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IMPROVING THE SELF-COMPACTING CONCRETE PROPERTIES BY INCORPORATING A NEW MICRONIZED LIMESTONE FILLER

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ABSTRACT:

Self -compacting concrete composition results from several approaches to satisfy specific criteria. SCCs must be able to fill small, confined formwork without the need for vibration. To ensure the homogeneity and mechanical characteristics of the concrete, they must have good resistance to segregation throughout the setting time. The self-compacting aspect is controlled by a high volume of paste and an important fines content ensured by incorporating mineral additions that are expensive and not always available. The main objective of this paper is to utilize a new type of micronized limestone filler that may be characterized and incorporated into concrete to guarantee self-compacting quality. In the first part, a detailed characterization of the limestone filler was carried out to investigate its effects on the concrete properties. The identification has been physical, chemical, and specific to the concrete's formulation. The second part is devoted to the experimental tests on different SCCs mixed with various amounts of filler to determine the optimal incorporation percentage. Moreover, a parametric study, involving the content of filler, the granular structure, and the quantity of superplasticizer, allowed an evaluation of the effect of limestone filler incorporation on fresh and hardened concrete characteristics. Through this study, it was demonstrated that with a proportion of limestone filler of about 25% of the quantity of cement used, the quality of the concrete has recognized appreciable improvements.

1. INTRODUCTION

The complexity of structures, sophisticated formworks and the heavy reinforcements have put concrete plants in front of great challenges. Ordinary concrete, requiring considerable vibration, no longer satisfies the requirements for form filling, non-segregation, and non-blocking. This led to the design of a fluid concrete with satisfactory properties known as self-compacting, recognized by its high deformability and ease of casting under the effect of its own weight, without the requirement for vibration, even with dense reinforcement. A new contribution to concrete technology was made by improving productivity and producing homogeneous structures with high mechanical strength.

Numerous studies have been conducted and are still in progress with the objective of developing a suitable formulation of self-consolidating concrete. Different SCC formulation techniques, including Japanese (Okamura and Ouchi, 2003), Swedish(Bui and Montgomery 1999) and French approaches (T. Sedran and De Larrard, 2000), have been developed to provide workability requirements. Currently, there is no generalized formulation method for SCC, like the Dreux-Gorisse method for ordinary concrete. Consequently, the main objective of SCC formulation is to achieve a balance between opposed qualities, notably fluidity, resistance to bleeding and segregation, and mechanical properties.

Since the 2000s, producers and researchers have collaborated in experimental studies that highlighted multiple scientific problems with the SCC formulation, casting, durability, and mechanical strengths (Thierry Sedran, 1999; Zhu and Gibbs, 2005; De Schutter et al., 2008; Diederich, 2010; De Schutter, 2011).

The originality of SCC consists of its behavior in the fresh state. The objective of this study is to design fluid concrete that satisfies (AFGC ,2008) and (EFNARC, 2005) requirements. The SCC fluidity is significantly governed by the particle size distribution of the components. Inevitably, to provide the required workability, a superplasticizer and/or a viscosity agent must be incorporated into the mix, but they generate a high concrete cost. Furthermore, excessive amounts of those chemical admixtures may result in segregation.

Typical concrete additions such as fly ashes, silica fume, and blast furnace slags are rare and expensive in Tunisia. However, limestone fillers are typically abundant and have various applications especially in paint and tile products, but it is not yet exploited in the concrete industry. For these reasons, this work was conducted to identify limestone fillers and to study their incorporation into cement-based materials, specifically for self-compacting concrete. Where, the behavior of fresh and hardened concrete depends on the intrinsic characteristics of fines, the so-called filler effect (Topçu and Uğurlu, 2003). Before utilizing these by-products, a rigorous characterization is required.

According to standard NF P 18-508(AFNOR 2012c), limestone

filler is classified as a type I mineral addition with a filling, thinning, and mechanical resistance-increasing function. These mineral additions have been the subject of various research studies (Thierry Sedran, 1999; Zhu and Gibbs, 2005; De Schutter et al., 2008; Diederich, 2010; De Schutter, 2011; Ahmad et al., 2014; Care S. et al., 2000).

The main issue with this addition is the non - availability of limestone filler made especially for concrete production. Furthermore, there are currently no criteria for choosing filler additions that will improve the rheological properties of a formulation (Joudi-Bahri, 2012). A few attempts have been made valorizing by-products: fillerized crushing (Joudi-Bahri, 2012) , marble waste (Tennich, Kallel, and Ben Ouezdou, 2015), or natural products such as sand dunes (R'mili and Ben Ouezdou, 2012).

To satisfy the demand for SCC, the supply of filler must be regular and sufficient to maintain continuous concrete manufacturing. In fact, the objective of this experimental study was to find limestone filler that satisfies the requirements requested to be used in SCC. This will have an impact on the development of the concrete production technique and permit a wider range of applications, particularly for self-compacting concretes, as well as benefit from their properties in both the hardened and fresh states.

A practical methodology for the SCC formulation has been adopted using the software BétonLabpro2 (T Sedran and De Larrard, 2000), where the self-compacting aspect is provided by a high slump value (A ≥ 250 mm), a low-yield stress and plastic viscosity, and a tightness index K = 7. The mixtures were generated with various amounts of limestone filler. In addition, other parameters were considered, such as the superplasticizer quantity and the granular structure (G/S). The workability of the prepared concretes was evaluated using slump flow, L box, V funnel, and the J-Ring tests. In addition, other characteristics were measured, including density, sieve stability, and air content. The mechanical strength and density are the only properties that have been determined for the hardened state.

2. CHOICE OF A MICRONIZED LIMESTONE FILLER

Four varieties of micronized limestone filler with calcite as the primary component were delivered by the Tunisian Company of Mineral Products (STPM). Figure 1 displays the particle size distribution curves by comparing them with the cement distribution curve.

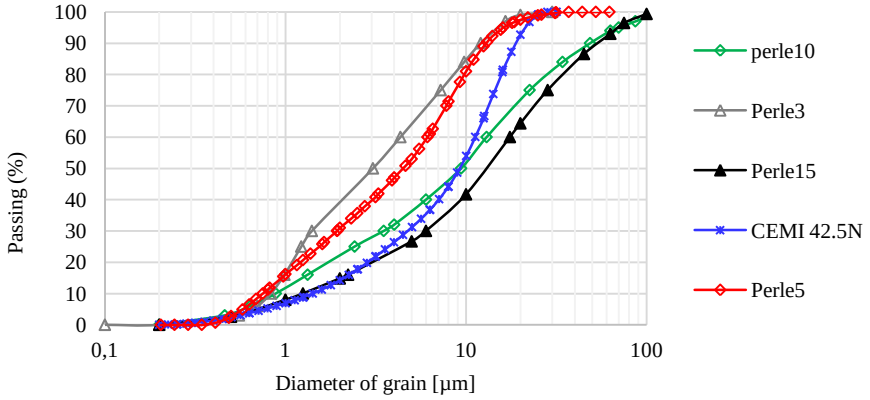

Figure 1. Particle size distribution of the different limestone

Physical properties of limestone fillers are listed in Table 1. The uniformity coefficient Cu (d_{60}/d_{10}) and the typical percentile diameters d_{10}, d_{50}, and d_{90} are provided. Limestone fillers are very fine products with d_{50} between 3 µm and 15 µm and high calcite content (Table 1).

Characteristics	Perle3	Perle5	Perle10	Perle15
d_{10}[µm]	0.83	0.748	0.9	1.25
d_{50}[µm]	3	5	10	15
d_{90}[µm]	12	13	48.5	55
Cu	0.522	8.17	14.77	14
Cc	0.055	0.81	1.07	1.65
Fines (<63µm)[%]	100	100	94	93
$CaCO_3$ [%]	99	99.2	99.2	55.3
Water requirement [%]	23.8	22.05	20.75	20.75

Table 1. Physical characteristics of the proposed micronized limestone fillers

Choosing a filler to be used in concrete must be made with full precision, considering its compatibility with other components. After examining the distinctive characteristics of micronized limestone fillers, the Perle5 product was chosen to be incorporated in the concrete for the following reasons:

-Regular granulometry which adapts well to the formulation of SCCs, allowing the production of fluid and compact concrete.
-The high calcite content improves the strength of hardened concrete.
-The grain size is close to or even finer than that of cement, making it possible to improve the compactness of the mixture.

3. USED MATERIALS

In this experimental investigation, concretes were manufactured and evaluated at JOB Béton, a ready-mixed concrete plant in Tunisia. Concretes have been made with cement, aggregates, sand, limestone filler, water, and superplasticizer admixture. According to the NF EN 197-1 (AFNOR 2012a)standards, the

cement used is a CEM I 42.5N containing more than 95% of clinker with a specific surface area equal to 3277.54cm^2/g. The cement density is equal to 3141.4kg/m^3. The clinker mineralogical composition (Bogue method was specified by: C3S = 53.67%; C2S = 22.77%; C3A = 1.27% and C4AF = 12.74%. The XRD analysis is shown in Figure 2.

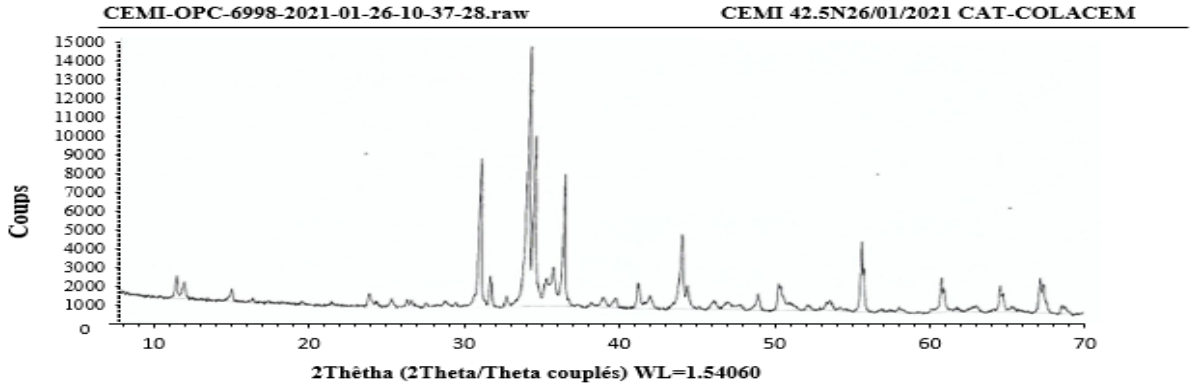

Figure 2. X-rays diffraction of anhydrous cement CEM I

Figure 3 shows the granular distribution of the different components.

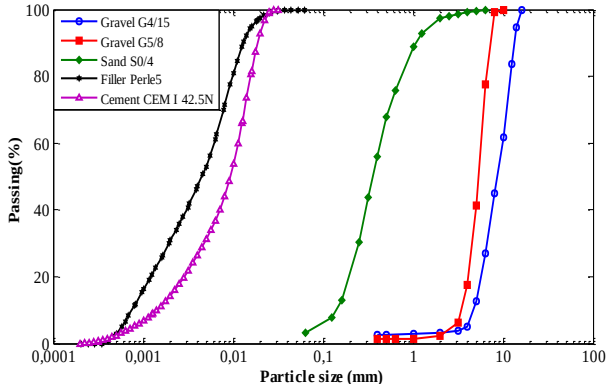

Figure 3. Particle size distribution of concrete components

Materials characteristics were detailed in Table 2. Deflocculation of the fines was ensured by the addition of a poly-carboxylate and modified phosphonate super-plasticizer (SP), called CHRYSO-Optima67. It is a high water-reducing (HRWRA) for ready-mixed concrete that conforms to standard EN934-2 (AFNOR 2012b, 1) having a dry extract of 24.56% with a density of 1.053.

Characteristics	S	G1	G2
d/D	0/4	4/15	5/8
Fines (≤63µm) [%]	3.28	2.6	1.37
Fineness modulus	2.09	-	-
Equivalent of sand [%] NF EN 933-8	86.51	-	-
Methylene Blue Adsorption (MBA)	1.05	0.06(fines)	
Bulk density [kg/m^3] NF EN 1097-6	1655	1359	1404
Absolute density: [kg/m^3] NF EN 1097-6	2631	2727	2706
Los Angeles [%] NF EN 1097-2	-	28.4	26.8
MDE [%] NF EN 1097-1	-	13.04	6.63
Absorption coefficient [%] NF EN 1097-6	0.3	0.77	0.61
Packing density : Φ	0.766	0.645	0.613

Table 2. Physical properties of aggregates

Two crushed gravels (G1, G2) were extracted from the Djbel Ouest quarry, located in the north of Tunisia, with a particle size between 4 and 15 mm.

The alluvial siliceous sand (S) comes from the sandpits of Borj Hefaiedh and is of granular class (0/4).

BetonlabPro2 software used to carry out the mix of concrete is based on the Compressible Packing Model (CPM). In fact, packing density, a specific property to the use of the CPM, was determined using Eq. (1). For particles with sizes greater than 80 µm a dry sample M_s (7 kg for gravel and 3 kg for sand) is put inside a metal cylinder with a diameter of (D) that is fixed to a vibrating table (50 Hz) and covered by a piston exerting a pressure of 10 kPa. For one minute, a vibration is applied to the assembly. The compacted sample's final height (H) is then determined. This process's associated compaction index is K = 9.

$$\Phi^* = \frac{4.M_S}{\rho_{abs}.\pi.D^4.H} \quad (1)$$

A thorough characterization of the limestone filler Perle5, that was selected to be used in the concrete, will be provided in the next section.

4. CHARACTERIZATION OF THE LIMESTONE FILLER PERLE5

The behavior of the fresh and hardened concrete will be affected by the physical and chemical characteristics of the limestone filler. Impurities may disturb the cement hydration process, extending the setting time and reducing the compressive strength. In fact, to be able to use filler in concrete, it is necessary to determine the required characteristics for its incorporation into cement-based mixtures. The mechanisms of its interaction with cement and chemical additives must also be investigated as appropriate.

According to standards, ***physical properties*** of the micronized limestone filler Perle5, were determined and included in Table 3.

Characteristic	Value	Characteristic	Value
d_{50}[µm]	5	Water requirement [%]	22.05
C_u	8.17	ρ_{Bulk} [kg/cm^3]	644.9
C_C	0.81	ρ_{abs} [kg/m^3]	2608.7
%fines (<63µm)	100	BSS [cm^2/g]	3416.8
$CaCO_3$[%]	99.2		

Table 3. Physical characteristics of the limestone Perle5

Particle size distribution of limestone filler was performed by means of laser diffraction and plotted in Figure 4. The limestone is well graded with an important amount of fine particles (around 50% of particles smaller than 5µm).

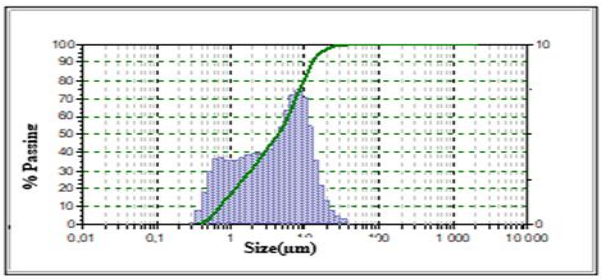

Figure 4. Laser particle size distribution of Perle5 filler

Table 4 shows the ***chemical analysis*** of the micronized limestone filler Perle5 using Inductively Coupled Plasma (ICP) spectroscopy. It should be mentioned that it is mainly composed of calcite (99.2%) and free of any impurities such as clay or organic material.

Element	Content (%)	Element	Content (%)
$CaCO_3$	99.2	MgO	0.09
Al_2O_3	0.01	Fe_2O_3	0.001
K_2O	0.001	SiO_2	0.22
Na_2O	0.05		

Table 4. Chemical characterization of the limestone Perle5

A quantitative ***mineralogical characterization*** was carried by means of X-Ray diffraction (XRD) at the National Center for Research in Materials Science (CNRSM). Figure 5 illustrates the XRD pattern of the limestone sample showing only the presence of calcite ($CaCO_3$).

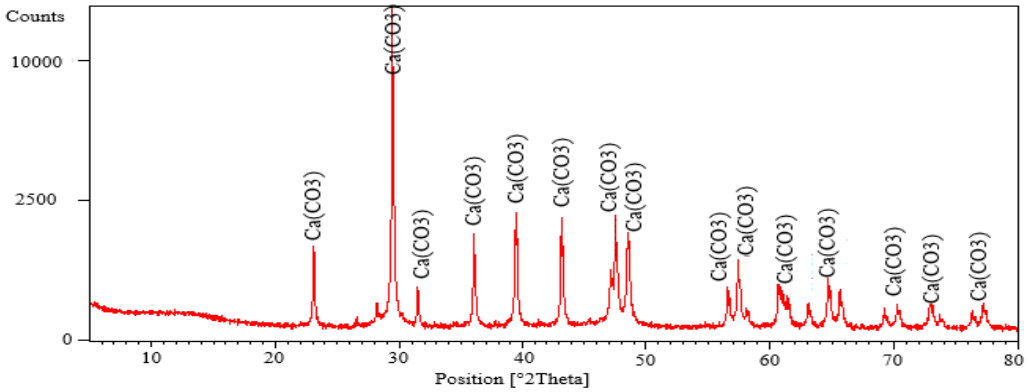

Figure 5. XRD patterns of Perle5 limestone sample

Packing density: Cement and limestone filler packing was measured using an experimental methodology different from that of the grainy fractions(Lecomte, Mechling, and Diliberto, 2009). For cement, the water/cement (W/C) ratio required to produce a paste of normal consistency is measured using a Vicat probe. The compaction index corresponding to this technique is K = 4.8. Cement packing density (Φ_c) was also calculated in terms of ((W/C) ratio using Eq. (2):

$$\Phi_c = \frac{1}{1+\frac{W}{C}.\rho_c} \quad (2)$$

For limestone filler, the same methodology is used to measure packing densities for two mixtures of 10% cement and 90% fillers, and then 20% cement and 80% fillers. The packing density of limestone alone was extrapolated from the curve in Figure 6.

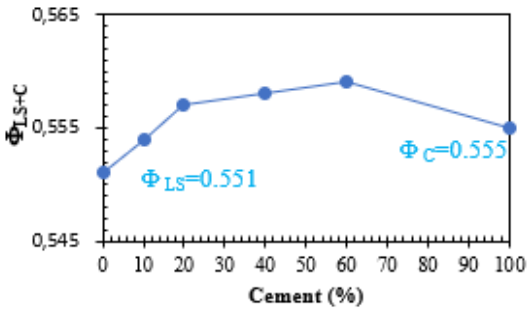

Figure 6. Packing density of limestone filler Perle5

The effect of limestone fillers on the workability of concrete depends particularly on its fineness. In this case study, the micronized limestone (30µm) improves workability and reduces the amount of water required, thereby increasing the mixture's

compactness. Nevertheless, there is a limit to the amount of limestone incorporation, beyond which the packing density decreases and the need for water increases. From the curve in Fig6, the packing density of the filler alone is deduced by extrapolation Φ_{LS}=0.551 and that of the cement alone Φ_C = 0.555.

Saturation degree of the superplasticizer: in concrete technology, the saturation dosage of the superplasticizer is extremely important. A superplasticizer can be added with a given amount of water to improve workability, or less water can be used to get the desired fluidity. The limestone filler incorporation into cement-limestone pastes leads to a reduction of the superplasticizer saturation dosage, which has economic advantages (Li et al., 2020).

The superplasticizer saturation degree of limestone filler corresponds to the amount from which the admixture reaches its optimal effect, and above that its impact on the mixture's fluidity becomes negligible. Without cement, the ionic environment and the superplasticizer's adsorption on the addition are significantly modified. Therefore, the approach used for cement is no longer directly applicable to mineral additions (Thierry Sedran, 2018). Indeed, the saturation degree was determined for a mixture containing complementary fractions of cement and filler.

According to the standard (NF P18-507), the Marsh cone method is used to determine the superplasticizer saturation degree for pastes with a normal consistency(Pamnani et al., 2013; Sarika and Alson, 2016). The test consists of a conical container with a volume (V>1litre) equipped with a bottom opening and fixed on a support, allowing the suspension flow in a graduated container with a capacity exceeding 500 ml. The Marsh-cone test is based on a simple approach to assess the rheological behaviour of cement paste at various superplasticizer quantities, where for each (SP/C) ratio, the time required for flowing a volume of 500 ml is measured. The superplasticizer saturation degree is defined as the (SP/C) ratio from which the flow time of the mixture does not significantly decrease (Roussel and Le Roy, 2005; Pamnani et al., 2013).

Grouts were prepared with an increasing superplasticizer amount and normal consistency (W/C, W/(LS+C)) ratios. The method used consists of measuring the saturation degrees of the cement alone and of a mixture composed of (A%) addition and (100-A)% cement. Consequently, the addition's saturation degree (SP^*_{LS}) is calculated with the following expression:

$$SP^*_{LS} = \frac{(100.SP^*_{C+LS} - (100 - A\%)SP^*_C)}{A\%} \quad (3)$$

where: the superplasticizer proportions (SP*) are expressed in dry extract.

The type of the studied concrete affects the determination of the addition's proportion (A%). In the case of SCCs containing a limestone filler, the dosage is limited to A=40% (Thierry Sedran, 2018; 1999). The amount of total water is kept fixed. It is the one that leads to normal consistency. The added water varies according to the amount provided by the superplasticizer (75.4% of its mass).

According to the Marsh-cone test results in Figure 7, the saturation degree of superplasticizer is 0.62% for cement and 0.255% for a mix of cement and limestone filler. The saturation dosage deduced for limestone filler alone is negligible. A standard value of SP^*_{SL}=0.01 has been recommended by (Thierry Sedran 1999).

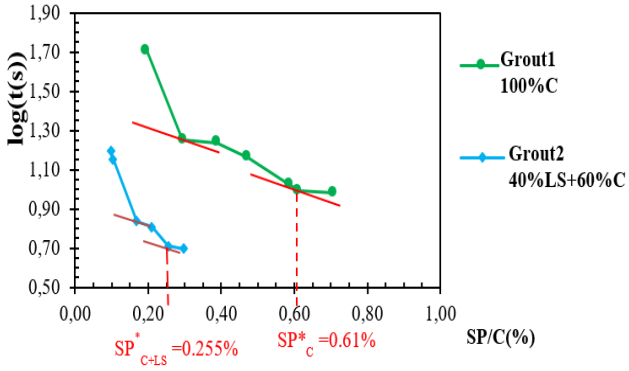

Figure 7. Superplasticizer saturation curve

The packing densities without and with superplasticizer of limestone filler were determined on normal pastes prepared with 60% cement and 40% LS, according to the principle described by (Lecomte, Mechling, and Diliberto, 2009). The process is the same as that used for cement, with an increasing dosage of superplasticizer SP until saturation. Then, packing densities are deduced using the results displayed in Figure 8.

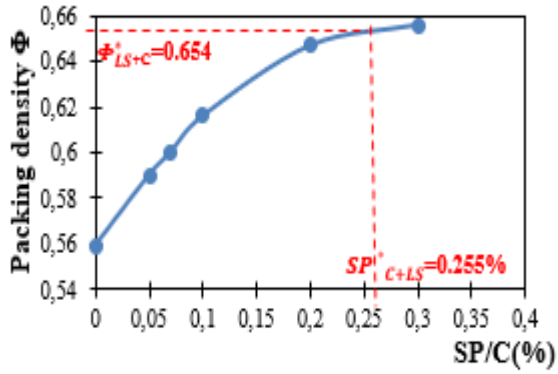

Figure 8. Packing densities of (60%C+40%LS) mix, with and without superplasticizer

With superplasticizer, obtained packing density of the filler-cement mixture ((Φ^*_{SL+C}=0.654) is much higher than that of the cement alone (Φ=0.555) and that of the filler alone (Φ=0.551). Indeed, the incorporation of micronized limestone filler will increase the packing density of the granular structure of concrete, improve its workability, and provide higher mechanical strength.

Results Interpretations

According to the standard NF EN 206-1, Perle5 limestone filler has physical and chemical properties that conform to the required criteria. Additionally, the results showed that the BSS admits a value greater than 3000 cm²/g, CaCO3 content (equal to 99.2%) is clearly higher than the standard value (62%) and a characteristic percentile diameter of d50%=5µm. Consequently, Perle5 is a category A-FM filler in accordance with standard NF P 18-508(AFNOR 2012c) and it was concluded that it can be used in the formulation of SCC.

5. FORMULATION OF SELF-COMPACTING CONCRETES

5.1 Design Method

The proportion of each concrete component must be carefully calculated to ensure a good balance between the fresh and hard properties deformability, segregation, filling ability and, resistance. In an overview of several mix design methods used to prepare different concrete types, each method has been developed under specific conditions and environments, and has its own limitations. It can be grouped into four classes: aggregate compactness method, empirical method, paste rheology model, and compressive strength method. In this study, the mix design was carried out using BétonlabPro2, which is a software developed at the LCPC laboratory (T. Sedran and De Larrard, 2000), (De Larrard, 2000). It is based on the maximization of the granular skeleton compactness, called the compressible packing model (CPM). This software allows the granular skeleton optimization of the mixture by optimizing the proportions of the aggregates based on packing densities (T. Sedran and De Larrard, 2000). With advances in self-compacting concrete manufacturing technology and the increased use of admixtures and mineral additives, many variables have appeared that cannot be controlled by conventional formulation techniques. The major advantage of BétonlabPro2 software is that it considers the presence of limestone filler in the mixtures and its contribution to the improvement of the concrete properties. Starting with material characteristics, BetonlabPro2 simulates most of the formulated concrete's properties. It is also provided with an optimization component that calculates the optimal formula from precise specifications and, according to a given criterion. The objective of this experimental study is to produce concretes and to test them with the L-box. Six formulations were prepared using BétonlabPro2 compositions described in Table 5.

	SCC0	SCC1	SCC	SCC3	SCC4	SCC5
G4/15[kg]	322.4	321.2	397.4	352.9	396.7	305
G5/8 [kg]	470.9	469.2	546.5	514	545.6	445.5
S 0/4 [kg]	991.8	988.2	856.1	913.6	854.6	938.1
C[kg]	350	350	350	350	350	350
Perle5[kg]	0	35	35	87.5	87.5	140
W |l]	195.4	183.7	169.25	145.35	140.9	164.9
SP [kg]	3.85	3.85	3.85	6.13	6.13	3.85
SP [%]	1.1	1.1	1.1	1.75	1.75	1.1
LS/C [%]	0	10	10	25	25	40
LS/(C+LS) [%]	0	9.1	9.1	20	20	28.5
G/S	0.8	0.800	1.1	0.95	1.1	0.8
$\rho_{theoretical}$ [kg/m^3]	2334	2351	2358	2369	2381	2362

Table 5. Composition of concretes

5.2 Formulation and Manufacture of the Concretes

In this investigation, concrete mixes were designed in accordance with the EN 206-1 Standard requirements. Cement quantity was fixed at 350 kg. According to the recommendations of (AFGC, 2008) and (EFNARC, 2005), the self-compacting aspect was obtained by keeping a slump value S> 250 mm, a plastic viscosity fewer than 200 Pa.s and a yield stress not exceeding 400 Pa. Several formulations were developed by changing the proportion of limestone filler LS (%) and the amount of superplasticizer SP (1.1%, 1.75%) with a variable-weight ratio of gravel/sand G/S (0.8, 0.95, 1.1).

The incorporated filler ratios were chosen in accordance with the guidelines of IFSTTAR (Care S. et al., 2000), and on the basis of the limits imposed by standard NF EN 206/CN, which indicates that the amount of type I mineral additions in concrete is limited to the ratio (LS/C+LS)<30%. Given that the cement dosage was fixed at 350 kg, the (LS/C) ratios were taken between 10% and 40%. Table 5 displays the adopted formulas for concrete preparation.

A covered planetary concrete mixer with a maximum capacity of 70 liters was used to make a batch of 50 liters for each concrete. The aggregates were delivered and preserved. On the day of manufacturing, they were weighed, and their water content was measured to be taken into account in the effective water calculation. The mixing was done in accordance standard with the following procedure: first, dry mixing of solid components for one minute, then gradually adding water over one minute, after that progressively introducing the superplasticizer, and finishing with mixing for three minutes. Obtained concretes were, next, tested in fresh and hardened sates.

6. RESULTS AND DISCUSSIONS

Several tests for fresh concrete evaluation were carried out on the manufactured mixes as described in Figure 9.



Figure 9. Testing fresh concrete

Cubic specimens (15 cm x 15 cmx15 cm) were prepared, unmolded after 24 h of curing, and submerged in water for 28 days at 20°C (NF EN 12390-1). In the hardened state, specific density, compressive and tensile strengths have been measured. The Table 6 displays the results of concrete's properties.

Concrete			SCC0	SCC1	SCC2	SCC4	SCC3	SCC5
Fresh state	Slump flow Sf [mm] NF EN 12350-8		610	600	500	720	720	740
			SF1	SF1	-	SF2	SF2	SF2
	L-Box NF EN 12350-10	T_{600}[s]	6.1	4.16	4.69	10.14	9.27	5.77
		H_1/H_2	0.72	0.44	0.52	0.855	0.85	0.78
	J-Ring NFEN 12350-12	ϕ [mm]	590	540	520	690	700	700
		Δh[mm]	22	20	19	10	9	18
	V-Funnel:T [s] NF EN 12350-9		13.4	5.42	4.93	18.78	23.39	7.52
	Sieve stability[%] NF EN 12350-11		2.5	0	0.06	4.88	5.67	18.37
	Air content [%] NF EN 12350-7		2	1	0.9	1	1.6	2
	ρ_{fresh}[kg/m3] NF EN 12350-6		2389.63	2401.48	2459.3	2496.3	2552.6	2483.5
Hardened state	$\rho_{hardened}$ [kg/m3] (NF EN 12390-7)		2411.85	2432.1	2474.07	2481.48	2549.63	2482.5
	R_{c7}[MPa] (NF EN 12390-3)		18.17	18.8	20.76	29.33	32.68	29.98
	R_{c28}[MPa](NF EN 12390-3)		30.24	32.21	31.69	32.31	36.63	36.62
	R_{t28}[MPa] (NF EN 12390-6)		2.41	2.53	2.5	2.54	2.8	2.8

Table 6. Properties of formulated SCCs

The main objective of this experimental investigation is to valorize micronized limestone filler produced by the Tunisian industry by using it in SCC manufacturing with an optimized amount. In fact, a parametric study was conducted to examine the ability to improve the concrete's fluidity and stability without encountering problems of bleeding, segregation, or blocking.

In particular, variations of the gravel/sand (G/S) ratio, the amount of limestone filler (LS/C), and superplasticizer percentage (SP) were taken into consideration. In the flowing sections, the properties of produced concretes in both the fresh and hardened states will be analyzed.

6.1 Characteristics of fresh SCCs

A detailed characterization of concretes formulated in the fresh state was based on the tests recommended for this category of fluid concretes.

6.1.1 Mobility in unconfined space: The V-funnel and the slump flow tests have been used to evaluate the SCC's ability to flow in unconfined space. In Figure 10, it can be observed that the addition of limestone filler Perle5 generated an increasing spread with the amount incorporated, resulting in a decrease in the mixes' viscosity. The Perle5 limestone filler has an effect on improving the fluidity of SCCs even at various ratios (G/S). An optimal value that can be recommended is LS/C = 25%, beyond which the contribution of the filler becomes significantly negligible.

The analysis of the flowability of concrete through the V-funnel was carried out by measuring the time required to empty the funnel filled with concrete. The results, which are shown in Figure 10, highlight a growing capacity to flow with the quantity of filler added, with an optimal LS/C value of 25%. Above this level, a considerable decline in the flow time was observed (LS/C = 40%), which reflected an increase in the mixture's viscosity.

6.1.2 Mobility in Confined Space: The L-box test, which allows the direct observation of flow and blockage phenomena, was used in this work as a reference test. It was used to study both the flow speed through confinement and the concrete's passing ability. By examining the graph in Figure 10, it can be noted that when a low proportion of filler (10%) is added, the obtained concrete is very fluid and flows rapidly in the L-box. However, their filling ability ratio (H2/H1) does not satisfy the SCC acceptance criteria, according to EFNARC. Concretes designed with increased filler content (25 and 40%) had a filling ratio (H_2/H_1) of around 0.8, achieving the required values.

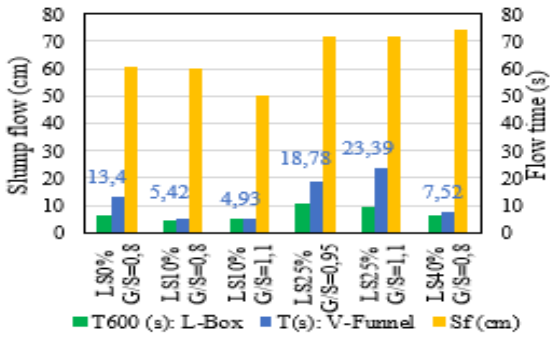

Figure 10. Slump flow, L-box, and V-funnel measurements

6.1.3 Sieve stability test: The suitability of the concrete for segregation was evaluated using the sieve stability test. As shown in Figure11, the variability of test results is poor for small fractions of limestone filler and increases for more important proportions. It has been highlighted that five tested concretes have a high resistance to segregation with milt loss percentages of less than 6%, respecting the restrictions (<20%) fixed by (EFNARC, 2005). The micronized limestone filler effectively has a stabilizing effect by increasing the solid phase's specific surface and minimizing bleeding.

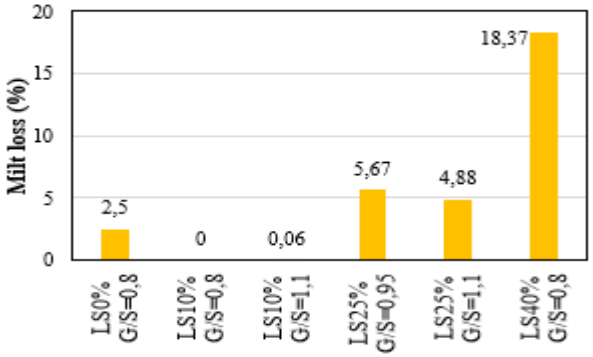

Figure 11. Milt loss measuring for tested concretes

With an increasing gravel/sand ratio (G/S) and Perle5 filler content, an improvement has been noticed in the fresh concrete properties. Concrete is better able to flow uniformly and smoothly. When the amount of filler added exceeds LS/C =25%, the impact on the rheology of concrete appears relatively low.

6.2 Characteristics of hardened SCCs

The test pieces were crushed at the ages of 7 days and 28 days. A visual examination of the tested specimens reveals a homogeneous structure of the concrete formulation and a good distribution of the granular fractions, as seen in the pictures in Figure 12, where no segregation has been observed. It was noted that the incorporated Perle5 micronized filler contributed to the filling of intergranular voids, resulting in a more compact and, consequently, more resistant concrete structure.



Figure 12. Granular fraction distribution of in hardened concrete

According to the results in displayed in Figure13, the addition of micronized limestone filler Perle5 has little or no effect on tensile strength (R_{t28}). Nevertheless, at the age of 28 days, the compressive strengths (R_{c28}) are relatively close to and greater than the resistance of 30 MPa. The incorporation of fine particles, which has been provided by increasing amounts of micronized limestone filler, has improved the granular distribution, filled the voids between the concrete's particles, and raised the packing density of the mixture. This has therefore accelerated the early development of compressive strength (R_{c7}). Furthermore, filler has a resistance-accelerating effect that increases with its fineness, where cement hydrates precipitate on filler grains and create preferential nucleation sites during cement hydration reactions.

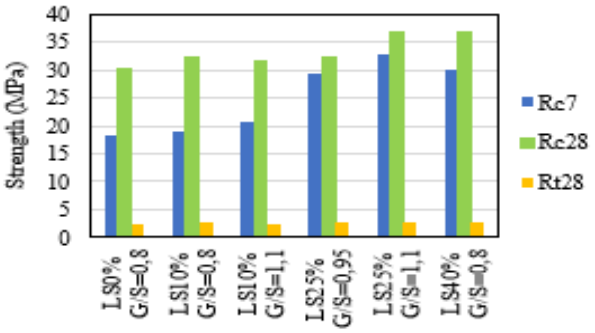

Figure 13. Compressive and tensile strengths

However, it has a slight binding effect where the cement aluminates form with the limestone filler carbo-aluminates, which contributes to the mechanical resistance. An improvement in the resistance was also observed with the incorporation of an increasing amount of micronized limestone filler, combined with an elevation of the gravel/sand ratio (G/S).

7. CONCLUSION

In this paper, Perle5, micronized limestone filler, was thoroughly characterized by evaluating its physical, chemical, and interactive aspects with concrete components. This identification revealed that it is a type I inert mineral addition with a very high calcite concentration of 99.2% and no trace of clay impurities. According to (EFNARC, 2005), Perle5 satisfies the acceptance criteria to be incorporated into the SCC. Perle5, limestone filler with a high specific surface, offers the advantage of improving consistency between the particle size distributions of the granular components, making it particularly suitable for SCC. In contrast to other pozzolanic type additions (silica fumes, fly ash), which are considered too expensive and not available on the Tunisian market, limestone is abundant and constitutes a source that can be valorized in the SCC manufacture in addition to its ordinary uses. A parametric study based on the characterization of formulated SCCs indicated that adding Perle5, a micronized limestone filler, at a ratio of LS/C=25% improves workability parameters in the fresh state (spreading, flow time). With a high content of limestone filler LS/C contents (> 30%), although mechanical strengths showed an improvement, the rheological characteristics no longer satisfy the SCC acceptance criteria, requiring an increase in the superplasticizer contents.

This study made it possible to locate the optimum fluidity at a Perle5 filler content of LS/C=25% and a G/S ratio=1.1, with significantly improved SCC performance and compressive strength at 28 days from the order of 36Mpa. The incorporation of Perle5 micronized limestone filler in the composition of SCCs can provide a solution for special projects without the risk of encountering problems such as a drop in workability or stability noted with other filler categories. The industrialized, regular production of this filler constitutes a major advantage for its use in concrete without worry of rupture, which encourages the SCCs' production on the Tunisian market.

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