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A Study on the Effects of Chemical Admixtures on the Strength of Portland Cement

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Cement is one of the essential engineering materials in the construction industry. It has always been the focus of attention to improve the related performance of cement. In view of the effects of chemical admixtures on the strength of Portland cement, this paper has conducted a quantity of experiments, respectively studied the effects of retarder, alcohol amine admixture and inorganic salt admixture on the physical and mechanical properties of cement, obtained the effects of various admixtures on improving the related performance of cement, and provided reference values for the improvement of the performance of cement binding materials.

1. Introduction

Cement, one of the essential engineering materials in the construction industry, has been widely applied in the construction projects and played a vital role. The quality of cement, the strength of cement, durability and other properties exert influence on the building components' use function, carrying capacity and so on (Tennis and Jennings, 2000; Lothenbach and Winnefeld, 2006). The addition of admixtures to cement is a breakthrough in the concrete technology (Owens et al., 2004). Depending on the properties required by the cement-based materials in the projects, corresponding admixtures, such as retarders, air entraining agents and early strength agents, are reasonably added to improve the physical and mechanical properties, durability and frost resistance (Cui et al., 2016; Geng et al., 2016; Rajabipour et al., 2008).

There exists a wide variety of chemical admixtures. In terms of how to play its greatest significance and to improve the corresponding performance, the right variety should be selected and its range of the added amount should be known (Kurudirek et al., 2009). For example, an appropriate amount of gypsum is added to improve the strength of the material (Chandara et et al., 2009); an appropriate amount of sodium silicate to improve impermeability (Ma et al., 2015); an appropriate amount of triethanolamine is added to improve early strength (Sandberg et al., 2004; Han et al., 2015). Furthermore, the appropriate range of the addition amount has always been a focused research topic (Wang et al., 2009). Only with the appropriate amount can the related performance be improved, and an excessive amount may reduce the performance of the cement (Uchikawa et al., 1992; Hanehara and Yamada, 1999; Wu et al., 2011).

This paper adopts different chemical admixtures, studies the effects of admixtures on cement strength, analyzes the influence of different admixtures on the physical and mechanical properties of cement, and provides reference significance for improving the performance of cement binding materials.

2. Experimental design

2.1 Experimental materials

Portland cement is purchased from Spring City Cement Co., Ltd. in Yutian County, and its relevant physical properties are demonstrated in Table 1. River sand is applied and the fineness modulus is 2.5.

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Table 1: Physical properties of the Portland cement

Specific surface area (m^2/kg)	Water consumption of normal consistency (%)	Initial setting time (min)	Final setting time (min)	Compressive strength (MPa)		Flexural strength (MPa)	
				3d	28d	3d	28d
352	26.5	90	250	30.5	50.2	6.2	8.1

Three types of admixtures are considered, including retarder, organic alcohol amine and inorganic salt. Retarders mainly apply tartaric acid, sodium tripolyphosphate and sodium gluconate. Five types of organic alcohol amines are primarily adopted, namely diethylenetriamine ($C_4H_{13}N_3$), aminoethylethanolamine ($C_4H_{12}N_2O$), triethanolamine ($C_6H_{15}NO_3$), triisopropanolamine ($C_9H_{21}NO_3$) and polyvinyl alcohol ammonium phosphate ($(C_2H_8O_4NP)_n$). Five kinds of inorganic salts are mainly used: $CaSO_4$, $CaCl_2$, $FeCl_3$, Na_3SiO_4 and NaCl.

2.2 Experimental methods and measurements

In order to evaluate the effects of various chemical admixtures on cement strength, three aspects are mainly measured: water consumption of normal consistency, cement paste fluidity and compressive strength. Therefore, the experiments are divided into three groups, and each group is divided into 18 groups according to the type of admixture. In each group, a corresponding number of experiments times are completed in view of the type of admixture. Water consumption of normal consistency is measured in accord with *Test Methods for Water Requirement of Normal Consistency of the Portland Cements* using a Vicat meter. The fluidity is measured on basis of *Methods of Testing the Uniformity of Concrete Admixture*. Neat cement paste is placed on the glass plate to measure the maximum diameter of its free flow. In the process, the temperature is controlled at 30±3 °C, and the humidity is controlled at 95%±1. Compression and flexural strength are measured according to *Methods of Testing Cements—Determination of Strength.* A cubic cement mortar test piece, with the dimension of 40mm×40mm×160mm, is first prepared. The material consumptions are 500g of cement, 1350g of sand and 225g of admixture and water, which are vibrated and smashed before being placed in the curing box for conservation. After 24 hours, the mold is demolished and the conservation is continued to until the required age. And then, the press machine is employed to measure the compressive strength of the test piece.

3. Experimental results and analysis

3.1 The effects of chemical admixtures on water consumption of normal consistency of Portland cement

The considered mixing amount of the retarder is 0.01‰, 0.05‰, 0.1‰, 0.2‰ and 0.3‰, and the measurement results of water consumption of normal consistency are illustrated in Figure 1. The considered mixing amount of the organic alcohol amines is 0.01‰, 0.15‰, 0.2‰, 0.5‰ and 1‰, and the measurement results are indicated in Figure 2. The considered mixing amount of inorganic salt is 0.01‰, 0.2‰, 0.5‰, 1‰ and 2‰, and the measurement results are demonstrated in Figure 3.

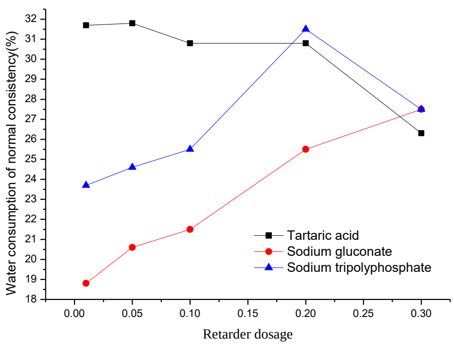


Figure 1: Effect of the retarder on water consumption of normal consistency

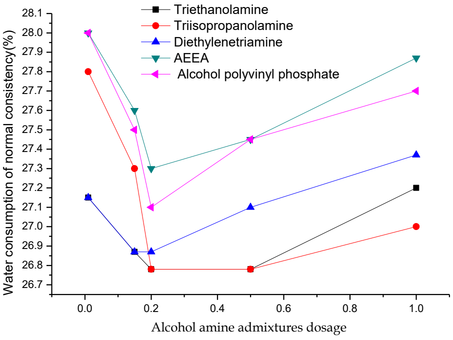


Figure 2: Effect of alcohol amine admixtures on water consumption of normal consistency

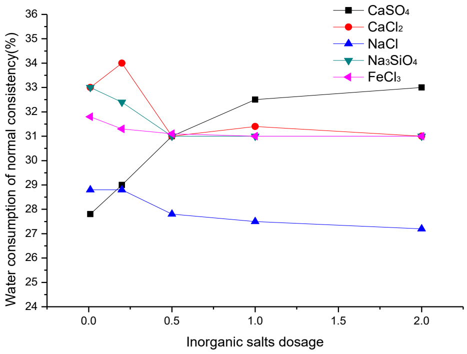


Figure 3: Effect of inorganic salt on water consumption of normal consistency

The water consumption of normal consistency of the cement without admixture is 26.5%. Figure 1 indicates that retarder has a more obvious effect on the water consumption of normal consistency. Regardless of the amount of added tartaric acid, its water consumption of normal consistency exceeds the amount in case of no addition of admixtures. When the mixing amount of sodium gluconate is less than 0.2 ‰ and the sodium tripolyphosphate is lower than 0.1 ‰, the water consumption of normal consistency could be cut down. Within this range, the higher the mixing amount is, the higher the water consumption is, both of which are below the amount in case of no addition of admixtures. It is indicated that these two retarders have a certain effect on reducing the water consumption of normal consistency, and sodium gluconate is better than sodium tripolyphosphate.

As seen from Figure 2, the admixtures of alcohol amines basically elevate the water consumption of normal consistency and they do not change linearly with the increase of the mixing amount. Among these five admixtures, the amount of aminoethylethanolamine experiences the largest increase. According to Figure 3, after adding the inorganic salt, the water consumption of normal consistency is also higher than the reference value. To be specific, the impact is small when the mixing amount of NaCl is 2 ‰, and it reaches 27.2%, slightly higher than the reference value.

3.2 The Effects of chemical admixture on cement paste fluidity of Portland cement

The cement paste fluidity of the cement that adds admixtures in each group is illustrated in Figure 4 to Figure 6:

The cement paste fluidity of the Portland cement without additive is 210 mm. As seen from Figure 4, as the mixing amount of retarder augments, the fluidity of cement is raised gradually. When the mixing amount reaches a certain amount and exceeds the reference value, it is indicated that retarder can improve the cement paste fluidity of the cement and tartaric acid achieves the best performance. Figure 5 indicates that triisopropanolamine with the mixing amount of 0.5‰ and 1‰ of as well as aminoethylethanolamine with the mixing amount of 0.1‰ slightly advance the fluidity, and the other alcohol amine admixtures basically reduce the fluidity. According to Figure 6, concerning the inorganic salt admixture, cement paste fluidity of the cement basically declines with the increase in the mixing amount. Specifically, sodium silicate and sodium chloride help improve the fluidity, and the measured fluidity basically is larger than the reference value. When the mixing amount of ferric chloride is less than 0.2‰, the fluidity is improved, but when it exceeds 0.2‰, the fluidity is in sharp decline, indicating the significance of the mixing amount applied on the admixtures.

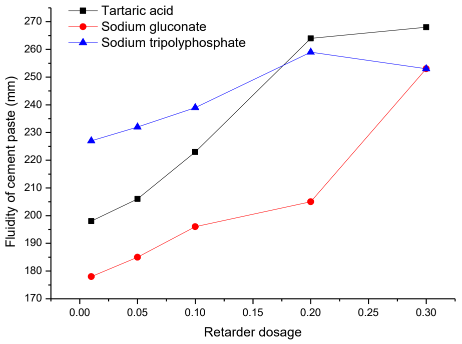


Figure 4: Effect of the retarder on cement paste fluidity

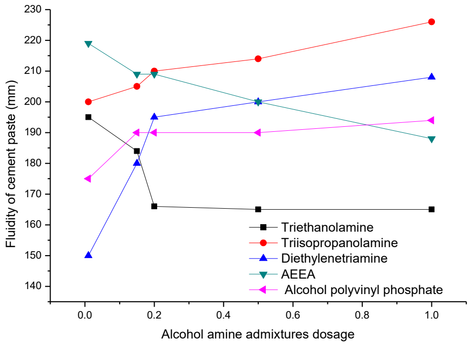


Figure 5: Effect of alcohol amine admixtures on cement paste fluidity

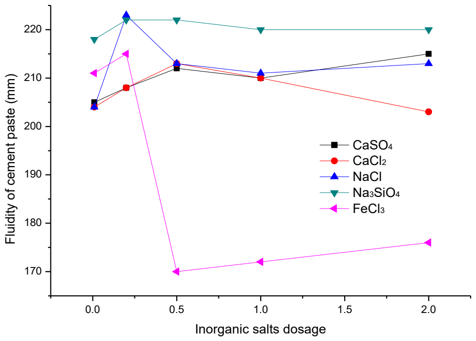
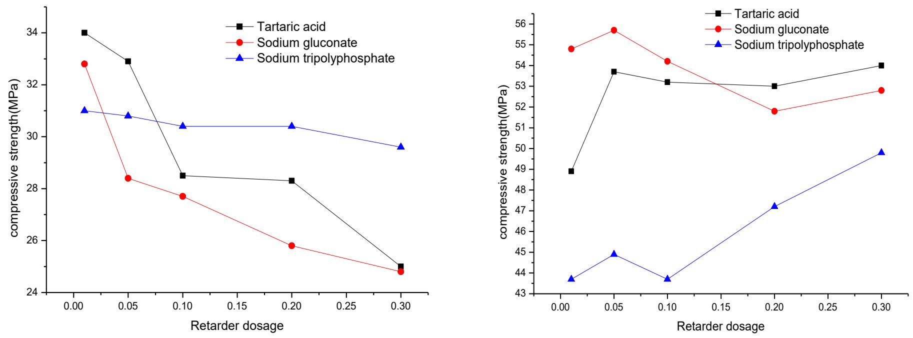


Figure 6: Effect of inorganic salt on cement paste fluidity

3.3 The effects of chemical admixture on the strength of Portland cement

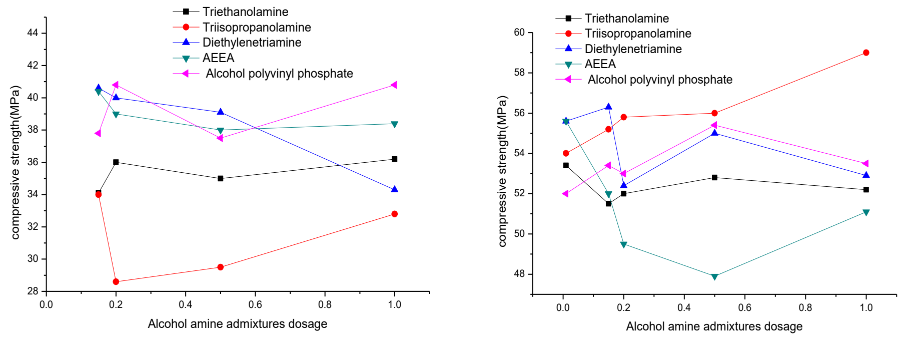
The compressive strength of the admixture added in each group is illustrated in Figure 7 to Figure 9:
The compressive strength of the mortar without adding the admixture is 30.5MPa at 3 days and 50.2MPa at 28 days. Figure 7 indicates that the early strength of the cement decreases with the increase of the mixing amount of the retarder, and sodium gluconate is at its best effects when its mixing amount is 0.1‰. In terms of the cement strength at 28 days, its strength augments with the increase of the mixing amount of the retarder, and the effects of sodium gluconate and sodium tripolyphosphate are better and its compressive strength exceeds the reference value. According to Figure 8, in addition to triisopropanolamine, the other alcohol amine admixtures are effective in improving the cement strength at 3 days, but most effective in improving the strength at 28 days. The range of mixing range should be paid attention in case of the application of

aminoethylethanolamine. When the mixing amount is greater than 0.15‰, the compressive strength of cement at 28 days is reduced. As seen from Figure 9, the addition of inorganic salts is helpful to improve the early strength of cement, and the effects of sodium chloride are the best. However, the mixing amount needs to be carefully considered when inorganic salts are used to improve the strength at 28 days. The compressive strengths measured by the five inorganic salts vary with the change of the mixing amount, and the reasonable mixing amount is selected according to the actual demands.



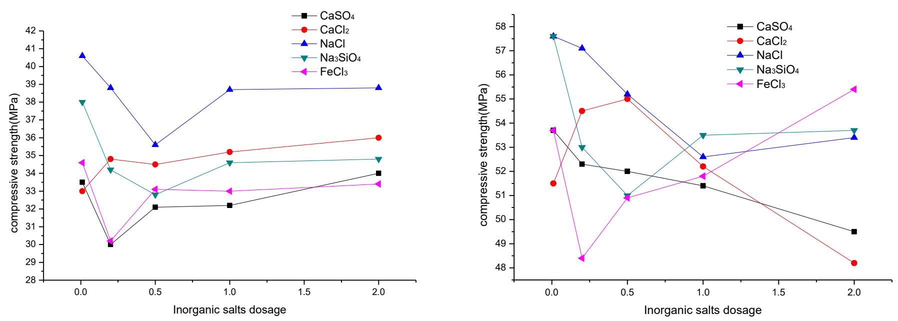
(a) 3 day (b) 28 day

Figure 7: Effect of the retarder on compressive strength



(a) 3 day (b) 28 day

Figure 8: Effect of alcohol amine admixtures on compressive strength



(a) 3 day (b) 28 day

Figure 9: Effect of inorganic salt on compressive strength

4. Concluding remarks

In order to study the effects of chemical admixtures on the strength of Portland cement, this paper has carried out the effects of retarder, alcohol amine admixture and inorganic salt on the cement-related physical and mechanical properties by means of a substantial number of experiments. It has been found that retarder has a better performance than the other two types of admixtures in terms of reducing the water consumption of normal consistency of cement and improving the cement paste fluidity of the cement. Concerning compressive strength, inorganic salt admixtures achieve better effects on improving the early strength, but comprehensive considerations should be taken in the later stage according to the type and the mixing amount of inorganic salt. Retarder limits the development of the early strength, but it has a significant effect on the increase of the long-term strength.

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