Heat Optimization in Internal Curing Process of Geopolymer Mortar by Using Steel Dust

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Abstract— Endothermic is one of the fundamental characterics in geopolymer that involves external source of heat to activate the polymerization process to form strong hardened geopolymer. However, high temperature during curing process may lead to the drying shrinkage to the specimen and affecting the mechanical properties of hardened geopolymer. Therefore, this research investigates the effect of steel dust as partial replacement of fine aggregate towards the heating optimization of internal curing process in geopolymer mortar. Experiments was conducted by replacing 5% and 10% fine aggregates with steel dust and cured at 50 °C and 60 °C for 24 hours. After 24 hours, the hardened specimens were kept in room temperature until the testing days (1, 7 and 28 days). Based on the result, the addition of 10% steel dust in geopolymer with 60°C curing temperature had the highest compressive strength as compared to others. Nevertheless, it produced an unconventional porosity-compressive strength relationship that was caused by the disruption of dissolution and polycondensation process during geopolymerization process.

Keywords—geopolymer; fly ash; steel dust; internal curing

1. INTRODUCTION

The use of filler material in geopolymer system has been initiated since its first introduction in 1970 by Joseph Davidovits [1]. Named after the reaction between alumino silicate rich material and alkali solution, geopolymer gain the popularity as the alternative binder to Portland cement. Nevertheless, owing to its endothermic characteristic, geopolymer requires an elevated temperature during its early maturing process to achieve its optimum capability.

In this research, steel dust was used as the filler material to replace some portion of fine aggregate in geopolymer mortar. Steel dust was studied due to the presence of iron element as a conductive material that may assist the heat distribution in geopolymer system. Electric Arc Furnace Dust (EAFD), known as steel dust, was a solid industrial hazardous waste generated in the collection of particulate material during steel production process [2]. Environmental Protection Agency (EPA) has designated steel dust as K061 and classified it as hazardous waste [2], because it contains hazardous metals such as lead and Cadmium. Worldwide was estimated the production of EAFD to be more than 3.7 million tons per year [3]. In an electric arc furnace (EAF), about 15–25 kg of dust is produced per ton of steel [4]. Based on the chemical analysis the approximate order of abundance of major elements in EAF dusts is iron oxide (50 %) and zinc oxide (21 %). Whereas other constituents include: calcium oxide, silicon oxide, magnesium oxide, nickel and chromium [5]. Furthermore, the EAF dust is a highly dense material and fine, as the density of EAFD is 4.08 g. cm^{-3} and specific surface of 7310 cm^2. $^{g-1}$ with the size of particle distribution of d_{50} about 8.5 mm [6].

Numerous researches had been done by utilizing electric-arc furnace dust (steel dust) in the production of concrete. Most researchers utilized steel dust as partial replacement of Ordinary Portland Cement (OPC). Maslehuddin et al., 2011 investigated the use of electric-arc furnace dust (EAFD) in concrete and found that the addition of EAFD into the concrete was able to increase the compressive strength up to 15–30% higher [7]. Meanwhile, Sikaldis and Mitrakas, (2006) did the research on the inclusion of EAFD at various temperatures, which range from 850–1050 °C, on the properties of extruded clay-based ceramic building products [8]. The addition of 7.5–15% EAFD has improved the properties of the product, while the addition of 20 % EAFD was not beneficial for the product.

2. METHODOLOGY

In this research, fly ash was used as the main source material to be combined with alkali solutions. Fly ash was collected from Manjung coal fired power plant with oxide composition is as listed in Table 1. Sodium silicate solution with the detail composition of Na_2O=14. 73 %; SiO_2=29.75 % and H_2O=55.52 % was used as the main alkali solution. Table 2 shows the detail of mix proportion used in this study.

Geopolymer mortar was prepared with conventional mixing method. Fly ash, fine aggregate and steel dust (if any) were mixed in a bowl mixer for 1 minute to obtain a well dispersed dry mixture. Sodium silicate solution was poured into the dry mixture and continued with the second mixing process for 1.5 minutes. Fresh geopolymer mortar was then cast into 50 mm cube mould for the evaluation of its compressive strength and porosity characteristic. Detail observation on the effect of steel dust to the properties of hardened geopolymer was achieved via various elevated temperature exposure in the curing process. Geopolymer mortar in this study was cured in electronic oven (at 50 °C and 60 °C) for 24 hours and demoulded afterward. Oven cured specimens were then stored at room temperature until the testing day.

3. RESULTS AND DISCUSSION

A. Compressive strength

Compressive strength results of geopolymer mortar with partial replacement of the aggregate with steel dust is presented in Figure 1 and Figure 2. Compressive strength performance was observed after 1, 7 and 28 days curing in various temperatures (50 ºC and 60 ºC). As presented in these figures, the incremental amount of steel dust inclusion in fly ash based geopolymer undergoes elevated curing temperature 50 ºC and 60 ºC was able to increase the compressive strength performance. As demonstrated in Fig. 1, the inclusion of 10% of steel dust in 50 ºC curing temperature exhibited higher compressive strength than control and 5 % steel dust specimen. By increasing days of curing, the compressive strength was slightly enhanced. Rapid acceleration occurred during the stiffening process, initiated the formation of hardened geopolymer gel that contributed to the high early strength of steel dust specimen.

Table 1: Oxide composition of fly ash

Oxide	Percentage weight (% wt)
Al_2O_3	17.57
SiO_2	36.37
P_2O_5	0.28
SO_3	1.39
K_2O	1.77
CaO	10.58
TiO_2	0.88
Fe_2O_3	12.43
SrO	0.12
Mn_2O_3	0.11
MgO	3.05
Loss of Ignition (LOI)	1.19

Table 2: Detail of mixture proportions

Mix	A	B	C	D	E	F
Fly Ash (kg/m^3)	700	700	700	700	700	700
Fine Aggregates (kg/m^3)	1300	1170	1040	1300	1170	1040
Steel Dust (kg/m^3)	-	130	260	-	130	260
Na_2SiO_3 (kg/m^3)	200	200	200	200	200	200
Water (kg/m^3)	70	70	70	70	70	70
Curing Temperature	50 ºC	50 ºC	50 ºC	60 ºC	60 ºC	60 ºC

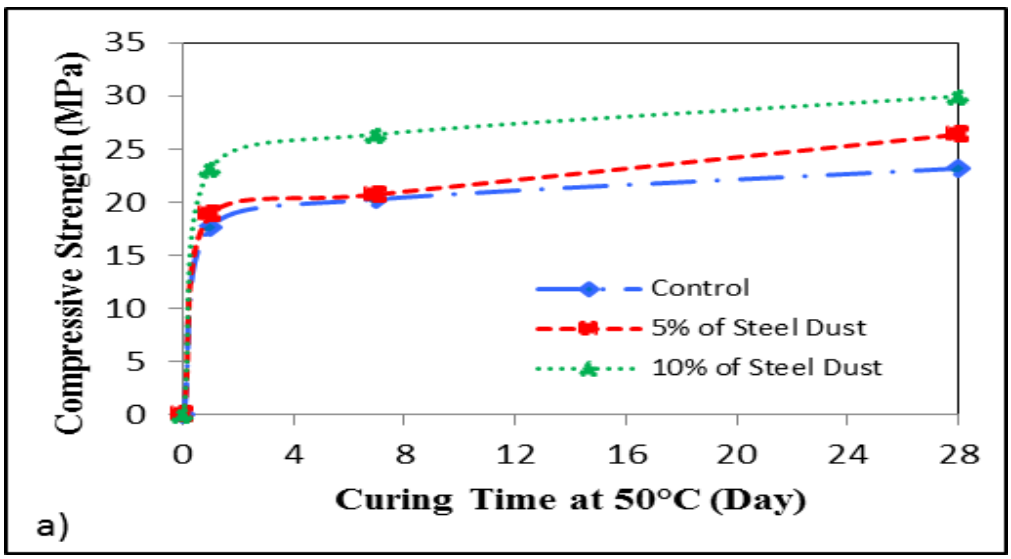

Figure 1: Compressive strength of geopolymer mortar with steel dust at 50 ºC

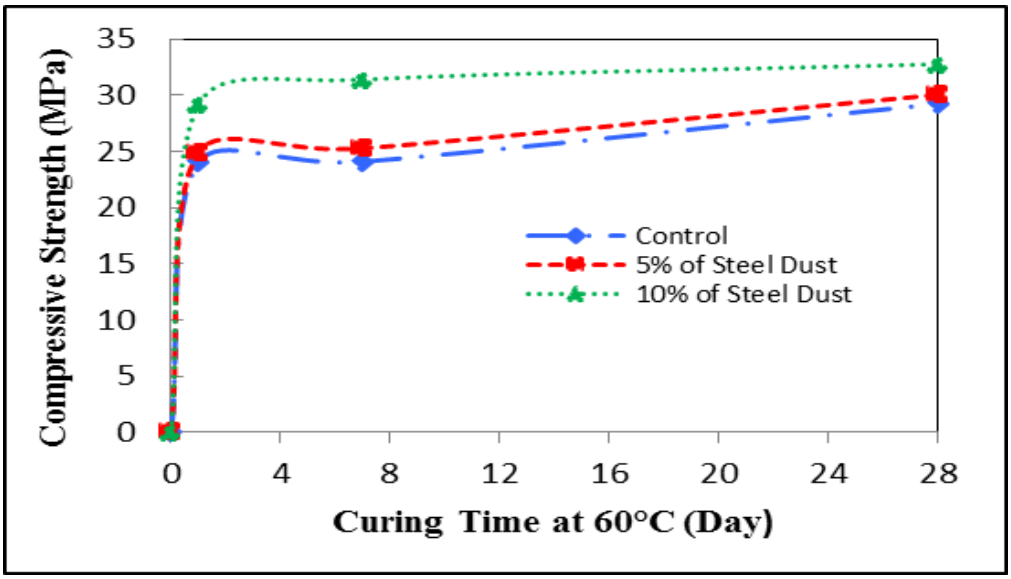

Figure 2: Compressive strength of geopolymer mortar with steel dust at 60 ºC

As observed in Figure 2, when the curing temperature was increased to 60 ºC, the inclusions of steel dust tend to present higher compressive strength than control and former 50 ºC specimen. After 28 days of curing, 10 % steel dust with curing temperature of 60 ºC possessed the highest compressive strength (32.78 Mpa) among geopolymer mortar specimens in this study. It is apparent in this study how steel dust functions effectively to distribute heat from external resource into the internal fragment of geopolymer mortar and accelerate geopolymerization process. These results **indicate** the importance of elevated temperature in geopolymerization, where after action on the dissolution and polymerization process of geopolymer precursors will affect the entire process [9].

B. Porosity

The results of porosity analysis for geopolymer mortar containing steel dust are shown in Figure 3. Unconventional porosity-compressive strength correlation was observed in this study, where the increasing compressive strength is also followed by the increasing porosity value. At day 1, 50 ºC curing regime presented 10% steel dust specimen with 6.02 % of porosity value, which is lower than 5 % steel dust (7.57 %) and control (8.42 %) specimen. Additional increment of curing temperature to 60 ºC was able to further decrease the volume of permeable voids in all geopolymer mortar specimens. Based on that result, it shows that voids in geopolymer mortar are able to be filled by the new reaction product, which reside within pores in the matrices. When the steel dust inclusion was further increased to 10 %, refinement on the geopolymer gel production was significantly improved as the elevated temperature has significantly accelerated the production of geopolymer gel.

After 28 days of curing, certain anomalies were detected in geopolymer mortar specimens. Volume of permeable voids was detected to be higher than Day-1 specimens, yet former compressive strength data presented an inversed trend. Figure 4 shows the correlation between compressive strength and porosity values of geopolymer mortar containing steel dust at Day-28. It appears that variation in heat distribution in geopolymer mortar caused this phenomenon. The increasing curing temperature has accelerated the dissolution and polycondensation process of geopolymer precursors from fly ash and steel dust surfaces. Rapid acceleration occurs in geopolymer has reduced the quality of geopolymer gel. Therefore, it deteriorated the microstructure of hardened geopolymer specimen. Another factor contributed to this anomaly was interracial spaces between partially reacted or unreacted fly ash particles in geopolymer gel [7].

4. CONCLUSION

In this study, 10% inclusion of steel dust was concluded as the optimum replacement percentage for fine aggregate in geopolymer mortar. The proportion has successfully contributed to the improvement of strength performance and porosity characteristic via better internal heat distribution during curing process. Therefore, the use of steel dust in geopolymer system has a good potential to be further explored in the future research.

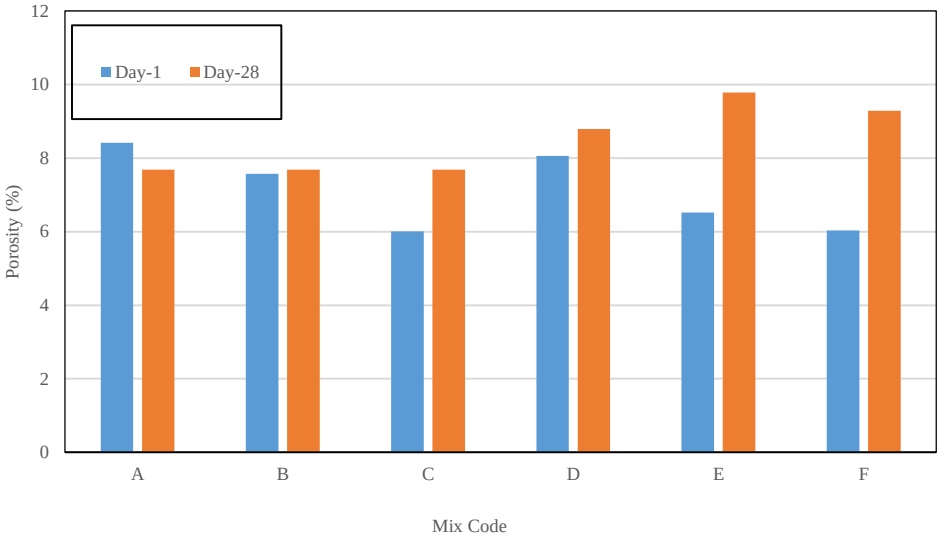

Figure 3: Porosity of geopolymer binder inclusion of steel dust

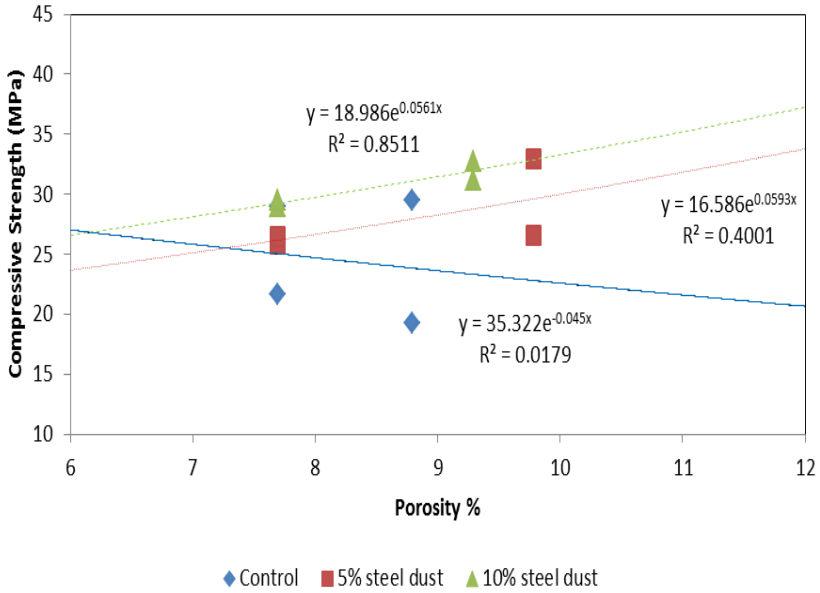

Figure 4: Correlation between compressive strength and porosity after 28 days

ACKNOWLEDGMENT

The authors would like to express their acknowledgment to YTL Slag Cement and financial support from Universiti Malaysia Pahang and Kementerian Pendidikan Tinggi Malaysia, under research grant RDU 130614.

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