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Effect of the Incorporation of Recycled Rubber Aggregates on the Behavior of Self-Compacting Concrete

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ABSTRACT

The use of self-compacting concrete (SCC) has developed considerably in recent years, and much attention is paid to the study of their mechanical and rheological properties. The environment is a very important issue, and its preservation is a common responsibility, the wastes thrown by human beings compose a great danger on the environment, so it is necessary to encourage their elimination by recycling operation and their use as aggregates in the manufacture of self-compacting concrete. The study is based on the idea that the incorporation of rubber aggregates improves some behaviors of the SCC and enhances the use of waste, so the incorporation of aggregates in the composition of self-compacting concrete (SCC) has an interest that deserves to be studied. The objective of this work is to valorize the use of waste, especially used tires as rubber aggregates and also consists in studying the influence of the incorporation of these aggregates on the mechanical behavior of the self-compacting concrete. The dosages used in aggregates are of the order of 1 and 2% by weight of the concrete. This study will examine the role and influence of the rubber aggregate content on the characteristics of the SCC. The incorporation of these aggregates in the SCC is beneficial for the improvement of the ductility of the concrete material known for its brittleness in traction. The results of this work suggest that the pneumatic aggregates can be compared to other aggregates used as reinforcement in self-compacting concrete. They are completely suitable for use as reinforcement in self-compacting concrete.

1. INTRODUCTION

The consideration of sustainable development in construction requires either the creation of new materials or the optimization of existing ones. The use of self-compacting concrete (SCC) has practically exploded in the last few years and a lot of attention is being paid to the study of their mechanical and rheological properties.

Self-compacting concrete is a special type of concrete, very fluid, which is placed and tightened under the sole effect of gravity, without any internal or external vibration, even in the most reinforced formwork. This concrete is obviously qualified as self-compacting only if the final material has homogeneous properties, i.e. if it has not undergone segregation [1].

The incorporation of rubber aggregates in the composition of self-compacting concrete (SCC) has an interest that deserves to be studied [2], since used tires present problems of environmental pollution and storage. More than 275 million used tires are stored in landfills across the United States [3, 4].

In Algeria, the number of used tires is estimated at about 1.5 million per year [5]. The disposal of this type of waste currently poses a serious problem for countries around the world due to its direct effect on the environment and human health [3, 6]. Recycling this waste in the construction industry is an appropriate solution for the production of eco-concrete and can contribute to improving some of its properties.

For this purpose; previous research has reported that the incorporation of rubber aggregates decreases the rheological properties and leads to much more viscous SCC mixtures due to the rough surface of these aggregates. In addition, the incorporation of rubber aggregates is very detrimental to the compression resistance. As far as the thermal conductivity decreases when the rate of incorporation in G.C. increases. Moreover, self-compacting concrete satisfying the requirements of the standard can be produced by using a rubber replacement rate (0-2 mm) with sand of up to 15% [7].

The recovery of natural materials and the recycling of waste are an effective way to deal with the economic and ecological constraints of recent years [8, 9].

Jiang and Zhang [10] investigated the influence of rubber aggregates on mechanical properties of rubberized self-compacting concrete SCC. The results show that SCC with the largest rubber volume ratio of 80% coarse aggregate has the compressive strength, elastic modulus and splitting strength of 14.3%, 25.5% and 16.9% of reference self-compacting concrete (SCC) respectively. Increase in SCC's toughness and gradient of post-peak slope is observed from compressive stress-strain curves, indicating higher ductility of SCC.

Wanasinghe et al. [11] studied the effect of age and crumb rubber aggregate ratio on fresh and mechanical performance. Eight different SCC mixtures using 2-5 mm rubber aggregates to replace 10%, 20%, 30%, and 40% natural aggregates by volume respectively, and 5-10 mm rubber aggregates to replace 10%, 20%, 30%, and 40% natural aggregates by volume respectively, are tested after 7, 28, 56, and 91 days for their mechanical properties. Results show that both the compressive and the tensile strength increase with the aging time, both of these properties drop with the amount and size of the crumb rubber content. Similarly to compressive and tensile properties, flexural toughness and the modulus of rupture showed an increase with the aging time. Small addition of crumb rubber has shown improvements in both rupture and fracture toughness properties, which diminishes when the crumb rubber content becomes significantly large.

Saleh et al. [12] worked on a new self-compacting sand concrete incorporated with rubber aggregates in three different shapes and sizes. It has been observed that the presence of rubber aggregates reduces the penetration of ions from acid solutions into the concrete matrix. All the characteristics studied were supplemented by the microscopic analysis of the adhesion of the different rubber aggregates in the cementitious matrix. The analyzes showed clear differences in the homogeneity of the rubber particles in the concrete material.

Nowadays, with regard to the automotive industry, the use of tires is increasing every year. We can cite some cases: Algeria in 2004 imports an average of 49.62 thousand tons of rubber tires, after use we find ourselves with about 45.65 thousand tons of used tires each year. France, in 2008, more than 366 thousand tons of tires were collected which is a 36% increase compared to 2004. These figures continue to increase each year with the number of vehicles in all countries [13].

The recovery of used tires is a very important issue for the entire planet. The recovery methods chosen are widely diversified: retreading (Reusable Used Tyres - URT), shredding in the form of granulates, energy recovery, particularly as fuel in cement works, and use in public works (Non Reusable Used Tyres - NRT) [14].

Tires are a mixture of rubber, steel and various textiles. Used tires are not hazardous waste, but they present a danger to the environment and health in the event of a fire on the storage site (emissions of toxic slime and possibly an oily liquid).

In some countries, it is forbidden by law to burn pneumatic waste because the pollution and smoke produced by this method is unacceptable, despite the fact that it is the cheapest and simplest solution to decompose the waste [1, 15, 16].

The incorporation of these wastes in concrete reduces the cost of the final product and also creates additional sources for the purpose of natural resource protection [13].

Although there is enough knowledge about SCC to allow their use, some aspects still need to be improved.

Indeed, their specific composition requires the implementation of a sustained control of their formulation, as well as a control of their properties in the fresh state, before implementation. The control of these materials is not yet acquired, as shown by the diversity of studies conducted in this field. The tests, developed to characterize the SCC in the fresh state, concern two essential and indissociable properties: fluidity and homogeneity. Appearing as contradictory, they are both necessary to obtain a final construction of an undeniable aesthetic quality, but also in accordance with the technical requirements recommended [17].

In addition, and in order to improve the mechanical performances in compression and traction of a self-compacting concrete, the incorporation of aggregates is often a solution, which gives convincing results. This concrete can be used easily in practice, in particular in the realization of pavements, concrete pavements for roads and landing strips of airfields, in prefabricated elements, and in the reinforcement of degraded works.

However, problems of elaboration still remain and require appropriate studies. The use of such concrete requires rigorous research of the influence of parameters such as, the type of aggregates, their percentage, length etc. [18].

The recycling of rubber tire waste with cement-based materials could be reduced their accumulation in landfills and protects the natural and environment facing their harmful effects [19].

The main objective of this study is to obtain a self-compacting concrete with higher compressive and tensile strength. The way most evoked in the literature to mitigate the weakness of behavior in tension consists in the addition of aggregates in the formulation of concrete. These aggregates play a reinforcing role to compensate the brittleness of the concrete by sewing microcracking and macrocracking. Aggregates also have the ability to control crack opening, acting as energy absorbers. Although, this improvement is a function of the geometry and percentage of aggregates as well as their characteristics.

The self-compacting concrete that was the subject of this study is a self-compacting concrete with the substitution of 1 and 2% of the sand of rubber aggregates from used tires and a substitution of 1 and 2% of the gravel, these aggregates are used to improve the performance of self-compacting concrete.

2. EXPERIMENTAL DETAILS

2.1 Characteristics of the materials used

2.1.1 Sand

We used a quarry sand from El Fateh (El Fedjoudje-GUELMA)

The characteristics of the sand used are illustrated in the following Table 1.

It can be seen that the sand is a very clean sand: the total absence of fine clay may lead to a plasticity defect in the concrete which will have to be corrected by increasing the water content.

Table 1. Characteristics of sand

Sand	**Equivalent**	**Absorption coefficient**	**Volumic**	**mass**
Visual sand equivalent (%)	Sand equivalent with the piston (%)	(%)	Apparent (g/cm^3)	Absolute (g/cm^3)
85.21	85.29	2,05	2.63	2.78

2.1.2 Gravel

We used the fraction 3/8 and 8/15 of the gravel of the crushing quarry El Fateh (El Fedjoudje-GUELMA).

The gravel used in this study was subjected to the following mechanical laboratory tests.

- Impact resistance test (Los Angeles test)

The test consists of measuring the resistance to fragmentation by impact of elements of a sample of gravel [NF18-573, 90].

- Wear resistance test.

The test consists of measuring [NF P18-572, 90] the quantity of elements smaller than 1.6mm, by subjecting the material to the wear of standardized balls in the Micro-Deval machine.

The results obtained are presented in Table 2.

Table 2. Mechanical characteristics of gravel

Characteristics	3/8	8/15
Coefficient of Los Angeles %.	19.6	19.8
Micro-Deval Coefficient %.	15.3	15.6
Apparent Density	2.72	2.73
Absolute Density	2.75	2.77
Absorption coefficient (%)	0.48	0.46
Flattening coefficient F (%)	10.36	10.36

Comments:

(a)- According to the procedure for the Los Angeles coefficient, the threshold is set at 40%. For the gravel used Coefficient of Los Angeles < 40, it can be concluded that it can be used for hydraulic concrete.

(b)- According to the NF P18-572 standard, the threshold is set at 35%. If Micro-Deval Coefficient < 35%: which is the case for our gravel. The result is that the gravel is acceptable for concrete.

(c)- The result shown on the table indicates that F = 10.36% ≤30%. Therefore, the gravel used is suitable for making quality concrete.

2.1.3 Admixture

- The admixture used is a high water-reducing superplasticizer called "SIKA VISCO CRETE TEMPO 12", in compliance with the NF EN934-2 standard, manufactured by SIKA.

- The VISCO CRETE TEMPO 12 are among the super plasticizers with high water reducers. They have been developed to optimize the production of ready-mixed concrete where quality, durability, performance, workability, low viscosity and strength are required. They differ from traditional superplasticizers by their ease of use, especially for fluid and self-compacting concrete, even with very low dosages. These low viscosities combined with a high strength of concrete allow SIKA VISCO CRETE TEMPO 12 to considerably improve the dynamic behavior and thus the implementation of concrete, while optimizing the dosage of binder in concrete. The Chemical analysis of the admixture is illustrated in the following Table 3.

Table 3. Chemical analysis of the admixture

Parameter	Result	Unit	Observation
Density	1.06±0.01	l/m^3	
PH	4.5±1	--	
Dry extract	29±1.5	%	/
Sodium oxide equivalent	≤1	%	
Chloride ion content	≤0.1	%	

2.1.4 Calcareous fillers

The limestone fillers coming from the quarry of Ben Azzouz (Figure 1) present a sieve pass of 0.08mm of about 75%, the properties of these fines are presented in Table 4:

Figure 1. Calcareous fillers used

The chemical analysis of this powder is given in the following Table 4:

Table 4. Chemical analysis of limestone fillers

Designations	CaO	Al_2O_3	MgO	Cl^-	SO_2	Fe_20_3	K_2O	SiO_2	Na_2O
Results in %	55.60	1.09	0.77	0.00	20-30	2.31	0.04	0.60	0.05

It can be seen that the dominant element in limestone is calcium oxide CaO. The physical characteristics of limestone fillers are given in the following Table 5:

Table 5. Physical characteristics of limestone fillers

Characteristics	Results
Apparent density (g/cm^3)	1.051
Absolute density (g/cm^3)	2.730
Water absorption in %	0.39

It can be seen that the limestone fillers have a lower density than the cement.

2.1.5 Mixing water

The mixing water used comes from the tap and its temperature is 28°C. The chemical analysis is represented in Table 6, the results show that it fulfills all the requirements of the NF P18-404 standards.

Table 6. Chemical analysis of the mixing water

Parameter	Result	Unit	Observation
T°	28	°C	Water of good chemical quality
PH	7.5	--	
Cl	0.1	Mg/l	
TDS	297	Mg/l	
Conductivity	541	Us/cm	
Salinity	0.2	--	

The water sample taken from the laboratory tank is in conformity with NF EN 1008 of 07/2003 for the mixing of concrete.

2.1.6 Cement

The cement used is a CPJ- CEMII/A 42.5 class cement, coming from the Hadjar Soud cement factory (Wilaya of Skikda, Algeria), meeting the Algerian norms NA 442/2000. The physical, mechanical and chemical characteristics of the cement are shown in Tables 7, 8 and 9 respectively:

Table 7. Physical characteristics of cement

Characteristics	Cement CPJ-CEM II-A 42.5
Absolute density	3.1
Apparent density	1.12
Specific surface	3702

It is a grey cement for high performance concrete intended for the construction of engineering structures (bridges, viaducts, tunnels ....).

Table 8. Results of mechanical tests on cement

Designation	2 days	7 days	28 days
Flexural tensile strength in MPa	3.20	4.45	7.01
Compressive strength in MPa	14.1	33.48	48.6
Tensile load (KN)	4.4	1.3	2.7
Compressive load (KN)	53.45	45.1	52.25

2.1.7 Rubber aggregates

The rubber aggregates come from a shredding plant of rubber tires located in the Wilaya of SETIF in Algeria (Figure 2). They have a particle size of 0 to 4 mm and a density of 940 kg/m^3. The characteristics of rubber aggregates are given in the Table 10.

Table 9. Chemical characteristics of cement

Designation	CaO	Al_2O_3	Fe_2O_3	SiO_2	MgO	Na_2O	K_2O	Cl^-	SO_3	CaO Free	PAF	RI
Results in %	64.02	5.12	3.30	22.05	1.25	0.12	0.52	0.005	1.84	1.40	1.40	2.56

Table 10. Characteristics of rubber aggregates

Density	940 Kg/m^3
Granulometry	0-4 mm

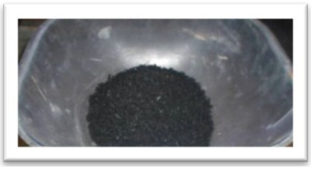

Figure 2. Rubber aggregates (0-4mm)

2.2 Test procedures for self-compacting concrete

2.2.1 Dimensions of specimens

The moulds used are made of steel. The different dimensions of the specimens are:

Cubic: 15×15×15 cm^3 for the compression test.

Cubic: 15×15×15 cm^3 for the split tensile test.

Prismatic: 7×7×28 cm^3 for the bending tensile test (Figure 3).

Figure 3. Test tubes tested

2.2.2 Compositions

The behaviour of the concretes developed in the hardened state was evaluated and compared to that of a control concrete initially composed of 100% quarry sand. The varieties of self-placing concretes developed within the framework of this study are represented in Table 11:

Table 11. Nomenclature of self-compacting concretes

SCC 0	Control self-compacting concrete without rubber aggregates.
SCC 1	Self-compacting concrete with 1% rubber aggregates of the sand quantity.
SCC 2	Self-compacting concrete with 1% rubber aggregates of the quantity of gravel.
SCC 3	Self-compacting concrete with 2% of rubber aggregates of the quantity of sand.
SCC 4	Self-compacting concrete with 2% rubber aggregate of the quantity of gravel.

2.2.3 Formulation method

The formulation approach that was used is empirical, based on an experimental methodology relying only on criteria recommended by the AFGC (French Association of Civil Engineering) [20].

These criteria are summarized in the following Table 12:

Table 12. Criteria used according to the French association of civil engineering

Characteristics	Values
G/S ratio	1
W/L ratio	0.38
W/C ratio	0.43

The masses of the constituents of the manufactured SCC are shown in Table 13.

Table 13. Compositions of SCC (Kg/m^3)

N°	Notation	C (Kg)	W (Kg)	rubber aggregate (Kg)	S 0/4 (Kg)	G 3 /8 (Kg)	G /15 (Kg)	Ad (l)	Fillers (Kg)
1	**SCC 0**	400	175	--	857	415	451	7	120
2	**SCC 1**	400	175	3.087	853.91	415	451	7	120
3	**SCC 2**	400	175	1.494	857	413.50	451	7	120
4	**SCC 3**	400	175	6.174	850.62	415	451	7	120
5	**SCC 4**	400	175	2.988	857	412.01	451	7	120

2.2.4 Tests carried out on concrete

The tests performed on hardened concrete are:

Compressive strength at 7, 14 and 28 days.

Flexural tensile strength at 7, 14 and 28 days.

Tensile strength by splitting at 7, 14 and 28 days.

(1) Compression test by crushing

The compression test consists of breaking the test body between the two plates of a 2000 KN compression press in accordance with standard NF P18-406 (Figure 4).

After a good centering of the specimen, the loading is launched, at the moment of the failure, the machine stops, we obtain the compressive stress which corresponds to the breaking load.

Figure 4. Compression test by crushing used

(2) The traction by flexion

The bending test is carried out on prismatic specimens (7×7×28) cm^3, according to the NF P. 18-407 standards. It consists in determining the resistance to bending (3 points) of the specimen subjected to a centered force exerted using a hydraulic press (Figure 5).

Figure 5. Flexural tensile test

(3) Split tensile test

The tensile test by splitting is performed on cubic specimens (15×15×15) cm^3 according to the NF P. 18-407 standards. It consists in determining the tensile strength by splitting the specimen subjected to a centered force exerted with the help of a hydraulic press (Figure 6).

Figure 6. Tensile test by splitting

3. RESULTS AND INTERPRETATION

3.1 Influence of the rubber aggregate content on the strength

3.1.1 Evolution of the compressive strength

According to the results obtained, it is worth noting that an increase in the resistance according to the age and the rate of rubber aggregates in the sand for all the compositions. This increase is of the order of 10% for SCC 1 and 16% for SCC 3. This is explained by the fact that the high content of rubber aggregates influences the good formation of the cementitious matrix. Figure 7 shows the mode of failure of specimens by the press.

Figure 7. Mode of failure of specimens by the press

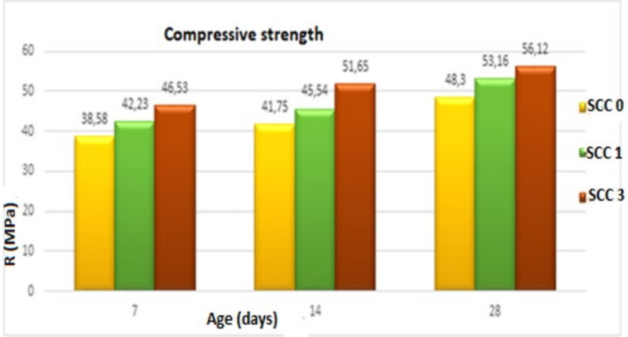

Figure 8. Evolution of the compressive strength as a function of the rubber aggregate content in the sand (0%, 1%, 2%)

The use of water-reducing admixtures, whose beneficial effect on mechanical strength is known, and the presence of a large quantity of filler and rubber aggregates, whose action has a positive effect on compactness and consequently on mechanical strength, thus improving strength (Figure 8).

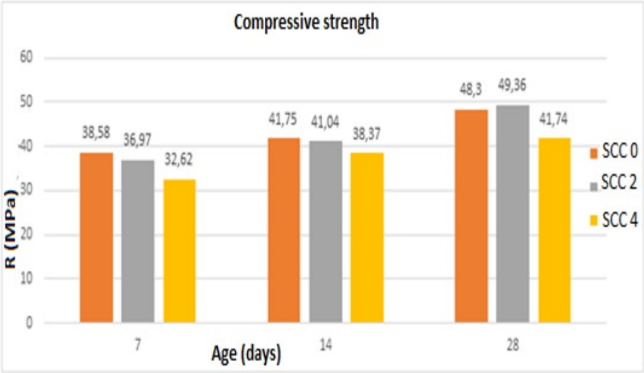

Figure 9. Evolution of the compressive strength as a function of the rubber aggregate content in the gravel (0%, 1%, 2%)

On the other hand, it can be seen that the compressive strength values for each SCC containing rubber aggregates in the gravel are a decreasing function of the age of the concrete and the proportion of rubber aggregates in the gravel. Therefore, the incorporation of rubber aggregates in the gravel does not bring any improvement in the compressive strength (Figure 9).

3.1.2 Evolution of the tensile bending strength of SCC

Figure 11 shows that the rate of rubber aggregate influences the flexural tensile strength.

An improvement in flexural tensile strength is observed for a rubber aggregate content of 2% in which the gain is 4% for SCC 1 and 8.5% for SCC 3. It can be concluded that the best results obtained in compression and traction by flexion are those obtained with a rubber aggregate dosage of 2% which can be considered as optimal dosage. Figure 10 shows the mode of flexural failure of specimens.

Figure 10. Mode of flexural tensile failure of specimens

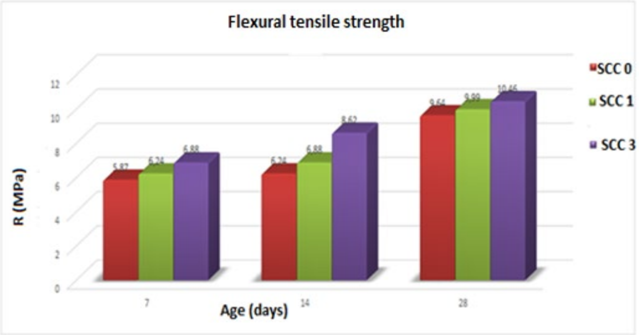

Figure 11. Evolution of flexural tensile strength as a function of the rubber aggregate content in the sand

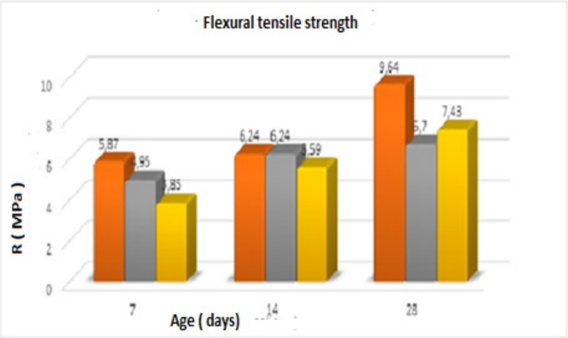

Figure 12. Evolution of flexural tensile strength as a function of rubber aggregate content in gravel

Figure 12 shows the evolution of the flexural tensile strength as a function of the percentage of rubber aggregate in the gravel of a control SCC and two others with a percentage of 1% and 2% of rubber aggregate in the self-compacting concrete mix design.

According to the results in the table and figure above, a decrease in tensile strength of about 30% is found in the mix design with 1% rubber aggregate, and 23% in the mix design with 2% rubber aggregate.

The introduction and increase in the dosage of rubber aggregates in the gravel leads to a decrease in mechanical strengths with high percentages. This decrease is due to the effect of the filling which improves the compactness and to the surface effect which leads to a better cohesion of the paste to the aggregates.

3.1.3 Evolution of the tensile strength by splitting

Figure 13 shows the Mode of tensile splitting failure of specimens. The evolution of the splitting tensile strength is similar to that of the compressive strength. This is evident from the fact that there is a proportionality between these two characteristics. The increase in this tensile strength is less pronounced than that of compression.

It is noticed that the values of the tensile strength by splitting are small compared to the values of the tensile strength by bending, which is known for concretes and it is also noticed that the variation of these values for each SCC is an increasing function with the age of the concrete and the rate of rubber aggregates in the sand (Figure 14).

Figure 15 shows that the proportion of rubber aggregate incorporated in the gravel influences the splitting tensile strength inversely. Two distinct phenomena can be observed: an improvement in the tensile strength by splitting as a function of the age of the concrete for all compositions and a drop in strength whose decrease is of the order of 4.5% for a rate of 2% of rubber aggregates, which indicates that beyond the optimum dosage of rubber aggregates, it is clear that the rubber aggregates do not bring a gain in the tensile strength by splitting to the concrete when they are introduced in the quantity of gravel.

Figure 13. Mode of tensile splitting failure of specimens

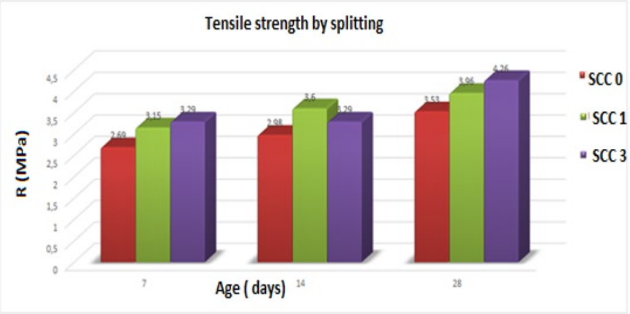

Figure 14. Evolution of the splitting tensile strength as a function of the rubber aggregate content in the sand (0%, 1%, 2%)

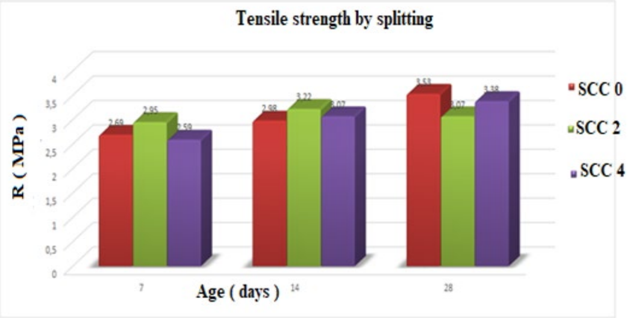

Figure 15. Evolution of splitting tensile strength as a function of the rubber aggregate content in the gravel

4. CONCLUSIONS

This work consists of studying the influence of the incorporation of rubber aggregates on the mechanical behaviour of self-compacting concrete by using recycled aggregates from the shredding of used tires with two percentages (1 and 2%) in order to see the influence of the addition of these aggregates on the characteristics of the concrete tested in the hardened state and to make a comparison with a self-compacting control concrete without rubber aggregates.

From the results obtained, the following conclusions can be drawn:

- The use of rubber aggregates in the formulation of SCC improves its stability against segregation.
- The SCC incorporating rubber aggregates of 2% in the sand represent higher values of resistance than the SCC incorporating rubber aggregates of 1% and reference.
- The substitution of 2% of the sand with rubber aggregates from the shredding of used tires increases the compressive and tensile strength of the SCC tested.
- The test results show that the incorporation of rubber aggregates in the sand is very beneficial in terms of compressive strength. This mechanical resistance increases with the increase of the dosage of rubber aggregates. This increase in resistance can be explained by extremely high compactness and an adhesion with the cement matrix.
- The low stiffness of the rubber aggregates has consequences on the mechanical resistance in compression and traction of the SCC which decrease with the increase of the substitution rate of a high percentage of the gravel by these rubber aggregates.
- For the influence of the percentage of rubber aggregates and according to the results obtained, it is observed that the increase of the dosage of rubber aggregates in the concrete has a positive influence on the characteristics of the concretes tested. Therefore, the tests on concrete with rubber aggregates showed that the use of 2% of rubber aggregates introduced in the sand, gives good results both in compression and in traction.
- The low tensile strength of the concrete can be compensated by the addition of these rubber aggregates. The rubber aggregates are introduced into the sand to compensate for the brittleness of the material in tension by sewing the macro-cracking.
- Rubber aggregates do not increase the strength of the concrete when they are added to the gravel.
- The best resistances are those obtained by the press test, which is the most suitable for the evaluation of the compressive strength of self-compacting concrete with rubber aggregates introduced in the sand.

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NOMENCLATURE

SCC	Self-compacting concretes
CaO	Calcium oxide (quicklime)
AlO_3	Aluminate
MgO	Magnesium oxide
Cl^-	Chloride
SO_2	Sulfur dioxide
Fe_2O_3	Ferric Oxide
K_2O	Potassium oxide
SiO_2	Silicon dioxide
Na_2O	Sodium oxide
T°	Temperature
CI	Chloride Ion content
CPJ	Composite portland cement
TDS	Total dissolved solids, Mg/l
NA	Algerian norms
NF	French norms
AFGC	French Association of Civil Engineering