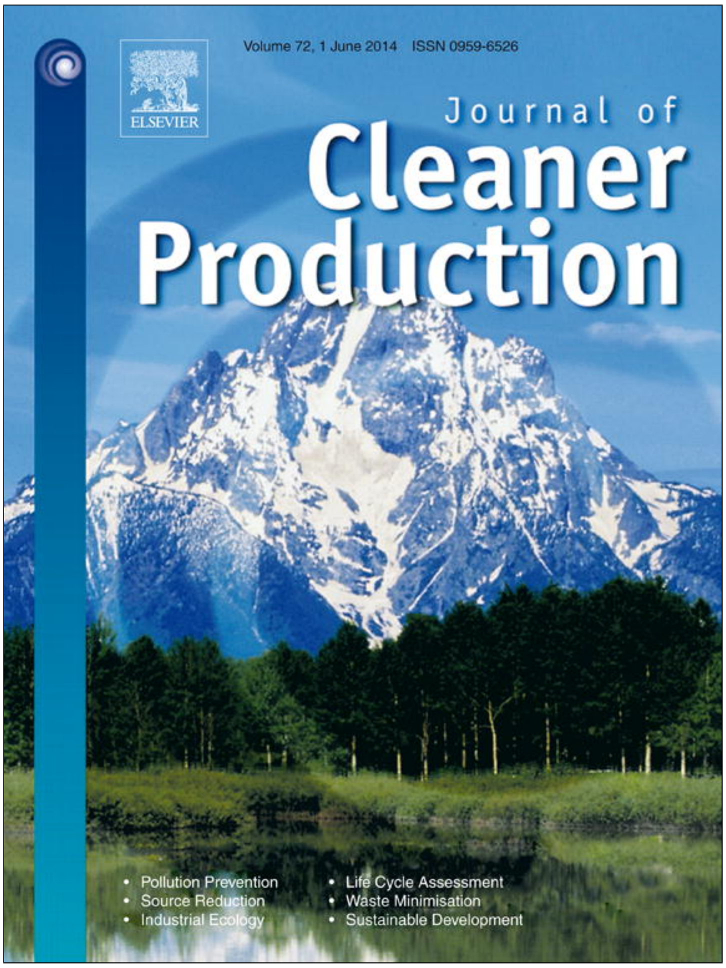
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# Use of shredded rubber tire aggregates for roller compacted concrete pavement

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ABSTRACT

Recycling of waste rubber tires in pavements is considered as ecological and economical solutions due to their advantages. It may help preserving natural resources and producing an eco-friendly material. Roller compacted concrete used in pavements (RCCP) has the same basic ingredients as in ordinary concrete. But unlike the conventional concrete, it is an enough drier mix-stiff to be compacted by vibratory rollers. This study aims to experimentally investigate the possibility of using shredded rubber tire in RCCP. The rubber particles are added to mixes as a partial replacement by volume of some parts of natural crushed aggregates. Unit weight, mechanical properties, modulus of elasticity and porosity are evaluated and compared according to the rubber content in the concrete mix. The effects of compaction energy and roughness of rubber surfaces are also studied. The results obtained showed that the inclusion of rubber particles in RCCP mixes will change their characteristics in fresh state as well as hardened state. Even though the mechanical properties decrease when rubber content in the mix is increasing, it should be noted that it is possible to use rubber particles in low traffic pavements project. In the other hand, rubber particles may improve some desired technical characteristics such as; porosity, ductility and cracking resistance performance.

In addition to that, it may be more environmentally efficient to use rubber aggregates in RCCP, because this helps to remove some parts of these wastes and protect the environment. The performance of RCCP with shredded rubber additions can be improved by modifying the roughness of rubber particle surfaces, when the optimal rubber content depends on technical requirements and the destination of project.



## 1. Introduction

The important increase in the number of vehicles in last decades is accompanied by rapid growing amounts of rubber tire wastes. The United States alone has about 275 million scrap tires stockpiled across the country, with an increase of 290 million tires generated per year (Batayneh et al., 2008). The rubber tires are considered as one of the major waste problems for all countries due to their direct effect on environment and human health; contaminating soils, water and air. The rubber tire wastes are not bio-degradable and can form a favorable environment for breeding rats, mice, vermin and mosquitoes (Naik and Singh, 1991; Siddique and Naik, 2004).

The storage of this type of wastes in landfills in high volumes could be a serious problem in case of eventual fire, due to their potential to generate toxic fumes. Although, the management of this type of solid wastes in civil engineering applications as pavements constitute an ecological and economical challenges due to their major impact on environment. In the other hand, the needs in terms of mineral aggregates are still increasing with intensive use of concrete in structures and transportation areas.

Several studies on the effect of the incorporation of shredded rubber tires as aggregates on concrete performance have been reported in the literature. These researches consist of analyzing the effects of the addition of rubber particles on physical and mechanical characteristics of concrete, in order to produce a new material which can satisfy some technical application requirements and help decision makers with a solution for the management of these wastes. The use of shredded rubber tire in concrete may significantly reduce the cost (economic interest), and help preserving natural resources and the environment (ecological interest).

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The studies carried out on the rubberized concrete show a reduction in unit weight and mechanical properties (compressive, tensile and flexural strengths) as well as a more ductile behavior according to the increase in rubber content (Khaloo et al., 2008; Bravo and de Brito, 2012).

Segre and Joekes (2000) who studied the adhesion between rubber particles and the cement past, reported that the loss in mechanical properties of rubberized concrete was due to the low adhesion between rubber particles and cement paste. They have compared the behavior of concrete containing treated rubber with NaOH solution to that made with untreated rubber. The reported results showed that the mechanical properties of concrete containing treated rubber were higher than that obtained with the untreated rubber.

RCCP is made of the same ingredients as conventional concrete: aggregates, cement, water and optionally admixtures. The RCCP differs from ordinary concrete by its zero-slump (very dry concrete), larger quantity of aggregates and smaller amount of cement; its densification requires the application of compaction energy to make it more consolidated. The main advantages of RCCP consist of lower costs and easier implementation. Little information is however available on performance of RCCP containing rubber, because the largest parts of researches are conducted on conventional concrete and have not been reported on RCCP mixes.

The aim of the present work is the study, of the possibility of using rubber tire wastes in RCCP. The shredded rubber particles are used as aggregates in concrete as partial substitution by volume of crushed calcareous gravels at rates varying from 0, 5, 10, 15, 20, 25 and 30%. Unit weight, consistency, mechanical properties (compressive and tensile strengths), elastic modulus and water absorption are evaluated and compared between them according to the rubber content in the mix. The relationship between the applied compaction effort level and the rubber content is determined and presented in this experimental investigation. The effects of roughness of rubber particles are also studied and reported in this work.

## 2. Materials

Portland cement CEM II/B42.5 from Ain El-Kebira Factory in Algeria was used throughout this study, with a density of 3150 kg/m$^3$. Natural dune sand with 5 mm maximum size was used for all mixes. Three fractions of crushed calcareous gravel were used with maximum size of 8, 15 and 20 mm. The rubber particles were provided from SAEL factory in Algiers (Fig. 1). Fig. 2 shows the grading analysis of mineral aggregates and rubber particles used in this study, while their physical and mechanical properties are shown in Table 1.

## 3. Experimental study

In order to assess the effect of rubber particles on the performance of RCCP, six mixes were prepared with different rubber content: 5, 10, 15, 20, 25 and 30%. These mixes were compared to the mix without rubber (control). The used rubber particles were added to the concrete as a replacement of some part of the total volume of crushed gravels. The aggregate ratios were chosen to obtain a combined grading size distribution curve between limits recommended by the US Army of Engineers (Nanni and Meamarian, 1993).

Cement and water contents were chosen using soil mechanics procedure according to ASTM D1557 standard (Marchand et al., 1997). The specimens were demoulded after 24 h of their preparation and were conserved in laboratory conditions (25 °C and 50-60 RH). VeBe time and density of fresh concrete were measured for each rubber contents according to ASTM C1170 standards. Compressive, bending and splitting tensile strengths were evaluated at ages of 7, 14 and 28 d according to ASTM C39, ASTM C78 and ASTM C496. Static modulus of elasticity was determined at 28 d, according to the standard ASTM C469. Cylinder and cube specimens; (160 × 320 mm) and (100 × 100 × 100 mm), were used for compressive strength measure. Prismatic specimens (100 × 100 × 400 mm) were used for bending strength, whereas, for splitting tensile strength, cylinder specimens were used (160 × 320 mm).

**Fig. 1.** Shredded rubber tire particles used.

For all tests the arithmetic mean of three values was taken. Table 2 shows the experimental program carried out and the various components of mixes. The compaction of cylindrical specimens was carried out using vibrating table procedure according to the ASTM C1176. However, for prismatic concrete specimens, pressure compared with that given by ASTM C1176 standards (4.9 kPa) was used for their compaction.

In order to study the effect of rubber surface roughness on the mechanical properties of RCCP, rubber particles were subjected to pretreatment before their use. Two procedures were used for changing the roughness of rubber surface;

- the first one was based on a chemical treatment of rubber with NaOH solution. After 24 h of their immersion in laboratory conditions, rubber particles were washed several times to eliminate NaOH traces and then there were dried at 60 °C for 24 h.

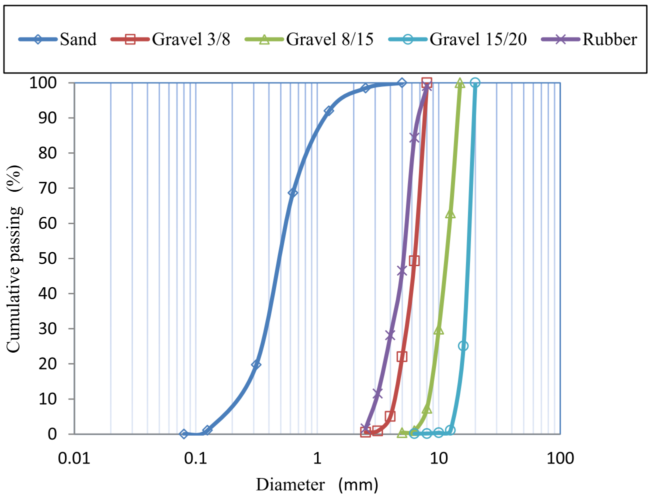


**Fig. 2.** Particle size distribution of natural aggregates and rubber.

**Table 1**
Physical and mechanical properties of aggregates.

| Properties | Sand | Calcareous gravel | | | Rubber particles |
|---|---|---|---|---|---|
| | | 3/8 | 8/15 | 15/20 | |
| Specific gravity (kg/m$^3$) | 2640 | 2595 | 2622 | 2604 | 1273 |
| Sand equivalent (%) | 82.4 | – | – | – | – |
| Fineness modulus | 2.2 | – | – | – | – |
| Water absorption (%) | 1.81 | 2.25 | 1.42 | 1.01 | 0.5 |
| Compactness (%) | 62 | 51 | 52 | 52 | 37 |
| Los Angeles (%) | – | 21 | 20.7 | 21 | – |

- the second procedure consists of gluing sand particles on rubber surfaces (Fig. 3) with resin (MEDAPLAST from Granitex Factory, Algeria).

**Fig. 3.** Rubber treated with gluing-sand.

## 4. Results and discussion

### *4.1. Effect of rubber content on fresh concrete properties*

Density and vibrating compaction time were measured for each rubber contents. It should be noted that regular decrease in density was observed with the rubber content increase in the mix. The unit weight deceased from 2433 kg/m$^3$ to 2292 kg/m$^3$ when rubber was incorporated at 30% of replacement. As shown in Fig. 4, the maximum loss of 5.8% in unit weight was observed for the mix containing 30% of rubber. This reduction might be due to the low unit weight of rubber compared to the substituted natural aggregates.

Since RCCP is a stiff concrete, its workability is commonly measured with VeBe test. The relationship between the vibrating compaction time and rubber content is shown in Fig. 5. It clearly appears that the addition of rubber particles to RCCP mixes improved their consistency and there was a tendency to decrease inversely in VeBe time as the rubber content increased. The VeBe time changed from 33 s for the mix (RCCP$_0$) to 23 s for the mix (RCCP$_{30}$). Therefore, the decrease in vibrating compaction time might be explained by the fact that the rubber particles were less water absorbent compared to mineral aggregates. In presence of rubber aggregates in the mix, the free water increased and consequently the compaction process became easier.

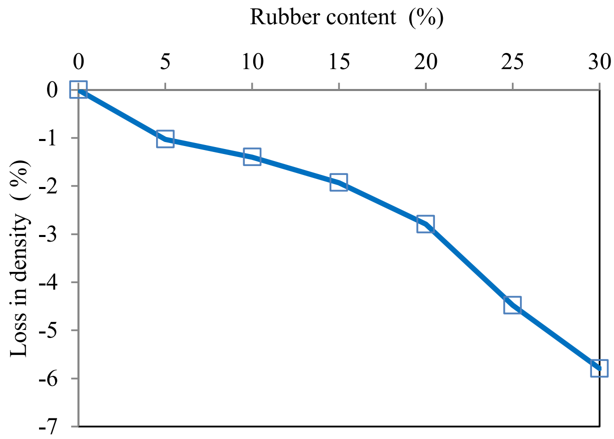


**Fig. 4.** Effect of rubber content on fresh density of concrete.

### *4.2. Effect of rubber content on hardened concrete*

#### *4.2.1. Mechanical properties*

The strengths and modulus of elasticity results obtained on RCCP mixes with different rubber contents are presented in Tables 3 and 4. It clearly can be noted that the increase in rubber content affected negatively the strength values. The variation of the strength loss ratios according to the rubber content in the mix is presented in Fig. 6. It can be seen that the compressive strength was highly sensitive to the increase in rubber content in comparison with the flexural and splitting tensile strengths.

These results are in agreement with previous investigations conducted on ordinary concrete with rubber additions (Eldin and Senouci, 1993; Al-Tayeb et al., 2013). The authors have indicated in their studies that the mechanical properties of concrete decreased with increasing rubber content in the mix. But it should be noted that the RCCP mixes were less sensitive to incorporating

**Table 2**
Mix concrete proportions.

| Mix | Rubber content % | Constituents Kg/m$^3$ | | | | |
|---|---|---|---|---|---|---|
| | | Cement | Sand | Gravel 3/8 | Gravel 8/15 | Gravel 15/20 |
| RCCP$_0$ | 0 | 295 | 727 | 596 | 299 | 241 |
| RCCP$_5$ | 5 | 295 | 727 | 566.2 | 248.05 | 228.95 |
| RCCP$_{10}$ | 10 | 295 | 727 | 536.4 | 264.1 | 216.9 |
| RCCP$_{15}$ | 15 | 295 | 727 | 506.6 | 254.15 | 204.85 |
| RCCP$_{20}$ | 20 | 295 | 727 | 476.8 | 239.2 | 192.8 |
| RCCP$_{25}$ | 25 | 295 | 727 | 447 | 244.25 | 180.75 |
| RCCP$_{30}$ | 30 | 295 | 727 | 417.2 | 209.3 | 168.7 |

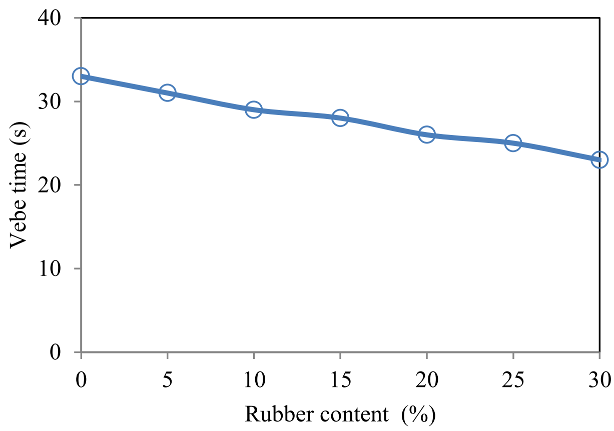


**Fig. 5.** Effect of rubber content on workability.

**Table 3**
Compressive strength and elasticity modulus.

| Mix | Compressive strength MPa | | | | Elasticity modulus GPa |
|---|---|---|---|---|---|
| | Cylinder | | | Cube | |
| | 7 d | 14 d | 28 d | 28 d | |
| $RCCP_0$ | 23.01 | 24.76 | 27.12 | 30.1 | 33.89 |
| $RCCP_5$ | 18.72 | 23.31 | 25.69 | 27.0 | 31.61 |
| $RCCP_{10}$ | 16.24 | 19.77 | 21.2 | 26.65 | 25.77 |
| $RCCP_{15}$ | 15.58 | 15.56 | 19.04 | 23.36 | 21.67 |
| $RCCP_{20}$ | 14.15 | 14.32 | 17.42 | 22.51 | 20.86 |
| $RCCP_{25}$ | 12.5 | 13.1 | 15.3 | 22.46 | 18.21 |
| $RCCP_{30}$ | 11.9 | 12.408 | 13.58 | 20.46 | 16.26 |

**Table 4**
Tensile strengths.

| Mix | Splitting tensile strength MPa | | | Bending strength MPa | | |
|---|---|---|---|---|---|---|
| | 7 d | 14 d | 28 d | 7 d | 14 d | 28 d |
| $RCCP_0$ | 2.53 | 2.75 | 2.79 | 4.9 | 5.03 | 5.82 |
| $RCCP_5$ | 2.54 | 2.73 | 2.76 | 4.7 | 4.68 | 4.42 |
| $RCCP_{10}$ | 1.87 | 2.02 | 2.47 | 4.25 | 4.7 | 5.3 |
| $RCCP_{15}$ | 1.74 | 1.77 | 2.24 | 4.12 | 4.5 | 4.7 |
| $RCCP_{20}$ | 1.69 | 1.96 | 2.17 | 4.15 | 4.34 | 4.49 |
| $RCCP_{25}$ | 1.14 | 1.89 | 2.15 | 2.89 | 3.19 | 4.25 |
| $RCCP_{30}$ | 1.63 | 1.81 | 2.13 | 3.23 | 3.57 | 4.0 |

rubber particles compared to ordinary concrete, this might be due to the effect of compaction which reduced the void content in the mix. Several other authors have reported, in the literature, that the low adhesion between rubber particles and the cement past was responsible for these losses (Raghavan et al., 1988; Segre and Joekes, 2000).

The computation of elastic modulus from the stress–strain relationships of RCCP as well as of ordinary concrete was generally assumed at 40% of uniaxial compressive strength (ultimate stress in compression test). The results indicated that the elastic modulus was affected by the incorporated rubber. It decreased with rubber content increase from 33.9 GPa for the mix ($RCCP_0$) to 16.26 GPa for mix ($RCCP_{30}$). The loss in the elastic modulus values was due to the low elasticity modulus of incorporated rubber.

In order to better understand the dependence of compressive strength on density of the mix, the relationship between the 28-d compressive strength and dry density of specimens is shown in Fig. 7. It could be seen that a good correlation between compressive strength and density was obtained as indicated by the higher R-squared values. Therefore, it could be more efficient to obtain a denser mix. It is shown on the same Figure that the

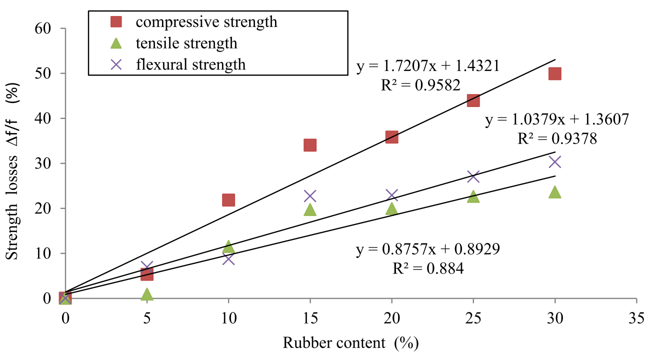


**Fig. 6.** Loss of strengths versus rubber content.

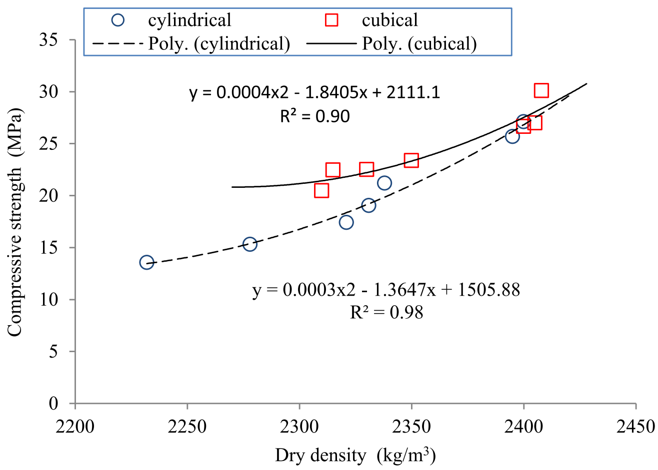


**Fig. 7.** Relationship between compressive strength and density.

two curves (cylinder and cube compressive strengths) were converging to the same point, which represented the maximum density achieved by compaction, or the ideal case where all voids were eliminated. In practice it is very difficult to reach this point, but it is very important to approximate as much as possible this level of densification.

The relationships between compressive strength and tensile strength (split and flexural) are shown in Figs. 8 and 9. The split tensile/compressive strength ratios were varying from 9 to 15% and the flexural/compressive strength ratios changed from 20 to 30% according to the curing time.

Fig. 10 shows the specimen failure type under flexural load. It appeared that the specimens were broken into two pieces with mixes $RCCP_0$ and $RCCP_5$. For the other mixes, with high rubber content, it was shown that the two parts of specimens were not separated and the cracks were inversely proportional to the percentage of rubber added. Therefore, the use of rubber particles in RCCP, gave to specimens more absorption energy capacity and the failure became more ductile. These results are in agreement with those observed by Raghavan et al. (1988) when conducting a study on mortar specimens with rubber shreds. He reported that these specimens were able to support additional effort at failure. The results presented in our study indicate that the incorporation of rubber in RCCP mixes improves their ductility and consequently their cracking resistance potential.

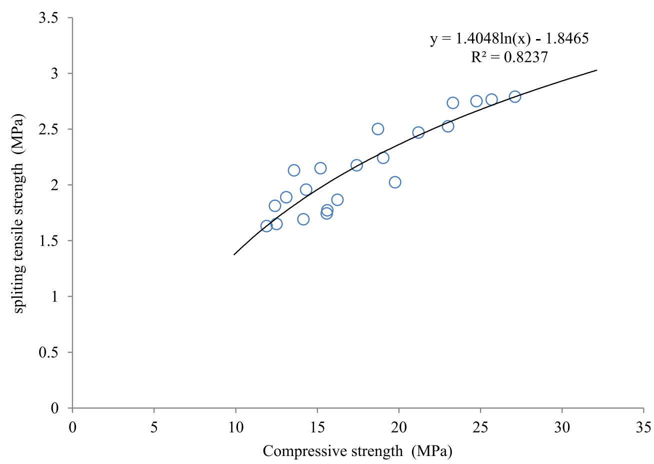


**Fig. 8.** Relationship between splitting tensile and compressive strengths.

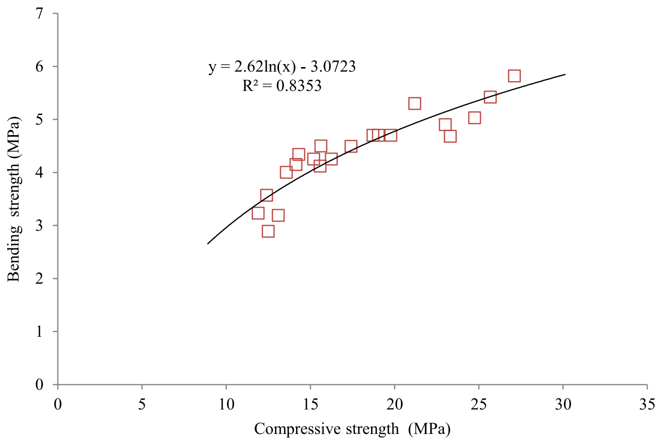


**Fig. 9.** Relationship between bending and compressive strengths.

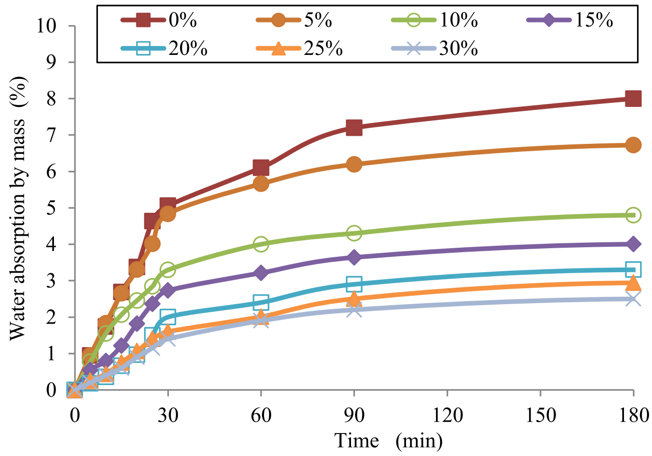


**Fig. 11.** Effect of rubber particles on absorption of water by capillarity.

### 4.2.2. *Water absorption*

Fig. 11, shows the effect of incorporated rubber on water absorption rate by capillarity. It should be noted that the absorption of water decreased with the increase of rubber content in the mix. This was due to the lower absorbency of rubber particles compared to natural aggregates, which reduced the effective area crossed by water. These results are in agreement with those obtained on ordinary concrete with rubber additions and reported in the literature. These former studies indicated a reduction in porosity of concrete with the increase of rubber content (Segre and Joekes, 2000; Yilmaz and Degirmenci, 2009).

## 4.3. *Effect of compaction effort*

In order to study the effect of the compaction quality on the density of the mix, concrete specimens were compacted using three stress levels: 3.9 kPa (80% of the standard compaction effort), 4.9 kPa (standard compaction effort) and 5.7 kPa (120% of standard compaction effort). The relationship between the applied compaction effort and hardened density was shown in Fig. 12. It should be noted that the final densification level of RCCP specimens was simultaneously affected by the applied compaction effort and rubber content in the mix.

The curves of Fig. 12 show that the increase in the compaction effort improved the density, while the rubber content was less than 20%. However, the density of specimen decreased for mixes $RCCP_{25}$ and $RCCP_{30}$. This behavior might be due to the deformability of rubber particles. During compaction under effort higher or equal to the standard compaction stress, the volume of rubber particles decreased. It should be noted that once the load was removed the rubber particles relaxed and decompressed. Therefore, a particular attention should be taken during compaction phases if the rubber particles were used at rates higher than 20%.

## 4.4. *Effect of rubber roughness*

The 28-d strength of RCCP specimens obtained with treated rubber at 25% of gravel replacement was evaluated and compared

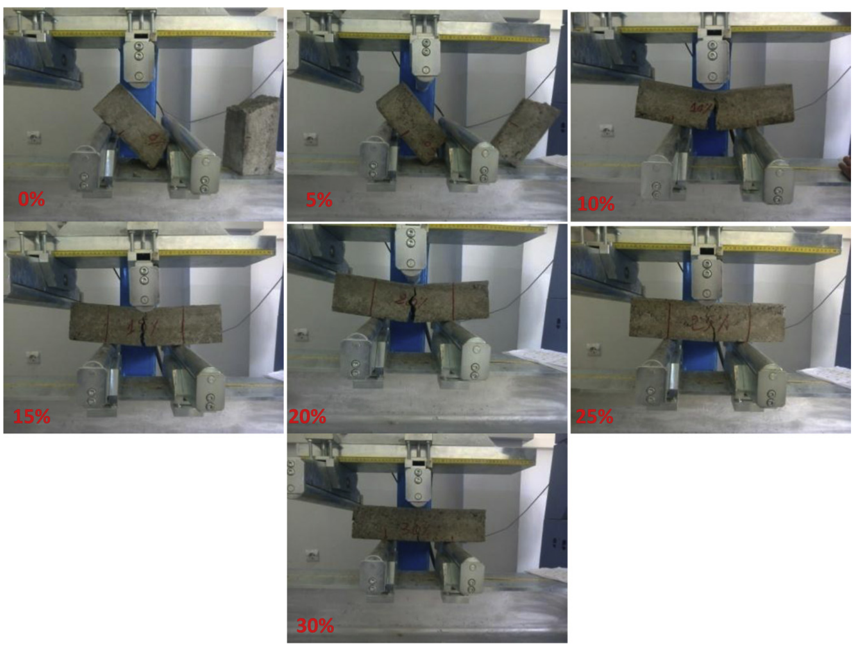


**Fig. 10.** Specimens at failure.

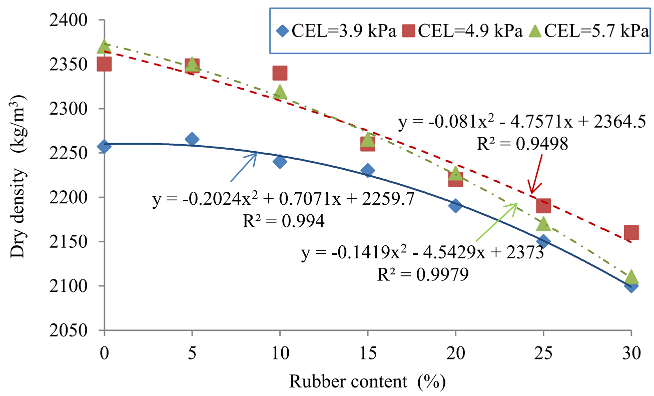


**Fig. 12.** Relationships between hardened density and rubber content.

to mixes made with untreated rubber for the same rate of replacement. The results obtained are reported in Fig. 13. It can be shown that the mechanical properties of mixes made with treated rubber particles are higher than that given by the mix with natural rubber (untreated). The compressive strength was improved by 11–28%, whereas the tensile strength was improved by 15–20%. Therefore, modifying rubber surface roughness has a positive effect on performance of RCCP containing shredded rubber and increased the adhesion between rubber particles and cement past. These obtained results are in accordance with that obtained by Segre and Joekes (2000) who conducted tests on ordinary concrete containing treated crumb rubber with NaOH. It has been reported that the adhesion between rubber particles and cement past can be improved by treating rubber in NaOH solution.

## 5. Conclusion

The possibility of incorporating rubber tire wastes in RCCP was experimentally investigated in this work. The results obtained show that the consistency of RCCP mixes was improved by incorporating rubber, which reduced the vibrating compaction time by 30% for a partial substitution of gravel content of about 30%. Unit weight, mechanical properties and water absorption decreased with increasing rubber content, while the ductility and cracking resistance of the mix increased. The compaction of RCCP mixes was affected simultaneously by the intensity of the applied stress level of compaction and the rubber content. However, particular attention should be taken in the field during

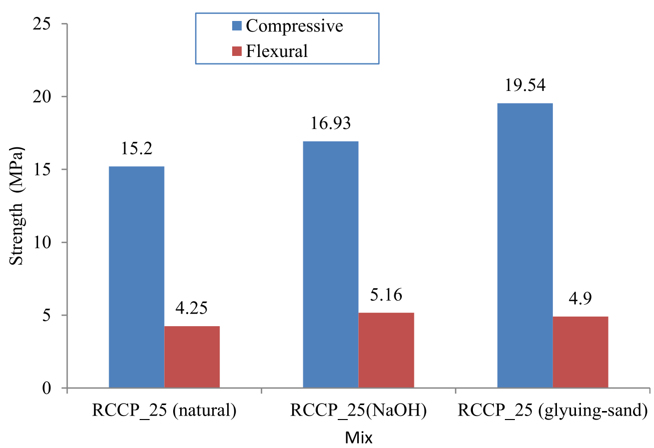


**Fig. 13.** Effect of rubber surface roughness on strengths.

compaction phases for mixes when using rubber particles at ratios higher than 20%. The compressive strength of RCCP made with rubber aggregates can be improved by 11–28% if the roughness of rubber surfaces was modified, whereas the tensile strength can be improved by 15–20%.

Despite the reduction in strengths of RCCP caused by incorporated rubber particles, their use remains possible in pavements because the technical requirements are not always the same. On the other hand, the addition of rubber particles to RCCP may be beneficial due to the improvement of some properties such as high ductility, low porosity and also the low unit weight. Recycling and valorizing shredded rubber in pavements may help eliminating some quantities of wastes and at the same time reduce the needs of natural aggregates. The rubberized RCCP can be used for some projects such as; low traffic pavements, rural roads and large areas of pedestrians. However, the optimal rubber content to be used depends on technical requirements and the destination of project. Finally, to make use of these results in situ, it is recommended to build an experimental full scale pavement.

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