Reduction of Cement Content in Concrete using Polycarboxylate Superplasticizer

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**Abstract.**  This study investigates the potential for cement reduction in concrete using a polycarboxylate-based superplasticizer. A consistency test was conducted on cement paste to evaluate the water reduction capabilities of polycarboxylate-based superplasticizer. Subsequently, cement and water contents were reduced in the concrete mixture to maintain the same water-cement ratio as a controlled mixture without admixtures. The primary objective was to assess the feasibility of reducing cement consumption while maintaining the concrete’s workability and compressive strength. The results indicate that incorporating 1.0% polycarboxylate-based superplasticizer into the mixture enables a 10% reduction in cement consumption, along with a simultaneous decrease in water, with an enhancement in the workability and compressive strength of the concrete.

**Keywords:** Concrete, polycarboxylate-based superplasticizer, cement reduction, workability, compressive strength.

# INTRODUCTION

Environmental issues due to global warming and greenhouse gas emissions have become one of the greatest concerns today. The rapid increase in atmospheric carbon dioxide, one of the greenhouse gases, has been a major factor in the rise in global temperatures [1], [2]. Cement, the binding component of mortar and concrete, has been observed to produces a significant amount of carbon dioxide emissions, particularly during the manufacture of Portland cement clinker [3], [4]. Strategies to reduce carbon dioxide emission need to be implemented, such as incorporating supplementary cementitious materials (SCMs) as partial substitution for Portland cement. It is widely acknowledged that maximizing the use of these cementitious and pozzolanic by-products can lead to the sustainable development of the cement and building industries [5]. Other alternatives to reduce greenhouse gas emissions can be achieved by minimizing the volume of cement in mortar or concrete mixtures using water reducing admixtures that can reduce the water content while preserving or even enhancing the mechanical properties of mortar and concrete [6], [7].

Superplasticizers, as high-performance water reducing admixtures, are effective in reducing water requirements without excessive loss of workability [8]–[10]. A lower water-cement (w/c) ratio leads to the improvement of concrete mechanical properties [11], [12]. Superplasticizer admixture can be used in cement materials to achieve the desired results: workability improvement for a given w/c ratio or reduction of water content for a target workability. In addition, while maintaining the constant w/c ratio, it is possible to reduce water and cement content simultaneously without worsening the fluidity and the compressive strength of the composite mixture [7]. The reduction of cement allows lower cement consumption and potentially minimize the environmental impact related to cement production [2]. The water reduction capacity of superplasticizer admixture will vary based on their chemical composition. Polycarboxylate (PCE) superplasticizers are known for achieving low water-to-cement ratios, enhancing strength and reducing cement content [13]. This superplasticizers demonstrates high water-reducing capabilities which reach up to 40% [14]. This reduction in water content allows for a decrease in cement usage without sacrificing performance, making PCE superplasticizer a key component in achieving more sustainable and eco-friendly concrete mixtures.

This study aims to explore the possibility for reducing cement usage in concrete production through the application of a polycarboxylate-based superplasticizer. The research focuses on estimating the reduction of both cement and water content in concrete mixtures while maintaining a fixed water-cement ratio, ensuring that the compressive strength and workability remain comparable to those of the control mixture.

# METHODS

The investigation was performed to determine the amount of cement reduction utilizing PCE superplasticizer as high-range water reduction admixture in concrete mixture. This research consisted of three steps: (i) assessment of PCE superplasticizer influence on water reduction in cement paste; (ii) determination of concrete composition using reduced cement content while maintaining consistency at the same level as the control mixture; and (iii) evaluation of the potential of cement saving while preserving the concrete compressive strength.

## MATERIALS

The concrete mixtures in this experiment were composed of Portland Cement conforming to Indonesian Standard SNI 7064:2014, with gravel (5–40 mm) serving as the coarse aggregate, and river sand (0–2 mm) as the fine aggregate. A polycarboxylate (PCE) superplasticizer admixture was incorporated as water-reducing admixture. The commercially available PCE superplasticizer widely used in Indonesia, Sika ViscoCrete-3115N, was selected for the study. This product is in a liquid form with the composition of aqueous solution of modified polycarboxylate copolymers, which is proclaimed by the manufacturer to have the ability to reduce water content by up to 30%.

## COMPOSITION OF CONCRETE MIXTURES

The testing of cement paste consistency was carried out to estimate the water reducing capacity of PCE superplasticizer with varying dosage. **FIGURE 1** reflects the influence of PCE superplasticizer on water reduction in standard cement paste. This result was obtained by adding PCE superplasticizer with mixing water from 0.5 to 2.5% according to the mass of cement. The amount of water in the paste was able to be reduced by 9.7 to 28.1% while keeping the required consistency to meet ASTM C187-16.

**FIGURE 1**. The PCE superplasticizer influence on water reduction in standard cement paste

Five concrete mixtures were made based on the water reduction capacity obtained in **FIGURE 1**: one mixture control, and four with PCE superplasticizer with dosage of 0.4%, 0.6%, 0.8%, and 1.0% according to cement mass. The water content was reduced by 9.0%, 13.0%, 17.0%, and 19.0 %, respectively. This preliminary test was conducted to investigate the increase of concrete compressive strength with the addition of PCE superplasticizer and reduced water content. The compressive strength test was performed according to ASTM C109M-20. Three specimens of each type of concrete were cured for 28 days and tested immediately afterwards. The results are presented in **FIGURE 2**. It is evident that the use of PCE superplasticizer can increase concrete compressive strength by up to 33.5%, supporting the potential to reduce cement consumption while maintaining the required strength. However, the concrete mix with 0.4% PCE superplasticizer did not achieve the target strength and will not be considered for the next experimental phase.

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| **FIGURE 2**. Concrete compressive strength with PCE superplasticizer and reduced water content | **FIGURE 3**. Slump value of concrete mixture with PCE superplasticizer and reduced water content |

In this study, PCE superplasticizer was used to reduce both cement and water content in the concrete mixtures, with dosages of 0.6%, 0.8%, and 1.0%, based on the mass of the cement. The mixture was designed to maintain constant w/c ratio and consistency, despite the reduction in water and cement. The removed cement paste was replaced with an equivalent volume of aggregates (gravel and sand) to preserve the overall volume of the concrete. Four concrete mixes were prepared with a constant w/c ratio of 0.5 and varying PCE superplasticizer dosages of 0%, 0.6%, 0.8%, and 1.0% by cement mass.

Based on the slump test in **FIGURE 3**, the reduced water content had to be adjusted to achieve the target slump of 90–110 mm. Therefore, for each mix, the rates of water and cement reduction were adjusted to match the consistency of the control mix, while maintaining the 0.5 w/c ratio. The adjustment was made in the mixing process using slump value as the controlling measurement. After several trials, the final concrete mix compositions were determined and are presented in **TABLE 1**. In the next phase, compressive strength tests in accordance with ASTM C109M-20 were conducted and analyzed for all specimens.

**TABLE 1**. Composition of concrete mixture

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Concrete mixture code | Amount of PCE superplasticizer as percentage of the cement mass (per 1 m3) | Amount of cement, kg/m3 | Amount of water, kg/m3 | Amount of sand, kg/m3 | Amount of gravel, kg/m3 | w/c | Reduction of cement amount, kg | Reduction of water amount, kg |
| CN | - | 370.0 | 191.0 | 930.0 | 922.0 | 0.52 | - | - |
| CS1 | 0.6% | 351.5 | 175.8 | 938.8 | 930.8 | 0.50 | 18.5 | 15.2 |
| CS2 | 0.8% | 336.7 | 168.4 | 945.2 | 937.2 | 0.50 | 33.3 | 22.6 |
| CS3 | 1.0% | 333.0 | 166.5 | 946.7 | 938.7 | 0.50 | 37.0 | 24.5 |

# RESULTS AND DISCUSSION

This study explores the potential for cement savings using PCE superplasticizer, while preserving concrete compressive strength. This approach is based on the fact that PCE superplasticizer significantly reduces water demand, while maintaining or improving the mixture’s workability and the quality of the concrete. In mixtures with PCE superplasticizer, both water and cement content were reduced simultaneously to maintain a constant w/c ratio. Since the use of PCE allows for a lower w/c ratio, the compressive strength of the concrete generally increases (**FIGURE 2**). Therefore, it is assumed that when applying PCE superplasticizer to reduce cement and water consumption, the mean compressive strength of the concrete after 28 days of standard curing will remain comparable to that of the control concrete.

From the result in Figure 2, adding 0.6% to 1.0% PCE superplasticizer to the standard concrete mixture allowed the water reduction of 13% to 19%, while maintaining adequate workability and compressive strength. However, based on the slump test result in **FIGURE 3**, the water content was adjusted to better achieve the target slump. Additionally, since the cement content was reduced to maintain a constant w/c ratio, the reduction needed to account for the minimum volume of cement paste required to fill the intergranular voids [2]. The adjusted water and cement consumption values are presented in **FIGURES 4** and **5**, respectively. It is evident that the use of PCE superplasticizer as a high-range water-reducing admixture effectively reduced both water and cement consumption, with higher PCE dosages enabling greater reductions. The application of PCE superplasticizer led to a reduction in cement consumption between 5% and 10% (**FIGURE 6**).

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| **FIGURE 4**. Water consumption for the concrete with and without PCE superplasticizer | **FIGURE 5.** Cement consumption for the concrete with and without PCE superplasticizer |

The reduction in water and cement content in the concrete mixture was designed to preserve consistent workability, with slump value used as the measurement tool. Analyzing the slump test result in **FIGURE 6**, it can be concluded that a higher dosage of PCE superplasticizer will result in greater water and cement reduction, while still achieving the target workability. In specimen CS3, with a 1.0% PCE dosage, the slump value exceeded the target, though it remained within the acceptable workability range. However, greater reductions in water and cement may potentially reduce the mixture's compressive strength, as shown in Table 1.

**FIGURE 6.** Slump value of concrete mixtures with the designed water and cement reductions

**TABLE 2**. Compressive strength of concrete

|  |  |  |  |
| --- | --- | --- | --- |
| Concrete mixture code | Density, kg/m3 | Compressive strength, MPa | |
| 7 days of age | 28 days of age |
| CN | 2389 | 13.8 | 23.5 |
| CS1 | 2355 | 18.7 | 28.6 |
| CS2 | 2339 | 19.4 | 30.6 |
| CS3 | 2358 | 17.9 | 23.6 |

The results of the density and compressive strength tests on concrete, with and without the addition of PCE superplasticizer (**TABLE 2**), highlight the significant influence of this admixture on compressive strength after 7 and 28 days of curing. The removal of cement and water in mixtures CS1 and CS2, while maintaining a constant w/c ratio, resulted in increased compressive strength with higher PCE dosages up to 0.8%. In mixture CS3, with a 1.0% PCE dosage, the compressive strength remained comparable to the control mixture without PCE. These findings suggest that cement consumption can be reduced by up to 10% using PCE superplasticizer as a water-reducing admixture, but further reductions may lead to lower compressive strength.

# CONCLUSIONS

This study investigated the possibility of reducing cement consumption in concrete production using a polycarboxylate-based superplasticizer. The findings demonstrate that incorporating 1.0% polycarboxylate-based superplasticizer can achieve a 10% reduction in cement consumption, with a simultaneous decrease in water content. Additionally, this reduction was achieved with an improvement in the workability and compressive strength of the concrete, indicating that polycarboxylate-based superplasticizer is an effective admixture for optimizing concrete mix designs without compromising performance.

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