Feasibility Study of One-Part Alkali Activated Material with MSWI Fly Ash

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Abstract. With the growing population, it is also expected that the municipal solid waste (MSW) generation would be increasing in the coming years. Management of MSW is already an identified issue and the incineration process is widely adopted as a disposal solution for non-compostable wastes. Incineration of MSW results in secondary waste residues such as almost 20% of fly ash and 80% of bottom ash. These are rich in silica and alumina content, naturally has the potential to be an aluminosilicate precursor to produce alkali-activated materials. Several issues are pointed out for the application of MSWI residues as cementing materials, either a Supplementary Cement Material (SCM) or an Alkali-Activated Material (AAM). One such issue concerning AAM application is the presence of metallic aluminium. Heavy metals from the MSWI residues are normally extracted before disposal, however metallic aluminium is not effectively removed in most of the cases. Metallic aluminium acts as a pore-forming agent by generating H_2 gas in the alkali environment, thereby reducing the strength properties. In the present study, an attempt is made to understand the influence of the metallic aluminium present in the MSWI fly ash of different size fractions, fine (0–0.5 mm) and coarse (0.5–1.0 mm). MSWI fly ash is activated with solid/liquid alkalis, such as sodium hydroxide (NaOH), sodium silicate (Na_2SiO_3) and combination of both. With the Na_2O content maintained constant across the activators, the sample activated with NaOH is the weakest and the one with sodium silicate is the strongest with small, well-distributed pore structure, irrespective of the size fraction of MSWI fly ash used. Solid activator performed equally well as that of the liquid one.

Keywords: MSWI ash · Fly ash · Metallic aluminium · Alkali activation · Porosity

1 Introduction

Waste to energy treatment is preferred for municipal wastes in places where recycling is not an option, owing to its various advantages including volume reduction and energy recovery [1]. In 2019, 502 kg of municipal waste per capita were generated in EU, of which 30% is incinerated which is double the capacity compared to 1995 [2]. However,

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it also comes with the problem of producing other residues such as fly ash, bottom ash, and air pollution control (APC) residues [3]. Such residues were studied for their use as secondary raw materials in construction sector [4, 5]. Utilization of municipal solid waste incinerated (MSWI) fly ash was examined for applications such as supplementary cementitious materials [6–9]. Though MSWI bottom ash falls under non-hazardous category and considered for various applications, the finer fractions (MSWI fly ash) are hazardous with heavy metals and organics content [10]. Hence, stabilization of MSWI fly ash became an important and interesting point of consideration before even considering them for secondary utilization. In this context, alkali activation of this material is regarded as an promising method to immobilize heavy metals while also serving as an alternative binder material [11, 12].

In the present work, MSWI fly ash was considered for its potential to be used as precursor in one-part alkali activated materials (AAM). One-part AAM are "just add water" material like ordinary Portland cements unlike the traditional two-part alkali activated material where the aluminosilicate precursors to be added with alkali activator solution [13]. Sodium silicate and sodium hydroxide solids were mixed with MSWI fly ash acting as binder material. Compressive strength results were compared between one-part and two-part AAMs with similar Na_2O content. Influence of milling of MSWI fly ash at different time (1 and 5 min) was also focused.

2 Materials and Methodology

2.1 Materials

The MSWI fly ash used in this study was obtained from municipal waste incineration plant in Oulu, Finland. Major elements of MSWI fly ash was analyzed using X-ray fluorescence spectrometer (XRF), and the results are presented in Table 1. The fly ash has higher silica and CaO content, but much lower alumina content. There are also high amount of lead and titanium (Table 1). 3.2% of chlorides are seen in this fly ash which is also mentioned in many literature as one of the deleterious element [14]. MSWI fly ash was initially sieved through 1 and 0.5 mm sieve, which resulted in 4 and 13% residues, respectively. The residues mostly comprised of unburnt carbon (Fig. 1). Samples passing 1 mm were taken into consideration in this study, so as to utilize maximum of the material. Anhydrous sodium metasilicate (silica modulus, $SiO_2/Na_2O = 0.9$) was procured from Alfa Aesar, Germany. Liquid sodium silicate with silica modulus 3.2 and 55% water content was supplied by VMR chemicals. Reagent grade sodium hydroxide (>97%) powder was used to adjust the Na_2O content to 5% across different activators.

Table 1. Chemical composition of MSWI fly ash*.

Oxide [%]	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Fe_2O_3
MSWI fly ash	3.7	3.2	11.1	32.9	1.8	6.9	3.2	2.1	26.8	2.4	3.7

* 2.2% other minor oxides excluded

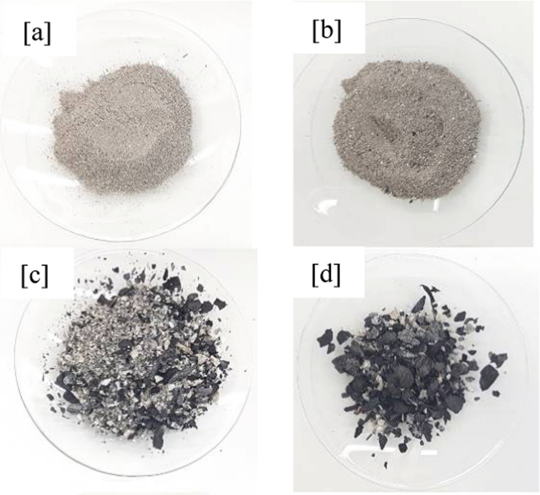

Fig. 1. MSWI fly ash passed through [a] 0.5 mm, [b] 1 mm size sieves and the residues retained in [c] 0.5 mm and [d] 1 mm size sieves.

2.2 Methodology

MSWI fly ash was dried in 100 °C for 24 h and ground in vibratory disc mill for 1 and 5 min. Disc mill Retsch RS 200 was employed at 1500 rpm in batches of 100g of MSWI fly ash. Three different activators were used, precisely, combination of solid sodium silicate and sodium hydroxide, liquid sodium silicate and liquid sodium hydroxide. Na_2O content was maintained as 5% in all the activators. Water to solids ratio was maintained constant as 0.45. To study one-part AAM, MSWI fly ash was mixed with solid sodium silicate and sodium hydroxide combination prior to introducing the water. In two-part, the alkali activator solution was mixed to the MSWI fly ash to make paste samples. Cylindrical specimens (20 × 25 mm) were cast using the one-part and two-part samples to observe their physical appearance and study the strength properties. AAM specimens were subjected to two different curing regimes; (1) 60 °C for 24 h, continued by room temperature curing, (2) room temperature curing until further testing.

3 Results and Discussion

3.1 Physical Appearance

Cylindrical specimens were demolded after 24 h and observed for physical form. Specimens cured at 60 °C for 24 h is shown in Figs. 2, 3 and 4. Unmilled MSWI fly ash appears disintegrated with solid activators and liquid NaOH, whereas, comparatively solidified with liquid sodium silicate (Fig. 2). This is also the case with room temperature cured specimens.

After milling, one-part activators performed better in MSWI fly ash pastes with solid specimens as that of two-part specimens made of liquid sodium silicate (Fig. 3).

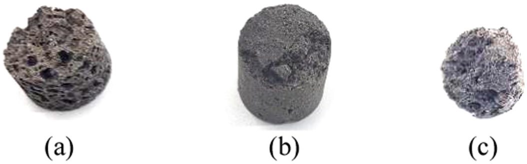

Fig. 2. Unmilled MSWI fly ash activated with [a] solid Na_2SiO_3 + NaOH, [b] liquid Na_2SiO_3 and, [c] liquid NaOH at 7 days of curing age.

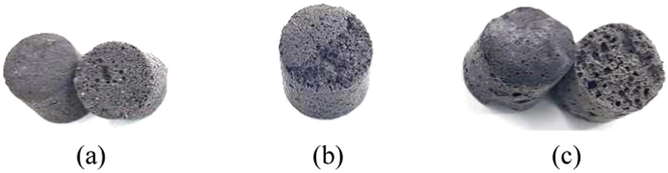

Fig. 3. Milled (1 min) MSWI fly ash activated with [a] solid Na_2SiO_3 + NaOH, [b] liquid Na_2SiO_3 and, [c] liquid NaOH at 7 days of curing age.

However, liquid NaOH does not produce stronger specimens though Na_2O content was maintained constant.

With increasing milling time to 5 min, one-part seems to be a better option as the pore size increased in two-part AAM specimens (Fig. 4). In all the three cases, Two-part specimens with liquid NaOH were very weak due to their high porosity and hence, were not considered for strength testing.

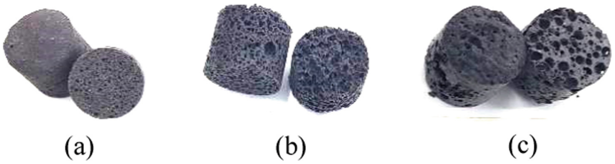

Fig. 4. Milled (5 min) MSWI fly ash activated with [a] solid Na_2SiO_3 + NaOH, [b] liquid Na_2SiO_3 and, [c] liquid NaOH at 7 days of curing age.

3.2 Compressive Strength

Solid activator performs equally good as that of liquid activator in the activation of MSWI fly ash as represented by compressive strength results in Figs. 5 and 6. Combination of Na_2SiO_3 and NaOH acted as solid activator making one-part AAM and liquid Na_2SiO_3 was used as activator for producing two-part AAM for the specimens used for strength testing.

It is to be noted that only two-part activation worked for unmilled MSWI fly ash samples, leading to a conclusion that one-part activation need milling as a pre-treatment. However, increasing the milling from 1 to 5 min was not favorable for alkali activation as this either does not impact (Fig. 5) or reduced the strength (Fig. 6) in case of solid activators. With the use of liquid activators, milling reduced the compressive strength, irrespective of the type of curing adopted. This can be related to the increasing amount of metallic aluminium with milling time and hence, swelling, porosity and strength reduction [15].

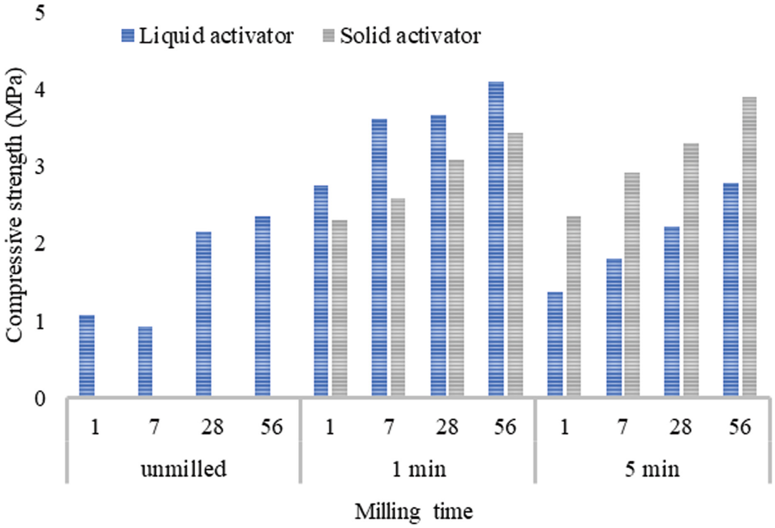

Fig. 5. Compressive strength of alkali activated MSWI fly ash pre-cured at 60 °C for 24 h and tested at different ages (1–56 days).

Type of curing shows noticeable impact on the strength development with age in one/two-part alkali activated MSWI fly ash (Figs. 5 and 6). Specimens cured at room temperature shows gradual increase in compressive strength with one-part activation (Fig. 6). It reaches a maximum strength of 4 MPa at 56 days of curing age which is similar to that of two-part AAM specimens. However, early age strength seems to be higher with two-part activation though strength improvement at later ages is not noticeable.

4 Conclusions

MSWI fly ash was studied as a source of aluminosilicate precursor for alkali activation. The possibility to use solid activators (one-part) was examined and compared with conventional two-part alkali activation method. The study concludes that milling helps in activation of MSWI fly ash in one-part method, however, it also can result in the increased release of metallic elements which can negatively affect the properties. Heat curing helps in achieving high early strength in one-part activation, however, does not contribute to the strength increase at later ages.

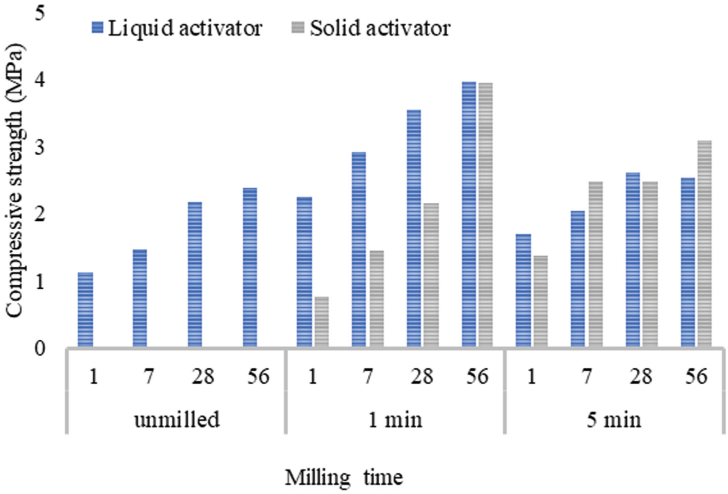

Fig. 6. Compressive strength of alkali activated MSWI fly ash cured at room temperature and tested at different ages (1–56 days).

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References

1. Scarlat, N., Fahl, F., Dallemand, J.-F.: Status and opportunities for energy recovery from municipal solid waste in Europe. Waste and Biomass Valorization **10**(9), 2425–2444 (2018). https://doi.org/10.1007/s12649-018-0297-7
2. Eurostat, F., Union, E., Regulation W.S.: Municipal waste statistics. Eurostat, pp. 1–6 (2021). http://ec.europa.eu/eurostat/statistics-explained/
3. Quina, M.J., Bordado, J.C., Quinta-Ferreira, R.M.: Treatment and use of air pollution control residues from MSW incineration: an overview. Waste Manag. **28**, 2097–2121 (2008). https://doi.org/10.1016/j.wasman.2007.08.030
4. Clavier, K.A., Paris, J.M., Ferraro, C.C., Townsend, T.G.: Opportunities and challenges associated with using municipal waste incineration ash as a raw ingredient in cement production—a review. Resour. Conserv. Recycl. **160**, 104888 (2020). https://doi.org/10.1016/j.resconrec.2020.104888
5. Dou, X., et al.: Review of MSWI bottom ash utilization from perspectives of collective characterization, treatment and existing application. Renew. Sustain. Energy Rev. **79**, 24–38 (2017). https://doi.org/10.1016/j.rser.2017.05.044
6. Wang, K.S., Lin, K.L., Huang, Z.Q.: Hydraulic activity of municipal solid waste incinerator fly-ash-slag-blended eco-cement. Cem. Concr. Res. **31**, 97–103 (2001). https://doi.org/10.1016/S0008-8846(00)00423-3
7. Shih, P.H., Chang, J.E., Chiang, L.C.: Replacement of raw mix in cement production by municipal solid waste incineration ash. Cem. Concr. Res. **33**, 1831–1836 (2003). https://doi.org/10.1016/S0008-8846(03)00206-0

8. Lin, K.L., Wang, K.S., Lee, T.Y., Tzeng, B.Y.: The hydration characteristics of MSWI fly ash slag present in C3S. Cem. Concr. Res. **33**, 957–964 (2003). https://doi.org/10.1016/S0008-8846(02)01002-5
9. Kan, L., Zhang, L., Shi, H.: Hydration kinetics of municipal solid wastes incineration (MSWI) fly ash-cement. J. Wuhan Univ. Technol. Mater. Sci. Ed. **34**(3), 596–603 (2019). https://doi.org/10.1007/s11595-019-2093-z
10. Joseph, A.M., Snellings, R., Van den Heede, P., Matthys, S., De Belie, N.: The use of municipal solid waste incineration ash in various building materials: a Belgian point of view. Materials (Basel) **11**, (2018). https://doi.org/10.3390/ma11010141
11. Tian, X., Rao, F., León-Patiño, C.A., Song, S.: Co-disposal of MSWI fly ash and spent caustic through alkaline-activation consolidation. Cem. Concr. Compos. **116**, (2021). https://doi.org/10.1016/j.cemconcomp.2020.103888
12. Tian, X., Rao, F., León-Patiño, C.A., Song, S.: Co-disposal of MSWI fly ash and spent caustic through alkaline-activation: immobilization of heavy metals and organics. Cem. Concr. Compos. **114**, (2020). https://doi.org/10.1016/j.cemconcomp.2020.103824
13. Luukkonen, T., Abdollahnejad, Z., Yliniemi, J., Kinnunen, P., Illikainen, M.: One-part alkali-activated materials: a review. Cem. Concr. Res. **103**, 21–34 (2018). https://doi.org/10.1016/j.cemconres.2017.10.001
14. Alam, Q., Lazaro, A., Schollbach, K., Brouwers, H.J.H.: Chemical speciation, distribution and leaching behavior of chlorides from municipal solid waste incineration bottom ash. Chemosphere **241**, 124985 (2020). https://doi.org/10.1016/j.chemosphere.2019.124985
15. Aubert, J.E., Husson, B., Vaquier, A.: Metallic aluminum in MSWI fly ash: quantification and influence on the properties of cement-based products. Waste Manag. **24**, 589–596 (2004). https://doi.org/10.1016/j.wasman.2004.01.005