OPTIMIZATION AND MECHANICAL CHARACTERIZATION OF SELF-COMPACTING CONCRETE INCORPORATING RUBBER AGGREGATES

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ABSTRACT

Concrete material suffers from a relatively low tensile strength and limited deformation capacity. Such defects of the concrete are very fragile and sensitive to shrinkage cracking materials. The Self-Compacting Concrete (SCC) are highly fluid concretes whose implementation without vibration. This material replaces traditional vibrated concrete mainly seen techno-economic interest it presents. The SCC has several advantages which are at the origin of their development crunching. The research is therefore to conduct a comparison in terms of rheological and mechanical performance between different formulations to find the optimal dosage for rubber granulates. Through this research, we demonstrated that it is possible to make different settings SCC composition having good rheological and mechanical properties. This study also showed that the substitution of natural aggregates (NA) by rubber aggregates (RA) in the composition of the SCC, contributes to a slight variation of workability in the fresh state parameters still remaining in the field of SCC required by the AFGC recommendations. The experimental results show that the compressive strengths of SCC decreased slightly by substituting NA by RA. Finally, the decrease in free shrinkage is proportional to the percentage of RA incorporated into the composition of concrete. This reduction is mainly due to the improvement of the deformability of these materials.

Keywords: Self-compacting concrete; rubber aggregate; rheological characterization; mechanical performance; shrinkage.

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1. INTRODUCTION

Construction materials have experienced growth in recent decades, and the demand has skyrocketed in line with the country development, however, the supply does not satisfy this high demand. The imbalance, which seems to persist into the next few years, can only be overcome by ensuring a exploitation of local materials available in our country. The valorization of used or raw local materials has now become a necessary solution to the economic problems of developing countries. Each year items like tires reach the end of their usable life, more than two million tires end up in landfills [1]. These waste resulted from economic development including industrial and transportation areas, can be recycled to another form without any environmental damage. Using scrap tires is necessary from an environmental preservation perspective and the effectiveness utilization of local resources, this ecological recovery of tires can result less pollution than landfills disposal.

The new composite material that can reach the intended goal is a concrete where it incorporates aggregates deformable enough and more specifically of rubber aggregates from used tires not reusable [2].

On this subject, several works concerning the use of rubber aggregates was completed. Many authors studied the influence of the incorporation of rubber aggregates in the mortars, the concretes and even the self-compacting concrete. If some of them have approached the properties in the fresh state of these new composites, the greater part of the research focuses on the influence of these aggregates on the mechanical properties. In most cases the research work focused on the influence of the dosage and the size of the aggregates of rubber [3-10]. Thus, according to Topçu and Bilir [11], one observes a loss in resistance compression of 50% or 60% when one respectively substitutes 45% of sand or the gravel by RA of equivalent granulometry. Eldin and Senouci [7] measured a loss of 85% when the whole of the gravels is replaced by an equivalent volume of RA and a loss of 65% when the totality of sand is substituted by finer RA. Shafieyzadeh [12] observed adding 15 % of styrene-butadiene rubber SBR the compressive strength of concrete decreases about 14 %. [13] There was no definitive correlation between the compressive strength and the crumb rubber particles size, although the rubberized concrete had an average strength loss of 5.24% after 28 days. Segre and Joekes [14] who studied the adhesion between rubber particles and the cement paste reported that the loss in mechanical properties of rubberized concrete was due to the low adhesion between rubber particles and cement paste. [15] shows that the compressive and flexural strengths decreased with the increase in rubber content, and the decrease in flexural strength was significantly lower than the decrease in compressive strength. [16, 17] also show that The increased replacement RA a negative impact on mechanical properties. Balaha et al.[18] observed reductions in the compressive strength and tensile strength of concrete containing crumb rubber.

The present research work is therefore to conduct a comparison in terms of rheological performance (density in a fresh state, slump-flow, L-box test, and sieve stability) and mechanics (resistance in compression, flexural Strength and free shrinkage) between the different formulations of self-compacting concrete SCC is to find the optimal dosage in rubber aggregate RA.

For this, we have substituted the quantity of the natural sand (NS.0/3) introducing to the
formulation of the SCC by a quantity of rubber aggregates (RA.0/3) which varies from 0% to 5%, and the quantity of naturel coarse aggregates (NA 3/8) by a quantity of (RA 3/8) which varies from 0% to 20%.

2. CHARACTERIZATION OF BASIC MATERIALS

2.1 Cement
Cement chosen in this study is of the type made up Portland CPJ CEM II/A 42, 5. It is in conformity with the Algerian standard NA 442. Specific surface Blaine is equal to 3600 cm²/g.

2.2 Addition
The crushed sand of Taghit, which is in the commune of Taghit (Bechar), was used as addition for the various formulations of the SCC. The percentage of fines (lower than 80 µm) accounts for 10% of the mass of cement. Table 1 presents the chemical analyses of the raw material.

2.3 Aggregates
The aggregates play an important role in the behavior of concrete. Their influence is very strong in terms of mechanical performance [19]. Natural sand of 3 mm maximum size was used as fine aggregates and two size gravel ranges (NA.3/8) and (NA.8/15) of Career Zarouati of the region of Bechar.

The consumption of sand has been increasing fast along with the boom of engineering construction in the past few years [20].

The rubber aggregates (RA) resulting from the crushing of worn tires were used by replacing sand. The rubber particles were provided from Techno-flex factory in Algiers Fig. 3 shows the grading analysis of mineral aggregates and rubber particles used in this study.

| Table 1: Chemical analysis of the crushed sand of Tafraoui [21] |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Elements        | SiO₂           | Al₂O₃          | Fe₂O₃          | CaO            | MgO            | SO₃            | Na₂O           | TiO₂           | Others         | Loss of ignition (%) |
| %               | 97,15          | 0,79           | 0,21           | 0,11           | 0,05           | 0,14           | 0,18           | 0,05           | <0,02          | 0,58           |

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2.4 Super-plasticizer

The incorporation of superplasticizer (SP) increases the fluidity [22]. Super-plasticizer used is the SIKAPLAST 5045 (Superplasticizer /High Redactor) of Water/Retardate of catch for ready-mixed concretes and self-compacting concrete Conformed to standard NF INTO 934-2.

2.5 Water

The mixing water comes from the tap (drinking water of the town of Bechar). It is in conformity with standard NF P18 404.

3. FORMULATION OF THE CONCRETES AND MIXING PROCEDURE

The final formulations of the self-compacting concrete are given in Table 2:

- The concretes self-compacting are made according to the following method:
- To introduce elements in the form of respective layers: gravels, sands, rubber, cement and crushed sand then mixed during 1 minute dry.
To introduce water with half of the additives mixed together and to mix the whole during 2 minutes.

To add the remainder of the additive (super plasticizer) and to continue mixing during 2 minutes other minutes to let act the additives. The time of total mixing is of 5 minutes.

<table>
<thead>
<tr>
<th>Component (kg/m$^3$)</th>
<th>SCC 0% RA</th>
<th>SCC 2.5% RA</th>
<th>SCC 5% RA</th>
<th>SCC 10% RA</th>
<th>SCC 20% RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (C)</td>
<td>473</td>
<td>473</td>
<td>473</td>
<td>473</td>
<td>473</td>
</tr>
<tr>
<td>Crushed sand (CS)</td>
<td>47.3</td>
<td>47.3</td>
<td>47.3</td>
<td>47.3</td>
<td>47.3</td>
</tr>
<tr>
<td>Water W</td>
<td>246</td>
<td>232</td>
<td>228</td>
<td>227.14</td>
<td>226</td>
</tr>
<tr>
<td>Natural sand (NS. 0/3)</td>
<td>900</td>
<td>878</td>
<td>834</td>
<td>900</td>
<td>900</td>
</tr>
<tr>
<td>Coarse aggregate (NA.3/8)</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>135</td>
<td>120</td>
</tr>
<tr>
<td>Coarse aggregate (NA.8/15)</td>
<td>580</td>
<td>580</td>
<td>580</td>
<td>580</td>
<td>580</td>
</tr>
<tr>
<td>Fine rubber (RA.0/3)</td>
<td>-</td>
<td>22.5</td>
<td>66.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coarse Rubber (RA.3/8)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Additive</td>
<td>8.21</td>
<td>8.21</td>
<td>8.21</td>
<td>8.21</td>
<td>8.21</td>
</tr>
<tr>
<td>W/(CS + C)</td>
<td>0.47</td>
<td>0.45</td>
<td>0.44</td>
<td>0.44</td>
<td>0.43</td>
</tr>
<tr>
<td>Unit weight</td>
<td>2404</td>
<td>2391</td>
<td>2386</td>
<td>2385</td>
<td>2834</td>
</tr>
</tbody>
</table>

4. RESULTS AND DISCUSSIONS

4.1 Fresh concrete properties

As a first part of this study, our objective is to determine the effect of rubber aggregate (RA) on the workability of concrete. Test methods such as slump-flow, L-box and Stability in sieve were conducted to assess the fresh properties.

<table>
<thead>
<tr>
<th>Test</th>
<th>Slump-flow (cm)</th>
<th>L–Box (H2/H)</th>
<th>Stability in sieve (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values limits</td>
<td>60 à 75 cm</td>
<td>≥ 0.8</td>
<td>≤ 15 %</td>
</tr>
</tbody>
</table>

The experimental results of various fresh properties are presented in Table 4. As shown in the Table 4, the five mixes have met the self-compactability acceptance criteria AFGC [23] presented at Table 3.

For the densities of the hardened concrete, The variation of the unit weight with the incorporation of rubber aggregates was also to be expected considering the low density of the rubber aggregates (RA) in comparison with that of natural aggregates (NA) [24, 25]. In addition, the increase in rubber content expand the air content, which in turn reduces the unit weight of the mixtures.
Table 4: Fresh properties of self-compacting concretes

<table>
<thead>
<tr>
<th></th>
<th>Slump-flow (cm)</th>
<th>L – Box (H2 / H1)</th>
<th>Stability in sieve (%)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCC 0% RA</td>
<td>74</td>
<td>0.86</td>
<td>4.2</td>
<td>2372</td>
</tr>
<tr>
<td>SCC 2.5% RA</td>
<td>73.5</td>
<td>0.94</td>
<td>3.7</td>
<td>2332</td>
</tr>
<tr>
<td>SCC 5% RA</td>
<td>70</td>
<td>0.9</td>
<td>12</td>
<td>2226</td>
</tr>
<tr>
<td>SCC 10% RA</td>
<td>72</td>
<td>0.85</td>
<td>7</td>
<td>2369</td>
</tr>
<tr>
<td>SCC 20% RA</td>
<td>74</td>
<td>0.95</td>
<td>13.2</td>
<td>2138</td>
</tr>
</tbody>
</table>

The results of the slump-flow test are shown in Table 4, we observe a decrease of slump flow value from 740 mm to 700 mm after replacing natural sand with rubber aggregates with 2.5% and 5%.[26] In substituent of sand by RA of equivalent granulometry noted a slight increase in the value of the Slump-flow (measured cone Abrams) for volume substitution rate of 22 to 33%. [3] Noted that a concrete containing 40% in volume substitution of natural aggregates by rubber aggregates had a null Slump-flow. They observed that the fine rubber aggregates concrete were more convenient than concrete containing coarse rubber granules. [27] Thus increasing the quantity of the superplasticizer in the mixtures could obtain a Slump-flow rate between 80 and 100 mm.

4.2 Hardened concrete properties

4.2.1 Compressive strength

The compressive strength is a basic mechanical characteristic of a concrete. It acts of an essential element of its identity card, we used test-tubes (70X70X280mm) which were unmolded 24 hours after the casting and were preserved under water at the ambient temperature. Figs. 3-4, shows the results of the compressive strength (the average value of the three tests).

![Figure 3. The effect of rubber (0/3) content on the compressive strength](image1)

![Figure 4. The effect of rubber (3/8) content on the compressive strength](image2)
The results of the compressive strength tests are presented in Fig. 3. First analysis of these results shows that:

- The compressive strength decreases with the increase of rubber aggregates content.
- The compressive strength of rubber content (RA.0/3) decreases from 37.9 MPa of (SCC0%RA) mix to 23.7 MPa of (SCC5%RA) mix.
- The compressive strength of rubber content (RA.3/8) decreases from 37.9 MPa of (SCC0%RA) mix to 24.3 MPa of (SCC20%RA) mix.

That could be explained by the low rigidity of the rubber aggregates and the bad interface existed between these types of aggregates and the paste cement. These results are in consistant with those observed by [28, 29, 30] the increase in rubber content affected negatively in unit weight and mechanical properties (compressive, tensile and flexural strengths).

The second reason is interested with the defects of adherence between the rubber and the matrix cementing or with the bad quality of the interfacial transition zone (ITZ) between these two phases.

The relationship between the 28- day compressive strength and dry density of specimens is shown in Fig. 5. It could be seen that a good correlation between compressive strength and density was obtained as indicated by the higher R-squared values.

### 4.2.2 Flexural strength

The results of the 7, 14 and 28 days of flexural strengths tests are presented in Figs. 6 and 7. The flexural strength, as well as the compressive strength, decreased with increasing rubber content. These results are in line with the work reported by Toutanji [2] on the effect of rubber particles on the properties of concrete, which showed that there was a reduction of about 7.9% in the flexural strength with the addition of 25% rubber aggregates as the natural aggregates alternative. The same results obtained for the flexural strength, showed that the flexural strength decreases when the amount of rubber is increased with percentage of 2.5 - 20%, regardless the size of the aggregates.
4.2.3 Microstructure analysis of the concrete with rubber

This analysis was performed by scanning electron microscopy (SEM) to determine the morphology and the interface between the rubber and the cement matrix. The results of this study, therefore, logically led us to study this interface by microscopic analysis SEM (Scanning Electron Microscopy). As we had hypothesized repeatedly, the results in (Fig. 8. a and b) present an image of the study surface allowed us to highlight an adhesion defect (non-negligible thickness seal the interface of about 20µm) between the rubber granulate and the cement matrix accordingly with the emergence of a high porosity zone. As we have already had occasion to clarify the fall of the mechanical strength can be partly attributed to the low adherence. [31] The quality of the link aggregates / cement matrix directly influences the mechanical properties and durability of concrete indicators. The Fig. (8.c) present an image of the rubber granules RA are obtained by grinding the end of tires life (darker particles), it is easy to think that these aggregates have much less smooth surfaces and cracked as those rolled natural aggregates NA.

The development of a connection between aggregates and cement matrix is derived from a number of mechanisms. According to [32] looking for the importance of the substitution of an aggregates by recycled rubber granulates, granulate type: The chemical reaction between the cement paste on one side and the aggregates constituting the other.

The use of non-natural aggregates as are the RA cannot lead to the creation of chemical bonds.[33] has shown that natural lightweight aggregates absorb water from the surrounding dough and thus it possible to modify the structure of the interface.

These mechanisms justify adhesion failure observed by SEM and also allow to explain the higher air content or large porosity observed for composite incorporating RA.and explain the reduction of resistance observed in compression but especially in traction for which we had considered that the limiting factor, in the case of concrete incorporating rubber aggregates was this connection between the rubber aggregates and the matrix cement.
4.2.4 Shrinkage

Shrinkage can be a critical factor for the design of structural members due to the length changes by the time dependent deformation [34]. The objective of this paper is to study the shrinkage of SCC by studying the shrinkage of paste and considering the influence of the rubber aggregates.

The evolution of hydration reactions at the origin of this shrinkage depends on the quantity of water available in concrete for hydration reaction. Consequently, the importance of this shrinkage will be directly related to the W/C ratio. In addition, autogenously shrinkage is influenced by quantity and type of mineral addition used in this concrete [7]. Drying shrinkage is usually more significant for SCC than for vibrated concretes [6, 8]. Drying shrinkage appears to be lower for higher G/S (gravels/sand) ratio [6].

For each formulation tested, we measured the dimensional variations of three prismatic test-tubes of dimension (40x40x160) mm for the evaluation of shrinkage. Test-tubes are unmolded 24 hours after the casting. The test-tubes are preserved without any protection; the hydrous exchanges with the ambient conditions are authorized.

Table 5: Shrinkage of different SCC

<table>
<thead>
<tr>
<th>Shrinkage (µm/m)</th>
<th>SCC 0% RA</th>
<th>SCC 2.5% RA</th>
<th>SCC 5% RA</th>
<th>SCC 10% RA</th>
<th>SCC 20% RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 days</td>
<td>901</td>
<td>797</td>
<td>602</td>
<td>800</td>
<td>404</td>
</tr>
<tr>
<td>90 days</td>
<td>1081</td>
<td>922</td>
<td>721</td>
<td>894</td>
<td>452</td>
</tr>
<tr>
<td>200 days</td>
<td>1143</td>
<td>963</td>
<td>762</td>
<td>924</td>
<td>467</td>
</tr>
<tr>
<td>300 days</td>
<td>1162</td>
<td>975</td>
<td>775</td>
<td>932</td>
<td>471</td>
</tr>
</tbody>
</table>
Figure 9. Effect of the rubber aggregates (0/3) on the Shrinkage

Figure 10. Effect of the rubber aggregates (3/8) on the Shrinkage

Figure 11. Shrinkage test

The analysis of the curves this graph (Figs. 9-10) shows that the deformation of shrinkage in the first time is fast and significant for SCC without RA (the stronger kinetics at the first 60 days). But thereafter, its kinetics becomes extremely slow. With regard to the amplitude of shrinkage, the effect of proportioning in RA for SCC makes decrease the end value of shrinkage. A reduction in shrinkage of 15% when one only substitutes 2.5% of sand. This reduction is due primarily to the improvement of the capacity of deformation of these materials. [34] In concretes using (granulated sizes (4–8 mm) of high quality recycled rubber) there is a reduction of shrinkage of almost 50% in series with 80% of rubber and a 20% of stone aggregates. In concrete series with (waste from recycled rubber) the reduction of shrinkage reaches a 77% with a 100% of rubber.

5. CONCLUSION

The following conclusions can be drawn from experimental results summarized in section 4:

- This study showed that the substitution of the natural aggregates (NA) by the aggregates
rubber (RA), in the composition of the Self-Compacting Concrete (SCC), contributes to a slight variation of the parameters of workability in a fresh state.

- The density of concrete containing RA tends to decrease due to lower density of rubber compared to natural aggregates NA.
- The compressive strength of the SCC decreases with the increase in the percentage of RA. But the compressive strengths of the SCC decreased slightly in substituent 2.5% of sand and 10% of coarse aggregates NA3/8 by the RA (more than 35 MPa measured at 28 days).
- This reduction is due to the bad quality of the interface between aggregates and the cement paste.
- The effect of proportioning in RA for SCC makes decrease the end value of shrinkage. A reduction in shrinkage of 15% when one only substitutes 2.5% of sand.

Finally, the possibility to increase the use of rubber aggregates RA in self-compacting concrete may be regarded as a great environmental and economical benefit.

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