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Steel fiber's effects on the physical and mechanical characteristics of self-compacting concrete (SCC) made of recycled gravel

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Abstract – In order to adapt the concrete to structures with more complex and highly reinforced sections, research has been carried out in recent years in Japan with the aim of developing concrete formulations characterized by high workability while being stable. (Low segregation, bleeding, and compaction), with good mechanical characteristics and durability. The culmination of this research has given rise to a new type of concrete that can satisfy the properties mentioned above, called self-compacting concrete (SCC). SCC is characterized by its high volume of paste, a large amount of fines, the use of superplasticizers, and a low volume of gravel. For the preservation of the environment and in the vision of sustainable development, due to the increasing demand for the use of aggregates, crushed gravel can be replaced by recycled concrete gravel. To improve the properties of SCCs based on recycled concrete gravel, metal fibers are added. The objective of this work is to study the effect of the introduction of metal fibers in self-compacting concretes based on recycled concrete gravel on the physico-mechanical properties of these SCCs. The results obtained show that 50% recycled concrete gravel is the best, and the 1% fibers improve the physico-mechanical characteristics of these SCCs.

Keywords – Self-Compacting Concrete, Steel Fiber, Physico-Mechanical Properties, Recycled Concrete Gravel, Open Porosity.

I. Introduction

The simplicity of manufacture and use of concrete and of its placement, its low cost, its mechanical performance as well as its durability, have contributed to increasing its use for a wide variety of works. After the search for improved strength and durability of concrete with high workability, a further step was taken with self-consolidating concrete (SCC) in the 1990s in Japan [1-3]. The (SCC) are special very fluid concretes, their specification is to be put in place under the effect of their own weight without input of external or internal vibration.

On the one hand, SCC is characterized by its high volume of paste, a large am ount of fines, the use of superplasticizers and a low volume of chippings, for environmental preservation and in a vision of sustainable development because of Increasing demand for the use of aggregates, crushed gravel can be replaced by recycled concrete gravel. On the other hand, the problem of introducing recycled concrete gravels leads to a modification in the physico-mechanical and self-compacting characteristics of concrete. For this the use of steel fibers to improve these performances [4]. This paper investigates is to study the physico-mechanical properties in the presence of steel fibers in self-compacting concrete made from recycled concrete gravel.

II. Materials and Method

II.1 Materials used

In order to achieve the objectives, we used natural and local materials available on the Algerian market. All the concretes that have been produced are made with the same materials. Table1 gives the materials which were used, Table 2 and 3 summarize the physical and mechanical characteristics of the materials which were used.

Table 1. Local materials used.

Materials used	Nature	Type
Cement (C)	Portland cement	CPA CEM II / 42,5
Sand (S)	Alluvial	(0/5)
Natural gravel (N)	Crushed, Calcareous	(3/8) and (8/16)
Recycled gravel (R_b)	Crushed, Demolition concrete	(3/8) and (8/16)
Fiber (F)	Metallic	Viscochape
Water (W)	Drinking water	Potable water
Superplasticizer	Water reducer	MEDAPLAST SP40

Table 2. Physical-mechanical properties of the aggregates.

Physical property	Sand	gravel			
		Natural		Recycled	
	(0/5)	$(3/8)_N$	$(8/16)_N$	$(3/8)_{Rb}$	$(8/16)_{Rb}$
Apparent volumetric mass (g/cm^3)	1,55	1,37	1,39	1,21	1,25
Absolute density (g/cm^3)	2,58	2,65	2,66	2,51	2,56
Absorption (%)	1,35	2,3	2,30	6,7	6,2
Fineness modulus	2,29	-	-	-	-
Sand equivalent (%)	91	-	-	-	-
Los Angeles coefficient (%)	-	-	21,5	-	23

Table 3. Physical and mechanical characteristics of the fiber.

Characteristics		**Fig.1.** The fiber used
Absolute density (g/cm^3)	502,5 kg/m^3	
Tensile strength	1100 MPa	
Geometry of fibers used	$Ø_f$ = 0,55 mm	
	L_f = 30 mm	
Slenderness ($L_f/Ø_f$)	55	

II.2 FORMULATION OF THE SELF COMPACTING CONCRETE (SCC)

Ordinary concrete is formulated by the Dreux-Gorisse method, but this method is not applicable and is not suitable for self-consolidating concrete (SCC) [5]. most SCC formulas are currently designed empirically. The formulation is therefore based on the experience acquired in recent years. To determine the dosage of superplasticizer and fiber required based on the results of tests on mortar, if necessary the ratios especially W/C and Sp/C will be adjusted in order to achieve the results adequate for a good spread without segregation or bleeding. Formulation of the reference SCCN with 100% crushed limestone gravel (0% recycled gravel), we have complied with the necessary conditions to guarantee self-placing while basing ourselves on compositions proposed in specialized literature. It is a question of choosing the proportions of the constituents in 1m3 of concrete, having as data the following parameters [6]:

Cement (C) + Gravel (GN) + Sand (S) + Water (E) + Air (A) = 1000 liters.

♦ a ratio G/S = 1 ♦ a cement dosage C= 450 kg /m^3
♦ a ratio W/C = 0.42 ♦ a percentage of 2.45 % of superplasticizer.

Once the reference SCC_N is obtained, the formulation of the fiber-reinforced SCC_N, we keep the same reference compositions, that of the control, with the exception of the sand we vary the substitute by (0%, 0.5% 1.5% and 2%) of the volume of fibers, and check the self-compacting concrete we find that with 1% and 1.5% of fiber, the characteristics in the fresh state of the self-compacting concrete are satisfactory, we set the percentage 1% as a reference. For the other SCC, we start by replacing part of the gravel with recycled gravel (50%) and we will proceed with all the tests on fresh concrete. five (05) mixtures were made, the different concrete compositions are summarized in Table 5.

The concretes were made according to the current recommendations of the French Association of Civil Engineering (AFGC) [7].

Table 4. The notations used for the different SCC tested.

Notations	Designations
SCC_N	SCC with 100% limestone crushed gravel
SCC_{Nf}	SCC with fiber, reference SCC with 100% limestone crushed gravel (G_{Cc})
SCC_{fRb100}	SCC with fiber, SCC with 100% recycled demolition concrete gravel (G_{Rb}) + 0% (G_{Cc})
SCC_{fRb75}	SCC with fiber, SCC with 75% recycled demolition concrete gravel (G_{Rb}) + 25% (G_{Cc})
SCC_{fRb50}	SCC with fiber, SCC with 50% recycled demolition concrete gravel (G_{Rb}) + 50% (G_{Cc})

Table 5. Composition of the different SCC in kg for 1m^3.

Composition	**Concrete**				
	SCC_N	**SCC_{Nf}**	**SCC_{fRb50}**	**SCC_{fRb75}**	**SCC_{fRb100}**
Cement	450	450	450	450	450
Sand 0/5	849.41	844.38	844.38	844.38	844.38
Gravel $(8/16)_N$	583.84	583.84	291.92	145.96	-
Gravel $(3/8)_N$	290,81	290,81	145.46	72.70	-
Gravel $(8/16)_{Rb}$	-	-	280.94	421.42	561.89
Gravel $(3/8)_{Rb}$	-	-	173.73	206.59	275.45
steel fiber	-	39.2	39.2	39.2	39.2
Water	191	191	211.9	222.4	232.9
S_p (%)	2,45	2,45	2,45	2,45	2,45
W/C	0,42	0,42	0,42	0,42	0,42

II.3 TEST RESULTS AND DISCUSSION

A. CHARACTERISTICS OF THE (SCC) IN A FRESH STATE

The characteristic tests on freshly-mixed concrete were carried out just after the mixing.

They are those recommended by the French Association of Civil Engineering [7]: spreading out with the slump test, the flow with the box in L and stability with the sieve. The purpose of they are to estimate fluidity, the static and dynamic segregation of the (SCC). Table 6 summarizes the characteristics obtained for the various (SCC) tested in the fresh state.

Table 6. Summary table of the test results in a fresh state of all (SCC).

Test	**Mixture descriptions**				
	SCC_N	**SCC_{Nf}**	**SCC_{fRb50}**	**SCC_{fRb75}**	**SCC_{fRb100}**
Slump test (cm)	74	70	71	72	74
	1,64	1,61	1,5	1,7	1,3
L-Box test (%) "Filling capacity"	88,5	85	89	80,5	86
	3,41	3,25	2,8	5,55	5
	1,4	1,22	1	2,5	2,6
V-funnel flow time (T_V) (s)	7,7	7	6,5	21	24,5
Sieve stability test Π (%) "Stability in the sieve"	8,95	7,9	7,1	8,2	9,5

It is noted that the characteristics in the fresh state of the self-compacting concretes are satisfactory for all concretes except for the V-funnel flow test for the two concretes SCC_{fRb75} and SCC_{fRb100}, because of the quantity of larges fines, and the visual assessment of the spreading wafer for all self-compacting concrete is good.

B. CHARACTERISTICS OF THE (SCC) IN A HARDENED STATE

The formulations of the studied concretes were made out of cubic test-tubes (10×10×10) cm^3. We follow the following steps:

The test-tubes were conserved with the free air under the conditions of laboratory (T=20 ±2°C and

HR= 45±10%), during: (28, 60 and 90 days) .et a cure in water during 28 days for the test of the absorption of water.

B1 TEST OF ABSORPTION OF WATER (INITIAL ABSORPTION BY CAPILLARITY)

The transfer of liquid in a porous material, due to surface stresses in the capillaries, is called the absorption of water. The absorption of water inside the no-slump concrete by capillary increase depends on open porosity and the porous networks of the concrete. This test comes to measure the rate of absorption of water by capillary suctions of the concrete test-tubes with 28, 60 and 90 days, unsaturated afterwards, put in contact with water without water pressure. Before measurements of the sorptivity, the specimens will be packaged in the drying oven with approximately 105 °C until a constant mass. The day of the test, the elaborate concrete test-tubes are weighed with a balance of precision of 0.1 G, to determine their masses before and after the absorption of water during (1 hour) that is to say:

$$A_{bi} = [(M_2-M_1) /S\ (t)\ 0.5] \qquad (1)$$

M_1: mass (test piece) before absorption of water;
M_2: mass after absorption of water (1h);
S: surface of the base of the test piece (10x10) cm^2;
t: time (1 hour).

Quantity of water absorptive at the end of one hour per unit of area east retained like size representative of volume of the largest capillaries present in the zone of skin [8, 9], these capillaries being most effective. The side faces are waterproofed using a plastic film (an adhesive ribbon plastic) which forces water to adopt a uniaxial advance and to avoid evaporation by these same faces. The absorptive water mass is determined by successive weighings of the test-tubes (see Fig.2).

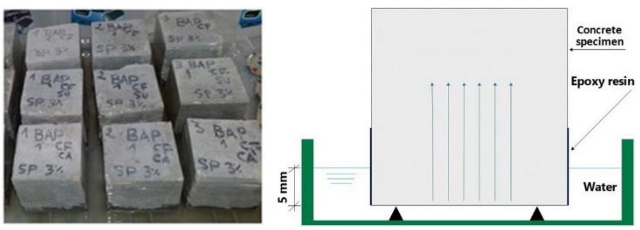

Fig. 2. Test of absorption of water by capillary of all SCC

The absorption coefficients of initial water obtained after a time of one-hour suctions (1h) will be noted A_{bi} (kg.m-2.h-1/2), the totality of the concretes are represented with the rate of gain in Table 7 and are illustrated in Fig.3.

Rate of gain:

$$A_{bi} = \left| \frac{A_{bi_{j\,(without\ cure)}} - A_{bi_{j\,(cure)}}}{A_{bi_{j\,(without\ cure)}}} \right| \qquad (2)$$

Table 7. Coefficients of initial water absorption A_{bi} of concrete at different ages and Rate in A_{bi} (%).

Differents SCC						
Age (days)	**Mode of curing**	**SCC_N**	**SCC_{fN}**	**SCC_{fRb50}**	**SCC_{fRb75}**	**SCC_{fRb100}**
28	Air	2,60	2,45	2,50	2,62	2,75
	Water	1,65	1,55	1,60	1,64	1,80
	Rate in A_{bi}	36,54	36,73	36,00	37,40	34,55
60	Air	2,55	2,41	2,44	2,58	2,65
	Water	1,60	1,53	1,55	1,66	1,79
	Rate in A_{bi}	37,25	36,51	36,48	35,66	32,45
90	Air	2,50	2,39	2,43	2,58	2,61
	Water	1,57	1,50	1,51	1,65	1,68
	Rate in A_{bi}	37,20	37,24	37,86	36,05	35,63

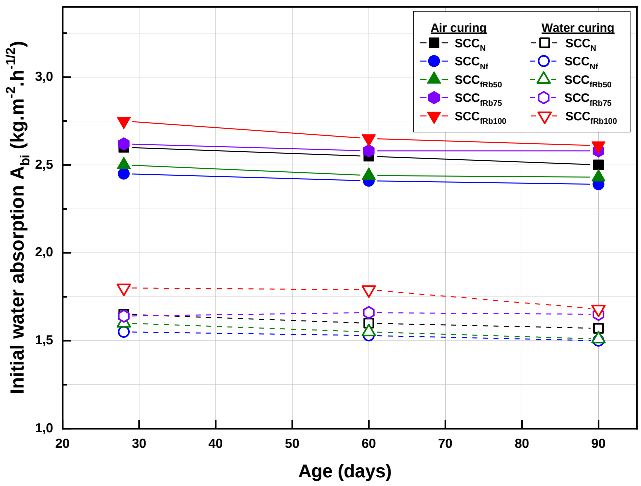

Fig. 3. Absorption of initial water (A_{bi}) of the various concretes with 28,60 and 90 days.

Fig. 3 presents the results of the initial water absorption (A_{bi}) of the concretes prepared, we note that the absorption decreases with age (28, 60 and

90 days) and according to the percentage of gravel additions recycled. The results shown in Fig. 3 show a decrease over time, of (A_{bi}), for all of the self-compacting concretes produced. We notice that the substitution of 50% of crushed gravel by the recycled concrete gravel in the presence of metallic fibers, gives an (A_{bi}) like the control concrete SCC_{Nf}. This means that SCC_{Nf}, SCC_N and SCC_{fRb50} are less porous and the transport properties are improved than other concretes. This can be explained on the one hand by a decrease in the porous network, by the fines of recycled concrete and the presence of metal fibers [10]. On the other hand, the improvement is due to the reduction in cracking by the fibers [11].

B.2 TEST OF UNİAXİAL PRESSİNG

The test of compression is carried out in accordance with standard (NF P 18-406) [12]. It consists in subjecting the concrete test-tube to crushing by axial compression. Loading must be done in a continuous way until rupture of the test-tube (see Fig. 4).

Fig. 4. Test-tubes before and after crushing.

The results of the direct compression crush test at 28, 60 and 90 days of age are shown by their averages in Table 8 and are shown in Fig.5.

Table 8. Compressive strength R_{Cj} of SCC at different ages.

Age (days)	Mode of curing	Differents SCC				
		SCC_N	SCC_{fN}	SCC_{fRb50}	SCC_{fRb75}	SCC_{fRb100}
28	Air	40,50	41,70	40,50	40,00	39,40
	Water	41,60	42,80	42,20	41,50	39,90
	Gain	2,64	2,57	4,03	3,61	1,25
60	Air	42,10	42,20	42,00	42,10	39,90
	Water	43,70	43,75	42,90	42,80	40,50
	Gain	3,66	3,54	2,10	1,64	1,48
90	Air	44,20	44,30	44,00	43,60	40,30
	Water	44,90	45,30	44,90	44,40	41,30
	Gain	1,56	2,21	2,00	1,80	2,42

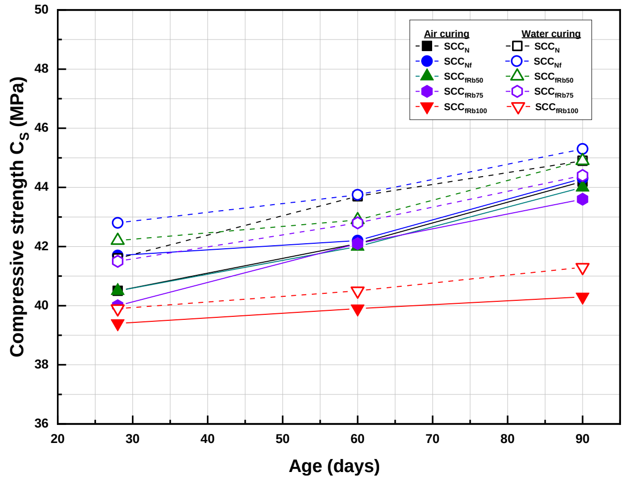

Fig. 5. Evolution of the compressive strength Rc of the concretes according to the age.

The results shown in Fig. 5 show, on the one hand, a clear change and increase in the compressive strength of different concretes produced as a function of age. We were able to conclude that SCC_{fN}, SCC_N and SCC_{fRb50} have better compressive strength compared to other concretes: SCC_{fRb75} and SCC_{fRb100}. These results can be explained by the nature of the gravel and their percentages and the presence of metallic fiber used and their consequences on the increase in the compactness of the solid skeleton.

B.3 TEST OF TENSILE STRENGTH (BY THREE-POINT BENDING)

The tensile strength test involves subjecting prismatic specimens (7 × 7 × 28) cm^3 resting on two supports to an increasing load concentrated in the middle until failure. The load is applied using a digital reading press connected to an acquisition system (PC) through which the loading speed (50 N/s) is entered. The breaking force is given by the same system. The tensile strength is obtained by doing a simple calculation of the strength of the materials.

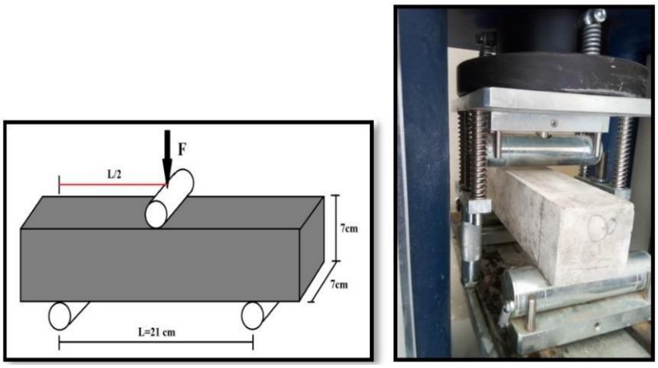

Fig. 6. Static diagram and device of the tensile test by bending.

The results of the three-point flexural tensile test at the age of 28, 60 and 90 days, are shown by their means in Table 9 and are shown in Fig. 7.

Table 9. Bending tensile strength R_{tj} of SCC.

		SCC				
Age (days)	**Mode**	**SCC_N**	**SCC_{Nf}**	**SCC_{fRb50}**	**SCC_{fRb75}**	**SCC_{fRb100}**
28	Air	5,60	7,37	7,12	7,05	6,89
	Water	5,85	7,82	7,66	7,60	7,23
	Gain	4,27	5,75	7,05	7,24	4,70
60	Air	5,68	7,48	7,23	7,12	6,97
	Water	5,91	7,99	7,79	7,77	7,35
	Gain	3,89	6,38	7,19	8,37	5,17
90	Air	5,71	7,62	7,29	7,22	7,01
	Water	5,96	8,01	7,89	7,84	7,44
	Gain	4,19	4,87	7,60	7,91	5,78

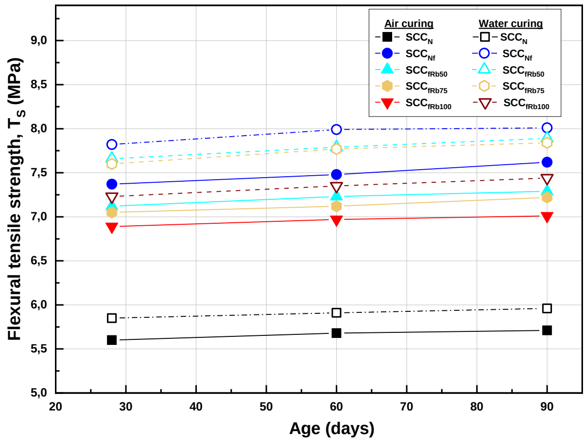

Fig. 7. The bending tensile strength R_{tj}.

The results shown in Fig. 7 show, on the one hand, a marked increase in the tensile strength of different concretes produced as a function of age. On the other hand, all the mixtures studied underwent an improvement in the presence of water treatment.

SCC_{fN} and SCC_{fRb50} marked resistance above the resistance of SCC_N, SCC_{fRb75} and SCC_{fRb100}. So the metallic fiber attributed to the improved bending strength of the SCC in the presence of recycled and natural gravel.

III. CONCLUSION

The article presents the results for SCC with natural gravel and recycled concrete gravel in the presence of metallic fiber. The main important findings are as follows:

- The studied Self compacting concrete have characteristics in conformity with the requirements of the French Association of Civil engineering (AFGC).
- The metal fiber chosen for the development of our study can have beneficial effects on the SCC in particular by improving the tensile and compressive strength..
- The compressive strength Rc and flexural tensile strength Rt of all self-compacting concrete tested increases with age and does not show any drop. This resistance is greater for SCCNf, SCCN and SCCfRb50 than for SCCfRb75 and SCCfRb100.
- The addition of fiber resulted in a change in the behavior of the SCC, the SCC reinforced with the metal fiber underwent an improvement in compressive and flexural strength.
- The substitution of crushed gravel by 50% recycled concrete gravel is the best compared to other concretes and has given us good results on the physico-mechanical properties.

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