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THE RECYCLING OF THE RUBBER WASTE BY INCORPORATION INTO THE CEMENT MATRICES

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ABSTRACT*.* The rubber wastes result mainly from the automobiles, but may also result from the construction or from other industrial activities as well as from households. Increasing the use of the rubber has generated an increase of the amount of rubber waste resulted. Thus, the increasing of the amounts of the rubber waste produces important environmental issues, especially when they are stored. The degradation of the tires take long times, by comparison, we can even say that rubber wastes have an unlimited lifetime compared to other organic wastes. In addition, in the case of an accidental ignition of the stored tires, their combustion releases gases containing hazardous chemical compounds, and fine particles, into the environment. Some of that gases produced by ignition are dangerous not only for the environment but also for the human health. These are some of the reasons why the European legislation prohibited the storage of rubbers in the landfills. In this context, the recovery and the recycling of the rubber waste to the detriment of their storage become very important.
This paper studies the possibility of the recycling of the rubber wastes by incorporating the crumbs of rubber in the cement. The rubber crumbs were added to the cement, partially replacing the fine aggregate in the cement matrix, in various proportions (10, 20, and 30% weight units). The characteristics of the resulting types of cement were evaluated from their mechanical and physical properties.

Key words*: rubber waste, recycling, sustainable waste management, cement*.

INTRODUCTION

The amounts of the wastes produced in the world are constantly increasing, and then it is very important to find different ways to recover or to recycle them. The first reasons are the significant environmental impact of the waste and too often to use the storage of the waste in the landfills, that is a solution that seems to be cheap at the moment, but it is an expensive and a polluting one in time. Also, it important to understand the fact the non-renewable resources decreasing in time and an efficient recycling of the waste could provide a balance between the resources consumed and the wastes produced.

The rubber wastes have certain characteristics that give them a special place in the waste management that recommend them for the recycling. Some of these characteristics are: the rubber wastes are produced in enough large quantities annually, especially from the industrialized countries, they have large dimensions, and they have a different chemical composition, they do not break down in the nature, and their accidental combustion produce a lot of toxic and dangerous gases for the environment and for the human health (Downard et al., 2015).

Many of the dangerous gases produced by the burning of the tires are toxic, carcinogenic and mutagenic, being more dangerous than those produced by the burning of plastics or the fossil fuels in the combustion boilers. If the combustion of the tires occurs with oxygen deficiency, as in the case of dumped tires in the higher piles, the amount of the polycyclic aromatic hydrocarbons (PAH) in the combustion gases are increasing. In addition to the PAHs, the combustion gases can also contain SO_2, PM-2,5, black carbon, acrolein, formaldehyde and CO, all of these compounds having a high risk for the health (Downard et al., 2015; Demarini, 1994).

The main source of the rubber waste is generated by the used tires resulted from the motor vehicles. Sienkiewicz et al. (2012) estimate at 17 million tons per year the world production of the used tires. Tiwari et al. (2016), estimate that 1.5 billion tires are produced annually in the world, and around 1,000 million tires complete their lifetime, and half of them are stored in the uncontrolled landfill without any prior treatment. He also estimates that at this rate, by 2030, the amount of dumped tire will increase and will reach about 1200 million tons annually, and the total number of the tires inadequately dumped may reach 5,000 million.

In the Europe, the Landfill Directive (1999/31 / EC) prohibits the storage of the used tires in the landfills. The End of Life Vehicle Directive (2000/53 / EC), also, proposes to reuse, to recycling or to do other different treatments of the waste resulted from the old vehicles (including the rubber waste). The End of Life Vehicle Directive proposes to use various methods for the rubber waste as: tires retreading, reuse, recycling or energy recovery in the cement kilns to the detriment of storage. Those legislative measures helped to promote the research into the field of the recycling of the rubber wastes, and also the monitoring the uncontrolled storage of the rubber waste. Also, the producers were directly involved in the rubber waste reuse or recycling process applying the principle of "producer responsibility" in the field of rubber waste management (Sienkiewicz et al., 2017).

The storage of the old tires may pollute the water and the soil due to the substances they may be containing (lead, zinc, mineral oils) or tire landfills located in the vicinity of the inhabited areas can be the shelters for the reproduction of some harmful insects or micro-organisms (Layachi et al., 2016).

The recycling of used tires is not very simple because they have a complex structure and composition. Sienkiewicz, M. et al. (2017) show that there are 8 types of natural rubber and 30 types of high-quality synthetic rubber and there are some various chemical compounds used to vulcanise them. The tires also contain steel wires or polyester and cellulose wires that need to be separated for recycling (Ramarad et al., 2015; Schnubel, 2014). Sienkiewicz et al., (2017) shows that the tires are resistant to biodegradation, and they also withstand at the high temperatures (100°C) and low temperatures (-30°C), so their recycling is complex and requires various technologies and equipment (Sienkiewicz, M. et.al, 2017).

Due to the large amounts of the resulted rubber waste every year, their recycling is welcome and their mixing into the concrete matrix has been studied by several researchers. It was shown the advantages of the rubber recycling in the concrete matrix as well as which is the impact of the addition of the crumbled rubber to the quality of the concrete.

It is important to recycling the tires after separating the other components of their structure, each component being recycled specifically then to produce suitable products according to the composition and the structure of each of them (Girskas and Nagrockiene, 2017).

The results of the experimental studies and the literature available have shown that recycling of the rubber by incorporating into the concrete matrix can be a viable solution in the areas where the mechanical strength of the concrete is not a major concern (Gupta et al., 2017). Sienkiewicz et al. (2012) shows that adding of the crumbled rubber wastes into the concrete reduces the compressive strength, the tensile strength and the elastic modulus of the concrete, but improves the energy absorption, the abrasion resistance, the freeze-thaw resistance, and the performance at the high temperature of the concrete with crumbled rubber compared to the regular concrete.

The other possibilities for the use of the rubber wastes in buildings sector may be for the sound insulation of buildings (Bujoreanu et al., 2017; Pitre, 2000), in the asphalt to increase the elasticity and the freeze-thaw resistance (Rezaifar et al., 2016) or to produce the rubber protective rugs (Rafique, 2012). The waste tires may also be used to produce the culverts, bricks, blocks and paving slabs, acoustic panels, sidewalks, running tracks, roller compacted concrete, self-compacting concrete, high strength concrete, masonry walls (Rezaifar et al., 2016).

The literature shows that, for some specific cases, the use of the crumbled rubber in the concrete matrix for the recycling of the rubber wastes may improve some properties of the concrete such as freeze-thaw resistance, the fatigue performance, the tear resistance, the deformation capacity (Rezaifar et al., 2016) or the resistance of the concrete at the high temperatures (Layachi et al., 2016).

MATERIALS AND METHODS

Shredding of the rubber wastes

Shredding of the rubber wastes reduces the volume of used tires. The crushed rubber has applications in different areas, depending on the dimensions to which it has been shredded, or the cost of shredding. The cost of shredding increases with the need to obtain pieces as small as possible (Rafique, 2012).

For the grinding of the rubber wastes are initially used mechanical cutters, roll crushers and screw shredders. To obtain the finer particles, shear crushers and granulators are further used. The final processing of the rubber wastes should be carried out on high-temperature shredding equipment such as rotary shredders where the degradation occurs during the compression with simultaneous shear and wear (Mikulionok, 2015).

In the initial phase, the shredding of rubber wastes is made at the dimensions approximate of 7.62 x 10.16 cm. The pieces resulted are then placed in the cutters that can cut them to the sizes of 0.63 x 0.63 cm (Rafique, 2012).

Incorporating the crumbled rubber into the concrete

The crumbled rubbers are incorporated into the mortar by replacing the aggregates in different weight percentages (10, 20, and 30%). The production of these types of concrete is done for certain types of concrete matrix structures, depending on the desired properties of the concrete at the end. It is possible to call for the removal of textile pieces and the metal wires, or could be used the complete the tires, including the metal and textiles wires (Sgooba et al., 2010).

For the experiment in this paper were used only the crumbled rubbers without metal insertions.

By incorporating the rubber granules in the mortar, some mechanical and physicochemical properties of the concrete have changed. There was a decrease in the specific weight of the final product as the amount of rubber used was increased. Also, the workability of the mortar has become more difficult than in the case of conventional concrete recipes, the difficulty of mixing increasing with the size of the rubber granules. The other research in the field has also shown that it is harder to work with large or coarse rubbers crumbs than with the medium, fine or superfine rubber crumbs (Girskas and Nagrockiene, 2017).

The durability of a concrete is characterized by the ability to withstand to the water absorption. Regardless of the degree of homogeneity of the mixture, the concrete will always have waterborne voids in its mass (Sgooba et al., 2010). The lowest possible presence of voids in the concrete mass ensures a lower permeability for it. For the concrete containing rubber, the permeability is reduced as the percentage of rubber used is higher. The result is probably due to the ability of the rubber to reject water (Oikonomou and Mavridou, 2009). Also, the concrete with rubber incorporated ensures a lower weight and a lower density of the concrete (Sgooba et al., 2010).

The mechanical strength of the concrete is the unitary effort to which the concrete is subjected, as long as the material retains its properties so that the structure or construction made of that concrete is not affected in terms of stability. The mechanical strengths differ on the concrete depending on the requirements to which the concrete are subjected (Manea, 2006).

Thus, the compressive strength is defined by the relationship:

$$R_c = \frac{N}{A} \ [\mathrm{N/mm^2}], \qquad [1]$$

where: R_c – the compressive strength; N – the compressive force; A – the area of the samples.

For the other types of the mechanical resistances this equation is similar. In the case of the torsion resistance or bending resistance, the force (N) from the fraction counter is replaced with the torsion moment or the bending moment (M), and the surface from the fraction denominator is replaced with the resistance modulus (W). The Equation will become:

$$R_T = \frac{M}{W} \quad [\text{N/mm}^2], \qquad [2]$$

where: R_T – the torsion or bending resistance; M – the torsion or bending moment; A – the resistances modulus.

The mechanical strengths of the concrete are affected by the percentage of embedded crumbed rubber from the concrete, the type of cement that was used, and the size and the texture of the crumbled rubber mixed in the mortar.

The concrete specimens for the mechanical tests

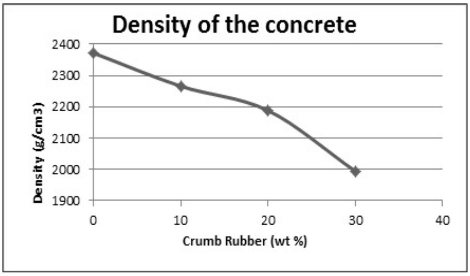
It was accomplished the concrete specimens in the cubes form with the 15 cm edge using concrete of the resistance class C25 / 30 without the addition of rubber, and specimens of the same shape and strength class with addition of crumbled rubber 10 to 20 and 30 (weight) %, that replacing a part of the fine aggregate from the concrete matrix. It has been noticed that if was adding more than 30% (by weight) of the rubber in the concrete it was is affected the workability of the concrete, their properties and also the posibilty to putting into concrete work.

The aggregates used to make the concrete have the maximum size of 16 mm. The rubber granules were shredded to have a size between 2 and 5 mm. The cement was made using a suitable mixture of water, coarse aggregates, fine aggregates, and sand. The concrete specimens were made and deposited in molds according to the practice standard for the concrete production CP 012 / 1-2007 and were kept under suitable temperature and humidity conditions for the 7 days and 28 days. The mechanical determinations were performed according to the same standard of practice, CP 012 / 1-2007.

The physical and the mechanical tests of the specimens containing crumbled rubber

The specific parameters of the concrete workability (the compaction and the air occlusion) and the mechanical compressive strengths of the concrete specimens with and without rubber addition were studied in the laboratory (figure 1.a, b, c). The compressive strength was determined by using a hydraulic press.

In the case of the concrete made with crumbled rubber, a constant increase in the concrete workability was observed proportional with the percentage of rubber addition that increase from 0% to 30% (wt). Another factor that can influence the workability of the mortar is the size of the used granules of the rubber.



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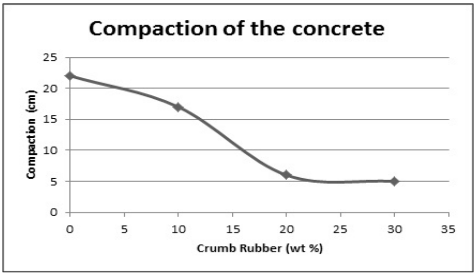

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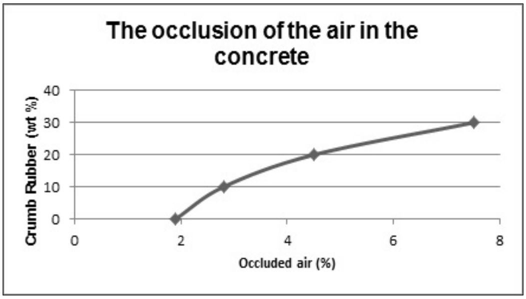

c.

Fig. 1. *Density, compaction and occluded air in the concrete specimens with adding of the 0, 10, 20, 30 % (wt) crumb rubber*

It has been noticed that if more than 30% of the weight of the natural aggregates in the concrete is replaced with crumbled rubber, the concrete will be no longer workable and the density of the samples has decreased as the more crumbled rubber are added to the mortar.

The granulometry of the aggregates is useful to separate the aggregates based on their size and to calculate the frequency with which particles in the different classes are present in mix to getting the mortar.

Theoretically, depending on the size of the aggregates used, the aggregates mixture that was obtained has an ideal granulometric curve to which it tends, based on the mode of the preparation of the concrete and the aggregates used to made the concrete (figure 2).

To investigate whether a mixture of aggregates can be used at the practical level, it is compared the granulometric curve with the accepted intervals for that type of the recipes.

On the basis of the sieve analysis curve, it can be noticed that the concrete without rubber addition (figure 2) complies with the provisions of standard CP 012 / 1-2007; Its sieve analysis curve being located within the accepted limits.

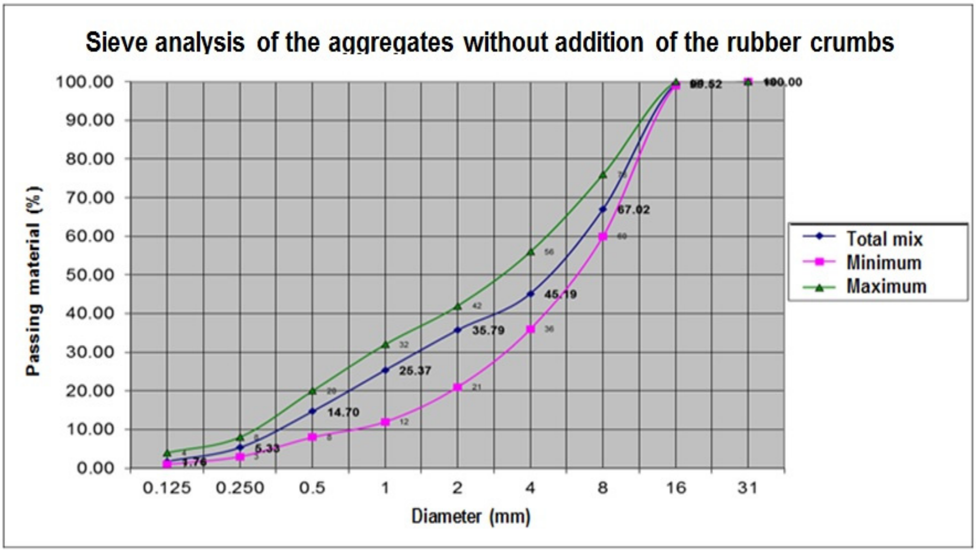

Fig. 2. *Sieve analysis of the aggregates without addition of the rubber crumbs*

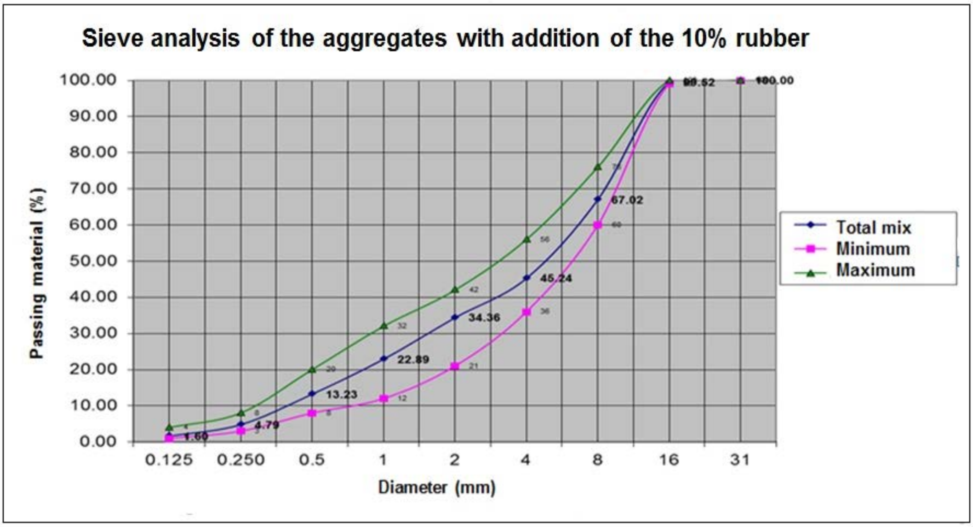

Fig. 3. *Sieve analysis of the aggregates with addition of the 10% of the rubber crumbs*

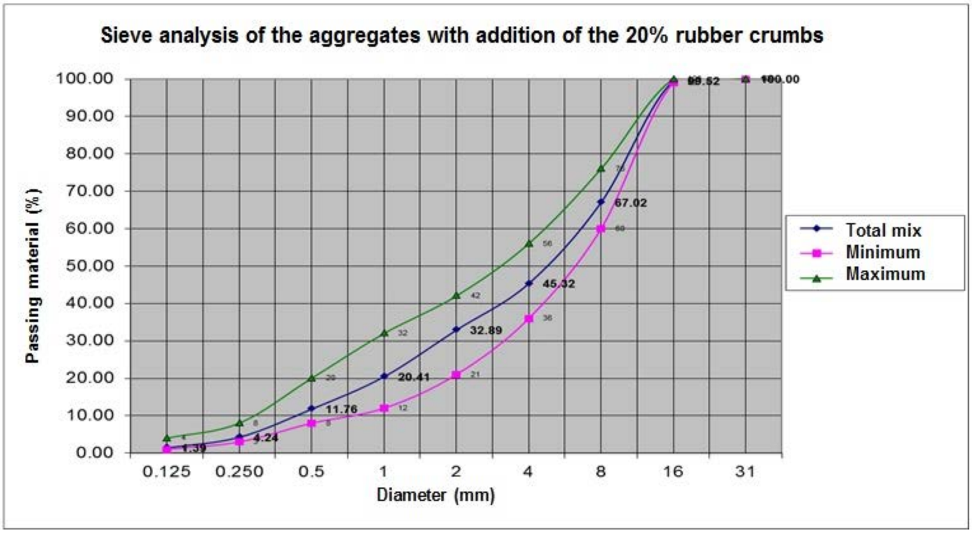

Fig. 4. *Sieve analysis of the aggregates with addition of the 20% of the rubber crumbs*

By partially replacing of the fine concrete aggregate with rubber crumbs (10, 20 and 30% by weight), the sieve analysis curve of the resulting mixture it remains within the acceptable limits (figure 3, 4, 5). This confirms that the concrete prepared by the partial replacement of the mineral aggregates with the rubber crumbs can be used for some certain types of construction.

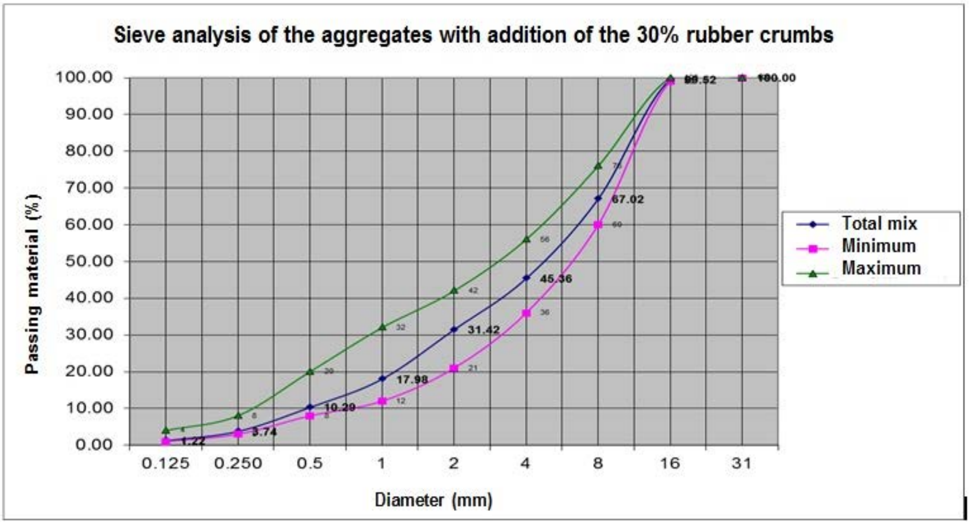

Fig. 5. *Sieve analysis of the aggregates with addition of the 30% of the rubber crumbs*

The resistance to compression of the samples (figure 6) was determined using a hydraulic press which was compressed on the side the cubic specimens with an edge of 15 cm. The samples were inserted between two slides platens and were pressed with an increasing force until the cracking or even the breaking the sides of the specimens occurred; The samples resulting after determining the compressive force have reaching a form of the hourglass.

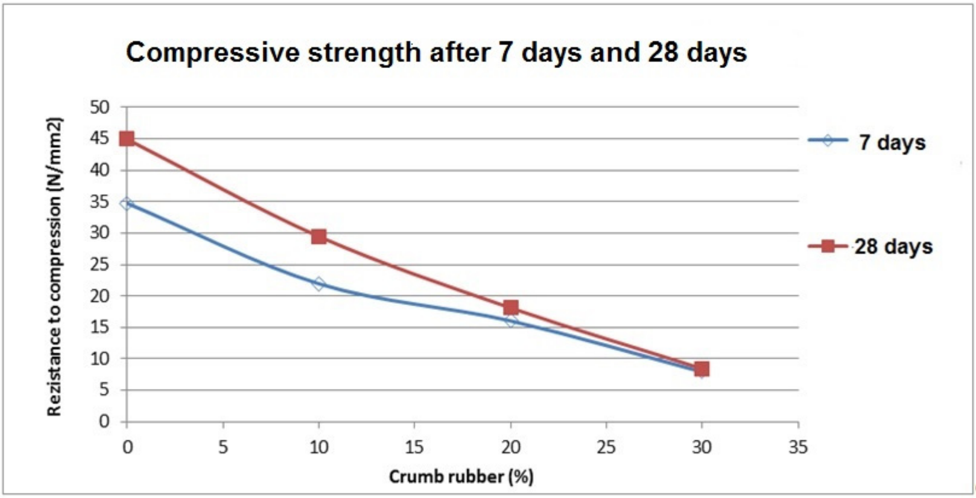

Fig. 6. *The compressive strength of the concrete samples with and without added of the rubber crumbs, after 7 days and after 28 days*

It can be noticed that the compressive strength of the specimens with rubber crumbs (figure 6.) is less influenced by the time passing than the compressive strength of the specimen that uses only mineral aggregates.

RESULTS AND DISCUSSIONS

From the sieves analysis of the aggregates, it can be noticed that the concretes in which the mineral aggregates are partially replaced with the rubber crumbs may be used for certain types of construction. Although the resistance to compression of the concrete containing rubber crumbs is lower than that of the concretes containing exclusively mineral aggregates, the resistance to compresion of the concrete with rubber crumbs is less influenced by the time. Thus, in time the specimens of the concrete made with rubber crumbs suffer less changes if they are subjected to compressive forces than the specimen made of traditional concrete. This was also emphasized by the compaction curve wich illustrating that the concrete with the addition of rubber suffers a lower compaction.

The literature shows that the tensile strength and the bending strength decrease in the case of the rubber additions to the concrete. The tests that were trying to introduce latex into the concrete matrix with rubber crumbs did not improved the mechanical properties of the concrete (Ling et al., 2009).

There are other studies is suggesting that the strength of concrete with embedded rubber may be superior to conventional concrete using certain methods of conditioning the used rubber before it is added into the mortar. Sodium hydroxide (NaOH) for example is proven to be effective for conditioning the rubber tires by improving the bond between the rubber particles and concrete paste (Al-Nasra and Torbica, 2013).

Rezaifar et al., (2016) proposes the use of the metakaolin in the concrete matrix, where the rubber crumbs replace partially the aggregates, and the metakaolin replaces partially the cement in the mortar mixture. He concluded that the optimal mix is about 3.3 vol.% for the sand replacing by the rubber crumbs and 19.5 vol.% for the cement replaced by the metakaolin.

The studies show that the modified concrete samples with the rubber crumbed from wastes provide a satisfactory hardness and an effective reduction in brittleness risk, which is beneficial to the materials which are subjected to the impact and for the dynamic tests (Xiaovei et al., 2017).

Mendis et al. 2017 shows that in addition to the compressive strength, the crumbed rubber concrete also offers an increased capacity of energy absorption that could be advantageous into the designing of the structures that are subjected to the dynamic loading and to the impact. Recently, the research in Australia has investigated the performance of the crumbed rubber concrete columns under seismic loads, and has shown that the crumbed rubber concrete use will increases the damping ratio of energy dissipation (Youssf et al., 2015). In the same study, Mendis et al. 2017, shows that because of the lack of the design rules it is hard to accept to use the crumbed rubber in the structure of the construction.

And other researchers have also shown that the use of the crumbed rubber in the concrete products improves the behaviour at the freeze-thaw cycles, the fatigue performance, the brittleness index and the kinetic of fracture processes, as well as the flexural impact strength, the deformation ability, and the explosive spalling resistance. However, the use of crumbed rubber in the concrete and the other cement-based products has also some important disadvantages such as the reducing of the mechanical properties of the concrete (Rezaifar et al., 2016).

It is also worth to mention that the inclusion of the recycled rubber crumbs in the concrete can reduce the risk of explosion of the concrete at elevated temperatures (Layachi et al., 2016).

CONCLUSIONS

From the available data from the present work, as well as from the literature, it can be noticed that the use of the crumbed rubber in the concrete has both, some advantages and also some disadvantages. One of an important advantage is the recycling of the rubber wastes, which can generate some specific environmental problems, but also the replacement of mineral aggregates that are a natural resource. The qualities that the embedded crumbed rubber it gives to the concrete could not to be neglected. Thus, the concrete with the embedded crumbed rubber has increased the fire resistance; it is respond better to the successive freeze-thaw cycles, it is increased the energy absorption capacity of the concrete, the flexural strength and the performance under the seismic loads. At the same time, the mechanical properties of the concrete with crumbed rubber are reduced, compared to the traditional concrete produced with the mineral agglomerates and drops even more, as the amount of the embedded rubber in concrete is increasing.

Whereas there are no specific normative and the standards for designing for the concrete with crumb rubber, the possibility to use it in the construction sector is now difficult to do.

The extensive research in the field, including the blending of the concretes with crumbed rubber with other substances used as binders for a better homogenization of the mixing paste are expected in the near future

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