Annals of the Academy of Romanian Scientists
Series on Engineering Sciences
ISSN 2066 – 8570 Volume **7**, Number **2**/**2015**

USE OF RECYCLED RUBBER IN REINFORCED CONCRETE STRUCTURES – AN IMPORTANT FACTOR FOR SUSTAINABLE DEVELOPMENT

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Rezumat. *Unul din obiectivele principale ale Uniunii Europene este acela de a reduce nivelul emisiilor de gaze cu efect de seră cu 20% sub nivelul celor din 1990 până în anul 2020 [1]. Betonul este unul din cele mai folosite materiale de construcţie la nivel mondial, iar sectorul construcţiilor din beton este unul dintre cei mai mari consumatori de resurse naturale şi materii prime. Cercetătorii şi inginerii din domeniul construcţiilor au realizat potenţialul uriaş pe care îl are betonul în înglobarea unor cantităţi semnificative de deşeuri rezultate din foarte multe ramuri ale industriei. În cadrul unui program complex de cercetare efectuat la Facultatea de Construcţii şi Instalaţii din Iaşi a fost analizată comportarea betonului cu granule din cauciuc sub aspectul rezistenţei şi deformabilităţii. Aceste caracteristici constituie baza unor încercări viitoare pe platforma seismică pentru a evidenţia eficienţa materialului menţionat la structuri cu o comportare favorabilă în cazul unor acţiuni excepționale din seism.*

Abstract. *One of the main objectives of the European Union (EU) is to reduce the greenhouse gas emissions by 20% below 1990 levels, by 2020 [1]. Concrete is one of the most worldwide used construction materials and the construction industry is one of the largest consumers of natural resources and raw materials. Civil engineers and researchers have found out the huge potential of concrete for embedding significant quantities of wastes resulted from many industries. In a complex research program carried out at the Faculty of Civil Engineering and Building Services Iasi, the mechanical characteristics, such as strength and deformability, of rubberized concrete have been assessed. These characteristics represent the basis of some future tests on the shaking table to reveal the efficiency of the mentioned material for structures with adequate behaviour to exceptional seismic actions.*

Keywords: sustainable development, rubberized concrete, strength, deformability

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1. Introduction

The growing awareness of the human activity negative impact on the present global climate changes is related to both the unsustainable consumption of the natural resources, and the waste production and disposal. The total amount of raw materials yearly used worldwide exceeds the stock of renewing capacity of planet Earth with approximately 50% [2]. The environment is also adversely affected as a result of the enormous amounts of non-biodegradable materials which are stockpiled in landfills all around the world.

To support the development of best environmental practices the wastes recycling and the reuse of the recovered energy and materials is encouraged with the clear aim of preventing the natural resources depletion and the improper land use.

Construction industry in general, with particular interest on reinforced concrete structures, is one of the largest consumers of natural resources and raw materials in the world, responsible for 24% of global material extractions [3]. That is why the materials selection must be governed by ecological considerations.

The plain concrete typically contains about 12% cement, 8% mixing water, and 80% aggregate by mass [4]. According to the latest report of World Construction Aggregates Market, the construction aggregates demand is expected to expand more than five percent per year through 2017, to 53 billion metric tons [5]. The mining, processing, and transport operations involving such large quantities of aggregate consume considerable amounts of energy, and adversely affects the ecology of forested areas and riverbeds [6].

In order to develop the most environmentally friendly solutions in its domain, the construction industry must embrace a comprehensive, integrated approach that necessarily involves the use of less concrete for new structures, consumption of less natural resources in concrete mixtures, and use of recycled materials for making concrete structures [7].

Consequently, one of the approaches to reduce the negative impact of concrete industry could be the partial replacement of natural aggregate in concrete mixtures. Researchers have found out that the use of rubber crumbs resulted from recycled tyres instead of natural aggregate provides the possibility of preserving resources, but also of developing new concrete mixes with improved properties.

In the EU countries, it is estimated that over 300 million tyres are removed per year and defined as waste. Almost a third of this amount is recycled and another third is incinerated for energy recovery in cement kilns [8].

During the past two decades, tyre recyclers, civil engineers, manufacturers and government authorities have identified a wide range of applications and products based on the use of recycled tyre materials. Civil engineers are using large quantities of recycled tyre materials for applications such as artificial reefs, sound barriers, insulation, lightweight fill, bridge abutments among many others. Product manufacturers are using smaller quantities for products such as sports surfaces, vibration and noise absorbing mats, rail and tram casings, automotive parts, as well as a range of new road surfacing and treatment materials [8].

The paper presents some of the experimental results from a complex research program carried out at the Faculty of Civil Engineering and Building Services Iasi related to the effect of natural aggregate replacement by recycled tyre rubber crumbs on the mechanical properties of concrete.

The research activity was focused on the assessment of the compressive strength and the static modulus of elasticity of plain and rubberised concrete. A comparative study based on the variation of the percentage of rubber crumbs added to the concrete mixes was also performed.

The complete stress-strain curve of plain and rubberised concrete was another concern of our team. The main objective was to investigate the favourable behaviour of the newly proposed material in concrete structures subjected to seismic action. An increased energy dissipation capacity was also found out as a great benefit of embedding rubber crumbs resulted from recycled post-consumer tyres in concrete mixtures.

2. Experimental set-up

2.1. Materials

The concrete mixes have been designed based on normally utilised components to which the rubber crumbs have been added to certain proportions.

For the experimental tests carried-out at the Faculty of Civil Engineering and Building Services Iasi, a CEM I-42.5R type of cement has been used, the rapid hardening property being necessary for the early age testing of concrete specimens.

The aggregate used was river gravel with rounded edges separated according to their maximum size in two sorts: 4-8 mm and 8-16 mm. The sand was also river sand with the grain size of 0-4 mm.

The rubber crumbs used to replace in different proportions the fine aggregate (FA) were provided by a local supplier. The crumbs resulted from heavy vehicle tyres shredding and are suitable for laboratory tests because they are free of impurities such as steel and textile fibres. The rubber crumbs have been sieved and sorted according to their maximum grain size in three sorts: 0-4 mm, 4-8 mm and 8-16 mm.

2.2. Methods

Four concrete mixes have been tested for this stage of the research. The concrete grade C30/37 was considered as the reference mix (Ref). For the other three mixes, the rubber crumbs replacement was of 40%, 60% and 80% by volume of the fine aggregates (0-4 mm). The water to cement ratio was of 0.47. The mix proportions for all the four concrete mixes are presented in Table 1.

Table 1. Mixture proportions of plain and rubberized concrete

Mix designation	*Cement*	*Water*	*Sand*	*Rubber crumbs*	*Coarse aggregate*	
	CEM I 42.5R			0-4 mm	4-8 mm	8-16 mm
	[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]
Ref	489	230	582	-	388	647
40%FA			532	50		
60%FA			514.8	67.2		
80%FA			492.4	89.6		
W/C	0.47					

A set of 33 cylinders having the dimensions of 100 mm×200 mm, was cast for each of the above mentioned concrete mixes. The casting and the curing conditions of the specimens have been in accordance with the standard recommendations [9]. The specimens were demoulded at 24 hours from the casting time and the tests have been carried out at two curing ages: 14 and 28 days.

At each of these curing ages 15 concrete specimens have been tested for the assessment of the modulus of elasticity in compression [10], as well as the compressive strength [11] closely following the standard provisions.

Three cylinders from each concrete mix were used to determine the complete characteristic curve at the curing age of 28 days.

The testing procedure and the equipment used to determine the stress-strain curve of concrete has been thoroughly described in a previous paper of the same authors [12].

2.3. Equipment

The device used for the static modulus of elasticity assessment is a compressometer-extensometer (see Figure 1).

The compressometer alone is used for evaluating deformation and strain characteristics of concrete cylinders while undergoing compression testing. The compressometer includes two cast aluminium-alloy yokes, mounting and central points, stainless steel control rods [13].

Fig. 1. Determination of the modulus of elasticity in compression.
a. The compressometer-extensometer assembly; **b.** The specimen instrumentation.

The concrete cylinder compressometer-extensometer is used to determine the static modulus of elasticity (Young's Modulus) and Poisson‘s ratio of concrete in compression. The combined compressometer and extensometer for concrete cylinders is a very useful device. It contains a third yoke located halfway between the two compressometer yokes and attached to the specimen at two diametrically opposite points. Middle yoke is hinged to allow the rotation of the two segments of the yoke in horizontal plane [13].

The instrument complies with the ASTM C469 specifications [14].

To solve the issue of determining the complete characteristic curve of materials, a special mechanical system was invented and patented [15] at the Faculty of Civil Engineering and Building Services from Iasi. The system can be attached to a common testing machine for uniaxial compression test to obtain reliable experimental results also for the post-peak range (see Figure 2) [12].

These results could be even more useful in case of rubberized concrete, where it can be anticipated a more extensive branch on the descending side of the stress-strain curve.

The tested specimens have been equipped with displacement transducers (LVDTs) and a loading cell. To ensure consistent data acquisition, it was necessary to fix the LVDTs on the testing machine plates. The top and the bottom faces of the specimens have been previously machined in order to obtain a perfect flat and smooth surface using specialized equipment.

This procedure was necessary to mitigate the friction between the cylinders and the testing machine plates, as much as possible.

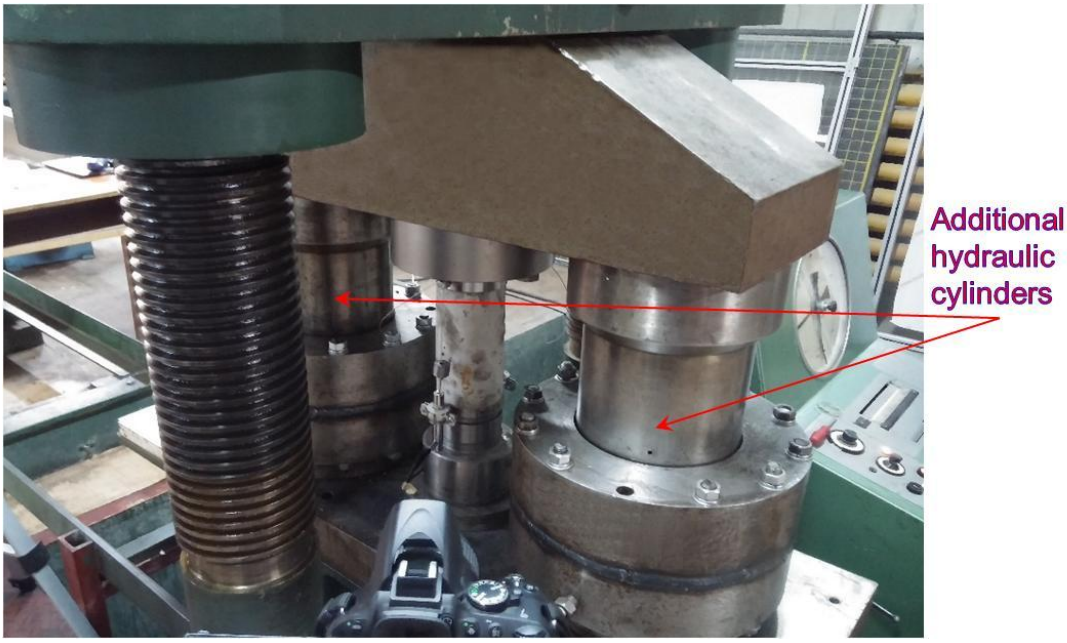

Fig. 2. The patented system used to determine the complete stress-strain curve.

3. Results and discussions

3.1. Compressive strength

The compressive strength has been determined at the ages of 14 and 28 days at a constant loading rate of 0.6 MPa/s, following the standard guidelines [11].

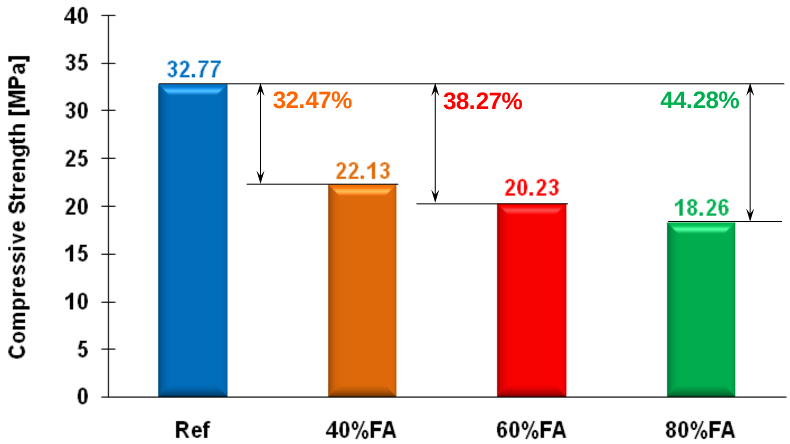

Fig. 3. The compressive strength of plain and rubberized concrete at 14 days.

The diagram from Figure 3 summarizes the obtained results for each concrete mix in terms of compressive strength at the age of 14 days. A sharp decrease of the compressive strength can be observed in case of rubberized concrete with respect to the reference mix (Ref), especially for the mix with 80% replacement with rubber crumbs by the volume of fine aggregate.

At the age of 28 days, the compressive strength of plain concrete and also of rubberized concrete increased, but there was still a difference with respect to the reference mix ranging between 33% and 41%, as shown in Figure 4 [16].

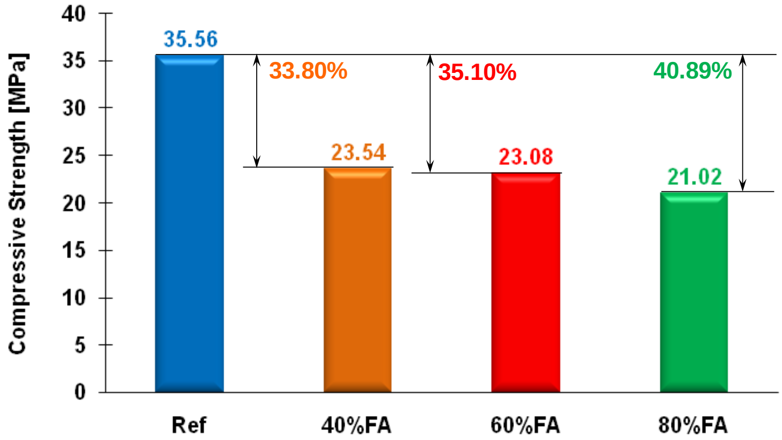

Fig. 4. The compressive strength of plain and rubberized concrete at 28 days.

3.2. Modulus of elasticity in compression

The modulus of elasticity in compression was determined according to the standard guidelines [10] at the curing ages of 14 and 28 days.

The obtained values at the age of 14 days are shown in the diagram from Figure 5. A similar decreasing tendency as with the compressive strength can be observed.

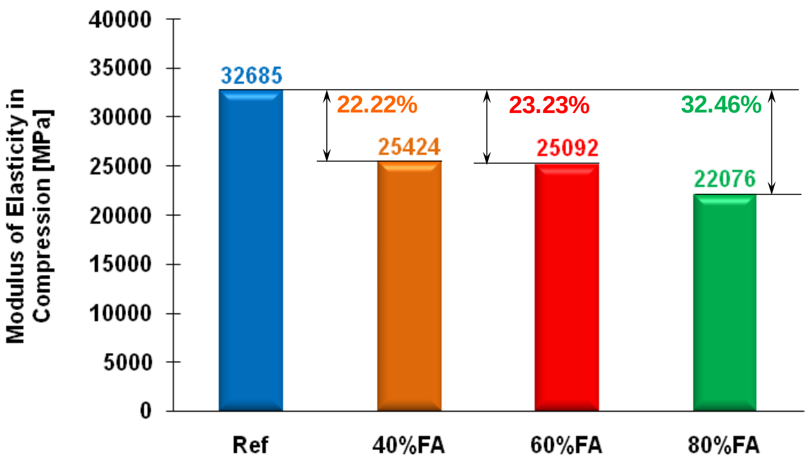

Fig. 5. The modulus of elasticity of plain and rubberized concrete at 14 days.

At the age of 28 days, higher values of the modulus of elasticity can be observed in case of all four concrete mixes, as shown in Figure 6. However, the differences with respect to the reference mix are slightly lower compared to the differences in terms of compressive strength, ranging between 23% and 29%, depending on the percentage of rubber crumbs added to the mix [16].

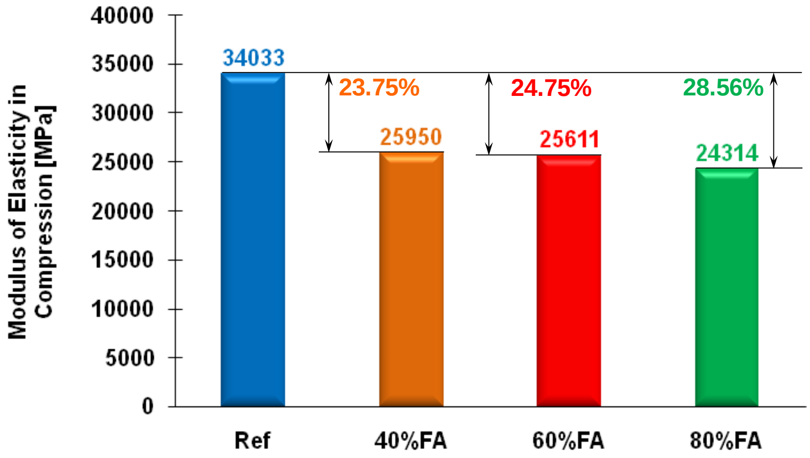

Fig. 6. The modulus of elasticity of plain and rubberized concrete at 28 days.

3.3. Complete stress-strain curve

The structural members subjected to extreme loads are expected to respond inelastically. The nonlinear response of structural systems depends on the redundancy of the structure, its ability to provide multiple load paths if a localized plastic behaviour develops, and the capacity of the structure to deform until the load is removed. This inelastic deformation capacity is termed its *ductility* [17].

The ductility of a structural member is typically associated with its capacity to dissipate significant amounts of post-peak strain energy and is an indicator of the extent to which a structure may deform before failure. Redundancy and ductility both contribute to the post-elastic capacity of a structure to resist extreme loads [18]. Consequently, the post-peak behaviour of materials is a very important feature when performing the structural analysis of systems subjected to seismic action that have to consider the post-elastic deformation capacity.

Based on the existing standard regulations [10], accurate data related to the post-peak behaviour of materials is very difficult to be obtained using the common testing machines. In case of the compression tests carried out on concrete specimens, the stress-strain curve is strongly affected after reaching the strength of the material, in the so called post-peak region. The sudden increase in the loading speed affects the displacement recordings.

To determine the complete characteristic curve of concrete by means of the patented system, a set of experimental tests has been carried out at the Faculty of Civil Engineering and Building Services Iasi. A number of 3 concrete cylinders per each of the four concrete mixes (see Table 1) have been tested at the curing age of 28 days. The final stress-strain curves for each concrete mix were obtained by averaging the results obtained on the 3 tested specimens.

Figure 7 summarizes the complete stress-strain curves constructed with the average values obtained for all the four concrete mixes.

It can be observed that by increasing the rubber content in concrete, results in a significant decrease of the compressive stress, but in a more gradual decrease of the stress-strain curve in the post-peak region compared to the reference mix.

The energy dissipation capacity may be assessed by determining the area under the complete stress-strain diagram. Since this area is much reduced on the last descending portion of the stress-strain diagram, at least in case of rubberized concrete, it is necessary to establish the point up to which the obtained information is relevant for practice. Based on the results of the activity carried out by our research team, it was concluded that a more appropriate approach is to plot the normalized stress-strain curves and the information from the curves could be considered useful up to the moment when the post-peak stress reaches 10% of the strength of the material on the descending side [12].

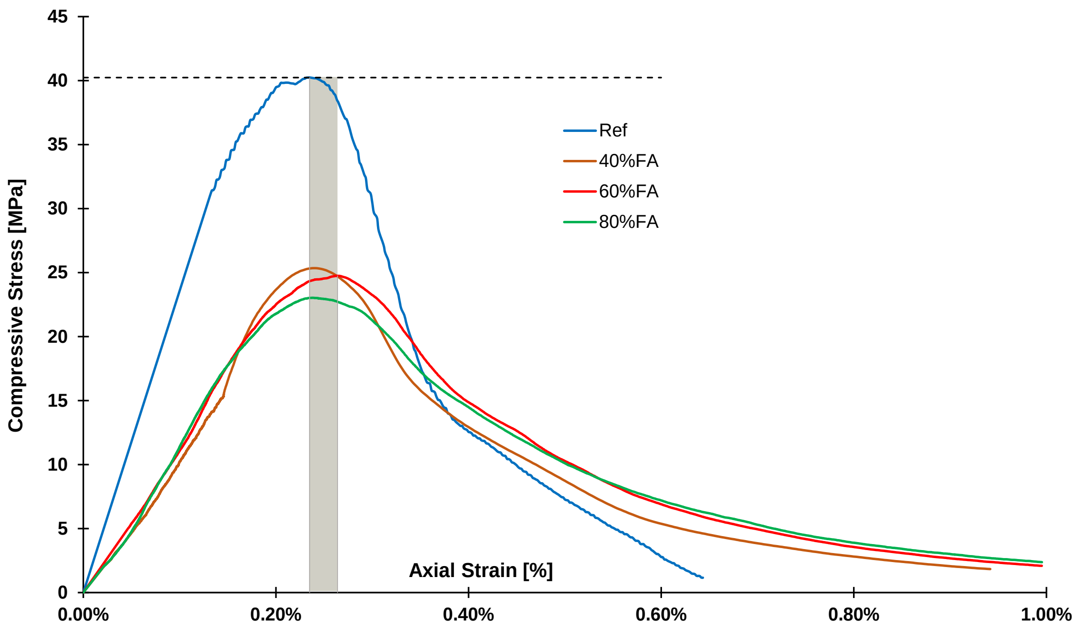

Fig. 7. The complete characteristic curves of plain and rubberized concrete.

The normalized stress-strain curves have been finally determined for all the 4 concrete mixes to achieve a better conclusion related to their energy dissipation capacity (see Figure 8). The information provided is of utmost importance. Now it can be seen that 50% of the strain energy of regular concrete is dissipated in the post-peak region. However, it can reach up to almost 70% in case of 80%FA mix.

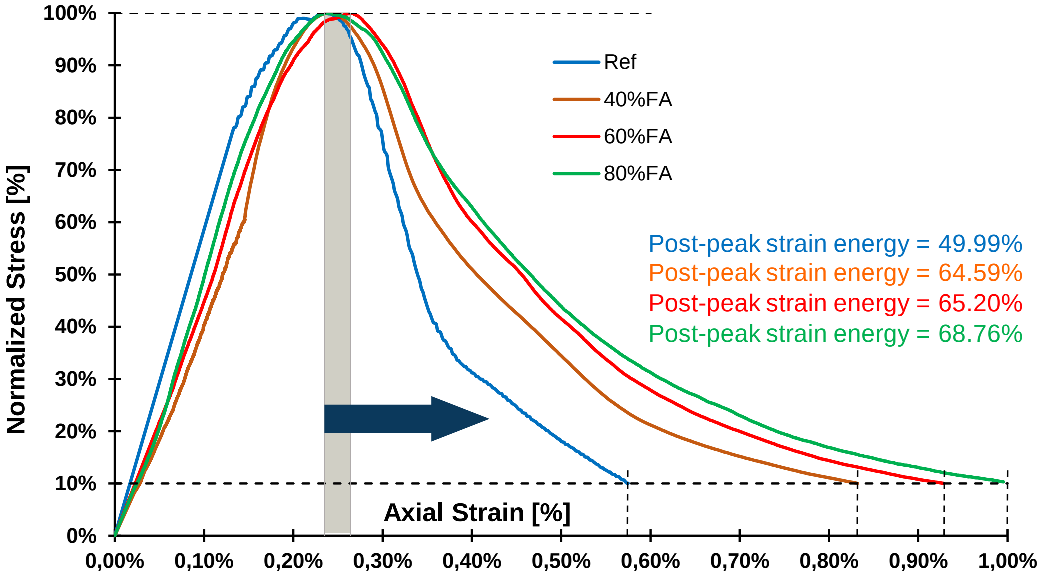

Fig. 8. Normalized stress-strain curves of plain and rubberized concrete.

4. Conclusions

The substitution of the natural resources with recycled materials, without affecting the needed mechanical properties of concrete, can substantially improve the environmental impact of concrete industry.

By embedding different quantities of rubber crumbs instead of normal fine aggregates in concrete, the general tendency is a decrease of the mechanical properties and an increase of deformability.

Increasing the rubber content in concrete results in a significant decrease of the compressive strength, but in a more gradual decrease of the stress-strain curve in the post-peak region compared to the plain concrete mix.

The complete characteristic curve provides relevant information related to the post-peak region in terms of energy dissipation capacity.

By increasing the rubber content from 40% to 80% by volume of fine aggregate, results in an increase of the strain energy stored by the concrete cylinders. In all studied cases, the stored strain energy is larger in the post-peak region and it can only be revealed when the complete stress-strain curve is plotted.

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