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Research on the Impact of Polycarboxylate Superplasticizers on the Surface Roughness of Cementitious Materials

Gongke Zhao, Guike Li, Li Zhang*

Xinjiang Laboratory of Phase Transitions and Microstructures in Condensed Matters, College of Physical Science and Technology, Yili Normal University, Yining 835000, China

***Corresponding author:** Li Zhang, zhangliyili@sina.cn

Abstract: As the construction industry increasingly demands higher performance in both the structural integrity and aesthetics of buildings, the performance requirements for cement materials also intensify. Superplasticizers have proven effective in enhancing the properties of cementitious materials. In this study, cementitious materials of silicate cement mixed with varying proportions of polycarboxylate superplasticizer (0/100, 1/100, 2/100, 3/100, 4/100, 5/100) were prepared with a water-to-cement ratio of 0.5 under environmental conditions of approximately 22°C and 72% RH. After about 18 hours of hydration, the surface profiles of these materials were measured using a 3D profilometer. The results indicate that the cementitious materials with a superplasticizer-to-cement mass ratio of 4/100 exhibited the lowest surface roughness values in terms of Rq, Ra, and Rt, suggesting this ratio minimizes surface roughness. This study explores the effect of different dosages of polycarboxylate superplasticizers on the surface profile of cementitious materials, providing a theoretical reference for the improvement of cement materials.

Keywords: Silicate cement; Polycarboxylate superplasticizer; Surface profile

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1. Introduction

With the rapid development of the construction industry and the swift progression of urbanization, the demand for improved quality and safety in building structures is increasingly evident [1]. Cement, as a fundamental component of building materials, has seen escalating performance requirements. Superplasticizers, serving as a crucial additive for regulating the performance of cement, have gained widespread recognition and use in concrete engineering [2].

Superplasticizers have become an essential component of concrete and mortar, enhancing the strength of cementitious materials, reducing water consumption, improving workability, and altering rheology which directly affects the material's processability and durability [3]. These attributes are instrumental in accelerating construction progress, enhancing project quality, and reducing construction costs. Different superplasticizers have distinct impacts on the performance of cement due to their mechanisms of action and varying dosages [4].

Polycarboxylate superplasticizers, characterized by their low dosage, high water reduction rate, excellent slump retention, and environmental friendliness, are widely used in regular concrete as well as in special concretes like high-strength, self-compacting, and exposed aggregate concrete [5]. When mixed with cement, polycarboxylate superplasticizers act to disperse, lubricate, and create steric hindrance. Their dispersing effect primarily manifests when cement is mixed with water, forming a flocculated structure due to the molecular attraction of cement particles, which affects the flowability of the mixture. However, the introduction of polycarboxylate superplasticizers disrupts this structure, releasing trapped water to participate in the flow, effectively enhancing the mix's fluidity [6]. The lubricating effect is due to the strong hydrophilic groups within the superplasticizer's structure, forming a stable hydrated water film on the surface of cement particles, thereby reducing the frictional resistance of cement particles and enhancing fluidity [7]. The steric hindrance occurs as the superplasticizer molecules, anchored by their main chains (acrylic acid and its salts) to the cement particle surfaces, arrange their side chains towards the water and hydrate fully in an extended state. When these coated cement particles gather, the molecular chains do not interpenetrate, and the free-stretching movement of the side chains produces a repelling force, dispersing the cement particles [8]. A thorough understanding of the characteristics and mechanisms of superplasticizers is essential for maximizing their effectiveness in practical engineering applications. This paper aims to explore the influence of polycarboxylate superplasticizers on the surface roughness of cementitious materials.

2. Experiment

In this study, the superplasticizer used was the CQJ-JSS02 type polycarboxylate superplasticizer, and the cement used was P·O 42.5 ordinary Portland cement. The measurement instrument utilized was the UMT-type nanoindentation instrument 3D profilometry module produced by Bruker (Beijing) Technology Co., Ltd. The optical profilometer employed a broad-spectrum white light, eliminating the need to measure interference fringes and thus reducing human error. Due to the uniqueness of white light, the measurements were more precise and efficient. Optical profilometry, based on white light interference principles, is an ideal method for detecting the surface profiles of objects with micro-step heights or measuring the thickness and roughness of thin film materials. It is an improved geometric profilometry instrument based on traditional interferometers.

Considering various factors such as the properties of the polycarboxylate superplasticizer and the type of cement, the experiments were conducted under fixed water-to-cement ratios of 0.5, preparing six different ratios of polycarboxylate superplasticizer to silicate cement mixtures. The ratios of superplasticizer to cement by mass were 0/100, 1/100, 2/100, 3/100, 4/100, and 5/100. This study investigates the effects of different dosages of polycarboxylate superplasticizers on the surface profiles of cementitious materials, providing a theoretical reference for further research and application of cement materials.

Initially, with a fixed water-to-cement ratio of 0.5, 10 grams of distilled water and 20 grams of a mixture of cement and superplasticizer were measured according to the ratios 0/100, 1/100, 2/100, 3/100, 4/100, and 5/100. Next, the components were mixed and stirred uniformly for 1 minute to ensure even distribution among the different groups. Finally, the mixture was poured into molds and the time was recorded for subsequent measurement and observation.

The polycarboxylate superplasticizer cementitious materials were prepared in an environment of approximately 22°C and 72% RH. **Figure 1** shows the images of the hydrated superplasticizer cementitious materials after about 18 hours, arranged from left to right with increasing proportions of polycarboxylate superplasticizer from 0/100 to 5/100 in the silicate cement mixtures. From **Figure 1**, it is evident that the addition of polycarboxylate superplasticizer significantly impacted the surface profile of the cementitious materials.

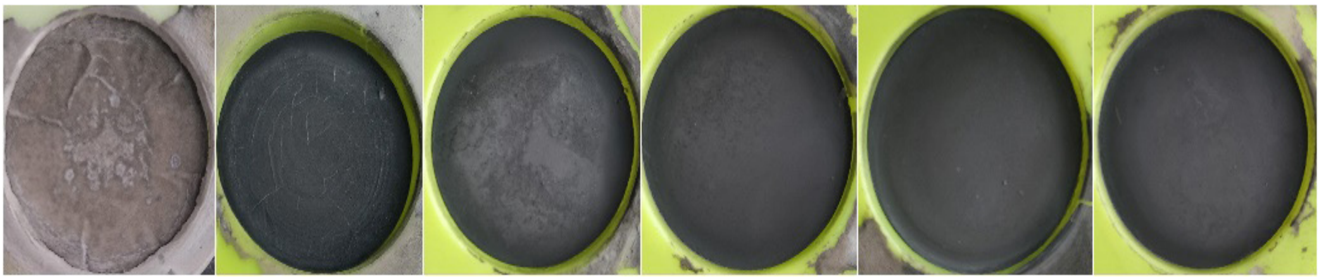

Figure 1. Images of cementitious materials hydrated for approximately 18 hours, with ratios of polycarboxylate superplasticizer to silicate cement by mass from left to right being 0/100, 1/100, 2/100, 3/100, 4/100, and 5/100

Under environmental conditions of approximately 22°C and 72% RH, the surface profiles of the silicate cementitious materials mixed with polycarboxylate superplasticizer were measured using a 3D profilometer after about 18 hours of hydration. **Figure 2** shows the surface profile of the cementitious material with a polycarboxylate superplasticizer to silicate cement mass ratio of 5/100 after approximately 18 hours of hydration. Similar surface profiles were obtained for other ratios of polycarboxylate superplasticizer to cement after 18 hours of hydration using the 3D profilometer.

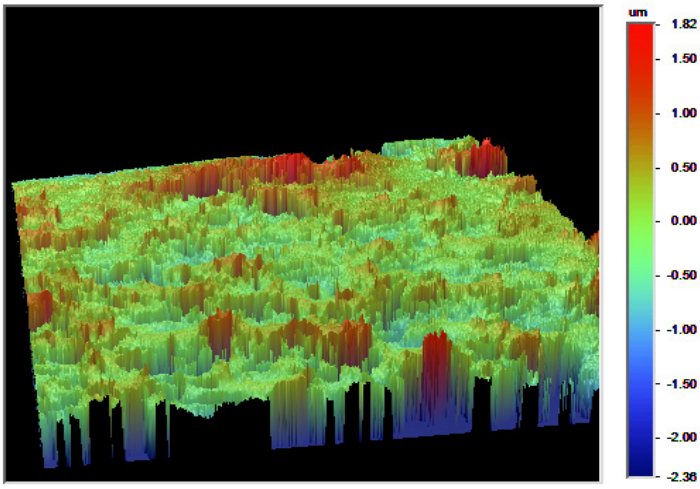

Figure 2. Surface profile of cementitious material with a polycarboxylate superplasticizer to silicate cement mass ratio of 5/100 after approximately 18 h of hydration

Measurements obtained using a 3D profilometer provided data on the surface profiles (Rq, Ra, Rt, Rp, Rv) of cementitious materials with different proportions of polycarboxylate superplasticizer. Here, Rq represents the root mean square roughness of the material surface within the sampled range, Ra represents the arithmetic mean deviation of the material surface profile within the sampled range, Rt is the total height of peak to valley of the material surface profile within the sampled range, Rp is the height of the highest peak of the material surface profile within the sampled range, and Rv is the depth of the deepest valley of the material surface profile within the sampled range.

Using Origin software, graphs were generated to show the relationships of Rq, Ra, Rt, Rp, and Rv as the proportion of polycarboxylate superplasticizer changes. The results are shown in **Figure 3**.

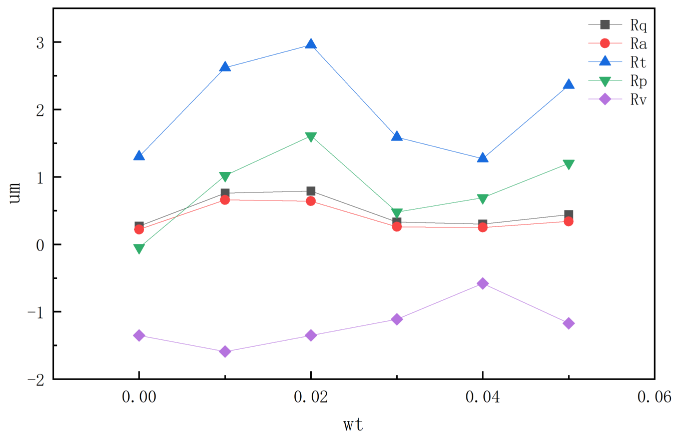

Figure 3. Graph showing the changes in the surface profiles (Rq, Ra, Rt, Rp, Rv) of cementitious materials hydrated for approximately 18 hours, about the varying ratios of polycarboxylate superplasticizer to cement by mass

According to **Figure 3**, it is clear that in an environment of approximately 22°C and 72% RH, with a water-to-cement ratio of 0.5, after about 18 hours of hydration of the cementitious materials, the surface profiles of Rq, Ra, Rt, Rp, and Rv of the materials, as the ratio of polycarboxylate superplasticizer to silicate cement increases, show a trend of initially increasing, then decreasing, and then increasing again for Rq, Ra, Rt, and Rp, while Rv shows a trend of decreasing, then increasing, and then decreasing. Specifically, as the ratio of superplasticizer to cement increases from 0/100 to 2/100, the Rq, Ra, and Rt of the cementitious materials increase; from 2/100 to 4/100, the Rq, Ra, and Rt decrease; and from 4/100 to 5/100, the Rq, Ra, and Rt increase again. The Rp increases as the ratio moves from 0/100 to 2/100, decreases from 2/100 to 3/100, and increases again from 3/100 to 5/100. The Rv decreases as the ratio moves from 0/100 to 1/100, increases from 1/100 to 4/100, and decreases again from 4/100 to 5/100.

The surface profiles of the cementitious materials, Rq, Ra, Rt, and Rp, reach their maximum values when the ratio of superplasticizer to cement is 2/100. The Rv profile reaches its maximum at a superplasticizer-to-cement ratio of 4/100. Conversely, the minimum values for Rq, Ra, and Rp are observed at a ratio of 3/100. The Rt profile reaches its minimum value at a ratio of 4/100, and the Rv profile reaches its minimum at a ratio of 1/100.

3. Conclusion

In this study, a 3D profilometer was employed to measure the surface profiles of cementitious materials with different proportions of polycarboxylate superplasticizers. The surface profile parameters Rq, Ra, Rt, Rp, and Rv were obtained, showing that the use of CQJ-JSS02 type polycarboxylate superplasticizer significantly improves the surface profile of cement. Under ambient conditions of approximately 22°C and 72% RH, and after about 18 hours of hydration, the surface profiles of cementitious materials (with mass ratios of polycarboxylate superplasticizer to silicate cement of 0/100, 1/100, 2/100, 3/100, 4/100, and 5/100) initially increase, then decrease, and finally increase again for Rq, Ra, Rt, and Rp, while Rv first decreases, then increases, and decreases again, indicating changes in smoothness and fineness.

The optimal use ratio of CQJ-JSS02 type polycarboxylate superplasticizer is not necessarily higher but has an optimal value: at a superplasticizer to cement mass ratio of 4/100, the surface profiles Rq, Ra, and Rt reach their minimum values, and Rv reaches its maximum value, indicating the lowest degree of surface roughness in the cementitious materials at this ratio.

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Disclosure statement

The authors declare no conflict of interest.

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