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# Physical Characteristics and Topographic Composition of Infectious Waste Combustion Residues in Toxic Hazardous Waste Processing Companies

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## ABSTRACT

The residue produced and left behind under the burning furnace (incinerator) from the burning of infectious waste is a category of hazardous and toxic waste. The residue from combustion contains heavy metals, which can harm the environment and the health of living creatures. Good management must be implemented to reduce the resulting impacts, one of which is utilization. Appropriate utilization can be done by knowing the characteristics of combustion residues both physically and topographically. The main objective of this research is to analyze the physical characteristics of infectious waste combustion residues and topographic composition. Physical characteristics include water content parameters using SNI 03–1971–1990, mud content parameters using the settling method, gradation parameters using the sieve method, specific gravity parameters using SNI 1970:2008, and water absorption parameters using oven drying. Topographic composition was analyzed using Scanning Electron Microscopy (SEM). The water content obtained in the residue was 9.55%, the mud content was 34.1%, the specific gravity result was 1.82, and the gradation of the ash fell into the zone 2 category, indicating that the fine aggregate tested fell into the medium sand size category, water absorption/absorption shows 10.65%. SEM results show the presence of crystalline particles with sharp edges and flat surfaces, as well as amorphous particles that are more irregular and hollow. Utilization can be done on residues from burning medical waste, one of which is as a substitute for sand in the medium category. Utilization can be made into several products that use medium category sand and are given a additives or pozzolan mixture to prevent leaching.

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## INTRODUCTION

Medical waste is a product of consumable waste from both biological and non-biological materials resulting from activities in health facilities such as clinics, health centers, hospitals, etc (Rangkuti et al., 2023). The waste problem in many countries is increasing rapidly due to activities carried out by several sectors, one of which is the health sector. Hazardous waste accounts for 10-25% of medical waste, yet the associated risks are undoubtedly significant. Medical waste generated from hospital activities consists of various types, such as chemical waste, infectious waste, cytotoxic waste, sharps waste, pathology waste, radiological waste, waste containing heavy metals, and so on (Yurnalisdel, 2023).

Several hospitals with types A, B, and C are known to have not implemented hazardous and toxic materials waste management efforts properly (Damayanty et al., 2022), and in addition, several elementary schools also did not provide efforts to manage disposable mask waste

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during the pandemic (Widowati et al., 2022). Medical waste is defined as waste that contains heavy metals and dioxins, which can pollute soil and water, pose a health risk if they enter the food chain, and potentially serve as a medium for disease transmission (Dehghanifard & Dehghani, 2018). PP 22 of 2021, concerning the implementation of environmental protection and management, regulates that those who produce B3 waste are required or obliged to carry out management. Of course, not all B3 waste producers have the permits mentioned in the previous sentence. Therefore, a third party holding the relevant management permit must handle it (Nursabrina et al., 2021). Based on Permen LHK Number 6 of 2021, it also explains that the hazardous and toxic materials waste processing process is one of which is the incineration process. The solution for processing medical waste involves applying appropriate technology (TTG) in conjunction with a high-temperature combustion system, specifically an incinerator. This incinerator can burn both dry and wet waste (Rizali et al., 2022).

Medical waste incineration products can be divided into two main parts. The first part is waste that is discharged into the external environment, such as fly ash (MWFA), carbon dioxide, sulphur oxides, and chlorides. The second part is the ash left in the incinerator called bottom ash (MWBA). The amount or quantity of ash waste from the combustion process has increased over the past two years during the pandemic (Rachmawati et al., 2022). The ash remaining in the incineration chamber is 75–90% of the total ash (Jaber et al. 2021). Bottom ash produces more residue than fly ash. This combustion residue will then be dumped in an open area (landfill), which has the potential to pollute the environment (Rini et al., 2022). Long-term landfilling of ash resulting from incineration of medical waste can affect the availability of land for storing ash, considering the high amount of ash produced. The failure of the lining system in the landfill area could potentially lead to groundwater pollution. This is supported by research conducted by Anamul, which states that the disposal of abundant ash causes reduced land availability, expensive costs in ash processing, and strict government regulations regarding licencing (Md Anamul et al., 2012).

Based on Minister of Environment and Forestry Regulation Number 6 of 2021 concerning procedures and requirements for managing hazardous and toxic waste (B3), the utilization of B3 waste must be carried out in accordance with applicable requirements. Utilization of B3 waste can be carried out by fulfilling the requirements, including that products produced as a result of waste utilization must have SNI, containing more than 50% total oxide (Permen LHK Number 6 of 2021). Examples of products produced include paving blocks, geopolymer, and mixed glass recycling (Rachmawati 2024; Tzanakos et al., 2014; Papamarkou, Sifaki, et al., 2018). Paving block products are known to have compressive strength that is not optimal, this is because calculations have not been carried out regarding the characteristics of the residue from burning medical waste; physical characteristics such as high mud content will affect the compressive strength of the concrete (Rachmawati et al., 2024).

Physical characteristics include parameters of water content, mud content, gradation, specific gravity, and water absorption capacity. Water content is the percentage of water contained in an object (Prasetyo et al., 2019). The water content contained in the residue indicates that the ingredients are still available. The higher the water content remaining in the bottom ash, the greater the quantity of content in the bottom ash (Bilen et al., 2015). High mud content can result in reduced binding between aggregates (Hudori et al., 2022). A good aggregate for mixing concrete has the following characteristics: being strong, hard, angular, graded, not containing organic substances, and not containing mud. However, the reality that is often found is that there is a lot of sand containing mud (Fatika et al., 2023). Gradation is a key factor determining the structure and composition of fine slag, which is only used for landfills so that it can be used as an adsorbent, catalyst, and inorganic filler (Ren et al., 2023). Specific gravity is usually defined as the ratio between the weight of a given volume of material and the volume of water. The relationship between specific gravity and absorption capacity is that the higher the specific gravity value of the aggregate, the smaller its water absorption capacity (Ginting et al., 2022).

The aim of this research is to analyze the physical characteristics of infectious waste combustion residues and topographic composition. Utilization of residue from burning infectious waste can be done by knowing its physical characteristics. Although there have been many studies using combustion residues in several products, some do not pay attention to the physical characteristics so that utilization is not optimal. It is hoped that the residue from burning infectious waste produced by medical waste companies in Indonesia can be utilized optimally and in accordance with applicable government regulations.

## MATERIALS AND METHODS

The ash from the incineration of medical waste was collected from companies engaged in the management of hazardous and toxic waste from various sectors, both from health facilities, shopping centers, office buildings, hotels and apartments, and other public facilities. The sampling method was carried out by probability sampling, which means that this sampling method assumes that all samples have an equal opportunity to become research objects. Simple random sampling is the type of probability sampling method used. The technique of simple random sampling ensures that every segment of the population has an equal chance to serve as research samples. The study employed a specific type of basic ash. The UNS Faculty of Engineering Materials Laboratory conducted physical characteristic tests, and the Diponegoro University Integrated Laboratory UPT used SEM for topographic composition tests. Energy Dispersion Spectroscopy (EDS) can analyze the SEM-evaluated sample area to identify specific elements that form the sample area. The sample surface also emits X-rays, which carry unique energy signatures for the elements present in the sample. These X-rays are detected with an EDS detector to provide basic information about the sample. EDS provides data on the chemical composition of the sample and provides additional data on the properties observed in the SEM micrograph. This combined technique is called SEM-EDS or SEM-EDX analysis.

*Analysis of Water Content Parameters*

The water content parameters are measured according to SNI 03 - 1971 - 1990 concerning the method of testing aggregate water content. The analysis method used is the oven drying method at a temperature of (110 ± 5) ° C until a constant weight (constant weight) is obtained. The water content in bottom ash can be calculated using the following formula:

$$\text{Bottom ash water content} = \frac{W3-W5}{W5} x100\% \quad (1)$$

*Analyzing the parameters of the particle size distribution (PSD).*

The sieve method, also known as sieve analysis, serves as the analysis method for particle size distribution parameters. This method involves sieving samples in a sieve until the amount retained is constant. We place the bottom ash sample for testing on a stack of sieves, and then sieve it using a vibrating or rotating motion. After the filtration process is complete, the bottom ash particles caught on each sieve will be weighed. From these results, the particle size distribution can be obtained by calculating the percentage of particle weight trapped in each sieve size.

*Specific Gravity Parameter Analysis*

SNI 1970:2008 divides specific gravity testing on fine aggregates into three types: dry bulk specific gravity, SSD specific gravity, and apparent specific gravity.

$$\text{Dry bulk specific gravity} = \frac{A}{(B+S-C)} \quad (2)$$

with :
- A: weight of oven dry test object (grams);
- B: weight of the pycnometer filled with water (grams);
- C: weight of the pycnometer with the test object and water to the reading limit (grams);
- S: weight of the test object in surface dry saturated conditions (grams).

Bulk specific gravity (JKP) = $\frac{S}{(B+S-C)}$ (3)

with :
- A : is the weight of the oven dry test object (grams);
- B : is the weight of the pycnometer filled with water (grams);
- C: is the weight of the pycnometer with the test object and water up to the reading limit (grams);
- S: is the weight of the test object in surface dry saturated conditions (grams).

Apparent Specific Gravity = $\frac{A}{(B+A-C)}$ (4)

with :
- A : is the weight of the oven dry test object (grams);
- B : is the weight of the pycnometer filled with water (grams);
- C: is the weight of the pycnometer with the test object and water up to the reading limit (grams);

*Analysis of water absorption parameters*

There are several steps involved in testing the water absorption of fine aggregates. The first is to weigh the fine aggregate sample as the initial weight. The two samples are equalized by the weight to be tested. Then, the fine aggregate sample is dried in using a heater, and this time the test uses an oven with a temperature of 110°C for 24 hours. The sand that has been ovened is left to reach room temperature, and then weigh the sand as the weight of the oven sample.

Water absorption = =(S-A)/Ax100% (5)

with :
- A : is the weight of the oven dry test object (grams);
- S: is the weight of the test object in surface dry saturated conditions (grams).

*Mud Content Parameter Analysis*

The stages for obtaining the mud content value in the test material are to prepare the materials and testing tools (sand samples and a 1000-mL measuring cup). Put 400 mL of sand into a measuring cup. Then, periodically, fill it with water with a pH of 7 so that the sand and water mix. After the sand and water are mixed, fill the measuring cup with water until full (1000 mL). Then, let the measuring cup containing the test sand and water stand until the water becomes clear. After the water looks clear, check the thickness of the mud in the measuring cup and record the height of the mud thickness (V2). Record the remaining sand's height under the mud layer (V1).

Mud content = V2/V1x100% (3.6)

with V1 being the sand height and V2 being the mud height

## RESULTS AND DISCUSSION

The Indonesian medical waste processing company Polokarto plant processes several types of infectious waste as follows: clinical and infectious waste, expired pharmaceutical products, laboratory equipment contaminated with B3, B3 packaging and product packaging. Processing infectious waste uses thermal technology (incinerator). At the end of the burning of medical waste, there are remaining materials that cannot be completely burned (residue). The remaining residue is called bottom ash, which is removed at the bottom of combustion chamber 1. Bottom ash is produced at around 5-10% by weight of the waste burned. The remaining bottom ash is theoretically harmless and can be used in other applications, such as aggregate in concrete or for road construction. However, in accordance with applicable regulations, bottom ash is treated as B3 waste (Hazardous and Toxic Materials). Therefore, the resulting bottom ash (residue) must be sent to a third party who has official permission to carry out further processing. This process aims to ensure that bottom ash is managed in accordance with environmental and safety standards set by regulations. Medical waste processing companies in Jawa Tengah, Indonesia, produce an average of 16 to 17 tonnes of residual ash in a 1-week period and send it to third parties. Figure 1 explains the residue that falls into the furnace during the combustion process, or what is called bottom ash.

*Physical characteristics of infectious waste combustion residues*
*Water Content*

The method of testing aggregate water content by drying is based on SNI 03-1971-1990. This method of testing total aggregate water content by drying includes determining the percentage of water that can evaporate from the aggregate sample by drying it in an oven. Aggregate water content is the ratio between the mass of water contained and the aggregate in an oven-dry state and is expressed in percent.There are several stages to the procedure for testing fine aggregate water content. The first is to weigh the fine aggregate sample at its initial weight. The two samples are averaged to the weight to be tested. Then, the fine aggregate sample is dried in using a heater, and this time the test uses an oven with a temperature of 110°C for 24 hours. The sand that has been oven-dried is left to reach room temperature, and then weigh the sand as the weight of the oven sample.

The table above averages the initial weight of both samples at 100 grams. Following a 24-hour oven at 110°C, the samples weigh 93 grams and 87.9 grams, respectively. The water content in the first sample is 7%, whereas the water content in the second sample is 12.1%. The average water content in the fine aggregate bottom ash from the incineration of hazardous and toxic waste at in toxic hazardous waste processing companies Indonesia is 9.55%. Based on ASTM C 566, the water content requirement for fine aggregate is between 3% and 5%. Water content that exceeds this threshold can be anticipated by storing it in a dry place and protecting it from rain or excessive humidity, designing a concrete mixture with an appropriate water-

**Fig. 1.** (a) Residues from burning infectious waste, (b)Residues from burning infectious waste that has been filtered

**Table 1.** Results of Water Content Measurement in Residues

| No | Sample | Initial sample weight | Oven sample weight | Water content |
|---|---|---|---|---|
| 1 | 1 | 100 gram | 93 gram | 7% |
| 2 | 2 | 100 gram | 87,9 gram | 12,1% |
| | | Average | | 9,55% |

**Table 2.** Results of Mud Content in Residues

| No | Sample | Initial sample weight | Oven sample weight | Water content |
|---|---|---|---|---|
| 1 | 1 | 100 gram | 59,3 gram | 40,7% |
| 2 | 2 | 100 gram | 72,5 gram | 27,5% |
| | | Average | | 34,1% |

cement ratio, using a stabilizer to help keep the water content low, and the simplest way is to dry it using an oven or other drying equipment to remove excess water from the fine aggregate.

Based on the explanation above, the water content of the bottom ash from the incineration of medical waste at toxic hazardous waste processing companies in Indonesia is 9.55%. This condition, when compared with previous research by Rahmaulina et al., stated that the water content of bottom ash from coal combustion in the textile industry is 2.58% (Rahmaulina et al., 2022), the water content of bottom ash from coal combustion for the PLTU industry is 1.23% (Husin & Setiadji, 2008), and the water content of bottom ash from coal combustion from textile factories is 27.57% (Sugiarto, 2011).

Low water content in bottom ash is desirable in geopolymer production because it reduces shrinkage that results in cracks (Osholana et al., 2022). Too much water can also cause cracks so that the concrete becomes less dense. The higher the cement water content ratio (w/c-ratio), the lower the compressive strength value of the concrete (Kushartomo et al., 2020). High water content is not optimal when used for concrete and geopolymer products.

*Mud levels*

The basic reference for the fine aggregate mud content testing method in this study is based on SNI 03-4142-1996, "Testing Method for the Amount of Material in Aggregates Passing Sieve No. 200 (0.75 mm)".

This study uses SNI 03-4142-1996, "Testing Method for the Amount of Material in Aggregates Passing Sieve No. 200 (0.75 mm)" as a guide for the fine aggregate mud content testing method. Table 2 shows that the test of fine aggregate mud content in bottom ash produces an average mud content of 34.1%. According to SNI S-04-1989-F and ASTM C 117, building materials can use fine aggregate with a mud content of no more than 5%. As a result, the fine aggregate of bottom ash from the incineration of medical waste at toxic hazardous waste processing companies in Indonesia exceeds the specified threshold. Of course, this can be anticipated by washing or cleaning the mud contained in the fine aggregate of bottom ash before being used as a mixture for making building material instruments.

Efforts to reduce the mud content in bottom ash can use a filtering or washing method to remove mud from the fine aggregate. This process entails using a filter or water filter to separate the mud from the aggregate. Washing with water can help dissolve and remove the mud from the aggregate. This process may need to be repeated several times until the mud content is considered appropriate. Based on the explanation above, the mud content in the bottom ash from the incineration of medical waste at toxic hazardous waste processing companies in Indonesia is 34.1%. This condition, when compared with previous research, states that the bottom ash mud content originating from coal combustion in textile factories is 3.42% (Sugiarto, 2011). The following are the characteristics of a suitable aggregate for concrete mixing: it must be robust, hard, angular, graded, free of organic substances, and free of mud. Nevertheless, the reality that

**Table 3.** Gradation/Particle Size Distribution Measurement Results on Residues

| Sieve Diameter (mm) | Weight Left Behind | | | Cumulative Pass Weight (%) |
|---|---|---|---|---|
| | Gram | % | Cumulative (%) | |
| 9,50 | 0,2 | 5,4% | 5,4% | 94,6% |
| 4,75 | 0,4 | 9,9% | 15,3% | 84,7% |
| 2,36 | 0,4 | 11,7% | 27,0% | 73,0% |
| 1,18 | 0,5 | 12,8% | 39,8% | 60,2% |
| 0,85 | 0,2 | 5,4% | 45,2% | 54,8% |
| 0,30 | 0,7 | 18,4% | 63,7% | 36,3% |
| 0,15 | 0,4 | 10,2% | 73,9% | 26,1% |
| 0,00 | 1,0 | 26,1% | 100,0% | 0,0% |
| Total | 3,7 | 100% | 370% | |

is frequently encountered is that there is a significant amount of sediment that contains mud (Fatika et al., 2023).

High mud content can result in reduced binding between aggregates (Hudori et al., 2022). There is a tendency to increase the use of water in building material mixtures that use fine aggregate; if these materials are present, one of which is high mud content, it cannot combine with cement, thus preventing the combination of cement and aggregate and reducing the compressive strength of the concrete (Pohan et al., 2023). It is known that the allowable mud content in fine aggregate cannot be more than 5% by weight of sand (Fatika et al., 2023). The mud content in the fine aggregate is high, so additional materials are added in the form of Master Sure 1007 and Master Glenium Ace 8595, amounting to 0.35% of the total binder. The addition of this additive is expected to increase the compressive strength of quality concrete (Fatika et al., 2023).

*Gradation/Particle Size Distribution*

The basic reference for the fine aggregate mud content testing method in this study is based on SNI 03-1968-1990 Concerning the Fine and Coarse Aggregate Sieve Analysis Testing Method. In this study, using bottom ash samples as fine aggregates of 3000 grams. The procedure for fine aggregate gradation testing involves multiple stages. The first is to prepare a bottom ash sample of 3000 grams. Then, take and arrange the sieves in an arrangement from bottom to top: pan; 0.075 mm; 0.15 mm; 0.30 mm; 0.60 mm; 1.18 mm; 2.36 mm; 4.75 mm; 9.50 mm, then place the sieve arrangement on the vibrating machine. Next, pour sand into the top sieve, close the sieve arrangement tightly, and then turn on the machine for 5 minutes. After 5 minutes, turn off the machine, then weigh and record the remaining aggregate on each sieve.

The requirements of SNI 03-6861.1-2002 regarding "Building Material Specification Part A: Non-Metal Building Materials" set the fineness modulus for fine aggregate in the range of 1.5 to 3.8. Examination of the fineness modulus of fine aggregate is a way to determine the fineness or roughness value of an aggregate. Based on the data in Table 3, a fineness modulus value of 2.7 will be obtained. The modulus value is still within the range specified in SNI 03-6861.1-2002. In the case of bottom ash gradation like this, the manufacture of concrete bricks can still be considered good. However, adding materials of a finer size, like fly ash, would be more beneficial. By adding finer aggregates, it is expected to fill the gaps or cavities between the fine aggregates, thus creating interlocking and filling between the fine aggregate particles. This condition will increase the compactness or density of the fine aggregate, which will result in better performance. The explanation above indicates that toxic hazardous waste processing companies in Indonesia bottom ash from medical waste incineration, fall under gradation number 2. This condition, when compared with previous research, states that the distribution of bottom ash particle size from coal combustion in textile factories is included in gradation type number 1 (Sugiarto, 2011).

Gradation can also be used in the environmental field, for example, in analyzing sediment

**Table 4.** Results of Water Absorption Capacity in Residues

| No | Sample | Initial sample weight | Oven sample weight | Bulk Specific Gravity | Bulk Specific Gravity SSD | Apparent Specific Gravity |
|---|---|---|---|---|---|---|
| 1 | 1 | 100 gram | 93 gram | 1,5 | 1,6 | 1,6 |
| 2 | 2 | 100 gram | 87,9 gram | 1,8 | 2,1 | 2,5 |
| | | Average | | 1,6 | 1,8 | 2,0 |

deformation due to slaking and crushing mechanisms that are influenced by the distribution of rock particles on hillsides (Triyanto et al., 2022). Coal bottom ash has a particle size distribution identical to that of natural sand. Bottom ash can be used on roads, embankments and as a filling material for retaining walls because it has a low specific gravity, is easy to compact, and has good friction properties. Bottom ash can be used in highway construction, embankments and as a filling material for retaining walls because of its higher shear strength, easy compaction and lower specific gravity. Utilization of bottom ash will solve the dumping problem and also contribute to environmental sustainability (Ullah et al., 2019).

*Specific gravity*

To use waste from an activity as building material, it is necessary to know the physical properties of the waste and the specific gravity, for example (Utomo et al., 2022). The specific gravity and light density of waste aggregate can be used as building materials that prioritise light weight. For example, for multi-story building blocks so that their own weight is reduced.

Table 4 shows the specific gravity of bottom ash samples resulting from medical waste incineration at PT Arah Environmental Indonesia. These data show that the aggregate used in this experiment has a specific gravity that is *(suitable/not suitable) for. According to ASTM C 128 standards, the specific gravity of fine aggregate usually ranges from 2.30 to 2.60. The test results listed in the table show that the specific gravity of fine aggregate in dry bulk conditions has an average of around 1.64, the average apparent specific gravity is around 2.03, and the average specific gravity of aggregate in dry saturated conditions (SSD) is about 1.82. Thus, it can be concluded that the specific gravity test results do not meet the specified specification standards.

Based on the explanation above, the mud content in bottom ash resulting from medical waste incineration at medical waste companies is 34.1%. When compared with previous research, this condition states that the specific gravity of bottom ash originating from burning coal in textile factories is 1.41% (Sugiarto, 2011), the specific gravity of bottom ash originating from burning coal in PLTUs is 1.86% (Azka et al. ., 2023), the specific gravity for Bottom Ash Geopolymer Sand (BAGS) originating from burning coal in textile factories is 2.59% (Yadav & Mahakavi, 2023), and the specific gravity of bottom ash originating from burning coal is 1.99% (Ullah et al., 2020). The specific gravity of a by-product from industry varies based on composition (Kirthika et al., 2020). Compared with ordinary natural aggregates, bottom ash has a lower specific gravity (Xuan et al., 2018).

*Absorption/Water Absorption Capacity*

Utilizing waste from an activity as a building material, it is necessary to know the physical properties of the waste and water absorption/absorption capacity is one example (Utomo et al., 2022).

The higher the ability of fine aggregate to absorb water, the lower the strength of the concrete. A good absorption value is less than 2% according to ASTM C 128 standards. However, Table 5 reveals that the absorption of bottom ash surpasses the ASTM C 128 standard, with a value exceeding 2%. Bottom ash still contains dust that can absorb water vapor or water from the surrounding environment, this can be seen from the results of the water absorption test of 10.7%.

**Table 5.** Results of Water Absorption Capacity in Residues

| No | Sample | Initial sample weight | Oven sample weight | Water content |
|---|---|---|---|---|
| 1 | 1 | 100 gram | 93 gram | 7,5% |
| 2 | 2 | 100 gram | 87,9 gram | 13,8% |
| | | Average | | 10,7% |

Bottom ash, when used as an aggregate, possesses porous properties due to its high ability to absorb water. For this reason, the use of bottom ash as an aggregate is limited to lightweight structural components and is recommended for use indoors that are protected from the effects of the weather.

However, if in the manufacture of building material components additives are used that can reduce the ability to absorb water, then bottom ash can be used outdoors. Based on the explanation above, the water absorption capacity of bottom ash from the incineration of medical waste at toxic hazardous waste processing companies Indonesia is 10.7%. Compared to earlier studies, this condition shows that bottom ash from coal combustion can absorb 21.29% of water in textile factories, 1.22% of water in PLTU, and 30% of water in textile factories (Sugiarto, 2011). The water absorption capacity of fine aggregate determines the mixture ratio of the materials used in its utilization (Cano et al., 2023). The high porosity of fine aggregate contributes to its high water absorption capacity (Li et al., 2019). Humidity has the greatest influence on water absorption (Ji et al., 2021).

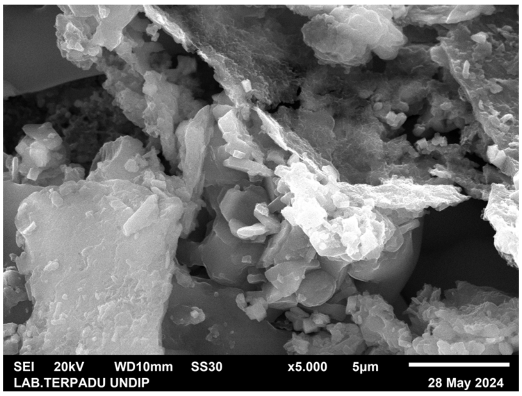
Materials that have high absorption values tend to have a negative impact on mortar (Xu et al. in Bunyamin et al., 2023). Fine aggregate has an excessive absorption value, causing the mortar formed to be too dry. Mortar that is too dry causes the slump value to decrease, so the concrete mixture is difficult to apply to the mould. This reaffirms that material quality plays an important role in influencing mortar quality. Therefore, when making concrete, it is necessary to test the materials and ensure that the materials used are suitable (Bunyamin et al., 2023).

*Topographic composition of combustion residues*

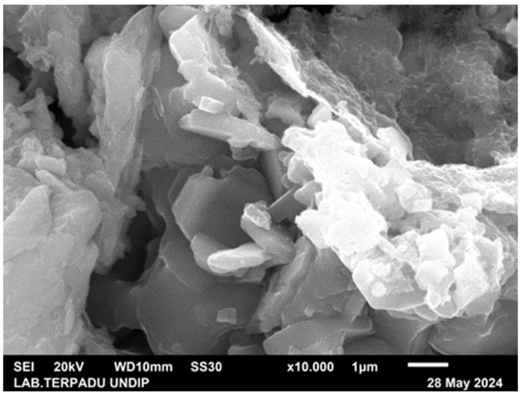
In the Scanning Electron Microscope (SEM) test sample showing the structure of medical waste incinerator ash with a magnification of 5000x. The results show the presence of particles with crystalline and amorphous characteristics. Crystalline particles have a sharp type and flat surface, while amorphous particles look more irregular and hollow. Having varying particle sizes and morphologies, with the majority in the micrometer range, indicates that the combustion process in the incinerator is quite effective, producing very small particles. Some particles have rough and uneven surfaces due to the combustion process and chemical reactions during incineration. The presence of incompletely burned particles indicates variations in the incinerator's combustion temperature or oxidation conditions.

The Scanning Electron Microscope (SEM) test sample reveals the structure of ash from a medical waste incinerator under a 10,000x magnification. The image shows ash particles with a rough, layered surface, indicating the formation of various layers during combustion. Some particles also show cracks and fragments due to thermal or mechanical stress. The particles vary in size, from a few micrometers to less than one micrometre. Having an irregular shape and rough texture indicates the presence of inorganic materials such as silicates, metal oxides, and carbon residues. This suggests a partial burning of organic materials.

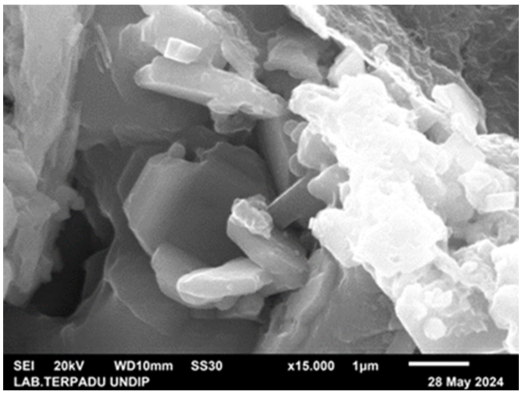
The Scanning Electron Microscope (SEM) test sample reveals the structure of ash from a medical waste incinerator at a magnification of 15,000x. Visual examination reveals ash particles less than one micrometre in size that have a clear crystalline structure. This suggests the presence of inorganic compounds like silicates or metal oxides. The particle surface varies from smooth to rough, indicating an intense combustion process and complex chemical reactions.



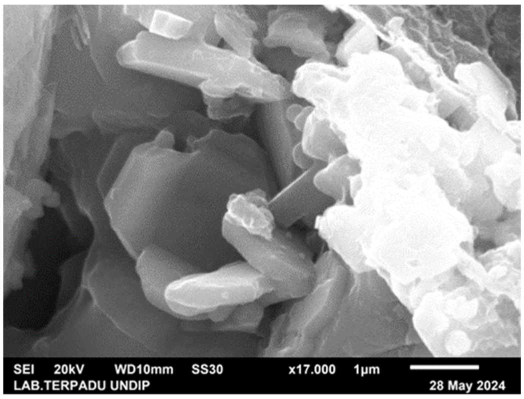

(a)




(b)




(c )




(d)

**Fig. 2.** SEM Test Results (a) Magnification 5000x, (b) Magnification 10000x, (c) Magnification 15,000x, (d) Magnification 17,000x

Differences in particle brightness indicate variations in chemical composition, with brighter particles containing elements such as heavy metals. The varying particle shapes, from prismatic to curved, indicate a mixture of materials with different structures.

We examined a test sample of medical waste incinerator ash using a Scanning Electron Microscope (SEM) at a magnification of 17000x. The analysis reveals tiny sub-micrometer particles with a clear crystalline structure, sharp edges, and flat surfaces. These particles also appear to aggregate in clusters. The variation in particle surfaces, from smooth to rough, indicates an intense and complex combustion process. The results of the EDS analysis show that medical waste incinerator ash contains various chemical elements.

The combustion process and chemical reactions during incineration are responsible for the presence of incompletely burned particles and variations in particle morphology. According to (El-Amaireh et al., 2023), the causes of non-combustible particles in incinerators are inadequate burning time, inadequate air quality, and low temperatures in the combustion chamber. The presence of particles of various sizes and shapes in samples indicates that the incineration process may not be completely uniform, with some materials not entirely decomposed. The analysis of the chemical composition of ash samples from medical waste incinerators uses additional methods such as EDS (Energy Dispersive X-ray Spectroscopy). EDS provides data on the sample's chemical composition as well as additional information on the properties observed in SEM micrographs (Patchaiyappan et al., 2021).

In the EDS analysis, the results showed that the incinerator ash contained a number of major elements. The analysis revealed that Carbon (C) accounted for 33.24% by weight and 47.95%

**Table 6.**

| Parameter | Mass (%) | Atom (%) |
|---|---|---|
| C | 33.24 | 47.95 |
| O | 28.89 | 31.29 |
| Na | 8.75 | 6.59 |
| Mg | 0.24 | 0.17 |
| Al | 1.10 | 0.71 |
| Si | 1.23 | 0.76 |
| S | 1.00 | 0.54 |
| Cl | 17.47 | 8.54 |
| K | 0.13 | 0.06 |
| Ca | 7.36 | 3.18 |
| Ti | 0.58 | 0.21 |
| Cr | 0.01 | 0.00 |

by atoms, indicating its dominance. Oxygen (O) was present at 28.89% by weight and 31.29% by atoms, while Chlorine (Cl) was present at 17.47% by weight and 8.54% by atoms. Other elements found included Sodium (Na) at 8.75% by weight and 6.59% by atoms, and Calcium (Ca) at 7.36% by weight and 3.18% by atoms. Other minor elements such as Magnesium (Mg) at 0.24% by weight and 0.17% by atoms. Aluminum (Al) has 1.10% weight and 0.71 atoms. Silicon has a weight of 1.23% and an atom count of 0.76%. Sulfur (S) has a weight of 1.00% and an atom count of 0.54%. Potassium (K) has a weight of 0.13% and an atom count of 0.06%. Titanium (Ti) with 0.58% weight and 0.21% atom, while Chloride (Cr) as much as 0.01% weight and 0.00% atom.

The Cl content indicates that polyvinyl chloride (PVC) and other chlorinated organic materials were burned in the incinerator. The presence of elements like Ti in combination with others suggests the use of alloys in metal instruments classified as biomedical waste (Vivek et al., 2019). Other heavy metal content in the ash samples from the medical waste incinerator also contains Zn and Cr caused by the disposal of items such as syringes, plastic, rubber, and medical adhesive plasters. The use of PVC plastic contributes to the Pb and Cd loads. Packaging materials used in medical waste, including plasticizers and adhesives often contain Cu, Zn, and other heavy metals due to the use of aluminum foil, PET, PVC, and PP. Cd and Hg are commonly found in dental clinics, damaged medical equipment, and discarded batteries (Ahmed et al., 2024). The presence of silica, which is relatively small, is caused by the burning of paper and marbles in the manufacture of incinerators. According to Debrah & Dinis (2023) studying the chemical characteristics of biomedical waste incineration, the chemical composition analyzed for the presence of silica is due to the presence of paper in the incinerator. This can also be caused by the presence of marbles in the manufacture of incinerators (de Oliveira et al., 2021).

According to the SEM and EDS analysis of medical waste incinerator ash, it has a diverse chemical structure and composition, including crystalline and amorphous particles with rough and layered surfaces. SEM analysis revealed that the ash contains micrometer to sub-micrometer sized particles, indicating an effective but not completely uniform combustion process. EDS analysis identified major elements such as carbon, oxygen, and chlorine, as well as various heavy metals, indicating the presence of organic and inorganic materials in medical waste. These findings emphasize the importance of proper medical waste management to reduce environmental and health impacts, and provide a basis for further research on the characteristics and potential uses of incinerator ash.

## CONCLUSION

The physical characteristics of residues resulting from burning medical waste include water content, sludge content, and water absorption, showing that this third parameter exceeds the existing quality standards listed in ASTM C 566, ASTM C 117, and ASTM C 128. There is a need to adjust the composition and add other additives that can be applied in the use of burning residues in making products such as concrete, paving blocks, etc. Good management, such as utilization, can be carried out for medical waste burning ash so that it can prevent the resulting impact on human health. Utilization can be carried out in accordance with applicable regulations, bottom ash from burning medical waste can be used as a sand substitute material in the medium category based on gradation parameters.

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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ASTM C117-17 Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

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