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**The combined effect of glass powder and marble powder on the behavior
of self-compacting concrete exposed to high temperature**

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Dedication

Praise be to Allah, by whose grace good deeds are completed and by whose help efforts are accomplished and goals are achieved.

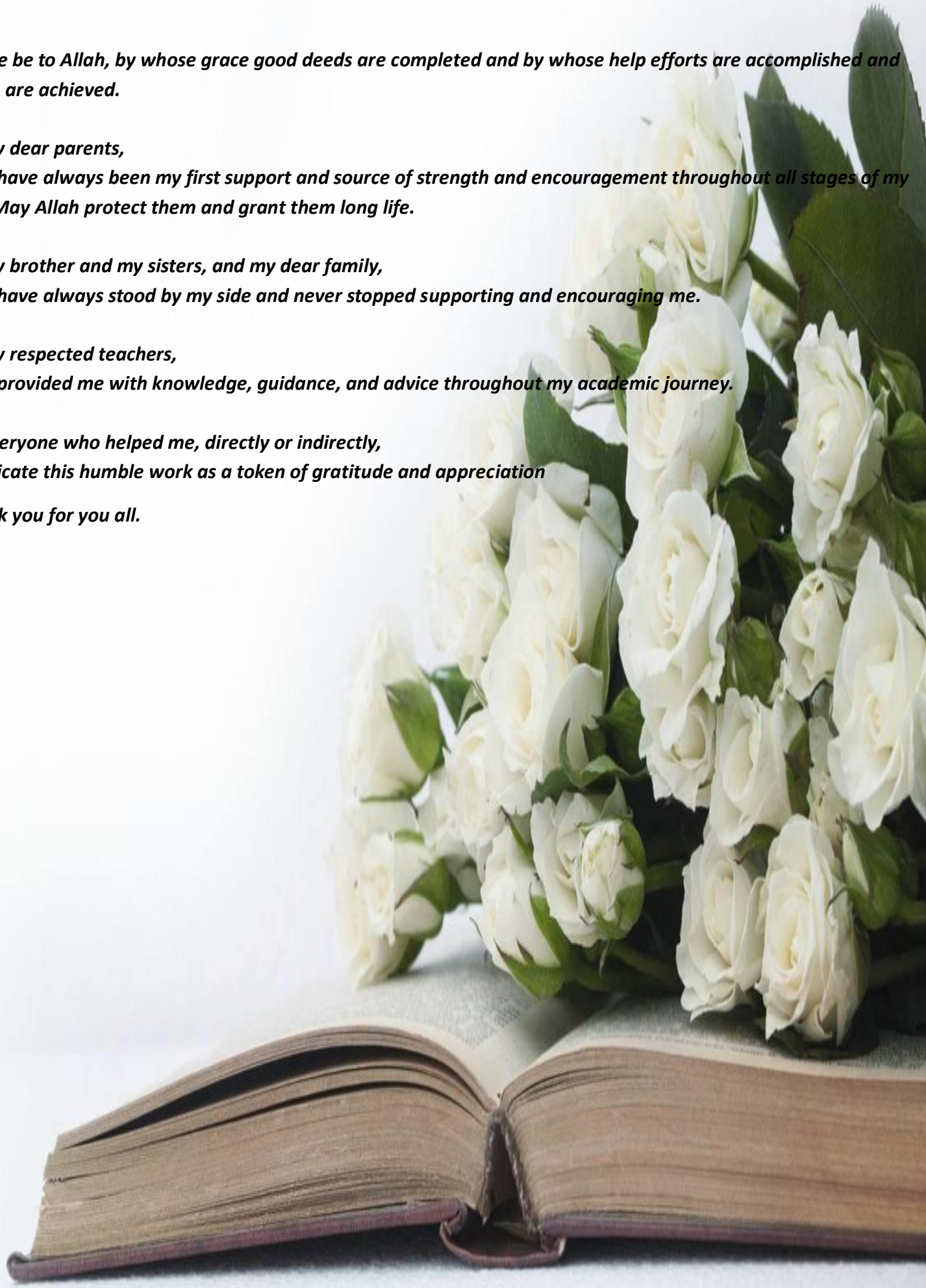
*To my dear parents,
who have always been my first support and source of strength and encouragement throughout all stages of my life. May Allah protect them and grant them long life.*

*To my brother and my sisters, and my dear family,
who have always stood by my side and never stopped supporting and encouraging me.*

*To my respected teachers,
who provided me with knowledge, guidance, and advice throughout my academic journey.*

*To everyone who helped me, directly or indirectly,
I dedicate this humble work as a token of gratitude and appreciation*

Thank you for you all.



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Abstract:

Self-compacting concrete (SCC) is a highly fluid and homogeneous concrete capable of flowing and filling formwork under its own weight, without requiring mechanical vibration.

This study aims to incorporate glass powder and marble powder into the self-compacting concrete mix design to evaluate their influence on the concrete's properties in the fresh state, particularly its fluidity and workability, as well as in the hardened state, such as its mechanical strength and durability.

The study also examines the concrete's behavior when exposed to high temperatures (100°C, 200°C, and 400°C) to assess its thermal resistance and suitability for use in harsh conditions and high-temperature environments.

Keywords: Self-compacting concrete, glass powder, marble powder, fresh-state properties, mechanical properties, durability, high temperatures.

الملخص

تهدف هذه الدراسة إلى إدماج مسحوق الزجاج ومسحوق الرخام في تركيبة الخرسانة ذاتية الدمك من أجل تقييم تأثيرهما على خصائص الخرسانة في الحالة الطرية، خاصة السيولة وقابلية التشغيل، وكذلك في الحالة المتصلبة من خلال دراسة مقاومتها الميكانيكية ومتانتها.

كما تتناول الدراسة سلوك الخرسانة عند تعرضها لدرجات حرارة مرتفعة (100°م، 200°م، و400°م)، بهدف تقييم مقاومتها الحرارية ومدى ملاءمتها للاستخدام في الظروف القاسية والبيئات المعرضة لدرجات حرارة عالية. الكلمات المفتاحية: الخرسانة ذاتية الدمك، مسحوق الزجاج، مسحوق الرخام، خصائص الحالة الطرية، الخصائص الميكانيكية، المتانة، درجات الحرارة المرتفعة.

Résumé :

Le béton autoplaçant (BAP) est un béton très fluide et homogène, capable de s'écouler et de remplir les coffrages sous l'effet de son propre poids, sans nécessiter de vibration mécanique.

Cette étude vise à incorporer de la poudre de verre et de la poudre de marbre dans la formulation du béton autoplaçant afin d'évaluer leur influence sur les propriétés du béton à l'état frais, notamment la fluidité et l'ouvrabilité, ainsi qu'à l'état durci, telles que la résistance mécanique et la durabilité.

L'étude examine également le comportement du béton lorsqu'il est exposé à des températures élevées (100 °C, 200 °C et 400 °C) afin d'évaluer sa résistance thermique et son aptitude à être utilisé dans des conditions sévères et des environnements soumis à de fortes températures.

Mots-clés : Béton autoplaçant, poudre de verre, poudre de marbre, propriétés à l'état frais, propriétés mécaniques, durabilité, hautes températures.

General Introduction:

Self-compacting concrete (SCC) is one of the most important developments in modern concrete technology. It is characterized by its ability to flow, spread, and fill formwork under its own weight without the need for mechanical vibration. This type of concrete has significantly improved construction quality, reduced defects such as honeycombing, and facilitated the casting of heavily reinforced or geometrically complex structural elements.

However, the performance of concrete can be severely affected when exposed to high temperatures. Thermal exposure leads to several internal changes, including evaporation of free and bound water, decomposition of cement hydration products, and the development of microcracks. These phenomena result in a reduction in mechanical strength, stiffness, and overall durability. Therefore, improving the thermal resistance of concrete has become an important research focus.

In this context, the use of mineral additions such as glass powder and marble powder represents a sustainable and effective solution. Glass powder, derived from crushed waste glass, is rich in silica and may contribute to pozzolanic reactions, leading to a denser microstructure and reduced porosity. Marble powder, a by-product of marble cutting and processing, acts mainly as a filler material that improves particle packing and reduces voids within the cement matrix, enhancing the overall compactness of the concrete.

When both materials are incorporated into self-compacting concrete, a synergistic effect can be achieved. Marble powder improves the granular packing and physical structure of the mix, while glass powder enhances the chemical and microstructural properties. This combination may improve both fresh properties, such as workability and stability, and hardened properties, including strength and durability.

Under high-temperature exposure, concrete undergoes different stages of degradation starting with the loss of free water, followed by the decomposition of calcium silicate hydrate (C-S-H), and finally the formation of cracks due to differential thermal expansion among constituents. The incorporation of mineral additives may help mitigate these effects by refining pore structure and improving thermal stability.

This study aims to evaluate the combined effect of glass powder and marble powder on the behavior of self-compacting concrete exposed to elevated temperatures, in both fresh and hardened states. A series of laboratory tests are conducted to assess workability, compressive strength, tensile strength, and density after thermal exposure, as well as the residual mechanical properties.

The significance of this research lies in its contribution to developing more sustainable and heat-resistant self-compacting concrete, while promoting circular economy practices through the recycling of industrial and household waste. It also aims to reduce the consumption of natural resources and improve the environmental performance of modern construction materials.

This thesis is divided into five chapters as follows:

- Chapter 1: General overview of self-compacting concrete
- Chapter 2: Waste valorization
- Chapter 3: Characteristics of the materials used
- Chapter 4: Experimental techniques
- Chapter 5: Results and analysis

Finally, in conclusion, our experimental study made it possible to develop effective SCC mix designs by investigating the role of superplasticizers and the influence of mineral additions on concrete properties.

Chapter 1:
General Information on Self-Compacting Concrete and high temperature

1.1 Introduction

This part presents a detailed overview of self-compacting concrete as a new material. It first presents the history of their development as well as their definition. This chapter summarizes the description of the constituents used in the manufacture of SCC and the characteristics in the fresh and hardened state. Finally, it highlights the innovations and advantages brought by SCC.

SCC is a material that is at the center of an important challenge to limit the arduousness of workers' work. Indeed, this form of concrete is very fluid and, as its name indicates, places itself alone in formwork due to the sole effect of its own weight. It contains two more constituents than "ordinary" concrete, which complicates the dosage of a mix. These 6 or 7 components are cement, water, sand, gravel, an additive (marble filler or corrective cement), a superplasticizer and/or a viscosity agent. The maximum size of gravel must not exceed 16 mm to be able to penetrate between reinforcement bars without difficulty.

1.2 Definition of self-compacting concrete

These concretes are special, very fluid concretes, which are placed and compacted under the sole effect of gravity, therefore without internal or external vibration, even in heavily reinforced formwork.

These concretes are obviously only qualified as self-compacting if the final hardened material has homogeneous properties (no segregation) and has very good short and long-term performance. [5]

The characteristic properties of SCC are:

- High fluidity and viscosity, with no tendency to segregate.
- Air entrainment during flow.
- Excellent ability to produce homogeneous concrete in the presence of dense reinforcement and embedded items. [5]

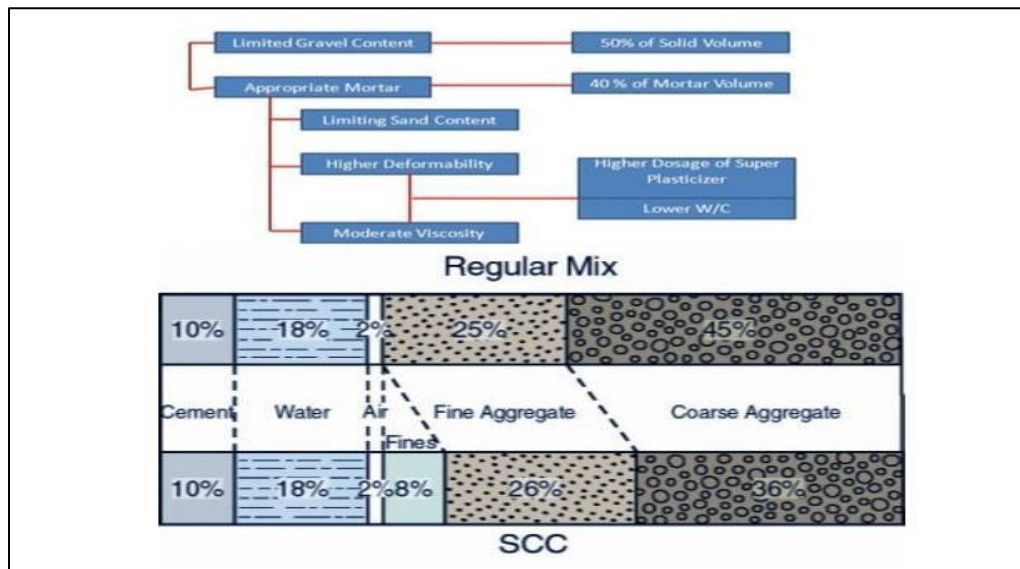


Figure 1: Comparison of the structure of SCC and OC

1.3 Field of use of SCC

SCC can be used for both horizontal and vertical structures, on all types of sites, buildings or civil engineering works and for the production of many precast concrete products [6]. Most structures can be made with SCC (walls, columns, piles, beams, floors, slabs, pavements, foundations, facade elements, urban furniture, etc.).

SCC are particularly suitable for structures where the implementation of conventional concrete is difficult, i.e., presenting:

- High reinforcement densities.
- Complex shapes and geometries: walls, curves.
- Thin and high walls: bridge piers.
- Complex walls with many embedded items or large openings.
- Architectural requirements and particular surface finish quality.

1.4 Main constituents of SCC

The constituents of SCC can be quite different from those of OC. They can differ in their proportions as well as in their choice. Given the placement method of SCC, the constituents used in the manufacture of SCC are divided, according to their use, into three categories: basic materials (cement, aggregates and mixing water), mineral additions, as well as chemical admixtures.

1.5 Basic materials

Aggregates, cement and water form the basic elements of all types of concrete. They are qualified as such because they were historically the only constituents of the concretes of our ancestors and because they still have the largest relative proportions in the SCC mix.

1.5.1 Aggregates

Rolled or crushed aggregates can in principle be used. Loose rolled aggregates have a smaller intergranular void volume, which requires a smaller amount of cement paste to fill it. However, the buoyancy of crushed aggregates in the cement paste is better, due to their larger specific surface for identical mass. In order to prevent any risk of blocking of SCC by reinforcing bars during pouring, the maximum aggregate diameter is generally limited to 16 mm. Experience has nevertheless shown that it is also possible to use aggregates of different maximum diameters. The concrete mix (gradation) is characterized by a high content of sand and fine particles. The passing at the 2 mm sieve should ideally be between 38 and 42%. Likewise, the proportion of fines (0.125mm) should not be too low, the optimum being between 4 and 8%. The choice of an appropriate continuous gradation is very important, given the high impact of void volume on the required amount of cement paste. To ensure good stability of SCC (avoid any segregation), it is recommended to choose a specially optimized sand, if necessary recomposed from several fractions.

1.5.2 Cement

In principle, all standard types of cement are suitable for the manufacture of SCC. However, the use of Portland cement (containing only clinker) gives us full latitude to vary and control the quantities of mineral additions introduced.

1.5.3 Mixing water

Any public water supply network water is suitable for the manufacture of self-compacting concrete. Recycled mixing and washing water is only suitable under certain restrictive conditions due to possible undesirable effects on concrete properties.

Given that the water dosage considerably influences the viscosity and self-compacting ability of the concrete, it is essential to deviate as little as possible from the planned value. It is thus very

important to measure and take into account the humidity of the aggregates, especially the sand. If necessary, the water content of the admixtures will also be taken into account.

1.5.4 Chemical admixtures

In order to obtain the very high fluidity required for self-compacting concrete, a fluidifying admixture of the latest generation, based on polycarboxylates, is generally used.

1.5.5 Superplasticizers

These are high-efficiency water reducers, and are generally in liquid form. They are composed of long organic molecules of high molecular weight.

The most commonly used are sodium or calcium salts of polynaphthalene sulfonate, and sodium salts of polymelamine sulfonate. Acrylate-ester copolymers or polyacrylates have recently been introduced to the market.

The mode of action of superplasticizers is extremely complex. It can be explained as follows:

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They trap a certain volume of water between the cement grains (captive water) which is no longer available to ensure good workability of the concrete.

Superplasticizers, by adsorbing on the surface of the cement grains, break this dynamic. They neutralize the different charges and give the same electrostatic charge to each cement grain. These charges of the same sign will create repulsive forces between the particles and, consequently, the dispersion of cement grains releases water which is now available to lubricate the mixture, hence the increase in workability.

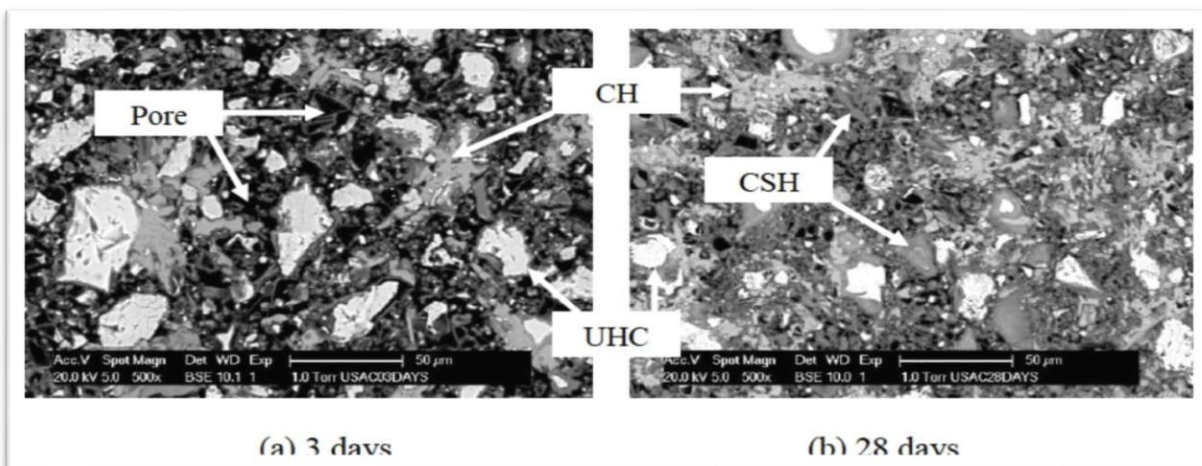


Figure 2: (a) Non-admixed cement paste, (b) Cement paste added with a superplasticizer [17]

1.5.6 Fillers

Mineral material, finely divided, intended to fill the voids left by a granular packing of gravels, crushed stones and sands.

The term filler refers to the small size of the grains that constitute it. The chemical-mineralogical nature of the filler can vary, it is generally crushed limestone but fly ash, silica fume, or a combination of these materials can be used as filler.

1.6 Characterization of self-compacting concrete

1.6.1 Characterization tests in the fresh state

1.6.1.1 Test evaluating fluidity (spread)

Self-compacting concretes formulated must satisfy several standardized tests [8-10] which allow their main properties to be characterized. The values recommended by standard EN 206 – 9 [11]:

- The mobility of self-compacting concrete in an unconfined environment is a test carried out to measure the slump flow with the Abrams cone (slump flow, SF). This test is completed by measuring the spread time for a defined diameter of 500 mm (T500) according to standard EN 12350 – 8 [8].
- The segregation resistance of self-compacting concrete is expressed by the sieve stability test according to standard EN 12350 – 11 [9].
- The mobility of self-compacting concrete in a confined environment is carried out by the filling ratio test in the L-box (PL), according to standard EN 12350 – 10 [10].
- Two other non-standardized tests, as rheological parameters, were chosen: viscosity (μ) according to the Sedran model [12] and the yield stress (τ) according to the LCPC box method [13] described successively in appendices 2 and 3. Each test is reproduced three times on three different batches of the same compositions.

The following figures clearly represent the slump flow test.



Figure 3: Slump flow test with Abrams cone.

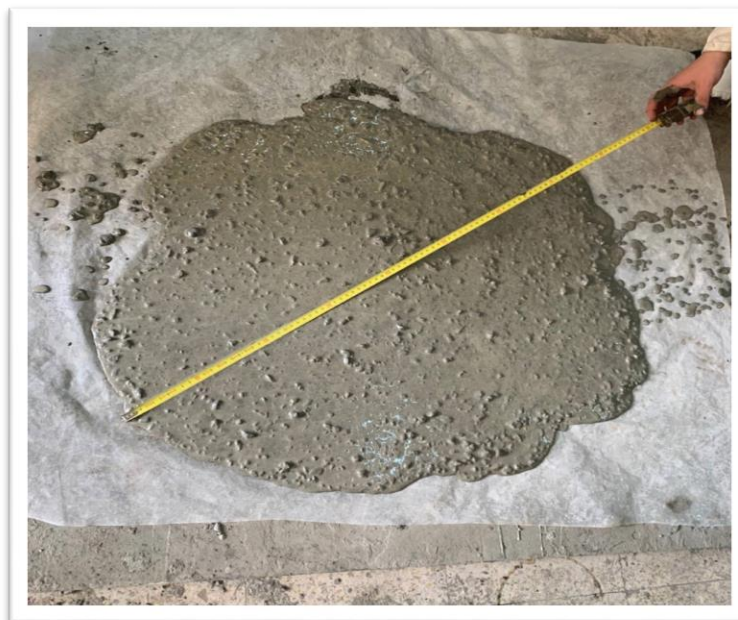


Figure 4: Slump flow test with Abrams cone according to standard SN EN 12350-8

1.6.1.2 L-box test

The L-box allows testing the mobility of concrete in a confined environment and checking that the placement of concrete will not be hindered by unacceptable blocking phenomena.

The operating mode is expressed according to [AFGC] as follows:

The vertical part of the box is completely filled with concrete (the required volume is about 13 litres). After leveling, the concrete is left to rest for one minute. Then the trapdoor is lifted and the concrete is allowed to flow into the horizontal part of the box through the reinforcement. The clear distance between the bars is 39 mm.

When the concrete no longer flows, the heights H_1 and H_2 are measured and the result is expressed as a filling ratio H_2/H_1 .

When the concrete flows poorly through the reinforcement and there is an accumulation of aggregates downstream of the grid, this is a sign of a blocking or segregation problem.

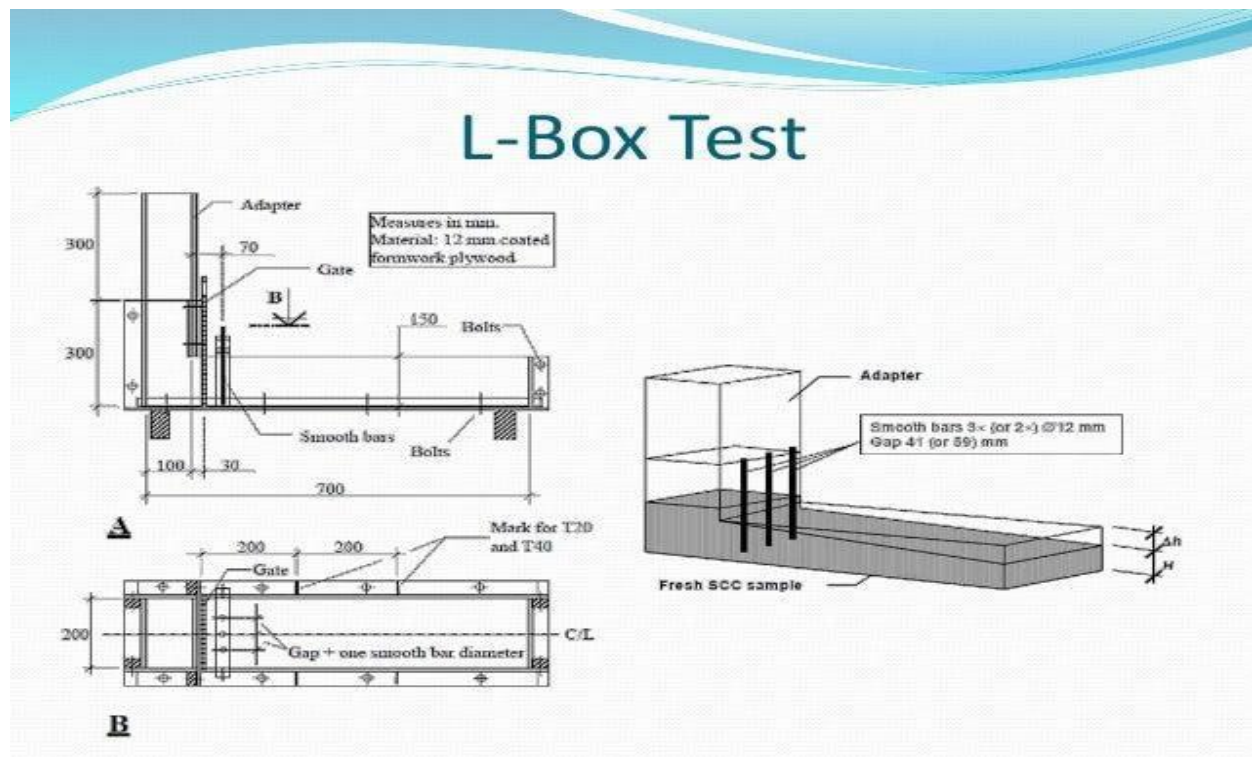




Figure 5: Schematic representation of the L-box test

1.6.1.3 Sieve stability test

This test aims to qualify self-compacting concretes with respect to the risk of segregation.

It can be used during the formulation study phase of a self-leveling concrete in the laboratory, or for checking the stability of concrete delivered on site. This test complements the tests for assessing mobility in confined or unconfined environments, by characterizing stability [AFGC].

This test consists of using a 10 L bucket with a lid, a 5 mm sieve with a diameter of 315 mm plus a bottom, and a scale with a minimum range of 20 kg and precision of 20 g.

The operating mode according to the recommendations of [AFGC] is as follows: At the end of mixing, ten liters of concrete are poured into the bucket. After fifteen minutes, a 5 kg sample is poured from the bucket onto the sieve, two minutes later, the quantity of paste (laitance) that has passed through the sieve is weighed. The percentage by weight of laitance relative to the weight of the sample gives the segregation index. The measurement of this index leads to classifying the SCC formulas as follows:

- $0 \leq \Pi \leq 15\%$: SATISFACTORY STABILITY.

- $15\% < \Pi \leq 30\%$: CRITICAL STABILITY, THE TEST MUST BE REPEATED IN SITU.
- $\Pi > 30\%$: VERY POOR STABILITY, UNUSABLE CONCRETE.



Figure 6: Representation of the sieve stability test

1.7 Formulation of self-compacting concretes

1.7.1 Formulation of SCC

The development of an SCC mix is much more complex because, firstly, there are at least six constituents, compared to four in the case of OC. Secondly, the specifications of an SCC include more clauses, particularly in the fresh state; it is necessary to ensure, in addition to the spread, the filling capacity and stability. Finally, and above all, the properties of SCC are contradictory; a concrete rich in a fluid paste is very sensitive to segregation [9].

Since the invention of SCC, no practical formulation methodology has been established.

The various sought-after properties make the formulation of SCC relatively complicated.

Multiple approaches have been developed around the world for the formulation of SCC.

Several SCC formulation methods have been developed worldwide (Japanese, Swedish, LCPC method, etc.) that meet the workability requirements of this type of concrete [1].

We report a general overview of the main approaches [8].

1.7.2 French method

French method (LCPC): Proposed by [2]:

At LCPC, a mathematical model based on interactions between the different components of the mixture to predict the compactness of the granular mixture. The following components are accurate to within 1%:

- Particle size distributions.
- Mix proportions.
- Owncompactness.
- Bulk density.

The binder proportion is predetermined (e.g., 90% cement, 10% added). Determine the amount of superplasticizer at saturation. According to LCPC experience, this determination of the quantities to give a high viscosity to the concrete, half of this quantity will be more related.

The viscosity is arbitrarily set at $5 \cdot 10^4$ reduction in water content, the result and the binder/filler ratio remain the same, the aggregate/binder step ratio is optimized.

The water content is adjusted to obtain the target strength, while the amount of superplasticizer is adjusted to obtain the desired spread and shear stress thresholds. Thus, the desired properties of self-compacting concrete are achieved [2].

1.7.3 Japanese method

The formulation of SCC by the approach developed at Kochi University (1990) is done safely, favoring the volume of paste to the detriment of aggregates. The concretes obtained are under-dosed in aggregates and therefore far from an economic optimum.

The formulation principles and their application are as follows:

a) Gravel dosage: Japanese researchers have shown that the risk of blocking is minimized when the volume of gravel per 1 m^3 of concrete is limited to half of its compactness. By definition, the compactness of a grain mixture is the ratio of the volume of grains to the total volume of the grains + voids system. It depends of course on the compaction method.

b) Sand dosage: The volume of sand is set at 40% of the mortar volume of the concrete. The fluidity of the concrete is guaranteed by the reduction of granular friction.

c) Binder dosage: The method does not specify how to dose the binder. Nevertheless, the amount of cement can be fixed, for example, by respecting the standard data (i.e., a minimum cement mass of 350 kg/m^3). The water/cement (W/C) and filler/cement (F/C) mass ratios can also be chosen based on strength criteria.

d) Water and superplasticizer dosage: The amounts of water and superplasticizer are determined by mortar tests, in which the sand volume is set at 40%. Spread measurements with a mortar cone and flow measurements with a funnel are carried out. [8].

1.7.4 The Swedish approach

This method is based on the Japanese method cited above. The principle is to integrate the approach of assessing the risk of blocking into the formulation process. For each G/S ratio, the critical paste volume for blocking is estimated, then the G/S ratio that satisfies the desired rheological properties is retained. The dosage of fines, water and superplasticizer is adjusted to obtain sufficient viscosity, a low yield stress, and the desired strength. This approach allows better optimization of the granular skeleton. However, the blocking criterion cannot be applied to any type of aggregate [8].

1.7.5 Formulation by minimum paste volume

In this method, concrete is considered as a biphasic material: a solid phase consisting of aggregates and a liquid phase which is the paste (water, binder, admixtures).

The researchers assume that the paste plays two main roles in SCC: On the one hand, it ensures the fluidity of the mixture, which limits friction between aggregates; on the other hand, it separates the gravel to avoid the blocking phenomenon. To ensure these two roles, the researchers consider that there must be a minimum paste volume [28].

1.7.6 Formulation by optimization of the granular skeleton

Knowing that the compressive strength increases with the compactness of the paste and that workability depends on the arrangement of the granular skeleton. The formulation of concretes is based on the optimization of the porosity of the system, taking into account all the solid grains, from cement to gravel. If the interstitial phase is the mixing water, and no longer the paste. The greater the amount of water that separates the grains, the more fluid the suspension is. For a constant amount of water, if we minimize the porosity of the grain packing, we consequently optimize the volume of water available to fluidize the mixture. This simple example therefore shows the link between compactness and rheology [28].

1.7.7 Method based on an experimental design

The principle of this method is the use of an experimental design to understand the effect of concrete composition parameters. Khayat et al. carried out such a study with the following factors:

The volume of gravel, the mass of fines (C+A), the water/fines mass ratio $W/(C+A)$, the mass of superplasticizer and the mass of viscosity agent. Each factor is varied over a range with five points, which raises the number of compositions made to 25. In the end, the obtained models are provided with the test results, including spread and filling ratio, as a function of the different factors. Even if these models are only usable for the constituents used in the study, this approach mainly provides a support for correcting a formula that does not meet, for example, the AFGC criteria.

1.8 Conclusion

This bibliographic synthesis was carried out in order to become familiar with self-compacting concretes, the objective being to define them, as well as to list their multiple properties, characterize them, and summarize the main formulation methods.

Self-compacting concrete is a concrete that compacts itself by gravity, without any compaction energy input (e.g., vibration, tamping).

The characteristic properties of this concrete in the fresh state are:

- High fluidity and viscosity, with no tendency to segregate,
- Passing ability in confined environments,
- Excellent ability to fill the smallest corners of the formwork with homogeneous concrete, even in the presence of dense reinforcement. The tedious work of vibration is thus eliminated.

Concrete is qualified as self-compacting when these three criteria are verified. Thus, a large number of standard empirical tests have been developed to characterize SCC with regard to workability properties and its mechanical performance.

Evolution of the Physical Properties of Concrete at High Temperature:

1.8 Physico-Chemical Changes in Concrete at High Temperature:

Table 1 : The main physico-chemical reactions occurring in concrete during heating are summarized in

Temperature Range	Temperature Range	Main Physico-Chemical Reactions in Concrete
20–100 °C		Evaporation of free water and surface drying
100–200 °C		Loss of physically bound water and microcracks formation
200–400 °C		Dehydration of cement hydrates and internal stresses increase
400–600 °C		Decomposition of Ca(OH)_2 and strength loss
600–800 °C		Decomposition of C-S-H and severe cracking
700–900 °C		Decarbonation of CaCO_3 in aggregates and paste
>900 °C		Severe structural damage and material degradation

Evolution of porosity:

Concrete is a biphasic porous material, composed of a solid phase and a porous phase. Total porosity can be measured by water saturation, while capillary porosity is generally measured using mercury intrusion porosimetry [21].

Several studies have been carried out on the variation of concrete porosity as a function of temperature. Research on ordinary concrete, high-performance concrete, and self-compacting concrete has shown a gradual increase in porosity in these concretes with rising temperature.

This increase is partly due to the growth in the overall volume of pores as well as the microcracking induced by thermal loading and internal stresses developed during heating. differential thermal expansion between the cement paste and the aggregates. Figure shows the variation of total porosity as a function of temperature.

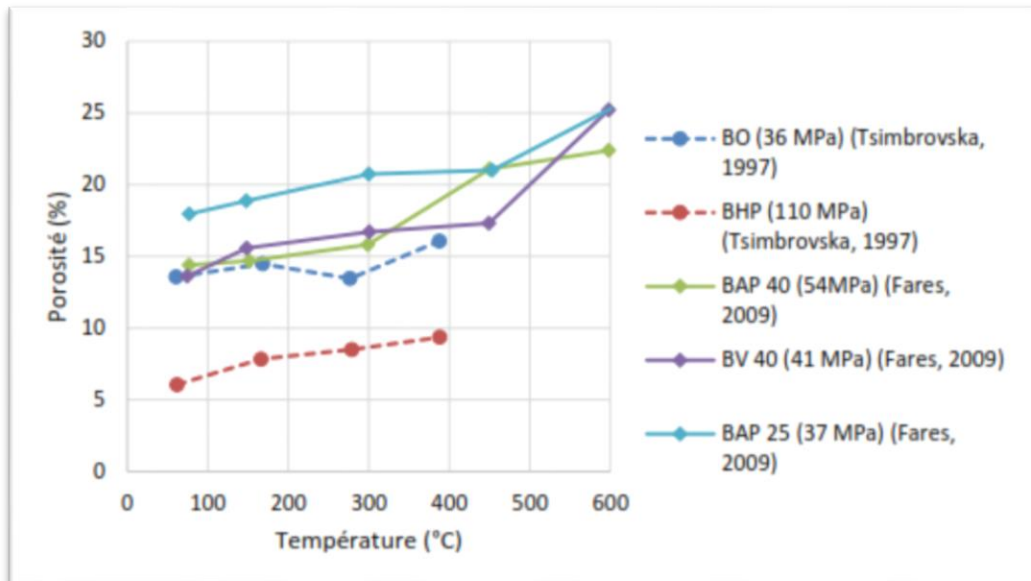


Figure 7 : Evolution of the porosity of different concretes as a function of temperature

Evolution of density:

At high temperatures, this parameter strongly depends on the nature of the aggregates in the concrete. Figure I.8 shows the variations in density of different types of concrete as a function of temperature. A nearly linear decrease is observed up to 800°C; however, concrete with limestone aggregates exhibits a strong reduction in density beyond 800°C.

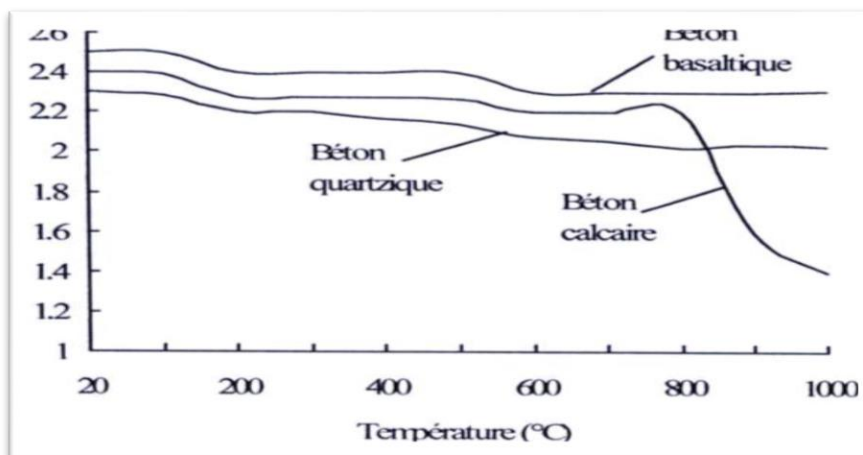


Figure 8: Variation of the density of different types of concrete as a function of temperature

Mass loss:

During the heating of concrete, its mass undergoes variation due to water evaporation and the progressive dehydration of the C–S–H gel. Figure 16 shows a characteristic curve of mass loss during heating, as well as the curve of the rate of mass loss.

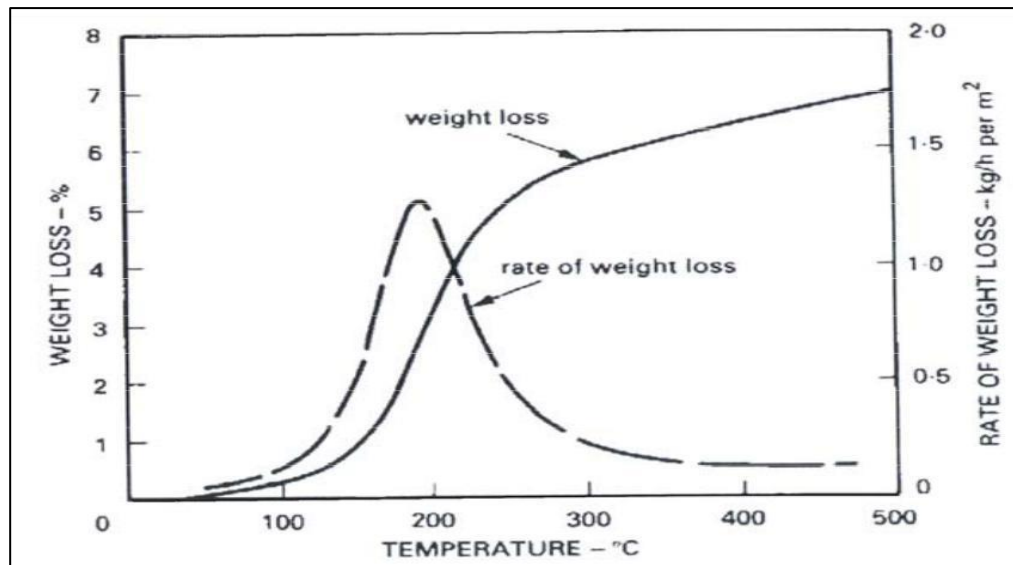


Figure 9 : Mass loss during heating and rate of mass loss as a function of temperature

Evolution of permeability:

The permeability of a porous medium characterizes its ability to allow a fluid to pass through under a pressure gradient. Although this permeability strongly depends on the porosity of the porous medium and other parameters such as connectivity, tortuosity, and the structure of the pore network related to pore size, the permeability of concrete also depends on its constituents.

It is a function of the water-to-cement (w/c) ratio, which is directly related to capillary porosity, as well as the nature and quantity of aggregates, which can modify tortuosity through the formation of the interfacial transition zone.

The permeability of concrete increases significantly when the temperature exceeds 100°C.

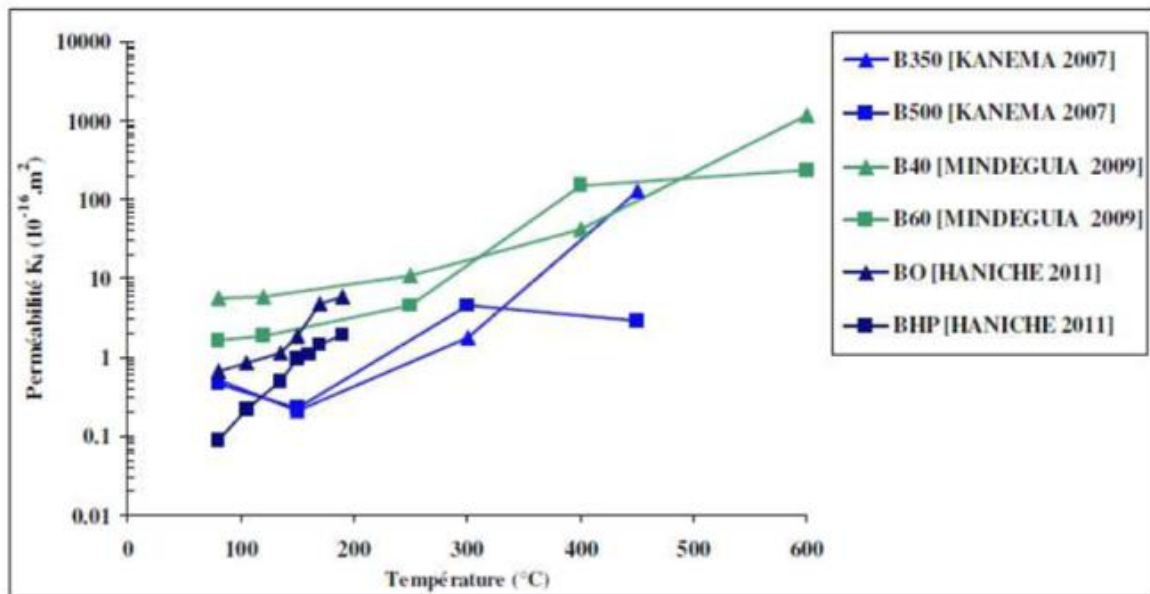


Figure 10: Evolution of the permeability of BO and HPC concretes as a function of temperature

Evolution of mechanical properties with temperature:

Thermal exposure of concrete leads to a gradual decrease in its mechanical properties, whether measured at high temperature or after cooling. Strength losses vary depending on temperature, heating rate, and concrete type.

The main mechanical characteristics considered are compressive strength, tensile strength, and elastic modulus.

Compressive strength:

Figure shows the evolution of residual compressive strength for self-compacting concrete, ordinary concrete, and high-performance concrete. In general, literature results indicate that the compressive strength of concrete (whether at high temperature or after cooling) decreases with increasing temperature.

The analysis of the curve reveals two main behavior domains:

- First domain (from ambient temperature to 300–400°C):

This range is characterized by a slight decrease, stabilization, or even an increase in strength. A reduction in strength is often observed around 100–150°C depending on authors. This initial decrease is associated with water loss; during heating, water expands and causes separation of

the C–S–H gel layers, reducing cohesion forces. Up to 300–400°C, an increase in strength may be observed, particularly in high-performance concretes, due to their low permeability which slows down water loss. The removal of free water can also increase bonding forces between hydrates by enhancing surface energy effects.

- Second domain (above 400–800°C): This range is characterized by a continuous decrease in compressive strength due to various physico-chemical transformations occurring within the cementitious matrix.

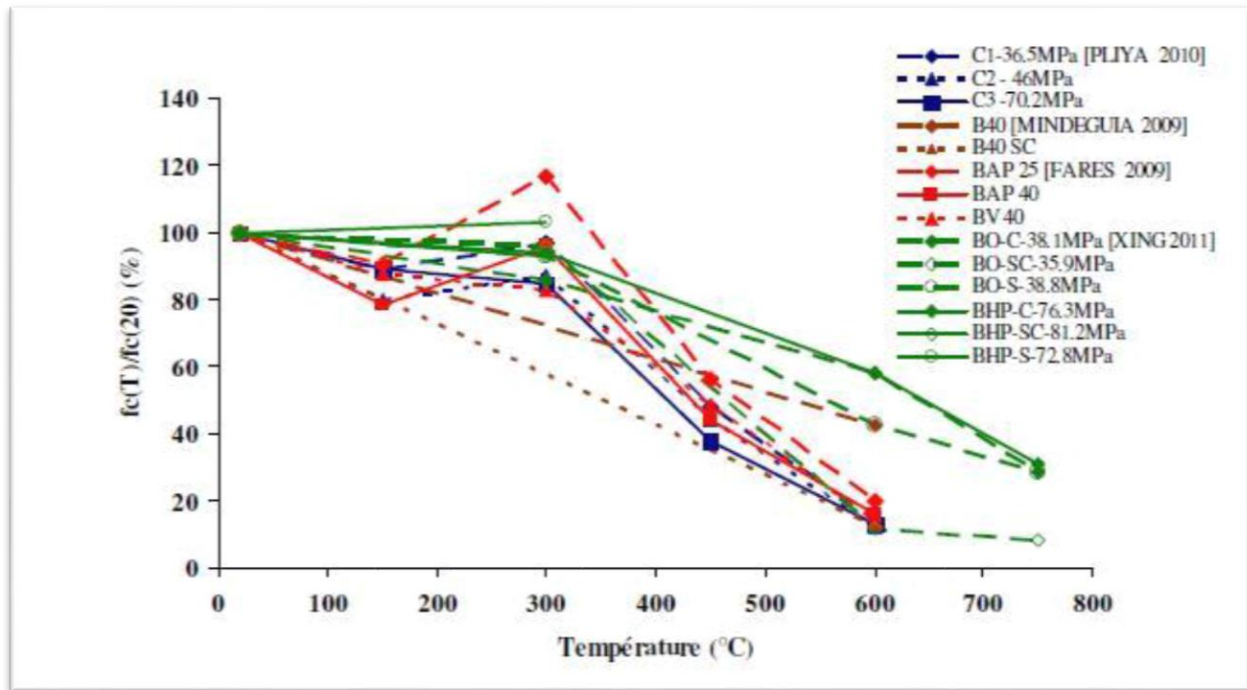


Figure 11: Evolution of the residual relative compressive strength of BO and HPC concretes

Tensile strength:

The evolution of tensile strength as a function of temperature has been studied less extensively than compressive strength. Indeed, direct tensile or flexural tests are difficult to perform due to the localization of damage and the development of a generally unstable macro-crack, which leads to sudden and brittle failure of the material.

Studies conducted at high temperatures show a decrease in tensile strength with increasing temperature. Figure I.12 compiles the residual strengths determined in both flexural and direct tensile tests. The measurements were carried out on specimens that were previously cooled. It can be observed that all obtained values are higher than those specified by

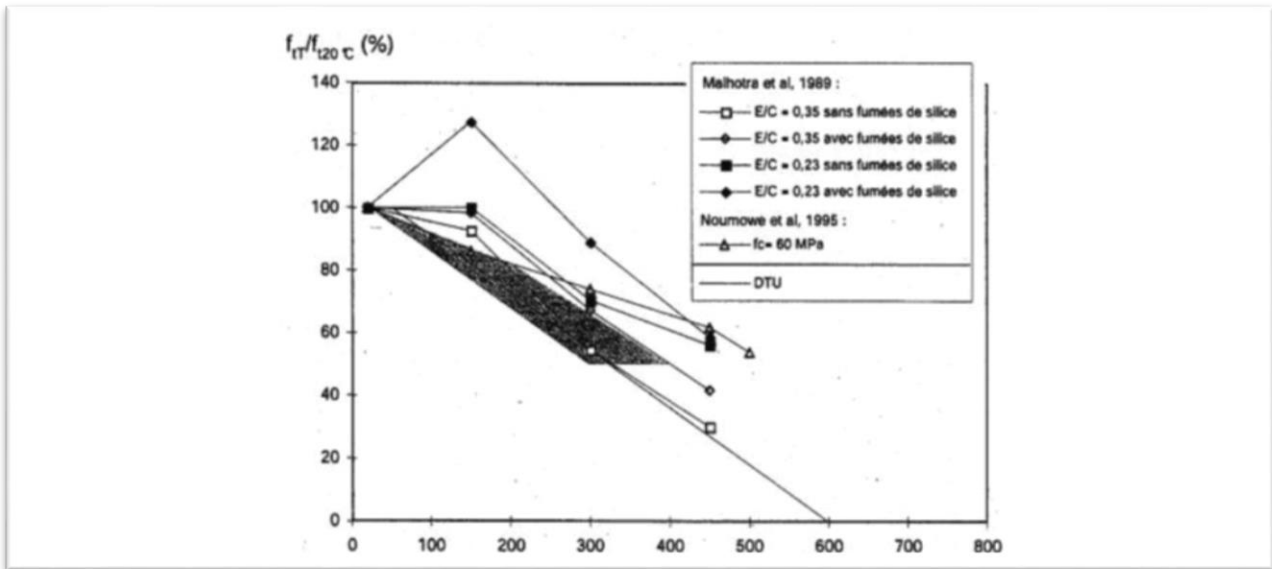


Figure 12: Evolution of tensile strength as a function of temperature

Chapter 2:

Waste Valorization

2.1 Introduction

Waste valorization is a positive, more economical, more responsible attitude that works towards protecting the environment and human health. Nowadays, waste constitutes a product that must be exploited as best as possible to derive the best profit. Valorization is not only useful, but also desirable. All human activity consists of creating wealth by starting from a product to manufacture another, by transforming things to create new ones. Waste can be that product that must be known how to use and transform to make a useful material, a true raw material or secondary material (Ademe, 1996) [2].

What is called waste?

Etymologically, the word "déchet" (waste) which appears in the 14th century in dictionary entries comes from the verb "déchier", a regular form of the past participle of the verb "déchoir" which reflects the decrease in value of a material or object to the point where it becomes unusable in a given place and time (Pichat, 1995).

Thus, waste carries the idea of decline, of fall. This devaluation is linked to parameters such as dirt, soiling or stench: it is garbage, from the Latin root *ord*, "repulsive, filthy dirt" (Rey, 1992a); it is also filth, from the Latin *immundus*, "dirty, impure matter" (Rey, 1992b). According to the Larousse dictionary of the French language (2000), "waste is what falls from a material being worked, debris, remains of a cut, prepared item that is unfit for consumption, for use." It is "what is lost" (Larousse, 1924). It is also "The unusable part of a material, a piece that is discarded or becomes detached" (Larousse de la langue française, 1992). In summary, waste is what is considered scrap. In this conception, waste is not a reusable element.

2.2 Economic definition of waste

According to the economic sense of the term, waste is defined as an object or material whose economic value is zero or negative for its holder, at a given time and place (Sané, 2002); (Kofoworola, 2007). To get rid of it, the owner will have to pay a service provider for its removal or take care of it himself.

2.2.1 Sociological definition of "waste"

Socially, waste is accompanied by negative value judgments. It is disqualified, has an unhealthy connotation, often arouses repulsion or even disgust, and requires separation, segregation, exclusion, rejection (Lhuillier and Cochin, 1999).

2.2.2 Legal definition of "waste"

On the legal level, the question is mainly how a thing is reclassified as waste: the answer does not concern so much technical or formal characteristics of a thing but is linked to the action of getting rid of it. At the European level, waste corresponds to any substance or object which the holder disposes of or is obliged to dispose of under national provisions in force (Directive 1975/442/EEC).

2.3 Different types of waste

2.3.1 Ultimate waste

The law of July 13, 1992 introduced the notion of ultimate waste and gives the following definition: "waste, resulting or not from the treatment of waste, which is no longer capable of being treated under current technical and economic conditions, in particular by extracting the recoverable part or by reducing its polluting or dangerous character." Ultimately, only waste that could not be recycled or incinerated with energy recovery may be landfilled.

Ultimate waste from household waste incineration plants and similar waste, called bottom ash, can be transformed after treatment into aggregates and used to build road foundations [2].

Household and similar waste: This term includes all waste produced in our daily lives: packaging, food leftovers, household appliances, old furniture, green waste, old clothes, etc. [3].

2.3.2 Inert waste

Waste that does not undergo any significant physical, chemical or biological modification, does not decompose, does not burn, and does not produce any physical or chemical reaction, is not biodegradable and does not deteriorate other materials with which it comes into contact, in a manner likely to cause environmental pollution or harm human health. This waste is admissible in storage facilities and comes mainly from building and public works sites or from the construction materials manufacturing industry. These are notably the following waste: concrete, tiles and ceramics, bricks, glass waste, earth, bituminous mixes [4].



Figure 13: Inert waste.

2.3.3 Hazardous waste

a) Special industrial waste (DIS):

These wastes appear because of their dangerous properties, example: waste containing arsenic, lead; consisting of paint sludge, hydrocarbons; from the petroleum industry, etc.

2.3.4 Non-hazardous waste from economic activities

This concerns business waste that is similar in nature and composition to household waste, such as waste related to commercial activities, construction waste and public service waste (school, administration, etc.). The law considers that they are "assimilable to household waste" and can thus be collected and disposed of like household waste [3].

b) Special household waste (DMS):

These are the hazardous waste contained in household waste, such as aerosols, glues, detergents, stain removers, insecticides, paints, batteries, fluorescent tubes, cleaning products.

These may also be called DTQS: toxic waste in dispersed quantities [5].

2.3.4 Non-hazardous waste from economic activities

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2.3.5 Industrial non-hazardous waste (DIB)

They include all non-hazardous waste produced by industrialists and by companies in commerce, crafts, services and administration, metallurgy, painting, chemistry and petrochemicals. These are packaging waste, maintenance waste and end-of-life equipment.

Non-hazardous and non-inert waste, known as industrial non-hazardous waste, is of the same nature as household waste. These are:

- Untreated wood or treated with non-hazardous products (packaging, formwork, joinery, flooring...),
- Plastics such as PVC, polystyrene, polypropylene (pipes, joinery, floor coverings, packaging...),
- Ferrous and non-ferrous metals such as aluminium, copper, steel, zinc (roofing, electrical equipment, pipes, equipment...),
- Textile wall and floor coverings,
- Expanded polystyrene, polyurethane,
- Mixed products from rehabilitation sites...
- Paints, varnishes, glues, sealants, which contain neither organic solvents nor dangerous substances. [5]

2.3.6 Medical and pharmaceutical waste

Any waste from diagnostic, monitoring and preventive, palliative or curative treatment activities in human or veterinary medicine and all waste resulting from the activities of public hospitals, clinics, scientific research establishments, analysis laboratories operating in these fields and all similar establishments. [6]

2.4 Waste management

Waste management is the collection, transport, treatment (recycling), reuse or disposal of waste, usually that produced by human activity, in order to reduce its effects on human health, the environment, aesthetics or local amenity. Waste management concerns all types of waste, whether solid, liquid or gaseous, each with its own specific stream. [25]



Figure 14: Photo of waste management

2.5 Principles of waste management

There are several principles of waste management, the use of which varies according to country or region. The hierarchy of strategies (the three R rule):

- Reduce.
- Reuse.
- Recycle. [25]

2.6 Waste management methods

Waste management consists of determining the type of treatment to be applied to each category of waste. Certainly, to ensure good waste management, financial and material resources must be provided; consequently, good management will limit health damage. Thus, we will successively examine the different waste management methods. These methods are currently four in number.

2.6.1 Landfilling

Landfilling is a method of disposing of organic waste which consists of digging a deep pit 0.5 to 1 m deep to pour waste, spray with petrol and cover with a layer of earth to burn the waste without smoke. This process uses chlorine, lime, fuel oil and petrol as disinfectants or deodorants. This method remains very appropriate in health facilities, it will limit health damage.

2.6.2 Incineration

It is an urban process for the final disposal of waste that consists of burning waste produced by hospitals with a fire. Incineration processes include collecting waste and garbage, sorting to separate

combustible and non-combustible waste. It can be considered as a process par excellence for treating garbage. It is a satisfactory method which nevertheless has some disadvantages, among which we can cite:

- It requires disposal of ashes after execution,
- It causes a danger of environmental pollution from its smoke,
- It requires high investment and operating costs for its construction.

2.6.3 Controlled landfill

The controlled landfill is a public dump planned in advance for the disposal of household garbage. It has the advantage of providing elements for feeding gardens or tree plantations. This method is not recommended for the treatment of hospital waste.



Figure 15: Photo of a controlled landfill.

2.6.4 Composting

Composting is a process of decomposing used organic matter so as to recover it in another form for later use as fertilizer.

It requires the following preparations:

Receiving waste, sorting waste, preparing compost, decomposition, presenting the finished product.



Figure 16 : Composting of organic waste

2.7 Waste used as concrete aggregates

2.7.1 Steel slag

This slag is formed by the elimination of impurities contained in pig iron. It is rich in phosphate or calcium and contains dicalcium silicate. It is used only as backfill material for roads. Slag in this concrete normally, fly ash but aggregates are not widely used. This slag is stored in piles for a period of up to one year before being used. The use of these slags is quite rare due to dimensional stability problems. Aging processes have been developed to control this instability and valorization initiatives, particularly in civil engineering. Also, the environmental risks associated with the use of slag in certain sectors are still poorly understood.

2.7.2 Fly ash

Fly ash could constitute very good lightweight aggregates, but they are not widely used. They come from the combustion of pulverized coal pushed into the combustion chamber of a furnace by exhaust gases. They are preferable to many other lightweight aggregates because they give more efficient combustion, since the carbon contained in the ash produces the amount of heat necessary to eliminate moisture from the pellets and to bring the pellets to the sintering temperature. Fly ash is classified according to its CaO content and the type of coal burned.

2.7.3 Glass waste

Glass is a solid, non-crystalline, homogeneous body, resulting from the progressive cooling of certain substances after fusion. Glass is one of the most useful materials because it has many qualities. It is easy to shape, transparent and can take many forms.

The environmental problem posed by non-biodegradable waste such as non-reusable bottles (glass) is becoming a major concern given the enormous quantities produced in large cities. One of the few ways to recycle this waste is to store it in construction processes (concrete). Thus, glass is a material rich in silica and sodium. Its use in a cementitious matrix causes two reactions with opposite effects: the alkali-silica reaction harmful to concrete due to the swelling it generates.

Millions of tons of glass are recovered each year and one way of recycling glass is to use it in construction materials. It is used in two main forms: aggregates (size > 4mm) and powders (size < 4mm). Aggregates are used to replace gravel in concrete and give it lower strength.

Powders are used in mortars to replace sand but also in the cement industry as fines.



Figure 17: glass waste.

2.7.4 Marble waste

Marble production in France is low and has decreased compared to countries like Italy, Portugal, and Great Britain. Algerian marble products are extracted and processed according to European standards: Italian and French in particular. The processes used in Algeria for working marble are those used worldwide:

- Sawing blocks with helical wire, diamond wire and frame saws for cutting and slicing raw blocks of natural marble in quarries.
- Finishing products using blades and discs, secondary cutting and sanding with pumice stones.

Algerian marble is currently exploited by the national marble company "Enamarbre" which has ten production units located in five Wilayas [10].

Marble block production (2018) by the subsidiaries of "Enamarbre" is 200,000 m².



Figure 18: Marble waste

2.7.5 Demolition waste

Concrete constitutes almost 75%, by weight, of all construction materials. It follows that the largest part of demolition waste consists of concrete. Moreover, disasters (mainly earthquakes) provide millions of tonnes of concrete debris each year.

Today, producers of recycled aggregates have a policy of selecting demolition materials. Thus, five categories of demolition materials are distinguished according to their nature:

1. reinforced concretes without coating or plaster,
2. materials composed of bricks, tiles, gravel, stones and rock blocks, etc.

3. mixed materials with low plaster, wood, plastic content, etc.
4. poor materials with wood, plaster, plastic content greater than 10%,
5. other materials not falling into the previous categories.

2.7.6 Production waste from the concrete industry

Recycled aggregates from production waste have two origins:

1. Concrete debris generated throughout the production stages; they result from the cleaning of concrete manufacturing and transport facilities (concrete fall); it can also be concrete from unused or unusable batches.
2. Defective, poorly formed, partially broken or non-conforming products; added to these defective products are products that have been subjected to breaking strength tests.

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2.7.7 Plastic waste

Plastic waste means residues from production, processing and consumption processes, or plastic products intended for abandonment. Plastic waste can be incorporated into cementitious matrices. Indeed, previous studies have shown that it was possible to use plastic waste in concrete as a binder for the production of high-performance composite material or added to concrete (in the form of grains and wavy and straight fibres [11]).

There are several types of plastic waste:

- Industrial plastic waste
- Production waste
- Processingwaste

2.7.8 Hardenedcement

In the event that a bag of cement is in contact with water, the powder crystallizes. This recrystallization of cement is followed by a hydrolysis reaction. These two reactions are rapid and cause the cement to harden. It becomes unusable as a binder on site. The cement thus hardened automatically becomes waste. It can be crushed and used as concrete aggregate. This waste is produced accidentally or through negligence, so it is important to eliminate hardened cement and work to prevent its production.

2.7.9 Brick waste

Brick waste comes from the red products industry. These products are among the oldest construction materials, they are ceramic products whose raw material is clay and sometimes additives. Bricks generally have a rectangular parallelepiped shape. There are two types of bricks: sun-dried clay bricks and fired clay bricks.

- Sun-dried clay bricks
- Fired Clay bricks

2.8 Recycling

Recycling is manufacturing a new object from old objects, but the new object obtained is different from the old one that served as raw material. Waste then becomes a resource. According to European Directive 2008/98/EC, recycling, unlike regeneration, is any recovery operation by which waste is reprocessed into products, materials or substances for their original purpose or other purposes. This includes the reprocessing of organic materials, but does not include energy recovery, conversion for use as fuel or for backfilling operations. (Article 3, paragraph 17 of Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives). Recycling is the direct reintroduction of a material contained in waste into the economic cycle (Gouillard et al., 2003) or into the production cycle from which it comes, in total or partial replacement of a new raw material. It mainly targets the following materials: paper-cardboard, packaging, glass and metals (Balet, 2008) in industrial countries and plastic waste in developing countries and occurs once the waste has been created. It therefore does not avoid it, but it has the merit of saving raw materials (Adec, 2006) (European Environment Agency, 2003).

2.9 Glass recycling

Glass waste from households consists of bottles, pots, flasks, jars, window panes, etc. Almost all of this resource consists of packaging waste also called "hollow glass". The methods for disposing of household glass waste are determined in Book V of the Environmental Code [2].

The consumer is the first link in the recycling chain. As such, he represents a privileged partner in the search for the quality essential for

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2.10 Recovered glass

Cullet is glass recovered from waste (household and similar, etc.) or directly from manufacturing offcuts. It is first sorted and cleaned to remove all impurities. Then, before being introduced with the raw materials to form the melting bed, it is ground very finely.



Figure 19: Recycling glass.

2.11 Valorization

2.11.1 Definition of valorization

Valorizing means giving value to something. According to Mayster (1994), valorizing waste covers any action that allows energy to be extracted, a new use to be found for the material that composes it, a secondary raw material useful for manufacturing the same product to be extracted, and a new use to be found or that allows waste to become useful again for others. According to European Directive 75/442/EEC of 15 July 1997, the essential characteristic of the recovery operation is to make waste serve a useful function. It thus replaces the use of other materials that would have had to be used to perform this function, in order to preserve natural resources.

2.11.2 Material valorization

Different forms of material valorization are distinguished, linked to economic, social and cultural conditions. These forms are: reuse such as the reuse of glass bottles, packaging, etc.; recycling which makes it possible to obtain new products by integrating these primary and secondary raw materials into a new production cycle (Aloueimine, 2006). Material valorization therefore includes: recycling and

waste recovery. A large part of the informal sector is based on this activity with the recovery of vehicle carcasses, plastics and metal.

2.12 Conclusion

Waste valorization is a crucial step in responsible waste management, offering multiple environmental, economic and social benefits. In conclusion, it is clear that waste valorization is a sustainable and necessary strategy to reduce our ecological footprint, preserve natural resources and promote a more environmentally friendly lifestyle. However, to maximize its effectiveness, it is essential to adopt a holistic approach, involving public awareness, investment in research and development of new technologies, as well as close collaboration between governments, businesses and civil society. By investing in waste valorization, we are investing in a cleaner, more sustainable future for generations to come.

Chapter 03:
Characteristics of the Materials
Us

3-1 introduction

In this section, we are interested in presenting the materials used in the preparation of the different self-compacting concrete (SCC) mixtures studied, as well as the tests carried out and the methodology adopted during the experimental research work.

3-2 Characterization of Materials

The tests on the materials used for concrete preparation were carried out in the civil engineering laboratory of Université Mohamed Boudiaf de M'Sila. The materials used are:

- Siliceous sand originating from Djamaa, Oued Souf Wilaya.
- Two fractions of crushed limestone gravel (3/8 and 8/16) supplied by COSSIDER in Bordj Bou Arreridj (BBA).
- CPJ 42.5 N cement supplied by the Lafarge cement plant in Hammam Dalaa, M'Sila.
- Admixture: Admixture (NOVSUPERLOW)
- Additions: limestone filler marble powder and glass powder
- Mixing and curing water: potable laboratory water.

3-3 Sand:

3.3.1 Granulometric Analysis

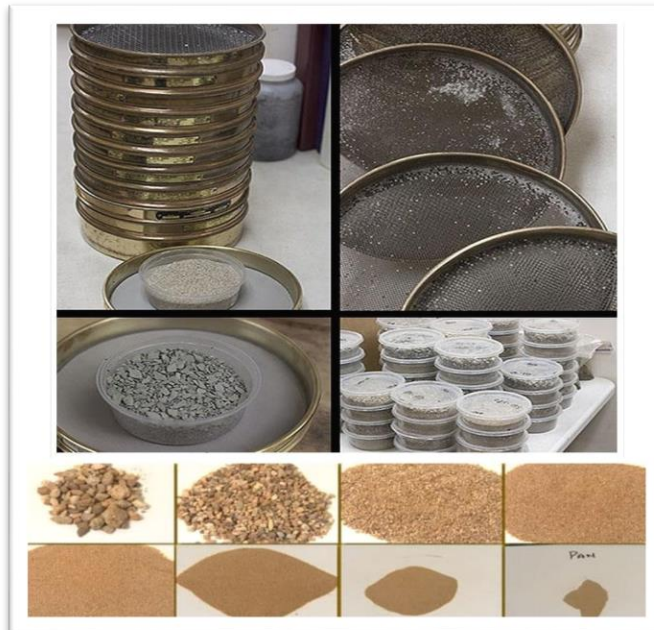
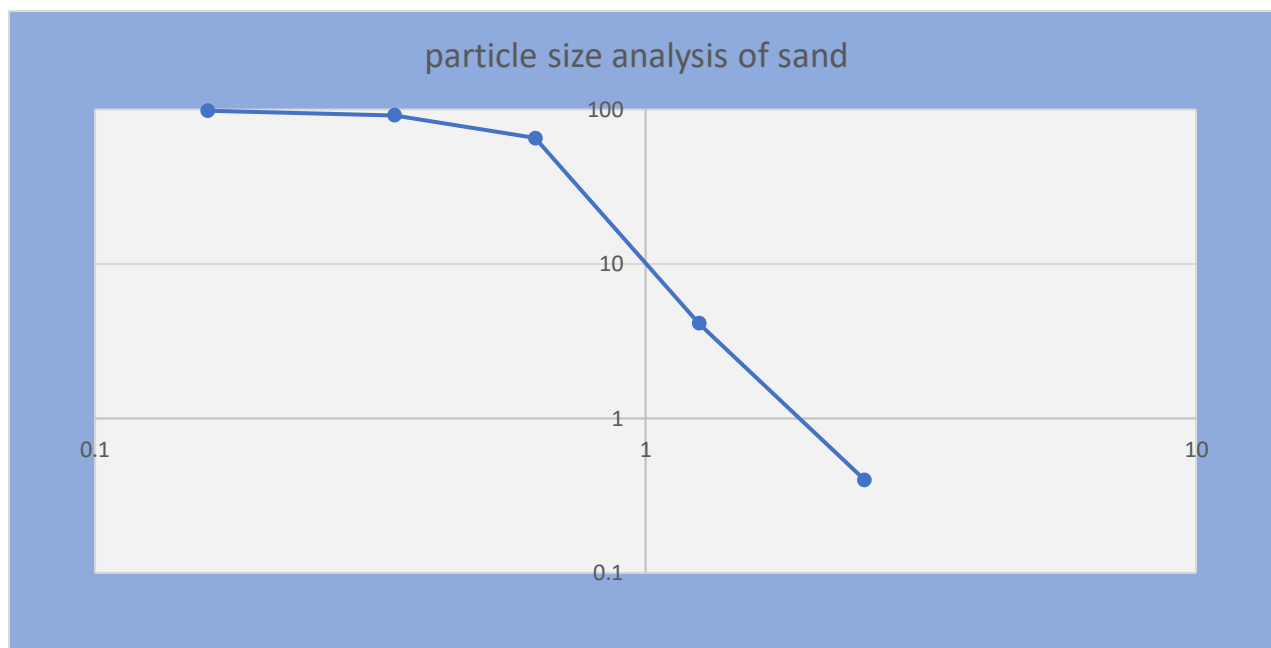


Figure 20:Granulometric Analysis of sand

Table 2: Granulometric Analysis of Djamaa Sand

Sieve	Weight + Sand	Sand residu	Residu cumulative	Residu %	Sieve %	Weight Sieve
5	874	0	0	0	100	874
2.5	751	6	6	0.4	99.96	745
1.25	708	56	62	4.13	95.87	652
0.63	1539	918	980	65.33	34.67	621
0.35	959	399	1379	91.93	8.07	560
0.16	613	96	1475	98.33	1.67	577
0	584	18	1493	99.53	0.4	566

**Figure 21 :** Granulometric Analysis Curve of Djamaa Sand

3.3.2 Sand Equivalent Test [NF EN 933-8]:

3.3.2.1 Visual Sand Equivalent (V.S.E)

After 20 minutes of sedimentation, the height **h1** corresponding to the upper level of the flocculating solution relative to the bottom of the graduated cylinder is measured using a ruler.

The height **h2**, corresponding to the upper level of the sedimented sand layer relative to the bottom of the cylinder, is also measured.

The visual sand equivalent is calculated using the following formula:

$$E.S.V = (h2/h1) 100 (\%)$$

Where:

- **h1**: total height of the flocculated solution.
- **h2**: height of the sand layer.

3.3.2.2 Piston Sand Equivalent (P.S.E)

The piston is carefully introduced into the graduated cylinder and slowly lowered until it rests on the sediment layer. At this moment, the piston sleeve is locked and removed from the cylinder.

A ruler is then inserted into the piston notch until the zero mark touches the inner face of the piston head. The measured value **h2'** corresponds to the height of the sedimented part.

The piston sand equivalent is calculated using the following formula:

$$E.S.P = (h2/h1)*100(\%)$$

Where:

- **h1**: height of the sand and flocculating solution.
- **h2'**: height of the sand layer only ($h2' < h1$).



Figure 22 : Principle of the Sand Equivalent Test

Table 3: Sand Equivalent

	h	h'	E.S.V %	moyen%	h'2	E.S.P%	moyen%
1	9.9	8.4	84.85	85.44	8.8	88.0	84.00
2	10	8.5	85	85.44	8.6	86.0	84.00
3	10.1	8.9	88.12	85.44	8.8	80.0	84.00

(E.S.V)moy = 85.44

(E.S.P)moy = 84.00

Very clean sand: the almost total absence of clay fines makes it perfectly suitable for high-quality concrete.

Table 4 : Classification of Sand Type According to Sand Equivalent (S.E.)

E.S.V	E.S.P	Nature and Quality of Sand
E.S<65	E.S<60	Clayey sand: risk of shrinkage or swelling; it should be rejected for high-quality concrete.
65<E.S<75	65<E.S<70	Slightly clayey sand: acceptable properties for ordinary-quality concrete when shrinkage is not a major concern.
75<E.S<85	70<E.S<80	Clean sand with a low percentage of clay fines: suitable for high-quality concrete.
E.S>85	E.S>80	Very clean sand: the complete absence of clay fines may lead to a lack of concrete plasticity, which must be compensated by increasing the water content.

3.4: Mass density:

3.4.1 Absolute Density (Mass Density)

The absolute density is defined as the mass of a material per unit of absolute volume of solid matter (i.e., the volume of the solid particles only, excluding the pores inside the grains), after drying in an oven at 105°C.

It is denoted and expressed in (g/cm³, kg/m³, or T/m³).

3.4.2 Procedure (Test Method)

- Weigh a dry sample of aggregates: **M1 = 120 g , M2=130 g M3=110g**
- Fill a graduated cylinder with water up to an initial volume: **V1 = 200 mL**
- Introduce the aggregates into the graduated cylinder, ensuring that air bubbles are removed, then read the new volume **V2**.
- Calculate the absolute density using the formula:

$$\rho_{abs} = M / (V_2 - V_1)$$

- Repeat the measurement **three times** to ensure accuracy and reliability of the results.

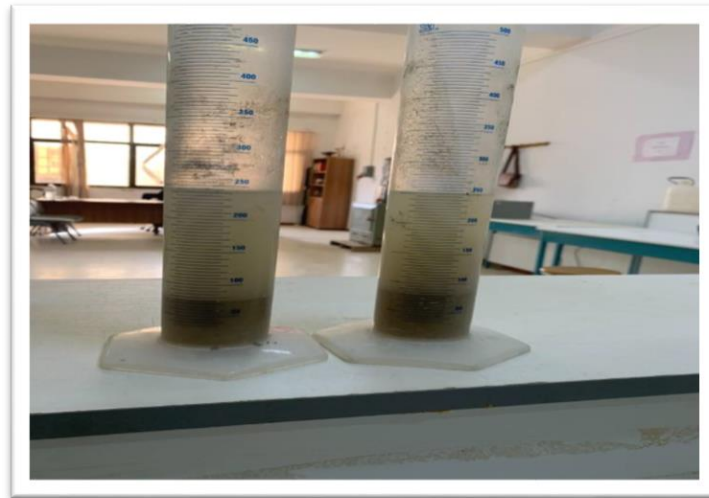


Figure 23 : Absolute Density of sand

Table 5 : Absolute Density of Sand

	m	V1	V2	ρ	moyen
1	120	200	245	2.67	2,61
2	130	200	250	2.60	2,62
3	110	200	243	2.56	2,63

3.5 Bulk density of sand:

The bulk density of a material is the density of one cubic meter of the material in a loose or compacted state (in bulk form). It includes both the permeable and impermeable voids within the particles, as well as the voids between particles.

$$\rho = \frac{m_2 - m_1}{V}$$



Figure 24 : bulk density of sand

N° d'essai	M1(g)	M2 (g)	papp (g /ml)	ρmoy (g /ml)
1	126	1517	1.546	1.54
2	126	1513	1.541	
3	126	1511	1.539	

Table 6: Bulk Density of Sand V=900 ml

Water content:

Water content is the amount of water present in a material (soil or aggregates), usually expressed as a percentage of its dry mass.

Formula:

$$w = \frac{M_{\text{wet}} - M_{\text{dry}}}{M_{\text{dry}}} \times 100$$

Table 7 : Water content

	m0	m1	m2	ms	w%
1	457	500	956	499.00	0.2
2	760	500	1250	494.00	0.21
3	561	500	1061	500.00	0
					0.47

3.6 the Gravel:

3.6.1 Granulometric Analysis of Gravel

* 3/8

Table 8: Granulometric Analysis of Gravel

Sieve	Weight empty	Weight + Gravel	Gravel residu	Residu cumulative	Residu %	Sieve %
8	0.652	0.718	0.066	4.1	4.1	95.9
6.3	0.642	1.401	0.759	51.5	47.47	48.5
5	0.627	1.011	0.384	75.5	24.01	24.5
3.15	0.604	0.964	0.36	98	22.51	2
0	0.451	0.483	0.032	100	2.01	0

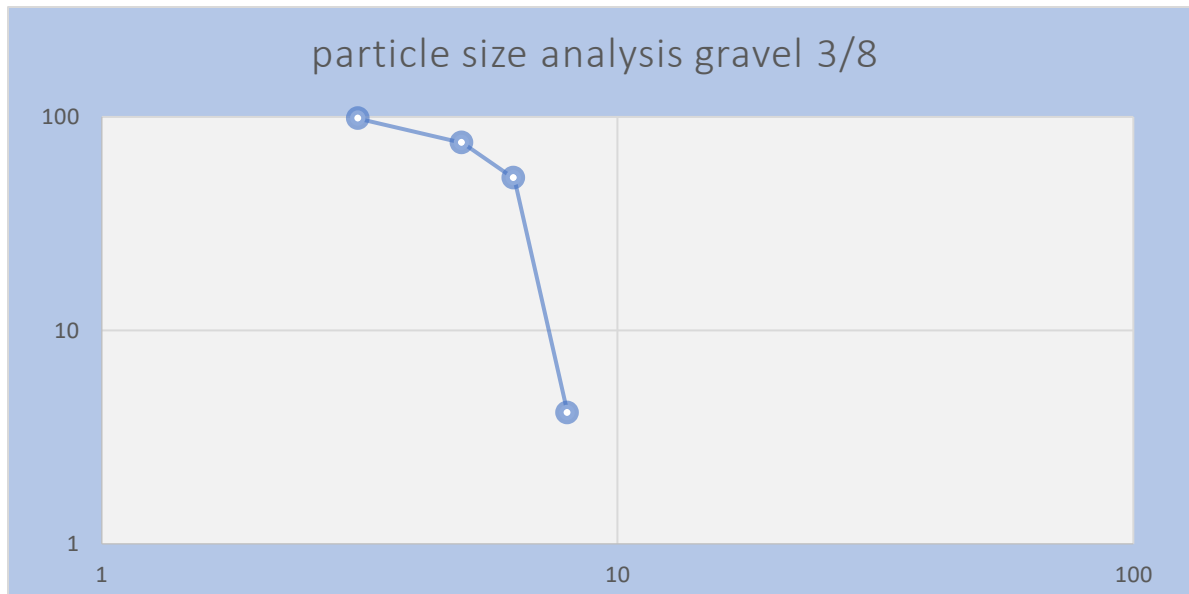


Figure 25 : Granulometric Analysis Curve of Gravel (3/8)

3.6.2 Physical Characteristics of Gravel:

- **Absolute Density**

The same procedure used for sand is applied for gravel.

Procedure

- Fill the graduated cylinder with an initial water volume: $V_1 = 300\text{mL}$.
- Weigh a dry aggregate sample: $M = 300\text{g}$.
- The absolute density is calculated using the following formula:

$$\rho_{\text{abs}} = \frac{M}{V_2 - V_1}$$

Table 9: Absolute Density of Gravel 3/8

	m	V	V'	ρ
1	300	300	420	2.5
2	300	300	415	2.6
3	300	300	417	2.6

Bulk Density

The principle of this test consists of filling a container of known internal volume and weighing the corresponding quantity of aggregates.

Procedure

- Pour the aggregates into the selected container and compact them in successive horizontal layers.
- Level the upper surface of the aggregates using a straightedge ruler.
- The bulk density is determined using the following formula:

$$\rho_{app} = \frac{(M_2 - M_1)}{V} \quad (III.10)$$

Where:

- ρ : bulk density
- **M**: mass of aggregates
- **V**: volume of the container

- **Table 10 :** Bulk Density of Gravel 3/8

	M g	V ml	ρ
1	115	1.309	1.320
2	115	1.288	1.300
3	115	1.276	1.290
moyenne			1.303

8/16*Table 11:** Granulometric Analysis of Gravel

Sieve	Weight empty	Weight + Gravel	Gravel residu	Residu cumulative	Residu %	Sieve %
16	0.939	1.18	0.241	7.5	7.5	92.5
12.5	0.891	1.848	0.957	37.8	30.3	62.2
10	0.958	2.37	1.412	81.6	43.8	18.4
8	0.837	1.346	0.509	97.4	15.8	2.6
0	0.565	0.651	0.086	100	2.7	0

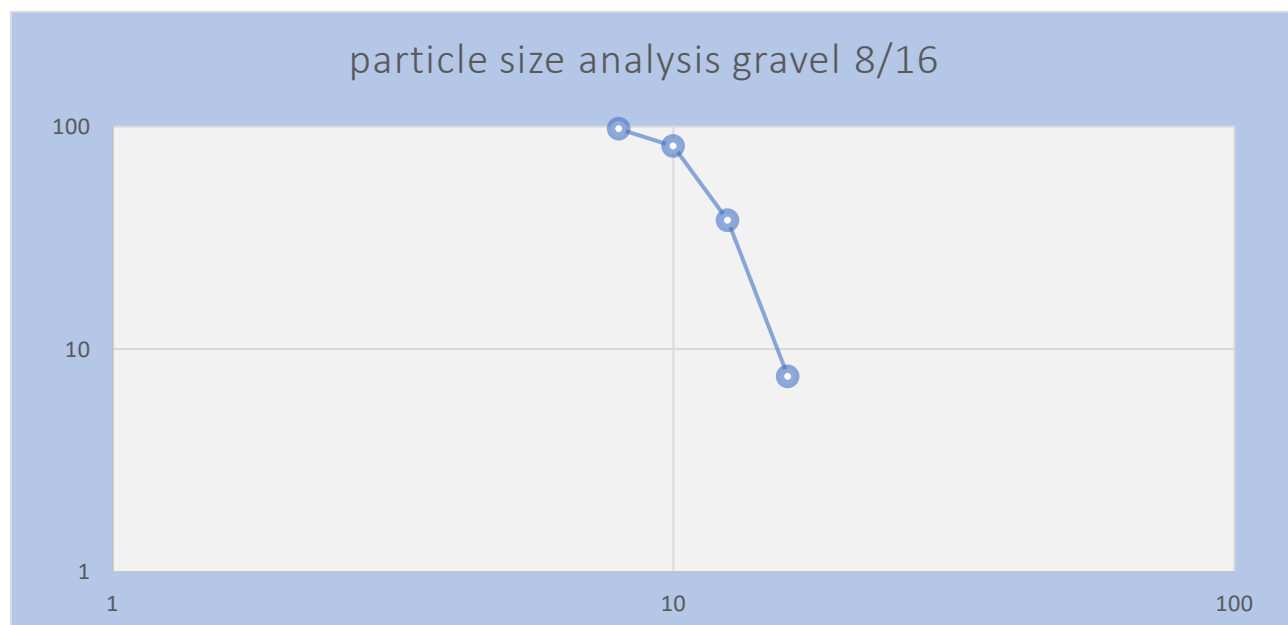
**Figure 26 :** Granulometric Analysis Curve of Gravel (8/16)

Table 12: Absolute Density of Gravel 8/16

	m	V	ρ
1	115	1.19	1.320
2	115	1.196	1.330
3	115	1.189	1.320
moyenne			1.323

	m	V	V'	ρ
1	300	300	410	2.7
2	300	300	415	2.6
3	300	300	417	2.6

Table 13: Bulk Density of Gravel 8/16

3.6.3 powder of Glass :

Glass recycling is considered an important economic and environmental solution, as it helps reduce the consumption of natural resources and the energy required for production. Recycled glass can also be used in several industrial fields, particularly in packaging and construction materials, which contributes to lowering the costs associated with extracting new raw materials.

In addition, the development of glass recycling technologies and the improvement of processing methods contribute to enhancing modern waste management practices by increasing resource efficiency and reducing the environmental impacts resulting from traditional glass waste disposal methods.

**Figure 27 :** powder of glass

Table 14: Composition of Glass.

Composant	Formule chimique	Rôle principal	Pourcentage approximatif
Silice	SiO ₂	Forme la matrice du verre (réseau vitreux)	70–75%
Oxyde de sodium	Na ₂ O	Réducteur du point de fusion	12–15%
Oxyde de calcium	CaO	Stabilisateur chimique	8–12%
Oxyde de magnésium	MgO	Améliore la durabilité	0–4%
Oxyde d'aluminium	Al ₂ O ₃	Renforce la structure	0–2%
Autres (Fe ₂ O ₃ , K ₂ O, etc.)	Divers	Donnent des propriétés spécifiques (couleur...)	<1%

Table 15 : Absolute Density of glass

	m(g)	V	ρ
0	0.206	90	x
1	30	102	0.294
2	20	110	2.500
3	15	116	2.500
4	10	120	2.500

Table 16 : Bulk Density of glass

	m	V	ρ
1	0.828	0.9	0.920
2	0.808	0.9	0.898
3	1.023	0.9	1.137
4	1.001	0.9	1.112
moyenne			1.017

3.6.4 Marble Powder :

Marble is a metamorphic rock formed by the transformation of limestone under the effect of pressure and high temperature. It is mainly composed of calcite and is white in its pure state.



Figure 28 :powder of glass

Physical and Chemical Characteristics of Marble:

The physical characteristics of this filler (marble powder) are presented in the following table.

Table 17:Caractéristiques physiques du marbre.

Physical Properties of Marble Powder	Marble Powder
Bulk density (g/cm ³)	0.83
Specific density	2.67
Blaine specific surface area (cm ² /g)	448

The chemical composition was determined at the Lafarge cement plant in M'Sila. It is presented in the following table:

Table 18 :chemical composition

Chemical Analysis of Marble Powder	Content (%)
SiO ₂	1.47
CaO	55.3
MgO	0.01
Fe ₂ O ₃	0.14
Al ₂ O ₃	0.35
Na ₂ O ₃	0.12
K ₂ O	0.04
SO ₃	0.01
Loss on ignition	42.56

Table 19: Absolute Density of marbel

	m	V	ρ
1	0.126	0.9	0.140
2	1.02	0.9	1.133
3	1.03	0.9	1.144
4	1.021	0.9	1.134
moyenne			0.888

Table 20 : Bulk Density of marbel

	m	V	ρ
0		90	
1	73.8	120	2.46
2	132.7	144	2.46

3	165	146	2.80
4	216	168	2.77

3.6.5 Cement:

Sulfate Resistant Cement (SC, Type V) is used primarily for concrete foundations where concrete is exposed to soil and groundwater with high sulfate content. In terms of demand, this is the second most demanded product in the kingdom. SC provides greater resistance to sulfate attack and exhibits lower heat generation without compromising on strength. SC conforms to SASO-GSO 1914/2009(Type V), ASTM C-150M-2021(Type V), and BS EN 197-1:2011 CEM | 52.5N SR3. Special features of SC: High Strength which is comparable to OPC, can be used in a moist environment, and high resistance to sulfate attack due to the low content of gypsum



Figure 29 : Cement

Characteristics	Specification SASO 855/1994	Typical Range
Chemical Properties		
Insoluble Residue %	Max. 1.5	0.16
Loss on Ignition %	Max. 3.0	1.23
Ferric Oxide %		5.07
Magnesium Oxide %	Max. 5.0	0.95
Total Alkalis Equivalent %	Max. 0.6	0.36
Sulphur Trioxide %	Max. 2.3	2.20
Lime Saturation Factor %	66 - 102	94.88
Tricalcium Silicate %		
Dicalcium Silicate %		
Tricalcium Aluminate	Max. 5.0 (For ASTM & SASO), Max. 3.0 (For EN)	2.76
2C ₃ A+C ₄ AF	Max.25	21.63
Physical Properties		
Air Content	Max. 12	9.5
Sp. Surface(Blaine),m ² /Kg.	Min. 280	317
Setting Time: Initial Minutes	Min. 45	149.0
Setting Time: Final Minutes	Max.375	202
Expansion Autoclave %	0.8	0.1
Compressive Strength MPa SASO 1914/2009		
3 Days	Min. 8	19.0
7 Days	Min. 15	27.5
28 Days	Min. 21	43.1
Compressive Strength MPa SASO 570/1994		
3 Days	Min 12	23.5
7 Days	Min 22	33.0
28 Days	Min 30	54.0

Properties of Sulfate Resistant Cement (SC, Type V)

Advantages and disadvantages of CEM II/B 42.5 (CPJ MATINE cement):

Advantages:

- High early strength, allowing fast stripping of formwork

- Good mechanical performance for structural concrete
- Good workability of fresh concrete
- Suitable for general construction and reinforced concrete works
- Improved durability compared to lower cement classes
- Reliable performance for normal and moderately aggressive environments

Disadvantages:

- Not ideal for very aggressive environments (high sulfate or chemical exposure) compared to special cements
- Slightly higher heat of hydration than low-strength cements (can cause cracking in massive concrete if not controlled)
- Requires careful water control to avoid shrinkage and cracking
- More expensive than basic cement types (CEM I 32.5 or lower classes)
- Performance can be sensitive to curing conditions (needs proper curing for best results)

3.6.6 Admixtures: Admixture (NOVSUPERLOW)

Table 21 : Characteristics of the admixture “NOVSUPERLOW”

Etat physique à 20 c °	Couleur	PH à 20°C	Density	Teneur en Chlorure	Extrait sec
Liquide	Brun	5 – 6	1.05 ±0.02	< 1 g/l	23%

Table 22 : Properties of “NOVSUPERLOW” in the fresh and hardened state

«NOVSUPERLOW” in the fresh state	“NOVSUPERLOW” in the hardened state
Obtaining a very low W/C ratio	Increases mechanical strength at early and long term ages
Improves fluidity and workability	Reduces porosity
Prevents segregation and facilitates placing	Reduces shrinkage and cracking risk

Conclusion

This chapter is devoted to the characterization of the materials used (cement, glass powder , marble powder, superplasticizer, sand, and gravel). The results obtained from the tests carried out in the civil engineering laboratory of the Université Mohamed Boudiaf de M'Sila for the preparation of concrete in our experimental program, including the different chemical, physical, and mechanical properties, have been presented.

Chapter 04 :
Experimental Techniques for
Self-Compacting
Concrete (SCC)

The dosage of superplasticizer is: $SP = 1.5\% \times (C + F)$
 $SP = 1.5\% \times (420 + 10) = 6.3 \text{ kg/m}^3$

The absolute density of the SP superplasticizer is equal to 1.1.

Thus, its volume is: $6.3/1.1 = 5.94 \text{ L/m}^3$

The absolute density of cement is equal to 3.1.

The cement volume is therefore: $420/3.1 = 135.48 \text{ L/m}^3$

The proportions of gravel and sand can now be calculated.

The paste volume for 1 m^3 of concrete is:

$C + E + F + SP = 135.48 + 210 + 15.73 + 5.94 = 368.37 \text{ liter}$

The aggregate volume for 1 m^3 of concrete is:

$G + S = 1000 - 368.37$

$G + S = 631.63 \text{ liters}$

With $G/S = 1$

We obtain:

$G = S = 315.815 \text{ L/m}^3$

For the two gravel fractions, 50% of G3/8 and 50% of G8/16 were selected.

- Gravel (3/8): 157.907 L/m^3
- Gravel (8/16): 157.907 L/m^3
- Sand: 315.815 L/m^3

In terms of mass:

- Gravel (3/8): $157.907 \times 2.60 = 410.61 \text{ kg/m}^3$
- Gravel (8/16): $157.907 \times 2.62 = 413.73 \text{ kg/m}^3$
- Sand: $315.815 \times 2.62 = 843.25 \text{ kg/m}^3$

Table 23: Composition of One Cubic Meter of Self-Compacting Concrete

	V(l)	M(/m ³)	M(v)
Ciment	135.48	420	4.25
Grave l(3/8)	157.912	410.6	4.15
Gravel (8/6)	157.912	413.73	4.18
sand	315.825	843.25	8.53
Glass powder	8.4	21	0.21
Marble powder	8.53	21	0.21
sp	6.5	6.3	0.07
water	210	210	2.12

Specimen Preparation Procedure:

Samples were manufactured and tested in the Construction Materials Laboratory at the University of M'Sila. The preparation of self-compacting concrete requires greater care and precision compared to ordinary concrete. After determining the proportion of each constituent, the following procedure was adopted:

- First, check the quantity and condition of the prismatic and cubic molds required for the tests. The molds must be lubricated with oil to facilitate demolding.
- Gather all the equipment necessary to perform the test. Ensure that the materials are not wet; otherwise, they must be dried beforehand in an oven.
- Prepare the required quantity of mixing water. Add the superplasticizer to one-quarter of the mixing water.
- Weigh and introduce the dry materials (gravel, sand, cement, and glass powder/marble powder) into the mixer and mix them.

The concrete batches were prepared using a vertical-axis mixer with a capacity of 30 L. A strict and identical operating procedure was followed:

- Dry mixing of sand + gravel + cement + marble powder for 30 seconds.
- Addition of water + superplasticizer, followed by mixing for 210 seconds.
- The tests are carried out immediately after stopping the mixing process, and each test is performed at least twice to validate the obtained results.

- The molds are filled in two or three layers without vibration for self-compacting concrete.

4.4 Equipment Used:

In the experimental program, the following equipment was used:

- A weighing balance.
- A concrete mixer.
- Masonry tools such as: a ruler, container, trowel, wheelbarrow, molds, etc.
- The Abrams cone for slump measurement.
- A testing machine (“compression testing press”) with dimensions appropriate for the tested specimens and complying with the requirements of standards NF P 18-411 and NF P 18-412.



Figure 30 : Concrete mixer and Concrete specimens



Figure 31 : Preparations of concrete specimens



Figure 33 :Compression Testing Machine



Figure 32: Tensile Testing Machi

4.5 Fresh State Characterization Tests of Self-Compacting Concrete:

Self-compacting concrete (SCC) in the fresh state has been the subject of numerous studies in the field of construction materials in recent years. Among the most commonly used tests to characterize fresh SCC, the following can be cited:

- Determination of consistency using the Abrams cone (slump flow test).
- Determination of blocking risk using the L-box test.
- Determination of segregation resistance using the sieve stability test.

4.5.1 Slump Flow Test (NF EN 12350-8):

The slump flow test is considered the simplest test to perform, and it allows the consistency of concrete to be measured. This test is carried out in a similar way to the standard Abrams cone slump test. It also helps to detect whether horizontal segregation occurs.

This test, which can be performed on site, requires only a small concrete sample. A flow diameter ranging from 60 to 75 cm is generally required for producing self-compacting concrete.

Equipment used:

- A square plate with a side length of 120 cm
- An Abrams cone

- A measuring ruler

Procedure:

- Place the plate on a stable and horizontal support.
- The surface of the board is wetted to prevent the concrete from sticking, and any excess water is wiped off using a cloth.
- The Abrams cone is placed at the center of the board, and the concrete is poured continuously until it reaches the top of the cone.
- If necessary, the top is levelled using a trowel, and the board is cleaned with a damp cloth if required.
- The cone is then lifted vertically without any lateral movement.
- Once the concrete has spread on the table, the final diameter is measured along two perpendicular directions, and both values are recorded. If the difference between the two measurements exceeds 5 cm, the test is considered invalid and must be repeated.
- The final result is the average of the two measured diameters:
- $(D1 + D2) / 2$.



Figure34: Abrams cone slump flow test

4.5.2 L-Box Test:

This test is performed using an L-shaped box. Specific tests are carried out in a controlled environment and confirm that the concrete flow is not hindered by unacceptable blocking phenomena, such as the presence of reinforcement bars.

The principle of this test is as follows:

The vertical section of the box is completely filled with concrete, while the horizontal section contains reinforcing bars through which the concrete must flow. The gate is then lifted, allowing the concrete to flow into the horizontal section through the reinforcement.

When the flow stops, the heights **H1** and **H2** are measured.



Figure 35 : Test box L

4.5.3 Sieve Stability Test:

This test aims to verify the resistance of self-compacting concrete (SCC) to segregation, i.e., its ability to maintain a homogeneous distribution of its components without the separation of aggregates from the cement paste. The standard procedure for this test is as follows:

Sample preparation:

A representative sample of fresh self-compacting concrete is taken.

Sieving:

The concrete is poured through a standard sieve (usually with a 5 mm or 8 mm mesh) placed above a container.

Weighing:

The concrete passing through the sieve and the material retained on the sieve are weighed.

Stability calculation:

The percentage of concrete passing through the sieve is calculated. A low percentage indicates good stability (low segregation). Standard limits may vary, but generally high-quality SCC should have a passing percentage lower than 15%.

Laitance measurement:.

$$P_{\text{laitance}} = P_{\text{bottom}} + \text{laitance} - P_{\text{bottom}}$$

The percentage of laitance is calculated relative to the total sample weight:

$$d = (P_{\text{sample}} / P_{\text{laitance}}) \times 100$$

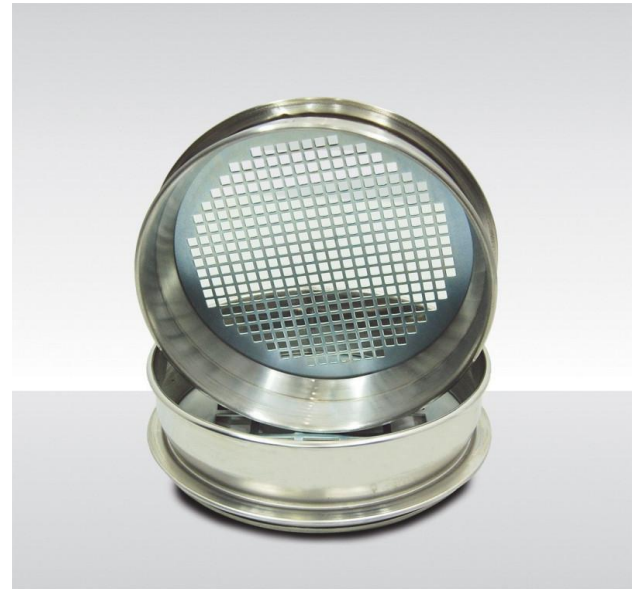


Figure 36 : Sieve stability test principle for SCC

4.5.4 Density (Fresh Concrete):

The density (unit weight) of fresh concrete is another essential property, influencing the strength and durability of hardened concrete. The density test is generally carried out as follows:

Equipment preparation:

A container of known volume (usually a cylinder or bucket) and a precise weighing balance are used.

Filling the container:

The container is filled with fresh concrete while avoiding air voids.

Leveling:

The surface of the concrete is leveled to ensure accurate measurement.

Weighing:

The container filled with concrete is weighed.

Density calculation:

The density is calculated by dividing the mass of concrete by the volume of the container:

density=Mass (m3) /Volume of concrete (kg)

The typical density of SCC ranges between 2200 and 2500 kg/m³.



Figure 37: Density of fresh concrete

4.6 Tests for Characterization of Self-Compacting Concrete in the Hardened State:

Curing of Specimens:

After mixing the Self-Compacting Concrete (SCC), the molds are kept in a room at ambient temperature and demolded after 24 hours.

Once demolded, in order to ensure proper curing of the concrete, the specimens are stored in a water tank at a temperature of 20°C. This helps prevent water loss and ensures the normal progress of the cement hydration process.



Figure 38:Concrete in the Hardened State

Finally, the specimens intended to be exposed to high temperatures were first cured in water for more than 30 days and then dried in an oven for 48 hours. After that, the specimens were subjected to elevated temperatures ranging from 20°C, 100°C, 200°C, 400°C, and 600°C, with a heating rate of 10°C/min and a temperature holding time of 1 hour in a muffle furnace.

The experimental procedure applied was based on thermal loading followed by mechanical loading.



Figure 39 : The furnace used for temperature increase.

4.6.1 Compression Test (NF EN 206-1):

The compressive strength is determined at 28 days using the formula:

$$R = F/S$$

Where:

- **R** = compressive strength
- **F** = failure load
- **S** = specimen cross-sectional area (100 cm²)



Figure 40: compression test specimens

4.6.2 Flexural Tensile Strength Test:

This widely used test allows the simulation of the most common type of loading in structural elements. The specimens used for this test are specifically prism-shaped and are commonly used for mortars, with dimensions of **7 × 7 × 28 cm**.

The flexural tensile strength is determined using the following strength of materials formula: $\sigma = M_f / W$

Where:

- σ = flexural tensile strength
- M_f = bending moment

The bending moment is given by:

$$M_f = F \cdot L / 4$$

Where:

- F = applied load at failure
- L = span length between supports



Figure 41: Tensile test

4.7 Specimen Preparation:

4.7.1 Type and Size of Molds:

The molds used for specimen preparation are made of steel and plastic, with the following shapes

- Prismatic ($7 \times 7 \times 28 \text{ cm}^3$)
- Cubic ($10 \times 10 \times 10 \text{ cm}^3$)

4.7.2 Curing of Specimens:

All specimens were demolded 48 hours after casting and then stored in water at a temperature of $20 \pm 2^\circ\text{C}$.

4. 8 Measurement of Water Porosity (P_{water}) [NF P 18-459]:

- Hydrostatic weighing:
 M_{water} = mass in grams measured under water.
- Weighing in air of the water-saturated specimen:
 M_{sat}
- Drying at a temperature of (105°C) until constant mass is reached
(two weighings taken 24 hours apart must not differ by more than 0.05%).
- Weighing in air of the dry specimen:
 M_{dry}
- Calculation of the water-accessible porosity.

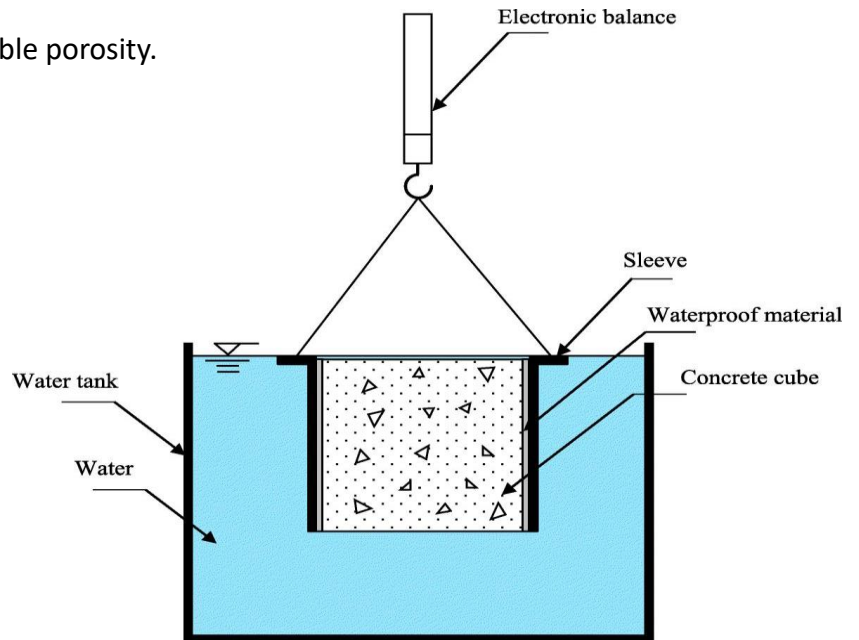


Figure 42 : Water Porosity Test.

Conclusion:

In this chapter, we have described all the tests carried out, both in the fresh and hardened states. We also presented the mix design procedure for this type of concrete, as well as the calculation formulas and the fundamental criteria of each test.

Chapter 05 :

Results and discussion.

5-1 Introduction:

In this chapter, we present a synthesis of the results of rheological, physical, and mechanical tests carried out on self-compacting concrete (SCC) incorporating mineral additions (glass powder and marble powder) at different percentages . This is done to evaluate the influence of both the type and the proportion of these additions on the properties of SCC in the fresh and hardened states.

5-2 Formulations of the studied concretes:

The mix designs of the concretes produced are as follows:

SCC 1: self- compacting concrete with 0% glass powder and 0% marble powder

SCC2: self- compacting concrete with 0% glass powder and 10% marble powder

SCC3: self- compacting concrete with 10% glass powder and 0% marble powder

SCC4: self- compacting concrete with 5% glass powder and 5% marble powder

SCC5: self- compacting concrete with 10% glass powder and 10% marble powder

SCC6: self- compacting concrete with 5% glass powder and 10% marble powder

SCC7: self- compacting concrete with 10% glass powder and 5% marble powder

SCC8: self- compacting concrete with 15% glass powder and 15% marble powder

SCC9: self- compacting concrete with 15% glass powder and 5% marble powder

SCC 10: self- compacting concrete with 5% glass powder and 15% marble powder

5-3 Fresh State Test Results:

The results in the fresh state are obtained immediately after mixing in order to characterize this type of concrete. They allow the study of the properties of self-compacting concrete (SCC) in the fresh state through:

- Slump flow test (Abrams cone test).
- L-box test (to assess flowability).
- Sieve stability test (to study segregation resistance).

The fresh state results of the concretes are presented in the following table:

Type of concrete	Flow stability (mm)	Sieve stability (%)	L-box (H2/H1)	Concrete density (kg/m ³)
SCC 1	65	7.9	0.8	2400
SCC2	73	8.9	0.85	2406
SCC3	73	6.2	0.82	2310
SCC4	70.5	8,12	0.77	2446
SCC5	73	13,84	0.90	2447
SCC6	85.5	10,7	0.92	2321
SCC7	77.5	11.77	0.94	2293
SCC8	78	13.55	0.94	2387
SCC9	78.5	12.32	0.94	2453
SCC10	77	8.5	0.92	2432

Table 24 : Fresh state test result

Comment:

All SCC mixtures show slump flow diameters between 65 cm and 85.5 cm, confirming self-compacting behavior. The highest fluidity is observed for SCC6 (85.5 cm), where the combination of glass and marble powder improves workability. Sieve stability values range from 6.2% to 13.84%, all within the satisfactory stability class (<15%). L-box ratios (H2/H1) vary from 0.77 to 0.94; most mixtures meet the recommended limit (≥ 0.8), except SCC4 (0.77) which shows slightly reduced passing ability. Concrete density ranges from 2293 to 2453 kg/m³; mixtures with higher glass content tend to have lower density due to the lower specific gravity of glass.

5-4 Slump Flow Test Using Abrams Cone

The objective of this test is to verify the ability of self-compacting concrete to flow and spread homogeneously under its own weight without vibration while maintaining good stability and resistance to segregation.

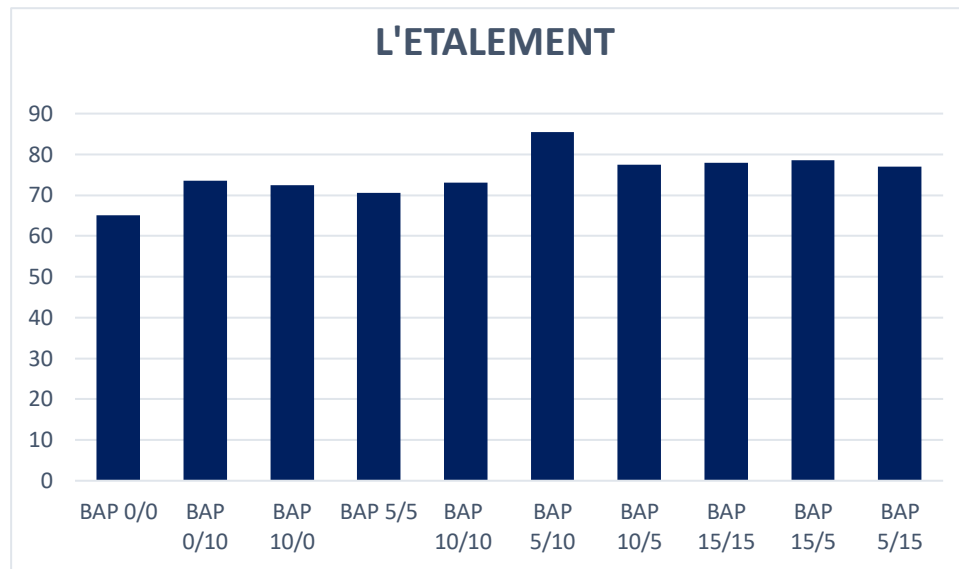


Figure 43 : Flow spread as a function of concrete type.

Commentary:

The obtained slump flow diameters range between 65 cm and 85.5 cm, confirming the self-compacting character of the mixtures.

The SCC 5/10 concrete shows the highest slump flow value (85.5 cm), indicating excellent fluidity. The incorporation of recycled glass appears to improve workability due to the smooth surface texture of glass particles, whereas an excessive amount of marble powder may increase the viscosity of the mixture.

5-5 L-box test:

The objective of this test is to determine the ability of concrete to flow through a confined area without being hindered by unacceptable blocking phenomena.

The results obtained from this test (for the different concrete mixtures formulated) are presented in:

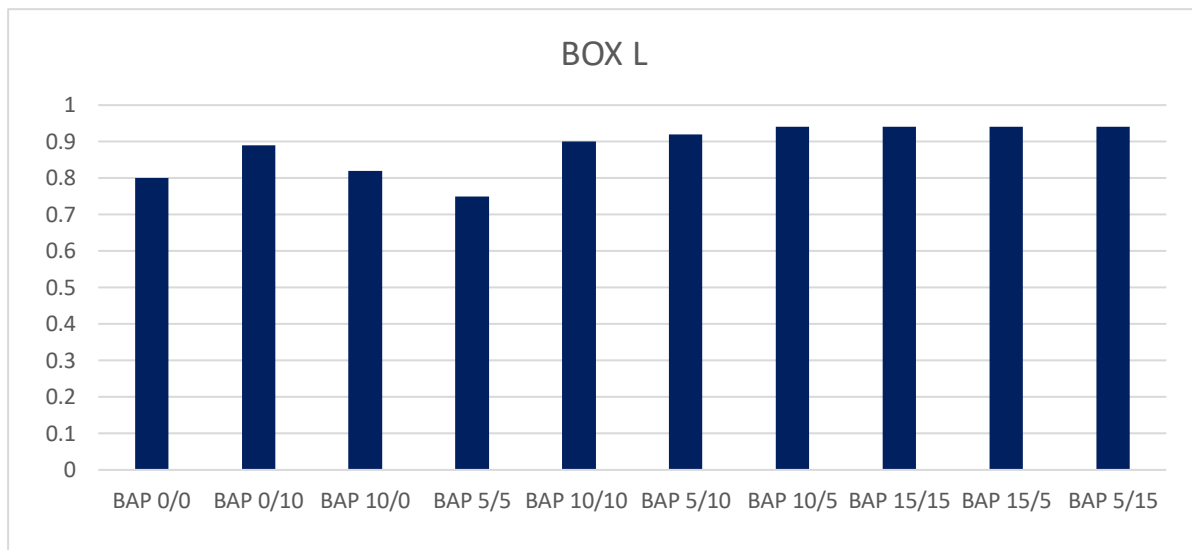


Figure 44: L-Box Test as a Function of Concrete Type.

Commentary:

The L-box test results show the passing ability of the self-compacting concrete (SCC) mixtures through reinforcing bars, which is an indicator of their workability and segregation resistance.

The measured **H2/H1 ratios** vary according to the mixture composition. In general, mixtures with higher workability present values closer to **1.0**, indicating a good flow through the obstacles without blocking. Conversely, lower ratios indicate a higher tendency to blockage and reduced passing ability.

It is observed that the incorporation of mineral additions (such as marble powder and recycled glass) influences the flow characteristics of the concrete. Some mixtures show a reduction in the L-box ratio, which may be attributed to increased internal friction and reduced paste fluidity.

Overall, the results indicate that the SCC mixtures maintain acceptable passing ability, confirming their suitability for reinforced concrete applications, provided that the L-box ratio remains within the recommended limits (typically ≥ 0.8).

5-6 Sieve Stability:

This test characterizes the ability of self-compacting concrete (SCC) to remain homogeneous after placement until the beginning of setting.

The “sieve stability test” consists of evaluating the percentage by mass of mortar (laitance) from a concrete sample passing through a 5 mm sieve.

The acceptance criteria for an SCC mix are divided into three classes:

- $0 < \text{mortar percentage} < 15\% \rightarrow$ satisfactory stability.
- $15\% < \text{mortar percentage} < 30\% \rightarrow$ critical stability.
- Mortar percentage $> 30\% \rightarrow$ very poor stability.

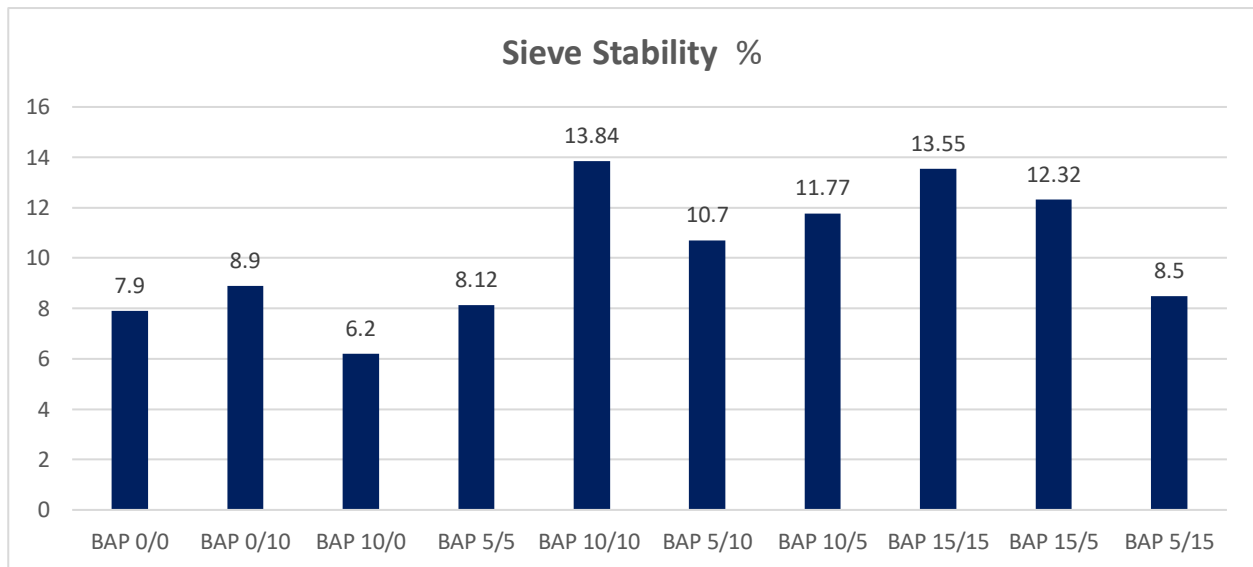


Figure 45 : Sieve Stability as a Function of Concrete Type.

Commentary:

The sieve stability values range between **6.2%** and **13.84%**.

The **SCC 10/0** mixture presents the best stability with the lowest value (**6.2%**), indicating good resistance to segregation.

On the other hand, mixtures containing high replacement rates, particularly **SCC 10/10** and **SCC 15/15**, show an increase in segregation, probably due to changes in particle grading and the increase in fine materials content.

5-7 Density (kg/m^3):

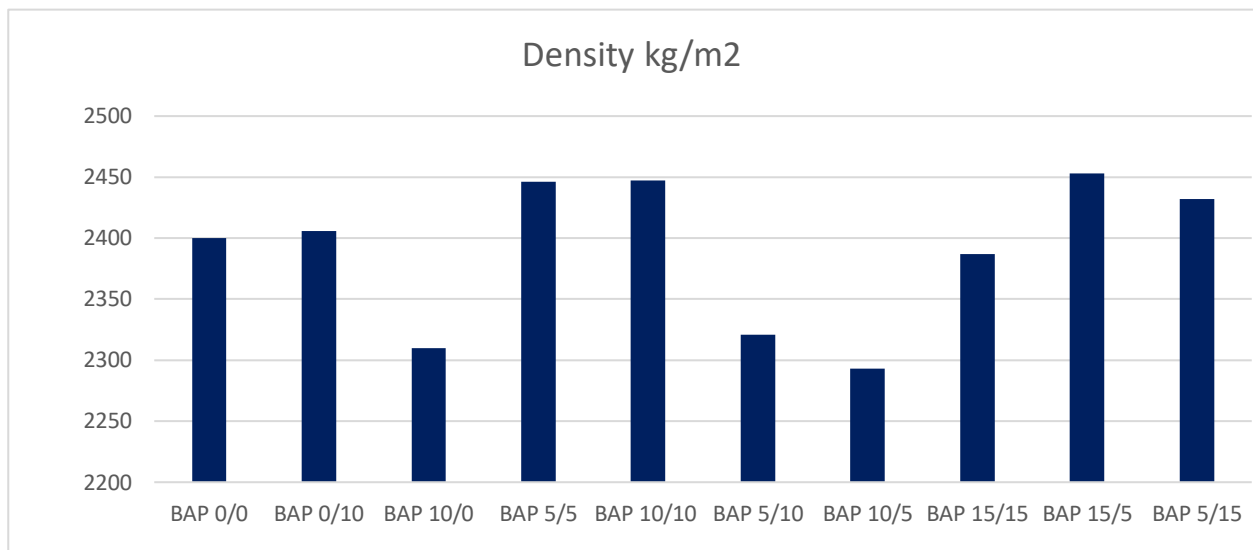


Figure 46: Density (kg/m^3)

Commentary:

The density values vary between **2293 kg/m^3** and **2453 kg/m^3** .

Mixtures containing higher amounts of recycled glass generally exhibit a slight reduction in density, which may be attributed to the lower density of glass compared to natural aggregates. The **SCC 15/5** mixture presents the highest density (**2453 kg/m^3**), reflecting a more compact internal structure.

5-8 Compressive Strength

In this section, the influence of glass powder on the compressive strength of self-compacting concrete (SCC) was investigated. The specimens were cured for 30 days, and then exposed to different elevated temperatures (100°C , 200°C , and 400°C).

The objective of this study is to evaluate the effect of glass and marble powder content on the mechanical performance of SCC under both normal and high-temperature conditions. The variation in compressive strength is analyzed in order to determine the optimal replacement level and to assess the thermal resistance of the different mixtures.

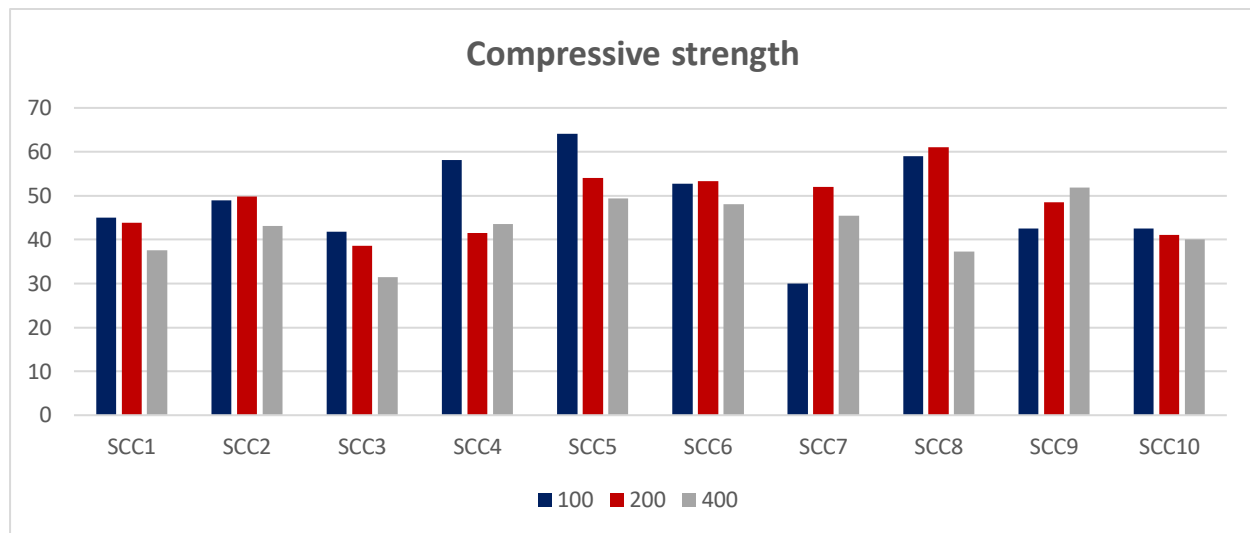


Figure 46: Compressive Strength

Commentary:

Maximum Strength: SCC5 outperformed all other mixtures, peaking at approximately 60 MPa at 100°C and maintaining a high residual strength of about 45 MPa at 400°C.

Anomalous/Atypical Behavior: * SCC7 showed an unconventional trend; its strength was remarkably low at 100°C (~26 MPa) but significantly surged at 200°C to around 46 MPa before slightly decreasing at 400°C.

5-9Tensile Strength

The results obtained from the flexural tensile strength tests are presented in Figure.

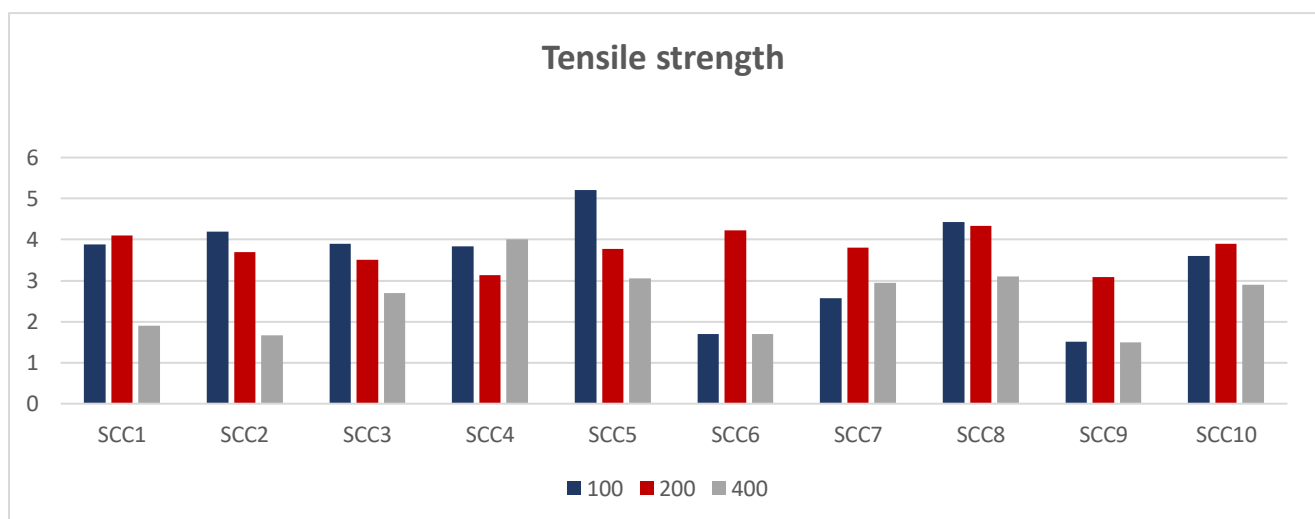


Figure 47: tensile strength

Commentary:

Peak Performance: SCC5 achieved the highest tensile strength at 100°C, exceeding 5 MPa, followed closely by SCC8.

High-Temperature Vulnerability: SCC1, SCC2, SCC6, and SCC9 experienced a sharp drop at 400°C, falling to or below 2 MPa, indicating poor thermal resistance in tensile bonding.

Thermal Stability: SCC4 demonstrated exceptional stability, maintaining a consistent tensile strength of around 4 MPa across all tested temperatures (100°C, 200°C, and 400°C) without significant degradation.

5-10 Mass loss of self-compacting concrete exposed to high temperatures:

Table 25 : Compression and tensile strength by bending with weight SCC 0%V

Compressive strength (10*10*10 cubicspecimen)						
	température		Weight before being placed in the water (kg)	Weight after soaking in water and Weight before being placed in the oven (kg)	Weight after placement in oven (kg)	La Résistance
BAP 0%G 0 %M	100°	i1	2.289	2.322	/	40.60
		i2			/	
		i3			/	
	200°	i4	2.358	2.386	2.301	49.80
		i5				
		i6				
	400°	i7	2.253	2.280	2.153	43.11
		i8				
	Flexural tensile strength (7*7*28 prismatic specimen)					
	100°	i1	3.226	3.263	/	Résistance=4.75
		i2			/	la charge=7.763
	200°	i3	3.247	3.283	3.167	Résistance=3.70
		i4				la charge=6.048
		i5				Résistance=1.66

	400°	i6	3.261	3.295	3.124	la charge =2.766
		i8				

Comment:

For the reference concrete without mineral additions, compressive strength at 100°C is 40.60 MPa, increases to 49.80 MPa at 200°C, then decreases to 43.11 MPa at 400°C. The increase at 200°C may be due to internal curing or further hydration. Flexural tensile strength drops sharply from 4.75 MPa at 100°C to 1.66 MPa at 400°C, indicating poor thermal resistance of the plain mixture under tensile loading at high temperatures.

Table 26 : Compressive and tensile strength by bending with weight SCC 5%G .5%M

Compressive strength (10*10*10 cubicspecimen)							
	température		Weight before being placed in the water (kg)	Weight after soaking in water Weight before being placed in the oven (kg)	Weight after placement in oven (kg)	Résistance	
SCC 5%G 5%M	100°	i4	2.387	2.409	2.345	49.49	
		i5					
		i6					
	200°	i7	2.396	2.428	2.298	56.63	
		i8					
		i9					
	400°	i10	2.384	2.416	2.256	39.01	
		i11					
		i12					
	Flexural tensile strength (7*7*28 prismatic specimen)						
	100°	i1	3.417	3.463	/	Résistance=4.62 la charge =7.560	
		i2			/		
	200°	i3	3.428	3.477	3.360	Résistance=4.36 la charge =7.208	
		i4					
	400°	i5	3.445	3.489	3.309	Résistance=1.55 la charge =2.551	
		i6					

Comment:

This mixture exhibits good mechanical performance. Compressive strength reaches 49.49 MPa at 100°C, peaks at 56.63 MPa at 200°C, and remains at 39.01 MPa at 400°C. Notably, tensile strength is very stable across temperatures: 4.62 MPa (100°C), 4.36 MPa (200°C), and 1.55 MPa (400°C). The drop at 400°C is similar to other mixtures, but the retention at 200°C is excellent, showing that moderate dual additions enhance thermal stability of tensile strength.

Table27: Compressive and tensile strength by bending with weight SCC 10%G and 10%M

Compressive strength (10*10*10 cubicspecimen)							
	température		Weight before being placed in the water (kg)	Weight after soaking in water Weight before being placed in the oven (kg)	Weight after placement in oven (kg)	Resistance	
SCC 10%G 10%M	100°	i4	2.381	2.402	2.334	48.73	
		i5					
		i6					
	200°	i7	2.377	2.400	2.274	54.28	
		i8					
		i9					
	400°	i10	2.381	2.404	2.256	42.15	
		i11					
		i12					
	Flexural tensile strength (7*7*28 prismatic specimen)						
	100°	i1	3.395	3.424	/	Résistance=4.71 la charge =7.704	
		i2			/		
	200°	i3	3.432	3.457	3.360	Résistance=3.95 la charge =6.457	
		i4					
	400°	i5	3.380	3.421	3.242	Résistance=1.41 la charge =2.328	
		i6					

Comment:

SCC5 shows the highest overall mechanical performance. Compressive strength is 48.73 MPa at 100°C, increases to 54.28 MPa at 200°C, and remains at 42.15 MPa at 400°C. Tensile strength at 100°C is 4.71 MPa, then decreases to 3.95 MPa at 200°C and 1.41 MPa at 400°C. Although tensile

strength declines more sharply after 200°C, the compressive strength retention at 400°C is among the best, confirming that 10% glass + 10% marble is a very effective combination for high-temperature resistance

Table 28: Compressive and tensile strength by bending with weight SCC 15%G .15%M

Compressive strength (10*10*10 cubicspecimen)							
	température		Weight before being placed in the water (kg)	Weight after soaking in water Weight before being placed in the oven (kg)	Weight after placement in oven (kg)	Resistance	
	100°	i4	2.357	2.415	2.340	62.2	
		i5					
		i6					
	200°	i7	2.388	2.435	2.298	56.63	
		i8					
		i9					
	400°	i10	2.366	2.401	2.222	49.01	
		i11					
		i12					
	Flexural tensile strength (7*7*28 prismatic specimen)						
	100°	i1	3.417	3.463	3.301	Résistance=5.62 la charge =7.560	
		i2					
	200°	i3	3.428	3.477	3.360	Résistance=4.36 la charge =7.208	
		i4					
	400°	i5	3.445	3.489	3.309	Résistance=1.55 la charge =2.551	
		i6					

Comment:

This high-replacement mixture achieves the highest compressive strength at 100°C (62.2 MPa), but it drops to 56.63 MPa at 200°C and further to 49.01 MPa at 400°C. The strength loss from 100°C to 400°C is about 21%, which is relatively moderate. Tensile strength at 100°C is 5.62 MPa (the highest among all), then decreases to 4.36 MPa at 200°C and 1.55 MPa at 400°C. While initial tensile strength is excellent, the high-temperature tensile performance remains similar to other mixtures, suggesting that very high addition rates improve initial strength but do not significantly enhance thermal tensile resistance.

5-10 Water Absorption:

Water Absorption is the ability of a material to absorb and retain water within its pores.

In concrete and construction materials, absorption indicates the amount of water absorbed compared to the dry mass of the specimen.

The common formula is:

$$\text{Absorption (\%)} = \frac{M_s - M_d}{M_d} * 100$$

Where:

- (Ms) = saturated mass (after immersion in water)
- (Md) = dry mass

Visual formula:

$$\{\text{Absorption}\}(\%) = \frac{M_s - M_d}{M_d} * 100$$

Steps of the Water Absorption Test

1. Dry the specimen in an oven until constant mass.
2. Measure the dry mass (M_d).
3. Immerse the specimen in water (usually 24 h).
4. Remove surface water.
5. Measure the saturated mass (M_s).
6. Calculate absorption percentage.

Importance in Concrete

- High absorption → more pores and lower durability.
- Low absorption → denser and more durable concrete.
- Used to evaluate:
 - Quality of concrete

- Durability
- Resistance to aggressive environments

Typical Values for Concrete

- Good quality concrete: < 5%
- Medium quality: 5–10%
- Poor quality: > 10%

Table 29: Water Absorption Result

	Mdry (kg)	Mwet (kg)	(Mwet – Mdry) (kg)	Absorption A (%)
SCC(5M/5G)	2.148	2.280	0.132	6.15%
SCC(10M/10G)	2.307	2.434	0.127	5.51%
SCC(15M/15G)	2.134	2.307	0.173	8.11%
SCC(10M/5G)	2.260	2.290	0.030	1.33%
SCC(5M/10G)	2.352	2.380	0.028	1.19%
SCC(5M/15G)	2.337	2.370	0.033	1.41%
SCC(15M/5G)	2.319	2.330	0.011	0.47%
SCC(10M/0G)(	2.304	2.333	0.029	1.26%
SCC(0M/10G)	2.289	2.411	0.122	5.33%
SCC(0M/ 0G)	2.200	2.282	0.08	3.73%

Comment:

Water absorption values vary significantly depending on the combination of glass and marble powder. The lowest absorption is observed for SCC(15M/5G) with only 0.47%, indicating a very dense and durable microstructure. Similarly, SCC(5M/10G) and SCC(10M/5G) show very low absorption (1.19% and 1.33% respectively). In contrast, high equal replacements such as SCC(15M/15G) give 8.11% absorption, which exceeds the typical limit for good quality concrete (<5%). The reference concrete (0M/0G) has 3.73% absorption, which is acceptable. Overall,

moderate and balanced additions reduce porosity and water penetration, whereas excessive amounts (especially 15% of both) create more interconnected pores.

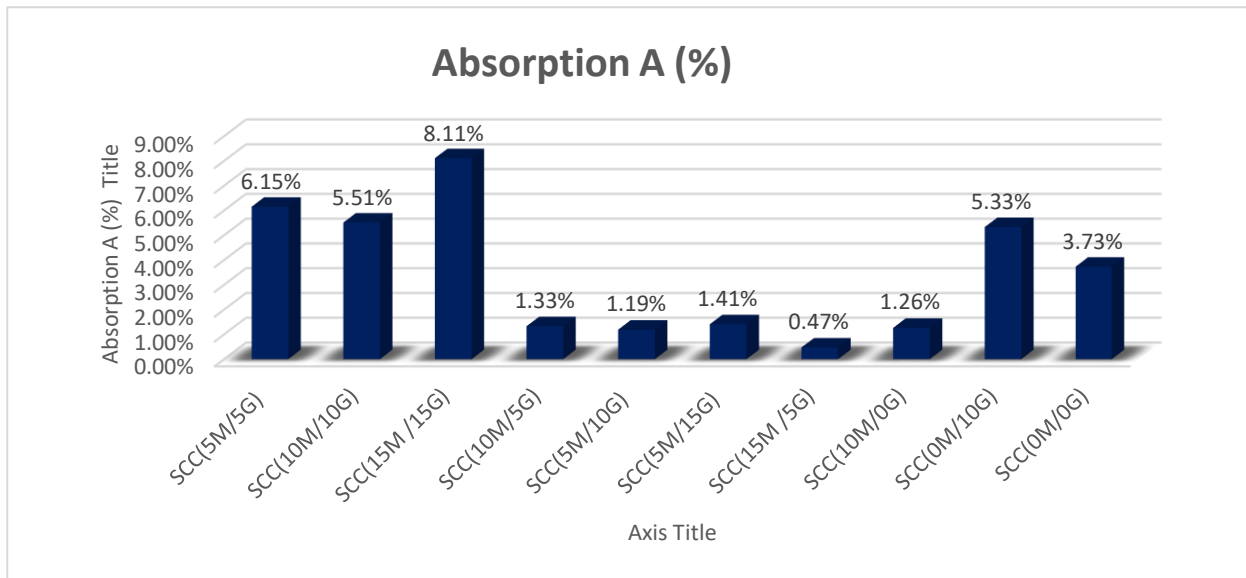


Figure 48 :Water Absorption

Commentary:

The water absorption results indicate that the incorporation of marble powder and recycled glass affects the porosity and durability of self-compacting concrete. Some mixtures, especially **SCC(15M/15G)**, showed high absorption values, indicating increased porosity and weaker durability. In contrast, mixtures such as **SCC(15M/5G)** exhibited very low absorption, reflecting a denser and more compact concrete structure. Overall, moderate replacement ratios improved the concrete microstructure, while excessive additions increased water penetration and porosity.

Table 30: Test of porosity:

Mix	Porsity %
SCC1	12.8
SCC2	11.9
SCC3	11.4
SCC4	10.7
SCC5	10.2
SCC6	10.5
SCC7	10.8
SCC8	11.3
SCC9	11.5
SCC10	12

Comment:

Porosity decreases progressively from SCC1 (12.8%) to SCC5 (10.2%), indicating that the addition of up to 10% glass and 10% marble improves particle packing and reduces voids. After SCC5, porosity increases slightly, reaching 12% for SCC10. The increase in porosity for high replacement levels (SCC8, SCC9, SCC10) is attributed to excess fine materials that may cause agglomeration or improper filling of the granular skeleton. Thus, the optimal replacement range for minimizing porosity is around 5–10% of both additions.

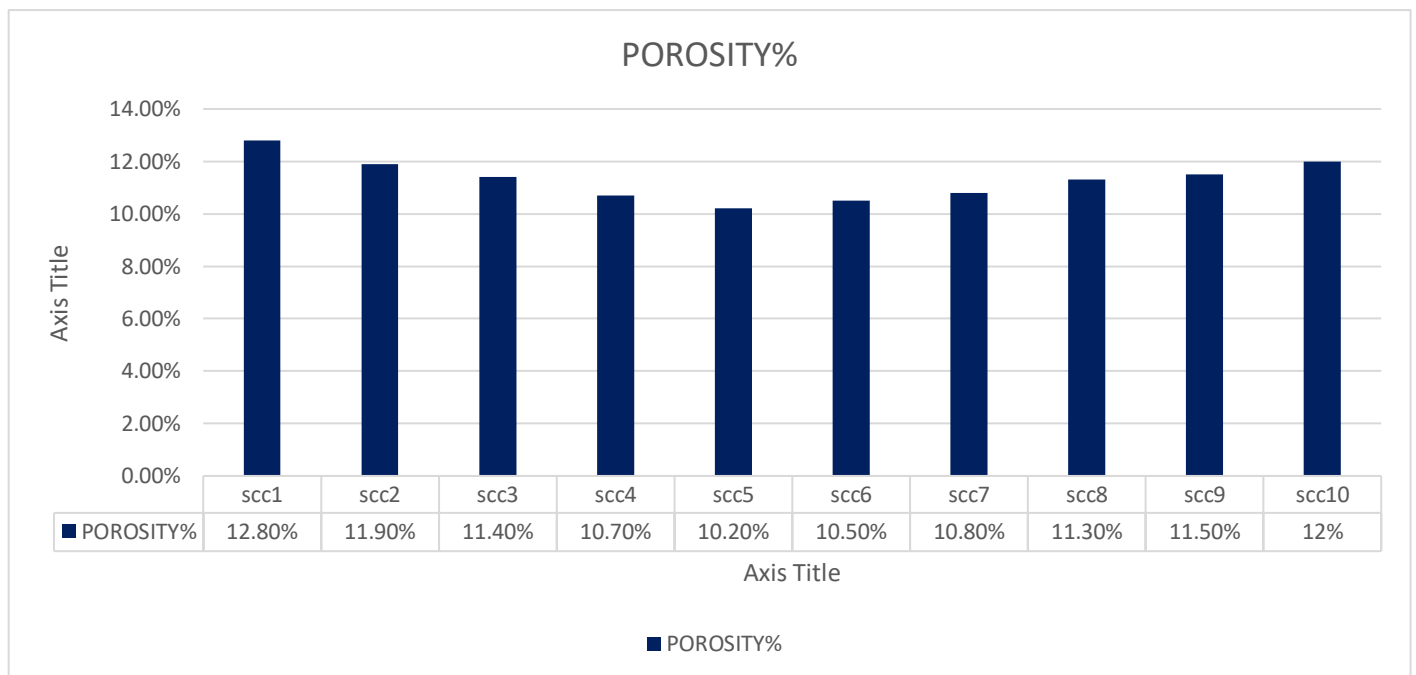


Figure 49 : porosity %

Commentary:

The porosity of the SCC mixtures decreased from **12.8% (SCC1)** to **10.2% (SCC5)**, showing an improvement in the compactness and density of the concrete due to the incorporation of marble powder and recycled glass. After SCC5, the porosity slightly increased up to **12% (SCC10)**, which may be due to excessive replacement levels causing additional void formation. Overall, moderate additions improved the internal structure and reduced the porosity of the self-compacting concrete.

General Conclusion

This research was carried out to evaluate the combined effect of glass powder and marble powder – two types of industrial and household waste – on the behaviour of self-compacting concrete (SCC) in both the fresh and hardened states, with special attention to performance after exposure to elevated temperatures.

An extensive bibliographic study (Chapters 1 and 2) recalled the main characteristics of SCC, the degradation mechanisms at high temperature, and the principles of waste valorisation. The experimental part (Chapter 3) characterised the local materials: siliceous sand, crushed limestone gravel (3/8 and 8/16), CPJ 42.5 N cement, superplasticiser, glass powder and marble powder. Tests such as granulometry, sand equivalent, absolute and bulk densities, and water content confirmed that all materials were suitable for manufacturing SCC.

Chapter 4 presented the mix design according to AFGC recommendations. Ten SCC formulations were prepared, varying the proportions of glass powder (0%, 5%, 10%, 15%) and marble powder (0%, 5%, 10%, 15%). Fresh state tests included slump flow, L-box, sieve stability, and density. Hardened state tests comprised compressive strength, flexural tensile strength, water porosity, and water absorption. Specimens were also subjected to 100 °C, 200 °C and 400 °C to evaluate residual mechanical performance.

The analysis of results (Chapter 5) led to the following conclusions:

1. Fresh state properties

All mixtures exhibited self-compacting behaviour with slump flow between 65 cm and 85.5 cm. SCC6 (5% glass, 10% marble) gave the highest fluidity (85.5 cm). L-box ratios (H2/H1) were all ≥ 0.8 , confirming good passing ability. Sieve stability values remained below 15% for all mixtures, indicating satisfactory segregation resistance. The best stability was obtained for SCC3 (10% glass, 0% marble) at 6.2%.

2. Mechanical performance

SCC5 (10% glass, 10% marble) achieved the highest compressive strength – approximately 60 MPa at 100 °C – and the highest flexural tensile strength (>5 MPa at 100 °C). SCC4 (5% glass, 5% marble) showed remarkable thermal stability, maintaining a tensile strength of about 4 MPa across all tested temperatures (100 °C, 200 °C, 400 °C). The reference concrete (SCC1) and mixtures with high addition rates showed greater strength loss at 400 °C.

3. Porosity and durability

The use of moderate amounts (5–10%) of glass and marble powders reduced porosity from 12.8% (SCC1) to 10.2% (SCC5). Water absorption was as low as 0.47% for the mixture with 15%

marble and 5% glass (SCC15M/5G). Higher replacement levels (15% each) increased porosity and water absorption due to excessive fines. These results indicate that optimal additions produce a denser, more durable concrete matrix.

4. High-temperature resistance

Mixtures with combined additions showed better residual properties after exposure to 400 °C than the reference concrete. The pozzolanic activity of glass powder and the filler effect of marble powder refined the pore structure, reduced microcracking, and limited thermal damage. SCC4 and SCC5 proved to be the most thermally stable formulations.

5. Environmental and economic contribution

The incorporation of glass and marble powders provides a sustainable solution for waste valorisation. It reduces landfill burden, saves natural resources (cement and aggregates), lowers CO₂ emissions associated with cement production, and promotes a circular economy in the construction sector.

Recommendation for practice

For optimal overall performance (workability, strength, durability, and thermal resistance), a combination of 5–10% glass powder and 5–10% marble powder by mass of cement is recommended. Specifically:

- SCC4 (5% glass, 5% marble) is suitable for applications requiring stable thermal behaviour (e.g., fire-exposed structures).
- SCC5 (10% glass, 10% marble) is preferred for high mechanical performance (e.g., structural elements).

Limitations and future work

This study was limited to laboratory scale and temperatures up to 400 °C. Further research should investigate:

- Behaviour at higher temperatures (>600 °C).
- Long-term durability (carbonation, chloride penetration, freeze-thaw resistance).
- Optimisation of grinding fineness of glass and marble powders.
- Full-scale structural behaviour and life-cycle assessment (environmental and economic).

In conclusion, this research demonstrates that the simultaneous use of glass powder and marble powder at optimal levels (5–10% each) significantly improves the fresh properties, mechanical strength, thermal resistance, and durability of self-compacting concrete. The

findings contribute to the development of sustainable, high-performance construction materials while providing an effective route for recycling industrial and household waste.

Recommendations:

Based on the experimental results obtained in this study, the SCC8 mixture, containing 15% marble powder and 15% recycled glass powder, can be considered the optimum mix among all the investigated formulations. This mixture exhibited superior mechanical and physical performance, achieving higher compressive and tensile strengths, as well as better cohesion, compactness, and overall durability compared with the other mixtures.

Therefore, the use of this proportion is recommended for the production of self-compacting concrete when improved mechanical performance and durability are required, while simultaneously promoting the recycling of glass waste and marble powder and contributing to sustainable construction practices.

Further studies are recommended to:

- * Investigate the long-term behavior of this mixture.**
- * Evaluate its resistance to various environmental conditions and chemical attacks.**
- * Examine the effect of higher or alternative replacement ratios of glass and marble powders.**
- * Assess its economic feasibility for large-scale industrial applications.**

Reference

- [1] BOUDIAF Sabrina, MAHFOUDI Intissar. *The effect of using waste glass powder and marble powder in the formulation of self-compacting concrete in the fresh and hardened state*. University Mohamed Boudiaf M'sila, June 2024.
- [2] DJEBRI Noura. *Formulation and characterization of fiber-reinforced self-compacting concrete based on local materials exposed to high temperatures*. PhD thesis, University Mohamed Boudiaf M'sila, May 2018.
- [3] AFGC (French Association of Civil Engineering). *Self-compacting concrete – provisional recommendations*. Scientific and technical document, p. 63, 2000.
- [4] MAEL A., XAVIER G.H., CHRISTIAN M., DORIS N. *Glossary for waste management stakeholders*. Collection "Reference" of SEEIDD, CGDD, May 2012.
- [5] EL HAFIANE S. *Solid waste management in the Urban Commune of Agadir and its impact on the natural environment*. Master thesis, Marrakech, March 2012.
- [6] FEBELCEM (Belgian Cement Industry Federation). *Self-compacting concretes*. Brussels, August 2005.
- [8] BENKHALFA Khalid, ZALANI Mohammed. *Behavior of self-compacting concrete at high temperature*. Master thesis, University of Guelma, June 2015.
- [9] NF EN 12350-8. *Testing fresh concrete – Part 8: Self-compacting concrete – Slump-flow test*. AFNOR, November 2010.
- [10] NF EN 12350-10. *Testing fresh concrete – Part 10: Self-compacting concrete – L-box test*. AFNOR, November 2010.
- [11] NF EN 12350-11. *Testing fresh concrete – Part 11: Self-compacting concrete – Sieve stability test*. AFNOR, November 2010.
- [12] NF EN 206-9. *Concrete – Part 9: Additional rules for self-compacting concrete*. AFNOR, June 2010.
- [13] SEDRAN T. *Rheology and rheometry of concretes: application to self-leveling concretes*. PhD thesis, ENPC, 1999.
- [17] CHATRA Yassine. *Effect of limestone fillers on the behavior of self-compacting concrete (SCC) based on local materials*. Master thesis, University Mohamed Boudiaf M'sila, June 2016.
- [18] TURCRY P.H., LOUKILI A. "Different approaches for SCC mix design". *French Journal of Civil Engineering*, Vol. 7, No. 4, 2003.

- [21] ADEME (French Environment and Energy Management Agency). *Waste collection and treatment*. 1996.
- [23] BENHANIA Hamza, GASMI Youcef. *Valorization of composite waste*. University Kasdi-Merbah Ouargla, June 2022.
- [24] MEHDI C. *Construction site waste and material recycling in the building sector*. Thesis, 2007.
- [25] STAMBOULI M. *Valorization of glass debris in road infrastructure – Application to industrial glass, household glass and mixed glass*. Master research thesis, 2016.
- [28] EL HAFIANE S. (same as [5]).
- [32] ALOUEIMINE S.O. *Methodology for characterization of household waste in Nouakchott (Mauritania) – Contribution to waste management and decision support tools*. PhD thesis, University of Limoges, 2006.
- [35] DENOËL I.J.F. *Fire safety and concrete structures*. FEBELCEM, Brussels, 2007.
- [36] GHARBI FAYZA / FALI MALIKA Evaluation de la qualité des bétons auto -plaçant (BAP) exposés à haute température aux moyens des essais non-destructifs (END) et essais direct UNIVERSITE MOHAMED BOUDIAF - M'SILA 2019
- [37] Hager, I. "Comportement à Haute Température Des Bétons à Haute Performance - évolution Des Principales Propriétés Mécaniques." Thèse de doctorat, Ecole Nationale des Ponts et Chaussées et l'Ecole Polytechnique de Cracovie. 2004.
- [38] Van Thai NGUYEN- Thèse de Doctorat Comportement des bétons ordinaire et à hautes performances soumis à haute température : application à des éprouvettes de grandes dimensions
- [39] KAOUANE Malika- Mémoire de Magister Analyse des contraintes mécaniques et de la fissuration des éléments en béton armé sous l'effet thermomécanique. UNIVERSITE MOULOUD MAMMERI, TIZI OUZOU. 2011