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DESIGNING SELF-COMPACTING CONCRETE USING LOCAL MATERIALS FROM THE ARID REGION OF ADRAR, ALGERIA

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KEY WORDS: Arid region, Local materials, Limestone filler, Dune sand, Self-compacting concrete.

ABSTRACT:

In the construction sector, the non-renewable world resource of sand is largely used to produce mortar and concrete. It has been estimated that over 10 billion tons of sand have been produced, with 1.2 billion tons used in concrete over the last decade, which leads to a progressive reduction of available construction materials and environmental impacts. Since desert sand resources are abundant in arid region of Adrar (Southern Algeria), it would be viable to use desert-sand as an alternative material for the production of self-compacting concrete. Therefore, self-compacting concrete is experiencing significant demand in that arid region since it offers socio-technical and economic solutions to stakeholders in the construction and public works industry. Furthermore, the present study aims to address the concerns of these stakeholders. The results obtained showed that the self-compacting concrete that was made with local materials, behave correctly, both in the fresh and hardened states. This concrete included a 1% super plasticizer dosage, a gravel-to-sand (G/S) ratio varying between 0.8 and 1.1, and additions of limestone fillers up to 50% relative to the mass of cement for self-compacting concrete made with dune sand, while this percentage could go up to 38% for self-compacting concrete made with corrected sand (63% crushed sand with 37% dune sand).

1. INTRODUCTION

Sand is a major component in concrete mixes. Sand from natural gravel deposits or crushed rocks is a suitable material used as a fine aggregate in concrete production (Al-Harthy A.S. et al., 2007). Sand is frequently used in mortar or concrete as a finely grained aggregate and has an important part to play in the building construction. Nevertheless, the high demand associated with the development of construction has necessitated an excess of sand over time. The extractable yield of river sand has surpassed 10 billion tons in the latest decade (Liu N., 2018), which poses a threat to the environments. Consequently, it is crucial to find alternative materials to decrease the dependency on this non-renewable sand. Thus, regionally available desert sand (DS) has been used in this investigation.

Previous studies have reported the potential application of DS in concrete manufacturing (Al-Harthy A.S. et al., 2007; Zhang G.X. et al., 2006; Luo F.J. et al., 2013). The workability of desert sand concrete (DSC) increases with increasing desert sand replacement ratio (DSRR) up to 50%, since the spherical geometry of DS is more easily transported than angular or awkward grain geometries (Al-Harthy A.S. et al., 2007; Benabed B. et al., 2012). The sand/cement ratio also had a significant impact on the workability of the DSC. DS filled the internal void of the concrete when the sand/cement ratio was less than 1.14, which did not reduce the workability of DSC (Zhang G.X. et al., 2006; Luo F.J. et al., 2013). Nevertheless, the workability decreased when the sand/cement ratio was above 1.14, due to the excess water layer absorbed on the surface of the DS. Thus, DS had high workability under appropriate or suitable conditions.

In addition, many studies have been conducted to investigate the mechanical behaviors of DSC and mortar that contains DS (Al-Harthy A.S. et al., 2007; Luo F.J. et al., 2013; Khay S.E.E. et al., 2011). The findings were not the same because the DS region or experimental conditions were different. The compressive strength and tensile strength of dry shrinkage cracking of concrete increased at first and then showed a decrease as the DS increased (Lee E. et al., 2016). The reported increases in both strength levels are due to the fact that compaction increased with the improvement in DSRR. Meanwhile, the decreases in both strength values were due to the round particles of the DS decreasing the cohesive strength between the coarse aggregate and the grouts.

In addition, the both strength values had the maximum level when the DSRR was 20%. Meantime, the mechanical behaviors of concrete incorporating desert sand of region Mu Us (desert in northern China) after high temperature (tensile strength, axial compressive strength and modulus of elasticity) had the same tendency with the increasing DSRR and achieved the optimum level with DSRR of 40% (Sun S. et al., 2019; Douara T.H. et al., 2019). Nevertheless, the tensile strength, compressive

strength and static modulus of concrete progressively reduced with the increasing of DS (Oman) (Al-Harthy A.S. et al., 2007). This is due to the fact that the increase in the surface area of fine aggregates requires more mortar to embed them and the embedding mortar of coarse aggregates decreases. At the same time, the greatest value of the decrease in strength levels was under 15%. The 20% DS (Algeria) and 20% crushed sand, 60% DS (Tunisia) and 40% crushed sand could give high compressive strength for both concrete and self-compacting concrete for pavement operations (Douara T.H. et al., 2019; Khay S.E.E. et al., 2011).

Self-compacting concrete has been well recognized in the civil engineering industry for the past few decades and is often used on various construction sites. Due to its increased flow ability, high segregation resistance and flow capacity, it is able to settle by its own weight, even when reinforced, in narrow and deep sections with irregular design. For this particular type of concrete, supplementary cementitious materials (Kemer H. et al., 2021; Mesboua N. et al., 2021) (such as limestone filler or silica fume) and chemical additives are used in conjunction with cementitious materials (such as water, cement, sand and super plasticizer). Measurements of plastic viscosity and yield strength, as well as empirical experiments, are carried out to achieve a prediction of the quality of the flow.

A wide range of approaches have been developed around the world for the formulation of a self-compacting concrete (SCC) while taking into account a certain number of criteria for optimizing the volume of paste (pure paste or mortar) and the granular skeleton. These approaches all revolve around five categories, namely experimental results, mechanical strength, granular stacking, statistical analysis and rheology (De Larrard F., 2000).

In addition to the AFGC provisional recommendations (AFGC, 2008) and studies carried out by Domone (Domone P., 2006) on the formulation of SCCs, our methodology for formulating SCCs was based on the combination of similar criteria, namely:

- Optimization of the volume of paste by adding sand-limestone fillers with dosages of 0, 100, 150 and 200 kg/m^3 relative to the mass of cement, or in percentages of 0, 25, 38 and 50 % relative to the binder weight,
- Optimization of the granular skeleton by the graphic method of Dreux - Gorisse (Festa J., Dreux G., 2007) which makes it possible to highlight the missing classes while varying the (G/S) ratio (by volume) for the recommended values for SCCs, i.e., 0.8, 0.9, 1, 1.1 and 1.2 (Taleb A., 2017),
- Optimization of the saturation dosage of the super plasticizer (Aitcin P.C., 2001).

No one can deny the fact that local contractors in the construction and public works industry have always preferred these concretes because of their very interesting rheological properties in the fresh state.

It should be specified that these properties can be achieved by incorporating a specific super plasticizer and fillers to increase the volume of the concrete paste and therefore obtaining a better dispersion of the coarse aggregates.

It is worth indicating that to have a sufficient paste volume, two possibilities are offered:

- The first one consists in increasing the dosage of cement, which generates an additional cost, on the economic level, and shrinkage problems, on the technical level,
- The second one involves using mineral additions which are, more often than not, by-products or wastes that are locally available.

Therefore, the main objective of this study is to find the best combination of local compatible materials, and to use the appropriate dosages for each of the constituents in order to obtain a self-compacting concrete that is suitable for our arid region.

2. MATERIALS

2.1 Cement

The cement used is a CPJ - CEM II42.5R (STG), which is consistent with the Algerian Standard NA 442 (NA 442, 2013), comes from the cement plant of Sidi Moussa in Timoktene-Province of Adrar. Its chemical, mineralogical and physical characteristics are summarized in Tables 1 and 2, respectively (Moulay-Ali A. et al., 2021).

Components	CaO	Al_2O_3	Fe_2O_3	CaO_{free}	SiO_2	SO_3	MgO	C_3A	C_4AF	C_3S	C_2S
Contents (%)	64.53	4.83	3.31	0.61	21.30	2.28	1.43	7.20	10.07	46.56	25.93

Table 1. Chemical and mineralogical characteristics of cement

Physical and mechanical characteristics	Units	Values
Absolute density	kg/m^3	3100
Bulk density	kg/m^3	984
Normal consistency	%	33
Blaine specific surface	cm^2/g	3350
Loss on ignition (LOI)	%	2.06
Lime saturation factor (LSF)	-	91.77
Initial setting time	Minutes	162
Final setting time	Minutes	192
Compressive strength at 28 days	MPa	49.9
Compressive strength at 2 days	MPa	23.7

Table 2. Physical and mechanical characteristics of cement

In the present study, it was decided to formulate SCCs in order to build structures that are suitable to an environment of moderate aggressiveness of class XA1 (C30/37) according to the specifications of standard NF EN 206 / CN which recommends a minimum dosage of 363 kg/m^3.

For safety reasons, and particularly for the sake of respecting the optimal ratio of effective water/equivalent binder (W_{eff}/L_{eq}) as recommended by the standard in force, it was decided to use a cement dosage of 400 kg/m^3.

2.2 The gravel

In this study, crushed gravels, natural limestone rock, granular fractions of (2/8) and (8/16) were used.
The main physical and mechanical characteristics of gravels are summarized in Table 3.

Physical characteristics	Units	Gravel2/8	Gravel 8/16
Class (d/D)	-	2/8	8/16
Bulk density	kg/m^3	1250	1360
Absolute density	kg/m^3	2530	2635
Los Angeles test	%	14.88	13.55
Deval test	%	33.46	29.96
Flattening coefficient	%	25.59	11.87
Uniformity coefficient (Cu)	-	1.13	5.11
Coefficient of curvature (Cc)	-	1.67	0.79
Water content	%	0	0
Absorption coefficient	%	2.06	1.56
Surface cleanliness	%	0.5	0.39

Table 3. Physical and mechanical characteristics of gravel

2.3 Sand

The types of sand used in this study are:

- Siliceous and fine rolled dune sand from the dunes of Ksar Bouda in the region of Adrar,
- Crushed sand from the crushing station of Harouchi.

The main physical and chemical characteristics of these sands are given in Tables 4 and 5.

Physical characteristics	Units	Dune Sand (DS)	Crushed Sand (CS)
Class (d/D)	-	0/1	0/4
Bulk density	kg/m^3	1580	1290
Absolute density	kg/m^3	2670	2615
Percentage of fines	%	0.97	13.32
Fineness modulus (FM) (Normative requirement: $1.5 \leq FM \leq 2.8$)	-	1.95	2.82
Uniformity coefficient (Cu)	-	1.13	5.11
Coefficient of curvature (Cc)	-	1.67	0.79
Methylene blue value (VB)	ml/g	0.02	0.06
Water content	%	0	0
Absorption coefficient	%	0.21	2.70
Equivalent of sand to piston (ESp)	%	94.40	59.26
Loss on ignition (LOI)	%	25.58	24.08
Lime saturation factor (LSF)*	-	20.28	23.31

Table 4. Physical characteristics of sands

Components	CaO	Al_2O_3	Fe_2O_3	SiO_2	SO_3	MgO	$CaCO_3$	Cl^-	NaCl	pHi (initial)	pHt (titration)
DS (%)	25.34	1.33	0.04	44.06	2.65	1.00	6	0.034	0.056	7.7	6.95
CS (%)	23.99	5.74	7.60	33.11	0.11	4.93	9	0.062	0.102	7.84	6.80

Table 5. Chemical characteristics of sands

*If LSF >99: Difficult baking and increased free lime
If LSF <90: Easy baking and low energy consumption

2.4 Additions

The additions used are dusts, called fillers, which come from the Harouchi crushing plant, in the region of Adrar. These dusts are generally abandoned and considered as waste and can therefore favor the development of the Oligonychus Afrasiaticus disease to the palm grove during windy periods. Consequently, the incorporation of these fillers into a construction material, such as self-compacting concretes (SCCs), can therefore be very interesting both economically and environmentally.

It is worth indicating that the annual production of these fillers at Harrouchi crushing plant and three other crushing plants in the region of Adrar is estimated at around 108 thousand tons (Belhadj Aissa D. et al., 2018). This large production of fillers can be explained by the ever-increasing activity of the quarries in the region.

The DRX chemical analyses (Table 6) carried out at the cement plant laboratory of Sidi Moussa in the province of Adrar indicate that these fillers are of the silico-limestone type. The physical characteristics of the fillers are given in Table 7 below.

Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	$CaCO_3$	Cl^-	NaCl	pHi (initial)	pHt (titration)
Values (%)	30.56	5.53	8.88	24.99	6.68	2.24	7	0.062	0.102	7.94	6.85

Table 6. Chemical characteristics of fillers

Physical characteristics	Units	Values
Bulk density	kg/m^3	1005
Absolute density	kg/m^3	2664
Fines < 63 µm	%	74
Methylene blue value	ml/g	0.58
Water demand*	%	28
Activity index	%	72.29
Loss on ignition (LOI)	%	21.12
Lime saturation factor (LSF)	-	25.54

Table 7. Physical characteristics of fillers

*Water demand determined by the test described by Sedran (Sedran T., 1999).

2.5 Adjuvant

The adjuvant used is a new generation high-range water-reducing polycarboxylate ether-based super plasticizer of the MEDAFLOW 145HR type, produced by the Company GRANITEX. It is a product for ready-to-use fluid concrete with a retarding effect, density = 1.065 ± 0.02, pH = 5 - 6, chlorine content < 0.1 g/liter, and dry extract = 30 ± 1.5 (%). The recommended dosage varies between 0.3 and 2% of binder weight. The dosage used in the present study represents approximately 1% of the weight of cement (saturation dosage, determined by the test described by Standard NA 5000 [24] which requires to prepare a grout with a water-to-cement ratio (W/C) = 0.51 and to measure its flow time through the Marsh cone, at 5 and 60 minutes of conservation, for several superplasticizer assay values.

The Marsh cone was used to verify the compatibility of the superplasticizer with the cement used (De Larrard F.,2000). It should be known that incompatibility between the cement and the superplasticizer can result in loss of sag, delayed setting, stiffening or disturbed air content (Aitcin P.C., 2001).

2.6 Mixing water

Drinking water from the city of Adrar was used for the preparation of various concretes. The chemical analysis of this water was carried out at the laboratory of the National Agency for Water Resources (NAWR) in Adrar. The results are summarized in Table 8.

Components	Ca	Mg	Na	K	Fe	SiO_2	Cl^-	SO_4	pH
Value(mg/l)	80	33	160	7	0	0	214	228	7.57

Table 8. Chemical and physical characteristics of the mixing water

3. FORMULATION

Multiple approaches have been developed around the world for the formulation of a self-compacting concrete (SCC); they are based on criteria for optimizing the volume of concrete paste (in the form of pure paste or mortar) and for optimizing the granular skeleton. All of these approaches revolve around five categories which are based on experimental findings, mechanical strength, granular stacking, statistical analysis and rheology (Shi C., 2015).

In addition to the AFGC provisional recommendations (Mesboua N. et al., 2021) which are characterized by:

- A gravel-to-sand (G/S) ratio (by volume) close to 1;
- A paste volume of 330 to 400 liters/m^3;
- A quantity of fines (around 500 kg/m³) higher than that of conventional concrete.

The analysis of 68 studies around the world, carried out by Domone over a period of 11 years (1993 - 2003) (Domone P., 2006), allowed drawing the following points:

- A volume of gravel varying between 28 and 38% of the total volume of SCC;
- A volume of paste varying between 30 and 42% of the total volume of SCC;
- A (water weight-to-cement weight) ratio less than 0.48;
- A dosage of binder (cement + additions) varying between 385 and 635 kg/m^3;
- A superplasticizer dosage close to its saturation dosage.

The SCC formulation methodology adopted in this study is based on the combination of the following criteria:

- Optimization of the volume of paste by adding sand-limestone fillers with dosages relative to the mass of cement equal to 0, 100, 150 and 200 kg/m^3, or in percentages equal to 0, 25, 38 and 50 %, with respect to the binder weight;
- Optimization of the granular skeleton by the graphic method of Dreux - Gorisse (Festa J., Dreux G., 2007) which makes it possible to highlight the missing classes while varying the (G/S) ratio (by volume) for the recommended values, i.e. 0.8, 0.9, 1, 1.1 and 1.2, for the SCCs to be formulated (Festa J., Dreux G., 2007);
- Optimization of the saturation dosage of the super plasticizer (Aitcin P.C., 2001).

Four self-compacting concretes were formulated for each (G/S) ratio value (by volume), namely 0.8, 0.9, 1, 1.1 and 1.2,

by introducing the fillers with dosages between 100 and 200 kg in 1 m^3 of binder mass, or in percentages of 0, 25, 38, and 50%.

The filler additions are then deducted from the volume of aggregates (according to their granular proportions) in order to keep the dry weight constant.
The Dreux-Gorisse method was used for the optimization of the granular skeleton with the data: Dmax = 16 mm, fc28 = 30 MPa, fc = 34.5 MPa (nominal resistance targeted with 15% increase), G (granular coefficient) = 0.45, Fce = 49.9 MPa (average strength of cement at 28 days).

The granular fractions were determined considering two types of sands, namely:

- Pure dune sand,
- Sand corrected using the Abrams law which is based on the fineness modulus FM. Note that the target modulus FM is taken equal to 2.5. This sand is composed of 37% dune sand and 63% crushed sand.

The results obtained are summarized in Figs. 1 and 2 as well as in Tables 9 and 10 below.

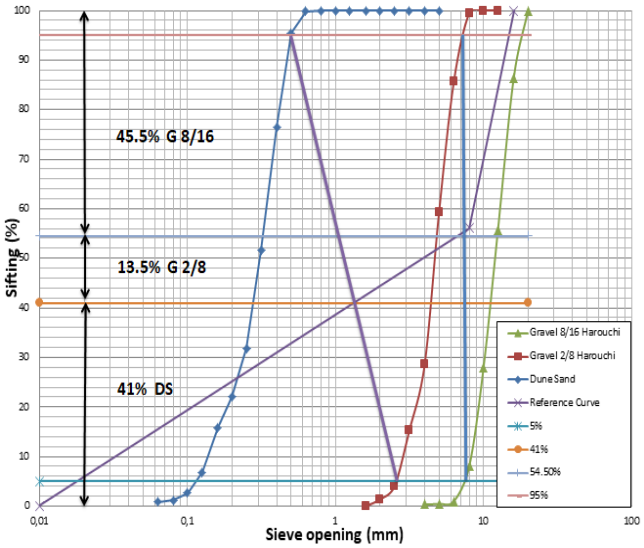


Figure 1. Particle size curves and dividing lines with dune sand

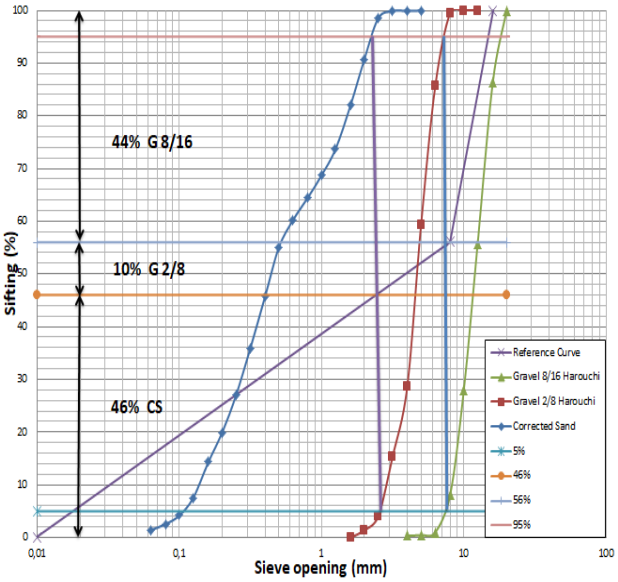


Figure 2. Partition size curves and dividing lines with corrected sand

Component	Dune Sand	G 2/8	G 8/16	Total	G/S (by volume)
Initial % (by volume) of granular components	41%	13.5%	45.5%	100%	1.44
Corrected % (by volume) for various values of (G/S) ratio	55.7%	13.5%	30.8%	100%	0.8
	52.5%	13.5%	34%	100%	0.9
	49.9%	13.5%	36.6%	100%	1.0
	47.7%	13.5%	38.8%	100%	1.1
	45.5%	13.5%	41%	100%	1.2

Table 9. Initial granular distribution corrected with dune sand (DS)

Component	Corrected Sand	G 2/8	G 8/16	Total	G/S (by volume)
Initial % (by volume) of granular components	46%	10%	44%	100%	1.27
Corrected % (by volume) for various values of (G/S) ratio	55.5%	10%	34.5%	100%	0.8
	52.5%	10%	37.5%	100%	0.9
	50%	10%	40%	100%	1.0
	47.6%	10%	42.4%	100%	1.1
	45.5%	10%	44.5%	100%	1.2

Table 10. Initial and corrected granular distribution for a mixture including corrected sand (63% crushed sand + 37% dune sand)

The different compositions of the formulated SCCs are presented in Tables 11 and 12 below.

Component	Units	SCC 01 0%LF	SCC 02 25%LF	SCC 03 38%LF	SCC 04 50%LF
Cement (C)	kg/m^3	400	400	400	400
Limestone fillers (LF)	kg/m^3	-	100	150	200
Water (W)	kg/m^3	202	202	202	202
W/C	-	0.51	0.51	0.51	0.51
Efficient water (W_{eff}) *	kg/m^3	168	144	128	116
W_{eff}/C	-	0.42	0.36	0.32	0.29
Paste volume	liter/m^3	344	381	400	419
SP	kg/m^3	13,33	13,33	13,33	13,33
	% Cement	1	1	1	1
For G/S (by volume) = 0.80					
Dune Sand	kg/m^3	337	316	306	295
Crushed Sand	kg/m^3	586	551	534	516
Gravel 2/8	kg/m^3	162	152	147	142
Gravel 8/16	kg/m^3	583	548	531	514
Dry weight	kg/m^3	2067	2067	2067	2067
Paste volume Eff	liter/m^3	375	410	428	446
For G/S (by volume) = 0.90					
Dune Sand	kg/m^3	318	299	289	280
Crushed Sand	kg/m^3	554	521	505	488
Gravel 2/8	kg/m^3	162	152	147	142
Gravel 8/16	kg/m^3	633	596	577	558
Dry weight	kg/m^3	2068	2068	2068	2068
Paste volume Eff	liter/m^3	373	409	427	445
For G/S (by volume) = 1					
Dune Sand	kg/m^3	303	285	275	266
Crushed Sand	kg/m^3	528	496	481	465
Gravel 2/8	kg/m^3	162	152	147	142
Gravel 8/16	kg/m^3	676	636	616	596
Dry weight	kg/m^3	2069	2069	2069	2069
Paste volume Eff	liter/m^3	372	408	425	443
For G/S (by volume) = 1.1					
Dune Sand	kg/m^3	289	271	262	253
Crushed Sand	kg/m^3	503	473	458	443
Gravel 2/8	kg/m^3	162	152	147	142
Gravel 8/16	kg/m^3	716	674	653	631
Dry weight	kg/m^3	2070	2070	2070	2070
Paste volume Eff	liter/m^3	370	406	424	442
For G/S (by volume) = 1.2					
Dune Sand	kg/m^3	276	259	251	242
Crushed Sand	kg/m^3	480	452	437	423
Gravel 2/8	kg/m^3	162	152	147	142
Gravel 8/16	kg/m^3	752	707	685	663
Dry weight	kg/m^3	2070	2070	2070	2070
Paste volume Eff	liter/m^3	369	405	423	441

Table 11. Different compositions of SCCs with corrected sand and for different values of the (G/S) ratio

Component	Units	SCC 01 0%LF	SCC 02 25%LF	SCC 03 38%LF	SCC 04 50%LF
Cement (C)	kg/m^3	400	400	400	400
Limestone fillers (LF)	kg/m^3	-	100	150	200
Water (W)	kg/m^3	202	202	202	202
W/C	-	0.51	0.51	0.51	0.51
Efficient water (W_{eff}) *	kg/m^3	196	168	152	140
W_{eff}/C	-	0.49	0.42	0.38	0.35
Paste volume	liter/m^3	344	381	400	419
SP	kg/m^3	13.33	13.33	13.33	13.33
	% Cement	1	1	1	1
For G/S (by volume) = 0.80					
Dune Sand	kg/m^3	913	857	829	801
Gravel 2/8	kg/m^3	219	205	199	192
Gravel 8/16	kg/m^3	520	489	474	459
Dry weight	kg/m^3	2052	2052	2052	2052
Paste volume Eff	liter/m^3	347	384	403	422
For G/S (by volume) = 0.90					
Dune Sand	kg/m^3	860	808	782	755
Gravel 2/8	kg/m^3	219	205	199	192
Gravel 8/16	kg/m^3	574	540	523	506
Dry weight	kg/m^3	2054	2054	2054	2054
Paste volume Eff	liter/m^3	347	384	403	422
For G/S (by volume) = 1					
Dune Sand	kg/m^3	818	768	743	718
Gravel 2/8	kg/m^3	219	205	199	192
Gravel 8/16	kg/m^3	618	582	563	545
Dry weight	kg/m^3	2055	2055	2055	2055
Paste volume Eff	liter/m^3	347	384	403	421
For G/S (by volume) = 1.1					
Dune Sand	kg/m^3	782	734	710	686
Gravel 2/8	kg/m^3	219	205	199	192
Gravel 8/16	kg/m^3	655	617	597	578
Dry weight	kg/m^3	2056	2056	2056	2056
Paste volume Eff	liter/m^3	347	384	403	421
For G/S (by volume) = 1.2					
Dune Sand	kg/m^3	746	700	677	655
Gravel 2/8	kg/m^3	219	205	199	192
Gravel 8/16	kg/m^3	692	651	631	610
Dry weight	kg/m^3	2057	2057	2057	2057
Paste volume Eff	liter/m^3	346	384	402	421

Table 12. Different compositions of SCCs with dune sand, for different values of the ratio (G/S)

* Efficient water = Hydration water - Water absorbed by aggregates + Water in aggregates - Water demand of fillers + Water in super plasticizer.

In order to remain within the extreme temperature and humidity conditions of our study region, the mixing of the concretes under study was carried out in a concrete mixer, at an ambient temperature of 44 °C in the shade, according to the protocol given below:

- Introduction of the aggregates into the concrete mixer in the following order: Gravel (8/16 and 2/8), followed by the equivalent binder (cement + addition), and finally sand,
- Dry mixing for 1 min,
- Introduction of 1/3 of mixing water, then mixing for 30 seconds,
- Introduction of the remaining 2/3 of mixing water along with the adjuvant (superplasticizer), then mixing for 3 min.

4. RHEOLOGICAL BEHAVIOR OF SELF-COMPACTING CONCRETE IN THE FRESH STATE

The rheological behavior of the self-compacting concretes thus formulated must satisfy the standardized tests and values recommended by standard NF EN 206-9 and EFNARC; these values are summarized in Table 13. This makes it possible to summarize the main properties of SCCs in the fresh state as follows:

- The Abrams cone (SF) spreading test, which is carried out according to standard NF EN 12350-8, can help to describe the mobility of SCC in an unconfined environment. The mobility is characterized by the measurement of the Abrams cone spreading as well as by T_{500} which is the time

that is required to achieve a spread of diameter 500 mm,

- The sieve segregation (SR) test with a 5 mm mesh, according to Standard NF EN 12350-11,
- The L-box (PL) filling test, according to Standard NF EN 12350-10 which describes the mobility of SCC in a confined environment.

Furthermore, two other additional non-standardized tests were also carried out:

- The LCPC box spreading test (Roussel N., 2007) to determine the shear threshold (τ),
- The viscosity (μ) according to the Sedran model (Sedran T.,1999) from the results of spreading of the Abrams cone (SF) test and the time T_{500}.

Tests	Slump-Flow (SF) by Abram's cone (mm)		Sieve segregation (SR) in %		Passing ability ratio (PL) (%)		T_{500} viscosity (Sec)		V-Funnel viscosity (Sec)	
Class	SF1	550 to 650	SR1	≤ 20	PL1	≥ 80%[a]	VS1	< 2	VF1	< 8
	SF2	660 to 750	SR2	≤ 15	PL2	≥ 80%[b]	VS2	≥ 2	VF2	9 to 25
	SF3	760 to 850	-	-	-	-	-	-	-	-

Table 13. Values recommended by Standard NF EN 206-9 and EFNARC

Where: - a: Test carried out with 02 bars
- b: Test carried out with 03 bars

5. RESULTS AND DISCUSSIONS

5.1 Fresh concrete

5.1.1 Slump-Flow (SF) by Abram's cone

The results presented in Figs.5 and 6 show that the spread of the ready-made concrete is between 625 and 855 mm; this allows asserting that these are self-compacting concretes according to the European Standard NF EN 206-9, regardless of the value of (G/S) that was taken between 0.8 and 1.2.

However, the following situations can be noted:

- For concrete with dune sand and (G/S) ratio equal to 1.2 and an addition percentage of 38%, the spread was beyond 850 mm (class SF3);
- For concrete with corrected sand and (G/S) equal to 1 and an addition percentage of 25%, the spread was between 625 and 855 mm (class SF3). The difference with that of dune sand concrete is mainly due to the high level of fines in the crushed sand, as reflected by its sand equivalent that was found equal to 59.26;
- In the absence of additions (concrete without addition), the test showed a very significant bleeding and a slight accumulation of aggregates at the center, which indicates the beginning of segregation (Figure 3). After adding 25% of limestone fillers, the signs of bleeding and segregation observed before practically disappeared right after, while the spreading diameter increased (Figure 4), which confirms the role and advantage of the addition.



Figure 3. Spreading test for SCC without addition of limestone fillers (bleed-through and start of segregation)



Figure 4. Spreading test for SCC with 25% of limestone filler additions

- For SCC with sand dune with 38% filler additions, a maximum spread was noted for all the values of ratio (G/S), except for (G/S) = 0.9 for which a loss of workability was noticed beyond 25% of filler addition. This may be explained by a decrease in the paste volume (Figure 7);
- For SCC with sand corrected, with 25 % of filler additions, a maximum spread was noted for all values of (G/S). It should be noted that beyond this percentage, a loss of workability was noticed due to the excess in paste volume; this may be explained by the high rate of fines in the crushed sand (Figure 8).

The different results of these tests are presented in Figs.5, 6, 7 and 8 given below:

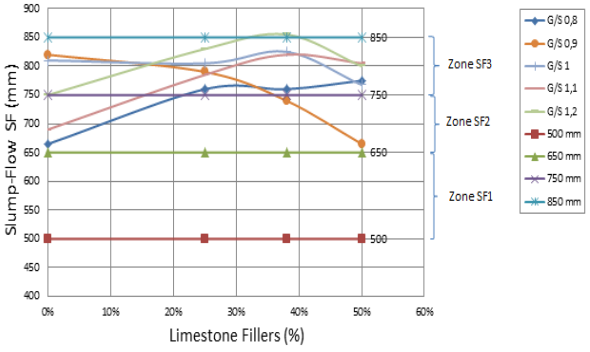


Figure 5. Dosage in additions as a function of slump-flow (SF) of the Abrams cone for SCC with dune sand

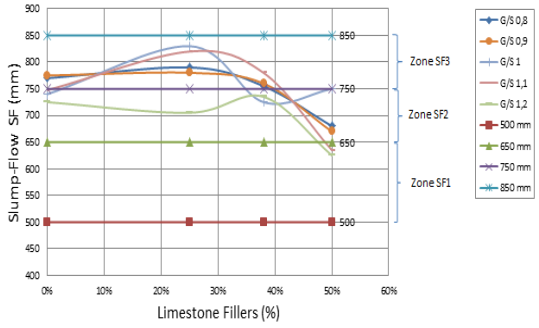


Figure 6. Dosage in additions as a function of slump-flow (SF) of the Abrams cone for SCC with corrected sand

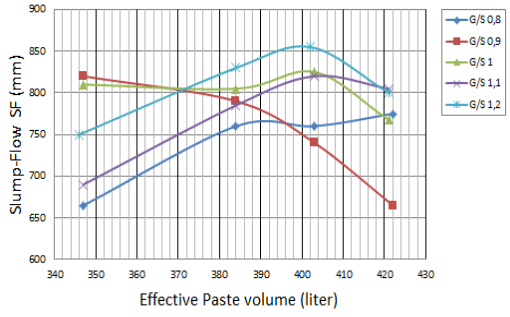


Figure 7. Effective paste volume as a function of cement spread in Abrams Cone (SF) for SCC with dune sand

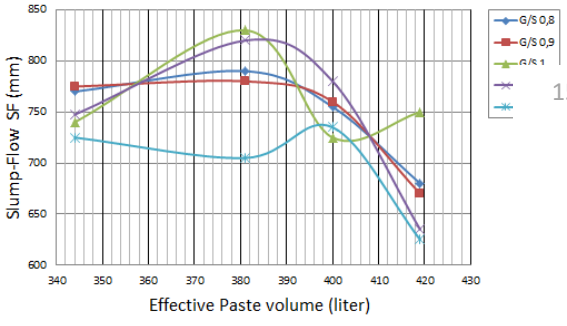


Figure 8. Effective Paste volume as a function of cement spread in Abrams Cone (SF) for SCC with corrected sand

5.1.2 L-box filling test (PL)

The results presented in Figure 9 show that all the SCCs with dune sand give a satisfactory filling rate (PL ≥ 0.8) for additions between 12% and 38%, and for all the values of the ratio (G/S).

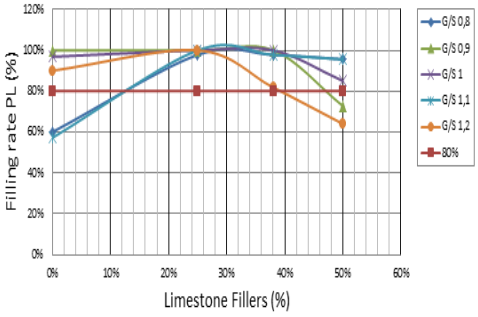


Figure 9. Dosage in additions as a function of the filling rate (PL) for SCC with dune sand

However, Figure 10 shows that the self-compacting concrete with corrected sand with additions between 21% and 33% gives an acceptable filling rate for all values of the (G/S) ratio, except for (G/S) = 1.2; this is certainly due to the insufficient volume of paste.

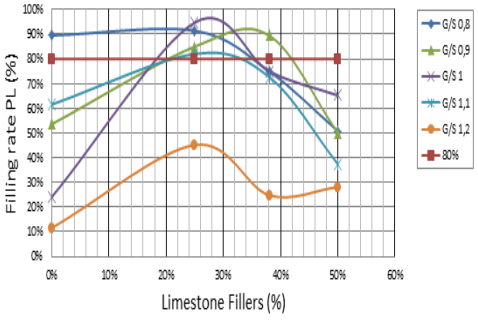


Figure 10. Dosage in additions as a function of the filling rate (PL) for SCC with corrected sand

5.1.3 Sieve segregation test (SR)

The results of the sieve segregation test, as presented in Figure 11, show that the formulations tested for SCC with dune sand exhibited satisfactory stability (SR < 20%) for additions above 44% and for all values of (G/S), and excellent stability (SR < 15%) for additions greater than 47%.

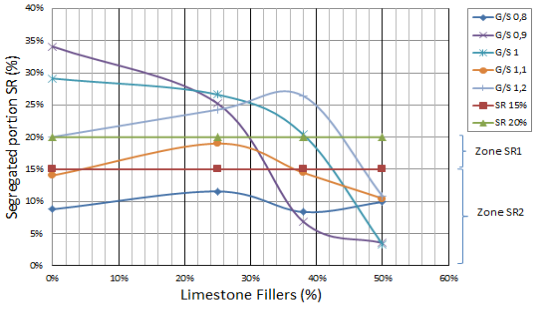


Figure 11. Dosage in additions as a function of sieve stability (SR) for SCC with dune sand

However, for a ratio (G/S) = 0.8, the segregated portion (SR) remained excellent regardless of the percentage of additions below 50%, except for that of 0% which presents a risk of blockage and loss of workability due to insufficient paste volume. For (G/S) values equal to 0.9, 1 and 1.2, concretes

without and with additions above 30% presented a risk of instability (SR > 20%).

The results of the sieve segregation test, presented in Figure 12, show explicitly that the SCCs formulated with corrected sand have a satisfactory stability (SR < 20%) for additions above 30%, and for all values of the (G/S) ratio. This stability proved to be excellent (SR < 15%) for addition rates greater than 32%.

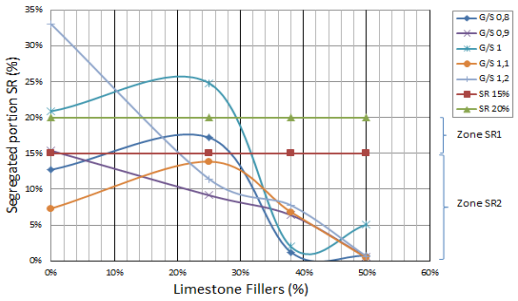


Figure 12. Dosage in additions as a function of sieve stability (SR) for SCC with corrected sand

It is also useful to note that for (G/S) = 1.1, SR remained excellent. It should be mentioned that whatever the percentage of addition below 50%, except for the one at 0%, it was observed that there was has a risk of blockage and loss of workability due to insufficient paste volume. Moreover, for a (G/S) ratio equal to1 and 1.2, concretes without and with additions above 12% presented a risk of instability (SR > 20%).

This difference between SCC with dune sand and SCC with corrected sand is mainly attributed to the large volume of paste due to the high level of fines present in crushed sand.

5.1.4 The spreading time (T_{500})

This is the time (in seconds) needed for the SCC to reach a diameter of 500 mm. This time T_{500} gives an idea of the strain rate of concrete. In general, for a self-compacting concrete, the literature gives average values between 2 seconds and 7 seconds.

The results obtained, presented in Figure 13, show that for dune sand SCCs, the T_{500} time is stable for addition rates less than 40%. Beyond this value, this time increases rapidly due to the paste thickening, which induces an increase in viscosity.

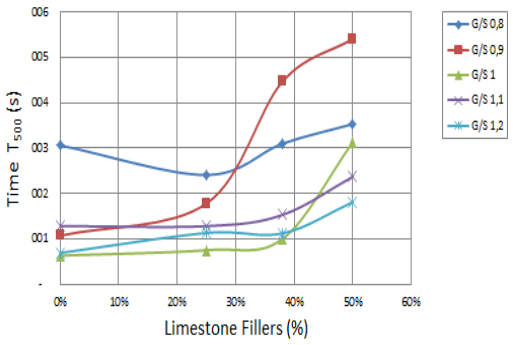


Figure 13. Dosage in additions as a function of time T_{500} for SCCs with dune sand

On the other hand, for the results obtained, presented in Figure 14, it was noticed that the time T_{500} of the corrected sand SCCs increased as the addition rates increased, which is certainly due to the thickening of paste, which reflects a viscosity increase.

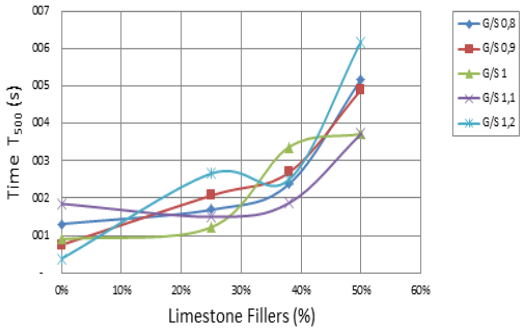


Figure 14. Dosage in additions as a function of time T_{500} for SCCs with corrected sand

5.1.5 Plastic viscosity (μ)

The most relevant correlations between rheology and workability are those relating viscosity to time T_{500}. Indeed, the Eq. (1), established by Sedran (Sedran T.,1999) and confirmed by Emborg [34], gives a relation between the viscosity and the spreading time T_{500}. It is expressed as:

$$\mu = (\rho/1000)\,(0.0268\,SF - 2.39)\,T_{500} \quad (1)$$

where:

μ: is the plastic viscosity of the material (Pa.Sec),
ρ:is the density of concrete (kg/m^3),
SF: the spread at the Abrams cone (mm),
T_{500}: the time needed for the SCC diameter to reach adiameter of 500 mm (seconds).

The results presented in Figs. 15 and 16, obtained by Eq. (1), indicate that the volume of concrete paste increases with increasing addition rates, which engenders an increase in viscosity. These findings make it possible, on the one hand, to confirm the results obtained for the measurements of T_{500} and, on the other hand, to validate the Eq. (1). In addition, it was found that this increase in paste viscosity gives allows the aggregates to be driven away and consequently achieve a better stability of the SCC. These findings corroborate the results obtained with the L-box and sieve stability tests.

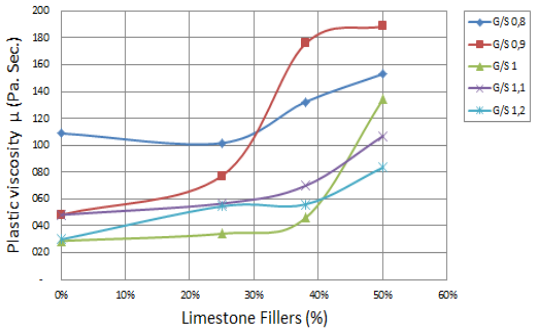


Figure 15. Dosage in additions as a function of viscosity for dune sand concrete

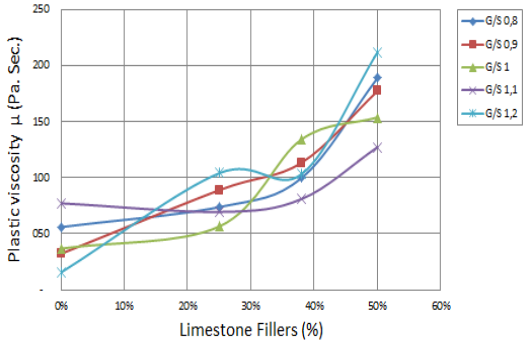


Figure 16. Dosage in additions as a function of viscosity for corrected sand concrete

5.1.6 The shear or flow threshold (τ)

The shear or flow threshold (τ) was determined using the LCPC method (Roussel N.,2007) which is based on the measurement of the spread length (L) of concrete in a box 120 cm long, 15 cm high and 20 cm wide (Figure 17). This was done according to the following procedure:

- Fill a pre-wet bucket with 6 liters of concrete;
- Slowly pour the concrete from one end of the box (emptying the bucket should take about 30 seconds) and wait for the flow to stop (2 minutes at most);
- Measure the flow length L of concrete in the box (the average between the maximum length and wall length).

Furthermore, the abacus shown in Figure 17 makes it possible to read the shear threshold-to- density (τ / ρ) ratio, and to deduce analytically the numerical value of the shear or flow threshold (τ).

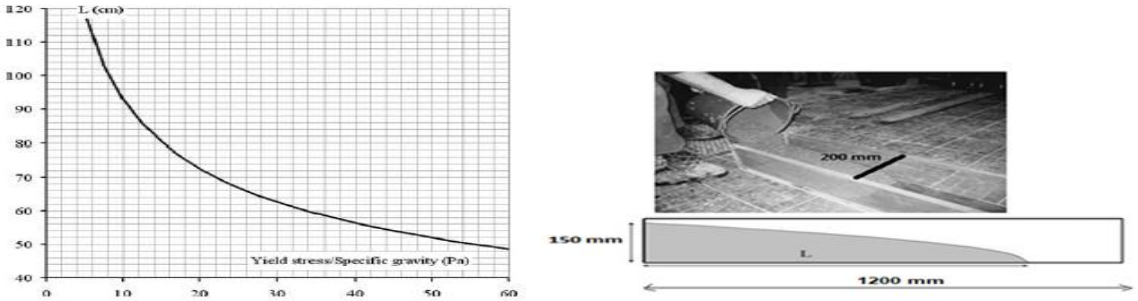


Figure 17. LCPC box and shear threshold-to-density (τ / p) ratio diagram as a function of concrete spread L

The results obtained, presented in Figs. 18 and 19, corroborate those obtained from the T_{500} and plastic viscosity (μ) tests.

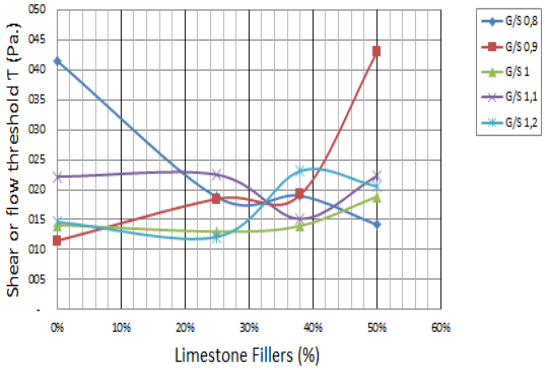


Figure 18. Dosage in additions as a function of shear threshold for dune sand concrete

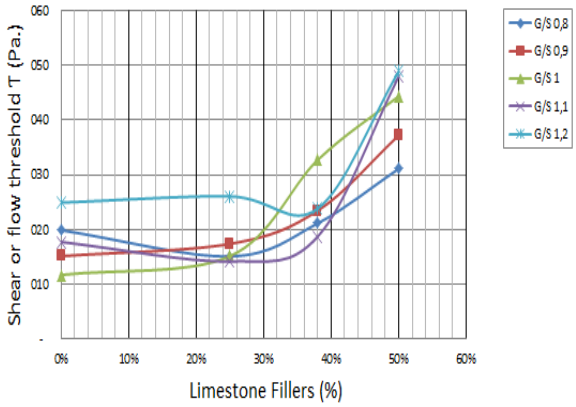


Figure 19. Dosage in additions as a function of shear threshold for corrected sand concrete

5.2 Behavior of self-compacting concrete in the hardened state

5.2.1 Mechanical resistance to compression

The classic characterization of the mechanical resistance to compression of the manufactured SCCs was carried out, in the hardened state, on 240 cubic specimens of 15 cm side, which were previously kept in water at the temperature of 20 °C, for 28 days. The results thus obtained for the two types of sand are presented in Figs.20 and 21.

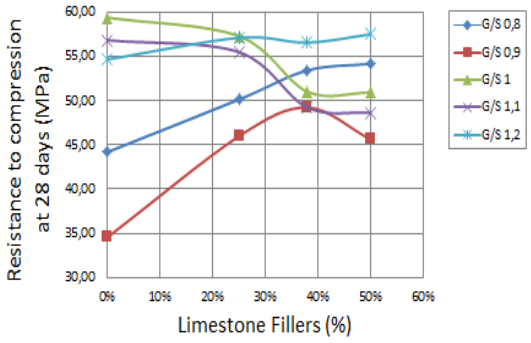


Figure 20. Dosage in additions as a function of compressive strength, at 28 days, for SCCs with dune sand

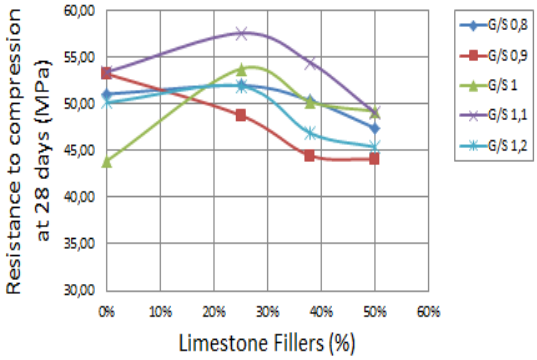


Figure 21. Dosage in additions as a function of compressive strength, at 28 days, for SCCs with corrected sand

Self-compacting concretes often have a mechanical resistance to compression slightly higher than that of ordinary concrete without additions, with similar water-to-binder (W/B) ratios (Assié S.,2004). For the SCC with dune sand (Figure 20), there is a slight resistance increase that is proportional to the increase in addition rates, for (G/S) values equal to 0.8, 0.9 and 1.2 due to the filling effect induced by these additions. However, the resistance augmentation is inversely proportional to the increase in addition rates for values of (G/S) equal to 1 and 1.1. It is noted that the resistance is stable beyond the addition rate of 38%, which is probably attributed to the increase in the (W/Leq) ratio as a function of the addition rate because of the retarding effect of the adjuvant. With regard to the sand corrected SCC (Figure 21), it was found that the optimal addition dosage was around 25%. Beyond this value, the resistance decreased as the solid phase volumetric concentration of paste went up, for the values of (G/S) ratio equal to 0.8, 1, 1.1, and 1.2. For the SCC with (G/S) equal to 0.9, it was observed that the decrease in resistance was inversely proportional to the addition rate; this was probably due to the increase in the (W/Leq) ratio with the addition dosage due to the retarding effect of the adjuvant.

5.2.2 Visual control of granular distribution

A visual check of the state of the granular distribution of the hardened concrete was performed on test pieces crushed and sawn along the axis (Figs.22 and 23). The observations allowed showing that the aggregates were adequately distributed through the SCC volume, which confirms the absence of segregation that was previously observed during the spreading tests carried out on fresh concrete.



Figure 22. Longitudinal section of a hardened specimen of SCC with corrected sand (SCC 25%, (G/S) = 1.1)

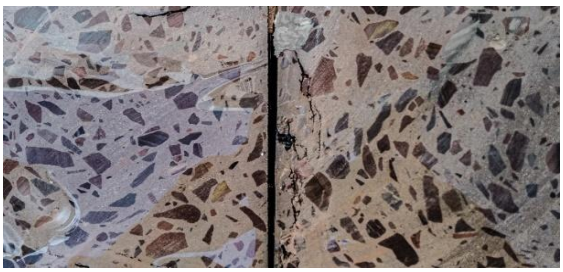


Figure 23. Longitudinal section on a hardened specimen of SCC with dune sand (SCC 38%, (G/S) = 0.9)

6. CONCLUSION

The formulation of a self-compacting concrete (SCC) for our region, is a complex operation that requires finding a good combination of local materials that are compatible with a suitable dosage of each of its constituents in order to obtain a composition that is in accordance with the SCC properties, such as fluidity and homogeneity, in an arid climate region. Therefore, our formulation method of SCCs from local materials allowed achieving interesting and encouraging results with regard to the fixed objectives. The mixtures tested by our method for the two types of SCC with a dosage of 1% super plasticizer brought us to the following results:

(1) For the SCC with sand corrected with a (G/S) ratio (by volume) within the range [0.8 - 0.9], it was noted that an optimal addition dosage between 25 and 38% was sufficient to produce SCCs that meet the recommendations of the standards in force, with a slight improvement in the mechanical resistance to compression (52.01 MPa for an addition rate of 25% and G/S = 0.8).

(2) For the SCC with dune sand and a (G/S) ratio (by volume) within the range [0.8 - 1.1], it was found that an optimal addition dosage between 25 and 50% was sufficient to produce SCCs that meet the recommendations of the standards in force, with an improvement in the mechanical resistance to compression (55.49 MPa for an addition dosage of 25% and G/S = 1.1); this is certainly due to the filling effect of the sand-limestone filler additions.

(3) Ultimately, for the purpose of formulating SCCs suitable to our arid region, it is strongly recommended to:

(4) Limit only to SCCs based on dune sand. This type of SCC, which presents no risk of segregation or blockage in confined spaces, proved to be quite interesting from an economic and especially environmental point of view with the valorization of:
   - Silico-limestone fillers which are currently abandoned in crushing stations; they are used in proportions between 25 and 50% relative to the mass of the cement,
   - Dune sands that are found in abundance in the Sahara and cause the silting up of Ksours (villages) and Oases,

(5) Use the graphic method of Dreux - Gorisse, which is widely used by our regional laboratories, for the optimization of the granular skeleton in order to highlight the missing classes while varying the (G/S) ratio (by volume) in the range [0.8 - 1.1],

(6) The correction of the (G/S) ratio (by volume) is done between sand and gravel with the largest fraction. It should be noted that the gravel can be responsible for a possible blockage when concrete flows between the reinforcements (L-box test),

(7) The filler additions are deducted from the volume of aggregates (according to their granular proportions) in order to keep a constant dry weight,

(8) The optimal dosage of the super plasticizer is obtained at saturation. This super plasticizer is based on latest generation polymers with a setting delay effect and the highest possible dry extract in order to minimize the dosage.

It would be highly desirable to study, in the long term, the behavior of these concretes with respect to their durability in environments with hot and arid climates. In these regions, structures built with these concretes are subject to large temperature variations and sandstorms; they are also exposed to a chemically aggressive environment (chlorides and sulphates).

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