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Research Article

Optimization of Superplasticizer Dosage on Compressive Performance in Self-Compacting Concrete Mixtures with Silicafume as a Cementitious Material

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Abstrak

Self-Compacting Concrete (SCC) telah menarik perhatian di dalam industri konstruksi karena kemampuannya yang luar biasa dalam mengalir dan mengisi cetakan yang rumit tanpa memerlukan pemadatan eksternal. Optimasi dosis superplasticizer memegang peranan penting dalam meningkatkan kinerja tekan dari SCC. Penelitian ini bertujuan untuk mengkaji pengaruh variasi dosis superplasticizer terhadap kuat tekan campuran beton self-compacting serta menentukan dosis optimal untuk memperoleh kinerja tekan yang lebih baik. Metode eksperimen yang ekstensif telah dilakukan, mencakup persiapan dan pengujian campuran SCC dengan berbagai variasi dosis superplasticizer. Pengujian kuat tekan dilakukan pada beberapa umur perawatan untuk mengevaluasi kinerja jangka panjang. Temuan penelitian menunjukkan adanya korelasi non-linier antara dosis superplasticizer dan kuat tekan. Meskipun peningkatan dosis awal memberikan peningkatan kuat tekan, dosis yang berlebihan justru menyebabkan penurunan kinerja. Melalui analisis statistik dan teknik optimasi, diperoleh rentang dosis optimal superplasticizer yang menghasilkan nilai kuat tekan tertinggi. Selain itu, pengaruh dosis superplasticizer terhadap sifat beton lainnya, seperti kemudahan pengerjaan (workability) dan kemampuan alir (flowability), juga dievaluasi. Temuan ini memberikan wawasan berharga dalam mengoptimalkan dosis superplasticizer untuk mencapai peningkatan kinerja tekan pada campuran beton self-compacting. Dosis yang telah dioptimalkan ini berpotensi mendukung pengembangan campuran SCC yang lebih efisien dan tahan lama, sehingga memperluas aplikasinya dalam berbagai proyek konstruksi.

Kata-kata kunci: *Self-compacting concrete*, superplasticizer, kuat tekan, optimasi

Abstract

Self-compacting concrete (SCC) has garnered significant attention in the construction industry due to its exceptional flowability and ability to fill intricate forms without the need for external compaction. The optimization of superplasticizer dosage plays a critical role in enhancing the compressive performance of SCC. This research aims to investigate the impact of superplasticizer dosage on the compressive strength of self-compacting concrete mixtures and determine the optimal dosage for achieving improved compressive performance. An extensive experimental program was conducted, involving the preparation and testing of SCC mixtures with varying superplasticizer dosages. Compressive strength tests were performed at different curing ages to evaluate long-term performance. The finding revealed a non-linear correlation between superplasticizer dosage and compressive strength. While increasing dosage initially led to improved compressive strength, excessive dosages resulted in diminished performance. Through statistical analysis and optimization techniques, an optimal range of superplasticizer dosage was determined, exhibiting the highest compressive strength values. Additionally, the influence of superplasticizer dosage on other concrete properties, such as workability and flowability, was also assessed. These findings offer valuable insights into optimizing superplasticizer dosage to achieve enhanced compressive performance in self-compacting concrete mixtures. The optimized dosage can contribute to the development of more efficient and durable SCC mixtures, facilitating their application in various construction projects.

Keywords: Self-compacting concrete, superplasticizer, compressive strength, optimization

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1 INTRODUCTION

Concrete, as a universally recognized construction material, has been extensively used in various structural applications due to its remarkable compressive strength and durability (Gupta, et al., 2021; Shi, et al.,2015). However, it is not without its limitations. Traditional vibrated concrete requires significant labor and machinery to ensure proper compaction, leading to additional costs and potential inconsistencies in the final product. In addition, hard-to-reach areas or intricate formwork designs often pose significant challenges in terms of achieving the desired compaction and concrete quality.

Self-compacting concrete (SCC) has emerged as a promising solution in the construction industry, offering enhanced workability and flowability without the need for external compaction (Kamal et al. 2020; Monika et al. 2021; Prayuda et al. 2018; Wang et al. 2014). Self-compacting concrete, an advanced concrete variant, demonstrates a favorable viscosity and reduced yield stress. These attributes facilitate superior compaction, yielding an exceedingly fluid mixture devoid of component segregation, especially between the binder and aggregate. This has fostered its growing utilization in experimental research and practical construction projects, enhancing its appeal to contractors (Abdel-Mohti, et al., 2016; Saleh, et al., 2015).

While various methods display a broad range of approaches and complexity levels, the common objective is to yield preferred attributes in fresh concrete. These attributes include passing ability, filling ability, and resistance to segregation (Brouwers & Radix 2005). For SCC mix design, consensus highlights the importance of controlling the aggregate system, along with the quality and quantity of the paste. By reducing the void content among aggregate particles, more paste can be allowed to envelop aggregate surfaces in a specific concrete system, thereby enhancing workability. A further step to boost the concrete's strength and durability is to minimize capillary pores (Koehler & Fowler 2007).

Previous study has investigated to obtain the best design mixture in order to obtain good workability and good mechanical properties of SCC. In addition, the compressive strength of SCC is a crucial parameter for ensuring structural integrity and durability in various applications. Among the factors influencing compressive strength, the optimization of superplasticizer dosage holds particular significance. Superplasticizers, commonly used in SCC, improve fluidity and reduce viscosity by dispersing cement particles, thereby enhancing the workability and flowability of the concrete mixture. The impact of different mixing durations and increased superplasticizer doses on the properties of self-compacting concrete has been investigated by previous researchers (Zeyad and Almalki 2020) . This study explored the effects of varying mixing durations (specifically, 15, 30, 60, and 90 minutes from the point of water introduction) and enhanced superplasticizer concentrations (1.5%, 2%, 2.5%, and 3% of the cement's mass) on the characteristics of self-compacting concrete (SCC). The result indicates that the mixing duration and superplasticizer dosage significantly influence the properties of self-compacting concrete (SCC). An extended mixing time, despite decreasing some SCC parameters, results in improved bleeding and segregation rates. However, this extended mixing time can also lead to a decline in hardened concrete properties. Countering these negative impacts by increasing superplasticizer dosage boosts SCC's performance, but it also increases bleeding and segregation percentages. These findings underscore the critical balance between mixing time and superplasticizer dosage for achieving optimal SCC performance (Ahari, et al., 2015).

The optimization of superplasticizer dosage in SCC is a complex task, as an insufficient dosage may result in inadequate flowability, while excessive dosages can lead to detrimental effects on compressive strength. Achieving the optimum dosage is therefore essential to attain the desired compressive performance. Several researchers have investigated the impact of superplasticizer dosage on SCC properties, including workability, flowability, and strength. a comprehensive understanding of the optimal dosage specifically for compressive strength enhancement in SCC is necessary to facilitate the production of high-performance concrete structures.

In prior studies, researchers have extensively investigated the optimization of superplasticizers in self-compacting concrete (SCC) mixtures using fly ash and slag as cementitious materials. However, limited attention has been given to optimizing superplasticizer dosage (0.6%, 1.0%, 1.6%) specifically in SCC mixtures where silica fume serves as the cementitious material. Addressing this gap in the literature, the present study aims to delve into the crucial aspect of superplasticizer optimization for SCC containing silica fume. By optimizing the superplasticizer dosage in SCC, the construction industry can benefit from improved compressive performance and the ability to design and construct more efficient and durable concrete structures.

Furthermore, optimizing dosage can contribute to reducing material waste and environmental impact, aligning with sustainable construction practices. The findings of this study will provide valuable insights into the relationship between superplasticizer dosage and compressive strength in SCC, aiding in the development of optimized mix designs for specific construction requirements. The research involves a systematic experimental program, encompassing the preparation and testing of SCC mixtures with varying superplasticizer dosages. Compressive strength tests are performed at different curing ages to assess both short-term and long-term performance. Additionally, the effects of superplasticizer dosage on other relevant properties such as workability and flowability will also be evaluated.

2 RESEARCH METHOD

2.1 Materials

This research paper investigates the different superplasticizer content on the self-compacting concrete start from 0.6%; 1.0%; 1.6%. Three concrete mixes were studied in this study which named SSC-SF-0.6; SSC-SF-1.0; SSC-SF-1.6. The binder component used is cement type I from Gresik company. Superplasticizer type 1003 and Silica fume were selected in this study which manufactured from SIKA company. The specific gravity of fine aggregate and coarse aggregate were 2.63 and 2.60, respectively. Water sourced UMY laboratory was used to blend the materials. Table 1 lists the mix proportion of the three SHCC mixtures

Table 1 Mix Proportion of Self Compacting Concrete at 1 m^3

Materials	Fine Aggregate	Coarse Aggregate	W/C	Cement	Silicafume	Superplasticizer
SSC-SF-0.6	18.12	10.41	0.45	8.99	0.899	0.6%
SSC-SF-1.0	18.12	10.41	0.45	8.99	0.899	1.0%
SSC-SF-1.6	18.12	10.41	0.45	8.99	0.899	1.6%

2.2 Experimental Method

Fresh Properties Test

The slump flow test evaluates the flowability and workability of self-compacting concrete (SCC) by measuring the maximum horizontal diameter of the concrete spread when the slump cone is lifted. The slump flow T50 test determines the time it takes for the SCC to reach a specific spread diameter, usually 500 mm. These tests are conducted according to the guidelines provided by EFNARC (European Federation for Specialist Construction Chemicals and Concrete Systems). The SCC sample is prepared, placed in the slump cone, and lifted vertically to allow the concrete to flow freely. The maximum spread diameter is measured for the slump flow test, while the time taken to reach a diameter of 500 mm is recorded for the slump flow T50 test. Adhering to standardized procedures ensures accurate assessment of the flow properties and workability of the SCC mixture.

V-funnel

The V-funnel test is used to evaluate the flowability and workability of self-compacting concrete (SCC). The test involves measuring the time it takes for the concrete to flow through a V-shaped funnel. The SCC sample is poured into the funnel without compaction, and the timer is started as soon as the concrete begins to flow. The flow time is measured as the duration for the entire volume of the concrete to pass through the funnel. The V-funnel flow time provides valuable information about the flowability and workability of the SCC, aiding in the assessment and optimization of the mixture design for specific construction needs.

The L-Box test is commonly employed to assess the passing ability and flow characteristics of self-compacting concrete (SCC) in confined spaces and congested reinforcement. This test involves measuring the filling ability and blocking ratio of the concrete using an L-shaped box apparatus. The SCC sample is poured into the upstream compartment of the L-Box and allowed to flow into the downstream compartment through an opened gate. The height of the settled concrete in both compartments is then measured to determine the blocking ratio. The blocking ratio serves as an indicator of the concrete's ability to pass through narrow openings without significant blockage. Lower blocking ratios suggest improved passing ability, indicating that the SCC can flow smoothly through restricted areas. It is important to note that specific test procedures may vary depending on regional standards or specifications. Therefore, adherence to relevant guidelines and standards is recommended to ensure accurate and consistent testing. The L-Box test provides valuable insights into the flowability and passing ability of SCC, facilitating the optimization of mixture designs to ensure efficient concrete placement in complex construction scenarios.

Compressive Strength Test

The compressive strength test was conducted in accordance with ASTM C39 to evaluate the maximum load-bearing capacity, commonly referred to as compressive strength (Fc'), of self-compacting concrete. Cylindrical specimens measuring 150x300 mm (diameter x height) were utilized for the compressive test. The specimens were subjected to a curing process in water. The test was performed at specific time intervals of 7, 14 and 28, respectively. The results were obtained by averaging the values from three separate specimens for each testing age.

3 RESULTS AND DISCUSSIONS

3.1 Fresh Properties Characteristics

The T50 test was conducted with varying superplasticizer dosages (0.6%, 1.0%, and 1.6%). The results reveal a notable trend, demonstrating that an increase in superplasticizer dosage leads to a consistent decrease in the T50 spread time in centimeters (cm) which can be seen in Figure 1. This observation indicates that the addition of superplasticizer positively influences the flowability and workability of the fresh concrete, facilitating quicker spreading and improved flow properties. The detailed analysis and discussion of these findings offer valuable insights into the effect of different superplasticizer dosages on the T50 parameter and contribute to the optimization of self-compacting concrete mixtures for enhanced construction performance. It represents that the addition of superplasticizer in the SCC mixture enhances flowability, reduces internal friction, and lowers water content, all of which lead to quicker and smoother spreading during the T50 test. The resulting reduction in T50 test time is indicative of the improved flow and workability characteristics of the self-compacting concrete

The addition of superplasticizer was observed to reduce the T50 flow time in this study. A lower T50 value indicates that the self-compacting concrete (SCC) mixture becomes more fluid, resulting in a shorter time required for the concrete to spread and reach a 50 cm diameter. This finding aligns with the study conducted by Boukendakdji et al., which reported that increasing the superplasticizer dosage leads to a decrease in T50 flow time (Boukendakdji, et al., 2012). This phenomenon can be explained by the mechanism through which superplasticizers functions that they adsorb into the surface of cement particles, generating electrostatic repulsion or steric hindrance that prevents particle agglomeration. As a result, cement particles are better dispersed, internal friction is reduced, and the concrete flows more freely (Chiranjeevi & Rao 2020; Oualit, Irekti, & Hami 2022). Consequently, the flow time to reach the

50 cm spread diameter becomes significantly shorter with the addition of superplasticizer.

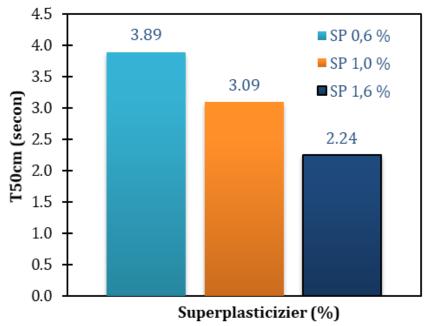

Figure 1. Influence of superplasticizer dosage on T50 parameter in Self-Compacting Concrete with silica fume

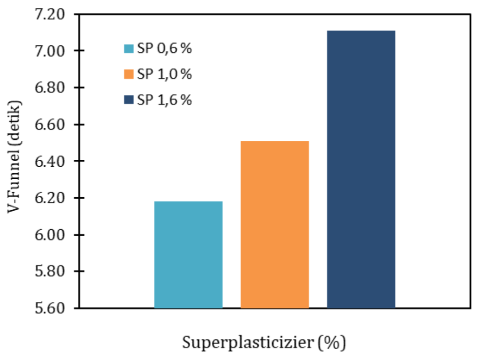

Figure 2. Influence of superplasticizer dosage on V-funnel parameter in Self-Compacting Concrete with silica fume

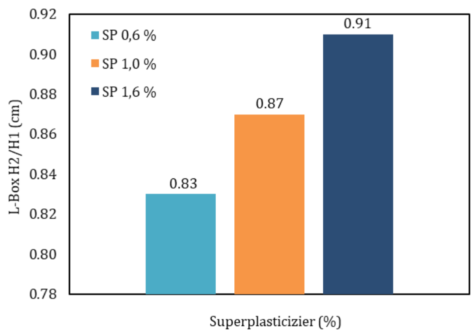

Figure 3. Infleunce of superplasticizer dosage on L-Box parameter in Self-Compacting Concrete with silicafume

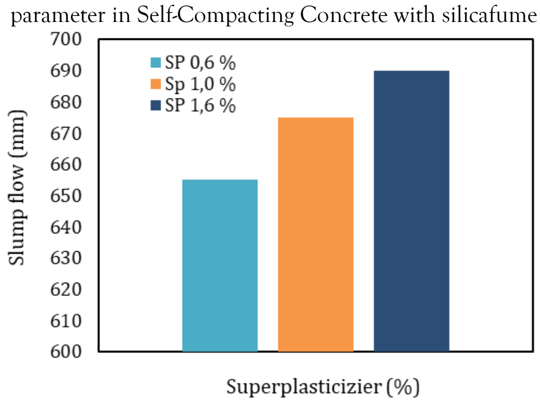

Figure 4. Influence of superplasticizer dosage on slump flow parameter in Self-Compacting Concrete with silica fume

Figure 2 depicts the results of the V-funnel fresh concrete test, showcasing variations in the performance of the three superplasticizer dosage levels. The recorded times for the 0.6% dosage level, 1% dosage level, and 1.6% dosage level were 6.18 seconds, 6.51 seconds, and 7.11 seconds, respectively. As the superplasticizer dosage increased, the filling ability and segregation resistance of the self-compacting concrete (SCC) improved continuously. The longer flow times observed in the presence of silica fume can be attributed to its water-absorbing characteristics, leading to an increase in concrete viscosity. However, the flowability of the SCC is enhanced by the presence of superplasticizer, mitigating the adverse effects of silica fume and promoting concrete flow. In addition, superplasticizers facilitate the separation of cement particles, thereby lowering both internal resistance and mix viscosity. This improved dispersion enables the concrete to pass through the V-funnel more smoothly, leading to a reduced flow time (Benaicha et al. 2019; Hamed 2012; Olowofoyeku et al. 2019). It is noteworthy that all variations of fresh SCC concrete met the standards established by EFNARC (2002), affirming the successful implementation of the optimized superplasticizer dosages in SCC mixtures.

Figure 3 presents the results of the fresh L-Box concrete test, highlighting the impact of three different superplasticizer variations (0.6%, 1%, and 1.6%). The recorded measurements for each superplasticizer dosage were 0.82 cm, 0.88 cm, and 0.93 cm, respectively. As the superplasticizer dosage increased, the passing ability of the concrete mixture through reinforcement demonstrated consistent improvement. This enhancement can be attributed to the flowability characteristics associated with higher superplasticizer levels, contributing to increased concrete flow. The observed increase in flowability of the self-compacting concrete (SCC) is a significant indication of the improved passing ability of the material through narrow spaces and congested reinforcement. When SCC exhibits higher flowability, it means that the concrete can easily navigate intricate forms, densely packed reinforcement, and tight construction spaces without encountering significant blockages or resistance. This enhancement in passing ability is especially crucial in modern construction practices where densely reinforced elements and complex geometries are common.

The improved passing ability directly stems from the efficacy of the selected superplasticizer dosages used in the SCC mixtures mixtures with silicafume as cementitious material. Superplasticizers are high-range water-reducing admixtures that effectively disperse and separate cement particles within the concrete mix. This dispersion allows for enhanced mobility of the concrete, reducing internal friction and facilitating smoother flow. As the superplasticizer dosage increases, the flowability of the SCC also improves. The superplasticizer's ability to reduce the amount of water required in the mix without compromising workability contributes to the concrete's enhanced cohesiveness and reduced viscosity. Consequently, the SCC becomes more fluid and maneuverable, effortlessly passing through tight spaces and complex structural elements.

Figure 4 displays the results of the fresh concrete slump flow test, revealing a notable increase in slump flow with higher percentages of superplasticizer, attributable to its enhanced flowability. As the superplasticizer dosage in the SCC mixture increases, the fresh concrete achieves a diameter of 500 mm more rapidly. The recorded Slump Flow values are 655 mm, 675 mm, and 690 mm for superplasticizer dosages of 0.6%, 1%, and 1.6%, respectively. These findings indicate that all variations of fresh SCC concrete conform to the standards specified by EFNARC (2002). The observed increase in slump flow aligns with the expected behavior of self-compacting concrete (SCC) with higher superplasticizer contents. Superplasticizers effectively disperse cement particles, reducing internal friction and enhancing concrete fluidity. This improvement in flowability allows the fresh concrete to flow more freely and achieve a greater spread within a shorter time, as demonstrated by the increased slump flow measurements.

The results highlight the successful optimization of superplasticizer dosages to improve the flow properties of SCC, ensuring its compliance with industry standards. The enhanced slump flow characteristics of SCC with higher superplasticizer contents signify improved workability and maneuverability, making it an attractive material for complex construction applications. The findings have significant implications for the design and implementation of self-compacting concrete in high-performance construction projects, enhancing both construction efficiency and structural integrity. All fresh cocnrete observation such as T50, V-funel, L-Box and Slump flow can be seen in the Table 2.

Table 2. Fresh properties observation based on variation of superplasticizer

SP (%)	T_{50cm}	V-funnel	L-Box H_1/H_2	Slump Flow
	(secon)	*(secon)*	*(secon)*	*(secon)*
0.6	3.89	6.18	0.83	655
1.0	3.09	6.51	0.87	675
1.6	2.24	7.11	0.91	690

3.3 Compressive Strength

The study conducted compressive strength tests on concrete specimens aged 7, 14, and 28 days, with varying superplasticizer dosages and the addition of silica fume as an additive. The superplasticizer dosages used were 0.6%, 1%, and 1.6% by weight of cement. The results, presented in Figure 5, the average compressive strength values for each dosage at different curing ages.

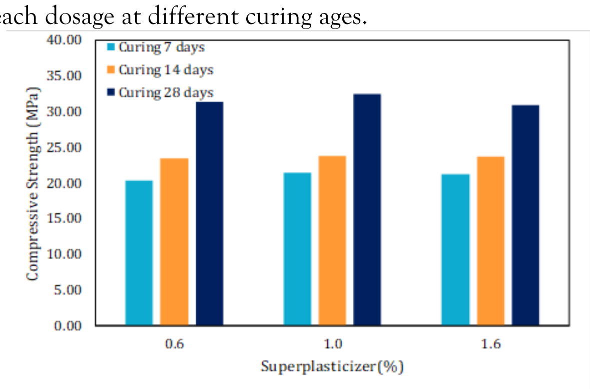

Figure 5. Influence of superplasticizer dosage on compressive strength in Self-Compacting Concrete with silica fume

Specimens treated with a superplasticizer dosage of 0.6% by weight of cement and silica fume demonstrated the highest average compressive strength after 28 days of curing. On the other hand, specimens treated with a superplasticizer dosage of 1.6% by weight of cement and silica fume exhibited comparatively lower compressive strength values across all curing ages.

3.4 Regression analysis

Figure 6 illustrates the relationship between concrete compressive strength and varying levels of superplasticizer dosage. According to regression analysis, The data reveals that the highest compressive strength within the range of superplasticizer dosages (0.6%, 1%, and 1.6%) is attained at the 0.6% dosage level, measuring 32.3 MPa. The graph indicates a decreasing trend in compressive strength as the superplasticizer dosage increases. The observed decrease in compressive strength with higher superplasticizer dosages is attributed to the flowability of the superplasticizer. As the dosage increases, excess air voids and concrete pores are introduced into the mixture, leading to a reduction in compressive strength.

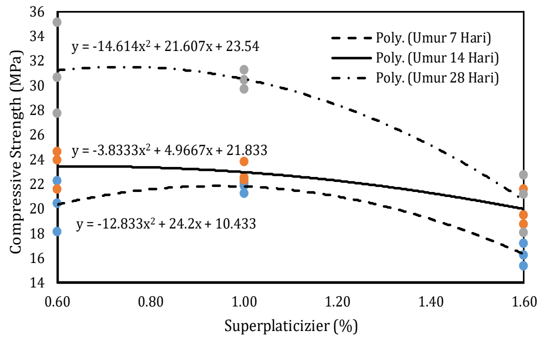

Figure 6. Regression relationship between superplasticizer dosage with compressive strength

The graph's trend emphasizes the significance of optimizing the superplasticizer dosage to achieve the best compressive strength for the self-compacting concrete. The findings contribute valuable insights for concrete mix design, emphasizing the importance of striking a balance between superplasticizer content and concrete strength. Understanding this relationship aids in the development of high-performance self-compacting concrete mixtures, ensuring their effective and sustainable application in construction projects.

In the case of concrete, the highest compressive strength value is initially obtained at the 1% superplasticizer dosage level, while the 0.6% dosage level exhibits lower compressive strength values during early curing periods. However, at the 28-day curing age, the 0.6% dosage level achieves the highest compressive strength value compared to the 1% and 1.6% dosage levels. Conversely, the 1.6% dosage level consistently demonstrates the lowest compressive strength value until the 28-day curing age as shown in Figure 7.

These results lead to the conclusion that excessive superplasticizer content negatively impacts the compressive strength of concrete. The initial strength gain at the 1% dosage level suggests an optimum dosage for early curing stages, while the superior compressive strength achieved by the 0.6% dosage level at 28 days indicates the importance of selecting an appropriate dosage to optimize the long-term performance of self-compacting concrete. Understanding the influence of superplasticizer dosages on concrete strength is vital for designing high-performance concrete mixtures and ensuring the sustainability of construction materials in various applications.

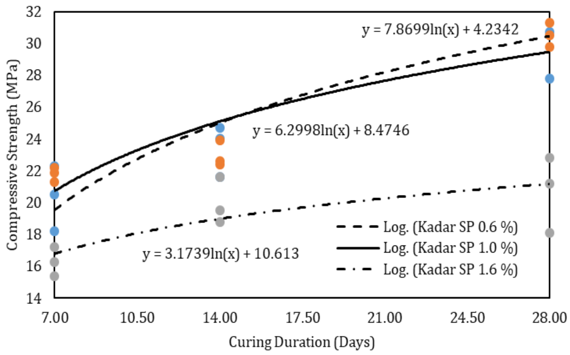

Figure 7. Regression relationship between curing duration with compressive strength

4 CONCLUSIONS

The compressive strength values of SCC at the ages of 7, 14, and 28 days are significantly influenced by the Superplasticizer variations. Specifically, for the 0.6% Superplasticizer dosage, the compressive strength values are recorded as 20.3 MPa, 23.4 MPa, and 33.4 MPa, respectively. For the 1% Superplasticizer dosage, the corresponding values are 21.8 MPa, 23.0 MPa, and 30.5 MPa. Lastly, the 1.6% Superplasticizer dosage results in compressive strength values of 16.3 MPa, 20.0 MPa, and 20.07 MPa, respectively. The three tests evaluating the fresh concrete mix properties successfully meet the standards set by EFNARC. The Superplasticizer dosage greatly impacts the flowability of fresh properties testing, with increased dosage leading to a faster flowability of the SCC mixtures. The duration of treatment (curring time) significantly influences the compressive strength of concrete. As the curing time progresses from 7 to 28 days, the compressive strength values generally increase for all Superplasticizer variations. However, the rate of strength development varies with different Superplasticizer dosages.

The findings from this research provide crucial insights into optimizing SCC mix design for enhanced compressive strength. The results suggest that selecting an appropriate Superplasticizer dosage is essential to achieving desired compressive strength values at different curing ages. Moreover, the study confirms the positive effect of Silica Fume and Superplasticizer on the fresh properties and flowability of SCC mixtures, supporting their application in diverse construction projects. These results contribute to the advancement of self-compacting concrete technology, fostering more sustainable and durable construction materials for future infrastructure development.

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