement (%)	BAMW (%)
K	86	14	0
A1	86	12	2
A2	86	10	4
A3	86	8	6
A3	86	6	8
A4	86	4	10
A5	86	0	14

Table 2. Composition of paving blocks with variations in BAMW particle size

Sample code	Sand (%)	Cement (%)	BAMW (%)	BAMW particle size (mesh)
B1	86	6	8	10
B2	86	6	8	30
B3	86	6	8	60
B4	86	6	8	100
B5	86	6	8	200

The manufacture of paving blocks starts weighing followed by mixing, and molding. Stirring the mixture of materials manually and preparing a vibrating press machine for the process of printing paving blocks measuring 200 mm x 100 mm x 60 mm. The paving block are left at room temperature for 2 days until hardened. Furthermore, the maintenance process is carried out by soaking the paving blocks in various soaking variations until the paving block is 28 days old to maintain moisture and achieve the ideal age of 99% concrete strength.

Analysis of Total Organic Carbon (TOC) Content

The best quality paving blocks were soaked for 70 days. The leachate from the soaking was analyzed for TOC.

Testing of compressive strength, wear and water absorption

The paving blocks testing procedure is carried out based on the Indonesian National Standard (INS) number 03-0691-1996. The paving blocks that had been stored for 28 days were cut into cubes measuring 60 mm x 60 mm x 60 mm. The samples were cleaned from dirt and the dimensions were measured using a caliper with an accuracy of 0.1 mm (ρ) and (l). Then the sample was placed in the middle of the compressive strength tester and given a load that continued to increase until the maximum load was reached and the sample was destroyed. After the paving block was destroyed, the compressive strength was calculated using the following formula:

$$\text{Compressive strength} = \frac{P}{L}$$

P = Compressive load, N
L = Area of pressure mm^2

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Wear testing

The paving blocks were cut into cubes measuring 50 mm x 50 mm x 20 mm. The samples were cleaned from dirt and weighed to the nearest 0.001 grams (initial weight), then the samples were subjected to a wear test. The results of the wear test were calculated using the formula:

$D = 1{,}2\ G + 0.0246$

Average wear of sample A (D_m) = $\frac{\sum D}{n}$

Increase in wear value = $\{\frac{\text{Wear n\%} - \text{Wear 0\%}}{\text{Wear 0\%}}\}$ x 100%

Information:
D = Wear (mm/min)
G = Weight loss/wear duration (gr/min)
∑D = Total wear value of one variation (mm/min)
n = Sample size

Water absorption test

The paving blocks are cut into cubes measuring 60 mm x 60 mm x 60 mm. The test specimens are cleaned of dirt, then soaked in water until saturated for 24 hours, then weighed the base weight (Wb), then the sample is dried using an oven for approximately 24 hours at a temperature of 105 °C until the weight on the two weighings differs by no more than 0.2% of the previous weight (Wk). Water absorption is calculated using the formula:

$$\text{Water absorption} = \frac{A - B}{B} \times 100\%$$

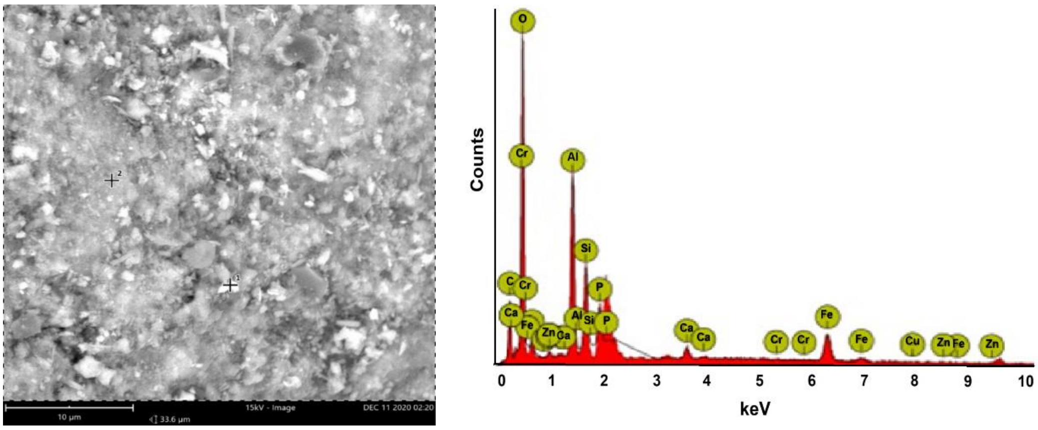
Information:
A = Weight of wet paving blocks
B = Dry paving block weight

Microscopic Analysis

Microscopic analysis using the best composition paving block samples at the age of 28 days using Scanning Electron Microscope-Energy Dispersive X-Ray (SEM-EDX).

Results and Discussions

BAMW Characterization using SEM-EDX



(a)

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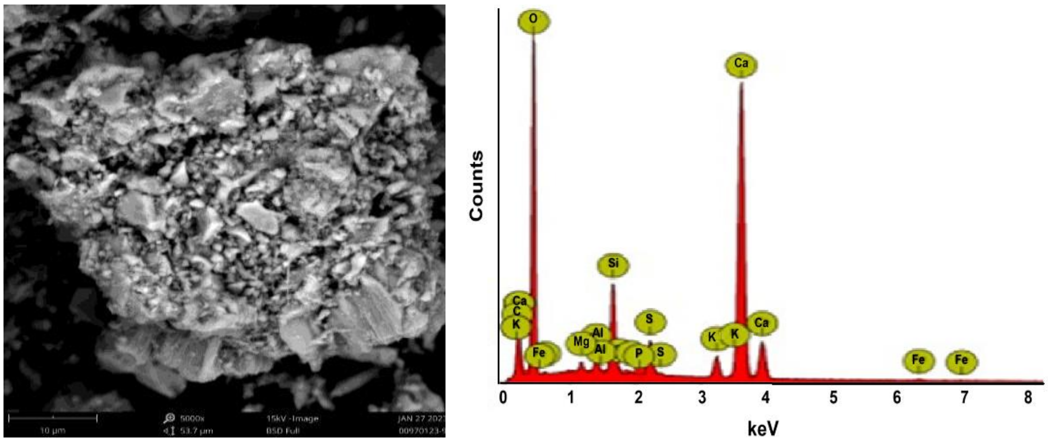

(b)

Figure 2. SEM-EDX image of (a) BAMW, and (b) portland cement

The results of the analysis of 200 mesh BAMW with SEM-EDX are shown in Figure 2a with a magnification of 5000x. BAMW shows that the material has an irregular surface. Furthermore, the characterization of the elemental content was carried out using EDX. Based on Figure 2a, the BAMW material contains elements O, C, Al, Si, P, Fe, Ca, Na, Cu, Cr, which are dominated by oxygen and carbon elements. Figure 2b portland cement contains elements O, C, Ca, Si, Al, S, K, Mg, Fe, Na, P. The results of the analysis of bottom medical waste ash with X-ray fluorescence contain the main compounds SiO_2 of 57.5%, CaO (19.34%), Al_2O_3 (7.32%), and compounds Fe_2O_3, MgO, K_2O, and Na_2O with low concentrations [26]. The results of other studies show that bottom ash medical waste contains SiO_2 and CaO reaching 67.51% [27]. In addition, bottom ash medical waste contains the highest concentration of CaO [28].

The effect of BAMW composition on paving block quality

The steps for testing the compressive strength, wear, and water absorption of paving blocks were carried out based on SNI 03-0691-1996. This paving block quality test was carried out at the age of the paving block 28 days, with the original paving block size of 200 mm x 100 mm x 60 mm which was then cut into a size of 60 mm x 60 mm x 600 mm. The results of paving block testing with parameters of compressive strength, wear, and water absorption are shown in Figure 3.

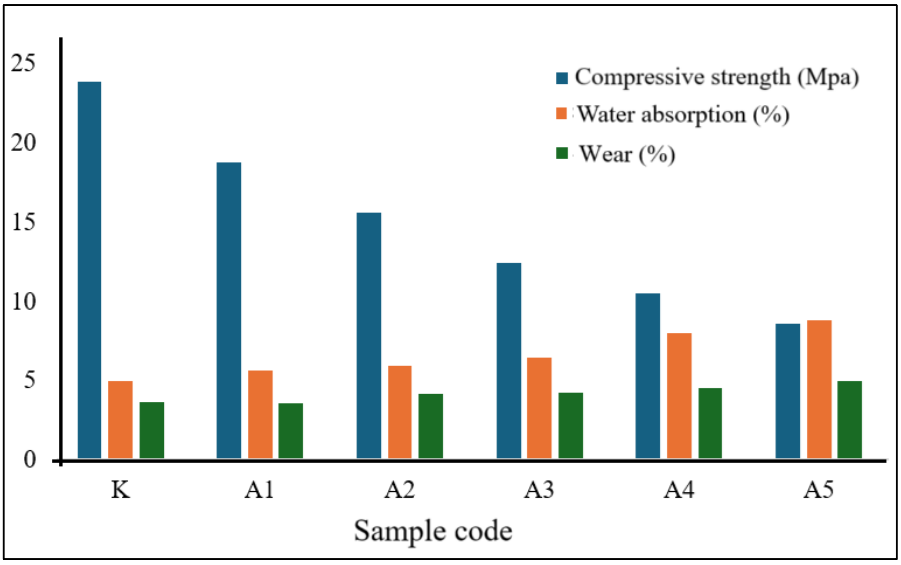

Figure 3. Paving block test results on the effect of BAMW addition

Figure 3 shows that the greater the addition of BAMW, the lower the compressive strength while the

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parameters of water absorption and wear increase. Good paving blocks have high compressive strength, low water absorption and wear. The increasing content of BAMW in pavers causes a decrease in compressive strength and increases the ability to absorb water and wear. BAMW contains the metals Al, Ca, Fe, K, Mg, Mn, Na, P and Si [4]. These metal minerals inhibit the formation of bonds between sand and cement. Cement contains tricalcium silicate compounds ($3CaO.SiO_2$) and dicalcium silicate ($2CaO.SiO_2$). Sand contains SiO_2 compounds which play a role in forming bonds with cement. The bond between cement, sand, and water produces calcium silicate hydrate (C-S-H) which gives hard properties to paving blocks, so that they have good compressive strength and by-products in the form of $Ca(OH)_2$ which will give solid properties to paving blocks. Furthermore, the by-product $Ca(OH)_2$ will bind to SiO_2 from the sand, so that the $Ca(OH)_2$ compound will be reduced which will enhance solid properties to the paving block. The binding reaction of $Ca(OH)_2$ by SiO_2 takes place as follows:

$$Ca(OH)_2 + xSiO_2 + nH_2O \rightarrow xCaO.SiO_2.nH_2O$$

The addition of BAMW causes the quality of paving blocks to decrease. This is because BAMW contains very high content of metals, O and C atoms. Carbon and oxygen atoms can inhibit the cement hydration process. The interaction of organic compounds with cement will result in the inhibition of cement hydration [24]. The addition of silicon dioxide (SiO_2) and calcium oxide (CaO) in the manufacture of concrete can increase compressive strength. SiO_2 and CaO have been proven to increase the compressive strength of concrete modified with fly ash [32].

The effect of BAMW particle size on paving block quality

Figure 4 shows that the smaller the BAMW particle size, the higher the compressive strength of the paving block produced, the lower the wear value, and the lower the water absorption. The smaller the particle size, the larger the surface area. In addition, the smaller the BAMW particle size, the better the interaction between cement material, incinerator bottom ash and sand. Particle size has a significant effect on concrete quality [29]. In addition, it also affects the aggregate surface, and the volume of cavities filled by cement [30].

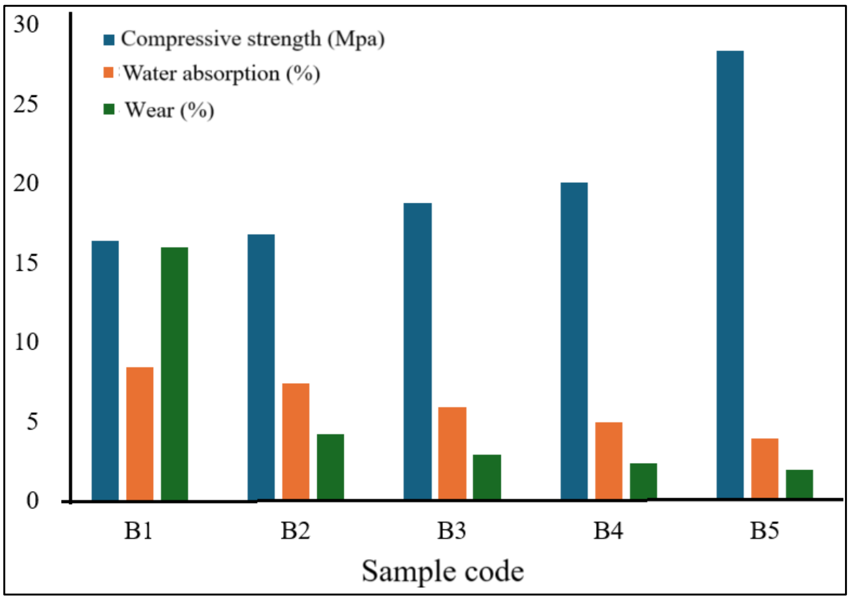

Figure 4. Results of paving block tests on the effect of BAMW particle size

Figure 4 shows the effect of variation in BAMW particle size on the compressive strength, water absorption and wear of paving blocks. The variation in BAMW particle size used is 10, 20, 30, 60, 100 and 200 mesh with sample codes B1-B5. Paving blocks are made with a composition of sand, cement and BAMW of 86%, 6% and 8%, respectively. The BAMW particle size is 200 mesh with compressive strength, water absorption and wear of 28.38 Mpa, 3.93% and 1.97 mm/min, respectively. The particle size of BAMW has a very significant effect on reducing wear. Paving blocks made with BAMW particle sizes of 10 and 20 mesh have wear of 16.03 and 1.97 mm/min, respectively. Based on the Indonesian National Standard (INS)

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number 03-0691-1996, the quality of paving blocks is divided into four groups, namely A, B, C and D. Based on data on compressive strength, water absorption and wear, paving block code B5 is included in group B. Paving block group B has the requirements of a minimum compressive strength of 17 Mpa, a maximum water absorption of 6% and a minimum wear of 0.149 mm/min. Category B paving blocks are suitable for car and motorbike parking.

Total Organic Carbon (TOC) Analysis in Paving Blocks

Figure 5 shows that the TOC concentration of soaking water for control paving blocks and paving blocks with 200 mesh incinerator bottom ash size is lower. Control paving blocks (without adding bottom ash material) produce leachate with a TOC concentration of 0.52 mg/L. Very low TOC indicates that no organic compounds are released into the water. This paving block is good quality, so it is safe to be installed in the environment. Paving block B5 with a particle size of 200 mesh causes the bond between cement, incinerator bottom ash and sand to be better so that no organic compounds are released into the environment. TOC is a parameter to indicate the content of organic compounds in water [30].

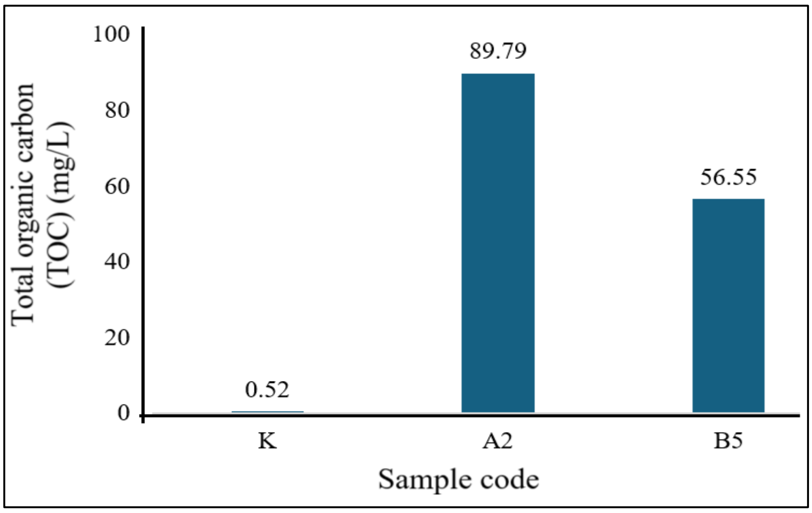

Figure 5. TOC test results on paving block soaking water for 70 days

Characterization of paving blocks with SEM-EDX

Paving blocks were characterized with SEM-EDX to determine the bonds that occur between cement, BAMW and water. The morphology of paving blocks shows that the C-S-H phase surrounds some or all of the hydrated silicate clinker, C-H. The morphological form shows that C-S-H surrounds the silicate clinker (aluminate and belite) [31]. The results of the SEM-EDX analysis of paving blocks are shown in Figure 6. Based on the morphology, there is no significant difference between the control paving blocks (without BAMW) and paving blocks added with BAMW.

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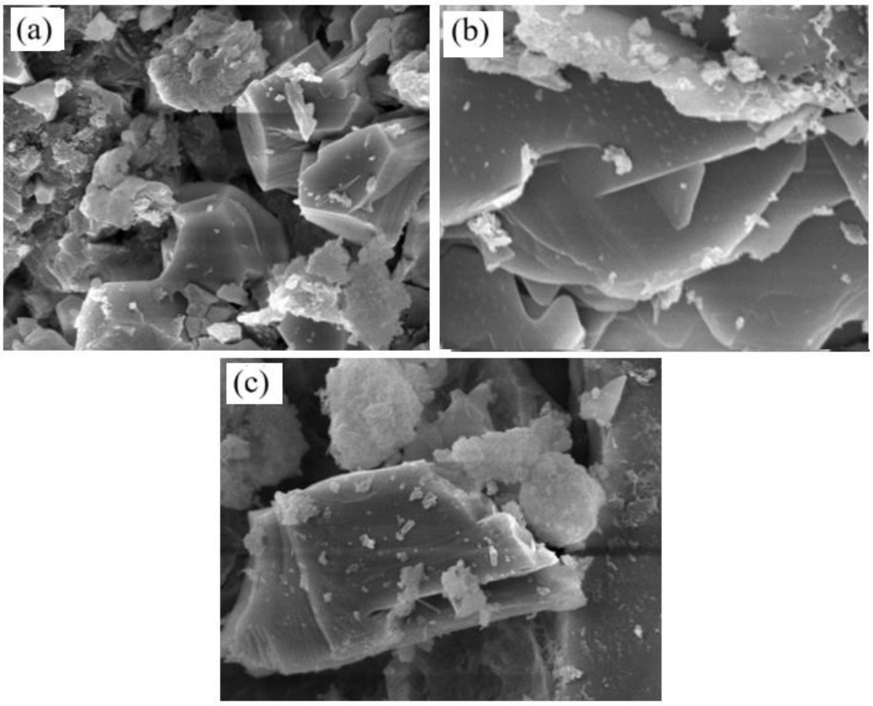

Figure 6. SEM image of paving block without adding BAMW (a) adding 2% BAMW (b) adding 2% BAMW with a particle size of 200 mesh (c)

Conclusions

BAMW contains elements of O, C, Al, Si, P, Fe, Ca, Na, Cu, and Cr. The largest composition is the elements of O and C, each of which is 49.78% and 30.82%. The higher the composition of the BAMW material in pavers, the lower the compressive strength, the higher the water absorption and the higher the wear rate. The smaller the particle size of the BAMW, the better the quality of the paving block. In addition, particle size affects the concentration of TOC in leachate after the paving block is soaked for 28 days. The quality of paving blocks needs to be compared with the standard paving block quality standards. Further research that needs to be done is to use cheaper and environmentally friendly adhesive materials to improve the quality of paving blocks. In addition, adhesive materials are expected to increase the amount of BAMW so that it is increasingly used and reduces the spread to the environment.

Acknowledgments

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