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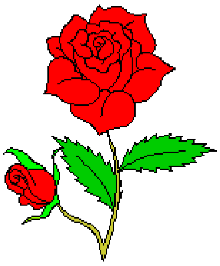
M'HAMDI Faiza

Evaluating the Effects of Viscosity-Modifying Agent on the Flow Behavior, Segregation Resistance, and Strength of Self-Compacting Concrete

Publicly defended on: 13/01/2025 before the following members of the jury:

BOULEKBACHE Bensaid	Professor	University of Chlef	President
ADJOUDJ Mhamed	Professor	University of Chlef	Examiner
BENTCHIKOU Mohamed	Professor	University of Medea	Examiner
HADJI Ben salah	MCA	University of Djelfa	Examiner
BOUKENDAKDJI Otmane	Professor	University of Medea	Director of Thesis
EZZIANE Karim	Professor	University of Chlef	Co-Director of Thesis
ZAITRI Rebih	Professor	University of Djelfa	Invited



Dedication

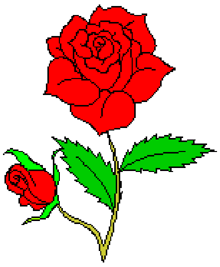
First and foremost, I would like to express my deepest, most heartfelt gratitude to my beloved family. To my dear mother, your endless love, patience, and unwavering support have been my foundation. Through every trial and triumph, you've been my guiding light, and words cannot express how much your presence has meant to me. To my late father, though you are no longer with us, your spirit, wisdom, and the lessons you instilled in me remain ever-present in my heart. I dedicate this work to your memory, with love and respect for all that you continue to inspire in me.

To **my sister** and all **my brothers**, your constant encouragement and belief in me have been a true source of strength. You've stood by me unconditionally, through the highs and the lows, and your love has given me the courage to chase my dreams without fear. To **my nieces** and **nephews**, your innocent laughter, joy, and light have been a reminder of the beauty in life, even during the toughest times. You have all touched my heart in ways that fuel my determination.

To my friends (**BELKHEIRI Nassira**, **TALEB Soumaia**, **DOUARA Taha Houcine**), thank you for your unwavering companionship and kindness. Your support, motivation, and the many moments we've shared along this journey have been precious beyond measure. You've made this experience more fulfilling and meaningful, and for that, I am eternally grateful.

This accomplishment belongs not just to me but to all of you. It was your love, encouragement, and unwavering belief that brought me to this point, and for that, I am profoundly grateful.

I dedicate this thesis



Acknowledgment

I would like to express my sincere gratitude to my supervisor, (Pr. BOUKENDAKDJI Otmane), for their invaluable guidance, mentorship, and constant support throughout this journey. Your insightful feedback and encouragement have been instrumental in shaping this work. I would also like to extend my heartfelt thanks to my co-supervisor, (Pr. EZZIANE Karim), for your expertise, constructive suggestions, and unwavering support, which greatly contributed to the success of this project.

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Thank you all for your contribution to this achievement.

الملخص

إحدى الخصائص الأكثر أهمية في الخرسانة ذاتية الصب هي مقاومتها للتفكك، مما يضمن بقاء الخليط متجانسًا طوال عملية الصب والتصلب. عندما تكون مقاومة التفكك غير كافية، يمكن ملاحظة عدة معايير، بما في ذلك تسرب المياه الداخلي والخارجي، وتراكم المكونات الأخف وزنًا، وتشكيل طبقة غنية بالعجينة في الجزء العلوي، واستقرار الركام الخشن في الجزء السفلي. هذه الاختلالات يمكن أن تؤثر بشكل كبير على السلامة الهيكلية طويلة الأجل للخرسانة. تلعب عوامل مثل لزوجة الخليط، وحجم وكثافة الركام، وسرعة التدفق دورًا أساسيًا في تحديد احتمالية ترسيب الركام. لكي تكون الخرسانة ذاتية الصب فعالة، يجب أن تحافظ على التجانس في جميع أنحاء الخليط، مما يضمن احتفاظها بالخصائص الميكانيكية الضرورية.

تستكشف هذه الدراسة اختبار التفكك باستخدام العمود الأسطواني، والذي يُستخدم لمراقبة التفكك الثابت بمرور الوقت في كل من الحالة الطازجة والصلبة للخرسانة ذاتية الصب. تم تضمين كميات مختلفة من عامل تعديل اللزوجة في الخلطات الخرسانية لتقييم فعاليتة في تحسين الريولوجيا واستقرار الخرسانة ذاتية الصب. تركز البحث على فهم تأثير عامل تعديل اللزوجة على المعلمات الرئيسية مثل تدفق الهبوط، وزمن التدفق، والوقت المستغرق للتدفق ضمن قطر 500 مم، ومقاومة التفكك الرأسي .بالإضافة إلى ذلك، تم تقييم مقاومة الانضغاط والشد للخرسانة المصلدة لتحديد التأثيرات طويلة الأجل لعامل تعديل اللزوجة على أداء الخرسانة.

يلعب اختبار التفكك باستخدام العمود الأسطواني دورًا حيويًا في تحديد وقياس التفكك الثابت في خلطات الخرسانة ذاتية الصب. يوفر هذا الاختبار تقييمًا مباشرًا وكميًا لاستقرار الخرسانة خلال حالتها الطازجة. تحديدًا، يقيس الاختبار كمية الركام الخشن (أكبر من 8 مم) في عينة بارتفاع 300 مم على فترات 15 و30 و45 دقيقة بعد الصب. من خلال إجراء هذه الاختبارات الترسيبية، يقدم اختبار العمود الأسطواني صورة مفصلة عن كيفية حدوث التفكك بمرور الوقت. وقد أظهر تضمين عامل تعديل اللزوجة تحسنًا كبيرًا في الخصائص الريولوجية للخرسانة ذاتية الصب، مما يعزز مقاومتها للتفكك، وفي النهاية يزيد من مقاومة الانضغاط والشد مقارنةً بالخليط المرجعي بدون عامل تعديل اللزوجة يبرز هذا الدور المفيد لـه في تحقيق أداء أفضل بشكل عام في الخرسانة ذاتية الصب.

الكلمات المفتاحية : الخرسانة ذاتية الصب (خ ذ ص)، عامل تعديل اللزوجة (ع ت ل)، التفكك الثابت، اختبار التفكك باستخدام العمود الأسطواني.

Abstract

One of the basic characteristics that self-compacting concrete (SCC) possesses is resistance to segregation; the mix is homogeneous through its placement and hardening. Poor resistance to segregation will be manifested by internal and external water leakage, accumulation of lighter components, a paste-rich layer forming at the top, and coarse aggregate settling at the bottom. Such imbalances may grossly compromise the long-term structural integrity of the concrete. A few of the key factors determining the potential for aggregate sedimentation include mix viscosity, size, and density of the aggregates, along with flow rate. To be effective, the SCC needs to retain homogeneity throughout the mix in retaining required mechanical properties.

This paper presents the cylinder-column segregation test for monitoring static segregation with time in both fresh and hardened states of SCC. Concretes containing different amounts of viscosity modifying agent (VMA) were prepared to investigate the effectiveness of viscosity modifying agent (VMA) in enhancing the rheology and stability of SCC mixtures. In this respect, the study concerns the understanding of the aptitude of VMA to influence important parameters such as slump flow, flow time, and time of flow in a diameter of 500 mm and resistance to vertical segregation. Other issues related to the study include the determination of the long-term VMA effects on compressive strength and tensile strength by testing the cured concrete.

The segregation test of the cylinder column is very important, as it determines and quantifies the static segregation within the mixtures of SCC. This test provides a direct and quantitative determination of stability in regard to the fresh state of concrete. More specifically, the experiment calculates the contents of coarse aggregate above 8 mm in a specimen that is 300 mm high in time lapses of 15, 30, and 45 minutes after casting. These sedimentation tests conducted provide a clear picture of segregation with regard to time through the cylinder-column segregation test. Additions of VMA have shown immense improvements in the rheological properties of SCC, hence improving segregation resistance and thereby improving both compressive and tensile strengths compared to a reference mixture without VMA. This underlines the favorable role of VMAs for better overall performance in SCC.

Keywords: Self-compacting concrete (SCC), Viscosity Modifying Agent (VMA), Static segregation, Cylinder-column segregation test.

Résumé

L'une des caractéristiques les plus critiques du béton autoplaçant (BAP) est sa résistance à la ségrégation, qui garantit que le mélange reste homogène tout au long de son application et de son durcissement. Lorsqu'il y a une insuffisance de résistance à la ségrégation, plusieurs signes peuvent apparaître, tels que des fuites d'eau internes et externes, l'accumulation des composants plus légers, la formation d'une couche riche en pâte en surface, et le dépôt des gros granulats au fond. Ces déséquilibres peuvent compromettre de manière significative l'intégrité structurelle à long terme du béton. Des facteurs tels que la viscosité du mélange, la taille et la densité des granulats, ainsi que la vitesse d'écoulement jouent un rôle crucial dans la détermination du potentiel de sédimentation des granulats. Pour que le BAP soit efficace, il doit maintenir une homogénéité dans tout le mélange, garantissant ainsi qu'il conserve les propriétés mécaniques nécessaires.

Cette étude explore le test de ségrégation par colonne cylindrique, utilisé pour surveiller la ségrégation statique au fil du temps, tant à l'état frais qu'à l'état durci du BAP. Différentes quantités d'agent modificateur de viscosité (AMV) ont été incorporées dans les mélanges de béton afin d'évaluer l'efficacité de l'AMV dans l'amélioration de la rhéologie et de la stabilité du BAP. La recherche se concentre sur l'analyse de l'impact de l'AMV sur des paramètres clés tels que l'affaissement, le temps d'écoulement, le temps d'écoulement dans un diamètre de 500 mm, et la résistance à la ségrégation verticale. En outre, l'étude évalue les résistances à la compression et à la traction du béton durci afin de déterminer les effets à long terme de l'AMV sur les performances du béton.

Le test de ségrégation par colonne cylindrique joue un rôle essentiel dans l'identification et la quantification de la ségrégation statique dans les mélanges de BAP. Ce test fournit une évaluation directe et quantitative de la stabilité du béton à l'état frais. Plus précisément, l'expérience mesure la quantité de gros granulats (supérieurs à 8 mm) dans un spécimen de 300 mm de hauteur, à des intervalles de 15, 30 et 45 minutes après le coulage. En réalisant ces tests de sédimentation, le test de ségrégation par colonne cylindrique offre une vue détaillée de la manière dont la ségrégation se produit au fil du temps. L'inclusion d'un AMV a montré une amélioration significative des propriétés rhéologiques du BAP, renforçant sa résistance à la ségrégation et augmentant ainsi ses résistances à la compression et à la traction par rapport à un mélange de référence sans AMV. Cela souligne le rôle bénéfique des AMV dans l'amélioration des performances globales du BAP.

Mots-clés : Béton autoplaçant (BAP), Agent modificateur de viscosité (AMV), Ségrégation statique, Test de ségrégation par colonne cylindrique.

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General Introduction

General Introduction

Self-compacting concrete (SCC) can be recognized as a special concrete with maximum achievable performance in terms of flowability, strength, and durability to meet the design lifespan for predefined loads and environmental conditions. SCC has excellent filling and flow capability while maintaining resistance to segregation.

Nowadays, SCC is under rapid development since its invention by Japanese researchers from Kochi University of Technology in the late 1980s. In fact, the concept of SCC was brought out due to the demand for durable, high-strength concrete with high fluidity that would be able to fill into complicated shapes of heavily reinforced formworks without any method of vibration or compaction. SCC with the great volume of cement paste has a high deformation capacity without segregation of its components and without bleeding. The volume of coarse aggregates is usually limited to 50%, with a maximum aggregate size limited to 16 mm, whereas the volume of sand is higher than 40% of the total aggregate volume. This amount of sand is taken as a basic quantity in SCC to guarantee the dispersion of coarse aggregates during SCC flow, because it lessens friction between them and ensures good compaction of the hardened concrete.

For hardened concrete to achieve optimum performances, its constituent materials, particularly coarse aggregates, should be distributed uniformly. On the contrary, SCC must achieve high fluidity more than conventional concrete and, therefore, may exhibit liquid-like behavior. The high flowability is realized by the free movement of particles inside the concrete, and such movement requires sufficient free water in the mix. With increasing water content, however, the viscosity and density of the cement paste are reduced. Thus, as the cement paste becomes less dense, its density falling below that of the aggregate, it can no longer support the aggregate particles; segregation then occurs.

In order to counteract segregation in SCC, there is an urgent need to incorporate inert powder materials at mix design rather than increasing the cement content. Such powders act to thicken the paste, increasing viscosity and density such that aggregates are evenly suspended in mortar. Such mineral powders, as seen previously, help in improving the passing ability of concrete.
Besides the use of powders, other viscosity-modifying agents may be added, which are of a chemical nature and which produce further improvement in the paste viscosity through chemical reaction with water. Such agents, also commonly referred to as thickeners or stabilizers, operate to make the mix less sensitive to minor variations in water content, hence ensuring consistency of batches that might be difficult to achieve by the use of mineral powders alone.

It is clear that viscosity represents one of the most basic and fundamental factors regarding the performance of self-compacting concrete. On one hand, it needs to have a low enough viscosity to have easy flow and be able to deform. It is this property that allows SCC to easily pass through complex formworks around dense reinforcement, into areas difficult to reach without the need for mechanical vibration. Within that respect, fresh concrete has to be flowable enough to ensure proper compaction and filling, one of the most valued advantages of SCC over conventional concrete.

The major challenge in SCC mix design actually lies in how to strike a balance between these two apparently opposite requirements, since for the concretes to possess the properties of selfcompaction, the viscosity has to be low enough to achieve high flowability on one hand, while on the other hand, it needs to be high enough to provide the resistance to segregation that prevents the uniformity of the mix from being lost. In fact, many call it the fragile balance, representing the art and science of SCC mix proportioning.

Ultimately, the successful design of SCC is a very complicated process that requires care in the consideration of flow behavior and mix stability. Of these factors, viscosity has become one of the core components. A properly designed mixture of SCC would assure not only ease in placement and compaction but concrete that is uniform and strong after hardening.

Objectives targeted

This thesis is multifunctional in studying the effects of a VMA-based additive on SCC performance both at fresh and hardened states. The main rheological properties focused on include flow time, slump flow, and segregation resistance, which are manipulated by a number of different volumes of VMA, while the compressive strength of the hardened concrete was measured. In this paper, the column of segregation test will be used to quantify static segregation in SCC mixtures as a means to understand the stability and distribution of coarse aggregate within the concrete matrix. All these will eventually be used to develop an optimum overall stability, minimum segregation, and strength of SCC with VMA inclusion.

Working methodology

In order to meet the objectives, this thesis is structured in four chapters:

Chapter I: This chapter is dedicated to a bibliographic synthesis of knowledge relating to self-compacting concrete and the phenomenon of static segregation, providing some research and experiments throughout the years.

Chapter II: We will review the experiments and research conducted over the years to investigate the impact of the viscosity-modifying agent on self-compacting concrete and the phenomenon of segregation in this bibliographic chapter.

Chapter III: highlights the main characteristics of the materials used, as well as an explanation of the approved experimental procedure, including the formulations of the concretes tested and a description of the different experiments carried out during this work.

Chapter IV: deals with the analysis and interpretation of the different results obtained, it contains four parts:

1. Analyze and discuss the effect of the viscosity modifying agent on the workability of self-compacted concrete.
2. The effect of viscosity modifying agent on stability of self-compacted concrete mixtures shall be discussed, that is, the static segregation.
3. Discussion and analyzes the impact of viscosity modifying agent on properties of hardened concrete, like compressive and tensile strength.
4. Analyze and discuss the effect that superplasticizer has on the workability, static segregation, and hardened properties of the self-compacting concrete.

All this is finally closed by a general conclusion bringing together the general synthesis of all the results obtained, followed by some perspectives.

Chapter I: Bibliographic synthesis on self-compacting concrete and the segregation resistance

I.1. Introduction

In self-compacting concrete (SCC), segregation resistance is the fundamental characteristic that ensures homogeneity in the mixture, facilitating equal distribution of particles throughout transit, placement, or while the concrete is stable. A balance between fluidity and stability is essential for ensuring quality and strength in SCC construction applications. Segregation is a phenomenon in which coarse aggregates separate from the cement paste, either due to variances in density or insufficient cohesion within the mixture. Numerous parameters, including as VMA, aggregate grade, and the rheological qualities of cement paste, must be meticulously regulated to avoid issues. It clarifies, among other aspects, the processes of resistance to segregation, how various admixtures may increase stability, and the techniques for assessing segregation behavior, so offering an overview of the development of SCC performance.

I.2. Definition of SCC:

Self-Compacting Concrete (SCC) is a specialized concrete that delivers superior performance regarding flow characteristics, strength, and durability, aligned with the Lifetime demands of certain loads and environmental circumstances. SCC is a fluid concrete that effortlessly traverses dense reinforcements, sufficiently fills the formwork, and consolidates under its own weight without requiring vibration or compaction techniques. SCC exhibits superior filling and flow capabilities and shows commendable resistance to segregation.

I.3. History of SCC

SCC are concretes capable of settling under the influence of gravity, eliminating the necessity for vibration, even within substantially reinforced formwork. The concept of these concretes was introduced in the mid-1980s by researchers at the University of Tokyo and was thereafter rapidly embraced by prominent Japanese industrial corporations.

The notable increase in this form of concrete is warranted by two techno-commercial advantages:

- Ease of installation: reduction in construction time, reduction in personnel thus lowering labor costs; as well as the possibility of using formwork with complex shapes and high reinforcement density.
- Improvement of concrete quality: (strength and durability), which is independent of the workers' skills.

The Japanese academics and manufacturers delayed the publication of their results until the practicality of self-compacting concrete had been verified. Numerous research and development teams committed to this effort, and comprehensive executions validated the efforts performed in Japan for over a decade.

Since its start in Japan, self-compacting concrete has progressively been adopted across Europe and appears ready to replace traditional vibrated concrete in numerous applications.

For instance, we shall highlight several Japanese achievements:

Probably the most famous SCC project is **the Burj Khalifa in Dubai**, currently the tallest building in the world. The complex geometry and densely reinforced sections of the Burj Khalifa necessitated a concrete that would flow readily to fill all voids without segregation.

The self-compacting ability of SCC reduced the need for mechanical vibration, which was critical in such a tall and intricate structure. Apart from improving the construction speed and efficiency, SCC helped in enhancing structural integrity with the help of ensuring uniformity and thereby reducing labor costs on this site. In one of the long suspension bridges around the world in Japan, that is, **the Akashi Kaikyō Bridge**, SCC is used for huge piers as well as anchorages. High and complicated structures of the bridge needed concrete for support, including good flowability and consolidation under its self-weight to be compacted suitably with durability in a harsh marine environment. Workability and stability of SCC ensured these results, having an impressive structure with fewer voids and good resistance against environmental factors, for example, saltwater exposure (Tanaka, 1993).

Another landmark project in which SCC was applied is **the Channel Tunnel, Eurotunnel, joining the UK and France.** In these curved, confined spaces of the tunnel, it was required that the concrete be highly flowable, to fill all voids without the need for mechanical vibration. The high workability and stability of SCC were crucial for the attainment of the long service life of this tunnel structure under hostile marine conditions. SCC improved construction efficiency in confined spaces, enhanced durability, and reduced labor and equipment costs. In Singapore, **the Marina Bay Sands** integrated resort-with its iconic sky park and hotel-also utilized SCC for its very complex structural elements. Given the project's intricate architectural design and highly reinforced sections, the concrete had to be one that could flow easily, gaining complete access and filling all air voids without segregation. SCC was able to be self-compacting, hence allowing proper compaction in areas difficult to reach, improving the speed of construction, enhancing structural integrity, and decreasing labor costs.

The **Millau Viaduct** in France, the tallest bridge in the world, is another example of SCC's application in large-scale projects. The bridge's tall piers and complex geometry required a concrete that could flow easily and fill all voids without segregation. SCC's ability to self-compact reduced the need for mechanical vibration, which was critical in such a tall and complex structure. The use of SCC ensured high-quality concrete with minimal voids, improved construction speed, and enhanced durability against environmental factors like wind and temperature variations. Similarly, **One World Trade Center** in New York, the tallest building in the Western Hemisphere, utilized SCC for its high-strength concrete core and other structural elements. The building's complex geometry and densely reinforced sections required a concrete that could flow easily and fill all voids without segregation. SCC's ability to self-compact reduced the need for mechanical vibration, improving construction speed, structural integrity, and labor efficiency.

The **Gotthard Base Tunnel** in Switzerland, the longest railway tunnel in the world, also relied on SCC for its tunnel lining and critical structural elements. The tunnel's curved and confined spaces required a concrete that could flow easily and fill all voids without the need for mechanical vibration. SCC's high workability and stability were essential for ensuring the long-term durability of the tunnel in a harsh underground environment. The use of SCC improved construction efficiency, enhanced durability, and reduced labor and equipment costs. In China, the **Hong Kong-Zhuhai-Macau Bridge**, the longest sea-crossing bridge in the world, utilized SCC for its massive concrete piers and deck. The bridge's complex geometry and densely reinforced sections required a concrete that could flow easily and fill all voids without segregation. SCC's ability to self-compact reduced the need for mechanical vibration, ensuring high-quality concrete with minimal voids, improved construction speed, and enhanced durability against saltwater exposure.

In the UK, the **Shard London Bridge**, the tallest building in the country, also employed SCC for its high-strength concrete core and other structural elements. The building's complex geometry and densely reinforced sections required a concrete that could flow easily and fill all voids without segregation. SCC's ability to self-compact reduced the need for mechanical vibration, improving construction speed, structural integrity, and labor efficiency. Similarly, the **Tokyo Skytree** in Japan, the tallest tower in the country, utilized SCC for its high-strength concrete core and other structural elements. The tower's complex geometry and densely reinforced sections required a concrete that could flow easily and fill all voids without segregation. SCC's ability to self-compact reduced the need for mechanical vibration, ensuring high-quality concrete with minimal voids, improved construction speed, and enhanced durability against environmental factors like wind and seismic activity.

I.4. Conditions for SCC

For concrete to self-compact, it needs to be stable, able to flow, and able to fill completely. Because SCC is a thick, uneven liquid concrete, it is hard to keep its parts from adhering together. It is common for parts with more mass to settle, which is also known as constituent sorting. Adding the right quantity of fine materials and superplasticizers (SP) can help with this problem. Adding superplasticizers to a mixture lowers the amount of water it needs, which makes very flexible concrete with very little water (EFNARC, Specification and Guidelines for Self-Compacting Concrete, 2022). Still, the main problem with making SCC is balancing properties that seem to be at opposition with each other, like flexibility and segregation resistance (Assié, 2004). A great deal of study has been done to find the exact specifications for raw materials, mix proportions, material qualities, and testing methods that are needed to make and evaluate SCC (Ouchi M. , 2000) (Khayat K. , 1999). The main goal of this study is to make an effective SCC formulation and predict its mechanical properties.

I.5. Constituents of Self-Compacting Concrete (SCC)

The chemicals that go into SCC are the same ones that go into regular concrete. The main things that affect the choice of materials are their availability and the type of building that needs to be done. In order to make sure that SCC performance stays the same, it is important to take extra steps when choosing materials and check their characteristics on a regular basis (Dhir R.K., 1994) (Hameed, 2005).

I.5.1. Cement

Fine powders called cement are made by grinding a mixture of minerals (usually limestone and clay) at high temperatures (around 1450°C). The name "hydraulic binders" comes from the fact that these powders are made up of unstable, dry mineral salts that mix with water to make a paste that sets and gradually hardens.
The primary needs of the concrete, such as its strength and durability, determine the type of cement that is used.
Ordinary Portland cement is the main ingredient used to make majority of types of concrete. It is also an important part of SCC. This substance can be used by itself or with other substances. Portland cement makes self-compacting concrete more flowing when mixed with water to make the particles more flexible (Okamura H., 1995).

I.5.2. Mineral Additions

Mineral fillers are small pieces of materials that make hardened concrete better in some way. The way they physically and chemically change the density and microstructure of materials makes concrete much better and lasts longer (P. Mehta Kumar, 2006) (C. Selvamony, 2010). They can be added to cement or used in place of some of it, depending on the desired properties and effects on the concrete (Neville A.M., 2010) (R. Ilangovana, 2008).

Mineral additions can be either native or man-made. Limestone fillers, natural pozzolana, calcined clay, and shales are all native types. Reactive additives are often made from industrial wastes like silica fume, fly ash, and powdered granulated blast furnace slag. Also, chemicals made in factories include metakaolin, which is very reactive. Most of the time, synthetic chemicals and limestone fillers are used in self-compacting concrete (SCC) (C.F. Ferraris, 2001) (L. Agulló, 1999) (A. Elahi, 2010). Some ingredients make concrete better in both its fresh and hardened forms without the need for viscosity agents, which are water keepers (P. Dinakar, 2008) (Samimi, 2016). The particle size distribution and water absorption of mineral additives directly influence the water requirements in the manufacturing of self-compacting concrete (SCC). Limestone fillers are extensively utilized and provide superior characteristics and an outstanding surface finish (Şahmaran M., 2006) (M. Uysal, 2012).

Fillers probably make SCC thicker and improve its mechanical properties (Felekoğlu, 2008). They also make it need more water and superplasticizers because they are finer and can absorb more (P. Nanthagopalan, 2011) (A. Rmili, 2009). Depending on the fines' properties, fillers can either improve or worsen the performance of regular concrete and self-compacting concrete (SCC) (Felekoğlu, 2008) (I.B. Topçu, 2003). They make compression and bending strength a lot better (C.F. Ferraris, 2001) (Domone, 2006) (A. Georgiadis, 2007) (W. Zhu, 2005).

Self-consolidating concrete (SCC) can be made better and last longer by adding high-quality fly ash (Şahmaran M., 2006) (L.A.P. de Oliveira, 2006). Fly ash makes things stick together better and less sensitive to changes in water content (Şahmaran M., 2006) (Khatib, 2008) (N. Bouzoubaâ, 2001).

Because it is very small and shaped like a ball, silica fume makes segregation resistance and mechanical properties better (Domone, 2006) (L.A.P. de Oliveira, 2006) (Yazici, 2008). It lowers the heat of hydration and improves the rheological properties of ground powdered blast furnace slag (Samimi, 2016) (Diederich, 2010).

I.5.3. Coarse Aggregates (Gravel)

As with any concrete mix, coarse materials are an important part of making self-compacting concrete (SCC). SCC can be made from natural, rounded, semi-broken, or crushed aggregates (EFNARC, 2002) (European, 2005) (Khaleel O.R., 2011). Aggregates have a big impact on the properties of SCC, such as its ability to flow, fight segregation, be strong, and last a long time (Assaad, 2017). For both new and hardened concrete to work properly, the qualities of the aggregates must be taken into account (Khaleel O.R., 2011).

How the concrete works and how long it lasts are affected by things like the size, shape, texture, and porosity of the coarse aggregates. The largest size that SCC can be can be 20 or 25 mm. But a smaller size (8 to 16 mm) is better for getting high strength and keeping fresh SCC from separating (EFNARC, 2002) (European, 2005) (Petersson, 1997).

For the best flexibility of SCC, spherical aggregates are better than angular (crushed) aggregates because they lower the plastic viscosity of SCC by reducing friction between its particles (EFNARC, 2002) (Geiker M., 2002). Angular or crushed pebbles, on the other hand, make the concrete stronger and better adhere to the cement paste because their particles are rough (Taylor M.R., 1996) (Bonen D., 2005).

I.5.4. Fine Aggregates (Sands)

Sand is the most common type of fine material used in concrete. During the composite step of SCC, it is the second part. Over 40% of the paste volume is made up of sand, which makes up a big part of SCC (Okamura H. O. K., 2000) (Okamura H. O. M., 2003) (Bonen D., 2005). Sand, like coarse materials, can change how well self-compacting concrete (SCC) works. It improves the flow capacity and segregation resistance of new concrete when used in the right amounts (Okamura H O. K., 1995) (Su N., 2001). This method makes sure that the coarse aggregates are spread out evenly during flow by lowering the friction between the grains. This makes the hardened concrete more compact, which affects its mechanical properties and durability (Xie Y., 2002).

I.5.5. Superplasticizers

Synthetic polymers made just for the concrete business are called superplasticizers. Sodium or calcium salts of poly naphthalene sulfonate and sodium salts of poly melamine sulfonate are the ones that are used most often. Superplasticizers are very good at reducing water. The main thing they do is make the concrete easier to work with. It is possible to use them as water reducers, though, to lower the W/C ratio and raise the compression strength of concrete, which has all the benefits that come with that.
The best next-generation superplasticizers for making self-compacting concrete (SCC) come from polycarboxylate ether (PCE) (Shetty, 2009) (Felekoğlu B., 2008). There are no later side effects for this group. It makes it easier to work with, lowers the water-to-binder ratio significantly, and raises the power from the first day (Şahmaran M., 2006) (Benaicha M., 2019) (Sonebi M. , 2004). This most likely has to do with the fact that a thicker microstructure forms when the cement particles are spread out enough (Ozyildirim C., 2003) (Felekoğlu, 2008). It makes things last longer and lessens leakiness by lowering the water-to-cement ratio and encouraging a firmer structure (Assié, 2004) (M. Nehdi, 2004) (Kanellopoulos A., 2012).

I.5.6. Viscosity Modifying Agent

Viscosity-modifying admixtures are new additives that are widely used in building with concrete. It makes cement-based systems in new concrete more adhesive and thicker by slowing down the rate at which material elements segregate (EFNARC, 2006). Most viscosity modifying agents (VMAs) come from biopolymers, which are made up of biological materials like polysaccharides, cellulose ethers, starch ethers, and natural gums. The VMAs dissolve in water, which makes the paste thicker and/or lowers its yield point (Khayat KH Y. A., 1997). Some VMAs use artificial substances like colloidal silica, which is granular and made up of very small particles that don't dissolve or spread out and stay in suspension in water without settling (EFNARC, 2006).

A superplasticizer (SP) and a viscosity-modifying agent (VMA) can be used to change how easy it is to work with concrete. Viscosity-modifying agents (VMAs) are used to keep the rheological properties and consistency of concrete stable, while superplasticizers (SPs) make the concrete easier to move. The main thing to think about is that VMAs, which are usually used with SP, shouldn't change the mixtures' qualities in any way other than making them thicker (Umar, 2011).

I.5.7. Mixing Water

Water is the most important part of SCC. For cement to harden, it needs to be mixed with water. Enough water is needed for the cement to harden, and when mixed with the superplasticizer, it makes SCC easier to work with by making the matrix less rigid (Okamura H O. K., 1995).
The water used to mix concrete must be clean and free of chemicals that are bad for you. Water that is tainted with harmful substances like silt, floating particles, organic matter, oil, or sugar can make cement less strong and less probable to cure (Neville A.M., 2010).
Chemical safety must be checked on the water used for SCC. This water must have a pH between 6.0 and 8.0 (Neville A.M., 2010) (Shetty, 2009) (AFNOR, 2003). It shouldn't have a lot of dissolved solids, chlorides, alkalis, carbonates, bicarbonates, sulfates, or other salts that could make the concrete less effective. Most of the time, water that has chloride ions, SO3 ions, and dissolved solids levels below 500, 1000, and 2000 mg/L is fine for making concrete (Neville A.M., 2010) (AFNOR, 2003). Because of this, the water must be checked to make sure it is safe to use.

I.6. Workability of SCC

Either rheological factors or how easy something is to place are used to describe how useful it is. Different types of tests show that it has to do with being able to fill, pass, and stay stable.

What makes a concrete mix filling-able is how well it can spread out and fill in shapes when it's put on its own. For concrete to pass, it needs to be able to move around things like rebar and other tight spots without sticking or leaving air holes. For the purposes of this description, stable concrete can keep its parts evenly spread out and not separate or bleed (water separating from the paste).

I.7. The segregation resistance

Resistance to segregation in concrete means that the concrete can keep its regular mix while it is being transported, while it is being put down, and after it has been put down. Static and dynamic stability are both parts of it: It is called "static stability" when the design of the concrete doesn't separate when it's at rest, and "dynamic stability" when it doesn't separate when it's being mixed and poured. Like filling and passing abilities, segregation resistance can be very different based on what SCC is going to be used for. On the other hand, costs usually go up when there is more pushback to segregation (Bui, 2002).

To make sure it is ready for production, SCC mixes should be able to show that they can pass through narrow spacing reinforcing bars and not separate. From the point of view of functional production, it is usually enough to just check for filling ability. Usually, the client's specifications or the contract documents set out the workability qualities that are needed on a particular location.

Concretes are made of different types of materials, and the best performance comes from how the different materials are spread out, especially the large grains. Because it flows so easily, SCC is more like a liquid than regular concrete. At this level of flexibility, the concrete particles can move around freely, which is possible because there is enough free water in the mix. The amount of water in cement paste, on the other hand, directly affects its viscosity and rigidity. When there is more water, viscosity and density also go down. Bartos (1992) says that the effect is like adding water to a thick paste to make it less thick. Settlement happens when the solid particles are bigger than the liquid around them. Increased water content decreases the paste viscosity and density. If the density of the paste becomes less than that of the aggregates, the paste can no longer support them and they settle down leaving the mix behind, in common language it is called segregation (Dirk Lowke, 2003).

In SCC, segregation resistance is typically improved by augmenting the quantity of inert powder in the mixture rather than solely raising the cement content. These particles function to thicken the paste, so augmenting its viscosity and density. A thicker paste improves the suspension of aggregate particles in the mortar, hence increasing segregation resistance. The mineral powders enhance the flowability of the concrete, as previously mentioned in this chapter.

In addition to the incorporation of particles, chemical viscosity-modifying agents may also be added to the mixture. This study includes compounds that interact with water, resulting in an increase in water viscosity, referred to as thickeners or stabilizers (Ozawa K., 1990). SCC combinations exhibit less sensitivity to minor variations in water content, hence ensuring consistent batch-to-batch repeatability that is often challenging to achieve with powder-based mixtures.

I.8. Experimental Insights into Segregation Resistance in Self-Compacting Concrete: A Comprehensive Literature Review

Over the years, several experimental research have been conducted to comprehend and enhance the segregation resistance of SCC. Multiple parameters influencing stability have been examined: aggregate grading, cement paste viscosity, and the incorporation of viscosity-modifying chemicals. The methodologies for segregation testing have evolved progressively, including static segregation tests that more accurately assess the behavior of SCC under various settings.

The emphasis is on a comprehensive analysis of experimental studies regarding the segregation resistance of self-compacting concrete (SCC), including critical variables, testing methodologies, and advancements aimed at enhancing the homogeneity and overall performance of SCC mixtures.

I.8.1. U test (Okamura et al., 1993) and Box test (Ouchi, 1998; Pelova et al., 1998)

Various methods and instruments have been created to assess the fresh properties of SCC. Notable tests from the early stages of SCC development include the U-test, illustrated in Fig.I.1, proposed by Okamura et al. in 1993, and its modified variant, commonly referred to as the box-test, depicted in Fig.I.2, which was independently created by Ouchi in 1998 and Pelova and al. in 1998 (Okamura H M. K., 1993) (Hajime Okamura M. O., 2003) (Ouchi M. , 1998) (Pelova GI, 1998).

In these tests, concrete transfers from one compartment to another via a gate reinforced with three bars. The ultimate height of the concrete in the second compartment at the conclusion of the flow is termed fill height, with a height exceeding 300 mm being appropriate for SCC. For a comprehensive evaluation.

The tests examined the flow of concrete from a left compartment via an aperture formed by three reinforcement bars into a right compartment. The fill height of the concrete at the end of flowing is considered sufficient for SCC when reaching 300 mm.

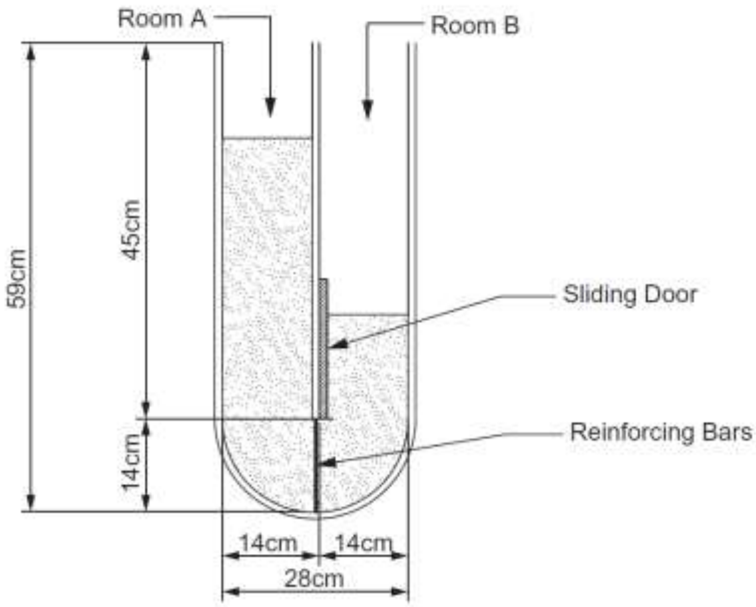


Fig.I.1. U test (Okamura H M. K., 1993)

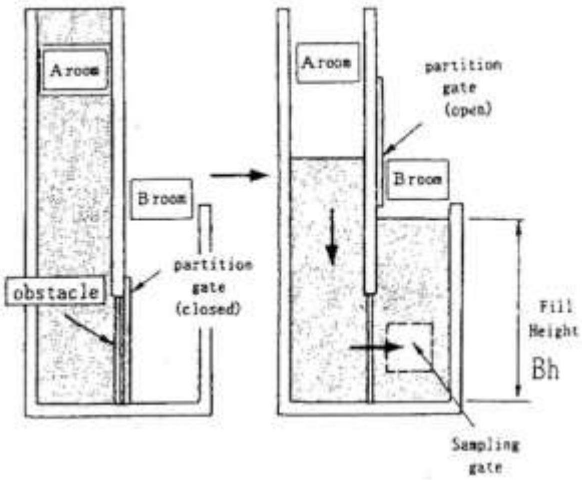


Fig.I.2. Box test (Ouchi M. , 1998) (Pelova GI, 1998)

I.8.2. Vertical mesh test (Ozawa et al., 1992a) and Fill box test (Pelova et al., 1998; Takada et al., 1999)

Alternative testing methodologies, such the horizontal mesh test (Fig. I.3) introduced by Ozawa et al. (1992a) and the fill box test (Fig. I.4) documented by Pelova et al. (1998) and Takada et al. (1999), have been established concerning deformability and segregation resistance. The tests required the pouring of concrete into formwork that included reinforcement meshes or bars, whereas the vertical mesh test includes bars at the base and several horizontal bars in the fill box test. The performance of SCC can be assessed by the volume that traverses the meshes during the vertical mesh test or by the height variations seen in the fill box test (Ozawa K, 1992a) (Pelova GI, 1998) (Takada K, 1999). The SCC height at both ends must be measured to determine the filling % using the next equation:

$$\text{Filling percentage} = \frac{(h1+h2)}{2*h1} * 100\% \qquad \text{(Eqn.I.1)}$$

where; h1 is the higher SCC height, h2 is the SCC height on the other side as shown in Fig.I.4.

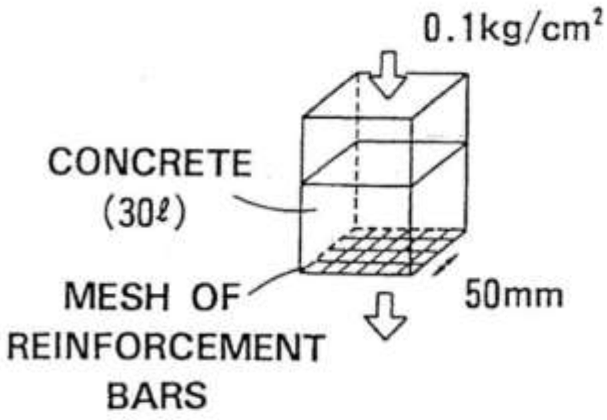


Fig.I.3. Vertical mesh test (Ozawa K, 1992a)

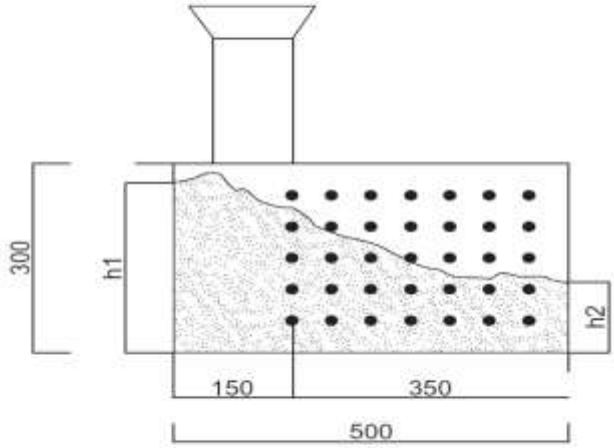


Fig.I.4. Fill box test (Pelova GI, 1998) (Takada K, 1999)

I.8.3. Penetration test

The static segregation was measured by the penetration depth of a cylinder, as illustrated in Fig. I.5; by Bui et al., 2002b, 45 seconds post-immersion in a concrete sample within the vertical limb of an L-box. No vertical segregation occurs when the penetration depth is less than 8 mm.

The device depicted in Fig.I.5 was utilized in the Testing-SCC project; however, in this instance, the penetration test was conducted on concrete contained in a bucket that had remained stationary for 2 minutes. The risk of segregation increases with more penetration. The segregation index derived from the sieve stability test shown a strong association with penetration depth (Bui VK, 2002b).

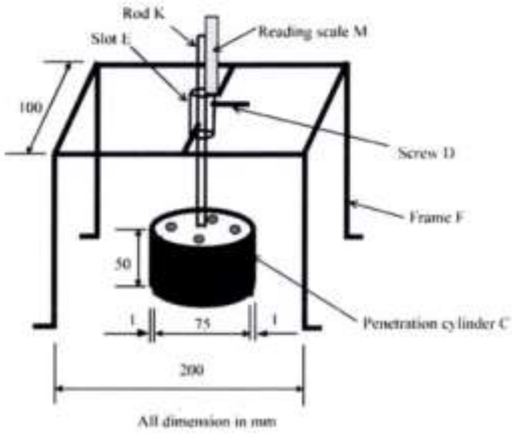


Fig.I.5. Penetration test by (Bui VK, 2002b)

I.8.4. Segregation Probe Test

The segregation probe, derived from the Penetration Apparatus method, serves as a rapid and efficient technique for assessing the thickness of the mortar or paste layer on the surface of fresh SCC. A thicker coating of mortar or paste is associated with reduced static stability. The test results obtained using the segregation probe technique and the thickness of the mortar or paste layer in cured concrete are notably comparable. The segregation probe consists of a ring with a diameter of 125 mm, affixed to a rod that is 150 mm in height, which features a marked scale, as illustrated in Fig. I.6. The entire probe is constructed from 1.6 mm diameter steel wire and weighs roughly 18 g.

Fresh concrete is poured into a 150 x 300 mm cylinder in a single lift and permitted to rest undisturbed for 2 minutes prior to testing. The segregation probe is meticulously positioned on the concrete surface and permitted to rest for one minute. The rod's penetration depth measurement is subsequently utilized to ascertain the stability rating, as outlined in Table I.1 (Shen L, 2005) .

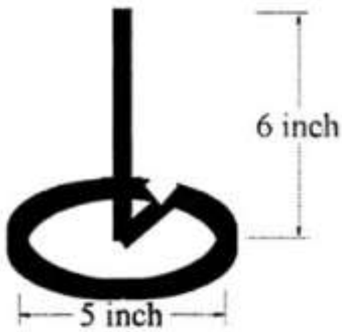


Fig.I.6. Segregation probe by (Shen L, 2005)

Table I.1: Stability Rating for Segregation Probe Method

Penetration Depth (mm)	**Rating**	**Corresponding Rating in HVSI of cut Cylinder**
< 4	0 Stable	0 Stable
4 ~ < 7	1 Stable	1 Stable
7 ~ 25	2 Unstable	2 Unstable
> 25	3 Unstable	3 Unstable

I.8.5. L-box Test

The L-box test is derived from a Japanese design for underwater concrete (EFNARC, 2002). The evaluation assesses the practicality of the concrete and the degree to which it is affected by reinforcement. The equipment comprises a 'L'-shaped rectangular section box, including vertical and horizontal segments divided by a movable gate, in front of which vertical lengths of reinforcement bars are secured. The SCC is situated in the vertical part, and the gate is elevated to permit the concrete to flow into the horizontal area. Upon cessation of flow, the elevations of the concrete are assessed at the terminus of the horizontal section and within the vertical segment. The L-Box result is the ratio of the height of concrete in the horizontal portion to the height remaining in the vertical part. ACI Committee 237 established a minimum height ratio of 0.8, with a ratio nearing 1.0 indicating improved flow characteristics of the SCC mixture. Figure 1.7 illustrates the L-Box testing apparatus (EN12350-10, 2007).

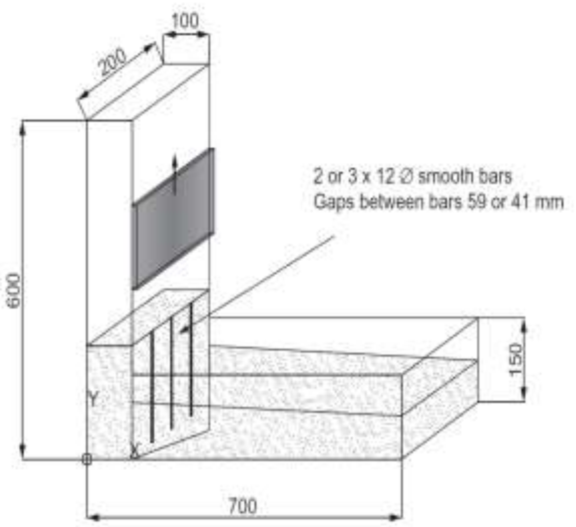


Fig.I.7. L-Box testing apparatus

I.8.6. Wet sieving stability test (GTM screen stability test)

The wet sieving stability (GTM screen stability) test is a method for determining the segregation resistance of SCC. This testing method was developed by a French contractor (EFNARC, 2002) (Bartos, 2002).

A bucket, a container, a sieve and a pan, balance and a stopwatch are required for this test. 10L SCC should be poured into a bucket and leave undistributed for a period of 15min to allow segregation occurs in SCC. It is important to seal the container to avoid any evaporation in the SCC. Then, 2L of the top SCC from the bucket will be transferred to a smaller size container and then poured onto a 5mm sieve from 500mm height. Leave the SCC to flow through the sieve and the pan freely for 2min. The mass of SCC remained on the sieve (Ma) and the mass of SCC passed the sieve and collected in the pan (Mb) should be measured by using the balance. The segregation resistance of SCC using the wet sieving stability is measured from the following equation:

$$\text{Segregation Ratio} = \frac{\text{Mb}}{\text{Ma}} * 100\% \qquad \text{(Eqn.I.2)}$$

Wet sieving stability test result analysis is summarized in Table I.2.

Table I.2: Wet sieving stability test result analysis

Segregation ratio	Segregation resistance
>30%	Severe
15–30%	High
5–15%	Acceptable
<5%	SCC is too harsh and will result in a poor surface finish

I.8.7. Slump Flow Test (ASTM C 1611)

The slump flow test is the predominant method for assessing the filling capacity and flowability of self-consolidating concrete (SCC) (ASTM1611, 2005). It was initially developed in Japan to assess fresh concrete mixtures for underwater application. The testing methodology is predicated on the traditional slump test. The diameter of an SCC "spread" is quantified. This spread is created from self-consolidating concrete (SCC) running freely from an inverted slump cone onto a flat surface. The typical slump flow range reported by ACI Committee 237 for SCC is 450 to 760 mm (ACI, 2007). A larger slump flow value indicates an enhanced capacity to fill formwork or molds, as well as an increased distance that self-consolidating concrete (SCC) may travel from the discharge point under its own weight. An illustration of a slump flow test is presented in Fig. I.8.

Fig.I.8. Slump flow test

I.8.8. Visual Stability Index (ASTM C 1611)

The Visual Stability Index (VSI) is a technique for assessing the segregation stability of a mixture and evaluating the relative stability of several batches of the same self-consolidating concrete (SCC) mixture. The VSI is assessed by visually evaluating the apparent stability of the slump flow spread according to particular visual characteristics of the spread. The SCC combination is deemed stable and appropriate for its intended application when the VSI rating is 0 or 1, while a VSI rating of 2 or 3 suggests a potential for segregation. Assigning a Visual Stability Index (VSI) value to the concrete spread based on the parameters illustrated in Fig. I.8 (ASTM1611, 2005) (ACI, 2007).

Table I.3: Visual Stability Index Criteria (ASTM1611, 2005)

Rating	Criteria
0	No evidence of segregation in slump flow spread or in the wheelbarrow.
1	No mortar halo or aggregate pile in the slump flow spread but some slight bleed or air popping on the surface of the concrete in the wheelbarrow.
2	A slight mortar halo (<3/8 inch) and/or aggregate pile in the slump flow spread and highly noticeable bleeding in the wheelbarrow.
3	Clearly segregating by evidence of a large mortar halo (>3/8 inch) and/or large aggregate pile in the center of the concrete patty and a thick layer or paste on the surface of the resting concrete in the wheelbarrow.

I.8.9. T500 (ASTM C 1611)

The T500 value is a novel metric for assessing the flow characteristics of SCC and offers a comparative index of viscosity. The assessment evaluates the duration required for the slump flow to attain a diameter of 500 mm. An extended T500 duration signifies a more viscous combination, whereas a reduced T500 duration implies a less viscous mixture (ACI, 2007) (ACI, 2007). The ACI Committee 237 indicates that a self-consolidating concrete (SCC) mixture is classified as lower viscosity when the T500 duration is 2 seconds or less, and as higher viscosity when the T500 time exceeds 5 seconds.

I.8.10. J-ring (ASTM C 1621)

The test assesses the capacity of SCC to flow through reinforcing steel and obstructions. A sample of fresh self-compacting concrete is positioned in a typical slump cone equipped with a J-ring containing steel bars. The mold is elevated, the SCC traverses the J-ring, and the diameter of the J-ring spread is assessed (EN12350-12, 2007) (ASTM1621, 2008). A higher J-ring slump flow value indicates an increased capacity of self-consolidating concrete (SCC) to fill a steel-reinforced form or mold, as well as an enhanced ability to flow through reinforcing bars from the discharge point under its own weight (ACI, 2007). The disparity between unconfined slump flow and J-ring slump flow is utilized to ascertain the degree of restriction of self-consolidating concrete (SCC) in traversing reinforcing bars. The capacity of the mixtures to pass and their inclination to block can be determined in accordance with the ASTM C1621 standard classification presented in Table I.4. Figure I.9 illustrates an example of a J-Ring test (ASTM1621, 2008).

Table I.4: Blocking assessment using J-ring

Difference Between Slump Flow and J-Ring Flow	Blocking Assessment
0–25mm	No visible blocking
25–50mm	Minimal to noticeable blocking
>50mm	Noticeable to extreme blocking

Fig.I.9. J-Ring test

I.8.11. Settlement column test (Ye et al., 2005)

The settling column segregation test established by Ye et al. (2005) involved positioning concrete in three cylindrical sections, each measuring 200 mm in height and 100 mm in diameter, and allowing it to rest for 20 minutes. Subsequently, concrete from the upper and lower sections was wet-sieved, oven-dried, and the degree of segregation was calculated as the percentage of weight discrepancy between the two sections relative to the average weight of oven-dried coarse aggregate retained on the sieve, Approach 1. A significant proportion indicated that the coarse aggregate content in the upper area was about equal to that in the lower section, signifying the absence of segregation. A minimal percentage indicated that segregation had occurred (Ye Y, 2005).

A version of the column segregation test, pertinent to SCC in its hardened form, involves the visual inspection, enumeration, or analysis of aggregate distribution at various levels within a cut cylinder, hence providing insight into segregation. A higher concentration of coarse aggregate at the base increases the probability of segregation.

Alternative forms of the column segregation test, incorporating vibration during the procedure, might be referenced in (Xie Y, 2005).

I.8.12. Column Segregation (ASTM C 1610)

The ASTM C1610 test method outlines a protocol for assessing static segregation in self-consolidating concrete (SCC) by quantifying coarse aggregate content in the upper and lower regions of a cylindrical specimen. As per ASTM C1610 (ASTM1610, 2007), the SCC mixture is poured into a cylinder as seen in Fig. I.10 and remains undisturbed for 15 minutes. The SCC is extracted from the upper portion of the column into a container, the middle section is discarded, and the lower section is put into another container. The SCC from both the upper and lower sections is passed through a No. 4 sieve to isolate the coarse aggregate only. The aggregate is desiccated to a uniform mass. Column segregation is quantified as the percentage ratio of the difference in aggregate mass between the top and bottom segments to the total aggregate mass of both segments. This is represented by the following equation:

$$S = 2 * \frac{CAB - CAT}{CAB + CAT} * 100; \quad \text{if } CA_B > CA_T \qquad \text{(Eqn.I.3)}$$

$$S = 0; \quad \text{if } CA_B \leq CA_T \qquad \text{(Eqn.I.4)}$$

Where:

CA_B = mass of coarse aggregate from the bottom section;

CA_T = mass from the top section.

Fig.I.10. Column segregation test

I.8.13. Static segregation column by Hassan El-Chabib and Moncef Nehdi

This work introduced a comparable penetration instrument to assess the segregation potential of various SCC combinations. The equipment utilized in the investigation comprises a modified penetration device as proposed by Bui et al. (2002) and a PVC tube with a diameter of 150 mm and a height of 300 mm. The tube is partitioned into three equal segments of 150 mm × 100 mm, utilizing leak-proof connections that are affixed to a vertical steel rod for effortless sliding. The revised penetration apparatus comprises four penetration heads, as opposed to one, affixed to a steel framework. Each penetration head has a mass of approximately 25 grams and a diameter of 20 millimeters, including a semi-spherical end (Fig.I.11) (Hassan El-Chabib, 2006).

The average depth of the penetration heads is determined by permitting the heads to penetrate into the concrete under their own weight immediately after the cylinder is filled. The three components of the cylinder are subsequently separated during a resting interval of roughly 30 minutes, and the concrete within each component is filtered through a 9.5 mm sieve. Coarse aggregates with particle sizes exceeding 9.5 mm in each section of the cylinder are subsequently collected, and their masses are measured. The segregation index (SI) is defined as the coefficient of variation (COV) of the coarse aggregate content over all three sections and is computed using the subsequent equation:

$$S=\frac{1}{3}\sum_{1}^{3}\left|\frac{Mi-Mavg}{Mavg}\right|*100 \qquad \text{(Eqn.I.5)}$$

Where:

$M_{avg}=\frac{1}{3}\sum_{1}^{3}Mi$

M_i equals the mass of coarse aggregate

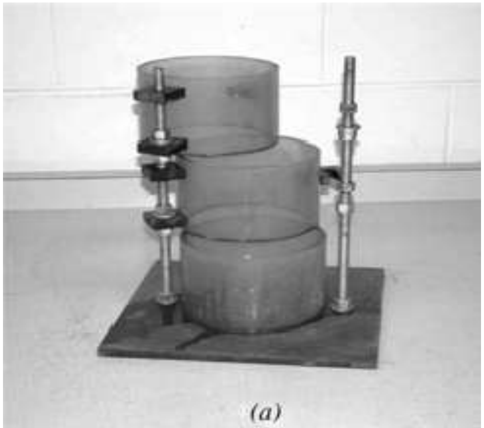


Fig.I.11. Static segregation column by Hassan El-Chabib and Moncef Nehdi

I.8.14. Column segregation test (2004)

Joseph Assaad, Kamal H. Khayat, and Joseph Daczko examine the static stability of SCC by evaluating various SCC testing methods in terms of their efficacy in assessing segregation and surface settlement during the plastic state. It is essential that SCC retains stability, avoiding segregation or settling, to preserve the uniformity and integrity of the cured concrete (Joseph Assaad, 2004).

The column segregation test was specifically designed for this study: SCC was poured into a column measuring 660 mm in height and 200 mm in diameter, divided into four parts of 165 mm each. Leak-proof couplings were engineered for the column to facilitate the separation of sections. The concrete underwent consolidation five times using a 20-mm-diameter rodding bar and was thereafter let to rest for 15 minutes before the test. After the extraction of concrete from each area, the weight was recorded, and mortar was passed through a 5 mm screen to isolate the coarse aggregate, which was subsequently dried to a nearly surface-saturated dry state. To achieve this, the coefficient of variation (COV) of the coarse aggregate distribution throughout the column was calculated, which will yield the I_{seg} required for practical applications, particularly in assessing the uniformity of self-consolidating concrete (SCC) (Joseph Assaad, 2004).

I.8.15. Settlement column (Schutter et al., 2001; Rooney, 2001)

In the late 1990s, Poppe and Schutter at the Magnel Centre of the University of Ghent, Belgium, and Rooney at the ACM Centre of the University of Paisley, Scotland, independently devised the settle column test (Rooney, 2001)(Schutter et al., 2001). The sieve segregation test just assesses static segregation, whereas the settling column test evaluates both static and dynamic segregation resistance of SCC.

A settlement column with internal dimensions of 500 x 150 x 100 mm and three hinged doors positioned at the top, middle, and bottom is necessary for collecting subsamples from various positions, as illustrated in Fig. I.12. Flow table jolting apparatus, sample bucket with a minimum capacity of 8 liters, scoop, stopwatch with 1-second precision, two small trays of 1.8 liters with a minimum diameter of 300 millimeters, one large tray of 3.3 liters with a minimum diameter of 300 millimeters, 5-millimeter sieve with a corresponding receiving pan, 10-kilogram capacity balance with 1-gram accuracy, and two clamps for securing the settlement column to the flow table. The utilization of a drying oven in this test is optional.

To assess static segregation, the self-compacting concrete (SCC) in the column must stay undisturbed; conversely, for dynamic segregation, controlled vibrations should be applied. To perform the test, the column must be entirely filled with concrete and left undisturbed for one minute. Subsequently, agitate the settlement column 20 times during a duration of 1 minute, and then allow the column to remain undisturbed for 5 minutes. Open the upper door and permit the SCC to discharge onto one of the little trays. The use of a scoop to facilitate the flow of concrete from the top door of the column is permitted. Subsequently, open the central door and let the SCC to flow into the huge tray once more. In the final stage, open the lower door and gather SCC in an additional tiny tray. Subsequently, place each sample onto the screen and rinse the concrete sample to obtain clean coarse aggregates. Utilize a drying oven to expedite the drying of coarse aggregates, or allow the surface of samples to air dry naturally and thereafter measure the weight of each sample. The settlement column segregation ratio (SCR) is calculated using the equation provided by De Schutter et al. (2008):

$$\text{SCR}=\frac{\text{Mass of top sample}}{\text{Mass of bottom sample}} \qquad \text{(Eqn.I.6)}$$

Table I.5 shows the SCR analysis based on the amount of SCR to determine the level of segregation.

Table I.5: Settlement column result analysis (Rooney, 2001).

Level of segregation	SCR
No segregation	0.96 and above
Mild segregation	0.95–0.88
Notable segregation	0.87–0.72
Severe segregation	0.71 and below

I.9. Conclusion

This chapter evaluates the static stability of self-consolidating concrete (SCC) throughout its plastic phase, which is crucial for maintaining uniform properties without segregation or settling. The authors conducted a comprehensive testing program to evaluate various methods for determining static stability, including surface settling tests and column segregation studies.

The study offers an extensive methodology for evaluating the static stability of SCC. The findings demonstrate the impact of alterations in rheological parameters, such as plastic viscosity, on segregation resistance. They provide valuable guidance in formulating stable and functional SCC mixes. The next section presents a historical analysis of viscosity-modifying chemicals, their influence on quality control in SCC production, and novel techniques for assessing stability in practical applications.

Chapter II: Bibliographic Synthesis on the viscosity-modifying agents in the self-compacting concrete

II.1. Introduction

The viscosity-modifying admixture is a useful addition for concrete mixes in the effective control and handling of viscosity in the designed cementitious materials for various works in concrete. In the light of improving the performance of conventional concrete, especially related to the SCC construction method, which is a non-vibration method that can flow easily, spreading under its own weight without segregation. SCC is characterized by its flow-ability and stability in that it flows to pour around bulky reinforcement and into a number of small areas with minimum effort.

Adding VMAs into the SCC is important in preventing segregation and bleeding of these types of mixtures of very fluidity. The addition of the VMAs raises the paste viscosity, mixtures have homogenous distribution of aggregates, and implies a high level of concentration of the concrete components that enable the paste to encase the aggregates during pouring and the curing of the concrete.

II.2. Viscosity Modifying Admixtures

Viscosity modifying admixtures are novel additives extensively utilized in concrete building. It enhances the viscosity and cohesiveness of the cement-based system in fresh concrete by diminishing the rate of separation of material constituents (EFNARC, 2006). The majority of viscosity modifying agents (VMAs) are derived from organic materials (biopolymers), including polysaccharides, cellulose ethers, starch ethers, and natural gums. The VMAs are water-soluble, which enhances the viscosity and/or yield point of the paste (Khayat K, 1997). Certain VMAs are derived from inorganic substances such colloidal silica, characterized by their amorphous structure and small, insoluble, non-diffusible particles that are sufficiently diminutive to remain suspended in water without sedimentation (EFNARC, 2006).

The workability of concrete can be regulated through the application of a superplasticizer (SP) and a viscosity modifying agent (VMA). Superplasticizers (SPs) are employed to improve flowability, while viscosity-modifying agents (VMAs) are utilized to stabilize the rheological characteristics and consistency of concrete (EFNARC, 2006). The primary consideration is that VMAs, often utilized with SP, must not deteriorate the features of the mixtures, aside from elevating viscosity (Umar, 2011).

II.3. Functions and applications of VMA

The purpose of the VMA is to alter the rheological characteristics of concrete mixtures. The rheology of fresh concrete can be characterized by yield value and plastic viscosity. The yield stress pertains to the force required to initiate the movement of concrete, while plastic viscosity characterizes the resistance of concrete to flow under applied stress (EFNARC, 2006). VMA is particularly successful in controlling bleeding due to its long-chain molecules, which stick to the periphery of water molecules, thereby adsorbing and fixing a portion of the mixed water, resulting in increased yield value and plastic viscosity of concrete (Khayat K. , 1998).

VMA can limit concrete bleeding, reduce segregation in self-compacting concrete, avoid washout in underwater concrete, and decrease friction and pressure in pumped concrete

(EFNARC, 2006). It can mitigate inadequate gap grading in aggregates, particularly sand deficient in particles.

II.4. Types of viscosity modifying agents

The VMAs are categorized into two categories based on their method of action: adsorptive and non-adsorptive (Nawa T, 1998) (Yammamuro H, 1997). Adsorptive VMAs influence cement. Subsequent to addition, they adhere to the surface of the cement particles, creating a bridging structure that enhances the viscosity of the concrete. Superplasticizers and viscosity-modifying agents will vie for the adsorption site.

Viscosity agents often consist of cellulose derivatives, polysaccharides, natural colloids, or suspensions of siliceous particles that engage with water to enhance its viscosity. Their objective is to mitigate bleeding and the dangers of segregation by enhancing the viscosity of the paste and ensuring a uniform distribution of the various components of concrete.

The predominant materials utilized in the formulation of self-compacting concrete (SCC) are:

- **Cellulose derivatives**: Hydroxypropyl methylcellulose (HPMC);
- **Hydroxyethyl cellulose** (HEC), **Carboxymethyl cellulose** (CMC);
- **Polymers derived from biotechnology**, which are polysaccharides obtained by fermentation (Xanthan gum, Welan gum, biopolymer, etc.).

Khayat et al. classify viscosity agents into three categories according to their modes of action (Khayat K., 2003):

- **Adsorption**: The long polymer chain adheres to the periphery of water molecules, which adsorbs and retains some of the added water. This increases the viscosity of the added water and, consequently, of the cement paste.
- **Association**: Molecules in contact with the polymer chain develop attractive forces. The movement of water is thus blocked by the creation of a gel, increasing its viscosity.
- **Entanglement**: At low shear rates and particularly at high concentrations, the polymer chain can become entangled, increasing the apparent viscosity. This entanglement can unwind as the shear rate increases, causing the polymer chain to align in the direction of flow and thus decreasing the apparent viscosity.

Andreas Leemann et al. investigated the impact of viscosity agent dosage on mortar and concrete. The authors indicate that the rheological parameters (shear threshold and plastic viscosity of a mortar) markedly escalated for a water-to-binder ratio (W/B) ranging from 0.36 to 0.48 as the polysaccharide-type viscosity agent (PS) rose from 0.2% to 0.8% (Andreas Leemann F. W., 2007).

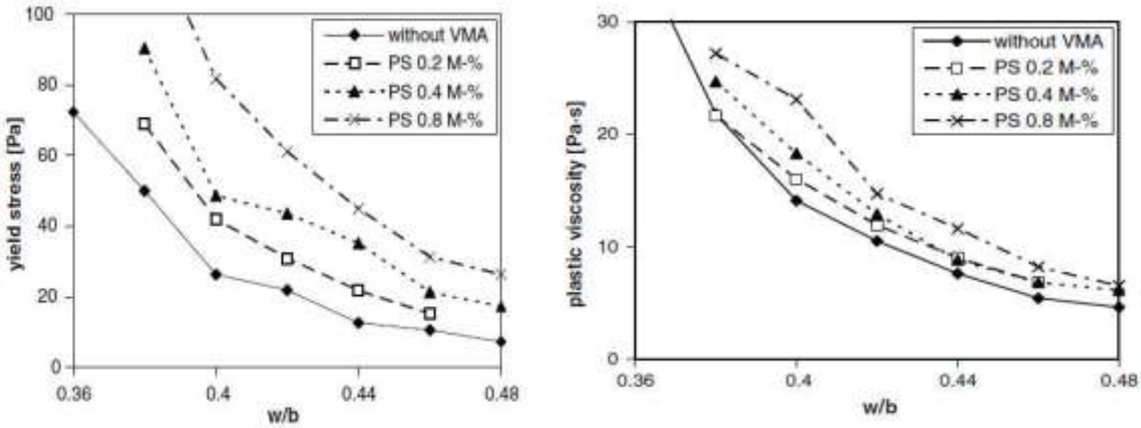


Fig.II.1. Left: Variation of the shear threshold as a function of the viscosity agent and the W/B ratio; Right: Variation of plastic viscosity as a function of the viscosity agent and the W/B ratio (Andreas Leemann F. W., 2007).

The authors (Andreas Leemann F. W., 2007) demonstrated that the spread diameter of mortar substantially diminished for a W/B ratio ranging from 0.36 to 0.48 as the concentration of PS (polysaccharide-type viscosity agent) increased from 0.2% to 0.8%.

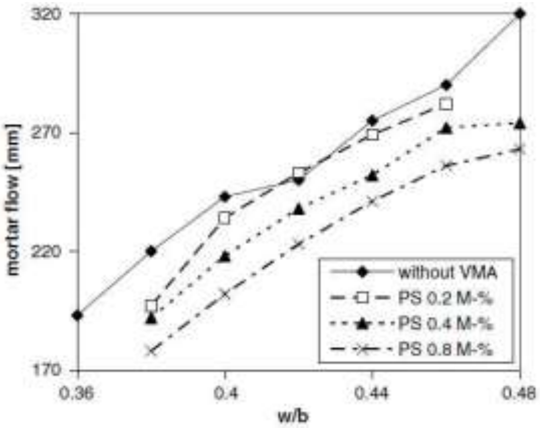


Fig.II.2. Variation of spread as a function of the viscosity agent and W/B ratio (Andreas Leemann F. W., 2007).

The findings of the authors (Jin, 2002) (Khayat K, 1997) indicate that the addition of a viscosity agent elevates the shear threshold and the apparent viscosity, irrespective of the water-to-cement ratio, the type, and the quantity of superplasticizer present in the cement paste.

A link exists between the dosage of the viscosity agent and the dosage of the superplasticizer. Figure II.3 illustrates that the demand for superplasticizer escalates with an increase in the dosage of the viscosity agent.

The incorporation of a superplasticizer enhances the workability of the concrete while simultaneously decreasing its viscosity. Formulating self-compacting concrete requires the selection of compatible quantities of viscosity agent and superplasticizer, as well as the optimization of their dosages.

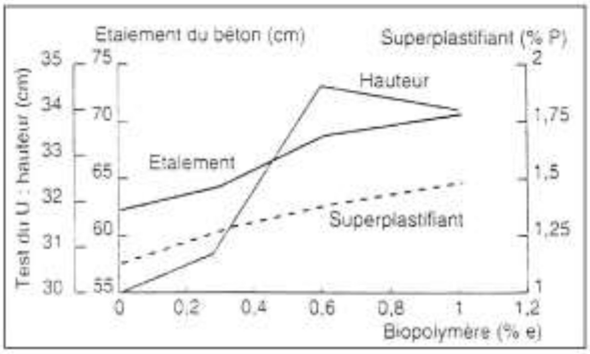


Fig.II.3. Optimization of viscosity agent – superplasticizer dosage (Turcry P., 2002)

The quantity of superplasticizers in the presence of adsorptive VMAs is illustrated in Fig. II.4 (Nawa T, 1998). An increase in the surface dimension of cement particles occupied by adsorptive VMAs results in a decrease in the adsorption of superplasticizers, hence reducing consistency. This category includes cellulose-based water-soluble polymers and acrylic-based water-soluble polymers.

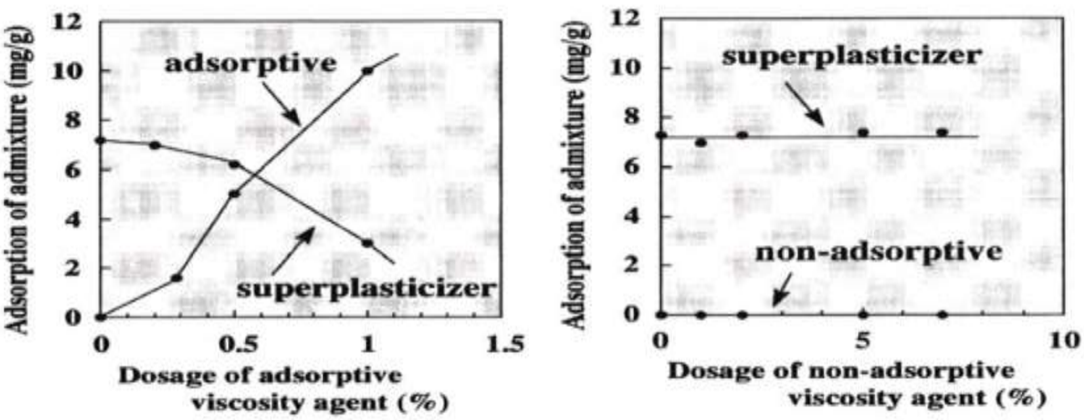


Fig.II.4. The quantity of superplasticizers adsorbed with different amount of viscosity modifying agents (Nawa T, 1998)

Conversely, non-adsorptive VMAs interact with water. Their water-soluble polymer chains either absorb free water or link their own molecules, so augmenting the plastic viscosity of concrete (Khayat K. , 1999b). Consequently, a degree of concrete consistency is preserved. Figure II.4 illustrates the quantity of superplasticizers in the presence of non-adsorptive VMAs (Nawa T, 1998). The quantity of adsorbed superplasticizers remains constant despite an increase in the non-adsorptive VMAs incorporated. Consequently, the plastic viscosity of mortar escalates, although the spread value may remain unchanged. Non-adsorptive VMAs do not compete with superplasticizers for the cement interface. This distinctive characteristic is particularly appropriate for SCC. Consequently, they can be used with appropriate superplasticizers to yield a self-consolidating concrete (SCC) with enhanced filling capacity and sufficient viscosity. This category encompasses glycol-based water-soluble polymers, biopolymers, polysaccharide polymers such as welan and diutan gum, microorganisms, and inorganic compounds with a high surface area, including silica fume.

Welan and diutan gums were initially utilized in Japan and are now commonly employed in North America. Both are ionized, long-chain biopolymers with sugar backbones modified by sugar side chains, generated by a regulated oxygen fermentation process (Khayat K. , Viscosity-enhancing admixtures for cement-based materials - An overview, 1998). They are high molecular weight polysaccharides, approximately 2 million for welan gum and 2.9 to 5.2 million for diutan gum; they show thixotropic properties and can be utilized at low concentrations to enhance the stability and robustness of self-compacting concrete (SCC) without significantly affecting consistency, thereby facilitating quality control. Diutan gum has a longer side-chain, an increased molecular weight, and has enhanced thixotropic properties in comparison to welan gum (Khayat K., 2003) (Phyfferoen A, 2002), welan gum was utilized at 0.05~0.20% of the mass of cementitious materials or 0.10~0.40% of the total amount of water (Khayat K. , Viscosity-enhancing admixtures for cement-based materials - An overview, 1998). Furthermore, they did not capture a significant volume of air (Khayat K. , 1995).

Nonetheless, both welan and diutan gums are costly. Research has been conducted on cellulose, precipitated silica, and novel polysaccharide-based viscosity-modifying agents (VMAs) to decrease costs (Lachemi M, 2004b) (Rols, 1999). Self-compacting concretes (SCCs) utilizing these new VMAs exhibited similar or better fresh and hardened properties compared to those incorporating welan gum, while requiring a reduced dosage to achieve the same consistency as SCCs made with welan gum (Lachemi M, 2004b).

Furthermore, additives like silica fume can function as a viscosity-modifying agent (VMA). silicon dioxide served as the Viscosity Modifying Agent (VMA) to examine the effects of constituent materials on the rheological properties of Self-Consolidating Concrete (SCC) paste (El Barrak M, 2009): it possessed an extremely small particle size and an important surface area; it influenced the concrete in a static state rather than during flow. The composition still uncertain.

Viscosity agents are essential for preserving the stability of cementitious mixes. They improve cohesiveness among the various phases of a mixture, therefore enhancing resistance to segregation and reducing free water flow (Turcry P., 2002).

Turcry et al. claim that the application of viscosity agents is appropriate for concretes with increased water-to-binder ratios, as the fines are insufficient to keep water inside the concrete (Turcry P., 2002).

II.5. Rheology

VMAs elevate the yield stress and plastic viscosity; mixtures containing a VMA demonstrate thixotropic behavior (Khayat K. , Viscosity-enhancing admixtures for cement-based materials - An overview, 1998), characterized by high viscosity at low shear rates, which diminishes with increasing shear rates. This facilitates placement: upon the introduction of SCC, viscosity is augmented due to the interaction and connecting of the VMA polymer chains at low shear speeds (Khayat K. , 1999b).

The consistency degradation of VMA-type SCCs doubles that of powder-type SCCs, presenting a disadvantage for the application of VMA in SCC. A greater quantity of superplasticizer may be necessary to compensate for the reduced consistency caused by the addition of VMAs, with the requisite dosage of superplasticizer increasing in proportion to the VMA concentration (Schwartzentruber LD, 2006).

Petersson and Billberg (1999) observed that the slump flow diminished more rapidly with an increase in welan gum concentration; mixtures containing VMA showed a quicker decrease of consistency compared to those without VMA (Petersson O B. P., 1999).

Table II.1. Variations in superplasticizer dosage due to welan gum added (Khayat K. , 1995)

Welan gum content (%)	0	0.12	0.20	0.24
A naphthalene-based superplasticizer (l/m3)	1.0	3.5	4.0	4.5

Table II.1 (Khayat K. , 1995) illustrates that to keep the initial slump of 190±5 mm in concrete with a W/C ratio of 0.41 and Type I cement, a higher VMA content necessitates an augmented superplasticizer dosage.

Table II.1 demonstrates that a minimal dosage of welan gum resulted in a significant change in superplasticizer requirements. This may eventually result in a significant modification in concrete's performance.

However, VMA did not influence the saturation of a superplasticizer; although a rise in VMA resulting in reduced spread and extended flow time, the saturation level of the superplasticizer remained at 0.2% (Schwartzentruber LD, 2006).

II.6. Thixotropy of SCC

A unique property of concrete that changes over time. When shear stress is given to it, like when it is being poured or pumped, the viscosity goes down. When that stress is removed, the viscosity goes up, which means that the concrete is at rest. Because it can change its behavior, SCC flows easily and fills complicated shapes when it is being placed, but when it is at rest, it stabilizes and stops breaking apart. VMAs like welan gum or cellulose ethers make it easier for thixotropy to happen. These chemicals make it easier for concrete to be both workable and stable. This is one of the most important properties of SCC because it lets the concrete move through the densely reinforced areas without mechanical vibration. It also keeps its shape, so the coarse aggregates don't settle out or the bleed water doesn't rise and weaken the structure of the concrete. Thixotropy will be important because it improves the quality of the concrete and the way it is placed.

The thixotropic SCC thins out under shear stress during placement, which lets it flow easily through complex shapes and places with a lot of reinforcements without getting stuck. Once the concrete is in place, it regains its stability and viscosity, which keeps the pebbles from separating and makes sure they are spread out evenly. When putting concrete up vertically or overhead, where normal concretes might lose their slump or separate, this trait is very useful. Thixotropic SCC also puts less pressure on the sides of the formwork, which makes designs lighter and cheaper. In general, thixotropy is one of the most important things that makes SCC work so well. It lets it meet the needs of modern building, which needs materials that are easy to work with and also very stable and long-lasting.

II.7. Effects on SCC

Adding a VMA into SCC will significantly enhance its durability and decrease the possibility of segregation.

The capacity to reduce the sensitivity of self-compacting concretes (SCCs) to water content was evidenced by the assessment of SCC filling ability (Okamura H O. K., 1994) : while a variation of ± 10 liters/m3 in water content, the U-shaped box values of SCCs with a viscosity-modifying agent (VMA) stayed within acceptable limits.

II.8. Setting time

The incorporation of a VMA typically leads to extended setting times, since the polymer chains adsorb onto cement particles and disturb the dispersion of minerals in the solution, hence affecting the hydration rate and setting duration (Khayat KH G. Z., 1997). As a result, VMAs diminish initial strength development but do not adversely affect later compressive strength (Nehdi ML P. M., 2004).

The effect is contingent upon the type and composition of the VMA, in addition to the superplasticizer, cement and powder formulation, and water-to-cement ratio.

The mixture consisted of Type I cement, a water-to-cement ratio of 0.40, and a naphthalene-based superplasticizer at 0.8% of the cement mass (Khayat K, 1997). The retardation was also demonstrated in concretes (Khayat K. , 1995): the concrete with a water-to-cement (W/C) ratio of 0.45, Type II cement, and a superplasticizer at 0.65% by mass of cement demonstrated a small delay in setting without a viscosity-modifying agent (VMA); however, the addition of 0.15% welan gum can prolong the initial setting time by 80 minutes. An augmentation of 3 to 6 hours in the initial and final setting times was seen in self-consolidating concrete (SCC) containing welan gum and polysaccharide-based viscosity-modifying agents (VMAs) (Lachemi M, 2004b).

Two characteristics of VMA must be evaluated when utilized in SCC: its properties and its interaction with superplasticizers. VMA should not significantly change the consistency of concrete. Consequently, the compatibility between VMA and superplasticizer can be evaluated by examining the consistency stability.

II.9. Other admixtures

Superplasticizers and viscosity-modifying agents (VMAs) are the most often utilized substances in self-consolidating concrete (SCC). Anti-foaming agents mitigate air entrainment caused by VMAs (Petersson O B. P., 1999); retarders and slump-retaining agents prolong consistency retention; accelerating agents enhance early strength (Petersson, 1997); thixotropy-enhancing agents diminish maximum lateral pressure and accelerate pressure drop (Khayat and Assaad, 2005); air-entraining (AE) admixtures ensure frost resistance (Khayat KH G. A., 2000); expansive agents counteract shrinkage, while chemical shrinkage-reducing agents minimize shrinkage in SCC. However, regulating the air content in concrete while utilizing air-entraining agents becomes challenging. The greater the number of admixtures employed, the more challenging it becomes to control their compatibility, requiring more experiments to attain the desired new qualities.

II.10. Experimental Insights into the viscosity modifying agents in Self-Compacting Concrete: A Comprehensive Literature Review

The influence of VMAs on SCC characteristics has been the subject of numerous investigations. The tests will include, among others, the assessment of variations in the consistency of concrete mixtures utilizing the V funnel and J-ring tests, in addition to evaluations of bleeding and segregation resistance. The investigations indicated that VMA utilization can significantly improve the stability of the mixture, particularly in concrete with elevated water-binder or superplasticizer ratios.

II.10.1. Viscosity-Modifying Admixtures and Rheology

This literature comprises a number of studies on VMAs in enhancing the rheological properties of SCC. Various studies have involved the use of welan gum to reduce "top-bar effect" by Khayat 1998 or exploration of advanced test methods for assessing SCC workability with an emphasis on viscosity and flow time by Ferraris et al., in 2000. For stability enhancement of SCC mixes, especially against segregation, Lowke et al. 2003, Khayat et al. 2004 and Assaad et al. 2004 explored the dynamic and static stability of SCC with some of the test methods, respectively highlighting the importance of VMAs. El-Chabib and Nehdi 2006 analyzed mixture design parameters influencing segregation with emphasis on the use of VMAs. Leemann and Winnefeld (2007) analyzed the effect of VMAs on the rheology of mortar and concrete, and Khayat and Assaad in turn conducted a review of thixotropy-enhancing admixtures and their effect on the stability of SCC in 2008. Nanthagopalan and Santhanam presented, in 2010, the empirical method for optimum dosage of VMA in SCC; Gołaszewski also in 2010 investigated the viscosity-enhancing agents and the influence of VEA on rheology and compressive strength of mortars. Grabiec (2013) and Shen et al. (2014) further emphasized the role of VMAs in improving the stability and flowability of SCC. Benaicha et al. (2015) introduced a new approach to measure plastic viscosity in SCC using VMAs, and Benaicha et al. (2015) studied the combined effects of silica fume and VMAs on SCC rheology and mechanical performance. For example, Wang et al. (2016) investigated the rheological properties of cement paste with a new type of VMA, and Mechaymech and Assaad (2019) evaluated SCC stability and deformability when VEA is used. Ren et al. (2019) discussed waste silicon carbide used as VMA in SCC, while Rami et al. (2019) and G Abdelouahab et al. (2019) have studied the use of Guar Gum as VMA in SCC. Patil and Tande 2022 discussed the role of VMA in SCC and their effect on concrete properties.

II.10.2. Segregation and Stability in SCC

The research related to segregation and stability in SCC has been of prime importance. Takefumi Shindoh and Yasunori Matsuoka (2003) prepared combination-type SCC and assessed its resistance to segregation. Lin Shen et al. (2008) investigated dynamic segregation in SCC and the effectiveness of VMAs in enhancing stability. Kränkel et al. (2010) studied SCC for stability and performance of VMAs. Lin Shen et al. (2015) designed an apparatus of flow through for measurement of dynamic segregation in SCC. Karimi et al. (2020) introduced ultrasonic pulse velocity as one of the nondestructive test methods to characterize segregation in SCC and proved it to be a reliable tool for quality control.

II.10.3. Mechanical Properties and Durability

Several tests have been performed to evaluate the mechanical properties and durability of SCC made with VMAs. Umar and Al-Tamimi (2011) have conducted research to study the properties of SCC containing VMAs. Mesbah et al. (2011) utilized an electrical conductivity method for monitoring early-age stability in SCC. Athulya Sugathan (2016) studied self-compacting high-performance concrete with steel fibers and VMAs, while Bhirud and Sangle (2017) compared shrinkage, creep, and elastic shortening in SCC with VMAs. Arunya et al. (2019) conducted an experimental study on the strength properties of SCC with VMAs, and He Liu et al. (2022) explored the stability of SCC in ballastless track systems, focusing on durability and service performance.

II.10.4. Sustainability and Alternative Materials

Sustainability and other ways to use materials have also been looked into for SCC. A study by Jolicoeur et al. in 2006 looked into how chemical additives and extra cementitious materials affected the longevity of SCC. The 2018 study by Hisseine et al. looked into using cellulose fibers as an eco-friendly VMA in SCC. The 2019 study by Ren et al. looked into using carbide from silicon waste as VMA in SCC.

II.10.5. Testing Methods and Quality Control

The research on testing methods and quality control in SCC has been immense. Jeremie Pourchez, in 2006, studied the physico-chemical interactions between cement and cellulose ethers. Khayat et al., in 2007, developed a multi-electrode conductivity method for the evaluation of SCC stability. Wolfram Schmidt et al., in 2013, discussed the role of rheology-modifying admixtures in concrete technology. Yusuke Baba et al., in 2013, introduced low-viscosity SCC with innovative VMAs. Peter Tumwet Cherop et al. (2017) discussed the influence of non-ionic cellulose ethers on the properties of white Portland cement, whereas Upendra Neupane et al. (2017) addressed VMAs in high-pressure applications and covered dewatering and bleeding, among other concerns. Karimi et al. (2020) used an ultrasonic pulse velocity for segregation detection in SCC and presented a rapid and nondestructive test method.

II.10.6. Thixotropy and Formwork Pressure

Thixotropy and its effect on the SCC formwork pressure have been investigated, as per Khayat and Assaad 2008, who studied the thixotropy-enhancing admixtures and their effects on formwork pressure. Andreas Leemann et al. (2008) have also investigated the thixotropy in SCCs containing VMAs; he emphasized that the thixotropy characteristic of SCC may help lower the formwork pressure upon casting.

II.10.7. Innovative Admixtures and Technologies

Another main area of research has been innovative admixtures and technologies. Yusuke Baba et al., in 2013, developed low-viscosity SCC with innovative types of VMA, while Hisseine et al., in 2018, presented cellulose filaments as a new type of VMA in SCC. Qiang Ren et al., in

2019, researched the use of silicon carbide waste as a VMA in SCC and demonstrated a promising way for sustainable construction.

II.10.8. Application-Specific Studies

Some works have been done on specific applications of SCC. Athulya Sugathan 2016 studied SCC with steel fibers for high-performance applications, while He Liu et al. 2022 researched the stability of SCC in ballastless track systems, putting great emphasis on the fact that SCC plays a very important role in long-term performance and durability in railway construction.

II.11. Conclusion

This chapter examines the role of viscosity-modifying admixtures in maintaining the stability of self-consolidating concrete (SCC) in its fresh condition, promoting uniformity and minimizing segregation. The authors conducted a comprehensive experimental program employing several methodologies to evaluate the efficacy of VMAs on the static stability of SCC, including rheological measurements and sedimentation experiments.

This study presents a comprehensive approach to analyzing the role of VMAs in the overall stability of SCC mixtures. The results emphasize the impact of varying VMA doses on key parameters that enhance segregation resistance, including yield stress and plastic viscosity. This information aids in making informed judgments when formulating SCC to attain best stability and performance. This chapter provides a historical overview of the VMAs, evaluating their evolution throughout the years and recent trends in quality control procedures pertinent to applications in SCC.

Chapter III: Characteristics of materials used, formulation and testing methods

III.1. Introduction

Basically, self-compacting concrete (SCC) is manufactured from a combination of materials; hence, the influence of such materials needs fundamental knowledge concerning various properties: physical, chemical, mineralogical, and mechanical. As a matter of fact, concrete in its fresh and hardened states and, most importantly, in its durability aspects needs such knowledge for the explanation of its behavior.

The present chapter gives an overview of the major characteristics of the used materials with an explanation of the accepted experimental procedure, including formulations of the tested concretes, description of the various experiments carried out within this study. The tests are carried out at the material's laboratory of the Civil Engineering Department, University of Djelfa, and at L.N.H.C. National Laboratory of Housing and Construction, South-East Regional Unit, Djelfa.

III.2. Materials characteristics

III.2.1. Cement

A composite Portland cement of type CEM II/B-L 42.5N was used in conformity with the Algerian standard NA 442. This cement is supplied by LAFARGE Holcim Algeria (see technical data sheet in Appendix "A". The physical characteristics are given in Table III.1. Its chemical and mineralogical compositions are given in Table III.2 and Table III.3, respectively. The mineralogical composition is calculated by the Bogue formula.

Table III.1. Physical properties of cement

Properties	value
Specific surface area Blaine (cm^2/g)	3917
Consistency (%)	27.48
Initial Set Time (mn)	140
Final Set Time (mn)	203
Absolute Density (kg/m^3)	3050
Apparent Density (kg/m^3)	1100

Table III.2. Chemical composition of cement

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	PAF
17.49	4.51	3.02	62.78	2.15	2.38	0.05	0.64	8.10

Table III.3. Mineralogical composition of cement

C_3S	C_2S	C_3A	C_4AF
55.41	13.65	2.25	14.83

III.2.2. Coarse Aggregates (Gravel)

Two classes of gravel, G 3/8 and G 8/16, were used during this study. They are of the crushed type, prepared from limestone rock sourced from a quarry located in the south of Djelfa, Algeria. Table III.4 summarizes the physical properties of the gravel, and Fig.III.1 presents their granulometric curves.

Table III.4. Physical Properties of Gravel

Properties	G 3/8	G 8/16
Apparent Density (kg/m^3)	1330	1380
Absolute Density (kg/m^3)	2640	2650
Los Angeles Coefficient (%)	38,7	30.3
Absorption Coefficient (%)	0.47	0.47

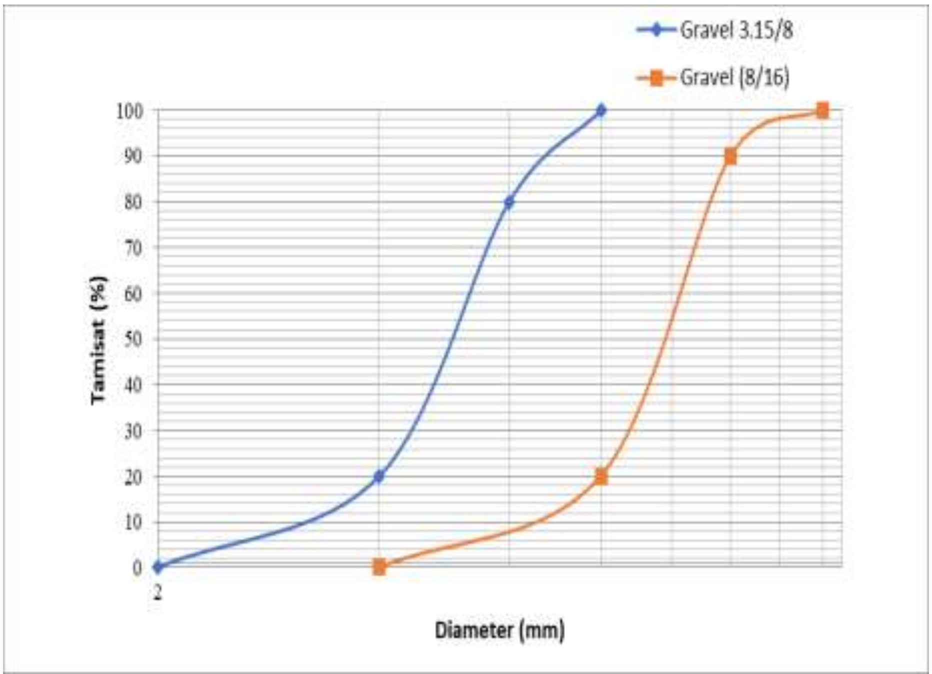


Fig.III.1. Granulometric curve of used gravel

III.2.3. Sand

In our study, we used siliceous alluvial sand from Wilaya of Laghouat, located 100 km south of Djelfa, Algeria. The granular fraction of this sand ranges between 80 µm and 5 mm (see Figure III.2 and Figure III.3).

Fig.III.2. Image of the Used Sand

Fig.III.3. Microscopic Observation of the Used Sand

The granulometry of the sands is presented in Figure III.4.

The physical properties of the sand used, such as Apparent density, absolute density, fineness modulus, sand equivalent, and absorption coefficient, are summarized in Table III.5.

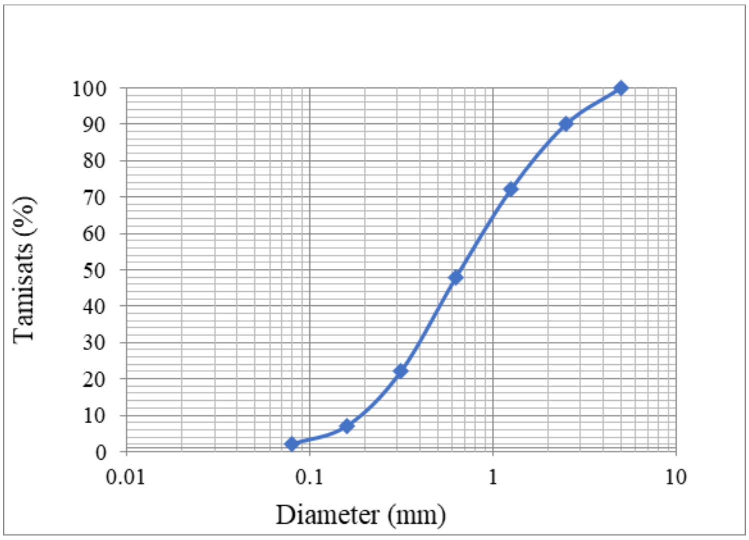


Fig.III.1. Granulometric curve of used sand.

Table III.5. Physical Properties of the Sand

Properties	value
Apparent Density (kg/m^3)	1.59
Absolute Density (kg/m^3)	2.45
Fineness modulus	2.54
Sand Equivalent (%) Piston	81.70
Sand Equivalent (%) Visual	90.32
Aabsorption coefficient (%)	1.29

III.2.4. Superplasticizer (SP)

Superplasticizer (SP) used was a high water-reducing based on third generation polycarboxylate ether. Its commercial name is MEDAFLOW 30 provided from Granitex Algeria (see Figure III.5). It has the following characteristics: light-yellow liquid, density of 1.07 ± 0.01, pH of 6, solid particle concentration of 30%. No retarding effect has been shown.

Fig.III.5. Superplasticizer GRANITEX-MEDAFLOW 30

III.2.5. Viscosity modifying agent

The use of viscosity agents in the formulation of fluid concrete has recently become a necessity to ensure good resistance to segregation. If the mix does not contain a viscosity agent, a larger amount of binder is required to achieve flow without segregation. Viscosity agents help maintain fluidity and filling capacity. Adding a superplasticizer to concrete increases its workability but reduces its viscosity. Consequently, the material becomes less stable in terms of segregation and bleeding. To minimize this effect, self-consolidating concretes (SCC) often contain a viscosity agent.

Concrete workability can be adjusted with superplasticizers (SP) and viscosity agents (VMA). SPs improve deformability whereas VMAs increase concrete viscosity in order to resist segregation (EFNARC, 2006). The most crucial point is that VMAs, often employed with SP, should only increase viscosity instead of fresh mixture qualities (Umar, 2011). Some viscosity agents (VMAs) control concrete bleeding (Lachemi M, 2004a). Various research (Khayat K. H., 1998) (Lachemi M, 2004a) (Rols, 1999) (Umar, 2011) found that VMAs increase paste viscosity and reduce segregation. Improves concrete bleeding and segregation resistance (EFNARC, 2006) (Khayat KH G. Z., 1997).

III.2.5.1. Medacol BSE (VMA1)

Medacol BSE is a powdered admixture specially intended for the production of concrete and mortar cast in water, and it is manufactured by Granitex Algeria. The product aims at improving concrete plasticity and viscosity to make the processes of underwater concreting without washout and segregation successful. Being in compliance with the severe prescriptions of the EN 934-2:2002 regulation, Medacol BSE can be regarded as effective and reliable for whatever kind of use, either in marine or submerged environments.

Two main parts building up the special properties of Medacol BSE are colloidal agents and ultra-fine micro silica. The product is a grayish powder and has a density of 0.5. Mix with concrete added to Medacol BSE gains more plastic and viscous consistence, quite important in underwater uses where the danger of washout and segregation is great. Non-shrinkability is the property that makes it an ideal choice for a number of difficult situations such as marine works, submerged caissons, quay block cells, dike cavities, and injection grouts. It also serves very effectively in pile concretes in absorptive grounds, ensuring adequate structural integrity and durability in such difficult conditions.

Mixing of Medacol BSE has to be carried out with care, always dry with all the concrete components -cement, sand and aggregates-before the addition of mixing water. Water is added in one step after which mixing has to be carried out for at least two minutes in order to obtain a homogeneous distribution of all the constituents. The workability of the resulting concrete mix should be fluid; the desired spread by DIN table is 600 mm and slump by Abrams cone is 200 mm. Such characteristics provide a highly workable mix that can be easily placed and compacted, even under submerged conditions.

III.2.5.2. Walocel™ MKX 15000 PP 20 (VMA 2)

Walocel™ MKX 15000 PP 20 is a kind of modified hydroxyethyl methyl cellulose product that is usually used for improving the physical properties of plasters based on either cement or gypsum. Walocel™ MKX 15000 PP 20 cellulose ether, supplied by The Dow Chemical Company, is used to improve performance requirements such as workability and water retention in dry mix mortars. This paper will discuss in detail Walocel™ MKX 15000 PP 20, its properties, applications, and benefits.

Walocel™ MKX 15000 PP 20 is a high-performance cellulose ether product. It is a fine powder, water-soluble, and the viscosity of a 2% aqueous solution usually lies between 13,000 to 17,000 mPa·s at an optimum pH close to neutrality. Maximum moisture content of the product is 7%. These features make Walocel™ MKX 15000 PP 20 an excellent additive for rheological property improvement of cementitious materials.

Because it works with common mineral binders and additives, it can be easily added to many different formulas. By keeping water in the mix, the product makes the cement easier to work with, makes it easier to apply, and makes sure that it dries better. It melts quickly because the particles are spread out in the best way, which speeds up the mixing process. It has been tested extensively and found to be safe in a wide range of situations, though it may cause mechanical fatigue in the worst cases. Since it is an organic polymer, it can catch fire and needs standard burning methods. To keep dust from forming, which can be explosive, safe handling practices should be followed.

III.2.6. Mixing Water (E)

The water (E) used during this investigation is potable tap water from the University of Djelfa. It has a temperature of 20 ± 2 °C and a pH of 8.04. Table III.6 presents some parameters of the chemical analysis of the water.

Table III.6. Mineralogical Analysis of Mixing Water

Total Mineralization	value mg/l
Calcium (Ca^{++})	104
Magnesium (Mg^{++})	23.32
Chlorides (Cl^{-})	92.3
Sulfates ($SO4^{--}$)	170
Ammonium ($NH4^{+}$)	0.04

According to Table III.6, the water used is considered suitable for concrete production. It meets the requirements of the NF EN 1008:2002 standard, which specifies a maximum chloride (Cl-) content of 500 mg/l for prestressed concrete or grout and 1000 mg/l for reinforced or embedded concrete. It also specifies a maximum sulfate ($SO4^{-2}$) content of 2000 mg/l.

III.3. Composition of SCC (Self-Compacting Concrete)

The rheological characteristics and the specific composition of SCC make its formulation sensitive. There are several approaches to formulating SCC: some are based on optimizing the paste volume, while others focus on optimizing the granular skeleton. These approaches are empirical. The formulation method adopted in our case is the empirical method based on paste volume. The total volume (V_t) of the dry mix for one cubic meter of concrete is equal to the sum of the cement paste volume (V_p) and the aggregate volume (V_g).

First, we determined the paste volume (V_p), which represents the sum of the volumes of the binder (cement, VMA), water, superplasticizer, and air. Then, we extracted the aggregate volume (V_g) by subtracting V_p from the total volume (V_t) with the following distribution: V_g = 50% sand + 25% G 3.15/8 + 25% G 8/16. The Water/cement ratio and the Gravel/Sand ratio are kept constant at 0.40 and 1, respectively.

The constant quantities by volume are: the cement (C), the water (E), sand, gravel (G 3.15/8 and G 8/16), and the air volume, which is fixed at 1%. The variables throughout the series are the viscosity agent in the first case and the superplasticizer in the second case. The following section details the calculation.

III.3.1. Method of calculating the reference composition

Parameters Fixed in 1 m^3:

The cement dosage: M_c = 400 kg

The Water/cement ratio: 0.40

Superplasticizer SP: 0.8% cement in the first case

Air volume :1%

III.3.1.1. Step 1: Calculate the volume of the paste and the volume of the aggregates

The volume of the paste is: $V_p = V_c + V_{sp} + V_e + V_{air}$

Hence :

$V_c = \frac{Mc}{\rho c} = \frac{400}{3.5} \longrightarrow V_c = 131.15$ L

$\frac{E}{B} = 0.40 \longrightarrow E = 0.40 * M_c = 0.4 * 400 \longrightarrow V_e = 160.16$ L

$Vair = \frac{1}{100} * 100 \longrightarrow Vair = 10$ L

Calculation of SP volume: we have the dry extract of the SP is ext = 30 %

$\rho_s = \rho_{sp} * ext = 1.07 * 0.3 \longrightarrow \rho s = 0.321$

where ρ_s is the density of SP in solid; ρ_{sp} is the density of SP in liquid

Therefore, the mass of adjuvant in solid

$M_{sp/solide} = \frac{\%Sp}{100} * Mc = \frac{0.8}{100} * 400 \longrightarrow M_{sp/solide} = 3.2$ kg

$V_{sp} = \frac{Msp/solide}{\rho s} = \frac{3.2}{0.321} \longrightarrow V_{sp} = 9.97$ L

The volume of the paste is therefore: $V_p = 131.15 + 10 + 171.50 + 9.97 \longrightarrow$

$V_p = 322.62$ L

So, the volume of aggregates will be: $V_g = 1000 – V_p$ Hence: $V_g = 677.38$ L

We have V_g=50% sand + 25% $G_{3.15/8}$ + 25% $G_{8/16}$ the volume distribution will be as follows:

$V_{G3.15/8} = V_{G8/16} = 160.92$ L   and $V_{sand} = 321.84$ L

III.3.1.2. Step 2: Calculate the mass of the aggregates

Sand mass: $\rho_s = \frac{Ms}{Vs}$ ⟶ $M_s = \rho_s * V_s = 2.64 * 321.84$ ⟶ Ms = 849.65 kg

$G_{3.15/8}$ and $G_{8/16}$ mass: $\rho_G = \frac{MG}{VG}$ ⟶ $M_G = \rho_G * V_G = 2.67 * 160.92$ ⟶

$M_{G3.15/8} = M_{G8/16} = 429.65$ kg

III.4. Experimental program

III.4.1. Formulation of the SCC and mix preparation

To better understand how viscosity-modifying agents (VMA) and superplasticizers (SP) work together in self-compacting concrete (SCC), we looked at two sets of concrete mixtures in this study. in addition of another mixture of SCC with superplasticizer, without VMA is considered as a reference for comparison the results called FTM which have segregation and bleeding to evaluate the effectiveness of viscosity modifying agents on improving of parameters of SCC. The goal was to see how these additives affect the concrete's performance, especially its ability to flow smoothly and fill molds without any need for mechanical vibration. Both sets of mixtures had the same basic ingredients, like cement, water, and aggregates. The only things that differed were the amounts of superplasticizer and viscosity-modifying agent used. This allowed us to focus on the role of these two key ingredients and how they change the concrete's behavior.

The first set of mixtures was all about finding out how changing the amount of VMA affects the fresh properties of SCC. We made six different mixtures, each with a different percentage of two types of VMAs, VMA1 and VMA2. For VMA1, we used 0.05%, 0.1%, and 0.15% by mass of cement, while for VMA2, the dosages were 0.04%, 0.09%, and 0.14%. The goal here was to figure out how much VMA is needed to make the concrete more viscous meaning it holds together better and doesn't separate during pouring without making it too thick or hard to work with.

To keep everything else consistent, we used a sand-to-aggregate ratio of 1 (meaning 50% sand and 50% fine and coarse aggregate), with a fine-to-coarse aggregate ratio of 0.5. This means that out of the total aggregate, 25% was made up of fine material (3/8 size) and 25% of coarser material (8/16 size). We also kept the superplasticizer at 0.8% by mass of cement across the board to make sure the concrete stayed workable and easy to handle. Finally, we used a water-to-powder ratio of 0.40 (by mass) for both sets of mixtures. This meant we were able to test how different VMA levels affected the fresh concrete without changing the water content, which could complicate the results. Mix proportions of all mixtures used within the frame of the study, as well as the qualitative aspect of each mixture, are given in table III.7. These specific values of SP and VMA were judiciously chosen from practical ranges. Selection of these values aims to ensure that slump flow, T500, and V-funnel values for all mixtures fall within the recommended specifications for SCC.

Table III.7. Proportions of all mixtures of the first set and the visual mark.

Formulation	W/C	VMA 1(%)	VMA 2(%)	SP (%)	Visual remarks
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

The studied compositions of mixtures for the first set are illustrated in the table III.8 below:

Table III.8. The studied compositions of mixtures for the first set

	Mixtures						
Components	FTM	SCC1	SCC2	SCC3	SCC4	SCC5	SCC6
Ciment (kg/m^3)	490	490	490	490	490	490	490
VMA (kg/m^3)	0	0.245	0.49	0.735	0.196	0.441	0.686
Superplasticizer (kg/m^3)	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Sand (kg/m^3)	829.22	815.26	813.73	812.20	815.57	814.04	812.51
Gravel 3/8 (kg/m^3)	414.61	413.83	413.05	412.28	413.98	413.21	412.43
Gravel 8/16 (kg/m^3)	414.61	413.83	413.05	412.28	413.98	413.21	412.43
Water (kg/m^3)	231.60	231.60	231.62	231.63	231.60	231.62	231.51

Where the FTM is the referenced mixture which is mixed without viscosity modifying agent (VMA), and have segregation and bleeding.

For the second set of mixtures, we shifted our focus to the superplasticizer (SP) and how different dosages would affect the concrete. Superplasticizers are what help the concrete flow without needing extra water, and this set of four mixtures was built on the best performing VMAs from the first set. Here, we increased the SP dosage gradually starting with 0.6%, then moving to 0.8%, and finally 1% by mass of cement. We wanted to see how these changes impacted the concrete's fluidity and ability to self-compact, while still keeping the rest of the mix ingredients the same as before.

Just like with the first set, we didn’t change any other variables, so we could get a clear picture of how the superplasticizer dosage affected the SCC’s fresh properties. This way, we could compare the results and see what combination of VMA and SP would give us the best performing concrete one that flows well but doesn’t segregate or bleed too much. Their proportions as listed in table III.9, and their studied compositions are illustrated in the table III.10 below.

Table III.9. Proportions of all mixtures of second set and the visual mark.

Formulation	W/C	VMA 1(%)	VMA 2(%)	SP (%)	Visual remarks
SCC7			/	0.60	bleeding
SCC2		0.10	/	0.8	good
SCC8	0.40		/	1.00	firm
SCC9		/	0.09	0.60	bleeding
SCC5		/		0.8	good
SCC10		/		1.00	firm

Table III.10. The studied compositions of mixtures for the second set

	Mixtures			
Components	SCC7	SCC8	SCC9	SCC10
Ciment (kg/m^3)	490	490	490	490
VMA (kg/m^3)	0.49	0.49	0.49	0.49
Superplasticizer (kg/m^3)	9.8	16.3	9.8	16.3
Sand (kg/m^3)	817.74	809.72	811.05	810.02
Gravel 3/8 (kg/m^3)	415.09	411.02	415.25	411.17
Gravel 8/16 (kg/m^3)	415.09	411.02	415.25	411.17
Water (kg/m^3)	234.13	229.11	234.13	229.11

Figure III.6. (a to i) shows the spread of all the mixtures.

Fig.III.6.a. Spread of mixture of FTM

Fig. III.6.b. Spread of mixture for SCC1

Fig. III.6.c. Spread of mixture for SCC2

Fig. III.6.d. Spread of mixture for SCC3

Fig. III.6.e. Spread of mixture for SCC4

Fig. III.6.f. Spread of mixture for SCC5

Fig. III.6.g. Spread of mixture for SCC6

Fig. III.6.h. Spread of mixture for SCC7

Fig. III.6.i. Spread of mixture for SCC8

III.4.2. Testing procedure

Preparation of SCC: The first step in preparing SCC is to mix the dry materials, namely cement, aggregate, and sand, for about 1 minute. This is the most crucial step in mixing since water is added afterwards. Proper mixing of the dry components will not only avoid clumping but, more importantly, ensure that the cement coats the aggregates more effectively for a better mix thereafter. After that was done, we added 75% of the total water and then mixed it all for another 2 minutes. This is done to allow the cement to start its reaction with the water and begin forming the paste that holds the concrete together.

We added the last 25% of water after the first mixing. We mixed this with the superplasticizer this time, though. It is very important to keep the strength of the concrete, so the superplasticizer helps make it more flexible without adding more water. The SP was added to the mixture and mixed for three more minutes to make sure it was well mixed in and make it easier to work with.

Working with SCC mixes, some with VMA, the procedure in case of other types of VMA had to be followed. For cellulose-ether-based VMAs, we dissolved the VMA in the superplasticizer and added it with the final 25% of water. This helped distribute the VMA evenly so that it could do its job of increasing the viscosity of the mix. Since in MEDACOLE the VMA was added together with the dry materials right at the very beginning, this allowed the VMA to be incorporated into the mix early on, thus it helped keeping everything cohesive right from the very beginning.

The fresh test series characterizes the flow and behavior of the mixed concrete. Since EFNARC recommendations from 2005 for testing self-compacting concrete are considered state of the art, these recommendations are adapted. First Test - Slump Flow Test, the first test we ran was the slump flow using an inverted Abrams cone. We essentially filled the cone with concrete, lifted it, and measured how far the concrete spread. This test is a quick, easy check on the flow characteristics, which are of primary importance since SCC needs to be sufficiently fluid to ensure complete filling of the mold without any external vibration and yet be able to pass around any reinforcement.

We have also measured T500 time, representing the time of concrete to reach a diameter of 500 mm. It gives an indication of the rate at which the concrete flows. A short T500 time would mean that the concrete flows fast and is highly fluid, while a longer one will be thicker and more viscous mixtures. The tests also included the V-funnel test, conducted to define the speed at which concrete is capable of flowing through a narrow opening in order to simulate passage through narrow places, for example between reinforcement bars.

Based on the slump flow, T500, and V-funnel tests, we could see that the new concrete was surprisingly flowing. The amounts of VMA and SP that were added to these mixes changed the state of the concrete was. We were able to fine-tune the flow and handling of concrete by changing these additives. This way, it could be harder to stop bleeding or more fluid to make pouring easier.

After these tests, the concrete's ability to pass, fill, and stay stable were checked again to make sure it fit the main requirements for self-compacting concrete. Filling ability is the concrete's ability to fill a mold without leaving any holes or honeycomb, which is important for keeping the building strong. The passing ability of concrete is how well it moves through places with a lot of rebar without getting stuck or separating. Stability keeps the concrete mixed and stops it from separating over time or while it's being poured. All of these checks are necessary because SCC has to be able to work well in molds that aren't ideal or in structures that are very strongly built, where regular concrete wouldn't be able to do the job.

III.4.3. Concept of ' The cylinder column segregation test '

This test method is intended to provide a quantitative measure of the susceptibility of coarse aggregate particles to become separated or settle out of concrete, with time, when the mixture is at rest. Specifically, this test method targets direct measurement of the tendency of coarse aggregate particles to become separated from the concrete mixture as opposed to an indirect assessment via other properties of fresh concrete mixtures. This is a direct observation because the even distribution of coarse aggregates in the mix is of critical importance for the structure and durability of the final product. These segregations usually give weak points in a structure; therefore, quantification of this behavior is very important for quality control and the optimization of concrete formulations.

The test apparatus consists of a 300-mm high cylindrical PVC mould with an internal diameter of 160 mm. For convenience, this cylindrical mould is divided into three equal segments, each having a height of 100 mm. The three segments are easily separable, allowing us to isolate different layers of the concrete mixture during the test. The above arrangement will ensure that the correct measurement of the distribution of coarse aggregate at varying height in the mould can be taken, which will represent the vertical segregation.

Freshly mixed concrete is placed in the cylindrical mould, carefully poured up to the top without any vibration and external compaction. This precaution has to be taken to avoid additional vibration that may artificially alter the behavior of the coarse aggregates and, under specific conditions, inhibit segregation that may take place in practice. The mould is covered by a lid to avoid water evaporation during the test. The first part simulates site conditions of natural concrete being poured into forms without further agitation, simply by not vibrating and covering the mould so that the action of concrete truly resembles the site conditions.

The test is carried out, after a certain elapsed time - 15 minutes, 30 minutes, and 1 hour, by segregating the concrete in three segments with a metal separating sheet. Each segment represents a different vertical level of the concrete mixture. The concrete in each segment is carefully removed, and the mass of each partial sample is weighed to record the total weight of concrete in each layer.

Therefore, the concrete samples are washed in an 8 mm sieve, where the fine material is separated from coarse aggregate particles, that is those bigger than 8 mm. This allows us to be able to segregate and measure only the coarse aggregates of interest in this segregation test. After sieving the aggregates, they are put in an oven and dried for 24 hours just to ensure that the correct mass of the coarse aggregates will be measured, without any form of water content that may affect the results. After 24 hours in the oven to drier, the mass of the aggregate is determined as shown in figure III.7.

The segregation index (Is) was calculated using the following formula:

$$Is=\frac{Mi}{(M1+M2+M3)} \qquad \text{(Eqn.III.1)}$$

Where Mi is the mass of coarse aggregate of the first, second and third part of the PVC mold. The above segregation index provides an easy ratio that reflects the comparative mass concentration of the coarse aggregates in each layer. The value of Is indicates the extent of segregation; the higher the value of Is, the greater is the degree of segregation.

The other measure of segregation, which gives a better measure, is the percent segregation, SI, which is based on the coefficient of variation of the coarse aggregate content in each of the three sections of the mould. This calculation considered the deviation of the mass of coarse aggregate measured in each section from the mean, hence providing a closer approximation to the actual distribution of coarse aggregates along the mould height. The SI can be calculated using the expression below, as suggested by Hassan EI-Chabib and Nehdi:

$$SI(\%)=\frac{1}{3} * \sum_{i=1}^{3}\left|\frac{Mi-Mavg}{Mavg}\right| * 100 \qquad \text{(Eqn.III.2)}$$

Where $M_{avg}=\frac{1}{3}\sum_{i=1}^{3} Mi$

Mi is the mass of coarse aggregate in each part of the PVC cylinder.

This formula gives the percentage variation in coarse aggregate content for the three sections. A low percentage indicates that the coarse aggregates have reasonably homogenous distribution and hence the segregation is negligible or non-existent. A higher percentage implies high segregation and this can be manifested either by the settling of coarse aggregates to the bottom or floating to the top.

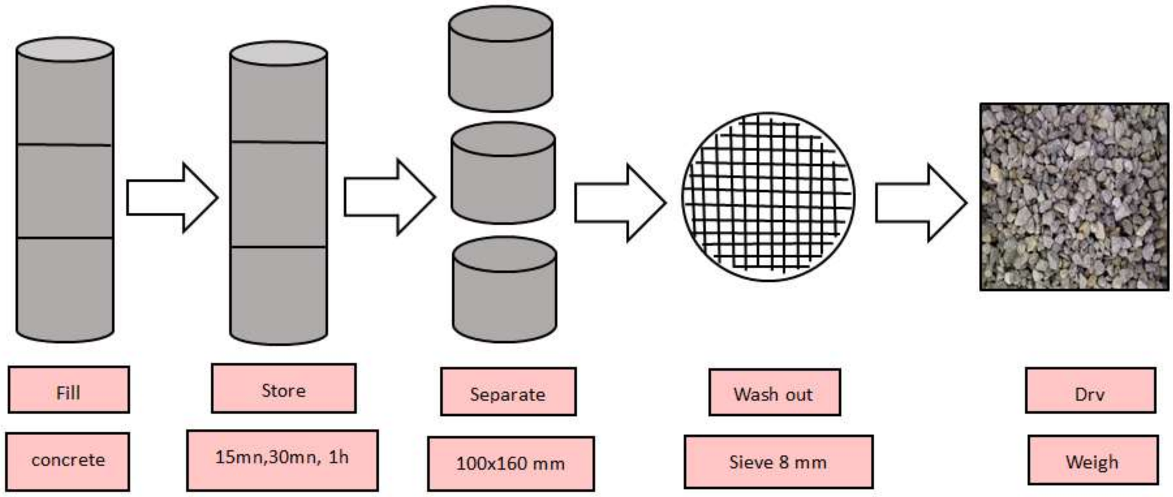


Fig.III.7. The procudure of the test ' The cylinder column segregation test '

III.4.4. Concrete Mixing Procedure

All the mixtures were mixed in a vertical-axis concrete mixer with a capacity of 70 liters. Figure III.7 shows this mixer. The total mixing duration was 4 minutes. This was done in several stages, as described before.

Fresh concrete at the end of the mixing process was taken from the mixer for assessing its workability characteristics in a container. The fresh concrete was cast into 7×7×28 cm prismatic molds for uniaxial compressive strength and flexural tensile tests.

Compressive and tensile strength of concrete is one of the key parameters which indicates the quality of concrete in hardened state. In order to study quality self-compacting concrete in hardened state along with other important parameters, Compressive and Tensile Strength of SCC mixes was measured through tests. As discussed earlier, two different case studies were considered. We made three rectangular pieces of concrete from each mix to test its compressive and tensile strengths after 3, 7, and 28 days of water curing. We poured the self-compacting concrete models in a vibration-free environment. We properly greased the molds before casting to facilitate their easy disassembly. We removed the models from their molds after 24 hours of casting and placed them in a curing tank in the lab, maintaining a temperature of 18 to 20°C. After 24 hours of casting. They were then left in the water tank for 3, 7, and 28 days to cure.

Fig.III.8. Image of the concrete mixer used

Fig.III.9. Machine and device for measuring compressive strength

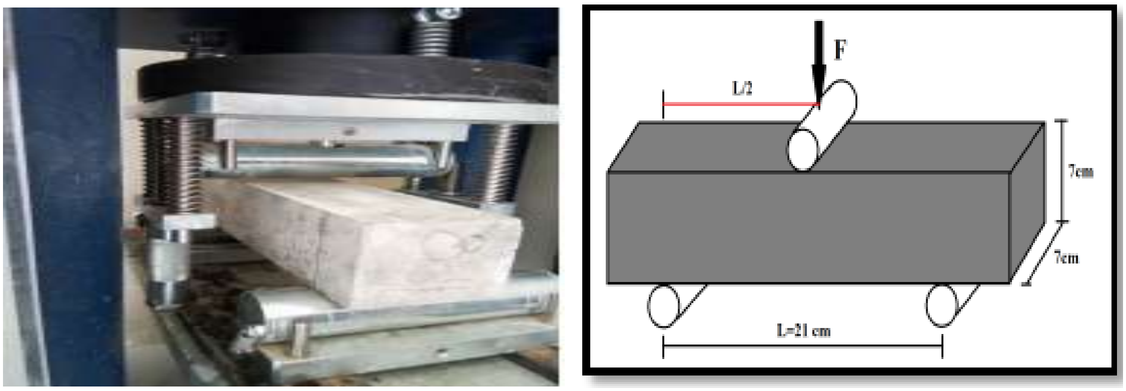


Fig.III.10. Static diagram and device of the bending tensile test

Fig.III.11. Image of test tubes stored in water

III.5. Conclusion

This chapter was supposed to answer the main objectives stated in the thesis. We have deeply gone into the experimental procedures that included the characterization of the various materials employed in the different formulations and the preparation of SCC mixtures with various percentages of VMA. Emphasis was given to the optimization of the performance of concrete through variations of the percentage of VMA with a view to reach an understanding of its impact on rheological properties as well as the workability in general.

In this chapter, we explained all the experiments carried out: tests on the workability of SCC, and the test of static segregation that evaluates the uniformity of aggregate distribution in concrete against segregation. Besides, we also conducted some mechanical tests of strength, such as compressive strength and flexural tensile strength experiments, to research the structural performance of SCCs with variable conditions of stress.

Detailed presentation and interpretation of the results obtained from such experiments will be shown in the next chapter, by studying how the viscosity-modifying agent influences SCC fresh and hardened performances. The formulation of conclusions on the variation of workability and stability provoked by the application of diverse VMA dosages, besides the changes of mechanical properties, will be allowed. It will be fundamental for understanding the role of VMA in view of enhancing the quality of SCC for practical applications in constructions.

Chapter IV: Results and discussion

IV.1. Introduction

In this context, the main goal of this thesis is to investigate the influence of different types and dosages of VMA on fresh and hardened properties of SCC. In this framework, this paper will discuss the VMAs' roles in determining rheological properties such as flowability, stability, and resistance to segregation, as well as mechanical properties including compressive strength and flexural tensile strength. Workability tests, static segregation tests, and mechanical performance tests were conducted for the different test series to develop an optimum SCC formulation.

This chapter will dwell on the details of methodology, experimental design, and a real-time and in-depth analysis of the results that give insights into how VMA can bring improvement in quality and performance in SCC for practical applications in real construction. This study intends to add to the knowledge base in the formulation of SCC by recommending guidelines on workability and durability in concrete structures.

IV.2. Characterization of fresh concretes

IV.2.1. First set (VMA is variable)

For the first set, SCC mixtures must be very well validated by three basic tests: flowing time test, slump flow test, and T500 test. In fact, these tests must be carried out to validate SCC mixtures in regard to the performance that is required both in terms of workability and stability.

IV.2.1.1. Workability of the SCC for the first set

The test data obtained from the flowing time test, slump flow test, and T500 is plotted in graphical form in Figures IV.1 and IV.2, to clearly present the performance characteristic of each mixture. In particular, EFNARC demonstrated that for the concrete to be considered an SCC, the value of slump flow must be between 600 mm and 750 mm. Values higher than 750 mm may segregate the concrete and thus damage its structural integrity, whereas values below 600 mm can indicate low flowability, which will not allow the concrete to pass through heavily congested reinforcement bars. Thus, slump flow values are needed to be within this range to enable obtaining the best performance of SCC for the various construction applications.

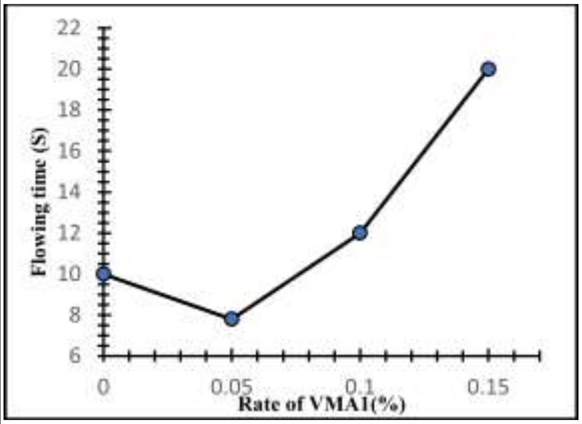


Fig.IV.1.a: Flowing Time Vs Rate of VMA1

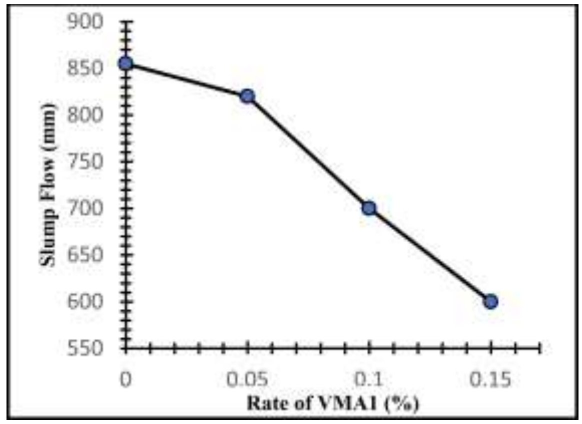


Fig.IV.1.b: Slump Flow Vs Rate of VMA1

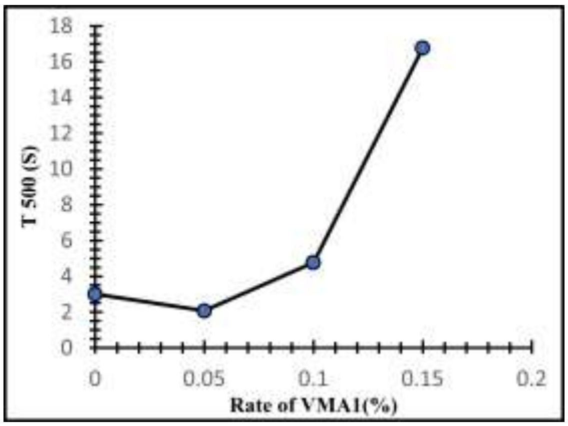


Fig.IV.1.c: T500 flow time Vs Rate of VMA1

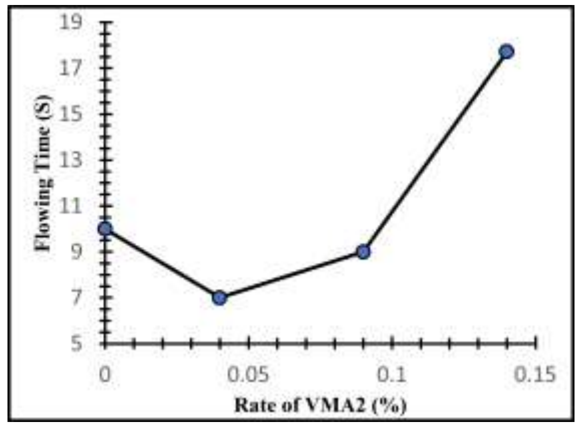


Fig.IV.2.a: Flowing Time Vs Rate of VMA2

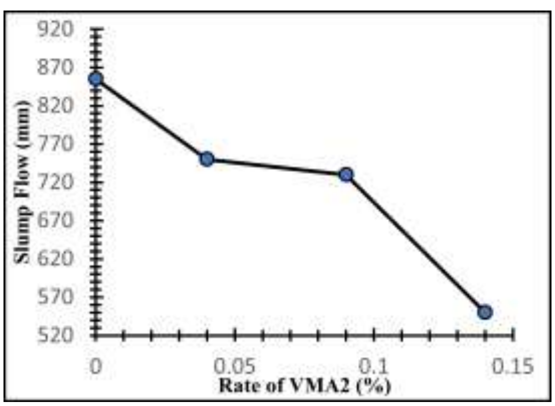


Fig.IV.2.b: Slump Flow Vs Rate of VMA2

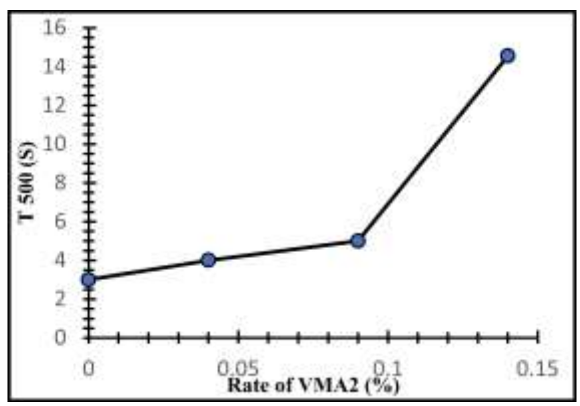


Fig.IV.2.c: T500 flow time Vs Rate of VMA2

The graphs in Figures 1.a and 2.a show that the flowing time depends on the amounts of VMA1 and VMA2. The flowability gets better as the amounts of VMA1 and VMA2 go up. This means that when the amount of cement used is low, the thickness of the concrete is also low, and the concrete tends to flow easily when it's put down on its own weight. At this point, the mix has a lower viscosity, which lets it flow faster. This means that the SCC would be easy to place and fill without having to be mechanically compacted (Prakash Nanthagopalan, 2010) (Karimi, 2021).

But after a certain amount of VMA, the curves jump up a lot, which shows that the moving time has increased. This shows that as the amount of VMA added goes above a certain point, the mixture keeps getting thicker and thicker, making it harder for it to move. As the viscosity goes up, the mix moves more slowly, which shows up as more flowing time and, in turn, less workability of the material. This trend shows that the viscosity-changing agents are very important because the amount of them that is needed to make the SCC more stable against segregation should be kept below a certain level, above which the lack of flowability is clear. In SCC, the viscosity and flowability should be just right. This is because the concrete needs to be able to flow easily enough to get through crowded reinforcements and fill difficult formwork, but it also needs to stay homogeneous and not separate (Khayat K. , 1998).

By this, we can say that the amount of VMAs used is important for finding the right mix between stability and flowability in SCCs. At smaller doses, they can improve flow, but at higher doses, they could make the mix harder to work with, which is the most important thing about SCCs. So, the right amount of VMA is one of the most important things for SCC to have the service life it's supposed to have while also being easy to use to keep its shape.

The slump flow curves in Figs. 1.b and 2.b show that as the VMA dosage goes up, the horizontal spread of all the concrete mixes keeps going down. One of the most important ways to tell how well concrete can flow and spread horizontally without any outside pressure is to do a slump flow test. The slump flow number goes down as more VMA is added because the concrete becomes less fluid and much less likely to flow. This loss of flowability is because the higher VMA content makes the mix thicker, which makes it harder for the concrete to move or fill formwork with its own weight.

For smaller amounts of VMA, both VMA1 and VMA2 still have slump flow values that are within the acceptable ranges for self-compacting concrete (SCC), as stated by EFNARC (2005). SCC should have a slump flow value between 600 and 750 mm. In this range, the concrete stays fluid enough to go through small areas between reinforcements and fill complicated forms, but it also stays cohesive enough to keep the segments from separating. But when the amount of VMA added goes above a certain point, the concrete sticks together too much, which makes the slump flow values drop below what is suggested. The mix can no longer spread out easily at this point, which means that the balance between flowability and stability has been set removed (EFNARC, 2005).

The reduction in slump flow that happens when more VMA is added shows that SCC mixes need to be carefully optimized. While VMAs help keep the mix stable and even by stopping bleeding and segregation, they also make the mixture thicker, which would make it harder to work with if used too much. One of the best things about SCC is that it can flow and balance itself, but too much coherence can make that harder to do. When the slump flow decreases below 600 mm, the concrete might not be able to get through dense reinforcements or complicated formwork, which could make SCC less useful for easy placement (EFNARC, 2022) (EFNARC, 2005).

It is always important for SCC mixes to find the right balance between being stable and being easy to work with. When VMA is applied, the right amount must be used to achieve the desired unity that can stop segregation. On the other hand, too much VMA should not be used. If the dosage is too high, the mix may not be as fluid, which makes mixing harder and lowers the real performance of the building. Because of this, the right amount of VMA needs to be used so that SCC keeps its flow properties for easy placement and its stability for long-term strength and durability. In the end, the slump flow charts show how the amount of VMA has a big effect on how easily SCC flows. To keep the slump flow within the range suggested by EFNARC, the VMA dose needs to be carefully considered. Too much VMA can damage the concrete's ability to compact itself, so it's important to avoid using too much. This balance is important for making an SCC mix that can be worked with and stays stable, which is what modern building needs. (Lachemi M, 2004b) (EFNARC, 2006)

Resistance to segregation and concrete flowability are directly related to the T500 flow time, which is represented by the time it takes for the spread of the SCC to achieve a diameter of 500 mm during the slump flow test as shown in Figures 1.c and 2.c. With increased VMA dosage, the T500 time increased proportionately, showing that concrete takes time to reach a 500 mm mark. It clearly indicates that with an increased VMA concentration, the viscosity of concrete increases, hence making flow slower. The increase in T500 time reflects internal resistance within the mix, as higher viscosity reduces how easily the concrete can spread under its own weight (Andreas Leemann F. W., 2007) (Khayat KH G. Z., 1997).

The T500 results are in line with patterns observed in both the moving time and slump flow tests. This shows that adding VMAs is important for making SCC more stable and cohesive, but adding too much of it makes the mix too thick and sticky. It makes it less likely that the concrete will be able to experience the smooth, fast flow that is so important for making sure the right placement in complicated formworks or buildings with a lot of reinforcement. In fact, SCC has to keep a balance between being able to flow and being stable. The T500 test results show visually that higher VMA dosages can really help keep the mix uniform and stop segregation, but they can also have the opposite effect and make it much harder for concrete to flow, to the point where it doesn't meet the minimum performance requirement for SCC.

In other words, the T500 flow time curves give insight into how VMAs influence the workability of SCC: while the cohesion and stability that VMAs impart are positive contributions to the mix, an over-increasing dosage of the same generates a concrete which is overly viscous and slow in flowing, which negatively affects its self-compacting properties. These results show the importance of fine-tuning the dosage of VMA to obtain flowability and structural integrity in SCC.

Regarding Self-Compacting Concrete (SCC), "favoring diameter overflowing time" means putting more emphasis on the size and shape of the formwork or the spacing between the reinforcements to make sure the concrete flows and is compacted properly, rather than just paying attention to how fast the concrete is poured or flows. Self-Compacting Concrete is made to flow and fill formwork without mechanical shaking. It does this by being very stable and fluid. By using a bigger diameter or spacing in the formwork or reinforcement, you can make sure that the SCC can flow easily, reach all the corners, and be compacted evenly without any separation or blockages. This way of doing things makes the end structure better because it lowers the chance of voids or honeycombing. To keep the desired flowing time and make sure the concrete keeps its self-compacting qualities, however, changes may need to be made to the mix design or the pouring process. In the end, this approach puts more emphasis on the quality and consistency of the structure than on how quickly it is put down. This is important for making sure that the concrete elements are permanent and free of mistakes.

IV.2.1.2. Static segregation index for the first set

The Is value refers to the segregation index, and it talks about the uniformity of distribution of coarse aggregates in concrete over time. The lower the value, the better the homogeneity, and the lesser the segregation of concrete. The segregation index curves for various SCC mixes represent the change that aggregate distribution goes through with time.

The static segregation test results bring out the importance of optimizing the VMA dosages so that well-balanced SCC mix is obtained. A low segregation percentage indicates better dispersion of aggregate, which is responsible for the quality and durability of concrete. Opposite to that, larger segregation percentages show improper distribution of aggregate, which negatively influences the performance of concrete. Accordingly, proper balance of flowability and stability is required to minimize segregation while deliver the promised workability and long-term performance by SCC.

The curves plotted in Figures 3.a through 3.g represent the static segregation index, which illustrates how the distribution of coarse aggregates within SCC changes with time and provides a distinct quantitative measure of the concrete's resistance to segregation. The segregation index defines the relative separation of the coarse aggregate from the cement paste matrix; hence, the lower the segregation indices, the better the homogeneity of concrete. Additionally, it shows that the large aggregates are evenly spread in the mix, as there is no obvious pattern for them to settle to the bottom or rise to the top. But making sure they are suspended correctly is very important for the quality, strength, and longevity of the concrete (Karimi, 2021) (Khayat Kamal, 2004) (Khayat Kamal Y. V., 2007).

Based on these figures, it's clear that SCC mixes with the right amounts of VMA have segregation scores that keep going down over time. This means that VMAs are very important for keeping concrete stable and cohesive because they keep the coarse pebbles from separating from the fine particles and cement paste. That mix with a low segregation index will not be able to lose its uniformity, which is very important for the structure's includes over time. Putting the aggregate in the right places is important for making sure that the strength of the concrete is spread out evenly and there are no weak parts.

On the other hand, mixes with either too little or too much VMA have higher segregation indices, which show that the coarse aggregate is separating. If there isn't enough VMA in the mixture, the aggregates may not be able to stay suspended. They will settle to the bottom of deep applications or mixtures that move easily. This will make weak spots in the concrete because the lower layers will have too many aggregates and the top layers will have too much cement paste. This will make the strength not spread out evenly. When too much VMA is added, on the other hand, the mix becomes too thick, which can bring coarse grains to the surface or stop them from moving, making the concrete less consistent in some places (Lin Shen H. B., 2015).

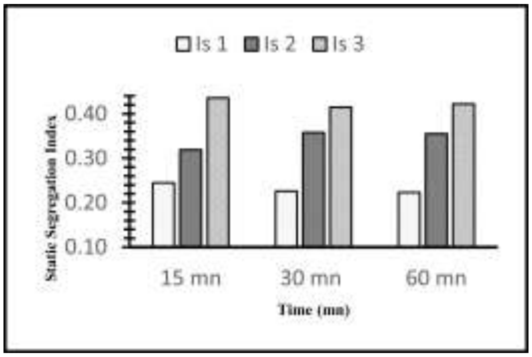


Fig.IV.3.a: Static Segregation Index Vs Time for FTM

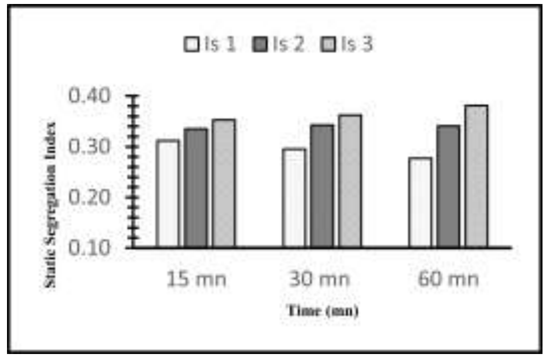


Fig.IV.3.b: Static Segregation Index Vs for SCC1

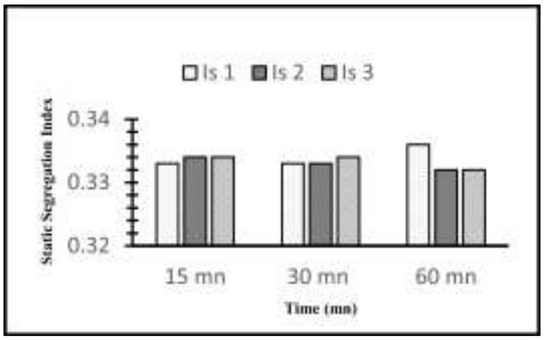


Fig.IV.3.c: Static Segregation Index Vs for SCC2

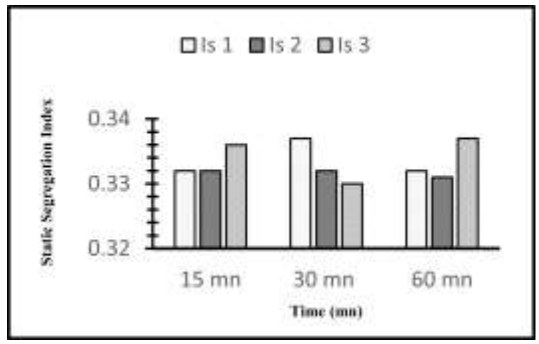


Fig.IV.3.d: Static Segregation Index Vs for SCC3

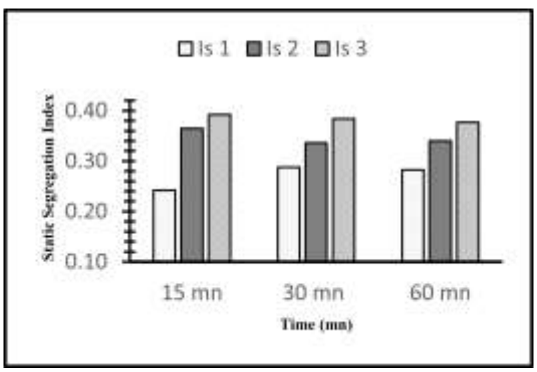


Fig.IV.3.e: Static Segregation Index Vs for SCC4

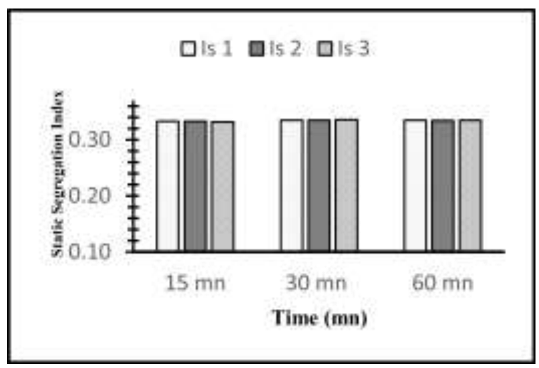


Fig.IV.3.f: Static Segregation Index Vs for SCC5

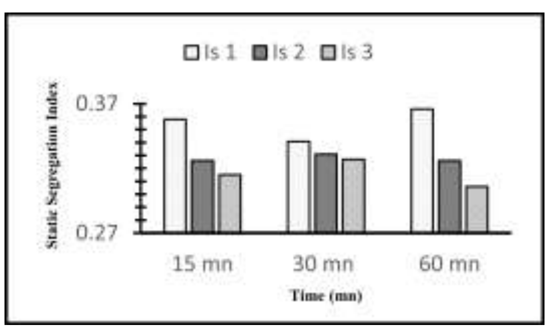


Fig.IV.3.g: Static Segregation Index Vs for SCC6

So, the static segregation index graphs show how important it is to get the VMA dosages just right in SCC. This is because getting the dosages just right lets you control segregation. In this case, VMAs need to make sure that the mix's viscosity is just right—it should be thick enough so that the aggregates don't sink or float, but not so thick that it makes it hard to place and move. This balance is important for both making the structure workable and making sure it stays strong over time. A well-mixed SCC will be the same when it is placed, when it sets, and when it hardens. This means that the building will have the same mechanical properties (Rols, 1999).

Lower segregation indices are important for keeping the look and surface quality of SCC and, more specifically, for exposed concrete buildings. They make sure that the strength is spread out evenly. Segregation could lead to problems on the surface like honeycomb structure or bleeding, which can show aggregates or cause the cement paste to collect irregularly on the surface. This not only changes how the finished structure looks, but it also makes it less durable because faults like these can let water and other harmful outside forces in (Grabiec, 2013) (Khayat K. H., 1998).

IV.2.1.3. Percentage of static segregation for the first set

SI, which is the percentage of segregation that describes, as a function of time, the uniformity and dissemination pattern of coarse aggregates within the concrete. Herein, the lower values mean homogeneity and lower segregation percentage. Fig.IV.4 (a and b) Percentage of static segregation (Hassan El-Chabib, 2006).

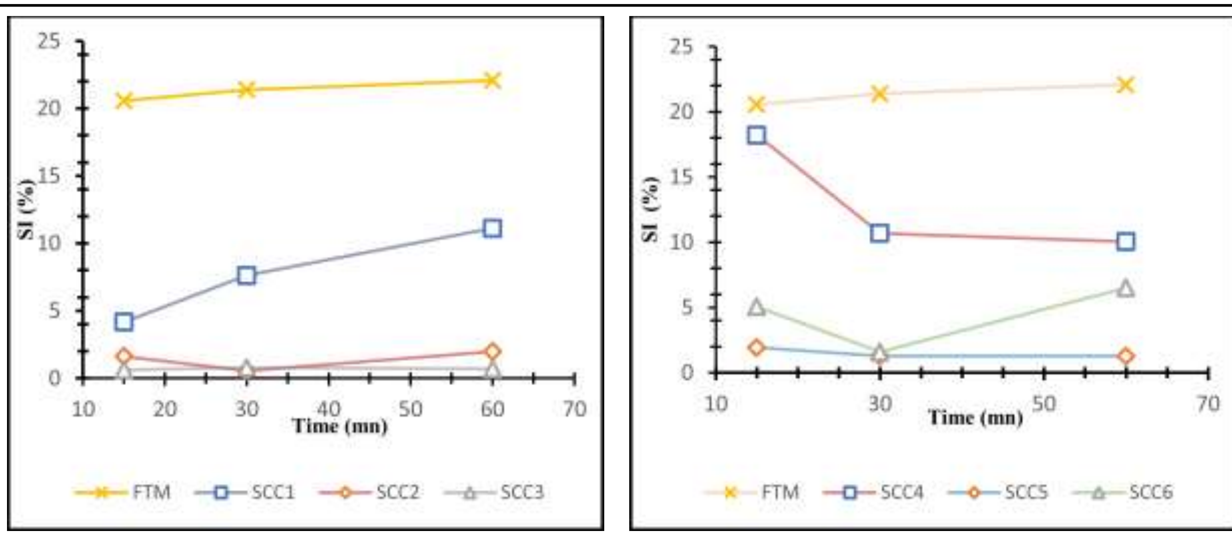


Fig.IV.4.a: %Static Segregation Vs Time for VMA1 Fig.IV.4.b: %Static Segregation Vs Time for VMA2

As shown in Figures 4.a and 4.b, the proportion of static segregation over time was used to measure the level of segregation seen in different mixes. These results show that segregation may get worse over time for VMA1 and VMA2. However, the rate of segregation is better controlled in mixes that have the right amount of VMA. It is better for coarse stones to be spread out, which would reduce settling, if the segregation percentages are low. This characteristic is very important for keeping the quality and durability of SCC high. High percentages only show that using the wrong amount of VMA causes the aggregate to be poorly distributed, which lowers total performance (Khayat Kamal, 2004) (Khayat Kamel, 2000) (Mesbah H.A., 2011).

IV.2.1.4. Hardened proprieties for the first set (compressive and tensile strength)

Compressive strength and tensile strength are two of the most important qualities that determine how well a material, like concrete, works mechanically. Compressive strength is a material's ability to hold loads that cause it to shrink. Because of this, it is very important for building parts that have to hold heavy loads, like columns and supports. In most cases, it is found by putting a compression force on a piece of concrete until it breaks. Tensile strength, on the other hand, measures how well a material resists forces that try to pull it apart. Even though concrete has a very high compressive strength, it has a relatively low tensile strength. This means that when it is extended, it is likely to fracture.

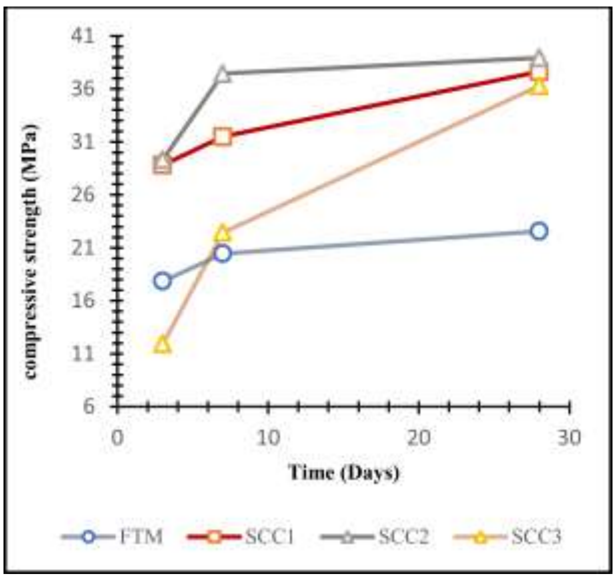


fig.IV.5.a: Compressive Strength Vs Time for VMA1

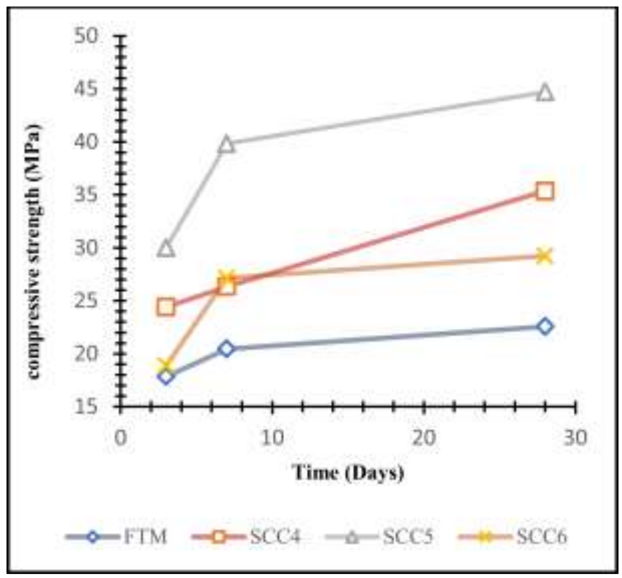


Fig.IV.5.b: Compressive Strength Vs Time for VMA2

With different amounts of VMA, Figures 5.a and 5.b show the SCC's compressive strength graphs and how its strength changes over time. As expected, the compression strength goes up as the material cures. But it looks like the amount of VMA also has an effect on building power. When the amount of VMA used is low, the compressive strength is at its best because the concrete stays flexible enough to properly pack down and fill the mold. But when VMA is used in larger amounts, it typically slows down the growth of compressive strength. This could be because the viscosity has gone up, which stops the concrete from compacting all the way and leaves tiny holes that weaken it. From these data, we can see that the right amount of VMA is needed to get the best workability and structural performance (M. Nehdi, 2004) (R. Ilangovana, 2008).

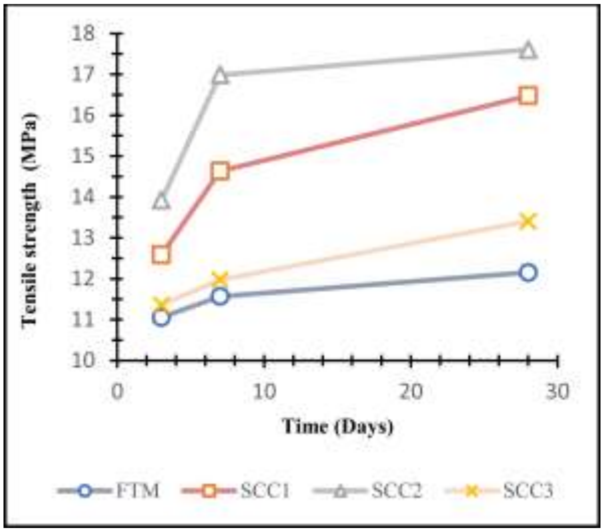


Fig.IV.6.a: Tensile Strength Vs Time for VMA1

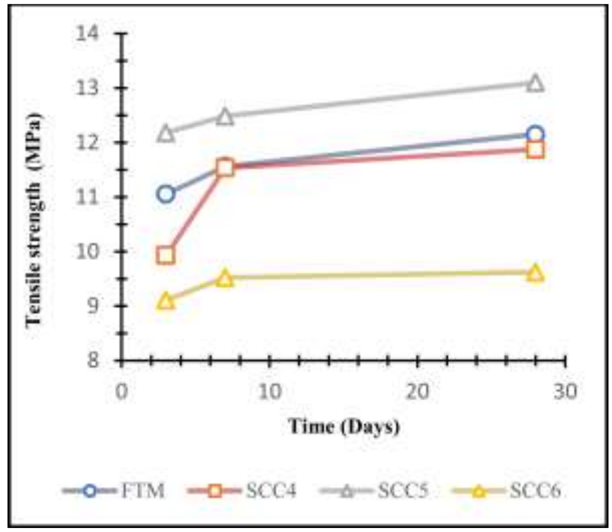


Fig.IV.6.b: Tensile Strength Vs Time for VMA2

In the same way that the results for compressive strength show positive curves, the results for tensile strength growth over time show positive curves for each series in Figures IV.6.a and IV.6.b. Tensile strength is a key factor in figuring out how hard it is for concrete to crack under stress. The results show that the best amounts of VMA give the mix a higher tensile strength because they make it more stable. However, using too much VMA can lower the tensile strength because the mix may be too cohesive for the stones and cement matrix to form a strong connection. This shows once more how important optimization is for making sure that SCC flows and compacts properly while also building up the right amount of power for long-term use.

When the amount of VMA in the SCC mixture is changed, these figures show how difficult it is to find the right balance. VMA is needed to keep the mix stable and stop it from separating, but too much of it can make it harder to work with, slow down the flow rate, and damage the mechanical qualities. These results show that too little or too much VMA hurts the ability to work with and stop segregation in SCC, as well as its compression and tensile strengths. For this reason, figuring out the right amounts of VMA and SP to use is an important part of designing an SCC mix that can give great flow and durable structural stability in the real world (Kanellopoulos, 2012).

IV.2.2. Second set (SP is variable)

These gradual increases in dosage in the SP were intended to establish an optimum dosage that would ensure a good balance between workability and stability without impairing structural integrity.

IV.2.2.1. Workability of the SCC for the second set

The results of the flowing time test and slump flow test, together with the results of the T500 test, are graphically presented in Figures IV.7 and IV.8, respectively, and give an overall view of the performance characteristics of each concrete mixture. These figures will provide a valuable insight into how each mixture behaved under different conditions.

Also, the flowing time shows how smooth and easy the concrete mix is to work with; it goes down as the amount of SP goes up for both VMA1 and VMA2. That means that the general viscosity of the concrete would go down. Adding more SP to the mix makes the concrete flow more easily, which makes it easier to work with. In other words, the superplasticizer works by lowering the friction inside the mix. This will make it easier for particles to move around, which will make the mix smoother. This effect is a little stronger for VMA1 at higher SP doses than for VMA2. This means that using VMA1 and SP together causes a bigger drop in viscosity. Adding more SP will not affect how easily the concrete flows, though, after a certain amount has been added. This would show that the mix has hit its maximum workable fluidity, and adding more SP won't help the flow as much as it used to.

The predicted behavior can be seen in the slump flow curves, and adding more SP makes the slump flow go up for both VMA1 and VMA2 mixes. The more SP that is added to the mix, the more flexible the concrete will be, and the more surface area the SCC will be able to spread out when it is put through this test. This is because the superplasticizer lowers the SCC's internal resistance. For VMA2, the slump flow is over 750 mm at higher SP values, which could mean that the mix is too fluid and there are chances of segregation. With such a high flowability, large aggregate pieces may separate from the paste, which would make SCC less strong. VMA1, on the other hand, had a bit better control over the flow, staying within the range of 600–750 mm that is suggested for slump flow in SCC mixes to keep a good balance between flowability and stability. This difference in dosage shows that the SP dosage needs to be just right so that the concrete is fluid enough to be poured without flowing too fast, which could cause the aggregates to separate, which is bad for the mix's stability and consistency (EFNARC, 2002) (EFNARC, 2005).

Adding more SP clearly makes the T500 flow time curves go down. These curves show how long it takes for the concrete to reach a width of 500 mm during the slump flow test. It takes less time for the mix to hit the 500 mm diameter when more SP is added. This is because higher doses of SP make the mix more flowable, which means it spreads faster. This shorter flow time shows that the superplasticizer lowers the friction inside the concrete, making it flow more easily. The flow time went down faster for VMA1 than for VMA2. This shows that the mix with VMA1 is very good at improving the flow, especially when SP levels are high. This might be because VMA1 reacts with the other ingredients in the mix in a way that allows for more viscosity reduction when higher doses of SP are added.

If, on the other hand, the flow time gets too short, it could mean that the concrete is moving too quickly, which could cause problems like segregation or bleeding. The heavier aggregates separate from the paste, which is called segregation. Bleeding is when water rises to the top too quickly. Both of these things make the mix less stable and less effective over time. Adding more SP makes the mix run more easily, but care must be taken not to make the mix too fluid, as that could ruin the consistency and strength of the concrete (Xie Y, 2005) (Khayat K., 2003).

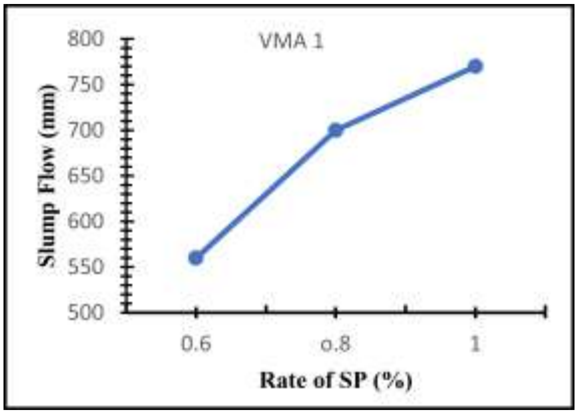


Fig.IV.7.a: Flowing Time Vs Rate of SP For VMA1

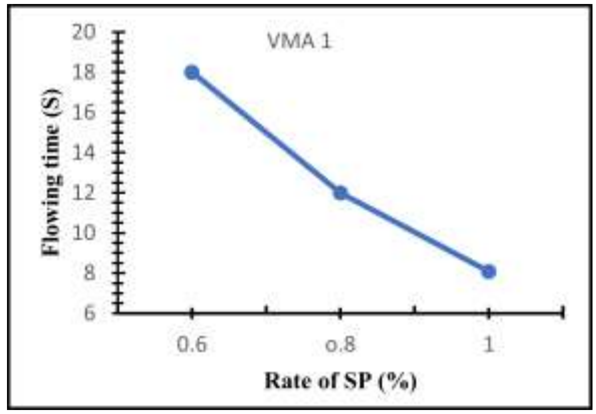


Fig. N.IV.7.b: Slump Flow Vs Rate Of SP For VMA1

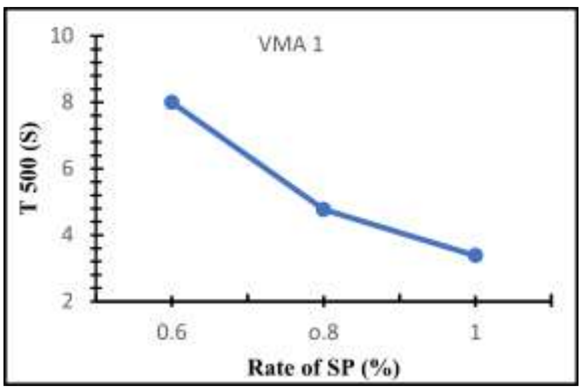


Fig.IV.7.c: T500 flow time Vs Rate Of SP For VMA1

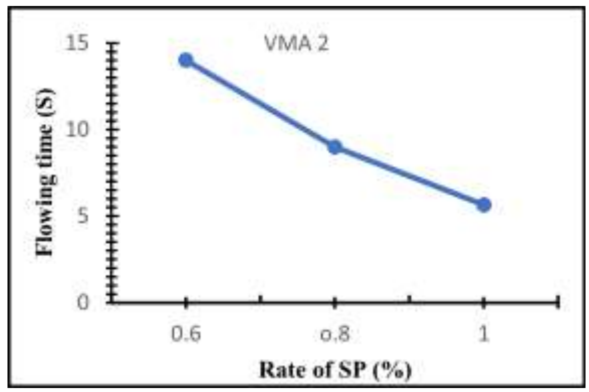


Fig.IV.8.a: Flowing Time Vs Rate of SP For VMA2

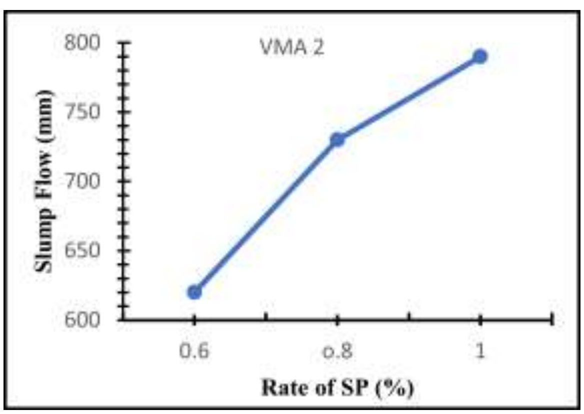


Fig.IV.8.b: Slump Flow Vs Rate Of SP For VMA2

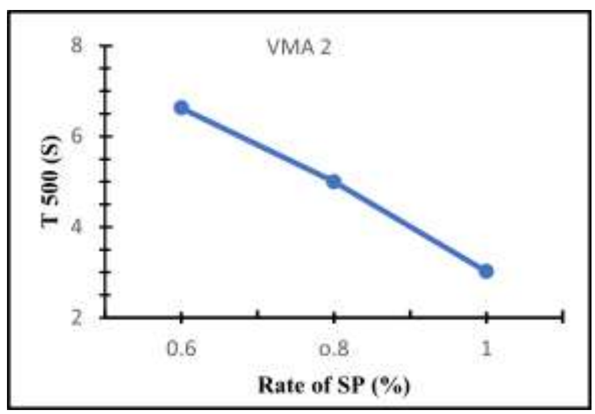


Fig.IV.8.c: T500 flow time Vs Rate Of SP For VMA1

IV.2.2.2. Static segregation index for the second set

The percentage of static segregation in Figure IV.9 and IV.10 represents the degree at which the aggregates tend to separate from the paste after some time. The greater the percentage of static segregation, the more the aggregates have separated, resulting in a possible nonhomogeneous concrete mixture that may produce weak points (Bui VK, 2002b) (Cussigh F, 2004) (Khayat K., 2003).

The static segregation index gives the measure of distribution of the coarse aggregates with time. Low values indicate better homogeneity, as can be seen from the curves, where some SCC mixes, more significantly for SCC2 and SCC5, maintain low and constant segregation indices, indicating stability of these mixes, and that the aggregate is well distributed. On the other hand, it can also be seen that mixes like SCC8 and SCC10 have shown an increasing segregation index with time, which implies that the coarse aggregates are segregating from the paste, and this can weaken the final structure. In other words, the moment the proper combination of SP and VMA dosages is attained, minimization of segregation will also be attained to ensure uniform strength in the structures.

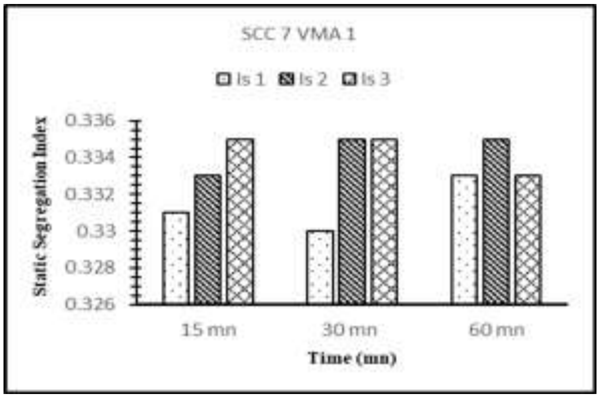


Fig.IV.9.a. Static Segregation Index Vs Time for SCC7

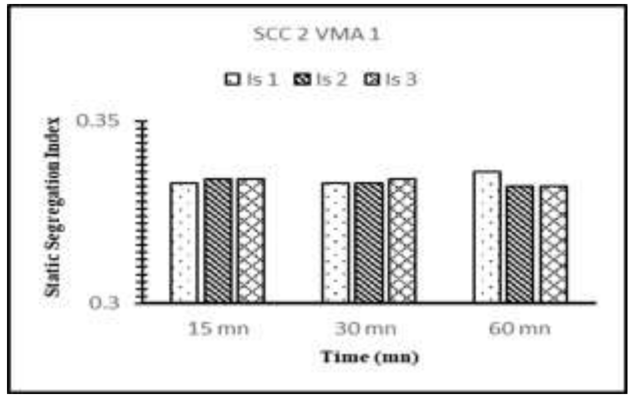


Fig.IV.9.b. Static Segregation Index Vs Time for SCC2

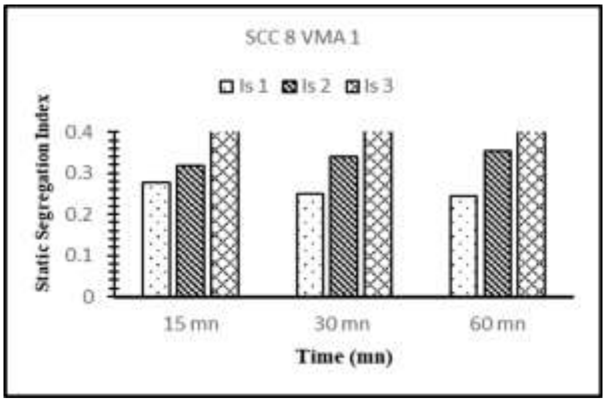


Fig.IV.9.c. Static Segregation Index Vs Time for SCC8

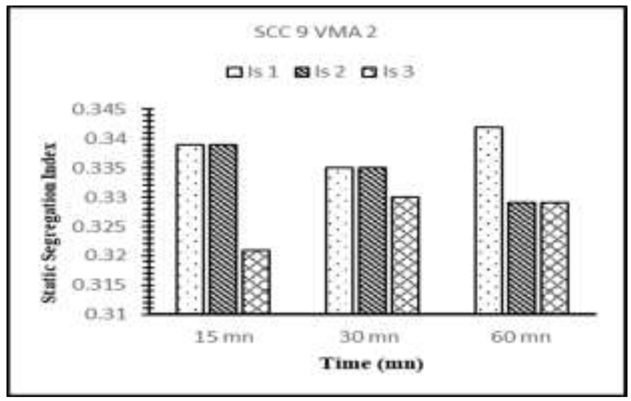


Fig.IV.10.a. Static Segregation Index Vs Time For SCC9

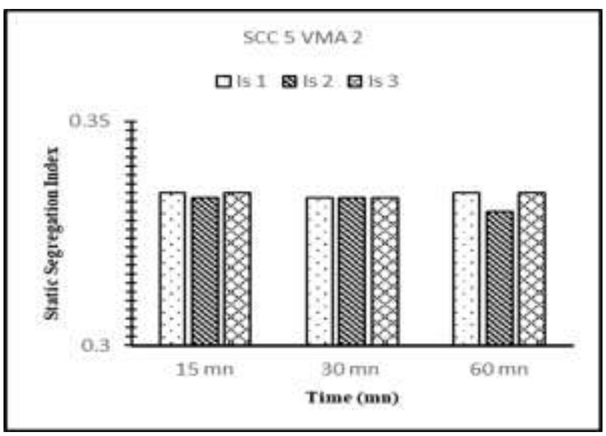


Fig.IV.10.b. Static Segregation Index Vs Time For SCC5

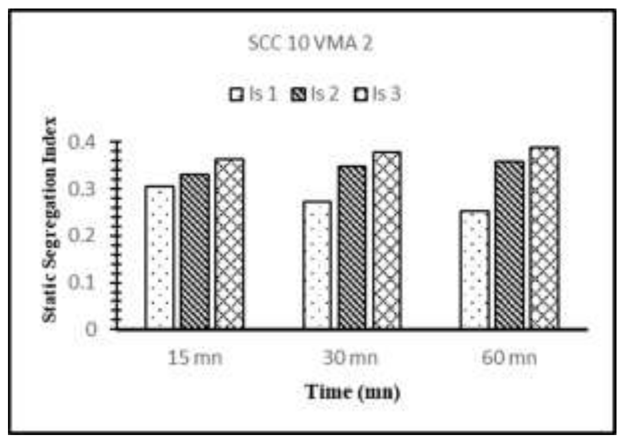
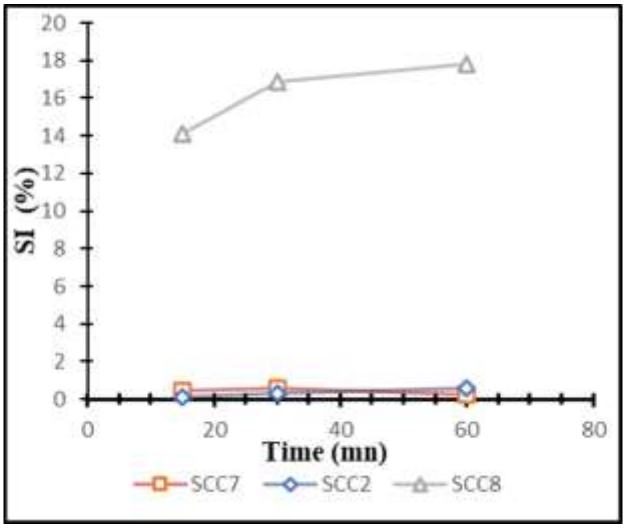


Fig.IV.10.c. Static Segregation Index Vs Time for SCC10

IV.2.2.3. Percentage of static segregation for the second set



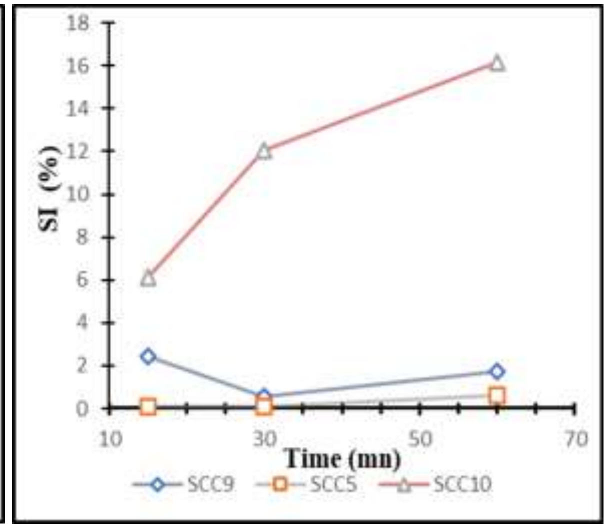


Fig.IV.11.a. % Static Segregation Vs Time For VMA1 Fig.IV.11.b.% Static Segregation Vs Time For VMA2

The percentage of static segregation gives a quantitative indication of the rate at which the coarse aggregates separate from the cement paste and may be used as an indication of the mix homogeneity. From both the VMA1 and the VMA2 curves, it can also be seen that, with increased time, some mixes tend to show an increasing level of segregation. This segregation of aggregates from the paste interferes with the homogeneity of the concrete that can eventually make an impact on its strength and durability. However, the mixes with optimal VMA dosages consistently show significantly lower percentages of segregation, pointing out the critical stabilizing role that VMAs play in respect to maintaining the even distribution of aggregates. Basically, VMA works by increasing the viscosity of the cement paste, preventing heavier coarse aggregates from settling down and lighter cementitious materials from rising up, which helps to maintain cohesion in concrete and mix stability over time.

However, adding more SP will make it easier to pour and pack, but it will also cause more segregation, which can't be fully balanced without adding the right amount of VMA. If you don't use enough VMA, high amounts of SP can make the concrete more fluid, which can make it easier for the aggregates to separate and weaken the structure. This shows how important it is to find the best amounts of SPs and VMAs in the SCC mix structure. There needs to be a balance between the VMA and the SP so that the SP has the right amount of fluidity to make the concrete easy to place and the VMA keeps the concrete stable and uniform while it is being handled and drying. It is very important to keep this balance. If you do, you will get a constant high-quality SCC mix that doesn't separate and keeps its shape for a long time.

IV.2.2.4. Hardened proprieties for the second set (compressive and tensile strength)

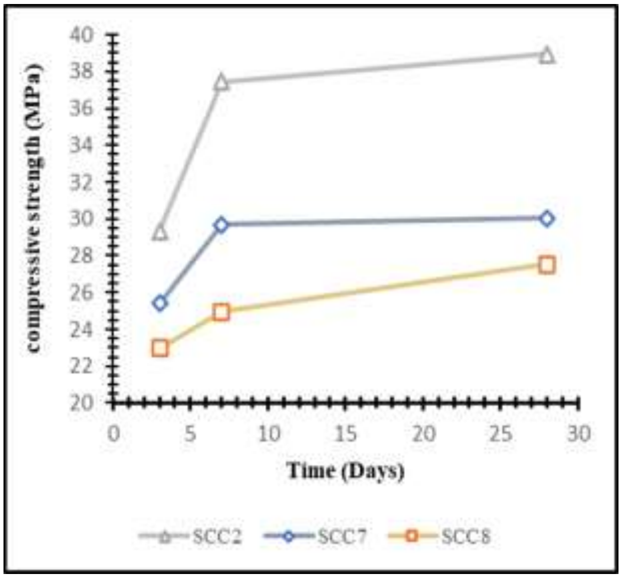


Fig.IV.12.a. Compressive Strength Vs Time for VMA1

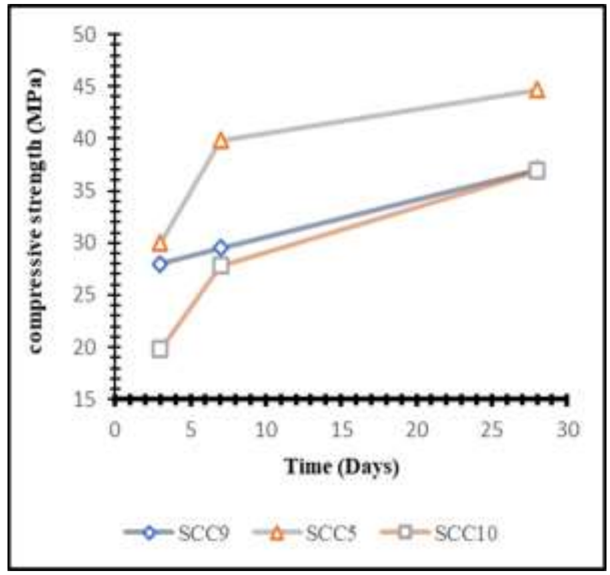


Fig.IV.12.b. Compressive Strength Vs Time for VMA2

The compressive strength curves give information on the strength gain with time for the different SCC mixes. As expected, compressive strength is seen to increase by the advancement of curing time; VMA2 generally provides higher compressive strength values than does VMA1. This can be attributed to the better stabilization of aggregates that exists in mixes of VMA2, resulting in a more homogeneous distribution and better compaction of the concrete. It is derived from this data that the optimal dosage of SP and VMA has the potential to contribute to an improved compressive strength on account of keeping concrete cohesive, with proper filling of formwork (Khayat K., 2003) (Selvamony, 2010).

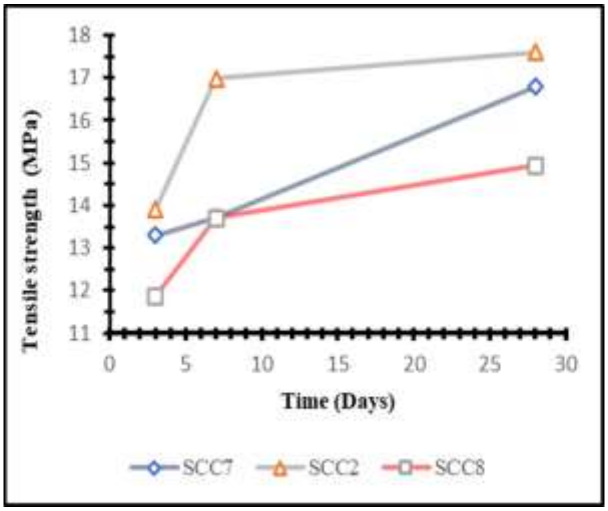


Fig.IV.13.a. Tensile Strength Vs Time for VMA1

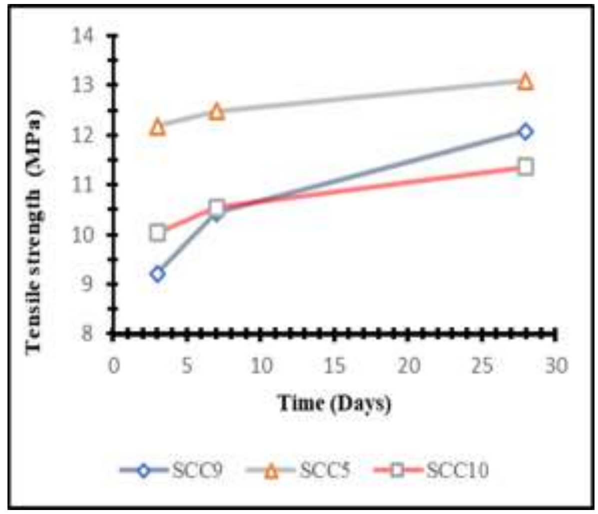


Fig.IV.13.b. Tensile Strength Vs Time for VMA2

In a similar way to the compressive strength results, the tensile strength curves show a positive development over time. Tensile strength is an important property, especially for assessment of resistance to concrete cracking. As will be shown, the results indicate that VMA2 tends to show better performance than VMA1 regarding the tensile strength development. Such a phenomenon may be accounted for by better control of segregation and improved particle distribution in the VMA2 mixes. The gain in tensile strength over time is similar for both the VMAs; however, optimization of the balance between SP and VMA has ensured that the concrete develops adequate tensile strength for its long-term durability.

IV.3. Conclusion

The result shows how important VMA agents are for improving both the flowability and stability of SCC mixes. VMA1 works better with SCC ingredients than VMA2, so bigger doses of SP make the mixture more fluid. This means that when VMA1 is more compatible, viscosity goes down and workability goes up, especially at the higher SP range. But there needs to be a perfect dose because too much SP will make the mix unstable if the right amount of VMA isn't added.

The flow has to be controlled by VMAs, but the segregations in the concrete mix also have to be controlled. The right amount of VMA and SP can keep the mix uniform so that the aggregates remain separate from each other, as shown by static segregation curves. So, this balance makes sure that the material is evenly distributed and properly compacted so that the compressive and tensile strengths are at their best. It is also very important to choose the right amount of VMA and SP to get the performance and stability you want in SCC uses.

General Conclusion
And
Perspectives

General Conclusion

This work provides a comprehensive analysis of the impacts of VMA and SP on the fresh and hardened characteristics of SCC, with the primary aim of optimizing the doses of VMA and SP to achieve an equilibrium of flowability, stability, and strength in SCC.

Results for both VMA1 and VMA2 indicate that some mixes have their segregation increased by increasing time, especially at high dosages of SP. Mixes with optimum VMA content, however, indicate much lower percentages of segregation, again reiterating the importance VMAs play in maintaining homogeneity. The VMAs improve the mix viscosity and prevent settling of coarse aggregates, hence maintaining the structural integrity and uniformity of SCC. However, with higher dosages of SPs, greater segregation may take place if the VMA support is not adequate, making the optimization of both SP and VMA levels necessary.

The optimal formulation was identified based on the parameters of flowing time, slump flow, T500 flow time, static segregation index, and the compressive and tensile strengths of SCC:

Dosage of VMA: The various percentages examined included 0.05%, 0.1%, and 0.15% of the cement mass for VMA1, and 0.04%, 0.09%, and 0.14% for VMA2. The ideal dosage of VMA is approximately 0.10% for VMA1 and 0.09% for VMA2, since this percentage range achieves a compromise between cohesiveness and flowability while maintaining mixture stability. Reduced dosages enhance flowability but may lead to segregation, whereas increased dosages significantly elevate viscosity and diminish workability.

SP Dosage: In SP, dosages ranged from 0.6% to 1.0% of the cement mass. The ideal range of 0.8% in VMA1 and VMA2 mixtures produced a suitable slump flow of 600-750 mm, as specified by EFNARC for self-compacting concrete (SCC), which can flow through reinforcement, fill formwork without mechanical compaction, and retain stability.

Flowing Time: their curves exhibited a progressive increase corresponding to the dosage of VMA. Dosages beyond the optimal range elevated viscosity and flow time, whereas slightly lower dosages facilitated faster flow. The increase in SP dosage enhanced flowability; however, excessive SP dosage led to segregation unless adequately balanced by sufficient VMA.

Slump Flow: The slump flow measured between 600 and 750 mm. The SCC, along with optimal dosages of VMA and SP, exhibited slump flow within this range, demonstrating regulated horizontal dispersion without requiring external compaction. High-dosage SCC mixtures containing VMA or SP demonstrated slump flow levels above this range due to the potential for segregation resulting from increased stability.

T500 Flow Time: The T500 flow time curves showed that as VMA dosage increased, T500 time increased, reflecting a slower flow due to higher viscosity. Optimal VMA dosage balanced this flow time, maintaining cohesiveness without hindering the mix's ability to spread.

The Static Segregation Index: indicated that low segregation values over time signified a homogenous aggregate distribution, attained with balanced doses of VMA and SP. Optimal doses of VMA can prevent aggregate settlement or flotation, hence minimizing segregation.

Excessive dosages of VMA, conversely, slowed the natural flow and caused irregularities in the mixture.

The compressive and tensile strength graphs: indicated that the optimal dosages of VMA and SP enhance strength with time, as the mixes attain a superior level of compaction and more effectively fill the formwork. Nevertheless, with elevated dosages, the rate of strength development decreased, and this process was impeded by increased viscosity. The results indicated that optimal doses enhance tensile strength, however elevated VMA diminishes the adhesion between aggregate and cement paste.

Thixotropy of SCC: Within the context of SCC, at dosages of approximately 0.10% for VMA1 and 0.09% for VMA2, thixotropy is considered to have been fairly effectively optimized. In spite of the fact that these doses cause the concrete to become fluid when shear force is applied, they allow the concrete to keep its shape while it is at rest without separating. Therefore, thixotropy is encouraged in such a way that the SCC is solid and cohesive when it is at rest, but it is able to flow easily through reinforcement and formwork when it is being set. Controlling the dosage of VMA in such a wise manner allows for the development of thixotropy, which is necessary in SCC in order to offer stability with a reduced possibility for segregation while maintaining workability.

When it comes to obtaining suitable workability, stability, and mechanical performance of self-compacting concrete, the results strongly stressed that the balance between viscosity-modifying agents and superplasticizers is a vital key to success. It is one of a kind due to the fact that it flows under its own weight without segregation and does not require mechanical compaction. This makes its formulation especially sensitive to the interactions that occur between VMAs and SPs. The primary roles of VMAs are to raise the viscosity of the concrete mixture, which in turn provides stability against the segregation of aggregates. Additionally, VMAs are responsible for the separation of water and cement paste. While this is happening, SPs work to reduce the amount of internal friction that exists between particles, which in turn offers flowability. As a result, concrete is able to flow and spread uniformly, as well as fill complex formations.

Perspectives

- **Optimization of VMA and SP Dosages:**
    - Further research is needed to fine-tune the dosages of viscosity-modifying admixtures (VMAs) and superplasticizers (SPs) for different types of SCC mixes, considering variations in raw materials and environmental conditions.
    - Explore the use of alternative or sustainable VMAs and SPs to reduce costs and environmental impact while maintaining performance.
- **Long-Term Durability Studies:**
    - Investigate the long-term durability of SCC with optimized VMA and SP dosages, focusing on resistance to environmental factors such as freeze-thaw cycles, chemical attacks, and carbonation.
    - Assess the impact of VMA and SP on the microstructure and pore structure of SCC, which influences durability.

- **Advanced Rheological Studies:**
    - Conduct in-depth rheological studies to better understand the interaction between VMAs, SPs, and other concrete constituents, particularly at the micro- and nano-scales.
    - Develop predictive models for SCC behavior based on rheological parameters, enabling more accurate mix designs.
- **Thixotropy and Formwork Pressure**:
    - Explore the role of thixotropy in reducing formwork pressure during SCC placement, particularly in tall or complex structures.
    - Investigate the use of thixotropy-enhancing admixtures to improve stability and reduce construction costs.
- **Dynamic Segregation and Stability:**
    - Develop advanced testing methods to evaluate dynamic segregation in SCC, particularly during pumping or pouring.
    - Study the effects of VMAs and SPs on the dynamic stability of SCC under real-world construction conditions.
- **Sustainability and Green SCC**:
    - Investigate the use of industrial by-products (e.g., fly ash, slag, silica fume) as partial replacements for cement or VMAs to enhance the sustainability of SCC.
    - Explore the potential of bio-based or renewable VMAs to reduce the environmental footprint of SCC.
- **Field Applications and Quality Control:**
    - Conduct field studies to validate laboratory findings and optimize SCC mix designs for real-world construction scenarios.
    - Develop standardized quality control procedures for SCC, including real-time monitoring of fresh and hardened properties.
- **Innovative Testing Methods**:
    - Explore non-destructive testing methods, such as ultrasonic pulse velocity (UPV) or electrical conductivity, to assess the stability and homogeneity of SCC in real time.
    - Develop new test methods to evaluate the workability, stability, and mechanical performance of SCC more accurately and efficiently.
- **Experience plan software and Optimization**
    - Statistical software for analyzing experimental data, performing regression analysis, and identifying optimal mix designs.
    - Useful for designing experiments (DOE) and analyzing the effects of variables (e.g., VMA and SP dosages).
    - Helps in identifying the optimal combination of VMA and SP dosages.

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Annex

ALGÉRIE

50kg

متين

Matine

LAFARGE
Construire des villes meilleures™

Ciment portland au Calcaire

NA442 CEM II/B-L 42,5 N

Matine Ciment gris pour bétons de haute-performance destiné à la construction des Ouvrages d'Art, infrastructure et superstructure pour bâtiments

Matine
NA442 CEM II/B-L 42,5 N

Matine est certifié, conforme à la norme Algérienne (NA442 – 2013) et Européenne (EN 197-1)

AVANTAGES PRODUIT

- Une résistance initiale élevée pour vos ouvrages nécessitants un décoffrage rapide
- Favorise la maniabilité du béton et le maintien de sa rhéologie
- Une Classe Vraie qui offre une haute performance au béton.
- Meilleure durabilité du béton.

A member of LafargeHolcim

NOTICE TECHNIQUE — 2 1 1 9

MEDAFLOW 30

Conforme à la norme EN 934-2:TAB 1, TAB 3.1 ET TAB 3.2 NA 774.

Super plastifiant

Haut réducteur d'eau

DESCRIPTION

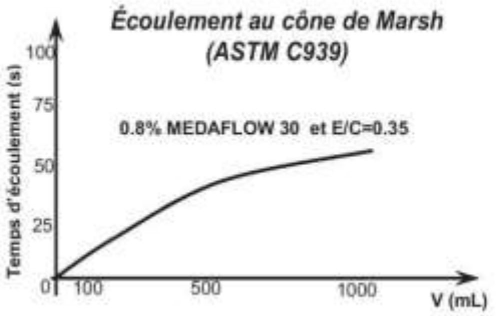
Le **MEDAFLOW 30** est un super plastifiant haut réducteur d'eau de la troisième génération. Il est conçu à base de polycarboxylates d'Ether qui améliorent considérablement les propriétés des bétons.
Le **MEDAFLOW 30** permet d'obtenir des bétons et mortiers de très haute qualité.
En plus de sa fonction principale de superplastifiant, il permet de diminuer la teneur en eau du béton d'une façon remarquable.
Le **MEDAFLOW 30** ne présente pas d'effet retardateur.

DOMAINES D'APPLICATION

- Bétons à hautes performances
- Bétons auto - plaçant
- Bétons pompés
- Bétons précontraints
- Bétons architecturaux.

PROPRIÉTÉS

Grâce à ses propriétés le **MEDAFLOW 30** permet :
Sur béton frais :
- Obtention d'un rapport E/C très faible
- Amélioration considérable de la fluidité
- Une très bonne maniabilité
- Éviter la ségrégation
- Faciliter la mise en œuvre du béton



Sur béton durci :
- Augmenter les résistances mécaniques à jeune âge et à long terme (voir tableau).
- Diminuer la porosité
- Augmenter la durabilité
- Diminuer le retrait et le risque de fissuration

Désignation	Rc (MPa)		
	3J	7J	28J
MEDAFLOW 30 (1.4%)	39.2	54.7	62.2

CARACTÉRISTIQUES

- Aspect .... Liquide
- Couleur .... Brun clair
- pH .... 6 – 6,5
- Densité .... 1,07 ± 0,01
- Teneur en chlore .... < 0,1 g/l
- Extrait sec 30%

MODE D'EMPLOI

Le **MEDAFLOW 30** est introduit dans l'eau de gâchage.
Il est recommandé d'ajouter l'adjuvant dans le béton après que 50 à 70% de l'eau de gâchage ait déjà été introduite.

DOSAGE

Plage de dosage recommandée :
0,5 à 2,0 % du poids de ciment soit 0.46 à 1.85 litre pour 100 Kg de ciment.

Le dosage optimal doit être déterminé sur chantier en fonction du type de béton et des effets recherchés.

CONDITIONNEMENT ET STOCKAGE

Les renseignements donnés dans cette notice sont basés sur notre connaissance et notre expérience à ce jour. Il est recommandé de procéder à des essais de convenance pour déterminer la fourchette d'utilisation tenant compte des conditions réelles de chantier.

Granitex
Zone industrielle Oued Smar – BP85 Oued Smar – 16270 Alger
Tél : (213) 021 51 66 81 & 82
Fax : (213) 021 51 64 22 & 021 51 65 23
www.granitex-dz.com - E-mail: granitex@granitex-dz.com

NOTICE TECHNIQUE 2 1 1 9

MEDAFLOW 30

Le **MEDAFLOW 30** est conditionné en bidons de 10Kg, fûts de 210 Kg et 240 Kg, cubiténaire 1100kg.

Délai de conservation :
Une année dans son emballage d'origine, à l'abri du gel et de la chaleur (5°C < t < 35°C).
Lors d'une exposition du produit au soleil, sa couleur est sujette à changer de ton.

PRÉCAUTIONS D'EMPLOI

Manipulation non dangereuse.
Se référer à la Fiche de Données de Sécurité disponible sur : **www.granitex-dz.com**

PV d'essais conforme aux normes, établi par le **CNERIB** en Avril 2005.

NB : Les produits à base de polycarboxylates d'Ether (PCE), exposé aux UV, changent dans la couleur mais sans aucun incident sur les propriétés et les effets de l'adjuvant.

Les renseignements donnés dans cette notice sont basés sur notre connaissance et notre expérience à ce jour. Il est recommandé de procéder à des essais de convenance pour déterminer la fourchette d'utilisation tenant compte des conditions réelles de chantier.

Granitex

Zone industrielle Oued Smar – BP85 Oued Smar – 16270 Alger
Tél : (213) 021 51 66 81 & 82
Fax : (213) 021 51 64 22 & 021 51 65 23
www.granitex-dz.com - E-mail: granitex@granitex-dz.com

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Le MEDACOL BSE

Adjuvant Pour Bétons Et Mortiers Coulés Dans L'eau

Conforme à la norme EN 934-2:TAB 4

Description :

Le MEDACOL BSE est un adjuvant en poudre destiné à la confection de bétons et mortiers coulés dans l'eau.

Domaines D'application :

• Travaux en milieux marins
• Caissons immergés
• Alvéoles pour blocs de quais
• Colmatage de cavernes pour digues à talus
• Coulis d'injection
• Bétons de pieux dans terrains absorbants

Propriétés :

Le MEDACOL BSE rend le béton plus plastique voir visqueux, ce qui facilite le bétonnage sous l'eau, sans lessivage ni ségrégation.

Avec l'ajout d'un super plastifiant, le même béton peut être pompé avec un rapport E/C très bas par rapport à un béton témoin pompé dans les mêmes conditions.

Caractéristiques :

Le MEDACOL BSE est composé essentiellement d'agents colloïdaux et de micro silice ultra fine.

• Aspect …….……........…………......... poudre grisâtre
• Densité…….................…….........……………........... 0,5

Mode D'emploi :

Le MEDACOL BSE doit être mélangé à sec avec tous les composants du béton (ciment, sable et agrégats) avant l'introduction de l'eau de gâchage.

Introduire l'eau de gâchage en une seule fois, puis malaxer pendant au moins 2 minutes pour permettre une bonne répartition de tous les constituants du béton. La consistance du béton doit être fluide ; les résultats recherchés sont :

- Étalement (table DIN) ………………..........… 600 mm
- Affaissement au cône d'Abrams .... 200 mm

Il est nécessaire de procéder à des essais de convenance afin de déterminer la quantité d'eau de gâchage nécessaire.

Consommation :

A titre indicatif, la consommation du MEDACOL BSE sera :

1- Pour béton coulé dans l'eau :

- Eau stable : 0,8% par rapport au poids du ciment
- Eau faiblement agitée : 1,6 % par rapport au poids du ciment
- Eau fortement agitée : 2,4 % par rapport au poids du ciment

2- Pour coulis d'injection :

- 0.3 à 2% par rapport au poids de ciment

Le dosage dépendra de la viscosité recherchée du coulis.

Conditionnement Et Stockage :

Livré en sacs en papier kraft de 10 kg.

Délai de conservation :

12 mois dans son emballage d'origine, à l'abri de l'humidité et de la chaleur.

Précautions D'emploi :

Manipulation non dangereuse.

Se référer à la fiche de données de sécurité disponible sur : www.granitex-dz.com

Construction Chemicals

Technical Data Sheet
for Europe, Middle East and Africa

WALOCEL™ MKX 15000 PP 20
Cellulose Ether

Product description

WALOCEL™ MKX 15000 PP 20 Cellulose Ether is a modified hydroxyethyl methyl cellulose (HEMC) .

Application / Advantages

WALOCEL™ MKX 15000 PP 20 Cellulose Ether was developed for cement spray plaster applications like one or two coat cement-based plaster and cement based lightweight plaster and for gypsum-based plaster. Usage is very multi-purpose.

It imparts good workability and enhances water retention. The selected particle size distribution helps to achieve quick dissolution. It is compatible with all conventional mineral binders and additives used in cement spray plaster and gypsum plaster formulation.

Typical Properties[1])

Form	powder
Solubility	water soluble
Viscosity[2])	13 000 to 17 000 mPa·s
pH	neutral (2% solution)
Moisture content	max. 7%

[1]) Please note that the viscosities and other values shown are typical values for your guidance. They are not to be taken as specifications and are subject to certain variability. Please consult the sales specifications for details.
[2]) 2% solution in water, Haake Rotovisko RV 100, shear rate 2.55 s^{-1}, 20°C

Health and Safety Considerations

Safety Data Sheets (SDS) are available from The Dow Chemical Company. SDS are provided to help customers satisfy their own handling, safety and disposal needs and those that may be required by locally applicable health and safety regulations. SDS are updated regularly, therefore, please request and review the most current SDS before handling or using any product. For further questions consult your Dow contact person.

Health

WALOCEL™ products have had extensive evaluation in both acute and long-term studies in a number of species, including humans. Their many years of use attest to their safety in a wide variety of applications. While the dust may cause mechanical irritation to the skin and eyes under extreme conditions, the products are considered to present no significant health hazard under normal handling conditions.

Flammability

Cellulose ether products are organic polymers that will burn when exposed to heat and a sufficient oxygen supply. Fires can be extinguished by conventional means avoiding any raising of dust by strong water jets. Dow recommends the use of water spray, carbon dioxide, or powder extinguishers.

Handling

During use or storage, safe handling is required to prevent dusts with air from reaching explosive levels as is true with other organic materials of similar particle size. When handling large quantities, local applicable regulations concerning the prevention of dust explosions should be followed. Additionally, WALOCEL™ products, like other organic chemicals, should not be stored next to peroxides or other oxidizing agents.

Spills/Housekeeping

Solutions of WALOCEL™ products are slippery. To prevent accidents, floor spills of dry powder should be swept up dry. If the spill is a viscous solution, it should be removed by further diluting with water before disposal.

Disposal

Typically, WALOCEL™ products can be disposed of by industrial incineration or in an approved landfill, providing regulations are observed. Customers are advised to review their local, state, provincial, or national regulations governing the disposal of waste materials to confirm the appropriate means of disposal in their area.

Product Stewardship

Dow has a fundamental concern for all who make, distribute and use its products, and for the environment in which we live. This concern is the basis for our Product Stewardship philosophy by which we assess the safety, health, and environmental information on our products and then take appropriate steps to protect employee and public health and our environment. The success of our Product Stewardship program rests with each and every individual involved with Dow products — from the initial concept and research, to manufacture, use, sale, disposal, and recycle of each product.

Customer Notice

Dow strongly encourages its customers to review both their manufacturing processes and their applications of Dow products from the standpoint of human health and environmental quality to ensure that Dow products are not used in ways for which they are not intended or tested. Dow personnel are available to answer your questions and to provide reasonable technical support. Dow product literature, including safety data sheets, should be consulted prior to use of Dow products. Current safety data sheets are available from Dow.

Additional Information	For more information you may call the following numbers: Europe*) +800-3-694-6367 (toll free) Italy 800-783-825 (toll free, national) Europe, Middle East, Africa +31-11567-2626 (toll call) South Africa +800-99-5078 (toll free, national) *) International toll free from Austria, Belgium, Denmark, Finland (prefix 990), France, Germany, Hungary, Ireland, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.