IOP Conf. Series: Materials Science and Engineering **739** (2020) 012032 doi:10.1088/1757-899X/739/1/012032

# Effect of Electric Arc Furnace Dust Treatment on the Properties of Fresh and Hardened Mortar

**R Syahyadi[1], A Fauzi[1,2*], E Majuar[1], F Rizal[1,2], M Reza[1, 2], dan Fajri[1,2]**

[1]Politeknik Negeri Lhokseumawe, (PNL), Acheh, Indonesia
[2]Geopolymer and Green Technology Research Center, PNL, Acheh, Indonesia

amirfauzi@pnl.ac.id

**Abstract.** Electric arc-furnace dust (EAFD) is generated in considerable amounts by the electric arc steelmaking process. Use of EAFD in concrete improved many properties of concrete. Yet, the prolonged setting time even at low dosages of EAFD was a serious limitation. This phenomenon was attributed to the presence of transition metal in the material of EAFD. Therefore, it was necessary to stabilize the transition metal in an insoluble crystalline matrix. The calcination with high-temperature was done to fix the transition metal in a complex matrix with the cementitious properties. This material was called Engineered Dust (ED). The use of ED with different replacement levels of 0, 5, 10, 15 and 20% at w/b ratio of 0.5 was carried out. The results showed that the use of ED solved the prolonged setting time which the replacement up to 20% had a normal setting time of 5 to 6 hours. Furthermore, the material of ED was used up to 15% replacement level with the replacement of 20% ED that gave the lowest electric charge values in the RCPT.

## 1. Introduction

Electric arc furnace dust (EAFD) is a by-product material from the electric steelmaking industry. It was known that every ton production of steelmaking generated 2% EAFD in the environment. Furthermore, the material of EAFD was designated by the European Union (EU) and the EPA (The United States Environmental Protection Agency) as a hazardous waste due to was an abundant in the heavy metals such as zinc (Zn), lead (Pb), Chromium (Cr), and Cadmium (Cd). It meant that the material of EAFD may not be disposed of at landfills without the treatment [1]. Consequently, it was an environmental issue in the world.

The composition of EAFD depended on the scrap charge, the used additive, and the type of steel manufactured. For example, the use of galvanized steel scrap increased the zinc content in the EAFD significantly. Content of Zinc in EAFD varied in the range of 7% to 40%, and the content of lead content in the range of 4 to 9% [2]. The use of EAFD in the concrete has attracted the researcher to explore more information regarding the material of EAFD. It was due to the cementitious matrix in the concrete was able to encapsulate the heavy metal and reduced the leachability [3]. Some studies [14-15] reported that the enhanced concrete properties were at 3% replacement of EAFD. However, higher replacement levels of EAFD affected fresh and early hardened concrete properties that retarded the setting time of concrete and lower compressive strength at an early age [4]. De Vargas et al [5] investigated the effect of 5%, 15% and 25% EAFD on the setting time of cement paste. They showed that the increased of EAFD replacement brought to prolong the setting time of concrete up to 70 hours. De Souza et al [6] found that the use of 15% EAFD replacement showed the reduction of chloride penetration in concrete. Al-Mutlaq [7] investigated the use of local EAFD in concrete and reported the excessive setting time even in the presence of a chemical accelerator. It was due to the transition metal (ferric, zinc and manganese) was too high percentage so that they were entrapped in the link of a chemical structure during the initial hydration.

Based on the prolong setting time, the use of EAFD at a high replacement was not recommended as a material in the application. However, the transformation of EAFD to solve the impact on setting time of concrete was able to increase the consumption of EAFD in the environment. This study is investigated to analyze the effect of EAFD transformation in the fresh and hardening mortar.

## 2. Materials and Experimental work

The material of EAFD was obtained from the Sabic Steel Industry (Hadeed) plant in Jubail. Ordinary Portland cement (OPC) was produced by Al-yamamah cement factory in Riyadh which referred to ASTM C150. The transformation of EAFD was investigated due to the transition metal was entrapped in the link of chemical structure so that prevent their release to a cementitious matrix during initial hydration. The engineered transformation of EAFD was by the calcination of EAFD in the furnace with the temperature of $1000^0$C within 5 hours which it was called the material of engineered dust (ED). The chemical composition of OPC, EAFD and ED material was analyzed by X-ray fluorescence (XRF). The fresh and hardening mortar was conducted by the sand-binder ratio of 2 and the water-binder ratio of 0.5 which the workability, the setting time, compressive strength and rapid chloride ion penetration test (RCPT) were used as a parameter.

## 3. Results and Discussions

### *3.1. Chemical composition*

The chemical compositions of OPC, EAFD and ED material are given in Table 1. The result shows that the material of OPC is high in calcium oxide and silica oxide content. The material of EAFD is high in ferric oxide, zinc oxide, and manganese content, whereas the material of ED is high in silica oxide, ferric oxide, and zinc oxide. It is seen that the calcination of EAFD material with the temperature of $1000^0$C reduced the content of transition metal. Even, it eliminates the content of manganese (Mn) from the chemical composition of EAFD. It was attributed to the unstable condition of transition metal in the material of EAFD which the calcination with high temperature transformed the material of EAFD to be more stable material. The calcination with high temperature improved significantly the content of Si in the material of ED, even more than the content of Si in the material of OPC.

**Table 1.** Chemical Composition of OPC, EAFD and ED.

| Oxide Composition | **Analysis, % by weight** | | |
|---|---|---|---|
| | **OPC** | **EAFD** | **ED** |
| $SiO_2$ | 20.2 | 1.91 | 36.54 |
| $Al_2O_3$ | 5.49 | 0.26 | 3.9 |
| $Fe_2O_3$ | 4.12 | 48.52 | 25.6 |
| CaO | 65.43 | 7.04 | 6.72 |
| MgO | 0.71 | 1.75 | 3.8 |
| $Na_2Oeq$ | 0.06 | 3.22 | 0.96 |
| $SO_3$ | 2.61 | 0.84 | 0.4 |
| ZnO | - | 27.73 | 18.2 |
| MnO | - | 3.04 | - |
| LOI | 1.38 | 5.68 | 3.88 |

### *3.2. Workbility*

The flow diameter of fresh mortar mixtures was conducted by flow table apparatus with using the water-binder ratio (w/b) of 0.5 as summarized in Table 2. It is observed that the material of EAFD in this study was only used 3% replacement. It was suitable with the recommendation of the previous study mentioning that the use of EAFD in high replacement brought to prolong setting time. The table shows that the workability in the fresh mortar of EAFD particle is higher than the fresh mortar of OPC. It was attributed to the smooth surface of EAFD that did not absorb the water content from the fresh mortar mixture. The same trend of workability occurred in the fresh mortar mixture of ED. It is seen that the workability of 5% ED is almost similar to the workability of 3% EAFD. It means that the calcination with high temperature did not change the particle surface of EAFD. Furthermore, the increase of EAFD replacement improved the workability. It is due to the increase of EAFD replacement causing the reduction of OPC in the fresh mortar mixture so that it reduced the absorption of water content.

**Table 2.** Flow diameter of OPC, EAFD and ED in the fresh mortar mixture.

| Mix ID | **Replacement Level (% )** | **Flow diameter (cm)** |
|---|---|---|
| OPC | - | 23.1 |
| EAFD3 | 3 | 23.7 |
| ED5 | 5 | 23.6 |
| ED10 | 10 | 23.7 |
| ED15 | 15 | 23.9 |
| ED20 | 20 | 24.0 |

*3.3. Setting time*

The setting time of OPC, EAFD, and ED in the fresh mortar mixture was shown in Figure 1. The setting time of OPC and EAFD is known about 6.4 hours and 26.4 hours, respectively. It is seen that there was contrast the setting time of OPC and EAFD. The prolong setting time was attributed to the presence of transition metal in the high percentage so that prevent their release to the cementitious matrix during the initial hydration. However, the calcination with the high temperature was succeeded to transform the material of EAFD so that was able to solve prolong the setting time in fresh mortar mixture. It can be proven in Figure 1 which the setting time of ED with the replacement of 5% to 20% is in the range of 5.6 to 5.9 hours. It means that the calcination with high temperature was able to reduce the percentage of metal content optimally which these metal in a high percentage had been entrapped in the link of the chemical structure. Furthermore, the increase of ED enhanced the setting time in the fresh mortar. It is linear with the workability. It means that the increase setting time was not due to the chemical content of ED but the drying time of initial water hydration. The result clearly demonstrated the potential of using ED material in term the restoring of setting time to its normal range.

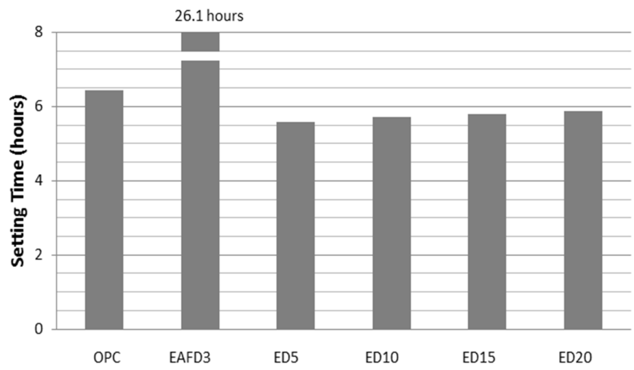


**Figure 1.** Setting time of OPC, EAFD and ED in the fresh mortar mixture.

*3.4. Compressive strength*

As mentioned in the previous study, the 1-day compressive strength of EAFD is not reported in Figure 2 since the fresh mortar mixture of EAFD was still unhardened condition. Furthermore, the compressive strength of OPC and 3% EAFD mixture at a later age are 60.4Mpa and 63.1Mpa. It means that the compressive strength of 3% EAFD mixture at a later age was higher than that given by the OPC mortar. This result gave the understanding that the material of EAFD was categorized as the cementitious material although it had not to impact at the early compressive strength. It was attributed to the high percentage of transition metal in the material of EAFD that caused the prevent of their release to the cementitious matrix during initial hydration so that retarded the pozzolanic reaction.

Furthermore, the compressive strength of ED with 5% to 20% replacement provides the early and later compressive strength. The early compressive strength of 5% to 20% ED is in the range of 16Mpa to 19Mpa, whereas the later compressive strength is in the range of 57Mpa to 65Mpa. It means that the pozzolanic reaction occurred in the short term which it was contrasted with the material of EAFD as described in the section of setting time. Furthermore, the material of ED improved the compressive strength up to 15% replacement. It was attributed to the increase of Si content during the calcination process which it reacted with $Ca(OH)_2$ to form the gel of C-S-H. However, the compressive strength of 20% ED is lower than that given by the OPC mortar. It means that the replacement of ED more than 15% was as the filler in the mortar and interfered the pozzolanic reaction. It was due to the optimum pozzolanic reaction that occurred in the replacement of 15 EAFD, whereas the rest of 5% replacement filled the pore. This result concludes that the use of 15% ED was considered as the optimum replacement level in the mortar mixture.

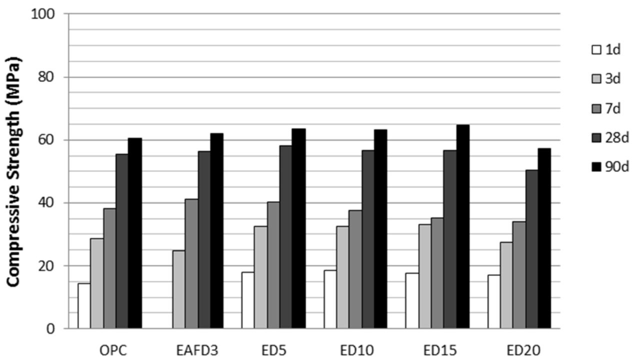


**Figure 2.** Compressive strength of OPC, EAFD and ED in the hardened mortar.

*3.5. Rapid chloride-ion penetration test*

The Rapid chloride-ion penetration test (RCPT) relies on the amount of electric charge passing through the mortar mixtures. The higher of electric charge passing into a mixture indicates the more permeable of mortar. Figure 3 shows that the material of EAFD with 3% replacement improves the chloride ion penetration resistance by 25% referred to the OPC mortar. It means that the material of EAFD was as the filler in the mortar. Furthermore, the material of ED with the replacement up to 10% ED has higher electric charge values (coulombs) compared to the OPC mortar whereas the material of ED with the replacement more than 10% ED has a lower coulomb compared to the OPC mortar. It confirms that the increase in compressive strength reduced the reading of RCPT. However, replacement of 20% ED did not provide the highest compressive strength. It is due to the replacement of 20% ED only improve the filler in the mortar but interfered the pozzolanic reaction.

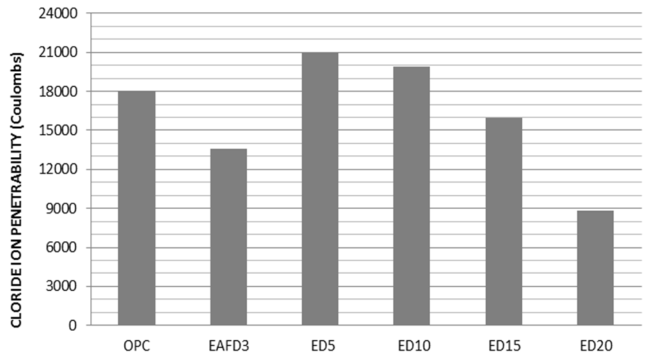


**Figure 3.** RCPT of OPC, EAFD and ED in the hardened mortar.

## 4. Conclusions

Based on the result of ED properties obtained from this study, the following conclusions can be drawn:

- The material of ED contained lower concentrations of transition metal than the material of EAFD;
- The production of ED was proven to successfully overcome the problem of prolonged setting time associated with the incorporation of 3% EAFD. This was confirmed by the normal range of setting times attained at all ED replacement levels up to 20%;
- The fresh mortar mixture of ED had slightly improved the flowability with the setting time in the range of 4 to 6 hours while the setting time of 3% EAFD was 26.1 hours;
- The use of 15% ED in the mortar mixture was the optimum replacement level which the RCPT of 15% ED was still higher than the EAFD of 3% replacement.

## References

[1] Rizal F, Fauzi A, Yunus Y 2019 Feasibility using electric arc furnace dust as cementing material in high performance concrete, *IOP conf. series: Mater. Sci. Eng.* **536** 012107.

[2] Oustadakis P, tsakiridis P E, Katsiapi A, Leonardo S A 2010 hydro metallurgical process for zinc recovery from electric arc furnace dust: Part I: Characterization and leaching by diluted sulphuric acid, *J. hazardous mater.* **179(1-3)** 1-7.

[3] Harahsheh M, Nu'airat J, Otoom A, Hammouri I, Jabali H, Zoubi M, Al'asal S A 2019 Treatment of electric arc furnace dust and halogenated plastic wastes: A review, *J. environ. chem. Eng.* **7(1)** 102856.

[4] Fares G, Zaid R Z, Fauzi A, Hozaimy A M, Negheimish A I, Khan M I 2016 Performance of optimized electric arc furnace dust-based cementitious matrix compared to conventional supplementary cementitious materials, *Construct. build. mater.* **112** 210-21.

[5] Vargas A S, Masuero A B, Vilela A C F 2006 Investigations on the use of electric-arc furnace dust (EAFD) in Pozzolan-modified Portland cement I (MP) pastes, *Cement Concrete Res.* 2006. **36** 1833-41.

[6] Souza C D C, Machado A T, Lima L R P A, Cardoso R J C 2010 Stabilization of Electric-Arc Furnace Dust in Concrete, *Mater. Res.* **13(4)** 513-9.

[7] Almutlaq F M 20011 Aspects of the Use of Electric Arc Furnace Dust in Concrete, *Civil Eng.* p. 301.