# FEASIBILITY OF UTILIZATION EAFD AS CEMENT REPLACEMENT IN CONVENTIONAL CONCRETE

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***Abstrak — Produk limbah industri dapat dianggap sebagai sumber daya terbarukan, salah satunya adalah manufaktur baja, yang menghasilkan limbah debu mengandung besi spons, besi bekas dan limbah baja lainnya yang berdampak pada lingkungan. Bahan limbah ini disebut Electric Arc Furnace Dust (EAFD). Studi ini meneliti kelayakan menggunakan EAFD sebagai pengganti semen dibandingkan dengan silica fume (SF) dan fly ash (FA) dalam hal komposisi kimia, kemampuan kerja, pengaturan waktu, kekuatan tekan dan ketahanan permeabilitas klorida cepat. Hasilnya menunjukkan bahwa kemampuan kerja EAFD hampir sama dengan kontrol bahkan jika persentase EAFD meningkat. Ini tidak mengacu pada FA lebih bisa diterapkan atau SF kurang bisa diterapkan dengan meningkatkan persentase penggantian. Selanjutnya, EAFD secara signifikan mempengaruhi waktu pengaturan, yang 3% EAFD penggantian membawa untuk memperpanjang waktu pengaturan akhir untuk lebih dari 24 jam, sementara waktu pengaturan SF dan FA tidak berpengaruh signifikan seiring dengan peningkatan persentase penggantian. Selain itu, EAFD 3% adalah pengganti optimal untuk kekuatan tekan dan itu adalah tingkat penggantian setara dengan 5% SF dan 15% FA. Akhirnya, EAFD meningkatkan resistensi untuk permeabilitas cepat klorida lebih dari FA tetapi kurang dari SF.***

***Kata kunci:* Komposisi kimia, ukuran partikel, kemampuan kerja, waktu pengaturan, kekuatan tekan, permeabilitas klorida cepat.**

***Abstract — Industrial waste products can be considered as renewable resources, one of them is a steel manufacturing, which produced dust waste contain sponge iron, scrap metal and other steel wastes that impacted to environment. This waste material was called Electric Arc Furnace Dust (EAFD). This study investigates the feasibility of using EAFD as a cement replacement compared to silica fume (SF) and fly ash (FA) in terms of Chemical composition, workability, setting time, compressive strength and rapid chloride permeability resistance. The results showed that workability of EAFD is almost similar to control even if percentage of EAFD was increased. It is not refer to FA more workable or SF less workable with increase percentage of replacement. Furthermore, the EAFD significantly affect the setting time, which 3% EAFD replacement bring to prolong final setting time to more than 24 hours, while the setting time of SF and FA did not significant affected along with the increase replacement percentage. In addition, the 3% EAFD is optimum replacement for compressive strength and it is equivalent replacement level to 5% SF and 15% FA. Finally, the EAFD enhance the resistance for rapid chloride permeability more than FA but less than SF.***

***Keywords:* Chemical composition, particle size, workability, setting time, compressive strength, rapid chloride permeability.**

## I. INTRODUCTION

Portland cement (PC) is used as binder in concrete have negative impact to environment especially air pollution. It was known that the production of PC about one ton relesed one ton $CO_2$ to the air [1]. It challenged the reasearcher to find new materials that can reduce use PC in concrete industry, such as used suplementary cementitious materials (SCMs). The SCMs was derived from by product or waste material that had impact to environment [2]. Using of SCMs as partially replacement cement in concrete industry has a dual effect where considered as pozzolanic materials or fillers, thereby the microstructure of a hardened cementitious matrix becomes more dense and stronger [3-5]. Some of SCMs are needed in high quantities, yet they were expensive and unavailable in certain areas. So that, it is important to create other local resources of similar materials from the highly available waste materials in the region such as Electric Arc Furnace dust (EAFD).

Utilization the modern electric arc furnace (EAF) process in the steel manufacture from sponge iron, scrap metal and other steel wastes is unavoidable in the world. The steel manufacture using EAF process is accompanied dust waste identified as Electric Arc Furnace Dust (EAFD). The amount of EAFD generated from steel production was estimated to approximately 2% of steel weight [6].

It was documented that the most abundant heavy metals found in EAFD were zinc (Zn), lead (Pb), iron (Fe) and other heavy metals, so that, EAFD is classified as a hazardous material [6, 7]. Furthermore, the EAFD contains two major size fractions consist of a very fine-grained portion and a coarser part. Particle sizes range from 2.8 to 176 µm. The majority (94%) of the particles are smaller than 5.5 µm in diameter [8].

The use EAFD in concrete has attracted the attention of many researchers. The cementitious matrix of concrete encapsulates the heavy metals and lowers leachability and negative environmental impact [6, 7]. It was investigated that the higher replacement levels of EAFD brought to prolong setting time up to 26 hours [9]. In addition, the other investigation reported enhanced hardened properties of concrete when EAFD is used at 3% replacement level. However, higher replacement levels had negative effect in early hardened concrete properties, because of it can retard the concrete setting, so that caused lower compressive strength [9].

## Experimental Program and Material

The use of SCMs such as SF and FA are mandatory as comparison in replacement cement due to improvement of concrete properties cannot be attained by using cement alone. The SCMs provide cementitious gel similar to those produced by the hydration of Portland cement [10]. The SCMs were usually used by replacement ranges about 5% to 20% of cement mass [3, 4]. Furthermore, this study used maximum replacement of SF and FA about 15%, whereas, maximum replacement for EAFD was 5%. It was conducted because of the previous research revealed that optimum replacement of EAFD was about 3% of cement. In addition, the water-to-binder ratio (w/b) is 0.5, and sand to binder ratio (s/b) is 2.

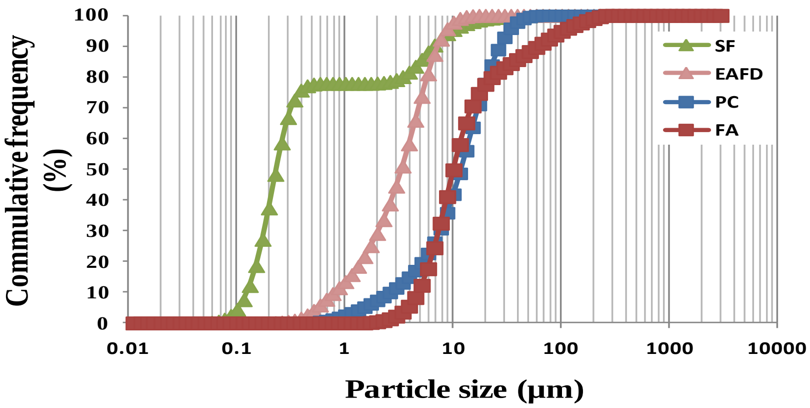


Figure 1 Grain size distributions of PC, SF, FA and EAFD

The material was used in this study consists of Portland cement Type 1, Silica fume and fly ash complying with ASTM C150/C150M [11], ASTM C1240 [12] and ASTM C618 [13], respectively. Whereas, EAFD was sourced from local steel producer, Southern Steel company, Malaysia. The particle size distributions of PC, SF, FA and EAFD as determined using laser scattering particle size distribution analyzer (LA 950 VR) are shown in Fig. 1. The particle size distributions display that EAFD particles are finer than PC and FA particles, on the other hand SF particles are finest. It confirms to previous research mentioned that a median grain size of PC, SF, FA, and EAFD powders were 11, 0.2, 10 and 3 µm, respectively [2, 9]. In addition, it can conclude that EAFD is as a filler better than FA.

Furthermore, the chemical analysis of PC, SF, FA and EAFD are summarized in Table 1. It shows that EAFD contains heavy metal such as Fe and Zn element compared to SF and FA, whereas Si element is too low compared to SF and FA. It means that EAFD will produce C-S-H less than SF and FA, hence, it effect to compressive strength. In addition, Fe element is almost 50% of total element, yet it is only 10% optimum in SF and FA. It confirm that EAFD has a significant Fe element caused prolong the setting time [9].

Table 1: Typical Composition of PC, SF, FA, and EAFD.

| Oxide Composition | Analysis, % by weight | | | |
|---|---|---|---|---|
| | PC | SF | FA | EAFD |
| $SiO_2$ | 20.2 | 86.2 | 55.23 | 1.91 |
| $Al_2O_3$ | 5.49 | 0.49 | 25.95 | 0.26 |
| $Fe_2O_3$ | 4.12 | 3.79 | 10.17 | 48.52 |
| CaO | 65.43 | 2.19 | 1.32 | 7.04 |
| MgO | 0.71 | 1.31 | 0.31 | 1.75 |
| $Na_2Oeq$ | 0.06 | 2.80 | 1.59 | 3.22 |
| $SO_3$ | 2.61 | 0.74 | 0.18 | 0.84 |
| ZnO | - | - | - | 27.73 |
| MnO | - | - | - | 3.04 |
| Loss On Ignition | 1.38 | 2.48 | 5.25 | 5.68 |

## II. RESULTS AND DISCUSSION

### Workability

The average flow diameter of each mortar mixture was measured using the flow table in accordance with ASTM C230/C230M [14]. The results are shown in figure 2. It is notable that the addition of SF percentage decreases workability respect to the control mixture, contrast with FA that increase the workability along as the percentage addition. However, the EAFD has workability almost similar like control although increased the percentage. From this study, it can be concluded that the SF powder in concrete mixture absorb the water. It means that the workability of SF will decline and sticky along with the increase replacement percentage. While, the FA in concrete release the water, which the workability will ascending and more flow along with the increase replacement percentage. So that, it conclude that both of SF and FA have opposite workability, yet, EAFD does not refer to one of them. It is because of particle size of EAFD is normal size between SF and FA that keep water stability.

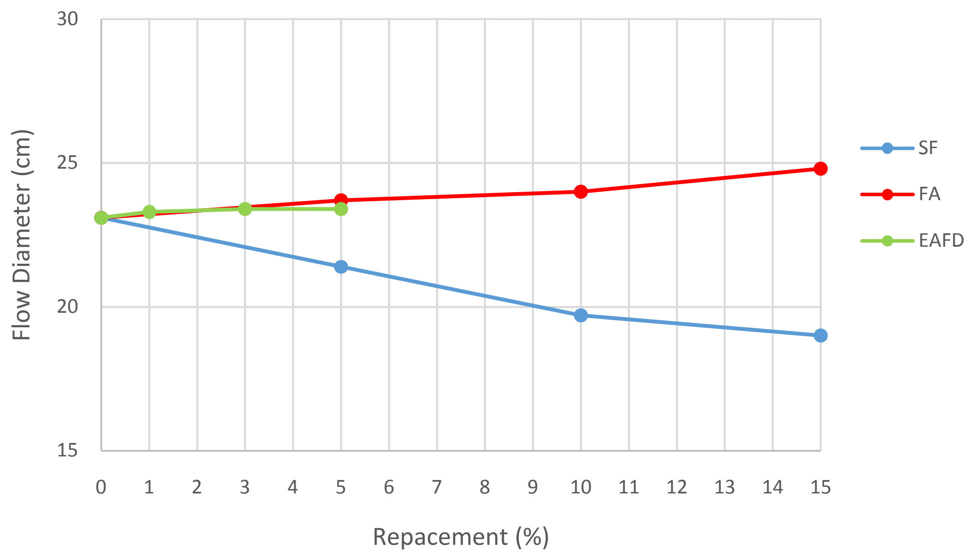


Figure 2. Flow diameter of mortar mixtures

### Setting Time

The figure 3 shows the setting times of mortar mixtures of SF, FA and EAFD. It is noted that the presence of EAFD with 1%, 3% and 5% significantly increase the final setting time. It is obviously that the percentage of EAFD bring to prolong setting time is about 8.8 hours, 26.1 hours and 51.4 hours, respectively. It is suspected due to the Fe element present in EAFD with significant percentage as 48.2% of mass content refer to SF and FA only 3.79% and 10.17%, respectively. In addition, increasing final setting time of FA along with the increase replacement percentage, but it is opposite with SF, which it is decrease along the increase replacement percentage. It means that it is linear correlation between workability and setting time, which workability increase along with setting time, but it is not applicable to EAFD. Finally, the overall effect of EAFD on setting time is critical as it extends the setting time of mortar mixture to more than one day. Therefore, higher replacement level of EAFD is not practical

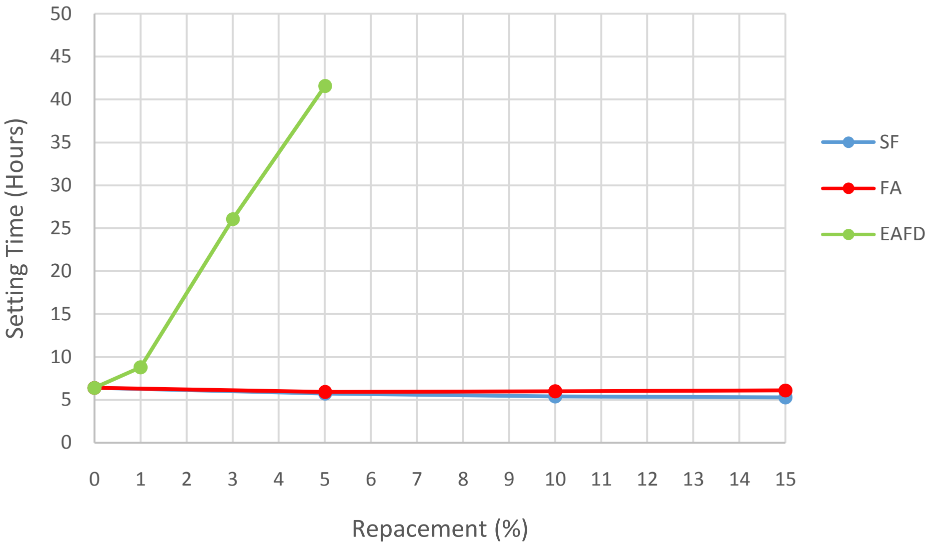


Figure 3. Final setting times

**Compressive Strength**

The equivalent replacement levels of SF and FA to the optimum EAFD content was determined figure 4, which it shows the compressive strength of SF, FA, and EAFD under curing ages of 1, 3, 7, 28 and 90 days. The equivalent optimum replacement levels of EAFD refers to SF and FA can be easily determined considering the best performance of compressive strength particularly at 28 and 90 days. The compressive strength of EAFD at 1- day is only in 1 percentage replacement, it because of the EAFD mixture was still fresh properties condition. It is evidenced with the prolonged setting time as 26.1 hours and 51.4 hours, respectively. It means that the concrete start to be hardened after that time. It is not similar with 1% EAFD which the concrete has been hardened after 8.8 hours or 2 hours after normal final setting time, so that after 24 hours, the compressive strength is directly obtained. However, use the optimum replacement of EAFD can be seen in long term properties, which, at the later age strength of the mixture containing 3% EAFD is higher than that given by the control mixture, 1% and 5% EAFD. It means that the use optimum percentage replacement of EAFD is about 3% of PC content. In addition, it is noted that it is two condition to use the EAFD in concrete viz. 1% EAFD for short term properties, which it approach normal concrete properties uses PC and the other is 3% EAFD that equivalent replacement levels with 5% SF and 15% FA, respectively.

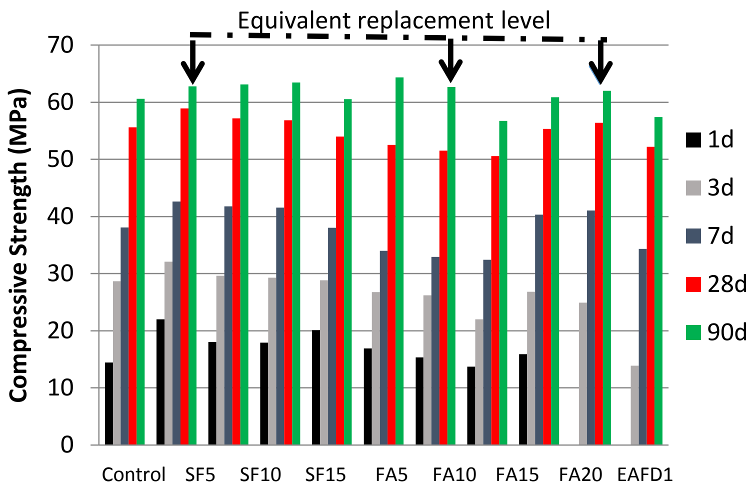


Figure 4. Compressive strength

## Rapid Chloride Permeability test (RCPT)

The rapid chloride penetration test (RCPT) relies on the electrical charge passing through the mortar mixtures. This test was done in accordance with ASTM C1202 [15]. It is known that the amount of electrical charge passes into the mortar sample is much higher than that in the corresponding concrete one. Figure 6 shows the RCPT results of control, SF, FA and EAFD mixtures. In general, SF, FA and EAFD mixtures are lower chloride permeability than the control mixture, it means that the EAFD can refer to SF and FA in terms of pore. However, SF mixtures show the lowest chloride permeability. In addition, it is an abrupt reduction the chloride permeability along with the increase SF replacement, yet, it is opposite with FA. However, the EAFD has almost similar chloride permeability for any replacement and it does not refer to SF and FA. It is important to be noted that the EAFD with all of percentage improved the resistivity to chloride ion penetration by approximately 24% refer to the control mixture. Therefore, the filling effect due to the fine particles in EAFD is predominant at water-binder ratio of 0.5 and the nature of calcium hydroxyl zincate gel (C-Z-H) formed under these conditions with the presence of Zn ions. Finally, it can be concluded that the optimum EAFD content provided an intermediate performance between the optimum SF and FA contents and exceeded that of the control.

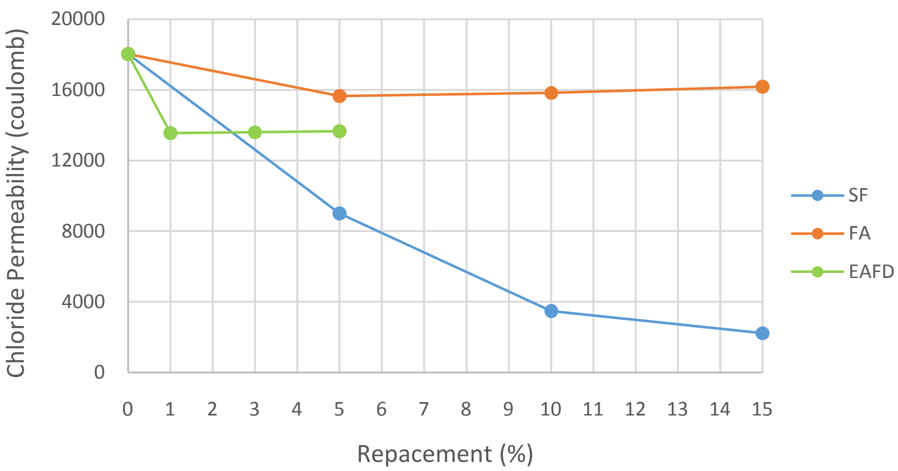


Figure 5. Rapid chloride permeability test

## III. CONCLUSION

On the basis of the equivalent replacement level concept, it is concluded that use EAFD as cement replacement is not significant percentage compared to SF and FA. It is due to significant replacement percentage bring mortar concrete to prolong setting time. However, the lower replacement percentage such as 1% and 3% EAFD are still acceptable, which the setting time of 1% EAFD is about 8.8 hours or 2 hours after normal setting time. It means the concrete has been hardened at that time. While the setting time of 3% EAFD is about 26.1 hours or 1 day after normal setting time. From this condition, the EAFD can be as retarder in concrete and it is suitable with the fresh ready mix that requires time for concrete to be hardened before it gets to the location due to traffic jam

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