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Microstructure and Strength of Alkali-Activated Bricks Containing Municipal Solid Waste Incineration (MSWI) Fly Ash Developed as Construction Materials

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Abstract: Alkali-activated materials (AAM) are widely applied in the field of building materials and civil engineering to substitute cement materials. This study used two types of municipal solid waste incineration fly ash (MSWI-FA): grate-firing fly ash (GFFA) and fluidized bed fly ash (FBFA) as brick raw materials. Various weight ratio of 20%, 30%, and 40% GFFA and FBFA were added to coal fly ash (CFA), GGBFs (Ground Granulated Blast-Furnace Slag), and an alkali-activating reagent to produce alkali-activated bricks. Microstructure and crystalline phase composition were observed to analyze their compressive strength, and a leaching test was used to prove the material's safety for the environment. It can be seen from the results of this study that the alkali-activated bricks containing FBFA had higher compressive strength than those containing GFFA in the same amount. Considering the engineering properties, the alkali-activated bricks containing FBFA are more suitable to be used as building materials. The difference in the compressive strength resulted from the large amount of calcium compounds and chloride salts present in the GFFA. From SEM analysis, it was observed that there was a large number of pores in the microstructure. It was also found from the results of XRD that the bricks containing GFFA contained a large amount of chloride salt. From the results of the two leaching tests, it was found that the amounts of six heavy metals detected in the leachates of the bricks in this study met the corresponding regulation standards. This described MSWI-FA is suitable for use as alkali-activated material, and its products have potential to be commercially used in the future.

Keywords: alkali-activated; municipal solid waste incineration fly ash; fluidized bed; brick

1. Introduction

According to China's 13th Five Year Plan, the total quantity of incineration waste is estimated to be 591,400 tons per day by 2020, and the annual municipal solid waste incineration fly ash (MSWI-FA) will reach 10 million tons. Waste MSWI-FA is a fine-particle material intercepted by the air pollution control equipment of waste incineration plants. It is rich in heavy metals and chloride salts. If it is disposed of haphazardly, it will cause harmful effect to the environment and human body. Therefore, China's National Hazardous Waste Inventory has clearly stipulated that domestic waste MSWI-FA is hazardous waste (No. HW18). The main treatment procedure of MSWI-FA consists in burying it in landfill sites after chemical treatment and cement solidification. However, the land in China is seriously insufficient nowadays, and the landfill treatment is no longer a suitable solution for MSWI-FA disposal [1].

The earth's resources are limited. International scholars are working together to find solutions to reduce the exploitation of natural resources, recycle wastes, and create sustainable environments. The recycling of inorganic waste is mainly applied to engineering materials. Recent researches and studies on the recycling of MSWI-FA include sintering of environmentally friendly cement [2], MSWI-FA as cement admixture [3,4], MSWI-FA as sintering bricks [5,6], melting/vitrification of MSWI-FA [7], and other technologies. However, there are still some issues in these technologies that prevent their wide application. Therefore, the treatment of MSWI-FA is still a difficult environmental problem. The above-mentioned MSWI-FA resource technologies face the following challenges:

1. In 2016, China government revised the National Hazardous Waste List. As long as the MSWI-FA meets Standard GB30485 (Cement Kiln Cooperative Disposal Solid Waste Pollution Control Standard), it can enter the cement kiln co-disposal. However, the chloride ion concentration of MSWI-FA in China is 15% [8] and, in order to meet Standard HJ662-2013 (Technical Specification for Environmental Protection of Solid Wastes in Cement Kiln Co-processing), it has to be lower than 0.04% to be eligible to enter the cement kiln. Therefore, washing with water is required to reduce the chloride ion concentration of MSWI-FA. As a result, the washing will produce a large amount of wastewater with high concentration of chloride salt, which will increase the treatment cost. In addition, heavy metals content in fly ash is higher than in the general cement raw material. Therefore, it is necessary to add a precipitation agent during the water washing pre-treatment, which in turns increases the cost of co-processing of cement kilns. Since the original concentration of the chloride ion in the MSWI-FA is too high, water washing can remove more than 90% of chloride ion concentration, but the amount of cement kiln added is limited to only about 10% [9].
2. The results from the study of replacing concrete with MSWI-FA to produce concrete showed that the metal elements contained in the incinerated fly ash will expand causing the specimen to crack, which in turns affects the strength of the product [10]. The MSWI-FA has a high chloride salt concentration, thus it is not suitable for cement mortar. MSWI-FA can be used as a substitute material after washing. However, it is recommended that the gray fly replacement rate should be less than 20%, and the amount of heavy metal leaching from MSWI-FA will increase. In a long-term situation, it may be harmful to the environment. [11,12]. Furthermore, some studies have shown that MSWI-FA can be added to concrete up to 50% after heat treatment at 750 °C. However, the quantity of MSWI-FA would be huge and rich in chloride salt. A high-temperature treatment can easily cause equipment corrosion, and the treatment cost is high [13].
3. The studies on the recycling of MSWI-FA melted bricks or pellets showed that the fly ash needs to be melted at 1400 ° C and then mixed with clay at 800 °C to make bricks, at a maximum proportion of 40% [5]. Alternatively, with a small amount of ceramic tiles sintered directly at 900–1060 °C, the maximum quantity can reach 30% [6]. However, high-temperature pre-treatment of MSWI-FA is also expensive, and harmful substances in the melting process may be converted into gaseous pollutants, causing secondary pollution problems.

According to the literature, the MSWI-FA technology needs to be stabilized by pre-treatment. However, there are energy consumption or secondary pollution issues, and the product stability is still insufficient. Hence, there is no relatively mature MSWI-FA resource technology at the moment.

The alkali-activated technology is commonly applied to waste source recovery of industrial wastes rich in Ca, Si, and Al through alkali activators, such as GGBFs, coal fly ash (CFA), etc., to induce a hydration reaction [14]. In addition, the literature indicates that the cementation reaction of the alkali-activated system can effectively control the deposition and diffusion of chloride ions. Also, the alkali-activated technology leads to products with better mechanical properties and durability than the general cement [15].

China has two common waste incinerators: mechanical incinerators and fluidized bed incinerators. Chemically, MSWI-FA consists of Ca, Si, and Al. It could be reused as an engineering material through the alkali-activated technology. However, the two types of MSWI-FA are different. It is necessary to clarify the compositional differences after recovering for recycling [16]. Moreover, the alkali-activated technology is currently applied to MSWI-FA mainly for solidification and stabilization of the contained heavy metals [17–19], and the engineering properties are rarely discussed. In addition, in studies on MSWI-FA, the natures of the MSWI-FA resource generated by two different types of furnace are rarely compared.

This study used two different types of MSWI-FA as raw material, together with industrial wastes such as GGBFs and CFA, to produce cold-bonded bricks by alkali-activated technology. This recycling process is more energy-efficient compared to other recycling processes. The results obtained from microstructure analysis and mineral crystal phase analysis, indicated that the difference in the compressive strength of the bricks was mainly caused by the different composition of the two types of MSWI-FA. In contrast to what previously reported, the leaching test results showed both types of bricks meet the regulation standards. In summary, this can be a very competitive recycled green product with a low cost.

The results from this study prove that MSWI-FA has the potential to be used as recycled material. The reported technologies could be considered as references for the recycling/handling of municipal solid waste (MSW) residue and industrial wastes.

2. Materials and Methods

2.1. Raw Materials for Manufacturing Brick Powders

This study utilized grate-firing bed fly ash (GFFA) and fluidized bed fly ash (FBFA) to produce alkali-activated bricks. Other raw materials used were coal fly ash (CFA), GGFBs and an alkali-activated reagent. GFFA and FBFA were obtained from waste incineration plants in Shanghai and Anhui. The coal fly ash (F-grade fly ash) was collected from a coal-fired power plant in Anhui. The GGBFs are commercial products purchased from the market. The chemical compositions of each material are shown in Table 1. CFA mainly consisted of Al_2O_3 and SiO_2. GGBFs consisted of Al_2O_3, SiO_2, and CaO. GFFA consisted of CaO, with a high content of chloride salt (23.08%). FBFA consisted of SiO_2 and CaO and contained 4.84% chloride salt, which is far lower than in GFFA. The heavy metal content of MSWI-FA is reported in Table 2. These two types of MSWI-FA contained various heavy metals, including Ba, Cu, Cr, Hg, Ni, Pb, Se, and Zn.

Table 1. Chemical compositions of coal fly ash (CFA), GGBFs, grate firing fly ash (GFFA), and fluidized bed fly ash (FBFA) (wt %).

Chemical Composition	Na_2O	MgO	Al_2O_3	SiO_2	CaO	Fe_2O_3	Cl
CFA	0.26	0.82	24.38	56.83	5.90	5.95	-
GGBFs	-	5.84	14.77	32.38	42.78	0.35	-
GFFA	2.08	1.26	0.68	3.14	57.78	0.93	23.08
FBFA	0.28	4.44	10.75	21.80	40.34	7.19	4.84

Table 2. Content of heavy metals in GFFA and FBFA (mg/kg).

Heavy Metal	Ba	Cu	Cr	Hg	Ni	Pb	Se	Zn
GFFA	245	3524	657	28	285	690	37	2368
FBFA	485	5861	754	34	348	864	62	4256

The alkali-activated reagent was prepared in-house. It contained sodium silicate and sodium hydroxide. The weight-ratio composition of the purchased sodium silicate (Wenhua Chemical Co., Ltd., Philadelphia, USA) was Na_2O:SiO_2:H_2O = 8.20:29.7:62.1. The concentration of sodium hydroxide was 46% (wt/wt), and the molarity was 21.30M.

The module ratio of SiO_2/Na_2O in the alkali-activated reagent was controlled at 1.20. The quantity of alkali-activated reagent to be added was calculated on the basis of the Na_2O content in the GGBFs (3.75% wt Na_2O). The density of the bricks was 1850 kg/m^3 with the different mixtures. The mixtures were designed on the basis of results of previous studies. The design of the mixtures is shown in Table 3.

Table 3. Design of alkali-activated bricks of municipal solid waste incineration fly ash (MSWI-FA)

Sample ID	MSWIFA (kg/m^3)	CFA (kg/m^3)	GGBFs (kg/m^3)	Alkali-Activated Reagent (g)	
				NaOH	Na_2SiO_3
GFFA 20%	370	740	555	64.7	135.3
GFFA 30%	555	555	555		
GFFA 40%	740	370	555		
FBFA 20 %	370	740	555		
FBFA 30 %	555	555	555		
FBFA 40 %	740	370	555		

2.2. Molding and Curing of the Brick Specimens

This study used the molding procedure to produce bricks.

1. Weigh the alkali-activated reagent and CFA according to the designed mix proportion.
2. Mix the alkali-activated reagent and CFA. Let the material sit for 10 minutes.
3. Add GGBFs and MSWI-FA (GFFA or FBFA) and mix. Add appropriate amount of water during the mixing to obtain a wet powder.

Place the well-mixed wet powder into a mold of 20 cm × 10 cm × 5 cm. Set the pressure to 100 kg/cm^2 and start the molding. Once the molding is completed, immediately release the brick from the mold and place it at room temperature (25 °C) for one day. Subsequently, soak the brick in saturated lime water to proceed with the curing.

2.3. Compressive Strength Test

In order to determine the compressive strength development in the alkali-activated bricks, this study performed compressive strength tests on alkali-activated bricks cured for 3 days, 7 days, 14 days, and 28 days. The compressive strength test was based on GB standard methods (GB 21144-2007). Stacked bricks, 40 mm to 90 mm thick, were used to measure the maximum amount of compressive load on the bearing area of each brick using the compressive mechanism (ADR Touch Control Pro 3000 BS, ELE, UK).

2.4. Scanning Electron Microscopy (SEM)

SEM was used to observe the microstructure of the bricks produced from the two kinds of incineration fly ash. The brick samples with particle size lower than 1 mm after the compressive test were collected and pasted with carbon-coated tape. Image observation at 1000- and 6000-fold magnification was performed, using a scanning electron microscope (Hitachi, Model SEM S-3000N, Japan) after gold-coating.

2.5. Analysis of X-Ray Eiffraction (XRD)

This study applied XRD technology to understand the crystal composition of the bricks produced with the two kinds of incineration fly ashes, investigating how the different amounts of fly ashes affected the chemical structure of the new-formed bricks. The brick samples were crushed and ground to a fine powder with particle size lower than 75 μm (No. 200 mesh, USA standard testing sieve) for the X-ray diffraction (XRD) analysis. The powder samples were analyzed using an XRD spectrometer (Bruker, D8 Advance, USA) with Cu Kα radiation to acquire their mineralogical composition. The XRD step-scan mode was used at 0.03°2θ per step in 15–75°2θ, with a data collection rate of 2 s/step [20,21].

2.6. Leaching Test of Heavy Metals

The alkali-activated bricks were made from industrial wastes. The recycled product needed to be tested not only for their compressive strength to meet the standards but also for their safety to pass the environmental compatibility test. This is necessary in order to later use these products in the industry. The leaching test of heavy metals was conducted referring to the methods HJ/T 299-2007 (Solid Waste Extraction Procedure for Leaching Toxicity—Sulphuric Acid & Nitric Acid Method) and HJ/T 300-2007 (Solid Waste Extraction Procedure for Leaching Toxicity—Acetic Acid Buffer Solution Method).

HJ/T 299-2007(Solid Waste Extraction Procedure for Leaching Toxicity—Sulphuric Acid & Nitric Acid Method) was used to examine whether the waste would leach in an acid rain environment, causing environmental damage. This study analyzed the level of the common heavy metals in the fly ash: Cu, Zn, Pb, Cr, Ba, Se. The test procedure is summarized as follows:

1. Sieve the dried sample through a 9.52 mm sieve mesh.
2. Prepare the simulated acid rain by adding a 2:1 weight percent mixture of sulfuric and nitric acids to water until the pH is 3.20.
3. Weigh approximately 150–200 g of sample into a 2L PE bottle, then add the simulated acid rain at a weight/volume ratio of 1/10.
4. Seal the PE bottle and place it in a rotary agitator; rotate at 30 ± 2 rpm for 18 h ± 2 h at 23 ± 2 °C.
5. Filtrate the leachate with a 0.45 mm membrane filter. The concentration of all metals in the leachate was analysed using ICP-OES.

HJ/T 300-2007(Solid Waste Extraction Procedure for Leaching Toxicity—Acetic Acid Buffer Solution Method) was used to simulate the condition of waste buried in a sanitary landfill and examine whether the waste formed humic acid, such as acetic acid, and leach into the surrounding environment, causing environmental damage. This study analyzed the level of the common heavy metals contained in the fly ash: Cu, Zn, Pb, Cr, Ba, Se. The test procedure is summarized as follows:

1. Sieve the dried sample through a 9.52 mm sieve mesh.
2. Dilute 17.25 mL glacial CH_3CH_2OOH with reagent-grade water to a volume of 1 liter. The pH of the reagent should be 2.64 ± 0.05.
3. Weigh approximately 75–100 g of sample into a 2L PE bottle, then add the prepared reagent at a weight/volume ratio of 1:20.
4. Seal the PE bottle, place it in a rotary agitator, and rotate at 30 ± 2 rpm for 18 h ± 2 h at 23 ± 2 °C.
5. Filtrate the leachate with a 0.45 mm membrane filter. The concentration of all metals in the leachate was analyzed using ICP-OES.

The ICP-OES (Perkin-Elmer 2100 DV, USA) was further used to detect the concentrations of Ba, Cu, Cr, Pb, Se, and Zn in the filtered leachate, having to fit the regulation of Chinese National Standard GB 5085.3-2007 (Standards for Hazardous Wastes–Identification for Extraction Toxicity) and GB 16889-2008 (Standards for Pollution Control on a Landfill Site of Municipal Solid Waste).

3. Results and Discussion

3.1. Compressive Strength of the Different Types of MSWI Fly Ashes

Both GFFA and FBFA are MSWI fly ashes, and their percentages into the new developed bricks probably affected the compressive strength of the products and their environmental safety.

3.1.1. Effects of GFFA Addition on the Characteristics of Alkali-Activated Bricks

MSWI fly ash is a by-product of incinerated municipal garbage or wastes. In China, garbage classification, including inflammable garbage, nonflammable garbage, and food waste, is not completely defined, increasing the variety of products that can be present in MSWI fly ashes. The chlorine content of GFFA can reach 27%, seriously affecting the compressive strength of the products [22].

To investigate the compressive strength of the GFFA-containing alkali-activated bricks, different percentages corresponding to 20%, 30%, and 40% of GFFA were added, and the samples were tested after 3-, 7-, 14-, and 28-day curing periods. Figure 1 shows that the compressive strengths of 20.19 MPa, 15.16 MPa, and 11.34 MPa were respectively reported after the addition of 20%, 30%, and 40% GFFA into the alkali-activated bricks, obtained from the mixture of fly ash and GGBFs. A decrease in the compressive strength of the bricks was observed by increasing the percentage of GFFA, indicating that the large amount of Ca in GFFA had a negative effect on the alkali-activated system.

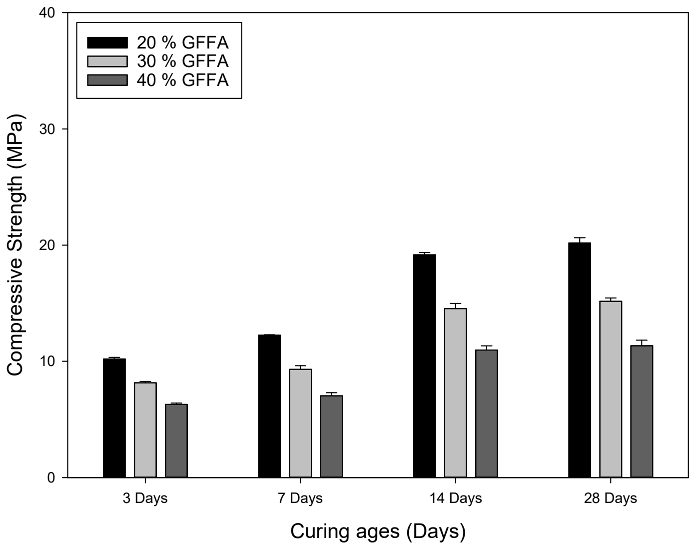


Figure 1. Compressive strength with different percentages of the GFFA in the alkali-activated bricks.

It was found in alkali activation related researches that an excessive amount of CaO will lead to decreased efficiency of the alkali activation system and result in an incomplete hydration reaction, which further affects strength development in the slurry [23]. In addition, the literature indicates that also in the alkali-activated or GEOPOLYMER system excessive $Ca(OH)_2$ has a negative impact on the development of compressive strength [24]. One of the probable reasons was that parts of chloride salts dissolved in the water during curing, forming many pores in the bricks and reducing the strength of the bricks. Excessive chloride salt may cause physical defects such as pores in the alkali-activated material, which damages its microstructure and affect the compressive strength [25].

3.1.2. Effects of FBFA Addition on the Characteristics of the Alkali-Activated Bricks

The FBFA contains high aluminum and silicon produced from the addition of quartz sand or slack, which were used to facilitate a complete combustion of the municipal waste in the fluidized bed [26], probably resulting in low residual chloride in the developed brick.

To investigate the compressive strength of the FBFA-containing alkali-activated bricks, different percentages of 20%, 30%, and 40% of FBFA were added, and the resulting products were tested after 3-, 7-, 14- and 28-day curing. Figure 2 shows that the compressive strengths of 36.67 MPa, 33.11 MPa, and 28.69 MPa were respectively reported after the addition of 20%, 30%, and 40% FBFA into the alkali-activated bricks, which were the mixture of fly ash and GGBFs. FBFA was more suitable for the alkali-activated system in comparison with GFFA. To fit the GB/T 21144-2007 standard of above

15MPa for compressive strength, the amounts of GFFA and FBFA to be added should be below 20% and up to 40%, respectively, to make the bricks.

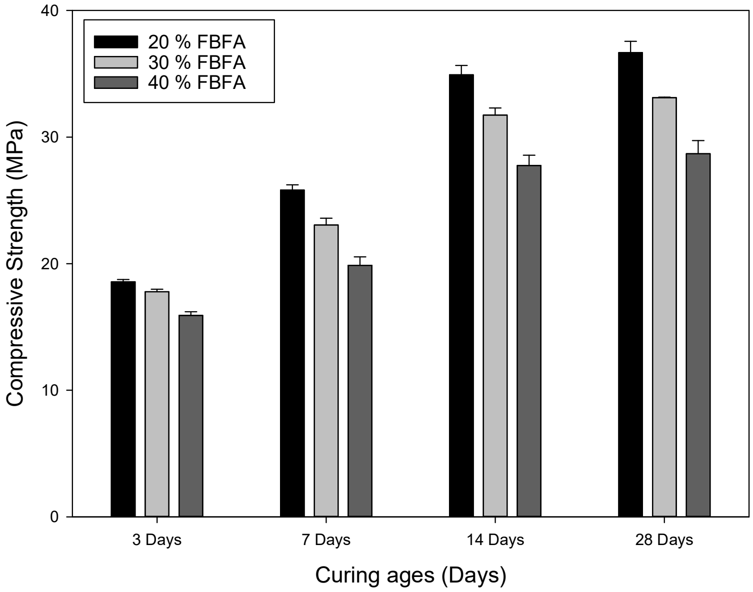


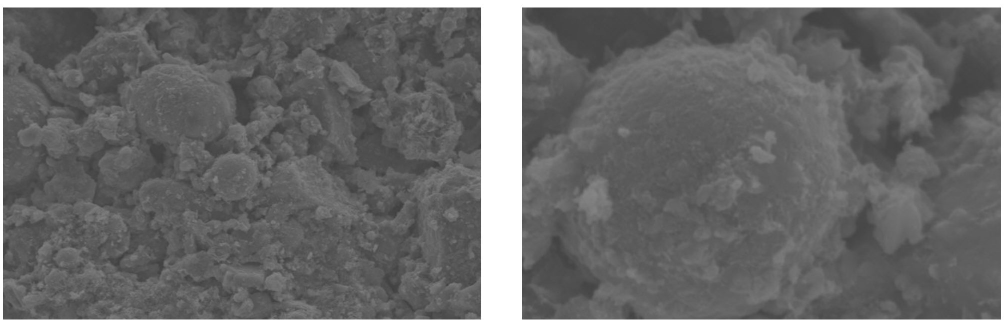
Figure 2. Compressive strength with different percentages of the FBFA in the alkali-activated bricks.

3.2. *Microstructures and Crystal Compositions of Two Types of Developed Bricks*

To further understand the microstructure and crystal composition of the developed bricks, SEM and XRD technologies were applied, suing to bricks with 20% GFFA or FBFA.

3.2.1. SEM Observation

The microstructure images of the two types of crushed bricks are shown in Figure 3a–d. Figure 3a,b show that GFFA-containing bricks had many pores, suggesting the insufficient development of hydration products in the bricks [27]. The FBFA-containing bricks formed a denser structure with many tabular crystalline elements, shown in Figure 3c,d. The complete crystalline structure in the new FBFA-containing brick allowed high compressive strength than for the GFFA-containing brick, in agreement with El-Yamany et al., 2018 [28].



(a) **(b)**

Figure 3. *Cont.*

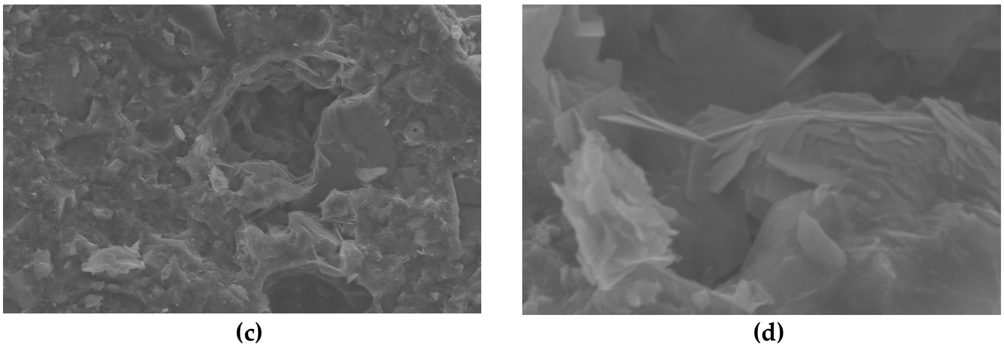


Figure 3. (**a**) Alkali-activated brick containing 20% GFFA, 1000-fold magnification; (**b**) Alkali-activated brick containing 20% GFFA, 6000-fold magnification; (**c**) Alkali-activated brick containing 20% FBFA, 1000-fold magnification; (**d**) Alkali-activated brick containing 20% FBFA, 6000-fold magnification.

3.2.2. XRD Analysis

The crystal compositions of the two types of brick are summarized in Figure 4, showing that both bricks presented three main peaks corresponding to calcium silicate hydrate (C–S–H), mulite (M), and quartz (Q). The FBFA-containing brick showed a larger peak area of mulite (M) and quartz (Q) than the GFFA-containing brick. In addition, it also had an extra peak of Gismodine (G), suggesting that it might influence the compressive strength of the brick, in agreement with Wang et al., indicating the suitable content of CaO to increase the hardness of the brick. On the other hand, the GFFA-containing brick had an extra peak of sodium chloride. The high chloride concentration probably decreases the compressive strength of brick or cement [22], indicating that the strength of the GFFA-containing brick was lower than that of the FBFA-containing brick.

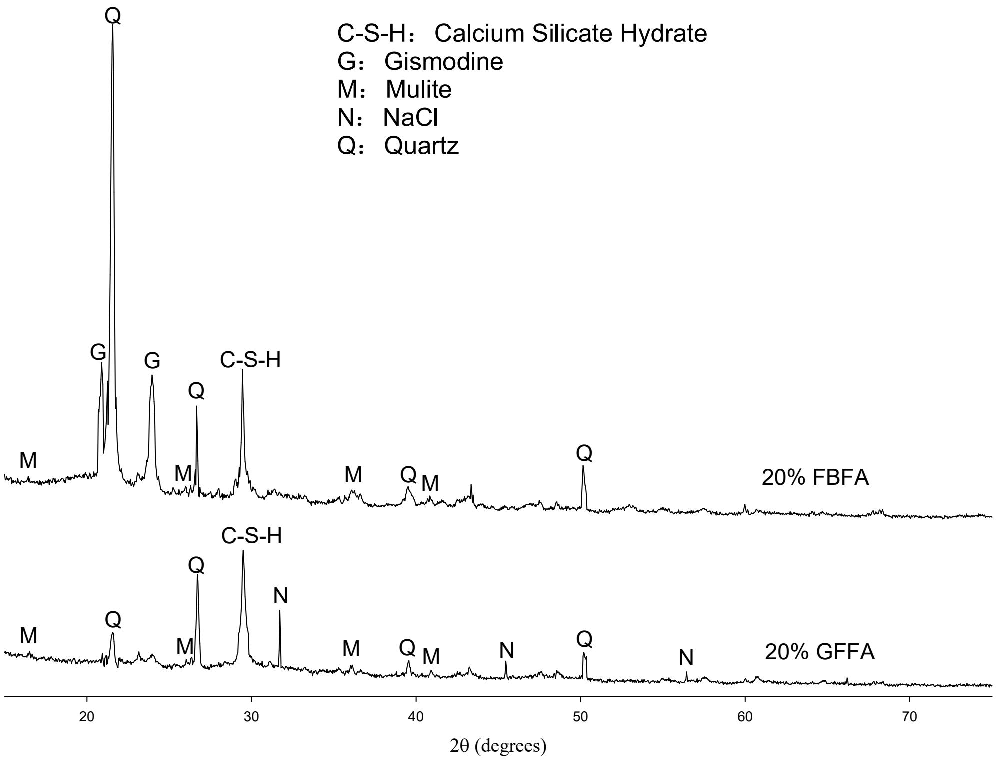


Figure 4. Results of XRD analyses for the new developed GFFA- and FBFA-containing bricks.

3.3. Leaching Test of the Two Types New Developed Bricks

MSWII-FA is a kind of hazardous waste; thus, the solidification and stabilization of heavy metals in the MSWII-FA-containing bricks was tested using two standard methods, i.e., HJ/T 299-2007 and HJ/T 300-2007. The concentrations of six heavy metals, i.e., copper (Cu), zinc (Zn), lead (Pb), chromium (Cr), barium (Ba), and selenium (Se) in the leachate has to meet the standards of GB5085.3-2007 and GB16889-2008.

3.3.1. Leaching Heavy Metal Concentrations of the Two Types New Developed Bricks by HJ/T 299-2007

Leaching of six heavy metals, i.e., Cu, Zn, Pb, Cr, Ba, and Se in two types new-developed bricks was determined using the method HJ/T 299-2007, and the results are summarized in Table 4. All metals in the GFFA-containing brick could be dissolved in the leachate, slightly more than that for the FBFA-containing brick. Fortunately, the amounts of all metals in the leachates of both new developed bricks were lower than the legal amounts according to GB5085.3-2007, indicating that both types of brick could be safely to applied in civil and building engineering, in replacement of cement materials.

Table 4. Concentrations of heavy metals in the leachates from alkali-activated bricks on the basis of the analytic method HJ/T 299-2007.

Incinerator FA Type	Amount of Addition	Elements				
		Cu	Zn	Pb	Cr	Ba
		Unit (mg/L)				
GFFA	20%	0.24	0.24	0.015	0.05	0.021
	30%	0.38	0.46	0.016	0.08	0.026
	40%	0.51	0.81	0.021	0.04	0.034
FBFA	20%	0.05	0.062	ND	0.02	0.008
	30%	0.04	0.094	ND	0.06	0.023
	40%	0.08	0.045	ND	0.05	0.015
GB5085.3-2007		100	100	5	15	100

ND: $< 0.2 \times 10^{-3}$ (mg/L).

3.3.2. Leaching Heavy Metal Concentrations of the Two Types New Developed Bricks by HJ/T 300-2007

Six heavy metals in the two types of new bricks were digested using the method HJ/T 300-2007, and the results are summarized in Table 5. The concentrations of four metals, i.e., Cu, Pb, Cr, and Ba in the GFFA-containing brick could be dissolved in the leachate, at higher concentrations than those observed for the FBFA-containing brick. However, Zn concentration in the GFFA-containing brick was lower than that of the FBFA-containing brick, probably due to the acetic acid buffer system [29]. Fortunately, the amounts of all metals in the leachates of both bricks were lower than those accepted according to GB16889-2008, when the amount of GFFA was lower than 40% in total. The above results indicate that the two types of new developed bricks could meet the pollutant control limits when MSWI fly ashes, determined as GFFA and FBFA, are used as raw materials to make new recycling products.

Table 5. Concentrations of heavy metals in the leachates from alkali-activated bricks on the basis of the analytic method HJ/T 300-2007.

Incinerator FA Type	Amount of Addition	Elements				
		Cu	Zn	Pb	Cr	Ba
		Unit (mg/L)				
GFFA	20%	1.84	1.84	0.16	2.82	2.92
	30%	1.64	2.67	0.19	3.04	2.68
	40%	2.63	3.68	0.24	3.55	3.48
FBFA	20%	0.94	9.48	0.09	0.83	1.54
	30%	1.08	8.97	0.17	0.66	2.16
	40%	2.17	10.65	0.21	1.64	2.67
GB16889-2008		40	100	0.25	4.5	25

ND: < 0.2×10^{-3} (mg/L).

4. Conclusions

This study used industrial wastes such as MSWI-FA, CFA, GGBFs to produce bricks to solve the current MSWI-FA treatment issues by the application of alkali-activated process technology. Two different types of MSWI-FA were used in this study: grate-firing fly ash (GFFA) and fluidized bed fly ash (FBFA). The large amount of calcium compounds and chloride salts existing in GFFA have a significant influence on the compressive strength of the alkali-activated bricks. It is suggested that these two types of MSWI-FA should be properly classified in future applications to effectively increase the recycling quantity of MSWI-FA and ensure the quality of the alkali-activated bricks.

After integrating GFFA and FBFA into the alkali-activated process to produce bricks, it was noted that with the same addition quantity, the bricks containing FBFA had a greater compressive strength than those containing GFFA. In this study, the highest quantity of GFFA was up to 30%, and the compressive strength of the brick met the requirements of GB21144-2007; FBFA could be added up to 40%, and the brick compressive strength was still higher than the GB21144-2007 standard. Moreover, it was also found with the leaching tests HJ/T 299 and HJ/T 300 that the leaching of six heavy metals met the standard requirements. This indicates the alkali-activated bricks also meet China Government's standard requirements for recycled products. The advantages of using MSWI-FA to produce bricks via alkali-activated process technology are their low cost, energy efficiency, and environmental friendliness. With proper mixture design, alkali-activated bricks can meet the required engineering properties and environmental safety standards and have the potential of commercial application.

Reference

Author Contributions: Conceptualization, P.X.; Data curation, Y.X.; Investigation, N.L.; Supervision, Q.Z. and W.Q.; Writing—original draft, P.X.; Writing—review & editing, P.X., Q.Z. and W.Q.

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