第Ｖ部門　Research on the bonding behavior between steel and AAM concrete activated by Sodium metasilicate nonahydrate

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1. Introduction

Recently, alkaline activated material concrete (AAM) has gained lots of attention as a sustainable alternative to ordinary Portland cement concrete (OPC) since its hardening mechanism leverages the activation of industrial wastes that are rich in Si and Al by alkaline solution, replacing the need for cement and effectively reducing CO_2 releases. Using sodium metasilicate nonahydrate (SS) as an alkaline activator provided unique benefits of low curing temperature and ease of handling. Still, AAM remains immature in the field of construction material, a thorough understanding of material and mechanical properties are vital to realize practical application.

2. Objective

This research aims to investigate bond response between AAM activated by sodium metasilicate nonahydrate and reinforcement steel using an unconfined pull-out test as well as comparing the to the OPC. The study focuses on the relationship between compressive strength and mechanical and chemical bond strength.

3. AAM proportion and casting procedure

The parameters used to determine the mix proportion are the following: 60% slag to fly ash replacement ratio, fine to coarse aggregate ratio of 0.45, water/binder = 0.4, and total water of 156 grams per 1 liter of concrete. Alkaline concentrations of 5-10% are used to vary AAM's compressive strength (f_c') to 20-40 MPa. All dry materials were mixed in the concrete mixture before adding water, with a total mixing time of 270 seconds. The concrete specimen's surface was covered with plastic sheets to prevent excess water loss and cured at ambient temperature (60% RH, 20 °C) for 20 days. The molds were removed on the day of testing.

4. Pull-out procedure

A total of 36 pull-out specimens were cast to match the dimensions required by JSCE-G 503-2013, as shown in Figure 1, using smooth and deformed bars. All-steel's nominal yield strength was 345 MPa, and the relative ribbed area of a deformed bar was 0.08. The load was then provided by a universal testing machine frame at a constant rate of 0.2 kN/s. Three LVDTs were used to measure the slip of rebar relative to concrete. The loading stopped when the specimens failed by either the splitting of the concrete or by the pulling out of the steel bar.

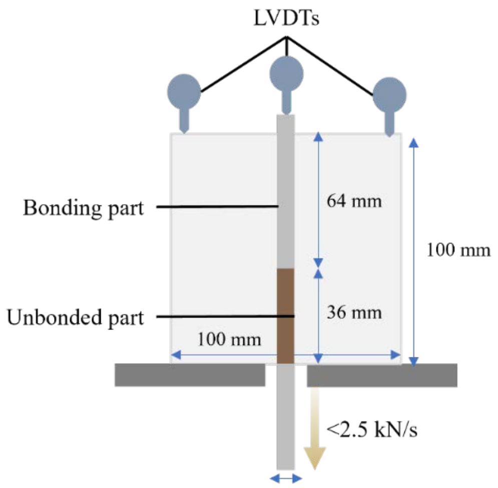

Figure 1. Pull-out specimen diagram

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5. Result and discussion

Tables 1. and 2. report the average bond strength and types of failure for AAM and OPC, respectively. Every smooth rebar specimen failed in a pull-out manner, while every deformed rebar failed in a splitting manner. Figures 2. and 3. illustrate the plot between the average bond strength and compressive strength of concrete made of smooth and deformed bars, respectively. Figure 4. shows an example of the stress-slip curve of a deformed bar. From the result, there is no significant difference in the bond strengths of AAM and OPC in smooth bars, implying that the chemical bond strengths are similar. For the deformed bar, AAM shows higher bond strength. However, since all the deformed bar specimens failed in splitting manner, it is reasonable to argue that this higher bond strength in deformed bar specimens derived from the better splitting tensile strength of AAM. The conclusion for the performance and bond stress-slip curve in the pull-out failure of a deformed bar still cannot be reached.

Table 1 Bond strength of AAM for smooth and deformed bars

Specimen	AAM-20	AAM-30	AAM-40
Smooth bar bond strength (MPa)	1.22 (pullout)	2.06 (pullout)	2.1 (pullout)
Deformed bar bond strength (MPa)	10.19 (splitting)	16.67 (splitting)	17.15 (splitting)

Table 2 Bond strength of OPC for smooth and deformed bars

Specimen	OPC-20	OPC-30	OPC-40
Smooth bar bond strength (MPa)	1.86 (pullout)	1.76 (pullout)	2.21 (pullout)
Deformed bar bond strength (MPa)	10.03 (splitting)	12.71 (splitting)	13.92 (splitting)

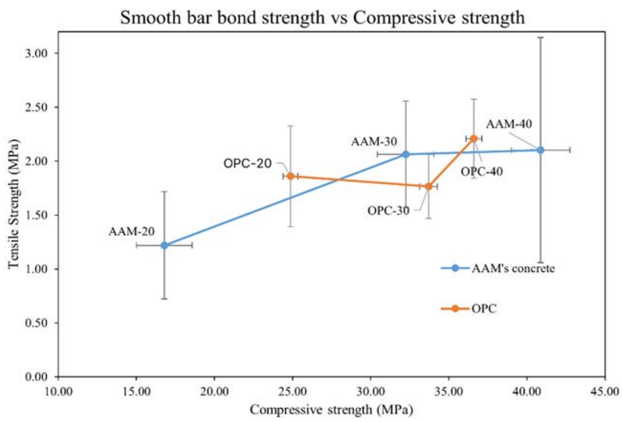

Figure 2 Bond strength using smooth bar and compressive strength

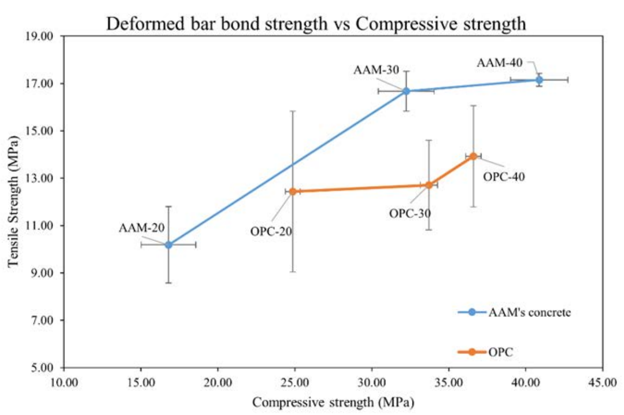

Figure 3 Bond strength using deformed bar and compressive strength

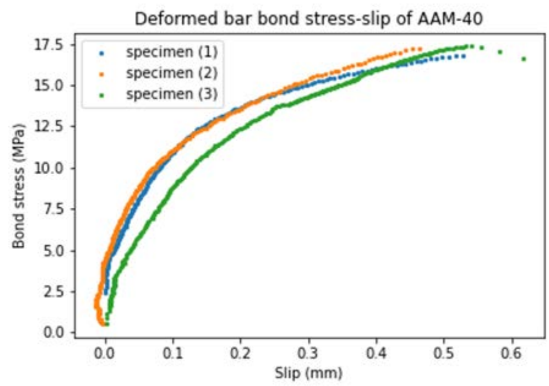

Figure 4 Bond stress-slip curve of AAM-40 deformed bar

5. Conclusion

Pull-out specimens of AAM concrete made from fly ash and slag activated by sodium metasilicate nonahydrate were conducted to quantify the bond strength and compare it with OPC. The result shows that there is no significant difference in chemical bond strength between the two materials. However, in case of bond failure in splitting, AAM performs slightly better, possibly due to its higher tensile strength at the same compressive strength.

6. Future work

The pull-out failure mode of the deformed bar will be obtained by increasing the concrete cover. Beam anchorage specimens will be used to obtain a realistic stress state in the actual beam elements.

7. Reference

メタケイ酸ナトリウム九水和物を使用したジオポリマーコンクリート梁の材料・力学的特性. (2023). (thesis).