Open Journal of Civil Engineering, 2023, 13, 756-770
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Comprehensive Analysis of the Effects of Superplasticizer Variation on the Workability and Strength of Ready-Mix Concrete

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How to cite this paper: Tareque, T., Tousif, F., Billah, M.A., Jabir, A.A.M, Mirmotalebi, S. (2023) Comprehensive Analysis of the Effects of Superplasticizer Variation on the Workability and Strength of Ready-Mix Concrete. *Open Journal of Civil Engineering*, **13**, 756-770.
https://doi.org/10.4236/ojce.2023.134050

Received: December 2, 2023
Accepted: December 25, 2023
Published: December 28, 2023

Abstract

This experimental study aims to examine the influence of many crucial parameters on the workability and compressive strength of Ready-Mix Concrete (RMC). The study utilized two distinct varieties of superplasticizers obtained from the local market. The fine aggregates utilized in this study were sourced from Sylhet sand, whereas the coarse aggregates were comprised of boulder crushed stone chips. The experimental procedures adhered to the requirements outlined by ASTM. A comprehensive investigation was conducted on a range of concrete compositions that used diverse chemical admixtures. The slump test was performed at regular intervals of 15 minutes until the slump value reached or fell below 3 cm after the mixing of the concrete. In the scenario involving two-stage admixture dosage, the second stage of admixture was introduced once the slump reached or dropped below 3 cm, following which the casting process was initiated. The process of curing concrete specimens consists of two distinct stages: the main stage and the final stage. Cylindrical specimens, with a diameter of 4 inches and a height of 8 inches, were manufactured for the purpose of evaluating their compressive strength at both 7 and 28 days. During the experimental trials, the water-cement (w/c) ratio was kept consistent, while different dosages of admixture were applied. The findings of the study indicate that the utilization of a two-stage dose of admixture resulted in enhanced and extended workability, along with higher strength of the concrete in comparison to specimens that did not incorporate any admixture. This research study enhances the comprehension of optimizing qualities of ready-mix concrete (RMC) by varying the superplasticizer, providing useful insights for the building sector.

Keywords

Admixture Dosage, Slump Test, Water-Cement Ratio, Concrete Compositions, Compressive Strength

1. Introduction

The construction sector plays a crucial role in influencing the configuration of urban environments and the advancement of infrastructure [1]. In the domain of civil engineering, the satisfactory achievement of construction projects relies on various aspects, among which the caliber of concrete employed is a crucial determinant. The preservation of concrete's durability, workability, and strength holds significant significance within the realm of construction [2] [3]. Workability in concrete refers to its level of ease in terms of mixing, placing, and finishing during the construction process. It is an essential attribute that is affected by factors such as the ratio of water to cement, the properties of the aggregate, and the presence of admixtures. In recent times, there has been a notable increase in the demand for Ready Mix Concrete (RMC) in various construction projects, encompassing both large-scale and small-scale endeavors [3].

The adoption of Ready-Mix Concrete (RMC) is driven by a confluence of compelling elements that strongly resonate with engineers and experts in the building industry [4]. Moreover, following the impact of asphalt in the roadways construction the attractiveness of RMC (Ready-Mix Concrete) stems from its capacity to consistently uphold accurate ratios of cement, sand, and aggregate, hence guaranteeing the essential quality of concrete [4]. Additionally, jerking, measured as a derivative of acceleration, is one of the most crucial factors affecting traffic comfort. The use of superior-quality RMC in the construction of concrete pavement results in reduced road roughness and jerking, thus enhancing passenger comfort [5] [6] [7]. With the current increase in high-rise building projects within the construction sector, Ready-Mix Concrete (RMC) emerges as a notable option due to its advantageous attributes of convenience and consistency. Consequently, RMC proves to be a favorable selection for ambitious vertical buildings. In addition, the use of Ready-Mix Concrete (RMC) has been found to greatly improve time efficiency by reducing construction durations. This provides projects with a considerable advantage in terms of time-saving [8]. However, in the case of high-rise buildings, increased vibrations have the potential to induce structural fatigue and undermine the operational effectiveness of the concrete. Thus, to create resilient and durable high-rise structures, the control of vibrations becomes essential which can be achieved by utilizing Stockbridge damper [9].

Furthermore, it is imperative to acknowledge that concrete conservation is significantly influenced by this factor, as it effectively reduces the amount of material that goes to waste. All these wastes are disposed of within landfills, resulting in the production of landfill leachate. Leachates contain a significant amount of organic nitrogen and are accountable for the detrimental occurrence of algal blooms in surface water bodies [10] [11] [12]. This not only leads to financial benefits but also coincides with the overarching objective of promoting environmental sustainability. In urban environments characterized by limited space availability, ready-mix concrete (RMC) plants may effectively function within compact spaces, making them well-suited for construction sites that are heavily congested [8]. RCC road construction instead of bituminous, can highly be benefitted using RMC [13] [14] [15] [16]. It is often used for slope protection or embankment construction purposes as well [17] [18] [19] [20]. Moreover, RMC has high uses in ground improvement and liquefaction mitigation [21] [22] [23] [24]. The appeal of RMC is further enhanced by its controlled manufacturing process, which guarantees the production of uniform and high-quality concrete that adheres to the stringent standards of the building industry. Several studies were conducted to optimize the parameters affecting the strength of RMC [25] [26]. Studies also referred to conducting triaxial tests to determine the strength properties of RMC [27]. Regressive and AI based parametric correlation were often inspired by the similar process from studies conducted to determine soil strength parameters [28] [29] [30] [31] [32]. AI based studies are even popular in structural health monitoring systems [33] [34]. The commendable consistency and composition of ready-mix concrete facilitate the utilization of shape memory alloys (SMA) as internal reinforcement. This is particularly significant, given the crack prevention and recovery properties of SMAs, which ultimately enhance the performance of the concrete member [35].

The growing adoption of Ready-Mix Concrete (RMC) has emerged as a prominent and influential pattern in recent times, with projections indicating its sustained growth in the future. Chemical admixtures are employed to preserve the structural soundness of concrete while simultaneously prolonging its setting time, particularly in situations involving heavy traffic or lengthy transit distances [36] [37]. The utilization of these admixtures, when applied appropriately, has the potential to prolong the duration of workability while maintaining the intended strength of the concrete [38] [39]. The utilization of chemical admixtures for enhancing the characteristics of construction materials has been a well-established practice. Previous research studies have explored the efficacy of chemical admixtures, exemplified by the application of fly ash, to enhance the bearing capacity of subgrade soil [40].

Nevertheless, the utilization of chemical admixtures in ready-mix concrete (RMC) is a sophisticated procedure that demands meticulousness and empirical investigation. Achieving an optimal equilibrium between workability and strength is of utmost importance, hence requiring comprehensive investigation to comprehend the impact of various superplasticizers on the characteristics of RMC [36] [37] [38] [39].

According to previous works, the average first setting time for concrete is roughly 45 minutes [41]. However, the transportation of ready-mixed concrete (RMC) within the specified timeframe can be rendered impractical due to obstacles such as substantial traffic volumes and considerable transportation distances. To effectively tackle this matter and maintain the concrete's ideal strength while enduring extended transportation durations, it is crucial to conduct a thorough examination and comprehension of the influence exerted by various superplasticizers on the characteristics of RMC.

The objective of this study is to determine the most favorable amalgamation of variables that enhances the workability of RMC while maintaining its structural integrity. The study entails a thorough analysis of the impacts resulting from differences in superplasticizers, admixture dosages, and application timing. It is crucial to acknowledge that this study specifically concentrates on chemical admixtures that are readily accessible in the local context. The examination of temperature's impact on workability and strength falls outside the scope of this research.

2. Materials and Method

2.1. Materials

The experimental materials comprised coarse aggregate in the form of boulder crushed stone chips, fine aggregate in the form of Sylhet sand, water, cement as the binding agent, and a range of chemical admixtures.

2.2. Coarse and Fine Aggregates

The selection of coarse aggregates, namely stone chips, was conducted in accordance with the guidelines outlined in ASTM C33. This standard was utilized to ensure that the sieve analysis of the aggregates adhered to the specified upper and lower limitations established by ASTM C33. The sieve analysis conducted on the coarse aggregate, specifically stone chips, adhered to the higher and lower limits prescribed by ASTM C33, as illustrated in **Figure 1**.

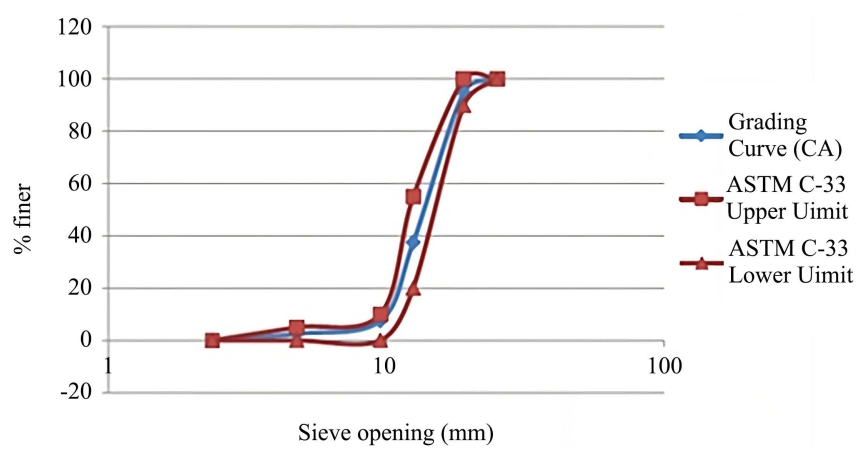

Figure 1. Gradation curve for coarse aggregate.

In contrast, the utilization of Sylhet sand was employed as the fine aggregate. Prior to utilization, the sand underwent a process of sieving and grading in line with the standards set forth by ASTM C33, ensuring that it met the necessary parameters for particle size distribution. The fine aggregate (Sylhet sand) underwent a sieve examination, which demonstrated conformity to the higher and lower limitations specified by ASTM C33, as depicted in Figure 2.

2.3. Binding Materials and Water

CEM Type II B-M were utilized in our experimental procedures which is a Portland Composite Cement. The production process of this cement involves the inter-grinding of three primary mineral components, namely Pulverized Fuel Ash (PFA), Blast Furnace Slag, and Limestone. These components are combined with conventional raw materials like Clinker and Gypsum. The cement concentration for each test was measured with careful precision. The concrete casting and curing process involved the utilization of tap water, which possesses a unit weight of around 1000 kg/m^3. Nevertheless, tap water contains numerous toxins that can be detrimental to human health when consumed [42] [43] [44]. These types of impurities can also impede the casting process. Tap water was selected with caution for our experiment.

2.4. Chemical Admixtures

The utilization of chemical admixtures in our experiment was significant, as it effectively enhanced the workability of concrete while maintaining its structural integrity. Two different chemical admixtures (Type F and G) were utilized in our study, and a three-step methodology was implemented for their incorporation. ASTM Type F and Type G are widely employed categorizations of high-range water-reducing admixtures that find common application in the realm of concrete building. Type F, which is composed of polycarboxylate ethers, demonstrates exceptional capabilities in the dispersion of cement particles, reduction of

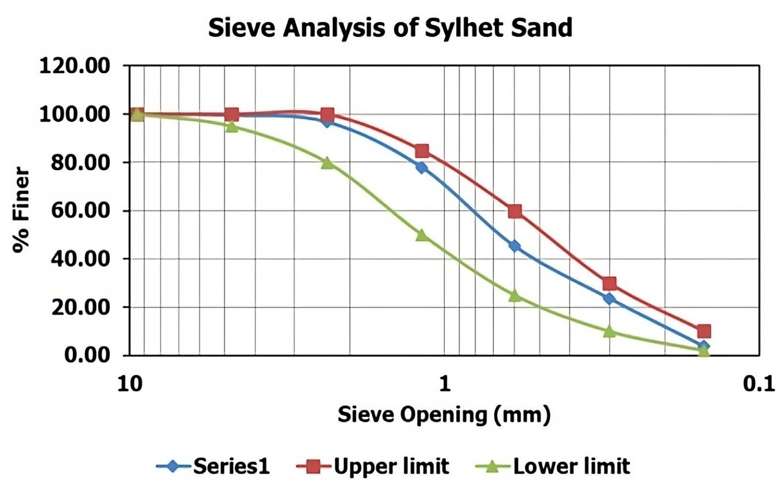

Figure 2. Gradation curve for fine aggregate.

water content, and is particularly well-suited for the production of high-strength concrete [45]. Type G, which is formulated using sulfonated naphthalene formaldehyde condensate, exhibits enhanced workability characteristics, rendering it highly suitable for various applications such as the preparation of ready-mix concrete [46] [47] [48]. Both factors are crucial in improving the quality and performance of concrete. The initial stage entailed the utilization of a mean admixture dosage that adhered to the prescribed limitations as outlined in the ASTM recommendations. To evaluate the highest level of efficacy, the second phase of the assessment implemented the maximum permissible dosage in accordance with the requirements set by the American Society for Testing and Materials (ASTM). The third methodology employed a two-step application of the highest possible mixture, with an initial addition of 70% followed by the introduction of the remaining 30% once the slump value of the concrete reached 3 cm or below. In order to use the RMC along with dampers and stiffeners as a part of vibration control, latex solutions are used as a chemical synthesizer [49] [50].

2.5. Workability Measurement

The accessibility of the concrete's workability was periodically assessed through the utilization of the slump test at 15-minute intervals. The initiation of the casting process was initiated whenever the concrete's slump value reached 3 mm or below. Three separate criteria were utilized for the implementation of chemical admixtures, namely: average dose application, maximum dosage application, and two-stage dosage application. The two-stage dosage strategy involved adding the remaining fraction of the admixture at a specific point in the casting process. This point was identified by monitoring the slump value, which initially increased and then decreased to 3 cm or less. By following this approach, the casting process could be carried out with greater accuracy and control over the workability of the mixture.

2.6. Mold Preparation and Casting

Precisely crafted cylindrical molds, with a diameter of 4 inches and a height of 8 inches, were methodically created. The molds were tightly fastened, and their internal surfaces were lubricated with grease, which was used as lubricant. The casting process for the cylindrical specimens was conducted utilizing a mixing machine, employing a manner that deviates from the conventional practice observed in Bangladesh. In the present methodology, a first step involved the introduction of 50% of the fine aggregate into the mixing apparatus. Following this, the entirety of the cement was incorporated, and the remaining sand was then introduced in each respective scenario. Following a 30-second mixing cycle, the water admixture mixture was subsequently poured, and the coarse aggregate was added. The slump test was performed at regular intervals of 15 minutes, and the casting process began whenever the slump value hit a threshold of 3 cm or lower. The procedural processes for concrete mix preparation, casting, curing, and conducting a compressive strength test using a Universal Testing Machine (UTM) are illustrated in Figure 3.

2.7. Compaction and Curing

The cylindrical specimens were compacted in a proper manner to maintain their integrity. The compaction process involved the placement of each specimen in two distinct layers, with 25 blows being applied to each layer, in accordance with the requirements outlined by ASTM. Void-free specimens were achieved with the implementation of post-compaction, hammering, and scaling techniques. The curing process was carried out in two distinct stages. In the initial stages, a damp cloth was applied onto the specimens after the casting process once the surface had achieved a state of solidification. Following a period of 24 hours, the molds were unsealed, and the specimens were immersed in a curing bath to speed up curing.

3. Result and Discussions

One of the principal purposes of chemical admixtures in concrete is to prolong the setting period, guaranteeing the workability of ready-mixed concrete (RMC) during its transportation to the construction site. To evaluate the optimal approach for improving workability, a series of experiments were done using three distinct concrete mixtures, each incorporating different levels of chemical additive dose.

In Figure 4, a noteworthy accomplishment was seen in the context of the Polycarboxylic ether-based superplasticizer (Type F). The slump value, as per JIS A 5308 criteria, remained consistent at 2 to 3 cm even after a duration of 120 to 150 minutes.

Figure 3. Concrete mix, casting, curing and compressive strength test in UTM.

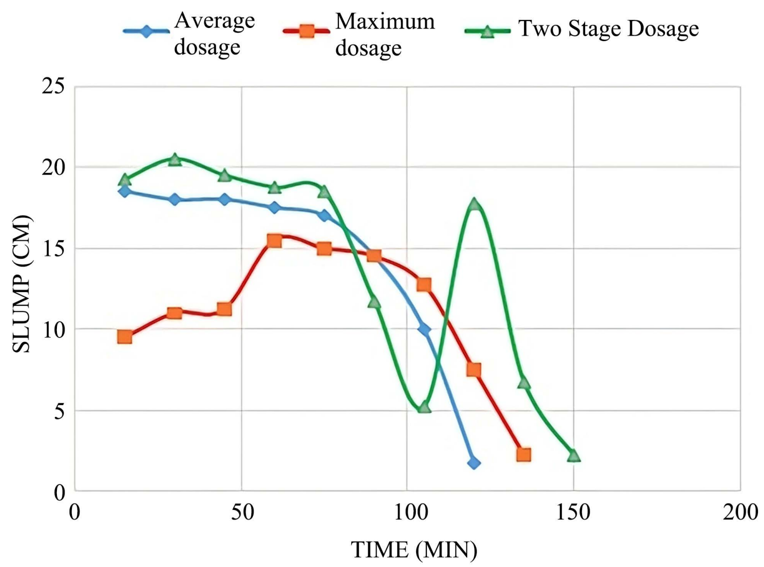

Figure 4. Workability after using type F admixture (Polycarboxylic ether-based).

The remarkable effects of including a superplasticizer possessing dual characteristics of high-range water reduction and retarding qualities, such as type G, were observed in **Figure 5**. In addition to the mean dosage, the efficacy shown a notable improvement, as it sustained a slump value ranging from 3 to 4.5 cm even after a duration of 150 to 180 minutes. The obtained outcome greatly surpassed the specifications given in JIS A 5308.

The study involved an assessment of the impact of several dosages of chemical admixtures on the compressive strength. The findings were particularly remarkable in the case of the maximal admixture dose condition, as the Naphthalene Sulphonate-Based admixture exhibited extraordinary workability. In this instance, the concrete exhibited a workability duration of 150 minutes, accompanied by a slump value of roughly 3 cm. Furthermore, it demonstrated enhanced strength in comparison to the non-admixture scenario.

Moreover, while employing a two-stage dosage of chemical admixture, a higher degree of workability were seen in the concrete compared to the other two methods of additive application. In this circumstance, the Naphthalene Sulphonate-Based admixture was determined to be the most favorable option. In the initial phase of dosing, the concrete exhibited a workability duration of roughly 100 minutes, as indicated by a slump value of 4 cm. Following this, the administration of the second dose resulted in a notable elevation in the slump value, reaching a measurement of 20 cm. Over the course of the experiment, the slump of the concrete gradually decreased. However, the concrete maintained its workability for a duration of 180 minutes, with a final slump value of 4.5 cm.

The incorporation of F and G admixtures led to a significant enhancement in compressive strength when compared to plain concrete, exhibiting improvements of 50% - 60% after 7 days and around 70% after 28 days of the curing period.

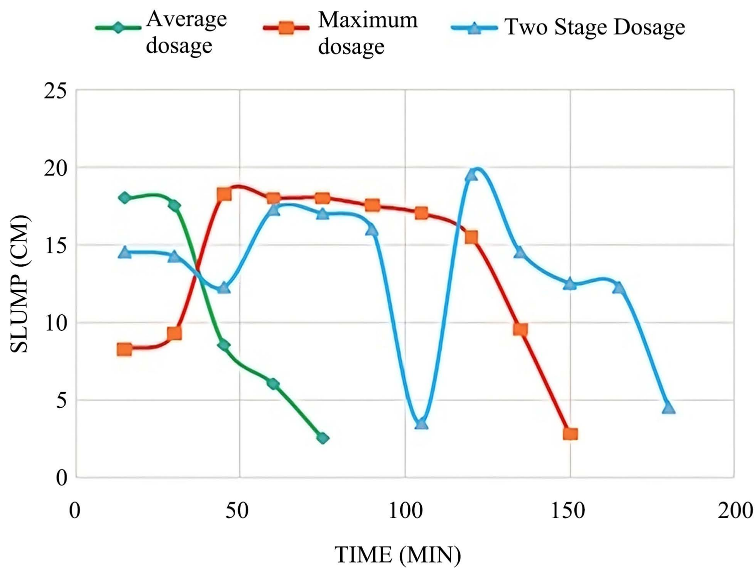

Figure 5. Workability after using type G admixture (sulfonated naphthalene formaldehyde condensate).

From Figure 6, the compressive strength for type F exhibited a sustained high level, approximately 4500 psi, throughout all three dosage types (Average, Maximum, and Two-Stage) following a 7-day period. In contrast, the Average dosage for type G demonstrated the highest strength, measuring at 4476 psi, which surpassed both the Maximum dosage (3950 psi) and the Two-Stage dosage (3898 psi). Following a 7-day period, a comparative analysis of F and G indicated that F exhibited superior compressive strength performance for both maximum and two-stage dosage applications.

It is clear from the data shown in Figure 7 that type F continuously maintained a high compressive strength in both Average and Maximum dose applications, reaching about 5700 psi. After 28 days of curing, the Two-Stage dose showed a modest decrease in strength, measuring 4861 psi. On the other hand, after 28 days, type G—that is, the Average dosage—showed the maximum compressive strength, peaking at 5809 psi, better than the Maximum dosage (5175 psi) and the Two-Stage dosage (5383 psi). After 28 days, the comparative evaluation shows that type G performed better in terms of compressive strength for both average and two-stage dosage administrations. As a result, our data indicates that although type F performed better during the first 7 days of curing, type G performed best overall after 28 days of curing, suggesting that type G has a slower start but performs better over the long run.

Overall, his study provides valuable insights into the use of chemical admixtures, specifically Polycarboxylic ether-based superplasticizer (Type F) and sulfonated naphthalene formaldehyde condensate (Type G), to improve the workability and compressive strength of ready-mixed concrete (RMC). The extended workability attained with Type F, maintaining a slump value of 2 to 3 cm for a duration of 120 to 150 minutes, corresponds with prior research highlighting the

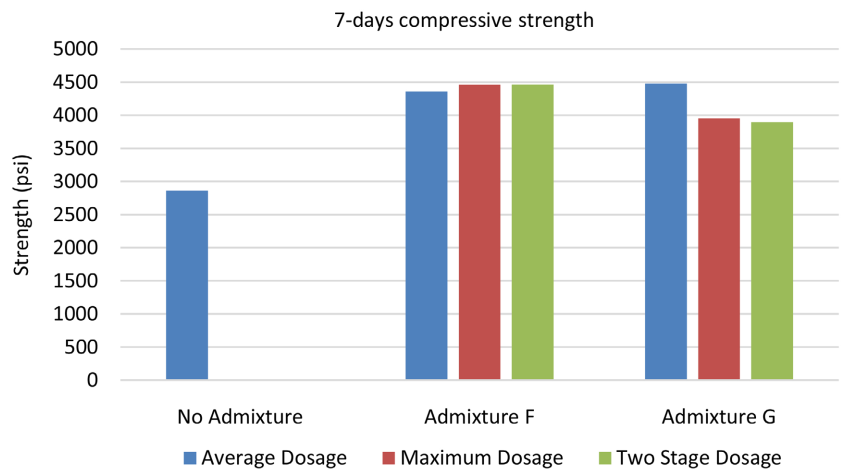

Figure 6. The impact of varying admixture dosages on the 7-days compressive strength (psi).

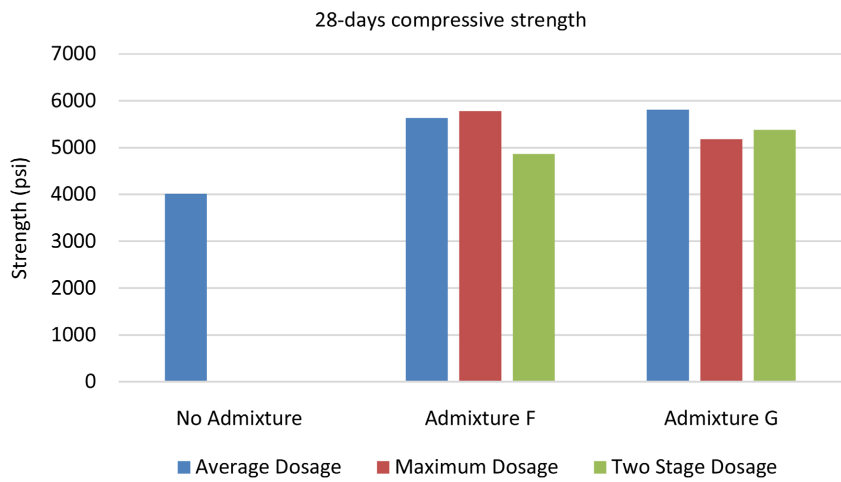

Figure 7. The impact of varying admixture dosages on the 28-days compressive strength (psi).

beneficial effect of this superplasticizer in delaying the setting time of concrete. The investigation demonstrates that Type G has exceptional workability even after 150 to 180 minutes, surpassing the standards given in JIS A 5308. This superplasticizer exhibits the capacity to maintain workability for a longer period of time while also preserving the ultimate strength of the concrete.

Upon comparing the compressive strength findings, it is evident that both Type F and Type G admixtures greatly augment the strength of concrete. These admixtures demonstrate notable enhancements of 50% - 60% after 7 days and around 70% after 28 days of curing, when contrasted with plain concrete. The observed trend in compressive strength is consistent with prior research that emphasizes the beneficial influence of superplasticizers on the mechanical characteristics of concrete. The comparison analysis of Type F and Type G demonstrates an intriguing dynamic, wherein Type F exhibits higher compressive strength during the first 7-day period, whereas Type G outperforms in total performance after 28 days of curing. This nuanced comprehension offers a comprehensive viewpoint for practical individuals, indicating that the selection between Type F and Type G relies on the desired performance schedule and underscores the need of taking into account the long-term durability enhancement in concrete mixture formulation.

4. Conclusions

Our study's result emphasizes the critical function that chemical admixtures play in extending ready-mixed concrete's (RMC) workability while it is being transported to building sites. Workability was greatly enhanced by the application of Type F (polycarboxylic ether-based) and Type G (sulfonated naphthalene formaldehyde condensate) superplasticizers. Type G showed remarkable endurance over an extended length of time, sustaining slump values in compliance with industry requirements. The study also showed that the compressive strength of RMC is greatly impacted by admixture dosages and application techniques. Compressive strength increased significantly with the addition of Type F and Type G admixtures; it increased by 50% - 60% after 7 days and by around 70% after 28 days of curing. Although Type F performed exceptionally well over the first seven days, Type G proved to be the stronger performer over the longer run, showing a slower start but overall greater performance. This study emphasizes the possibility of improving building methods and RMC qualities through the prudent use of chemical admixtures, which offers significant insights to the construction sector.

In anticipation of future investigations, there exist multiple potential areas for further scholarly inquiry. These include the examination of the mechanical properties of concrete, the exploration of a wider range of chemical admixtures, the manipulation of admixture dosages, and the consideration of various factors such as water-cement ratio, sand-to-aggregate ratio, cement content, aggregate sizes, and types of coarse aggregates. Furthermore, it is imperative that future research endeavors prioritize the consideration of seasonal and temperature fluctuations in the context of casting processes. In brief, our study contributes to the existing body of knowledge concerning the enhancement of Ready-Mix Concrete properties by employing superplasticizers. Continued investigation in these domains will further enhance our understanding of concrete attributes and facilitate the development of more effective construction methodologies.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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