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Analyzing the potency of Viscosity Modifying Agents on the Characteristics and Static Segregation of Fresh and Hardened Fluid Concrete

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Abstract
Self-compacting concrete (SCC) represents a recent advancement in the field of concrete technology due to its ease of handling and placement. In order to regulate the internal integrity of the concrete, a supplementary mixture component is employed. The term used to refer to this particular component is a viscosity-modifying agent (VMA). Different quantities of VMA were incorporated into the concrete mixture in order to evaluate its performance in both the fresh and hardened states. This study focused on the impact of VMA (Viscosity Modifying Agent) on various characteristics of concrete mixes. Specifically, the features under examination included flowing time, slump flow, flow time into a 500-mm diameter, and resistance to vertical segregation. In contrast, a measurement was conducted on the compressive strength of the cured concrete. The utilization of the column of segregation test allows for the identification and assessment of static segregation in SCC mixtures. This test offers a direct quantitative determination of the stability of segregation in fresh concrete. The purpose of this experiment is to determine the precise quantity of coarse aggregate with a diameter above 8 mm present within a specimen of 300 mm in height. This can be achieved by conducting sedimentation tests at a specific time interval of 30 minutes after the pouring of concrete. The research results indicate that the addition of VMA had a substantial impact on the rheological characteristics of the concrete mixture. It effectively stabilized the mixture, minimized static segregation, and improved the compressive strength when compared to the reference mixture without VMA. Furthermore, a comprehensive illustration of the segregation phenomenon is provided by the column of static segregation tests.
Keywords: Self-compacting concrete (SCC). Concrete mix. Viscosity modifying agent (VMA). Static segregation. the column of segregation test.

1. Introduction

One of the most recent developments in concrete technology is self-compacting concrete, abbreviated SCC for short. Research that Okamura and Ouchi (1998) and Ouchi and Okamura (2000) conducted in order to improve the durability of concrete led to the discovery of this phenomenon. In spite of the fact that SCC is one of the newest varieties of concrete, it is already possible to talk about its history due to the extensive testing that has been done and the wide variety of applications that have been found for it over the past two decades. The amount of development that has been made in Japan, the United States of America, Canada, and the bulk of European countries, including Poland, is very significant.

When considering SCC (self-compacting concrete) mixes, there are two fundamental criteria that must be satisfied: filling ability, which encompasses the capacity to flow and pass through reinforcing bars, and resistance to segregation. To satisfy these requirements, it is necessary to carefully select the primary constituents of the mixture, namely cement, micro-filler, superplasticizer, and water, in order to attain the desired rheological characteristics (Okamura & Ouchi, 1998; Khayat, 1998). Furthermore, it is necessary to incorporate a supplementary element in order to regulate the internal integrity of the concrete mixture. The term used to refer to this particular component is the viscosity-modifying agent. The VMA, or Viscosity Modifying Agent, is a substance that enhances the internal cohesiveness and resistance to segregation of freshly mixed concrete (EFNARC, 2006). VMA serves as a substance that enhances the viscosity of cement paste without necessitating a decrease in water content or an increase in dust content (Furkan Türk *et al*., 2022) (Boukendakdji, 2016) (Jolicoeur *et al*., 2000) (Assaad and Khayat, 2004) (Shen and Lange, 2015).

The most important aspect is that they do not change any properties of the mixes besides viscosity (Umar and Al-Tamimi, 2011). Although VMAs can be used individually, they are typically combined with superplasticizers. In this combination, the superplasticizers function to improve flow, while the VMAs provide stability (Khayat, 1998) (Grabiec, 2013).

An effective Viscosity Modifying Agent (VMA) should guarantee the attainment of a desirable plastic viscosity in a concrete mixture while also facilitating the integration of apparently incompatible characteristics like flowability, capacity to fill confined spaces, and resistance to segregation. In the context of self-compacting concrete (SCC), it is vital for the viscosity-modifying agent (VMA) to concentrate on conserving the mixture from segregation phenomena. This is primarily due to the notable fluidity exhibited by SCC. The process described includes both dynamic and static phenomena. The dynamic aspect refers to changes in the cross-section of reinforced concrete elements during concrete placement. On the other hand, the static aspect refers to the phenomenon of aggregate sedimentation following concrete placement, which can occur due to variations in the densities of the components in the concrete mix. The phenomenon of segregation has been observed to have adverse effects on various characteristics of hardened concrete, including the homogeneity of compressive strength in extreme cases (El-Chabib and Nehdi, 2006) (ASTM C 1610, 2019).

The concept of segregation resistance refers to the capacity to maintain a uniform dispersion of aggregates. The capacity of concrete to maintain a consistent composition from the time of placing until it reaches the setting stage. The concept of resistance to segregation covers both dynamic and static stability. In order to attain a significant level of resistance to segregation, in order to provide a consistent distribution of coarse aggregates throughout the mixture within the blending and placement phases, it is necessary to facilitate a uniform dispersion. (Assaad *et al*., 2004). The phenomenon of segregation commonly arises during the process of placement, leading to the production of heterogeneities. These heterogeneities have the potential to negatively impact several aspects of concrete performance, such as limiting the flow around reinforcement, increasing drying shrinkage, reducing strength, causing deformation, and weakening durability (Kovler and Roussel, 2011). According to Khayat and Feys (2010), Segregation tests are typically conducted on fresh concrete samples or during the early phases of the hardening process (Okamura and M. Ouchi, 2003;

Shindoh and Matsuoka, 2003; Nili *et al*., 2017; ASTM C 1610, 2019; Assaad *et al*., 2004; Sonebi and De Schutter, 2020).

This investigation applied two viscosity-modifying compounds, namely "MEDACOLE BSE" and Cellulose Ether "WALOCELTM MKX 15000 PP 20," which were obtained from GRANITEX and SIKA Algerian Companies, respectively.

The aim of this study is to investigate the influence of the Viscosity Modifying Agent (VMA) found in Algeria on the characteristics of self-compacting concrete in its fresh and hardened states. The investigations done on freshly mixed concrete included various criteria, including the measurement of slump flow, which quantified the time it required for the concrete to flow into a 500 mm diameter, as well as the flow time and the degree of vertical segregation (static segregation). The evaluation of the compressive strength of hardened concrete was conducted at the end of a 28-day period, demonstrating improved characteristics for self-compacting concrete (SCC). The main aim of this work is to present an innovative testing method, known as the "column of static segregation test," that can accurately assess the degree of segregation in recently created self-compacting concrete (SCC) mixtures. An effective Viscosity Modifying Agent (VMA) should guarantee the achievement of a desirable plastic viscosity in a concrete mixture, and facilitate the integration of apparently incompatible characteristics such as flowability, capacity for use in small spaces, and resistance to segregation. Due to its high mobility, SCC requires VMA to first keep the mix from segregating. After the concrete is poured, the aggregate settles down because of the different densities of the concrete mix's parts. The phenomenon of segregation has been observed to have a detrimental impact on various characteristics of hardened concrete, including the uniformity of compressive strength, particularly in severe instances (El-Chabib and Nehdi, 2006) (ASTM C 1610, 2019).

2. Experimental Program

2.1. Constituent Materials

Compound cement (CEM II/B) of the 42.50 MPa class had been employed; this cement was produced at the cement factory in M'sila (Algeria) and contained 35% fillers. A polycarboxylate-type superplasticizer (SP) called Medaflow-30 SP is one that the Granitex Company in Algeria produced. The superplasticizer has a specific gravity of 1.07±0.01, a pH of 6, and a solid particle concentration of 30%. One (VMA1), "MEDACOL BSE," is an ultrafine micro-silica and colloidal agent made by the Granitex Company (Algeria). It is added to the mix in the first stage, along with the cement and aggregates. The second is a cellulose ether (VMA2), "WALOCELTM MKX 15000 PP 20," which is an organic polymer that dissolves in water, has a neutral pH, and has a viscosity of 13000 to 17000 mPa. VMA dosages are always given as a percentage of the dry weight of the cement. At a temperature of 20 °C, the water utilized is safe for human consumption. Aghouat sand (Algeria) was used, which has a fine grain size of 0.50 mm, spherical geometry, a 0.94% absorption coefficient, and a finesses modulus (FM) of 2.37. Djelfa region (Algeria) crushed stone was employed in this research, including two fractions (3.15/8 and 8/16 mm) from the career.

2.2. Assumptions and scope

The primary objective of this study was to verify the claim that VMA would improve the consistency of the concrete by making it more homogeneous and less susceptible to segregation. Preliminary research informed the requirements used for making the concrete mixture. Seven different concrete mixtures, each with a different VMA value, were tested. Slump flow's maximum diameter (d_{max}), time to reach 500 mm diameter (T500), and flow time into the V-funnel experiment were measured. The reference mixture is FTM. As defined by these parameters' limits, they do not satisfy the self-compacting requirement. The following parameters were chosen for this investigation in accordance with EFNARC (2005, 2006) and certain recommendations from the literature: Konstantin Kovler and Nicolas Roussel (2011), Łaźniewska-Piekarczyk, B (2013), and Hela Bessaies-Bey *et al*. (2022): dmax = 650–800 mm and T500 = 2–6 s.

A mix was chosen within the limits of the preliminary tests, and VMA was applied to it to modify the qualities of the reference mix. It was quite fluid and may have been highly segregated. Rheological parameters such as d_{max}, T500, flow variations with time, and resistance to vertical component segregation were assessed after the application of varying doses of VMA to evaluate its efficacy. Taking the manufacturer's advice into account, it was determined to use a range of VMA concentrations between 0.05% and 0.15% (based on the total amount of mixed water). It was speculated that the VMA's starting dose would be in the middle of the advised spectrum.

2.3. Testing procedure

The cement, aggregate, and sand were thoroughly blended for a duration of one minute. Following a period of two minutes of agitation, approximately 75 percent of the water was mixed. The last 25% of the water and the right amount of superplasticizer were then added, and the mixture was mixed for three minutes. In the context of the VMA (Viscosity Modifying Agent) in concrete mixtures, the cellulose ether was initially dissolved in the superplasticizer before being combined with a 25% proportion of water. Conversely, in the case of MEDACOLE, the VMA was introduced together with the dry components from the beginning.

The researchers utilized the methods described in the EFNARC (2005) recommendations to conduct the required measurements to evaluate the slump flow of the concrete mixtures. The fluidity of recently mixed concrete was examined through the determination of the flow spread width, the T500 in the inverted Abrams cone, and the flowing time in the V-funnel. The fluidity of self-compacting concrete (SCC) mixtures was modified through the manipulation of the dosage of a viscosity-modifying agent (VMA). The evaluation of filling ability, passing ability, and resistance to segregation was carried out to confirm the adherence of the prepared mixtures with the essential criteria of Self-Compacting concrete (SCC). "The detailed compilation of the proportions and visual mark linked to each mix is illustrated in Table 1".

The study aimed to evaluate the resistance to segregation in the vertical direction by conducting a column segregation experiment. This experiment aimed to investigate the behavior of coarse particles in concrete with flowing capabilities when at rest, specifically focusing on vertical segregation. The aim was to explicitly and quantifiably establish segregation rather than relying on other properties of fresh concrete to describe this phenomenon.

The test cylinder is comprised of a PVC cylinder measuring 300 mm in height and 160 mm in diameter, divided into three equal pieces of 100 mm each, using two thin cuts designed for putting metal sheets. The mold has been duly filled with the concrete mix sample and subsequently covered with a lid in order to delay the process of water evaporation during the first test. Following an interval of 30 minutes, during which the vertical displacement of the aggregate within the cylinder was permitted, the dividers were then positioned within the cuts. The concrete mixture obtained from the upper, middle, and lower portions was cleaned by filtration using an 8-mm sieve. This process effectively removed all aggregate grains larger than 8 mm from the sample. The coarse aggregate obtained from three distinct portions was subjected to a drying process in an oven for an average of 24 hours; after that, its weight was measured. The equation 1 shown below is used to calculate the segregation index (Is).

$$Is = \frac{M_i}{(M_1+M_2+M_3)} \quad (1)$$

Where M1, M2 and M3 are the masse of coarse aggregate of the first, second and third part of PVC cylinder.

Table 1 – Proportions of all mixtures and the visual mark.

Formulation	W/C	VMA 1 / (%)	VMA 2/ (%)	SP/ (%)	Visual remark
FTM		-	-		bleeding
SCC1		0.05	-		bleeding
SCC2		0.10	-		good
SCC3	0.40	0.15	-	0.80	firm
SCC4		-	0.04		bleeding
SCC5		-	0.09		good
SCC6		-	0.14		firm

3. Test results and discussion

"As shown by Figures 1, 2, and 3 illustrate the duration of flow via the V-funnel for concrete mixes, the maximum diameter of slump flow (d_{max}), and the time it takes for the flow to reach a diameter of 500 mm", respectively. "Figures 4 and 5 present the segregation indexes for the column of the static segregation experiment, particularly for VMA1 and VMA2", respectively. "Figures 6 and 7 indicate the compressive strength of concrete of 28-day".

The results of the primary investigations demonstrated a considerable impact of VMA on the rheological characteristics of the mixture. The elevation of the VMA quantity resulted in a decrease in the maximum diameter of the slump flow, "as shown in Figure 2". Additionally, it caused an elevation in both the flowing time and the flow time to reach a diameter of 500 mm, "as illustrated in Figures 1 and 3", respectively. Hence, it can be inferred that the utilization of VMA resulted in an improvement of the internal cohesiveness of the mixture, leading to favorable alterations in its rheological characteristics in comparison to the unsatisfactory values observed in the reference mixture FTM without VMA. This improvement is particularly evident within the acceptable limits of d_{max} and T500.

After considering the rheological characteristics of concrete mixes, the maximum diameter of slump flow, and the flow time into the 500 mm of diameter, it was determined that the SCC2 mix with a VMA1 content of 0.10% and the SCC5 mix with a VMA2 content of 0.09% revealed optimal self-compacting properties. The maximum slump flow of d_{max} was measured to be 700 mm for VMA1, with a flow time of 4.77 s into a diameter of 500 mm. In the case of VMA2, the d_{max} value was found to be 730 mm, with a flow time of -5 s into a diameter of 500 mm.

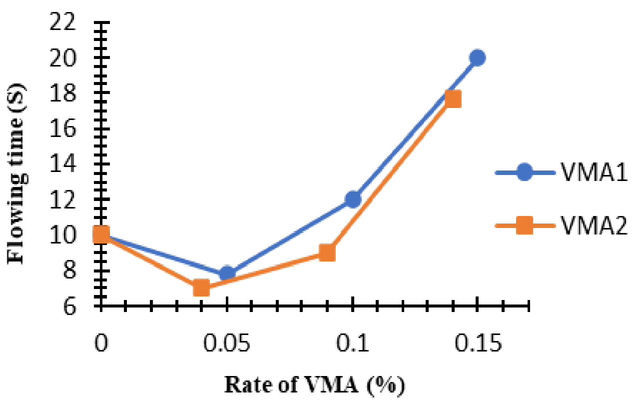

Figure 1 - Flowing Time Vs Rate of VMA.

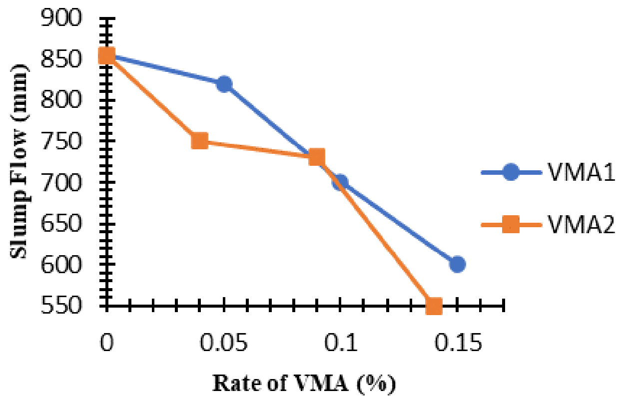

Figure 2 - Slump Flow Vs Rate of VMA.

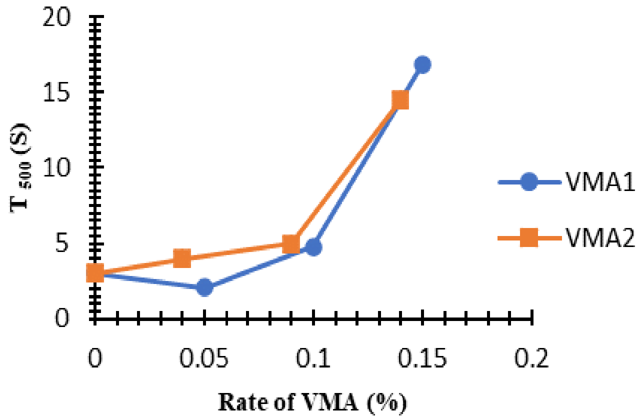

Figure 3 - T500 flow time Vs Rate of VMA.

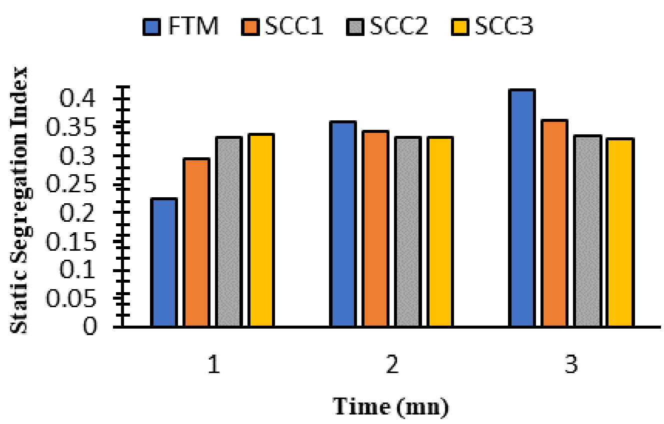

Figure 4 - Static Segregation Index Vs Time for VMA1 (30 mn).

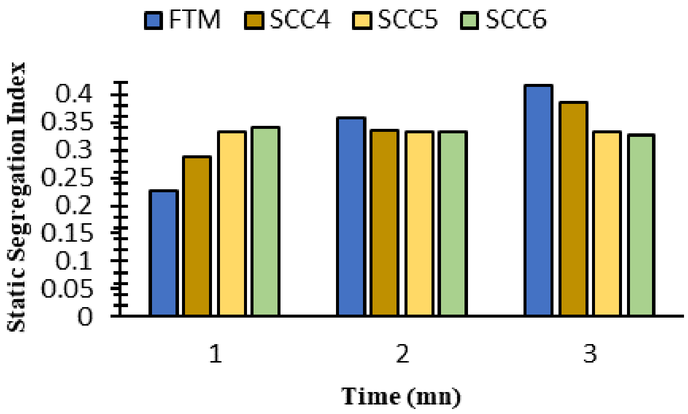

Figure 5 - Static Segregation Index Vs Time for VMA2 (30 mn).

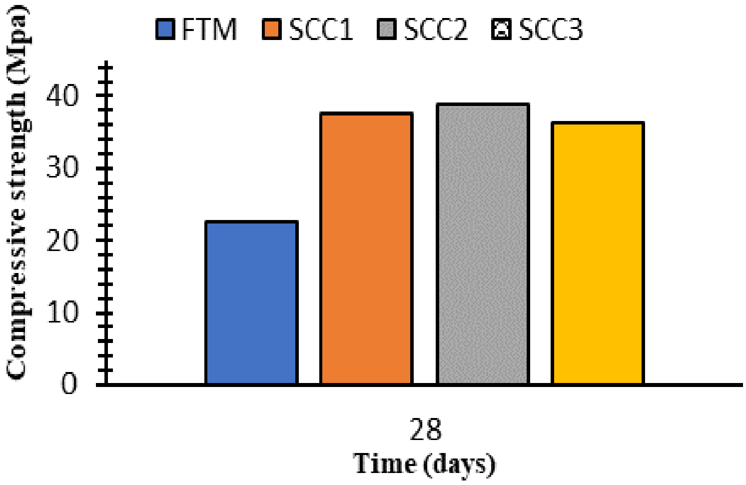

Figure 6 - Compressive Strength Vs Time for VMA1.

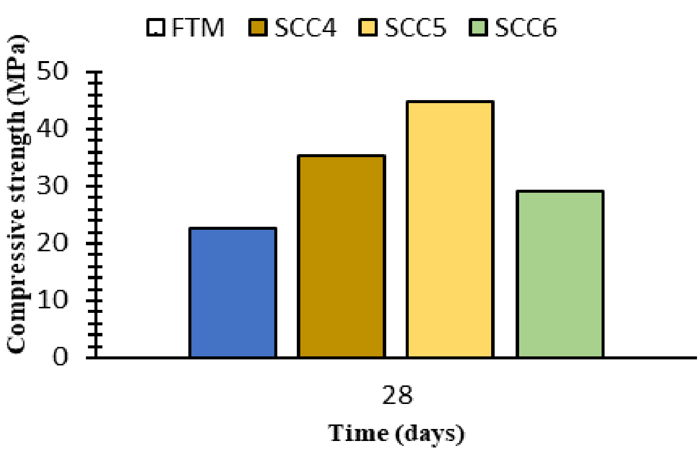

Figure 7 - Compressive Strength Vs Time for VMA2

The effectiveness of VMA was validated through the examination of testing results related to vertical segregation resistance, "as illustrated in Figures 4-5". In the absence of VMA, the components completed segregation in the reference mixture. The upper portion of the testing column indicated the smallest aggregate quantity. The difference in mass can be attributed to the insufficient viscosity of the mixture. The device missed a uniform distribution of VMA molecules, resulting in varying proportions of the combined components across various parts. The lowest section of the column included the majority of the missing aggregate as a result of the sedimentation process. The disparity in the quantities of the 8/16 mm aggregate fraction between the bottom and upper column portions exceeded the segregation level by a factor of two, as required by the testing methodology employed. In contrast, the resistance to segregation is enhanced in alternative concrete mixtures through the incorporation of higher volumes of VMA (0.10% VMA1(SCC2), 0.09% VMA2(SCC5)).

It is vital to point out that resistance to segregation plays a significant part in the technology of self-compacting concrete (SCC). This is due to the fact that inadequate segregation results in mediocre deformability, which in turn causes the aggregation of grains around the reinforcement, leading to blockage.

The measurement of compressive strength in concrete provides a crucial indicator of the general state of the material once it has reached its hardened stage. To evaluate the properties of self-compacting concrete (SCC) in its hardened form, the compressive strength of SCC mixes were examined. This was accomplished through using experiments with dimensions of (300×150×150) mm. As previously mentioned, a series of seven distinct mixtures were prepared. For each individual mixture, a total of three concrete specimens were cast in order to ascertain the compressive strength following a 28-day period of water curing.

“The figures shown in Figures 6-7” illustrate the 28-day compressive strength consequences, indicating a positive correlation between the quantity of VMA and the strength of the concrete.

The difference in strength between concrete without VMA and concrete containing 0.1% VMA was observed to be around 16.36 MPa. However, it should be noted that there is a significant difference in strength between the reference level and the 0.05% level, amounting to approximately 15.06. This finding was established by statistical analysis, which determined the significance of the VMA quantity on the strength of the concrete. Parametric analysis was employed to demonstrate the distribution of specific strength testing results that adhered to the widely recognized notion of a normal distribution.

4. Conclusion

In summary, this research investigated the effects of Viscosity Modifying Agent (VMA) on the characteristics of self-compacting concrete (SCC) in its fresh and hardened phases. The investigation spanned various parameters, including slump flow, flow time, flow time into a 500-mm diameter, segregation resistance, and compressive strength, shedding light on the correlation between VMA dosage and the performance of concrete.

- The rheological properties of the concrete mixtures were significantly influenced by the incorporation of VMA. The augmentation of VMA content led to a decrease in the diameter of slump flow, an elongation of the duration of flow, and an increase in the time required for the flow to reach a diameter of 500 mm. The observed modifications suggest an enhancement in the internal cohesion, resulting in more favorable rheological properties in comparison to the reference mixture without VMA.
- A notable contribution of this study is the introduction of the 'column of static segregation test' as an innovative method for evaluating segregation in freshly prepared SCC mixtures. The test demonstrated that VMA played a crucial role in reducing static segregation, as indicated by the enhanced distribution of aggregate throughout the column.
- Furthermore, the study highlighted the importance of resistance to segregation in SCC technology. Inadequate resistance segregation can result in mediocre deformability, leading to grain aggregation around reinforcement and blockage. The findings of the study indicate that increased volumes of VMA, particularly at concentrations of 0.10% for VMA1 (SCC2), and 0.09% for VMA2 (SCC5), resulted in improved resistance to segregation.
- The evaluation of the compressive strength in hardened concrete demonstrated a direct relationship with the dosage of VMA. The observed augmentation in the quantity of VMA

resulted in a notable improvement in the compressive strength of the concrete following a 28-day curing duration. Statistical analysis confirmed the significance of VMA quantity on concrete strength, emphasizing its role in influencing the material's overall performance.

- In conclusion, this study contributes valuable insights into optimizing self-compacting concrete through the strategic use of VMA. The findings suggest that the careful selection and dosage of VMA can lead to improved rheological properties, minimize segregation, and improve compressive strength in SCC. This knowledge is essential for advancing the understanding and application of self-compacting concrete in construction practices, particularly in the context of Algerian materials and conditions.

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