Curing Temperatures on the Compressive Strength and Drying Shrinkage of Alkali-Activated Fly Ash Mortars

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ABSTRACT

This study investigated the effect of curing temperature on the compressive strength and drying shrinkage of alkali-activated fly ash (AAFA) mortars. Class F fly ash was used as the raw material, and sodium oxide and liquid sodium silicate were used as alkaline activators. AAFA mortars with an alkaline-solution-to-binder ratio of 0.5 were prepared under four different initial curing conditions. Test results showed that the curing temperature appreciably influenced the compressive strength development and drying shrinkage of AAFA mortars at early ages. A higher temperature led to more effective alkali activation of fly ash. Based on the results, AAFA mortars cured at 65 °C for 12 h had superior mechanical properties.

INTRODUCTION

Alkali-activated fly ash (AAFA) is a chemical process in which fly ash is mixed with strong alkaline solutions and cured at a moderate temperature [1]. This binder is called geopolymer and has considerable potential as an alternative to OPC. Geopolymers formed at room temperature are amorphous. Curing conditions have a strong effect on both early-age and final mechanical properties of geopolymer materials [2, 3]. With an increase in the temperature, crystalline phases begin to appear. Most research has been conducted by curing at approximately 95% RH and in the temperature range 30–85 °C [4]. Swanepoel and Strydom [5] conducted a study on geopolymers cured at 40, 50, 60, and 70 °C for different durations and found that the optimal curing conditions involved a temperature of 60 °C and a

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duration of 48 h. Chi [2] found that curing at 80% relative humidity (RH) and at a
temperature of 60 °C yielded optimal alkali-activated slag concrete (AASC)
performance; followed the AASC obtained through air curing and saturated
limewater curing showed the next highest performance.

In this study, four different initial curing conditions—curing in air at ambient
temperature for 24 h, 30 °C for 24 h, 65 °C for 12 h, and 85 °C for 6 h—were
considered to investigate the effect of the curing temperature on the mechanical
properties of AAFA mortars.

EXPERIMENTAL PROGRAM

Materials

Class F fly ash (FA) from Xingda Power Plant in Kaohsiung, Taiwan, was used
as the main aluminium and silicate source for synthesising a geopolymeric binder.
Standard sand conforming to ASTM C778 was used as the fine aggregate for
preparing geopolymer mortars. In this study, the alkaline activation of the FA was
performed using sodium hydroxide pellets with a density of 2130 kg/m³ and sodium
silicate solution (Na₂O.γSiO₂.nH₂O) consisting of 29.2% SiO₂, 14.8% Na₂O, and
56.0% H₂O by mass.

MIXES DESIGN AND SPECIMENS PREPARATION

AAFA geopolymer specimens were prepared from fly ash, sodium hydroxide,
and sodium silicate. Alkaline solution to binder ratio of 0.5 denoted by M5 were
selected to produce AAFA mortars. Sodium oxide (Na₂O) with a mass of 121 kg
per cubic meter of mortar and liquid sodium silicate with a modulus ratio (mass ratio
of SiO₂ to Na₂O) of 1.23 were used as alkaline activators. The sand/binder ratio was
constant at 2.75. The mortar mix proportions are presented in Table 1.

The specimens were cast and kept in steel moulds for 24 h. Before demoulding,
the specimens were subjected to four different curing conditions with temperatures
ranging from ambient temperature to 85 °C and curing times ranging from 6 to 24 h.
In other words, the specimens were exposed to air at ambient temperature for 24 h,
30 °C for 24 h, 65 °C for 12 h, and 85 °C for 6 h; these conditions are denoted by A,
B, C, and D, respectively. After the initial curing, they were shifted to a curing room
with 80% RH and a temperature of 25 °C; they were stored in the room until they
were tested.
TABLE I. MIX PROPORTIONS OF AAFA MORTARS.

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Alkaline solution/binder ratio</th>
<th>SiO$_2$/Na$_2$O ratio</th>
<th>FA (kg/m$^3$)</th>
<th>FineAgg. (kg/m$^3$)</th>
<th>Activator (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M5</td>
<td>0.5</td>
<td>1.23</td>
<td>528</td>
<td>1453</td>
<td>148.8</td>
</tr>
</tbody>
</table>

Method

A compressive strength test and drying shrinkage test were conducted to evaluate the mechanical properties of the AAFA mortars at the ages of 7, 14 and 28 days.

Result and Discussion

COMPRESSIVE STRENGTH

The compressive strength development of AAFA mortars cured under four different conditions at the ages of 7, 14, and 28 days is shown in Figure 1.

As shown in Figure 1, the compressive strengths of the AM5 and BM5 mortars (AAFA mortars cured at ambient temperature and 30 °C, respectively) were lower than those of the CM5 and DM5 mortars at the age of 7 days. At ambient temperature, alkali activation of fly ash increased gradually, and an increase in the temperature accelerated the formation of a hardened structure, particularly in the early stages of the geopolymerisation reaction, and enhanced the compressive strength. For example, CM5 mortar reached a compressive strength of 31.5 MPa, which was approximately twice that of AM5 mortars at the age of 7 days. However, the compressive strengths of the AM5 and BM5 mortars steadily increased for 28 days. For example, the compressive strength of AM5 was 18.4 MPa at the age of 7 days, 24 MPa at the age of 14 days, and 32.7 MPa at the age of 28 days. CM5 and DM5 (AAFA mortars cured at 65 °C and 85 °C) showed a rapid increase in their compressive strength at the age of 7 days; however, the rate of increase in the compressive strength decreased after 14 days. The compressive strength of CM5 was 31.5 MPa at the age of 7 days, 34.8 MPa at the age of 14 days, and 35.2 MPa at the age of 28 days. The 28-day compressive strength of CM5 was only approximately 10% greater than the 7-day compressive strength. The compressive strength development of DM5 was similar to that of CM5. At early ages, a higher curing temperature accelerated the geopolymerisation reaction and increased the compressive strength development. However, in old specimens, the curing temperature has no appreciable influence on the compressive strength.

The results showed that the curing conditions appreciably influenced the compressive strength development of AAFA mortars. The curing temperature plays a crucial role in determining the compressive strength development of AAFA mortars at early ages. The compressive strength of AAFA mortars cured at 65 °C for 12 h was higher than that of AAFA mortars cured at other temperatures.
Compressive strength development of AAFA geopolymer vs. age.

DRIYING SHRINKAGE

The drying shrinkage of AAFA mortars cured at the four different conditions for 7, 14, and 28 days is shown in Figure 2. It shows the drying shrinkage of AAFA mortars with the alkaline solution to binder ratio of 0.5 and cured at four different temperatures (AM5, BM5, CM5, and DM5). Except for the DM5 mortar, the drying shrinkage of AAFA mortars increased with the curing temperature. On the basis of the drying shrinkage, the specimens aged 7 and 14 days were ordered as CM5 > BM5 > DM5 > AM5. After 14 days, the drying shrinkage of the AM5 mortars began to increase markedly. The 28-day drying shrinkage of the AM5 mortars was close to that of BM5, which had a drying shrinkage of 68%. This is because the alkali activation reaction was incomplete, leading to excess moisture and a high drying shrinkage. At early ages, higher temperatures accelerate the geopolymerisation reaction of AAFA mortars, resulting in higher drying shrinkage. However, at late ages, the drying shrinkage of AAFA mortars cured at high temperatures increases gradually because of a reduction in the amount of the alkaline solution.
CONCLUSIONS

The curing temperature influenced the compressive strength development and drying shrinkage of AAFA mortars at early ages. A higher temperature led to more effective alkali activation of fly ash. AAFA mortars cured at 65 °C for 12 h had superior mechanical properties.

REFERENCES