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ECO-FRIENDLY CONCRETE FROM WASTES

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Abstract

The paper presents the experimental results obtained on cement concrete with different types of waste and the analysis of their effects on density, compressive strength, flexural strength and splitting tensile strength. The tests results were compared with a control mix without aggregate substitution. The fly ash was used as replacement of cement and polystyrene granules, chopped plastic bottle (PET) and wood waste were used as substitution of 0-4 mm aggregate sort in different dosages from 0% to 100%. The density of mixes showed that the lightweight concrete was obtained for higher substitution of 0-4 mm aggregates for all mixes. The values of the mechanical properties for all mixes were lower than the values of control mix. Depending on the type and dosage of the substituted aggregate, the eco-concrete can be structural or non-structural.
The mix with PET showed higher values of the mechanical strengths compared to the value of the mixes with polystyrene granules and wood.

Key words: concrete, fly ash, mechanical properties, polystyrene, recycled plastic, wood waste

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1. Introduction

The building materials and construction industry try to satisfy the sustainable development criteria by recycling and use of wastes for minimizing their environmental impact. Sustainable structural engineering has to consider the ideas that the natural resources and energy involved in realizing and exploitation of buildings must be minimized (Motuzien et al., 2016). The concrete is a largely used material in construction and it has a great potential in sustainability because it can be developed in the future as green material having in view that it can be combined with different types of wastes such as fly ash, silica fume, ground granulated blast furnace slag, etc. (Barbuta et al., 2016; Habert et al., 2013; Mostofinejad et al., 2016; Rafieizonooz et al., 2016; Serbanoiu et al., 2017), recycled materials (demolished waste, post-consumer glass, used tires, PETs etc.), (Bignozzi et al., 2015; Blessen and Ramesh, 2016; Ciocan et al., 2017; Rahman et al., 2015), agro waste (rice husk, oil palm shell, bamboo leaves etc.) (Barbuta et al., 2009; Madurwar et al., 2013).

Concretes prepared with fly ash for replacing sand or cement in concrete showed compressive strength similar to that of ordinary concrete and the flexural and splitting tensile strengths were higher than that of the ordinary concrete. The main influence of fly ash on the properties of fresh concrete is in the reduction of water demand and improving workability. In combination with other additions fly ash concrete can present improved properties such as lower shrinkage and higher durability. (Dinakar et al., 2008; Leung et al., 2016). Concrete made with steel slag as replacement of aggregate had shown comparable or higher compressive strength, flexural strength and modulus of elasticity and that with waste

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glass presented a better workability and only a minor reduction of mechanical strengths (Bencardino et al., 2013; Faleschini et al., 2014; Pellegrino et al., 2013; Qasrawi et al., 2009). Both types of wastes presented excellent ability to improve fire resistance of concrete; also, glass powder can be used as replacement of cement which improve the mechanical and durability properties (Polley et al., 1998; Soares et al., 2014; Xin et al., 2016).

Recycled aggregates are used for obtaining concrete and numerous researches demonstrated that workability is not affected in comparison with ordinary concrete. Compressive strength can reach the same values as in the case of structural concrete by reducing the ratio water/cement. The values of the oxygen permeability coefficient and water penetration under pressure, obtained for the concrete with different substitution degrees of natural aggregates with recycled aggregates, are similar to those reported for the conventional concrete (Çakir, 2014; Simion et al., 2013; Thomas et al., 2014; Yazdi et al., 2015).

Another waste that is largely used in concrete is the used tires (Khaloo et al., 2008; Yilmaz and Nurhayat, 2009), case in which the failure under loads is more ductile. The mechanical characteristics of rubberized concrete are smaller than that of ordinary concrete, but these can be improved by adding some other materials, preferably wastes, like additions of silica fume, fly ash, lime etc. (Abaza and Hussein, 2015; Diaconescu et al., 2013) or fiber wastes, such as steel fiber, PET fiber, glass fiber, polystyrene fiber etc. (Carroll and Helminger, 2016; Noaman et al., 2016; Park et al., 2014; Rizzuti et al., 2014; Xie et al., 2015). The rubberized concrete presents instead a better behaviour under dynamic loads with a more ductile failure and a better resistance to abrasion (Noaman et al., 2016; Yazdi et al., 2015).

A huge problem for the environment is that of PET residues. By-products obtained from PET such as shredded particle, fibers, polymer can be used for obtaining eco-concrete. Concrete with additions of PET sub-products presents smaller mechanical strength than the ordinary concrete, but regarding the abrasion and corrosion resistance, impermeability these are improved and the PET fibers has a better control on the plastic shrinkage cracking. Used as replacement of aggregates, the mechanical properties of concrete with chopped PET wastes are comparable with that of lightweight aggregate, which recommends their use in lightweight concrete (Akçaözog˘lu et al., 2010; Albano et al., 2009; Gu and Ozbakkaloglu, 2016; Jahidul et al., 2016; Nabajyoti and Brito, 2014; Nhamo et al., 2016).

Natural wastes such as wood, cork, vegetable residues (corn, sun flower, rice husk, etc.) are used for obtaining eco-concrete as powder for cement replacing, as addition or substitution of aggregates (Jnyanendra et al., 2016; Jorge et al., 2016; Swaptik et al., 2015). The wood chippings can be used as aggregate substitution or as fibers in concrete. The researchers had shown that mechanical properties of concrete with wood waste are comparable with that of ordinary concrete and revealed the potential applications for acoustic and thermal insulation and fire resistance (Daian and Ozarska, 2009; Felix et al., 2013; Thandavamoorthy, 2016).

For obtaining lightweight concrete a lot of wastes such as: cork, vegetable residues, PET, expanded polystyrene etc. are used. (Herki et al., 2013; Kamlesh et al., 2016; Yi et al., 2012). The lightweight eco-concrete with polystyrene has some distinguished advantages like higher strength to weight ratio, better tensile strain capacity, lower coefficient of thermal expansion, and superior heat and sound insulation characteristics due to inclusion of air voids in the lightweight aggregate (Daneti et al., 2006; Kan and Demirboga, 2009; Ning and Bing, 2014). The wastes of different type are used for obtaining sustainable concrete as addition, replacement of cement, or substitution of aggregates. The principles for obtaining eco-concrete were applied in this work and the mechanical proprieties of concrete with wastes, type polystyrene, PET or wood, by substitution the aggregate in variable dosages was investigated.

2. Experimental program

2.1. Materials

For the experimental tests a mix of cement concrete was used as control. The components were the following: cement, 360 kg/m^3; aggregate sort 0-4 mm, 803.16 kg/m^3; sort 4-8 mm, 384.12 kg/m^3; and 8-16 mm, 558.72 kg/m^3. The density of aggregate was 2700 kg/m^3. The water was 180 l/m^3 and the MasterGlenium SKY 617 from BASF was used as super-plasticizer additive. The cement used for all mixes was CEM IIB-M-S-LL-42.5N, according to European Standard (EN 12390-1, 2012) with a density of 3000 kg/m^3. The mixes of eco-concrete with wastes were prepared with 10% fly ash as cement replacement and with different dosages of 20%, 40%, 60%, 80% and 100% as substitution of aggregate sort 0-4 mm with polystyrene granules, PET and wood waste. The diameter of polystyrene granules ranged between 1-4 mm with a unit weight of 1.6 kg/m^3.

PET wastes were obtained by cutting the bottles in small pieces with sizes between 1mm and 4 mm and an estimated unit weight of 433 kg/m^3. The wood waste derives from wood industry and has been sorted so that its dimensions ranged between 1 mm and 4 mm and the unit weight of 168 kg/m^3. The samples to which the aggregate sort 0-4 mm was replaced by polystyrene were noted A mixes (A1 to A5), the samples with PET were noted B mixes (B1 to B5) and samples with wood waste were noted C mixes (C1 to C5). The mixes were prepared on the base of control mix (Table 1).

All mixes were prepared by introducing firstly the dry components (aggregates, cement, and fly ash) in a mixer. After their mixing, the aggregate substitution was mixed with dry components and water plus superplasticizer were added.

Table 1. Components dosages of eco-friendly concrete mix

Sample	*Cement [kg/m³]*	*Water [l/m³]*	*Fly ash (10% from cement dosage) [kg/m³]*	*Sand [kg/m³]*	*Polystyrene granules substitution (in volume)*	*PET waste substitution (in volume)*	*Saw dust waste substitution (in volume)*	*Aggregate Sort 4-8 [kg/m³]*	*Aggregate Sort 8-16 [kg/m³]*	*Additive [l/m³]*
Control	360	180	-	803.1	-	-	-	384.1	558.7	3.60
A1	324	180	36	642.4	160.6	-	-	384.1	558.7	3.24
A2	324	180	36	481.8	321.2	-	-	384.1	558.7	3.24
A3	324	180	36	321.2	481.8	-	-	384.1	558.7	3.24
A4	324	180	36	160.6	642.4	-	-	384.1	558.7	3.24
A5	324	180	36	0	803.1	-	-	384.1	558.7	3.24
B1	324	180	36	642.4		160.6	-	384.1	558.7	3.24
B2	324	180	36	481.8		321.2	-	384.1	558.7	3.24
B3	324	180	36	321.2		481.8	-	384.1	558.7	3.24
B4	324	180	36	160.6		642.4	-	384.1	558.7	3.24
B5	324	180	36	0		803.1	-	384.1	558.7	3.24
C1	324	180	36	642.4		-	160.6	384.1	558.7	3.24
C2	324	180	36	481.8		-	321.2	384.1	558.7	3.24
C3	324	180	36	321.2		-	481.8	384.1	558.7	3.24
C4	324	180	36	160.6		-	642.4	384.1	558.7	3.24
C5	324	180	36	0		-	803.1	384.1	558.7	3.24

In the case of polystyrene granules, before mixing they were wet in half of mixing water. The wood wastes were also introduced in a small quantity of water for moistening. For all mixes the sample were prepared by placing the fresh concrete in cubic moulds with side of 150 mm, prisms of 100x100x550 mm sizes and cylinders of 100 mm diameter and 200 mm length.

The samples were kept at 20ºC for 28 days until testing for determining the compressive strength (f_c), flexural strength (f_{ti}) and splitting tensile strength (f_{td}) according to European Standard on three samples (EN 12390-3,5,6, 2012). The density of hardened concrete was also determined (EN 12390-7, 2012).

3. Results and discussions

The experimental tests had shown different types of failure depending to the substitution type used in the mix. In compression, a more ductile behaviour at failure presented the mixes with polystyrene granules. Some failure surfaces are shown in Fig. 1. It can be observed that the waste distribution in the concrete mass, is not uniform, consequently the values of mechanical strengths were influenced. In the case of mix the distribution of granules can be easily observed, but in the case of PET and wood their distribution can hardly be seen.

3.1. Concrete density

The concrete density ranged between 1510 and 2295 kg/m³ for fresh concrete and between 2187 and 1325 kg/m³ for hardened concrete, respectively. Increasing the substitution dosage, the density decrease (Fig. 2). All mixes presented densities under that of control mix that was 2288 kg/m³.

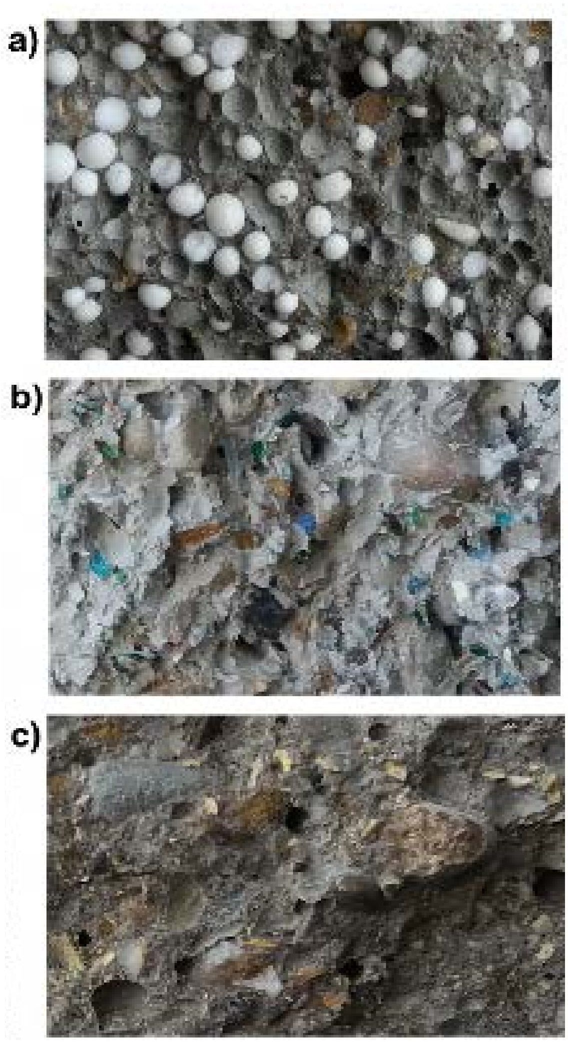

Fig. 1. Waste distribution in concrete for a substitution of 60%. a) Polystyrene granules; b) PET; c) Wood

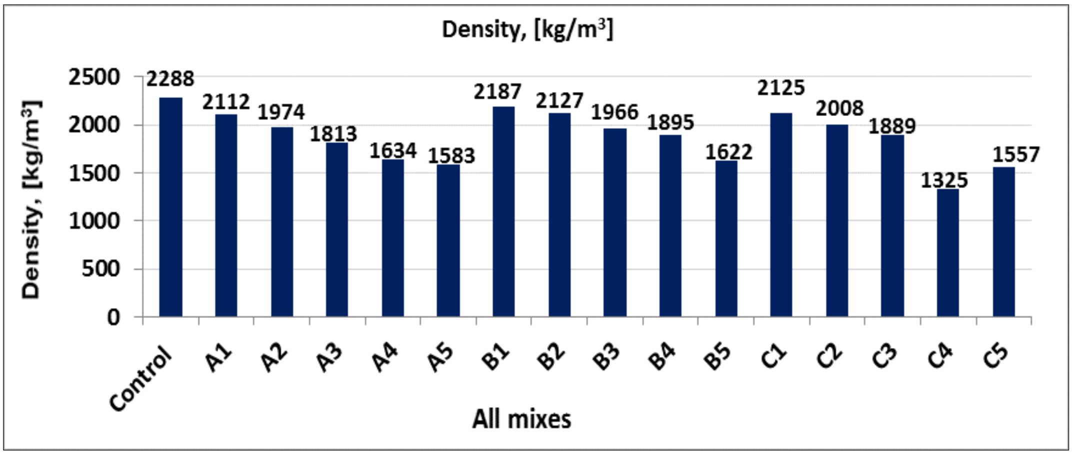

Fig. 2. Density of hardened concrete

In the case of Concrete A, the lightweight concrete with density under 2000 kg/m^3 is obtained for a dosage of polystyrene granule bigger than 40%. In the case of Concrete B and C the lightweight concrete is obtained for a dosage bigger than 60%.

3.2. Compressive strength

Comparing the results obtained on concrete with wastes substitution of aggregates with that of control mix it can observe that all values of compressive strengths are smaller than that of control, (Fig 3). All types of wastes are diminishing the compressive strength with increasing the substitution dosage. The highest value of f_c=25.19 N/mm^2 was obtained for mix B1. The smallest value of f_c=3.27 N/mm^2 was obtained for mix C5 (Fig. 3). Generally, when increase the dosage of aggregate substitution, the compressive strength of polymer concrete will decrease. The decrease in compressive strength is depending of the type of waste. For mixes A, the decrease in compressive strength was between 20.2% and 99%, in the case of mixes B was between 15.5% and 72.4% and in the case of mixes C between 25% and 89.1%.

All mixes B (with PET) presented higher values of compressive strength in comparison with mixes A (with Polystyrene granules) and C (with wood) (Fig. 3). The decrease of compressive strength function the substitution dosage can be observed in Fig. 4. For a substitution of aggregates:

- of 20%, the highest value of compressive strength was obtained for mix B, then was mix C and the smallest was for mix A.
- of 40%, the highest value of compressive strength was obtained for mix B, then was mix A and the smallest was for mix C.
- of 60%, the highest value of compressive strength was obtained for mix B, then was mix A and the smallest was for mix C.
- of 80%, the highest value of compressive strength was obtained for mix B, then was mix A and the smallest was for mix C.
- of 100%, the highest value of compressive strength was obtained for mix B, then was mix C and the smallest was for mix A.

The mix with PET waste presented the highest value of f_c for all substitution dosages. For 20% substitution it can observe that a better fc is obtained for wood in comparison with polystyrene granules. For the other dosages the mixes with polystyrene granules presented better compressive strength than mixes with wood.

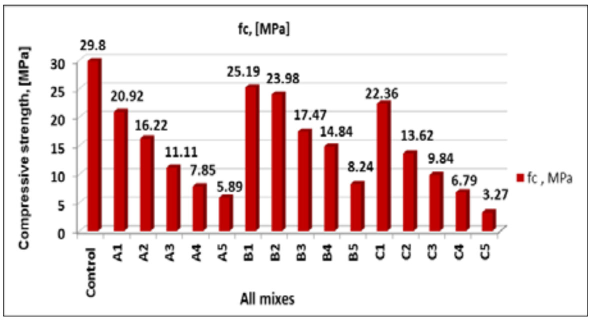

Fig. 3. Variation of compressive strength

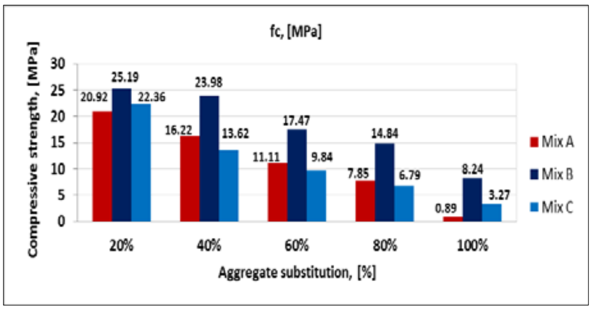

Fig. 4. Variation of compressive strength function of substitution dosage

3.3. Flexural strength

In the case of flexural strength all the values of f_{ti} for mixes with waste substitution were smaller than that of the control in percentages between 2.7% and 93.3% (Fig. 5). The highest value, f_{ti}=1.87 N/mm^2 was obtained for Mix C1 (with 20% wood substitution) and the smallest, f_{ti}=0.13 N/mm^2 was for mix C5 (with 100% wood substitution). At mixes A1 with polystyrene granules it can observe that the flexural strength decreases with increasing of substitution dosage. In the case of mixes B (PET substitution) and C (wood substitution), there are variations in values of fti, because probably the homogeneity of the mixture is more important than the substitution dosage.

A comparison between the substitution types function the substitution dosage is presented in Fig. 6. The mix with wood waste presented the highest value of f_{ti} for substitution dosages of 20% and 80%. The mix with Pet presented highest value of f_{ti} for substitution dosages of 40%, 60% and 100%.

3.4. Splitting tensile strength

In the case of splitting tensile strength all the values of f_{ti} for mixes with waste substitution were smaller than that of the control mix. The highest value of f_{ti}= 1.52 N/mm^2, was obtained for Mix A2 (with 40% polystyrene substitution) and the smallest (f_{ti}=0.03 N/mm^2) was for mix C5 (with 100% wood substitution), (Fig. 7).

For all mixes A, B and C there are variations in values of f_{td}, probably the homogeneity of the mixture is more important than the substitution dosage. A comparison between the substitution types function the substitution dosage is presented in Fig. 8.

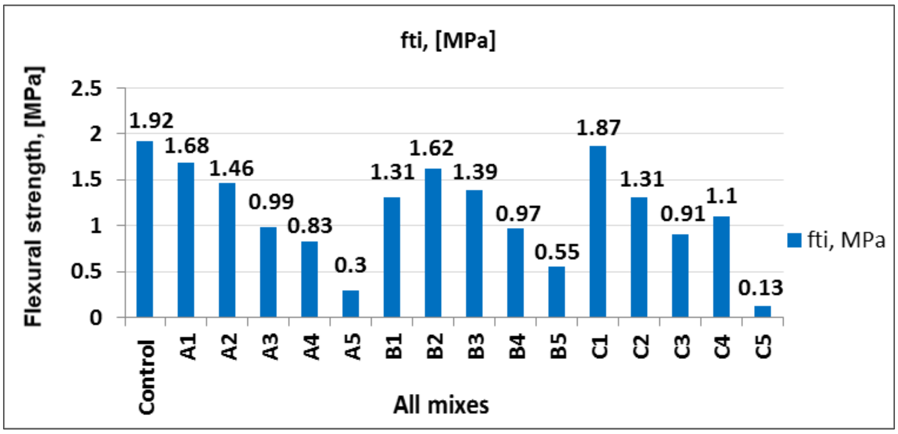

Fig. 5. Variation of flexural strength

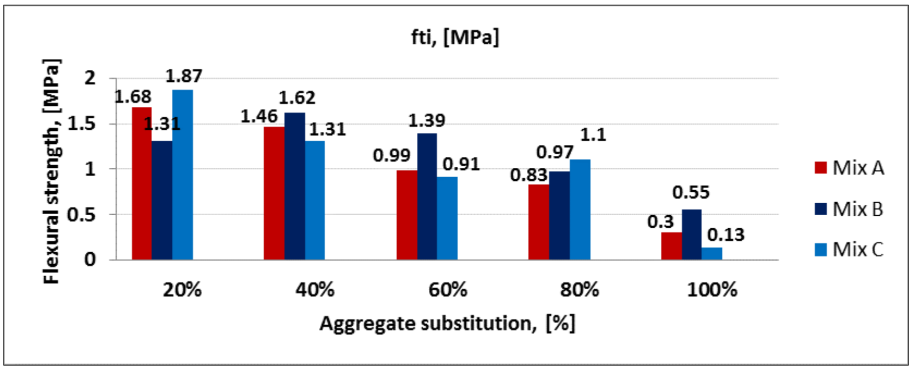

Fig. 6. Variation of flexural strength function the substitution dosage

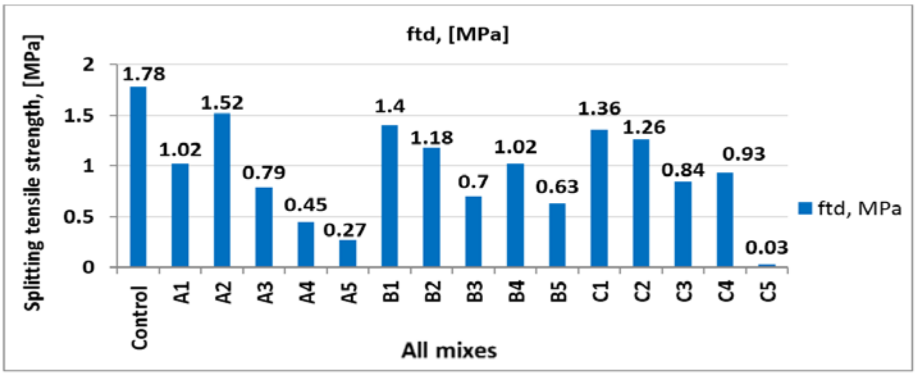

Fig. 7. Variation of splitting tensile strength

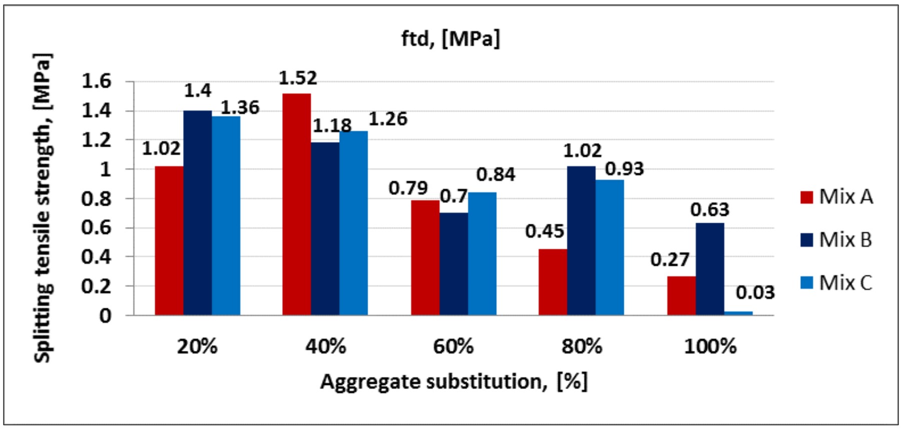

Fig. 8. Variation of splitting tensile strength function the substitution dosage

The mix with polystyrene waste presented the highest value of f_{td} for substitution dosages of 40% and 60%. The mix with PET presented highest value of f_{td} for substitution dosages of 20% and 80%.

4. Conclusions

In the experimental program, three types of wastes (Polystyrene granules, PET and Wood) were used as substitution of aggregate sort 0-4 mm in dosages from 0 to 100%. From tests resulted that all densities and mechanical properties were under the values of control mix. The lightweight concrete is obtained in the case of concrete A for a dosage of polystyrene granule bigger than 40% and in the case of concrete B and C for a dosage of substitution bigger than 60%.

The homogeneity of the mixture is more important than the substitution dosage in the case of mechanical properties. The compressive strength had good values for small substitution ratio: for polystyrene and wood a percentage of 20% is recommended and for PET the percentage can be under 40%, case in which the concrete can be used as structural concrete. For higher substitution percentages all types of concrete are lightweight concrete, case in which they can be used for non-structural elements or for thermal and acoustic protection.

In the case of the flexural strength and splitting tensile strength the decrease in strength with increasing of substitution dosage was not in direct proportionality as in the case of compressive strength, the mix homogeneity having a significant influence on test values. Function the type of the substitution, the mixes B (with PET) presented highest mechanical strength in comparison with other types of substitution (polystyrene granules and wood). On the base of present studies, it can conclude that wastes type polystyrene granules, PET or wood can be used in eco-concrete production as structural or non-structural concrete in developing future sustainable constructions.

References

Abaza O.A., Hussein Z.S., (2015), Flexural behavior of steel fiber-reinforced rubberized concrete, *Journal of Materials in Civil Engineering*, **28**, 04015076.

Akçaözogˇlu S., Atis C.D., Akçaözogˇlu K., (2010), An investigation on the use of shredded waste PET bottles as aggregate in lightweight concrete, *Waste Management*, **30**, 285–290.

Albano C., Camacho N., Hernández M., Matheus A., Gutiérrez A., (2009), Influence of content and particle size of waste pet bottles on concrete behavior at different w/c ratios, *Waste Management*, **29**, 2707–2716.

Barbuta M., Taranu N., Harja M., (2009), Wastes used in obtaining polymer composite, *Environmental Engineering and Management Journal*, **8**, 1145-1150.

Barbuta M., Bucur R.D., Serbanoiu A.A., Helepciuc C., Scutarasu S., Burlacu A., (2016), Combined effect of fly ash and fibers on properties of cement concrete, *The 10th International Conference INTER-ENG 2016 Interdisciplinarity in Engineering*, "Petru Maior" University of Targu-Mureş Romania, **181**, 280-284.

Bencardino F., Rizzuti L., Spadea G., Swamyc, R.N., (2013), Implications of test methodology on post-cracking and fracture behaviour of Steel Fibre Reinforced Concrete, *Composites Part B: Engineering*, **46**, 31-38.

Bignozzi M.C., Saccani A., Barbieri L., Lancellotti I., (2015), Glass waste as supplementary cementing materials: The effects of glass chemical composition, *Cement & Concrete Composites*, **55**, 45-52.

Blessen S.T., Ramesh C.G., (2016), Properties of high strength concrete containing scrap tire rubber, *Journal of Cleaner Production*, **113**, 86-92.

Çakir O., (2014), Experimental analysis of properties of recycled coarse aggregate (RCA) concrete with mineral additives, *Construction Building Materials*, **68**, 17–25.

Carroll J.C., Helminger N., (2016), Fresh and hardened properties of fiber-reinforced rubber concrete, *Journal of Materials in Civil Engineering*, 04016027, doi: https://org/10.1061/(ASCE)MT.1943-5533.0001541.

Ciocan V., Serbanoiu A.A., Dragoi E.N., Curteanu S., Burlacu A., (2017), Optimization of glass fibers used as disperse reinforcement of epoxy polymer concrete with fly ash, *Environmental Engineering and Management Journal*, **16**, 1115-1121.

Daian G., Ozarska B., (2009), Wood waste management practices and strategies to increase sustainability standards in the Australian wooden furniture manufacturing sector, *Journal of Cleaner Production*, **17**, 1594-1602.

Daneti S.B.K., Ganesh B.K., Wee T.-H., (2006), Effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete, *Cement & Concrete Composites*, **28**, 520-527.

Diaconescu R.M., Barbuta M., Harja M., (2013), Prediction of properties of polymer concrete with tyre rubber using neural network, *Materials Science Engineering*, B, **178**, 1259-1267,

Dinakar P., Babu K.G., Santhanam M., (2008), Durability properties of high volume fly ash selfcompacting concrete, *Cement & Concrete Composites*, **30**, 880-886.

EN 12390-1, (2012), Testing hardened concrete, Part 1: Shape, dimensions and other requirements for specimens and moulds, On line at: https://infostore.saiglobal.com/preview/is/en/2000/i.s.en12390-1-2000%2Bac-2004.pdf?sku=569566.

EN 12390-3, (2012), Testing hardened concrete. Part 3: Compressive strength of test specimens, On line at: https://www.scirp.org/(S(vtj3fa45qm1ean45vvffcz55))/reference/ReferencesPapers.aspx?ReferenceID=1884343.

EN 12390-5, (2012), Testing hardened concrete. Part 5: Flexural strength of test specimens, On line at: https://www.researchgate.net/publication/306204484_Testing_Hardened_Concrete_-_Part_5_Flexural_Strength_of_Test_Specimens_Testing_Hardened_Concrete

EN 12390-6, (2012), Testing hardened concrete. Part 6: Tensile splitting strength of test specimens, On line at: https://www.sis.se/api/document/preview/71970/.

EN 12390-7, (2012), Testing hardened concrete. Part 7: Density of hardened concrete, On line at: https://standards.globalspec.com/std/1171993/cen-en-12390-7.

Faleschini P., De Marzi P., Pellegrino C., (2014), Recycled concrete containing EAF slag: environmental assessment through LCA, *European Journal of Environmental and Civil Engineering*, **18**, 1009-1024.

Felix J.S., Domeno C., Nerín C., (2013) Characterization of wood plastic composites made from landfill-derived plastic and sawdust: volatile compounds and olfactometric analysis, *Waste Management*, **33**, 645-655.

Gu L., Ozbakkaloglu T., (2016), Use of recycled plastics in concrete: A critical review, *Waste Management*, **51**, 19-42.

Habert G., Denarié E., Šajna A., Rossi P., (2013), Lowering the global warming impact of bridge rehabilitations by using Ultra High Performance Fibre Reinforced Concretes, *Cement & Concrete Composites*, **38**, 1-11.

Herki B.A., Khatib J.M., Negim E.M., (2013), Lightweight concrete made from waste polystyrene and fly ash, *World Applied Sciences Journal*, **21**,1356-1360.

Jahidul I.Md., Salamah M.Md., Rakinul A.K.M., (2016), Effects of waste PET as coarse aggregate on the fresh and harden properties of concrete, *Construction and Building Materials*, **125**, 946-951.

Jnyanendra K.P., Sanjaya K.P., Basarkar S.S., (2016), Concrete using agro-waste as fine aggregate for sustainable built environment – A review, *International Journal of Sustainable Built Environment*, **5**, 312–333.

Jorge S.-P., Ignacio L.-F., Jesús B.-R., Xavier G., (2016), Introducing eco-ideation and creativity techniques to increase and diversify the applications of eco-materials: The case of cork in the building sector, *Journal of Cleaner Production*, **137**, 606-616.

Kamlesh S., Vijay C., Ankush B., Harshit A., Meghalal R., Sandeep S., (2016), Effect on strength properties of concrete by using waste wood powder as partial replacement of cement, *SSRG International Journal of Civil Engineering* (SSRG-IJCE), **3**, 172.

Kan A., Demirboga R., (2009) A new technique of processing for waste expanded polystyrene foams as aggregates, *Journal of Materials Processing Technology*, **206**, 2994-3000.

Khaloo A.R., Dehestani M., Rahmatabadi P., (2008), Mechanical properties of concrete containing a high volume of tire-rubber particles, *Waste Management*, **28**, 2472-2482.

Leung H.Y., Kim J., Nadeem A., Jayaprakash J., Anwar M.P., (2016) Sorptivity of self-compacting concrete containing fly ash and silica fume, *Construction and Building Materials*, **113**, 369-375.

Madurwar M. V., Ralegaonkar R. V., Mandavgane S. A., (2013), Application of agro-waste for sustainable construction materials: a review, *Construction and Building Materials*, **38**, 872–878.

Mostofinejad D., Nosouhian F., Nazari-Monfared H., (2016), Influence of magnesium sulphate concentration on durability of concrete containing micro-silica, slag and limestone powder using durability index, *Construction and Building Materials*, **117**, 107–120.

Motuzien V., Rogoza A., Lapinskiene V., Vilutiene T., (2016), Construction solutions for energy efficient single-family house based on its life cycle multi-criteria analysis: a case study, *Journal of Cleaner Production*, **112**, 532-541.

Nabajyoti S., de Brito J., (2014), Mechanical properties and abrasion behavior of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate, *Construction and Building Materials*, **52**, 236-244.

Nhamo C., Willis G., Tavengwa B., Deborah T. R., Innocent P., (2016), Potential uses and value-added products derived from waste polystyrene in developing countries: A review, *Resources, Conservation and Recycling*, **107**, 157-165.

Ning L., Bing C., (2014), Experimental study of the influence of EPS particle size on the mechanical properties of EPS lightweight concrete, *Construction and Building Materials*, **68**, 227-232.

Noaman A.T., Abu Bakar B.H., Hazizan Md. A., (2016) Experimental investigation on compression toughness of rubberized steel fibre concrete, *Construction and Building Materials*, **115**, 163-170.

Park Y., Abolmaali A., Mohammadagha M., Lee S., (2014), Flexural characteristic of rubberized hybrid concrete reinforced with steel and synthetic fibers, *Advances in Civil Engineering Materials*, **3**, 495-508.

Pellegrino C., Cavagnis P., Faleschini F., Brunelli K., (2013), Properties of concretes with black/oxidizing electric arc furnace slag aggregate, *Cement & Concrete Composites*, **37**, 232–240.

Polley C., Cramer S.M., de la Cruz R.V., (1998), Potential for using waste glass in Portland cement concrete, *Journal of Materials in Civil Engineering*, **10**, 210-219.

Qasrawi H., Shalabi F., Asi I., (2009), Use of low CaO unprocessed steel slag in concrete as fine aggregate, *Construction and Building Materials*, **23**, 1118-1125.

Rafieizonooz M., Mirza J., Razman Salim M., Warid Hussin M., Khankhaje E., (2016), Investigation of coal bottom ash and fly ash in concrete as replacement for sand and cement, *Construction and Building Materials*, **116**, 15-24.

Rahman A.Md., Imteaz M.A., Arulrajah A., Piratheepan J., Miri Disfani M., (2015) Recycled construction and demolition materials in permeable pavement systems: geotechnical and hydraulic characteristics, *Journal of Cleaner Production*, **90**, 183-194.

Rizzuti L., Bencardino F., (2014), Effects of fibre volume fraction on the compressive and flexural experimental behaviour of SFRC, *Contemporary Engineering Sciences*, **7**, Issue 5-8, 379-390.

Serbanoiu A.A., Barbuta M., Burlacu A., Gradinaru C.M., (2017), Fly ash cement concrete with steel fibers - comparative study, *Environmental Engineering and Management Journal*, **16**, 1123-1128.

Simion I.M., Ghinea C., Maxineasa S.G., Taranu N., Bonoli A., Gavrilescu M., (2013), Ecological footprint applied in the assessment of construction and demolition waste integrated management, *Environmental Engineering and Management Journal*, **12**, 779-788.

Soares D., de Brito J., Ferreira J., Pacheco J., (2014), Use of coarse recycled aggregates from precast concrete rejects: mechanical and durability performance, *Construction and Building Materials*, **71**, 263-272.

Swaptik C., Mihir M., Om S., (2015), The incorporation of wood waste ash as a partial cement replacement material for making structural grade concrete: An overview, *Ain Shams Engineering Journal*, **6**, 429-437.

Thandavamoorthy T.S., (2016), Wood waste as coarse aggregate in the production of concrete, *European Journal of Environmental and Civil Engineering*, **20**, 125-141.

Thomas C., Sosa I., Setién J., Polanco J.A., Cimentada A.I., (2014), Evaluation of the fatigue behaviour of recycled aggregate concrete, *Journal of Cleaner Production*, **65**, 397-405.

Xie J.-H., Guo., Y.-C., Liu L.-S., Xie Z.-H., (2015), Compressive and flexural behaviours of a new steel-fibre-reinforced recycled aggregate concrete with crumb rubber, *Construction and Building Materials*, **79**, 263-272.

Xin Y., Zhong T., Tian-Yi S., Zhu P., (2016), Performance of concrete made with steel slag and waste glass, *Construction and Building Materials*, **114**, 737-746.

Yazdi M.A., Yang J., Yihui L., Su H., (2015), A review on application of waste tire in concrete, *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, **9**, On line at: http://waset.org/publications/10003388/a-review-on-application-of-waste-tire-in-concrete.

Yi X., Linhua J., Jinxia X., Yang L., (2012), Mechanical properties of expanded polystyrene lightweight aggregate concrete and brick, *Construction and Building Materials*, **27**, 32-38.

Yilmaz A., Nurhayat D., (2009), Possibility of using waste tire rubber and fly ash with Portland cement as construction materials, *Waste Management*, **29**, 1541-1546.