# Management of radioactive contaminated electric arc furnace slag using cement immobilization method

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**Abstract**

Scrap steel metals have played an important role in the steel manufacturing industry because they can be recycled without any damage or degradation of its property. Like other countries, scrap steels are imported from abroad. Some were found radioactive contamination both natural and artificial radioisotopes. In case, once contaminated scrap steels are introduced into the melting process, radioactive electric arc furnace slag (EAFS) is produced. In order to prevent migration of radionuclide contaminated in the furnace slag, immobilization of such radioactive waste by cementation was conducted. The paper was studied the physicochemical and mechanical properties of waste form that is appropriate for store and transfer to long term disposal site. The element compositions of Portland cement type I (PC) and EAFS were characterized by X-ray fluorescence (XRF), they were found that the main element composition of PC and EAFS is Calcium oxide (CaO) and Iron oxide (Fe2O3), respectively. The EAFS waste forms were produced using water/cement ratio of 0.40 and EAFS replacement of 0%, 15%, 25%, 35%, and 50%. All samples were cured at ambient temperature for 14 days and 28 days. It was observed that the compressive strengths of EAFS replacement of 0%, 15%, 25%, 35%, and 50% were found to be 111.28, 109.35, 107.58, 93.64, and 65.02 kg⋅f/cm2, respectively, for 14 days curing. The compressive strengths of all samples were measured to be 93.57, 105.53, 80.73, 111.90, and 102.88 kg⋅f/cm2 for EAFS replacement of 0%, 15%, 25%, 35%, and 50%, respectively, for 28 days curing. The mixing between PC and EAFS of all conditions exhibited good workability for cementation. The EAFS replacement of 50% seems to be appreciable for cementation due to the high increasing compressive strength.

## INTRODUCTION

Electric arc furnace slag (EAFS) is a solidified waste from the melting steel procedure in the electric arc furnace. Radioactive contaminated scrap steel was used in the melting process, generating radioactive EAFS waste. Immobilization of radioactive waste by cementation was applied to reduce the migration or dispersion of radionuclides during handling, transportation, storage, and disposal [1], [2].

Radioactive waste conditioning is the waste transformation to contain radioactive material for preventing radionuclide transported into the environment. Radioactive waste form must have appropriate chemical, mechanical, thermal, and radiological properties until the radioactive substances contained in the waste form decompose that will not affect to the environment. Immobilization with cement is widely used for radioactive waste conditioning because of its inexpensive, high effective method, strong, durable, non-flammable, corrosion resistant, chemical resistant, radiation resistant, resistant to leaching, and high density [3], [4].

Waste form should have high compressive strength for protecting an accident occurs during the waste handling, transportation, storage, and disposal. The compressive strength of the waste product depends on type and properties of cement, waste to cement ratio, water to cement ratio, and the curing period of waste product. Portland cement (PC) has been used as matrix for immobilization of radioactive waste due to its low cost, good mechanical property, and high stability. In addition, cement can be used to shield the radiation inside and also inhibit the migration of radioactive substances into the environment [1], [3].

In the paper, Immobilization of EAFS waste was applied by cementation technique. The aim of the paper is to achieve the high compressive strength of radioactive waste form from various EAFS and PC ratio that is suitable store and transfer to long term disposal site.

## experiment

**2.1. Preparation of samples**

Portland cement type I (TPI Polene (Public) Co., Ltd., Thailand) was applied in this experiment. The Portland cement produced in accordance with the Thai Industrial Standards Institute's specification for Portland cement TIS 15-2555 Type I, and the ASTM C-150 Type I. All samples were prepared using PC replacement EAFS of 0%, 15%, 25%, 35%, and 50% by weight. The water to binder ratio was used to be 0.40. The mixed ratios of all samples were shown in Table 1. Firstly, PC and EAFS were mixed together for 5 mins. After that, tap water was poured in mixed of PC and EAFS, and stirred until homogeneity. Next, all mixtures of various condition were poured into cylindrical plastic molds with the height of 10 cm and the diameter of 5 cm. After 24 hours, all samples were cured in water at room temperature for 14 and 28 days. All samples were removed from cylindrical plastic molds and left for 24 hours for compressive strength testing.

TABLE 1. THE PERCENTAGE MIX PROPORTIONS OF ALL SAMPLES

|  |  |  |  |
| --- | --- | --- | --- |
| Sample | Portland cement (PC) | Electric arc furnace slag (EAFS) | Water to Binder ratio |
| 0%EAFS | 100% | 0% | 0.40 |
| 15%EAFS | 85% | 15% | 0.40 |
| 25%EAFS | 75% | 25% | 0.40 |
| 35%EAFS | 65% | 35% | 0.40 |
| 50%EAFS | 50% | 50% | 0.40 |

**2.2. Element composition characterization**

Element compositions of PC and EAFS were characterized using X-ray fluorescence (XRF, Bruker S8 Tiger), are shown in Table 2. The main element composition of PC and EAFS is Calcium oxide (CaO) and Iron oxide (Fe2O3), respectively.

TABLE 2. THE ELEMENT COMPOSITION OF PORTLAND CEMENT (PC) AND ELECTRIC ARC FURNACE SLAG (EAFS)

| Oxide composition | Portland cement (PC) | Electric arc furnace slag (EAFS) |
| --- | --- | --- |
| CaO | 66.99% | 1.87% |
| SiO2 | 19.14% | - |
| Al2O3 | 4.39% | - |
| Fe2O3 | 3.36% | 51.76% |
| SO3 | 3.10% | 0.27% |
| MgO | 1.59% | - |
| K2O | 0.49% | 4.95% |
| Na2O | 0.27% | - |
| TiO2 | 0.26% | - |
| Cl | 0.15% | 0.26% |
| P2O5 | 0.08% | - |
| MnO | 0.05% | 4.09% |
| SrO | 0.04% | - |
| ZnO | 0.03% | 35.19% |
| CuO | 0.02% | 0.24% |
| ZrO2 | 0.02% | - |
| MoO3 | 75 PPM | - |
| As2O3 | 44 PPM | - |
| PbO | - | 0.71% |
| Cr2O3 | - | 0.43% |
| Br | - | 0.12% |
| Ac | - | 0.10% |
| **Total** | **99.98%** | **99.99%** |

**2.3. Compressive strength testing**

The compressive strength at 14 and 28 days of all samples was measured using the Chun Yen testing machine, Taiwan. All samples were produced as cylindrical specimens with the dimension of 10 cm (height) and 5 cm (diameter). Three pieces of each condition were measured the compressive strength for breaking under the hydraulic press. The compressive strength of all samples can be calculated from Equation 1 [5].

 (Eq. 1)

Where:  is Compressive strength (Kg/cm2)

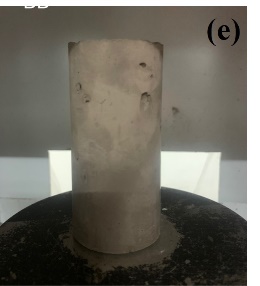
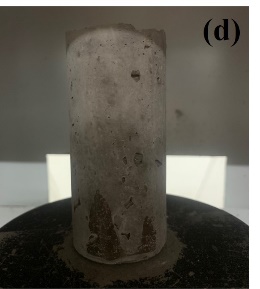
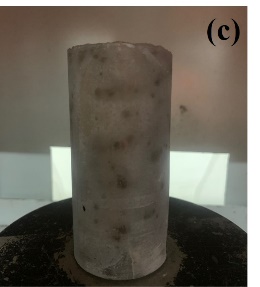
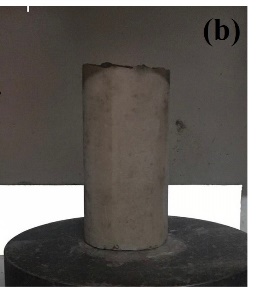
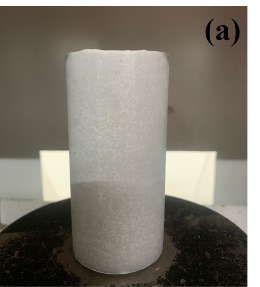
 is Total maximum load (Kg)

 is Area of load surface (cm2)

## RESULTS AND DISCUSSION

### Physical appearance

All samples were prepared using PC replacement EAFS of 0%, 15%, 25%, 35%, and 50% by weight. The water to binder ratio was used to be 0.40. Grey PC was mixed together with brown EAFS. All PC mixed EAFS samples present cylindrical in brown colour while the PC specimen shows grey colour, as shown in Fig. 1. The 15%EAFS and 25%EAFS samples show the smooth surface with same colour. The 35%EAFS and 50%EAFS samples show the rough surface with some pores. The average weight of all samples was found to be 370.34 g.

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*FIG. 1. The physical appearance of (a) 0%EAFS, (b) 15%EAFS, (c) 25%EAFS, (d) 35%EAFS and (e) 50%EAFS.*

**3.2. Compressive strength**

The compressive strength of all samples (PC replacement EAFS of 0%, 15%, 25%, 35%, and 50% by weight) is shown in Fig. 2. It can be observed that the 14 days curing of Portland cement (0%EAFS) presents the highest compressive strength, comparing with PC replacement EAFS samples. All samples were calculated to be 111.28, 109.35, 107.58, 93.64 and 65.02 Kg/cm2 for 0%EAFS, 15%EAFS, 25%EAFS, 35%EAFS, and 50%EAFS, respectively. The compressive strength of PC replacement EAFS decreased when increased the concentration of EAFS. In the other words, increasing EAFS addition caused decrease in cement compressive strength. However, the compressive strength of 28 days curing was measured to be 93.57, 105.52, 80.73, 111.90, and 102.88 Kg/cm2 for 0%EAFS, 15%EAFS, 25%EAFS, 35%EAFS, and 50%EAFS, respectively. It can be seen that 35%EAFS and 50%EAFS exhibits higher compressive strength than curing day of 14. Nevertheless, the compressive strength of 0%EAFS, 15%EAFS, and 25%EAFS decreased after increasing cured time. The CaO and SiO2 compounds are the major compositions on the hydration reaction (C-S-H formation) due to high compressive strength [6]. In this study, increasing EAFS decreased the compressive strength of 14 days curing because of low concentration of CaO and SiO2 compounds in EAFS. However, the compressive strength of 35%EAFS and 50%EAFS increased at the curing time of 28 days. Yazdi et al. studied the compressive strength of cement mortar after adding Fe2O3 nanoparticles. It was observed that the compressive strength increased after Fe2O3 nanoparticles. In this paper, the addition of EAFS increased the compressive strength of 35%EAFS and 50%EAFS increased at 28 curing days. It indicates that the Fe2O3 can be increased the compressive strength due to its reducing the quantity and size of Ca(OH)2 crystals. Moreover, Fe2O3 fills the voids of C-S-H structure, generating the denser and compact structure of hydrated products, resulting high compressive strength [7]. The criteria of compressive strength for permanent disposal should be more than 3.45 MPA or 34.5 Kg/cm2 [8], [9].



*FIG. 2. The compressive strength of (a) 0%EAFS, (b) 15%EAFS, (c) 25%EAFS, (d) 35%EAFS and (e) 50%EAFS.*

## CONCLUSIONS

The immobilization of EAFS was produced by cementation method. Portland cement was replaced with EAFS at the concentration of 0%, 15%, 25%, 35%, and 50% by weight. The main element composition of PC and EAFS is CaO (66.99%) and Fe2O3 (51.76%), respectively. The compressive strength of all conditions is more than 34.5 Kg/cm2, that follow the criteria of the US Nuclear Regulatory Commission (NRC) standard. The optimum condition for immobilization of EAFS is 50% of EAFS replacement with PC by weight. It was observed that the compressive strength of 50%EAFS at 14 curing days was increased from 65.02 Kg/cm2 to 102.88 Kg/cm2 at the curing time of 28 days. The PC replacement EAFS of 50% is suitable applied as waste form for immobilization radioactive waste management by cementation technique because of its high compressive strength and its maximum waste loading.

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