International Journal of Concrete Structures and Materials
Vol.3, No.1, pp. 3~9, June 2009

Incorporation of CrusHed Sands and Tunisian Desert Sands in the Composition of Self Compacting Concretes Part I: Study of Formulation

Abdelhamid Rmili,[1,2] Mongi Ben Ouezdou,[1] Mhamed Added,[3] and Elhem Ghorbel[4]

(Received December 1 2008, Revised April 30, 2009, Accepted May 4, 2009)

Abstract: This paper examines the incorporation of the crushed sand (CS) and desert sand (DS) in the formation of self compacting concrete (SCC). These sands have been substituted for the rolled sand (RS), which is currently the only sand used in concretes and which is likely to run out in our country. DS, which comes from the Tunisian Sahara in the south, is characterized by a tight distribution of grains size. CS, a by-product of careers containing a significant amount of fines up to 15%, is characterized by a spread out granulometry having a maximum diameter of around 5 mm. These two sands are considered as aggregates for the SCC. This first part of the study consists in analyzing the influence of the type of sand on the parameters of composition of the SCC. These sands consist of several combinations of 3 sands (DS, CS and RS). The method of formulation of the adopted SCC is based on the filling of the granular void by the paste. The CS substitution to the RS made it possible, for all the proportions, to decrease the granular voids, to increase the compactness of the mixture and to decrease the water and adding fillers proportioning. These results were also obtained for a moderate substitution of DS/CS (< 40%) and a weak ratio of DS/RS (20%). For higher proportions, the addition of DS to CS or RS did not improve the physical characteristics of the SCC granular mixture.

Keywords: self compacting concrete, desert sand, crushed sand, rolled sand, granular packing, formulation.

1. Introduction

In Tunisia and in most African countries, only rolled sands (RS) are currently used in the manufacture of concrete.[1] The use of crushed sands (CS), a by-product of the massive rocks quarries, is very rare in constructions and is limited to some road constructions.[1] Moreover, most of these countries suffer from an important lack of suitable aggregates. However, these countries contain inexhaustible quantities of desert dune sands which were never put to use seriously in constructions.

At the end of the 20th century, a new generation of concrete was born: self compacting concretes (SCC). These SCC, extremely fluid, require for their composition, a high percentage of sand and fillers. The control of their composition requires a constant development of their formulation, a rigorous control of their rheological properties and a perfect knowledge of the characteristics of their constitutive materials.[2,3]

[1]Civil Engineering Laboratory, Tunis National Engineering School, ENIT, BP 37, 1002 Tunis Belvedere, Tunisia. E-mail: mongi.benouezdou@enit.rnu.tn
[2]Higher School of Sciences and Technology of Tunis, ESSTT, BP 56 Bab Menara, 1008 Montfleury Tunis, Tunisia.
[3]Testing and Construction Techniques Center, CETEC, Av. 15 October 1963, El Ouardia 1009 Tunis, Tunisia.
[4]LM2GC, University Of Cergy Pontoise, 5 Gaiy-Lussac, Neuville sur Oise 95031 Cergy Pontoise Cedex, France.

The incorporation of the CS, which contains important fines proportion and which has a granulometry spread out, can bring a solution for the composition of the SCC. In the same way, desert sands (DS), which have a very fine granulometry, can allow for an increase in the compactness of the granular mixture of the SCC. This DS sand may constitute a local material of construction in the sub-Saharan regions. Some research projects focusing on the use of the river Dune sand and sea sand, similar to the DS, into the formulation of concrete, has been carried out by Bederina et al.[4,5] Moreover, an attempt has been presented by Zhang et al.[6] to study the performance of concrete made by Teggeli DS.

This paper deals with the study of the SCC formulation based on granular packing and the filling of the intergranular void by a binder paste. Several sand combinations are compared with the mixtures optimized so as to analyze the influence of the sand type on the formulation parameters of the SCC. These mixed granular are based on sand combinations of CS, RS and DS. The latter has been obtained from the Tunisian desert (south of Tunisia). The second part of this paper will present the results of the rheological at the fresh state and the mechanical strength at the hardened state of these SCC.

2. Identification of the constitutive materials of the studied SCC

2.1 Aggregates

- ***Rolled sand (RS)***: The RS is extracted from a quarry of siliceous movable rock located at the North-East of Tunisia. Its chemical and physical characteristics are given in Tables 1 and 4. It is a 0/2.5 mm sand having a low content of fine (grain < 0.08 mm) of about 1.80 %.

- ***Crushed sand (CS)*:** The CS comes from a calcareous quarry of rock in the north-east of Tunisia. Its chemical and physical characteristics are given in Tables 2 and 4. It has a continuous granulometry being spread out from 0.08 to 5 mm and a fine content of about 12.44 %.

- ***Desert sand (DS)*:** DS comes from the Tunisian Sahara desert of the south near the town of Kebili (south of Tunisia). Its chemical and physical characteristics are provided in Tables 3 and 4. The composition shows that this sand is silico-calcareous. It is a mono sand granular very fine of maximum granulometry of 0.4 mm and content of fine of about 14.4%.

- ***Gravel (G)*:** The gravel comes from the same quarry as that of the CS. Its physical granulometry and its characteristics are presented in Fig. 1 and Table 4. It has a granulometry being spread out from 4 to 16 mm.

2.2 Binders and additions

- ***Cement (C)*:** It is a Portland cement of the type CEM I 42.5 in conformity with Tunisian Standard NT 47.01. These physical characteristics are as follows: a Specific density of 3.1 and a Blaine specific surface of 440 m^2/kg. Its granulometry is illustrated by Fig. 2.

- ***Filler (F)*:** The used filler is the product of crushing of a calcareous rock, which comes from the center of Tunisia. Its physical characteristics are as follows: size range: 0/0.112 with 96.6 < 0.080 mm, a density of 2.739 and a Blaine specific surface of 460 m^2/kg. Its chemical composition and its granulometry are presented in Table 5 and Fig. 2.

- ***Admixture (A)***: The employed admixture is a superplasticizer (SP), a high water reducer of new generation and not chloride based on acrylic copolymer (Viscocrete-Tempo12, produced by "Tunisian SIKA"). Its physicochemical characteristics are given in Table 6.

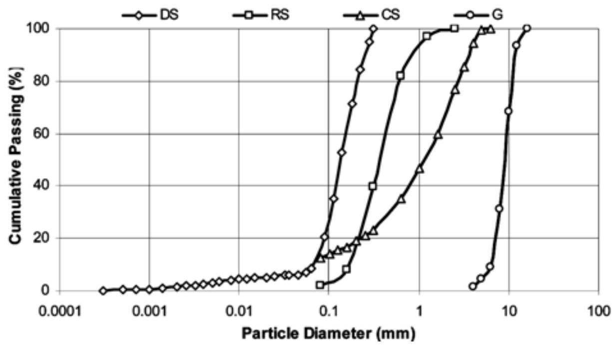

Fig. 1 Granulometry curves of the aggregates. The desert sand analysis was performed by laser granulometry.

3. Study of formulation

Several methods of SCC formulation are proposed in the literature. They are different in their design but they all lead to similar compositions.[7-10] The adopted formulation method in this study is based on the filling of the intergranular voids by the binder paste in order to have a maximum compactness and to guarantee a good behavior of SCC material.[9]

3.1 Comparison of the considered formulation methods

The method of formulation considered for the composition of the studied SCC is based on a method known to be a Chinese

Table 5 Chemical characteristics of the filler.

F	CaO_3	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
%	99.38	0.1	0.061	0.014	55.38	0.144

Table 1 Chemical characteristics of RS.

RS	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	Ignition loss
%	98.26	0.11	0.34	0.08	0.01	0.03	0.17	0.002	1.024

Table 2 Chemical characteristics of the CS.

CS	CaO	Fe_2O_3	Al_2O_3	MgO	Na_2O	SiO_2	SO_3	Ignition loss
%	54.892	0.523	0.035	0.436	0.049	0.436	0.192	42.32
CS	TiO_2	MnO	SrO	P_2O_5			P_2O_5	
%	0.009	0.509	0.015	0.019			0.019	

Table 3 Chemical characteristics of the DS.

DS	S_iO_2	$CaCO_3$	SO_4	Cl^-	Total gypsum	Insoluble residues	Soluble salts
%	92.05	4.58	0.94	0.1	1.68	89.36	1.28

Table 4 Physical characteristics of the aggregates.

	Finesses modulus, FM	Fines < 80 µm (%)	Absorp. coef., CAb (%)	Sand equivalent, SE (%)	Loose density, LD (kg/m^3)	Absolute density, AD (kg/m^3)	Max diameter, D_{max} (mm)
RS	1.73	1.80	0.25	7 5.70	1,612	2,659	2.5
CS	3.01	12.44	0.30	78.26	1,580	2,699	5
DS	0.38	14.40	2.30	61.50	1,366	2,562	0.4
G			0.30		1,397	2,705	16

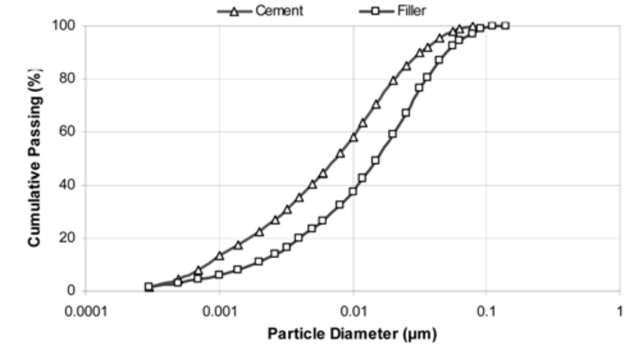

Fig. 2 Granulometry curves of the cement and fillers. These analyses were performed by laser granulometry.

Table 6 Physicochemical characteristics of the superplasticizer (A).

Viscocrete tempo 12	Density	pH	Na_2Oeq(%)	Dry extract(%)	Cl^-(%)
	1.06 ± 0.01	6 ± 1	1	30.2 ± 1.3	0.1

method.[7,10] It consists in piling up aggregates (sand and gravel) and filling up the granular voids with paste. Proportionings of the aggregates were calculated according to their loose densities, of the sands/aggregate ratio and of the packing factor. However, the method known as the Japanese method[2] suggests that the proportioning of the gravel in the mixture of concrete corresponds to 50% of its packed density and the proportioning of sand in the mortar corresponds to 50% of its packed density.

Furthermore, the method known as the French method[8] passes by an optimization of the porosity of the system formed by all the solid matter constituents. It is based on the modeling of the behavior of the concrete in a fresh state from the calculation of the compactness of its granular skeleton. It goes through the determination of the properties of the components by calculating the maximum compactness of the aggregates via the compressible packing model (CPM) and by using the Rene-LCPC software.[11] The water/binder ratio is calculated according to the standard (EN 206-1) for a volume of paste of about 370 liters. Proportionings in admixtures were adjusted by rheological tests in the fresh state. Optimization is made by the "Concrete Lab Pro2" software and by using the packing and shearing models and by applying the necessary requirements. In this study, the Rene LCPC software was used for the determination of the optimal packing of the three sands combined two to two (Fig. 3). The packing of various sands with the gravel was not optimized in order to study the effect of the type of sand on the granular arrangement of the mixture. Moreover, the sand/aggregate voluminal ratio was fixed at 0.5.

The Rene-LCPC software,[11] developed at the Laboratoire Central des Ponts et Chaussees in France, is based on the CPM. This model, considered as an ideal tool of predicting the compactness of a granular packing, allows the minimization of the porosity or the maximization of the compactness of the granular skeleton of a mixture by optimizing the proportions of the various size ranges. The data input necessary for each mixture are: granulometry, density, the index of tightening and real compactness. The main results are the proportions of the size ranges and the corresponding porosities. The drawing of the porosity curve as a function of the aggregates proportion allows

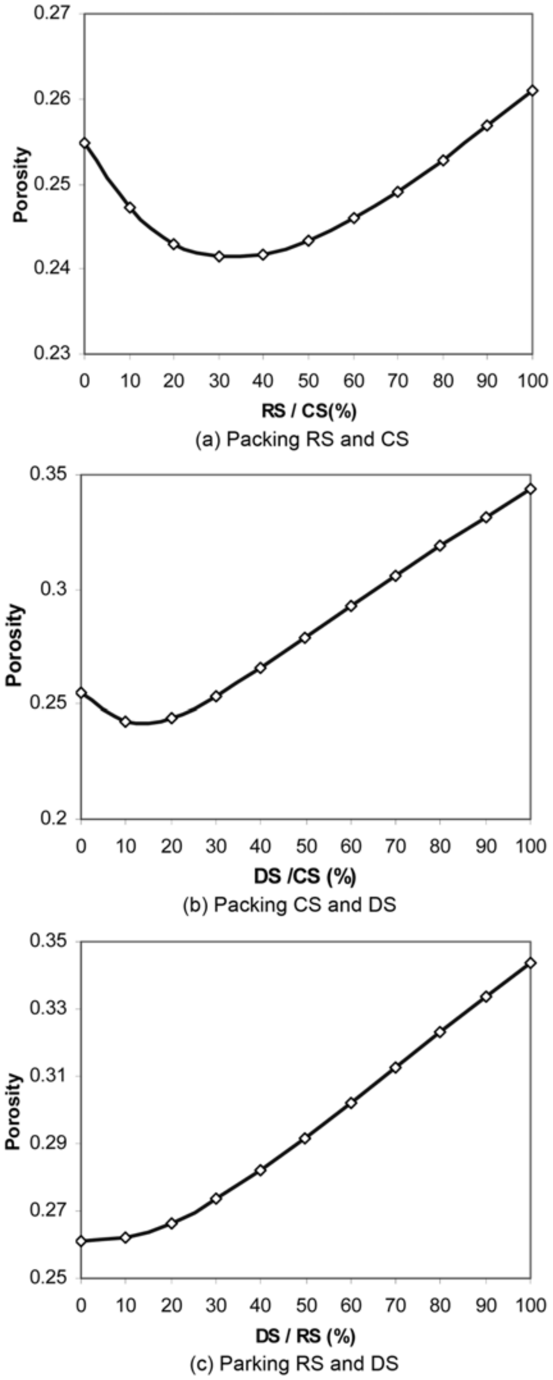

Fig. 3 Packing of the sands.

thus to obtain the optimal porosity and the maximum compactness and to deduce the optimal granular combination.

Water proportioning necessary for cement and filler is based on the condition of fluidity according to the method described by Domone and Wen.[12] However, in the Chinese, Japanese and French methods, water was given according to the current standard which generally depends on the foreseeable strength of the concrete.

The proportioning of the filler is calculated by the method known as the Dutch method,[9] which is based in its turn on the Chinese method and consists in drawing the quantity from the filler based on one cubic meter of SCC including all confused.

Cement proportionings were generally taken according to the country standards and the necessary requirements. The air content varies from 1 to 3% in the ordinary SCC for all the methods.

3.2 Determination of the aggregates proportioning

The granular mixture consists of gravel and a variation of three sands. The proportions of the sands optimal mixtures, combined between them, are determined by the CPM (through the Rene LCPC Software).[8,11]

The optimal proportions are given on the curves of Fig. 3. The optimal packing of sands gave the following combinations:

- 30% of RS and 70% of CS (Fig. 3(a)),
- 15% of DS and 85% of CS (Fig. 3(b))
- the packing of the DS and the RS did not show a net minimum. The porosity increased linearly with the DS. This increase indicated that the DS has not improved the compactness of the mixtures because of their high finesses.

In addition to these optimal mixtures, other combinations were added in order to take into account of the technical-economic factor (Table 7). The sand mass (M_s) and the gravel mass (M_G) are calculated by the following Eq. (1).[7,10]

$$M_S = PF \times LD_s \times \frac{V_S}{V_a} \text{ and } M_G = PF \times LD_G \times \left(1 - \frac{V_S}{V_a}\right) \quad (1)$$

where

- PF : packing factor, the ratio of mass of aggregates in the mixture to that of loosely packed state according to ASTM C-29,
- LD_S : sand loose density,
- V_s / V_a : volume ratio of fine aggregates to total aggregates, which ranges from 50% to 57%,
- LD_G : gravel loose density.

3.3 Determination of water proportioning

The calculation of water proportioning is based on the fluidity condition of the binder paste. The water needed for each powder follows from flow spread tests with the Haegermann flow cone, executed analogously to Domone and Wen[12] (Fig. 4). The results are presented on Fig. 5. For various water/powder ratios, the relative slump R_p was determined by the following Eq. (2) :

$$R_p = \left(\frac{d}{d_0}\right)^2 - 1 \quad (2)$$

where d: flow diameter in mm and d_0 the lower diameter of the cone (= 100 mm).

The water mass M_W is given by the Eq. (3):

$$M_W = (a_C R_p + b_C)M_C + (a_F R_p + b_F)M_F \quad (3)$$

where a_c and b_c (resp. a_f and b_f) are the terms of the right-hand sides of the line equation relative to cement (resp. filler) presented on Fig. 5(a). M_C and M_F are the masses of cement and filler respectively.

Fig. 4 Flow test on paste.

3.4 Determination of proportioning in superplasticizer

The SP mass M_{SP} is given by the Eq. (4):

$$M_{SP} = n(\rho_C V_C + \rho_F V_F) \quad (4)$$

where "n" is the SP proportioning, ρ_C and ρ_F are the absolute densities of cement and the filler, respectively, and V_C and V_F are their volumes.

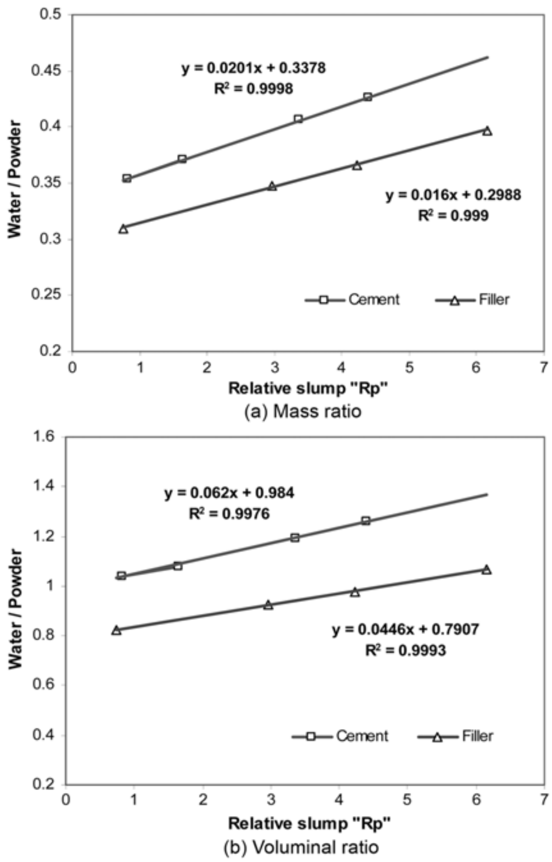

Fig. 5 Water/binder ratio according to relative slump.

Table 7 Combinations of sands of the studied SCC.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
RS (%)	100	30	50	70	0	-	-	-	-	-	40	60	80
CS (%)	0	70	50	30	100	85	70	55	40	0	-	-	-
DS (%)	-	-	-	-	0	15	30	45	60	100	60	40	20

The volume of the dry extract of SP, V_{SP}, is given by the Eq. (5):

$$V_{Sp} = \frac{m_{Sp} \cdot M_{Sp}}{\rho_{SP}} \tag{5}$$

where m_{Sp}, ρ_{Sp}, and M_{Sp} are the content of the dry extract, its density and the mass of the SP respectively.

3.5 Cement proportioning and of air void contents

Cement proportioning was taken equal to 350 kg/m^3 by considering that the studied SCC were concretes with prescribed specifications of current strengths and exposed to a moderate environment (ENV 206.1 Standard). The air void volume in the SCC was estimated at 1.5% by considering that, in Tunisia, the freezing weather is very rare.

3.6 Determination of the content of filler

One m^3 of SCC is generally made up of the volumes of Gravels (V_G), sands (V_S), cement (V_C), fillers (V_F), water (V_W), superplasticizer (V_{SP}) and air void (V_{air}), as presented by Eq. (6):

$$1m^3(SCC) = V_G + V_S + V_C + V_F + V_W + V_{Sp} + V_{air} \tag{6}$$

The paste volume is written as presented by Eq. (7):

$$V_{paste} = V_C + V_F + V_W + V_{Sp} + V_{air} \tag{7}$$

However, this paste volume (V_{paste}) must at least fill out the aggregates void volume (V_v), packed in one m^3 of SCC (Eq. (8)).

$$V_v = 1m^3(SCC) - V_{Aggregate} \tag{8}$$

By introducing the terms of Eqs. (3, 4, 5, 6 and 8) into the Eq. (7), the voluminal proportioning of the filler becomes as the following[9] (Eq. (9)):

$$V_F = \frac{V_v - V_{air} - V_C\left(1 + a_C R_p + b_C + \dfrac{m_{Sp} n \rho_C}{\rho_{Sp}}\right)}{1 + a_F R_p + b_F + \dfrac{m_{Sp} n \rho_C}{\rho_{Sp}}} \tag{9}$$

where a_c and b_c (resp. a_f and b_f) are the terms of the right-hand sides of the line equation relative to cement (resp. filler) presented on Fig. 5(b).

3.7 Composition of the studied SCC

The composition of the SCC of this study is based on the following data:

- A Packing Factor PF equal to 1.18,
- A volume ratio of fine aggregates to total aggregates equal to 0.50,
- A relative slump equal to 1,

The water proportioning was corrected, $M_{w,cor}$, by cutting off the fraction from water brought by the SP and by adding the water absorbed by the aggregates (Eq. 10).

$$\begin{aligned} M_{W,cor} = {} & (a_C R_p + b_C)M_C + (a_F R_p + b_F)M_F \\ & (1 - m_{Sp})M_{Sp} + C_{Ab,G}M_G + C_{Ab,S}M_S \end{aligned} \tag{10}$$

where $C_{Ab,G}$ and $C_{Ab,S}$ are the water absorption coefficients of the gravel and sands (Table 4).

By referring to the method of formulation suggested above, Table 8 presents the theoretical composition of the SCC to be studied. In addition to the physical characteristics of the granular components, this table contains also the volume of the intergranular voids, the filler quantity and the water proportioning calculated for various contents of superplasticizer (n = 0.7, 1, 1.3 and 1.5%).

4. Interpretations

The formulations obtained show that sand proportioning depends on their apparent loose densities.[13] The sand mass decreases with its density, such as in the case of the SCC containing uncombined sands (C1, C5 and C10) and the SCC containing the desert sand (C9, C11 and C12). Furthermore, for these latter SCC the intergranular voids volume and the gravel/sand ratio are high ($V_v > 0.35$ and $G/S > 0.9$). The effect of this result might cause problems of flow and SCC implementation. However, the SCC based on the other combined sands contains high sands mass and moderate V_v and G/S (Table 8).

The combination of sands has induced an increase in the loose densities (LD) and consequently the reduction in intergranular voids (V_v) and an increase in the aggregates volume (V_a) (Fig. 6). This result has also been found in the case of the sand concrete.[12] Fig. 6 shows also that an increase in LD by 4.65% (resp. 6.77%) was reached compared to the optimal combination (C4) of RS (resp. of CS). This increase is from 4.05 to 20.35% (resp. 1.74 to 20.05%) for CS and DS (resp. for RS and DS) with respect to C6 (resp. C13) combination. This figure shows also that a reduction of V_v by 4% (resp. 7.38%) was obtained compared to the optimal combination (C4) of RS (resp. of CS). Furthermore, this decrease is from 1.5 to 5.12% (resp. 2.12 to 2.42%) for SC and DS (resp. for RS and DS).

The packing of these various sands had also caused the increase in the absolute sands densities and thus the increase in the sands and the aggregates masses (Fig. 7). This increase requires only low filler proportioning resulting in a decrease in water demand and generating higher mechanical strengths as observed by Ayed et al.,[5] while using local materials in the SCC study.

High volumes of the intergranular voids required large quantities of fillers for their filling as described by many researchers. Indeed, the studied SCC based on the uncombined sand had required high quantities of fillers (about 210 kg of filler for the DS, 170 kg for the CS and 150 kg for RS). However, the contents of filler are the lowest for the optimized formulations (≈ 135 kg for C4, ≈ 147 kg for C6 and ≈ 143 kg for C13). Water proportioning follows the same order because it depends amongst other things on the content of fillers. These results are shown for example on Fig. 8 for 1% of SP (Fig. 8).

5. Conclusions

This study showed that the adopted method for the SCC formulation allowed the calculation of the majority of the compo-

Table 8 Theoretical composition of the SCC for various sand combinations and superplaticizer proportionings.

SCC code	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
Sand LD	1.612	1.648	1.670	1.687	1.580	1.644	1.648	1.610	1.492	1.366	1.487	1.534	1.640
Ms (kg)	951.080	972.320	985.300	995.330	932.200	969.960	966.420	949.900	880.280	805.940	877.330	905.060	967.600
RS (kg)	951.080	680.624	492.650	298.599	-	-	-	-	-	-	350.932	543.036	774.080
CS (kg)	-	291.696	492.650	696.731	932.200	824.466	676.494	522.445	352.112	-	-	-	-
DS (kg)	-	-	-	-	-	145.494	289.926	427.455	528.168	805.940	526.398	362.024	193.520
Sand AD	2.659	2.666	2.689	2.692	2.699	2.687	2.665	2.651	2.631	2.562	2.597	2.602	2.612
M_G (kg)	824.230	824.230	824.230	824.230	824.230	824.230	824.230	824.230	824.230	824.230	824.23	824.23	824.23
G/S	0.87	0.85	0.84	0.83	0.88	0.85	0.85	0.87	0.94	1.02	0.94	0.91	0.85
Aggregate AD	2.681	2.683	2.687	2.697	2.700	2.690	2.679	2.675	2.660	2.618	2.655	2.669	2.675
V_a (m^3)	0.662	0.670	0.673	0.675	0.651	0.667	0.668	0.663	0.641	0.623	0.641	0.648	0.670
V_v (m^3)	0.338	0.330	0.327	0.325	0.349	0.333	0.332	0.332	0.359	0.377	0.359	0.352	0.324
SP = 0.7 %													
Filler (kg)	155.671	144.626	138.922	137.103	173.010	148.525	146.416	154.118	187.497	214.453	187.355	176.898	144.272
Water (kg)	176.965	173.741	172.106	171.670	182.757	178.192	180.417	185.505	197.655	211.341	197.391	190.850	177.441
SP = 1 %													
Filler (kg)	155.029	143.998	138.301	136.485	172.345	147.891	145.785	153.477	186.815	213.736	186.672	176.228	143.644
Water (kg)	175.708	172.512	170.891	170.459	181.458	176.953	179.183	184.252	196.319	209.938	196.056	189.540	176.212
SP = 1.3 %													
Filler (kg)	154.388	143.371	137.681	135.868	171.683	147.260	145.156	152.839	186.134	213.021	185.992	175.561	143.018
Water (kg)	174.455	171.286	169.679	169.252	180.161	175.718	177.953	183.002	194.987	208.539	194.724	188.234	174.987
SP = 1.5 %													
Filler (kg)	153.962	142.955	137.269	135.457	171.242	146.840	144.738	152.414	185.681	212.545	185.539	175.117	142.601
Water(kg)	173.621	170.470	168.873	168.449	179.299	174.896	177.134	182.171	194.101	207.609	193.838	187.366	174.172

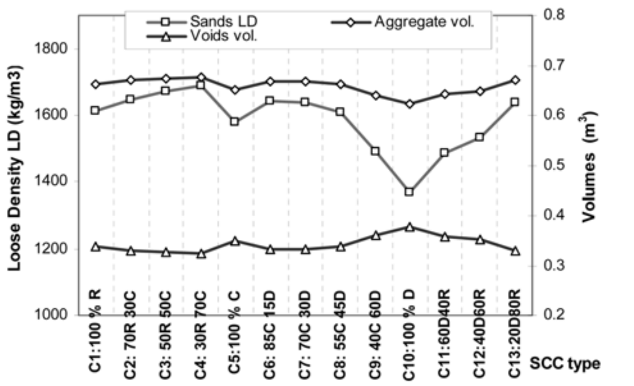

Fig. 6 Looses densities and aggregates volumes and their voids for various sands combinations: R: RS, C: CS, and D: DS.

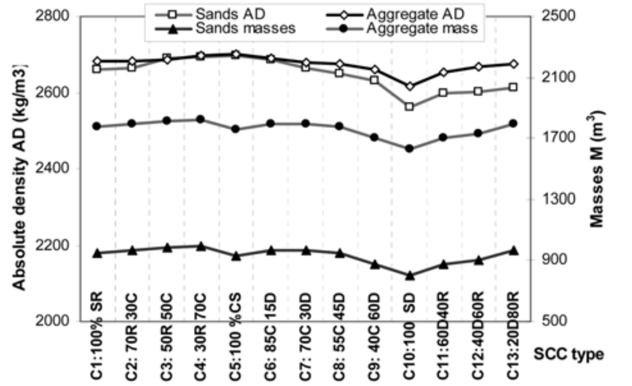

Fig. 7 Absolutes densities and masses of sands and of the aggregates for various sands combinations.

nents analytically. The sand combination having a varied granulometry had a positive effect on the granular arrangement of the SCC. The packing of several sands allowed a compactness increase of the granular mixture and a reduction in the intergranular voids. Consequently, the reduction of this volume led to a moderate content of the added filler and to a lower important water proportioning.

Crushed sand, which naturally encloses important contents of fines (10 to 18%) and whose grains are angular contributes to the improvement of the packing of the granular mixtures in the SCC. The loose density was improved between 4.65 and 20.35% for the combined sands compared with sands alone. In the same way, intergranular voids volume decreased between 1.5 to 7.38% for combined sands. The moderate incorporation of the

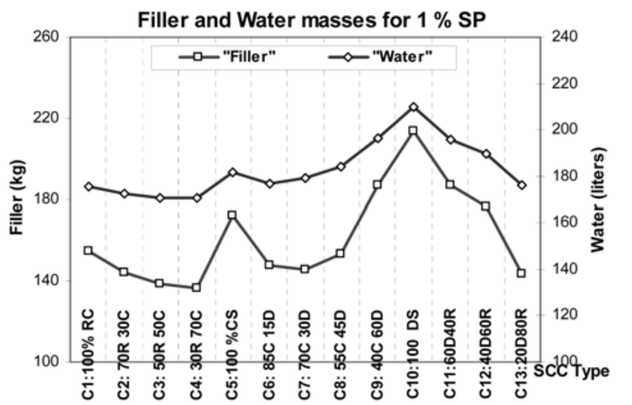

Fig. 8 Filler and water masses for various sands combinations for 1% of SP.

desert sand as a partial substitution of the crushed sand and rolled sand allowed increasing the compactness of the mixture. The optimal compactness increased by 15.5% by combining the crushed sand with the desert sand with respect to the crushed sand.

The second part of this work (part II) will consist in studying the effect of these various combinations of sands on the SCC characteristics of the in the fresh and hardened state.

Acknowledgments

The authors wish to acknowledge the "Tunisian SIKA" for providing the admixture and the fillers.

References

1. Achour, T., Lecomte A., Ben Ouezdou, M., Mensi, R., Joudi I., "Contribution of the Fillers Limestones to the Paste-Aggregate Bond: Tunisian Examples," *Materials and Structures*, Vol. 41, No. 5, 2008, pp. 815~830.

2. Okamura, H., Ozawa, K., and Ouchi, M., "Self-Compacting Concrete," *Structural Concrete*, No. 1, 2000, pp. 3~17.

3. Domone, P. L., "Self-Compacting Concrete: An Analysis of 11 Years of Case Studies," *Cement and Concrete Composites*, Vol. 28, 2006, pp. 197~208.

4. Bederina, M., Khenferb, M. M., Dheillyc, R. M., Queneudec, M., "Reuse of Local Sand: Effect of Limestone Filler Proportion on the Rheological and Mechanical Properties of Different Sand Concretes," *Cement and Concrete Research*, Vol. 35, 2005, pp. 1172~1179.

5. Ayed, K., Benaissa, A., Pons, G., Vidal, T., and Benhouna, M., *Optimisation de la Formulation des Bétons Autoplacants par les Matériaux Locaux*, Cmedimat, Oran Aléerie, 2005.

6. Zhang, G., Song, J., Yangb, J., and Liu, X., "Performance of Mortar and Concrete Made with a Fine Aggregate of Desert Sand," *Building and Environment*, Vol. 41, 2006, pp. 1478~1481.

7. Nan, S. and Buquan, M., "A New Method for the Mix Design of Medium Strength Flowing Concrete with Low Cement Content," *Cement and Concrete Composites*, Vol. 25, 2003, pp. 215~222.

8. De Larrard, F., *Concrete Mixture Proportioning. A Scientific Approach*, In: Mindess S, Bentur A (eds) Modern Concrete Technology, 9, E & FN Spon, 1999, London.

9. Brouwers, H. J. H. and Radix, H. J., "Self-Compacting Concrete: Theoretical and Experimental Study," *Cement and Concrete Research*, Vol. 29, 2007, pp. 1~12.

10. Su, N., Hsu, K.C., and Chai, H. W. "A Simple Mix Design Method for Self-Compacting Concrete," *Cement Concrete Research*, Vol. 31, 2001, pp. 1799~807.

11. Sedran, T. and de Larrard, F. RENE-LCPC, "Un Logiciel Pour Optimiser la Granularite des Matériaux du Génie Civil, Note Technique," *Bulletin de Liaison des Laboratoires des Ponts et Chaussées*, No. 194, 1994, pp. 87~93.

12. Domone, P. and Wen, C. H., "Testing of Binders for High Performance Concrete," *Cement and Concrete Research*, Vol. 27, 1997, pp. 1141~1147.

13. SABLOCRETE, "Béton de Sable, Caractéristiques et Pratiques d'Utilisation," Synthèse du Projet National de Recherche et Développement, Ed. *Presses de l' Ecole Nationale des Ponts et Chaussées*, Paris, France, 1994, (in French).