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IJIE

http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

A Properties of Municipal Solid Waste Incineration Fly Ash (IFA) And Cement Used in The Manufacturing of New Inventive Blended Cement

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DOI: https://doi.org/10.30880/ijie.2022.14.09.027
Received 29 August 2022; Accepted 24 October 2022; Available online 30 November 2022

Abstract: Municipal solid waste incinerator fly (IFA) ash is prone to accumulate high concentration heavy metals. Due to the increasing costs to treat remaining fly ash at the landfill, a lot of research has been done to recycle IFA. This study was focusing on the properties of IFA and cement as main raw materials in new inventive blended cement. The properties of blended cement were also being investigated. Properties of IFA and cement were examined through several test which includes density, specific gravity, X-Ray Fluorescence (XRF), Loss of Ignition (LOI) and through Toxicity Characteristic Leaching Procedure (TCLP) test. The density test and LOI test were also being done for the blended cement. From the tests for IFA and cement, it can be found that density the density of fly ash and cement that has been used for this study were found to be 0.76 g/cm^3 and 3.67 g/cm^3 respectively. Then, the specific gravity of fly ash and cement were 1.69 and 2.98, accordingly. XRF results shows that both materials have highest content of aluminium, silica and iron, as expected. LOI of fly ash and cement were found to be 17.33 % and 12.33 %, respectively. In terms of the leaching rates of heavy metals (Mn, Ni, Cd, Cr, Cu), only Cd leached at rate 2.39 mg/L, which is above the USEPA's regulatory level, 1.0 mg/L. 5 %, 10 % and 15 % of IFA was mixed with cement to produced blended cement. As the density of blended cement, it was found to be 1.12 g/cm^3, 1.08 g/cm^3 and 1.09 g/cm^3 for each of 5 %, 10 % and 15 % of fly ash in blended cement.

Keywords: Fly ash, cement, concrete, construction materials, leaching

1. Introduction

Municipal solid waste incineration (MSWI) is a technology that offers several important advantages such as reduced volume and weight, fast treatment speed and heat energy rehabilitation. It is extensively used worldwide. Incineration fly ash (IFA) is the residues that was produced from this technology. However, IFA contains significant amount of toxic heavy metal materials, for instance, Pb, Cr, Cd, Cu, Zn and more elements. An amount of them go back to the environment and it will gradually pollute the source of groundwater, soil and air and cause secondary

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pollution by acid rain. Consequently, adequate treatment processes for fly ash should be established and the final form of IFA should be ensured harmless to the environment especially to human. In recent years, global cement production has risen at a very high pace and is the third biggest source of anthropogenic carbon dioxide emissions which are around 8 % of global carbon dioxide (CO_2) emissions [1]. Thus, worldwide are produced more than 3.8 billion tons of cement per year. A ton of cement produces about 0.33 tons of CO_2 and takes approximately 4.14 GJ of energy. Besides, blended cement and concrete mineral admixtures have been used to partly substitute Portland cement because of its environmental advantages in terms of product efficiency, marketing, and financial profits.

The application of IFA in cement or concrete is mainly designed to save energy and reduce carbon emissions [2]. Fly ash was frequently recycled in the concrete and cement industry as an alternative cement substitute for a long time [3]. However, the relatively large size of the particles led to the lesser hydration and hydration percentage of normal fly ash. The early strength of concrete along with cement consists of fly ash and the strength production is also decrease, which means that the approach of cement or concrete content fly ashes is restricted to some degree and its technological use is also subject to some regulations. Due to worries about the environment, the economy, and product quality, there has been a significant rise in the use of supplemental cementitious materials (SCM), including natural, waste, and by-product materials. Employing local resources, especially waste materials, which are both affordable and have the potential to be used to dispose of hazardous waste that would otherwise contaminate the environment, is one of the most popular decisions made for economic reasons. The urge for the recycling of waste has become a major aim as it can help to achieve nation's sustainable development goals for the betterment of the world for our future generations.

2. Characterizations of Incineration Fly Ash and Cement

To accomplish the main objective of this research, several tests have been conducted aiming to study the characterization of IFA and cement as new inventive blended cement production. IFA was collected from Incineration Plant situated in Pahang, Malaysia. It has undergone a drying and sieving process before it can be used in this study. Test that has been conducted were density, specific gravity, X-Ray Fluorescence (XRF), Loss of Ignition (LOI) and Toxicity Characteristic Leaching Procedure (TCLP). The method for every test is clearly explained in the next subsection.

2.1 Density Test

In this study, the density of IFA and cement was determined by using the guidelines stipulated in [4]. The mass per unit volume of a substance is defined as its density (ρ). For this test, a pycnometer of known volume which is 50 ml (V) is used. At first, the sample was added to the pycnometer until it full, then the top of the pycnometer is scrapped to remove any excess residue of the sample. The weight of the sample was recorded (m). The density of the sample is calculated by dividing the mass over volume. The same test procedure is used to determine the properties of blended cement. In the equation m is mass of the sample in g, v is the volume and ρ is the density.

2.2 Specific Gravity Test

Specific gravity of IFA and cement is one of the important physical properties needed to be determined prior it can be used in the manufacturing of blended cement. This is because the specific gravity has a great influence for determining the strength and quality of any new concrete product [5]. Specific gravity test was conducted on cement and IFA following the method stipulated in [6]. Specific gravity is the ratio of the mass of dry particles to the mass of water they displace which is dimensionless quantity. Firstly, the dry pycnometer bottle with the stopper is weighed. Mass of dry sample is transferred into the bottle at 5 g. Inside the vacuum desiccator, the bottle is placed without its stopper. It is vacuumed until all the air is released. The lid is removed from the desiccator and the vacuum is released. The further steps are strictly following the method as mentioned in the standard. To calculate the specific gravity of the sample, the weight for each m values is measured where m_1 is the mass of pycnometer (g), m_2 is the mass of the pycnometer and dry sample (g), m_3 is the mass of pycnometer, sample, and water (g) and m_4 is the mass of pycnometer when full of water only (g). The formula used for calculation of specific gravity is as described in [6].

2.3 XRF

XRF test was conducted for identifying the elemental components for both IFA and cement. The element compositions for IFA should be in accordance with the cement content because the mixture of these two materials can create more enhanced materials. As IFA contained hazardous substances content, XRF proves to be an efficient method to identify the compositions. XRF analyzers determine the chemical content of a sample by measuring the fluorescent or secondary X-ray from a sample when a primary X-ray source excites it. For XRF test, XRF spectroscopy screening has been submitted to be tested at SIRIM QAS International Sdn. Bhd., Kuala Lumpur. For the preparation of the sample, cement and IFA were grinded to the size of 75 μm [7].

2.4 Loss of Ignition (LOI)

LOI describes how the sample weight changes after it was exposed in high temperature until it was burnt and volatilize its content. Unburnt carbon in the IFA can have a substantial impact on its future benefits. The ability of IFA to further volatize at a specific temperature will influence the properties of the materials that utilise IFA as one of the raw materials. The LOI is a widely used way to estimate the IFA carbon content of non-burned ash [8]. LOI test procedure for IFA and blended cement provides some general steps. Firstly, 5 g sample is exposed to temperatures in the range between 900 °C to 1000 °C in a muffle furnace where it experiences weight loss. The sample is subjected to constant temperatures changes and stop when the sample mass become constant. After the mass is constant, the samples were weighed again. An uncovered porcelain crucible is needed to hold the sample during the LOI test. LOI can be determined by finding the percentage different in mass where Mi is initial mass in gram and Mc is mass after ignited, also in gram. The same test procedure is used to determine the properties of new inventive blended cement in this study.

2.5 Toxicity Characteristic Leaching Procedure (TCLP) Test

Basically, TCLP is a chemical analysis method used to determine whether hazardous elements are present in a waste. The Environmental Protection Agency (EPA) developed a protocol known as the Toxicity Characteristic Leaching Procedure to determine the potential of specific wastes to leach dangerous concentrations of toxic chemicals that can polluted the groundwater sources. The TCLP is used to estimate how much of IFA toxic content would be released into landfill leachate under normal conditions if it contained one or more of the listed toxins. Metal toxicity testing was performed on IFA by extracting metal from sediment using the TCLP test. The standard operating procedure (SOP) of TCLP, United States Environmental Protection Agency (USEPA) Method 1311 [9] was strictly followed.

2.6 Mix Design for Blended Design

IFA are mixed with the cement to produce a new inventive blended cement. Part of the cement was replaced by IFA in several different percentages which begins with 5 %, 10 % and 15 %, respectively. The same test procedure for density and LOI that have been explained in subsection 2.1.1 and 2.1.4 is used to determine the properties of this new inventive blended cement for this study.

3. Properties of Incineration Fly Ash (IFA) and Cement

3.1 Density

The density result of IFA was found to be 0.76 g/cm^3. Finding from [10], the density of fly ash is in the range from 1.5 to 2.4 g/cm^3. The obtained result for the density of IFA was slightly lower from previous study. The differences in density resulted from various factors including the sources of the IFA itself. In general, the particle density tends to become low with the increased IFA particle diameter because the number of closed voids with the diameter of the particle is also increasing. The density of cement used in this study was found to be 3.67 g/cm^3. The commonly assumed density of ordinary Portland cement (OPC) is 3.15 g/cm^3 [11]. The density of a powder is the proportion of the mass and volume of an untapped powder sample, including the contribution of a void volume [12].

3.2 Specific Gravity

Based on the results obtained, the specific gravity of IFA and cement were found to be 1.69 and 2.98, respectively. Specific gravity is calculated by dividing the density of a substance by the density of water. The density units will cancel each other out, resulting in a unitless number for specific gravity.

3.3 XRF

XRF technique is a non-destructive elemental analysis method that is fast and suitable for simultaneous quantitative determinations. XRF is a method of analysis that determines the composition elementary to all types of materials. It can also determine materials in different forms, such as solid, liquid and powder. In the case of loose powder samples, the finer the sample, the more likely it is to have an even surface and thus provide a better analysis. The performance of X-Rays is affected by irregular sample surfaces and the size of the samples. For this research, XRF test was conducted on both IFA and cement samples. Table 1 shows the elemental composition of IFA and cement. It can be noted that the amount of Calcium (Ca) was the highest for cement sample with 61.99%, followed by Silicon, Aluminium and Iron which is 22.23%, 10% and 1.37%, respectively. The same elemental compounds can be found in IFA. These elemental compounds are very important as it contributed and have influence on the strength and durability of the mortar or concrete that utilizes the new inventive blended cement mixture. This is because the reactivity of IFA particle surface will enhance the pozzolanic reaction of IFA which attributes to the dissolved Na and K ions. The alkalisilica reactions which existed in Ca-Si and Ca-Al hydrates are occurred when the dissolved Si and Al ions react with $Ca(OH)2$, resulting from the cement hydration process. Thus, it will contribute to the cement matrix's structure increasingly dense and enhancing the mortar's compressive strength [13].

Table 1 - Elemental compositions in IFA and cement

Element	IFA (wt. %)	Cement (wt. %)
Magnesium, Mg	2.70	0.00
Aluminium, Al	16.60	10.0
Silicon, Si	22.78	22.23
Sulphur, S	1.00	0.47
Potassium, K	4.01	1.72
Calcium, Ca	44.58	61.99
Titanium, Ti	1.21	0.11
Iron, Fe	2.68	1.37
Barium, Ba	0.08	0.02

3.4 Loss of Ignition (LOI)

The LOI of IFA and cement were found to be 17.33 % and 12.33 %, respectively. The results obtained were slightly higher when compared with the limit requirement. Higher LOI of IFA can affect the strength of concrete. It is because the remaining carbon in fly ash can accumulate water and chemical admixtures, limiting their effectiveness or possibly causing an insufficient air-void system in the concrete. So as the coarser carbon particles have a lower fineness, the pozzolanic reaction of the fly ash will be reduced. The use of low-quality fly ash with a high LOI and low fineness is expected to have a substantial impact on the development of concrete strength.

3.5 Toxicity Characteristic Leaching Procedure (TCLP)

TCLP test was conducted on IFA and the results obtained are shown in Table 2. The results then are compared to USEPA (1992) regulatory levels. Based on the previous XRF results, seven (7) main chemical compounds or elements were detected in IFA. These 7 elements were selected to be tested using Atomic Absorption Spectrometry (AAS) for the leachability test. According to Table 2, the result showed that different chemical elemental leached out from the sample with different level of concentration. The highest rate of leached out from the sample is from Ca, Fe and Mg among other heavy metals which are 412.20 mg/L, 56.08 mg/L and 35.11 mg/L, respectively. According to [9] the regulatory level for Ca, Fe, Mg and Mn are not available because they do not categorize as heavy metals. However, for Ni, Cd, Cr and Cu, there was the limit concentration in accordance with USEPA (1992). USEPA allows for only an infinite concentration of each metal in waste.

The concentration of Ni and Cr that leached out from the IFA sample was at 3.85 mg/L and 1.76 mg/L, accordingly. The concentration rate of Ni and Cr still below the regulatory level which is 5 mg/L. Besides, the limitation concentration level for Cu is 100 mg/L. Its concentration was recorded lowest which is 0.05 mg/L from the IFA, so it was still under the regulatory level. Concentrations of Cu were marginally low throughout the TCLP test. Furthermore, the concentration of Cd in the MSWI fly ash sample is 2.39 mg/L. Only Cd leached above the USEPA's regulatory level which is 1.0 mg/L in this study. These compounds can have hazardous impacts to the environment and requires further treatment before it can be disposed. To avoid the heavy metals leached out from the IFA at the landfill, many researches have established that waste IFA can be used to replace cement in appropriate proportions and that it is an effective method for addressing the issues of solid waste landfill space scarcity, soil contamination and environmental pollution.

4. Properties of Blended Cement

4.1 Density

Density can be referred to either the unit volume of a packed powder or the specific gravity of the solid material [14]. Both are critical parameters in mortar design, and accurate measurement of density is required for the conversion of volume and mass for the calculation of particle size distribution and mortar unit weight. In this study, the density of IFA and cement were found to be 0.76 g/cm^3 and 3.67 g/cm^3, respectively. Blended cement was produced by mixing both IFA and cement with several selected percentages of IFA which were 5 %, 10 % and 15 %. To produce new inventive blended cement. Fig. 1 shows the density of blended cement produced in this study.

Table 2 - Allowable concentration level of IFA

Element	Concentration Level of IFA (mg/L)	Concentration Level (mg/L) [9]
Calcium, Ca	412.20	NA
Iron, Fe	56.08	NA
Magnesium, Mg	35.11	NA
Manganese, Mn	7.69	NA
Nickel, Ni	3.85	5
Cadmium, Cd	2.39	1
Chromium, Cr	1.76	5
Copper, Cu	0.05	100

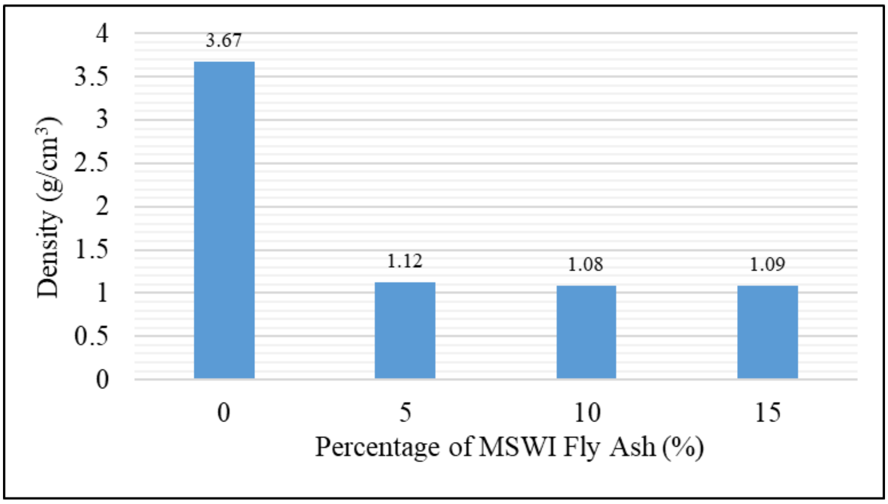

Fig. 1 - Density for 5%, 10% and 15% IFA content in blended cement

Based on Fig. 1, it can be concluded that the density of cement itself was higher than blended cement which is depicted from the first bar in the graph with the value of 3.67 g/cm^3. The density of blended cement is slightly reduced for other mixture because the lower density of the IFA contributes to lower density of the mixture. Density of blended cement decreasing from 1.12 g/cm^3 to 1.08 g/cm^3, accordingly in blended cement containing 5 % and 10 %. It is because the density decreases with increasing surface roughness and depends on particle size distribution as particle shape becomes more irregular. Density values increased as the grain diameter of IFA is decreased. However, more accurate density measurements for cement and other cementitious materials are required to properly design the mortar mix by volume.

4.2 Loss of Ignition (LOI)

Fig. 2 shows the result of LOI for blended cement containing 5 %, 10 % and 15 % of fly ash. Based on the result obtained, it can be concluded that the higher the percentage of IFA in blended cement, the higher the value of LOI can be achieved. Besides, LOI of cement used in this study was 12.33 % which is it lower than the blended cement containing IFA. From the data obtained, it can be observed that the LOI for 5 %, 10 % and 15 % of IFA in blended cement were found to be 12.33 %, 13.6 % and 16.33 %, respectively. LOI is gradually increasing when the percentage of IFA is increasing because LOI of certain pozzolanic materials may also contain unburned fuel contaminants which therefore contribute to an increase in the value of LOI [15]. LOI of blended cement is still much higher than the upper limitation of 6% as stipulated by ASTM C618. To conclude, various factors, such as sample size, exposure time and sample position in the furnace, are responsible for the LOI results. The chemical composition of IFA contains unburned carbon, as measured by loss on ignition, which has the greatest impact on mortar quality. Higher LOI resulted in a higher water requirement because residual carbon in IFA can absorb more water and chemical admixtures, by that, it will reduce the durability of concrete.

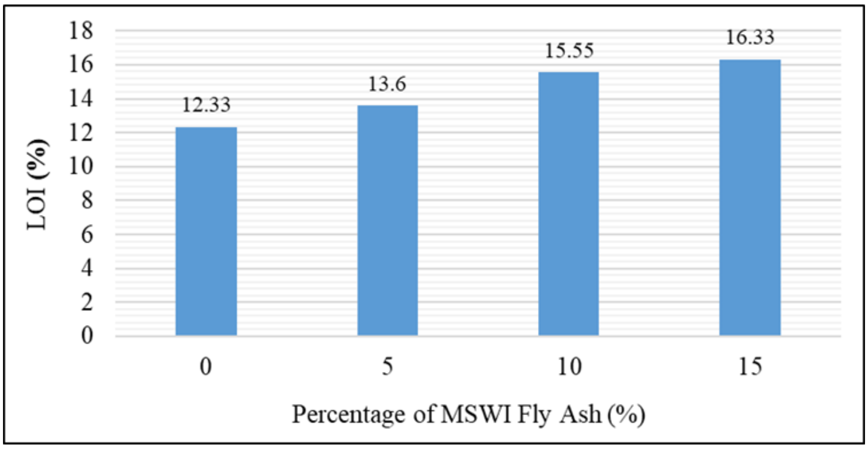

Fig. 2 - LOI for several mixture of new inventive blended cement

5. Conclusions

The characterization of IFA and cement were investigated according to physical and chemical properties. Density and specific gravity were the physical properties test that have been carried out on both samples. Based on the result obtained, the density of IFA and cement were found to be 0.76 g/cm^3 and 3.67 g/cm^3 respectively. Then, the specific gravity of IFA and cement were 1.69 and 2.98, accordingly. Density and LOI test were well carried out on blended cement that made from 5 %, 10 % and 15 % of IFA. Density of blended cement was found to be 1.12 g/cm^3, 1.08 g/cm^3 and 1.09 g/cm^3. Then, for the results of LOI for a blended cement, it can be indicated that the higher the fly ash in blended cement, the higher the LOI value.

The potential used of a new inventive blended cement produced in this study can be further investigated by applying the blended cement in the mortar or concrete production. By using an optimal amount of IFA, the mechanical properties of blended cement mortar expected to be improved. The amount of cement used for will be reduced by controlling the percentage of IFA. This reduces the cost of cementitious composites, increases the usage of waste materials, and reduces the release of carbon dioxide (CO_2) by using less cement. The optimum proportion will help the country's economy by reducing cement use, carbon dioxide emissions, and contributing to the economy as one of the efforts to achieve sustainable development goals (SDG).

Acknowledgement

Authors would like to thank Universiti Malaysia Perlis for funding this research under RESMATE (Grant Number: 9001-00623).

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