The use of municipal solid waste ash and calcium carbide waste as partially replacing cement raw materials for cement product

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Abstract:

An investigation on using municipal solid waste incinerator bottom ash (MSWI) and calcium carbide waste (CCW) as a part of the cement raw materials was performed. Cement raw meals were replaced by 5% and 10% of MSWI and CCW to study properties of the laboratory produced MSWI and CCW cements. Chemical composition, setting times, compressive strength and expansion in sulfate solution of the pastes and mortars made of MSWI cements and CCW cements were tested and compared with these made of conventional cement. It was found from the study that the chemical compositions of MSWI cements and CCW cements were similar to that of the control cement. However, SiO_2 content of MSWI cements was higher than that of the control cement, whereas CaO content was lower. Setting times of cement pastes were slightly delayed when MSWI or CCW were used to replace a part of raw meal in cement production. The longer setting times of these cement pastes were observed due to the lower C_3S but higher C_2S content than those in the control cement. Compressive strength of CCW cement mortars was close to that of the control cement. However, compressive strength of the mortars produced from MSWI cements was smaller than that of the control cement mortar, especially when the percentage of MSWI in the raw meal was increased.

Keywords: Municipal solid waste ash; Calcium carbide waste; Chemical composition; Setting time; Compressive strength

1. Introduction

The incineration of municipal solid waste (MSW), as a method for reducing volume of the waste, is currently receiving widespread attention. There are presently two methods of incineration of MSW [1] i.e. mass-burning and burning processed refuse-derived fuel (RDF). The mass-burning is the process to incinerate all MSW in the as-received condition, while the RDF process requires the removal of ferrous materials and shredding of the remaining MSW prior to burning. Volume reduction of MSW by either method of incineration ranges from 60 to 75 percent. The incineration of MSW creates two general types of ash: fly ash and bottom ash.

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MSW generation in Thailand is of critical concern, especially in big cities. Bangkok, alone, produced approximately 8,000 tons per day in 2002. The incineration of MSW is presently receiving attention as an effective disposal method for MSW in Bangkok. Like MSW, calcium carbide waste (CCW), another by-product from production of acetylene gas (C_2H_2), was produced approximately 30,000 tons in recent years. In general, CCW or calcium hydroxide ($Ca(OH)_2$) is obtained from the reaction between water and calcium carbide (CaC_2) as

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 \quad (1)$$

CaC_2 is produced by burning limestone ($CaCO_3$) to yield lime (CaO) and carbondioxide (CO_2) ($CaCO_3 \rightarrow CaO + CO_2$). Then CaO reacts with coal (C) and CaC_2 are obtained together with carbonmonoxide (CO) ($CaO + 3C \rightarrow CaC_2 + CO$).

MSW incinerator ash and CCW are normally disposed by landfilling that may create further problems, i.e. leaching of harmful compounds and alkali to groundwater. If MSW ash and CCW have a potential use in concrete, it will not only be able to reduce the consumption of cement raw materials but also be able to solve disposal problems of the MSW ash and CCW simultaneously.

Sisomphon K., Hongvinitkul S., Nimityongsakul P., Tangtermsirikul S. and Rachdawong P. [2] found that MSW ash has irregular grain surface and very high specific surface area. Other properties such as high loss on ignition, uncertainty in characteristics and low reactivity also caused problems to the reuse of MSW ash as a pozzolan. Hamernik J.D., and Frantz G.C. [3] studied the properties of concrete containing MSW fly ash and reported that different burning conditions affected the reactivity of MSW fly ash. In addition, samples from different waste compositions resulted in different chemical and physical properties of the final MSW ash cement. Krammart P., Martputorn S., Jaturapitakkul C. and Ngaopisadarn V. [4] studied the use of CCW as cement replacing material. The results show that the setting time of paste was delayed significantly. Compressive strength of mortars replaced with CCW was also greatly reduced compared with the control mortar. Sisomphon K., Tangtermsirikul S., Rachadawongs P., Sinthupinyo S. and Plang-ngern S. [5] classified the combustible MSWs into three major materials of papers, leaves, and foods. After preparation, leaves, papers and foods were separately burned in a ferrocement incinerator. Finally, each type of combustible MSW ashes was ground in a grinding machine for 45 minutes. The weight ratio of each combustible MSW ash to total raw meal was fixed at 0.05 for all series of the experiment. They found that chemical composition and setting property of these cements as well as the compressive strength of mortars made of these cements were equivalent to those of the control cement.

From the previous researches, the use of MSW ash and CCW as a pozzolan or cement replacing material gave various undesirable properties of the derived cementitious materials [2, 4]. The results of the research using MSW ash as a part of raw materials, by classifying the combustible MSW into paper, leaf and food, show that the general properties are similar to ordinary Portland cement (OPC) [5]. However, in practice, it is difficult to classify MSW before burning. Accordingly, this study presents the possibility of using MSW incinerator bottom ash (MSWI) and CCW as a part of raw materials in cement manufacturing. In real application, if MSWI or CCW is replaced in raw materials, it may be necessary to adjust the proportion of raw meal. However, to simplify the study, the raw meal was not adjusted. The properties of the derived cements, such as the physical properties, chemical compositions, setting time and compressive strength were tested and compared with the control cement derived from the conventional raw meal.

2. Materials preparation

2.1 MSW ash preparation

For the mass-burned MSW incinerator ash, the bottom ash obtained from an incinerator in Phuket province, Thailand was used in this study. The obtained bottom ash was dried in an electrical oven at 105°C for 24 hours and ground in the Los Angeles Abrasion machine about 45 minutes to obtain the municipal solid waste incinerator bottom ash (MSWI) with the Blaine fineness of approximately 1,000 cm^2/g.

2.2 CCW preparation

To prepare CCW used in this study, the CCW was dried at 105°C for 24 hours in an electrical oven and later ground in the Los Angeles Abrasion machine for 30 minutes to a Blaine fineness of about 4,000 cm^2/g.

3. Experimental investigation

3.1 Burning procedure of clinkers

The conventional raw meal composed of limestone, shale, clay and red earth was obtained from a cement plant at Kaeng Khoi, Saraburi, Thailand. For both MSWI cements and CCW cements, the weight ratio of MSWI and CCW to total raw material was varied at 0.05 and 0.10. Physical properties and chemical composition of the raw materials are shown in Table 1 and 2, respectively.

Firstly, each MSWI and CCW was blended with the conventional raw meal, with the designed replacement ratio, in a mechanical mixer and then water was added. Thus, a cylindrical-shape bar was molded with a diameter of one inch and dried in an oven at 105°C for 24 hours. Next, these prepared raw meal bars were burned in a high-temperature electrical furnace with the heating rate of 20°C/minute and maintained at 1,450°C for 30 minutes. Finally, the clinker bars were cooled with the rate of 20°C/minute to the room temperature and ground into cement powder. The finished products had the Blaine fineness of 3,100±100 cm2/g with 5 percent gypsum added during grinding.

3.2 Mix proportion of mortars

In this study, there were two sets of mortar mixes depending on the type of sand. For the first set, sand with the gradation according to ASTM C 778 was used. Four series of mixes, representing two types of MSWI cement mortar (5 and 10 percent of MSWI in raw meal) and two types of CCW cement mortar (5 and 10 percent of CCW in raw meal) were tested in the laboratory to compare their properties with the cement made from the control raw meal. All mix proportions were determined by fixing sand to cement ratio at 2.75 and water to cement ratio (w/c) at 0.70 constantly in order to produce the flow value of control mortar at 110±5. Another set uses the local, natural river sand, as the ingredient of mortar while the series of mixes used are to prepare mortar bar specimens and testing the sulfate expansion. Similarly, mix proportions were determined by fixing sand to cement ratio as in the first set and water to cement ratio (w/c) equal to 0.53 in order to produce the flow value of control mortar equal to 110±5

3.3 Setting times measurement and compressive strength test

The initial setting time and final setting time of all cements were determined. The times of set were measured using the Vicat needle in accordance with ASTM C 191. For determination of compressive strength, mortar cube specimens were prepared according to ASTM C109. All mortar specimens were cured in water at room temperature. The compressive strength of mortar specimens at 7, 14, 28 and 91 days was derived as the average of 5 tested specimens.

Table 1 Physical properties of the cement raw meal, MSWI and CCW

Physical Properties	Raw Meal	MSWI	CCW
Specific Gravity	n.o.	2.50	2.26
Blaine Fineness (cm^2/g)	n.o.	937	4,100

n.o.: not observed
MSWI: municipal solid waste incinerator bottom ash
CCW: calcium carbide waste

Table 2 Chemical composition of the cement raw meal, MSWI and CCW

Chemical Composition	Raw Meal (% wt)	MSWI (% wt)	CCW (% wt)
SiO_2	12.82	48.26	6.49
Al_2O_3	3.78	4.04	2.00
Fe_2O_3	2.24	4.44	1.87
CaO	43.53	19.07	56.41
MgO	0.63	1.16	0.70
SO_3	n.d.	1.06	0.36
Na_2O	0.09	2.41	0.18
K_2O	0.41	1.17	0.10
TiO_2	0.16	n.d.	n.d.
P_2O_5	n.d.	n.d.	n.d.
Total Cl^- Content	n.d.	0.01	n.d.
LOI	36.14	16.56	31.74

n.d.: non-detectable due to zero or small content
LOI: loss on ignition

4. Test results and discussion

The test results are shown and discussed for the effects of MSWI and CCW replacement on the following properties of cement.

4.1 Chemical compositions

The chemical compositions of all cements are shown in Table 3. Results indicate that the chemical compositions of MSWI cements and CCW cements are similar to those of the control cement (CC), except the SiO_2 contents, of which 5MSWIC and 10MSWIC are respectively equal to 23.34% and 24.85%, as higher than that of the CC (20.03%). On the other hand, CaO content of CC (65.88%) is higher than those of 5MSWIC (62.75%) and 10MSWIC (61.13%). Comparison of four major oxides is given in Fig. 1. As a result, C_3S calculated from Bogue's equation of 5MSWCI (30.80%) and 10MSWIC (13.17%) are considerably lower than that of CC (56.02%), whereas C_2S are significantly higher (43.89% for 5MSWIC, 61.44% for 10MSWIC and 15.24% for CC) as shown in Fig. 2. The higher the MSWI is replaced in the raw meal, the higher SiO2 and C_2S but the lower CaO and C_3S are obtained in the cement. For CCW cements, the same tendency can be observed, i.e. the SiO2 contents of 5CCWC (21.61%) and 10CCWC (20.89%) are higher than that of the CC (20.03%). In addition, the CaO content of the CC (65.88%) is higher than those of 5CCWC (64.00%) and 10MSWIC (64.85%). Consequently, the C_3S of 5CCWC (39.93%) and 10CCWC (43.07%) are lower than that of the CC (56.02%), but the C_2S are higher (32.07% for 5CCWC and 27.65% for 10CCWC).

All MSWI and CCW cements, except for 10CCWC, contain lower free lime. The excess free lime usually hydrates very slowly, causing unsoundness of the cement paste in hardened state. So, the reduction of free lime content results in not only the burnability improvement of the cement but also the volume stability of the concrete.

4.2 Setting time and compressive strength

Setting times, flow values and compressive strength of CC, 5MSWIC, 10MSWIC as well as 5CCWC and 10CCWC in the raw meal are given in Tables 4, 5 and 6.

The flow values of 5CCWC and 10CCWC cements are very close to that of CC. While 5MSWIC and 10MSWIC cements have lower flow values than that of CC, especially when increasing MSWI percentage in the raw meal. Results also indicate that times of setting are slightly different when MSWI and CCW are replaced as a raw material in cement. It is noted that 5MSWIC, 10MSWIC, 5CCWC and 10CCWC cement exhibited the longer setting time than CC due to the lower C_3S and higher C_2S than those in CC, according to the Bogue's composition in Table 3 and Fig. 2.

Moreover, results of the flow values in Tables 5 and 6 are in good agreement with results of normal consistency of all cements shown in Table 4. The higher the flow values of the cements are, the lower the normal consistency of the cement pastes is obtained. In the case of compressive strength, Figs. 3 and 4 show development of the compressive strengths with respect to age. For mortar specimens with 5CCWC and 10CCWC cement, compressive strength was equivalent to that of CC cement. On the contrary, compressive strengths of 5MSWIC and 10MSWIC, were lower than that of CC mortar, especially when MSWI percentage in the raw meal was increased. This is because MSWI cements have lower CaO and higher SiO_2 than those in CC, and thus C_3S content is lower than CC. It is noted here that the raw meal adjustment is needed when MSWI is replaced in the case that a similar compressive strength to that of CC is required.

Table 3 Chemical composition of control cement, MSWI cements, and CCW cements

Chemical Composition	CC (% wt)	5MSWIC (% wt)	10MSWIC (% wt)	5CCWC (% wt)	10CCWC (% wt)
SiO_2	20.03	23.34	24.85	21.61	20.89
Al_2O_3	5.69	5.17	5.00	5.75	5.60
Fe_2O_3	3.12	3.29	3.34	3.20	3.17
CaO	65.88	62.75	61.13	64.00	64.85
MgO	0.80	0.93	0.99	1.05	1.04
SO_3	2.33	2.01	2.26	2.14	2.14
Free CaO	2.59	0.50	0.48	1.72	3.40
LOI	0.57	1.44	1.41	1.74	1.25
Blaine fineness (cm^2/g)			3,100±100		
Specific Gravity	3.04	3.11	3.12	3.10	3.06
Bogue's Composition					
Computed C_3S	56.02	30.80	13.17	39.93	43.07
Computed C_2S	15.24	43.89	61.44	32.07	27.65
Computed C_3A	9.81	8.14	7.61	9.83	9.48
Computed C_4AF	9.48	10.00	10.15	9.73	9.64

CC: control cement, 5MSWIC: MSWI cement with 5 percent MSWI in the raw meal, 10MSWIC: MSWI cement with 10 percent MSWI in the raw meal, 5CCWC: CCW cement with 5 percent CCW in the raw meal, 10CCWC: CCW cement with 10 percent CCW in the raw meal

n.d: non-detectable due to zero or small content

Table 4 Normal consistency and setting time of paste

Type of Cement	Normal Consistency	Setting Time (hr:min) Initial	Setting Time (hr:min) Final
CC	0.245	2:25	3:05
5MSWIC	0.265	3:00	3:50
10MSWIC	0.290	2:25	3:20
5CCWC	0.240	2:40	3:35
10CCWC	0.230	2:25	3:20

Table 5 Flow values and compressive strength of mortars made with water to cement ratio of 0.70

Type of Cement	Flow Value	Compressive Strength (MPa)			
		7-days	14-days	28-days	91-days
CC	105	19.20	22.05	26.70	32.95
5MSWIC	92	9.96	12.25	13.85	19.20
10MSWIC	88	3.72	4.86	7.54	13.64
5CCWC	105	18.24	22.30	27.05	29.62
10CCWC	107	18.71	21.02	26.89	30.13

Table 6 Flow values and compressive strength of mortars made with water to cement ratio (w/c) of 0.53

Type of Cement	Flow Value	Compressive Strength (MPa)			
		7-days	14-days	28-days	91-days
CC	105	40.31	45.91	49.97	60.92
5MSWIC	93	27.26	31.21	36.16	47.52
10MSWIC	88	8.32	11.26	16.28	30.74
5CCWC	105	38.04	48.28	51.25	58.59
10CCWC	106	38.76	43.51	44.49	56.60

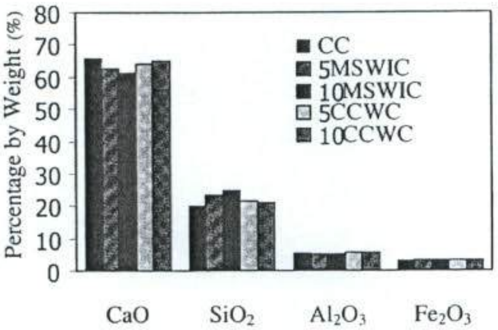

Fig. 1 Comparison of four major oxides of the tested cements

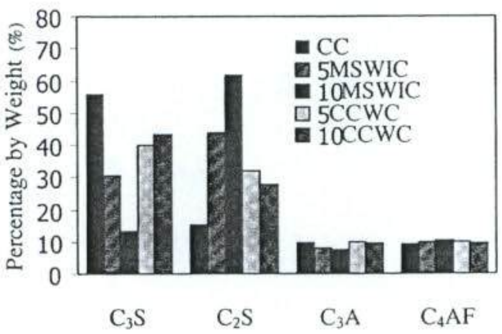

Fig. 2 Comparison of oxide compound compositions of the tested cements

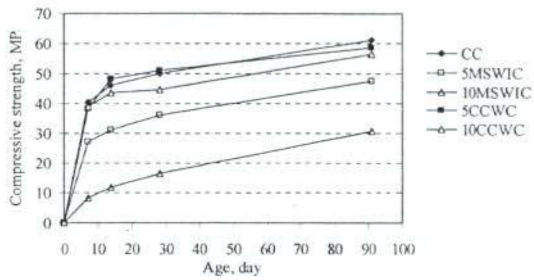

Fig. 3 Compressive strength development of mortars made from various cements with w/c 0.70

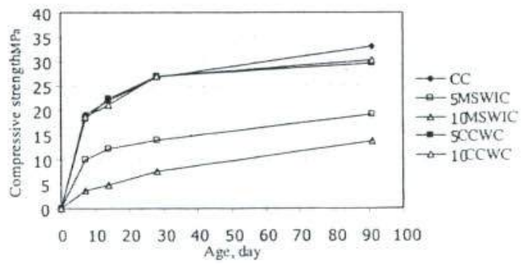

Fig. 4 Compressive strength development of mortars made from various cements with w/c 0.53

5. Conclusion

All MSWI cements and CCW cements tested show slightly different characteristic in terms of setting properties from the control cement. Compressive strength of mortars using CCW cements was not much different from that of the control cement. However, compressive strength of mortars using MSWI cements was lower than that of the control cement mortar, especially when the ash percentage in the raw meal was increased.

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