Preparation Process and Early Working Performance of Inorganic Polymer-based Fast-hardening Concrete

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Abstract. For the purpose of delving deep into the preparation process and early working performance of inorganic cementitious composite material, and analyzing its application prospect in pavement emergency repair, the slag, fly ash and silica fume are used as solid cementitious materials, and sodium hydroxide and sodium silicate are used as alkali-activators to prepare inorganic polymer-based fast-hardening concrete (IPFC). The early working performance of the specimens with different contents of slag, fly ash and silica fume were compared and analyzed. The results show that, all the kinds of concrete mixtures have good fluidity, cohesiveness and water retentiveness. The addition of fly ash and silica fume can prolong the initial setting time of concrete, and the higher the content, the longer the extension time. And the slump of the mixture is inhibited by the addition of fly ash. When the content of fly ash is 15%, the slump of the mixture decreases by 19.2%. However, silica fume can improve the slump of the mixture. When the content of silica fume is 15%, the slump of the mixture increases by 19.1%.

1. INTRODUCTION

The frequency of natural disasters such as earthquakes, floods and hurricanes has been increasing worldwide. What's worse is that natural disasters cause loss of life and severe damages to roads, bridges and other traffic infrastructures. These transportation infrastructures are not only the important link connecting each other, but also the lifeline of post disaster rescue operations. More importantly, the transport system is the guarantee for the normal operation and development of socio-economic activities of a country or region, and is the lifeblood of the national economy. Therefore, the emergency repair of traffic infrastructures after disaster is of great importance to timely recover the loss of people's lives and property, and ensure the normal operation of national social and economic activities.

At present, the common Portland cement material is widely used to repair the damaged rigid pavement, but the performance of the material is still affected by limitations, especially its early mechanical properties are poor. The early strength of ordinary Portland cement concrete can be improved to a certain extent by adding early strength agent [1-3], accelerator [4-6] and other additives, but the setting and hardening time of concrete is still long, and it is difficult to achieve satisfactory strength in a few hours. Also, it has low bond strength and poor crack resistance. A large number of construction practices of reinforcement and emergency repair project show that it is difficult to use general rigid material to quickly repair the pavement, the main reason is that the early performance of rigid material is unable to meet the requirements. In addition, using flexible material to repair rigid pavement, the combination of the two is poor, resulting in poor repair quality [7-10]. Therefore, the
development of high-performance rapid repair material is of great significance for the rapid repair of rigid pavement.

Based on this, in this paper, the slag, fly ash and silica fume were used as solid cementitious materials, and sodium hydroxide and sodium silicate were used as alkali activators to prepare five groups of inorganic polymer-based fast-hardening concrete (IPFC). The early working performance of inorganic polymer-based fast-hardening concrete was further explored.

2. TEST SPECIMEN PREPARATION

2.1. Raw material
Raw materials for IPFC preparation mainly include slag, first grade fly ash, semi densified silica fume, sodium silicate, sodium hydroxide, crushed limestone, medium sand and water. The slag powder used in the test was S95 slag produced by Tongyang building materials company of Danyang District, Shanxi Province, with density of 2.89 g/cm³, specific surface area of 478 m²/kg, fluidity ratio of 101%, loss on ignition of 0.6%, water content of 0.3%, 7-day activity index of 89%, 28-day activity index of 105%. The fly ash used was provided by Yuanheng water purification material factory of Gongyi City. The components are 58.2% SiO₂, 29.8% Al₂O₃, 4.3% Fe₃O₄, 1.5% CaO, 2.8% MgO and 3.2% Na₂O. Semi densified silica fume with density of 350 kg/m³, loss on ignition of 2.7%, silica content of 98.2%, alkali content of 0.54%, moisture content of 0.04%. The sodium silicate from Xi’an area was used, the modulus is 3.2~3.4, the mass fraction is about 34%, and the density is about 1370 kg/m³. Sodium hydroxide was produced by Inner Mongolia Wuhai Xinye Chemical Co., Ltd., with purity of 99%. The clean water in laboratory was used and the sand was natural medium sand from Bahe River.

2.2. Mixture ratio design
Three kinds of IPFC were prepared for the following tests: slag-based fast-hardening concrete (SFC), fly ash/slag-based fast-hardening concrete (FSFC) and silica fume/slag-based fast-hardening concrete (SSFC). The specific mix proportion design of the specimens is shown in Table 1, in which FSFC1 group and FSFC2 group indicate that the fly ash content is 5% and 15% respectively; SSFC1 group and SSFC2 group indicate that the silica fume content is 5% and 15% respectively.

| Specimen number | Slag | First grade fly ash | Semi densified silica fume | Sodium silicate | Sodium hydroxide | Water | Medium sand | Crushed limestone |
|-----------------|------|---------------------|---------------------------|----------------|----------------|-------|-------------|------------------|
| SFC             | 497.4| --                  | --                        | 159.5          | 39.0           | 79.2  | 551.3       | 1073.7           |
| FSFC1           | 465.2| 24.5                | --                        | 157.0          | 38.4           | 77.9  | 555.4       | 1081.6           |
| FSFC2           | 407.5| 71.9                | --                        | 153.7          | 37.6           | 76.3  | 560.8       | 1092.2           |
| SSFC1           | 454.6| --                  | 23.9                      | 153.4          | 37.5           | 76.1  | 561.3       | 1093.2           |
| SSFC2           | 393.8| --                  | 69.5                      | 148.6          | 36.3           | 73.7  | 569.3       | 1108.8           |

2.3. Preparation process
The specific preparation process of the composite mixture is shown in Fig. 1. And the specimen was done in 5 steps.

Step 1: According to the mix proportion shown in Table 1, combined with the characteristics of IPFC, alkali-activator was prepared in advance.
Step 2: The raw materials were mixed in proportion, stirred for 30 s and placed in a closed state.
Step 3: Poured the composite solid material, sand and stone into the mixer in turn, and dried mix for 30 s.
Step 4: Because there were several kinds of solid materials, if alkali-activator was directly added, it was not easy to stir evenly, and precipitation may occur. Therefore, only 70% of the total water consumption was used in the preparation of alkali-activator, and the remaining 30% was used to dissolve the additive.
Step 5: The mixture was filled into a mold. To achieve greater compression, the mold was shaken on a vibrating machine twice for 30 seconds. Between shaking, the mixture was pounded manually for 30 seconds. Finally, the top of the formed specimen was screeded manually.

3. EARLY WORKING PERFORMANCE
The appearance of the newly mixed concrete is shown in Fig. 2. From the observation and analysis of the appearance, it can be seen that the three kinds of mixtures have good fluidity, cohesiveness and water retentiveness. Due to the different kinds of pastes, there are differences in the color of the mixture. The color of SFC mixture is dark white or light yellow, and that of FSFC and SSFC is dark gray or gray black.
Fig. 3 shows the variation law of setting time of each group of mixtures. It can be seen from the figure that the addition of fly ash and silica fume can prolong the initial setting time of concrete, and the higher the content, the longer the extension time. SFC is used as control group, and its initial setting time is 15 min. In contrast, when the content of fly ash and silica fume is 15%, the initial setting time of concrete is prolonged by 20% and 53.3%, obviously, the effect of silica fume is more prominent. With the addition of fly ash and silica fume, the final setting time of the five groups of mixtures has no obvious change, and the final setting time is basically the same.

During the test, it was found that the slump loss of the mixture was very fast. In order to ensure the comparability of the results, a part of the mixture was taken out of the machine for slump test. The test results are defined as the initial slump, as shown in Fig. 4. The initial slump of the control group is 130 mm. Through contrastive analysis, it can be seen that the slump of the mixture is inhibited by the addition of fly ash. When the content of fly ash is 15%, the slump of the mixture decreases by 19.2%. However, silica fume can improve the slump of the mixture. When the content of silica fume is 15%, the slump of the mixture increases by 19.1%.
4. SUMMARY
Here, five groups of inorganic polymer-based fast-hardening concrete specimens were prepared, and their early working performance was evaluated. All the three mixtures have good cohesiveness and water retention. When the content of fly ash and silica fume is 15%, the initial setting time of the mixture can be prolonged by 20% and 53.3%, respectively, which has little effect on the final setting time. With this amount of fly ash, the slump of mixture decreases by 19.2%, while that of silica fume increases by 19.2%. Our analysis shows that IPFC has a bright future in the actual project application of pavement emergency repair.

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