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Mechanical behavior of sustainable building materials using PET waste and industrial by-products

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Abstract

The building industry is facing the challenge of satisfying a growing demand for housing spaces that can be mitigated by the use of construction materials manufactured with industrial by-products that allow the production of low-cost housing with a low environmental impact. In this research, an alternative building system to manufacture lightweight masonry blocks with polyethylene terephthalate (PET) bottles and fiber-reinforced panels using binary mixture (Portland cement and fly ash), was studied. This building system was tested under compressive and flexural loads until failure. The average design compressive strengths of concrete blocks for w/c ratios of 0.78 and 1.1 were fp^* = 1.9 and 1.2 MPa respectively, these results were similar to those typical masonry in accordance with the design and construction standards. On the other hand, the flexural strength, the modulus of elasticity and the stiffness on mid span of the fiber-reinforced concrete panels were improved with adding 20% of fly ash to both w/c ratios, mainly at 120 days. The experimental results obtained show that those building elements are viable alternatives with mechanical properties comparable to traditional building systems, besides the reduction of the environmental impact due to the incorporation of industrial waste materials.

Keywords: PET waste; flay ash; natural fiber; masonry.

Comportamiento mecánico de materiales de construcción sustentables a base de desechos de PET y subproductos industriales

Resumen

La industria de la construcción enfrenta el desafío de satisfacer una creciente demanda de espacios habitacionales que puede ser mitigado con el uso de materiales a base de subproductos industriales que permita la producción de vivienda de bajo costo e impacto ambiental. En esta investigación se estudió un sistema constructivo alternativo de fabricar bloques de mampostería aligerada con botellas de PET y páneles fibroreforzados utilizando concretos binarios (cemento y ceniza volante). El sistema constructivo fue ensayado bajo cargas de compresión y flexión hasta su falla. El promedio de la resistencia a compresión de diseño, para bloques de concreto con relaciones a/c de 0.78 y 1.1 resultó de fp^* = 1.9 y 1.2 MPa respectivamente, estos resultados son comparables con la mampostería típica según los estándares de diseño y construcción. Por otro lado, la resistencia a la flexión, el módulo de elasticidad y la rigidez al centro del claro de paneles de concreto fibroreforzado, se mejoraron con la adición del 20% de ceniza volante para ambas relaciones a/c principalmente a 120 días. Los resultados experimentales encontrados muestran que estos elementos constructivos son alternativas viables con propiedades mecánicas comparables a los sistemas de construcción tradicionales, además de reducir el impacto ambiental debido a la incorporación de materiales de desecho industrial.

Palabras clave: desechos de PET; ceniza volante; fibras naturales; mampostería.

1. Introduction

The building industry’s concern to promote a sustainable environment has caused a change in the community awareness regarding current construction techniques. Building materials research has focused on providing sustainable solutions to this problem. As a result, the current meaning of a sustainable building, understood as one that reflects the environmental impact of all of the processes involved in the construction of a structure, is being questioned. The implementation of low cost and low environmental impact materials and building methods as a solution to the imminent demand for basic housing in countries with emerging economies is a major global concern because housing to accommodate 65 million people should be offered annually in the coming years according previous studies [1]. This figure implies the construction of 15 million new houses, i.e., approximately 600 million new squares meters or its equivalent, to produce and use approximately 400 million cubic meters or one billion tons of materials, components and subsystems annually only to meet the construction of new housing.

According to this scenario, considering the impact of increasing CO_2 emissions, energy consumption, the exploitation of natural resources, sustainability issues and other factors involved in the production of materials and construction of these new housing developments is a priority. Therefore, current efforts aim to apply new sustainable processes to housing construction. For example, the reuse and recycling of polluting by-products as building materials, such as recycled aggregates [2,3], metallic copper and steel slag [4,5,6], fly ash (FA), and plastic [7], has been increasing. These materials are included in the cementitious matrix as additions, providing an environmentally friendly alternative to concrete production.

Conversely, the plastics industry generates a considerable amount of contaminants and low degradation by-products that have not been fully explored as an alternative for reuse. Therefore, this research aims to find an application in the construction area of a particular type of plastic, PET, which becomes waste after its use. Studies have been conducted to examine the application of PET in light landfills [8], as a partial replacement of fine aggregate in concrete when ground [9], as a binder [10,11,12], or as a fiber when crushed [13,14], where chemical degradation was observed as a result of its reaction with the calcium hydroxide $Ca(OH)_2$ after being embedded in the cementitious matrix [15]. Thus, the present study intends to explore the mechanical behavior of two building elements with a low environmental impact.

2. Importance of the research

During the development of low-cost buildings, different raw materials have been used to obtain materials with a low environmental impact, such as soil-cement blocks [16], clay based compressed earth blocks, Portland cement as an stabilizer and cactus mucilage with water as a mixing material [17]. An increase in the utilization of green materials or environmentally friendly materials in low-income housing is expected in the coming years to reduce their cost and CO_2 emissions; an example of these materials are natural fibers, which can be used as reinforcement in the cementitious matrix. By studying their physical-mechanical properties, morphology and durability, they can become an economical and sustainable alternative for steel reinforcement substitution [18,19, 20]. To this end, the objective of this research was to propose a cement-based building system with low environmental impact and adequate mechanical behavior that complies with current local quality standards. As such, this study examined blocks that reutilize an industrial waste (PET bottles) and binary concrete panels (Portland cement + FA) reinforced with natural fibers.

3. Experimental procedure

3.1. Materials

Cementitious materials

Portland cement CPC 30R was used in accordance with the Mexican specification NMX C-414; its density was 3.02 g/cm^3, as determined according to ASTM C188. A cementitious material in addition FA Type F was used. The chemical compositions of the cement and FA are shown in Table 1.

Table 1

Chemical composition of cementitious materials (% in mass)

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O
Fly ash	63.93	24.32	4.29	2.34	0.78	0.20
Portland cement	17.55	4.7	1.77	64.74	1.23	0.37

Aggregates

Crushed limestone aggregates from the region were used. The physical properties of coarse and fine aggregates are shown in Table 2 and were determined according to ASTM C127 and C128, respectively. The grading was determined according to ASTM C136 and complied with ASTM C33, as shown in Table 3.

Aggregates

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Table 2
Physical properties of aggregates.

Aggregate type	Bulk density kg/m^3	Dry weight kg/m^3	Absorption (%)	Specific density kg/m^3	Moisture content (%)	Fineness modulus
Fine	1651	2617	1.63	2660	0.1	2.71
Coarse	1453	2666	0.3	2674	0.05	

Table 3
Aggregates grading

Aggregate type	Percent passing (sieve in mm)							
	0.15	0.30	0.60	1.18	2.36	4.75	9.50	12.50
Fine	8.40	22.40	35.60	63.70	98.80	100.00	100.00	
Coarse					7.57	45.02	99.20	100.00

PET Bottles

Empty 2.0 l PET bottles with a 100-mm diameter at the largest point and 320-mm height were used. The bottles were cleaned with drinking water prior to embedment in the concrete matrix. The PET physical and mechanical properties are shown in Table 4.

Table 4
PET Physical properties [21,22,23]

Material	Bulk density kg/m^3	Compressive strength MPa	Bending strength MPa	Fracture resistance MPa	Tensile strength MPa	Elongation (%)	Poisson ratio
PET	1350	26-48	145	59.30	48.3-72.4	30-300	0.33

Natural fibers grid

A natural fiber from the *Agave lechuguilla* family was used to fabricate a textile type grid of 955×555 mm. The ultimate tensile strength of the natural fiber has been reported between 200 to 600 MPa. [20]. The joining of the longitudinal and transverse segments for the mesh was achieved using a polymeric adhesive applied at the points of contact. The adhesive was allowed to dry 24 h at a temperature of 23ºC in a laboratory environment. The longitudinal and transversal segments were separated every 65 and 55 mm respectively. The grid was oven dried at 100°C, subsequently coated with a protective paraffin base solution and allowed to dry at room temperature for 30 min.

3.2. Specimens molding

Concrete blocks

To mold the blocks, two mixtures with water/cement ratios (w/c) of 0.78 and 1.1 were prepared (Table 5). To determine the compressive strength, the mixtures were poured in 100-mm diameter metallic cylindrical molds. The mixtures were cast in metallic prismatic molds to make the blocks. The molds used to fabricate the blocks are shown in Figure 1. Figure 2 shows the schematic dimensions and arrangement of the six 2.0 l PET bottles that were embedded in the concrete matrix.

Table 5

Concrete mixtures proportioning, kg/m^3

Material	Blocks		Panels							
w/c ratio	0.78	1.1	0.65				0.75			
Number of specimens	5	6	8	8	8	8	8	8	8	8
Total water	204	220	229	229	229	229	263	263	263	263
Cement	260	204	350	280	210	140	350	280	210	140
Fly ash	0	0	0	70	140	210	0	70	140	210
Coarse aggregate	946	972	705	698	690	682	667	659	651	644
Fine aggregate	854	890	1055	1043	1032	1020	998	986	975	963
Slump (mm)	70	80	90	105	115	130	235	245	255	265

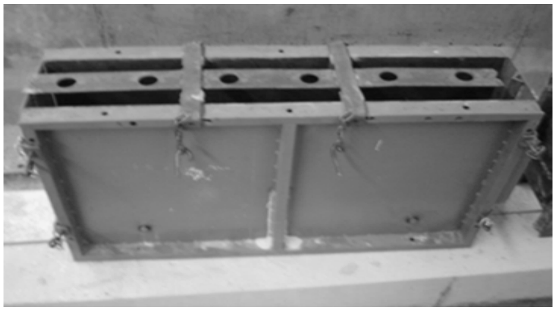

Figure 1. Block mold for PET bottles.

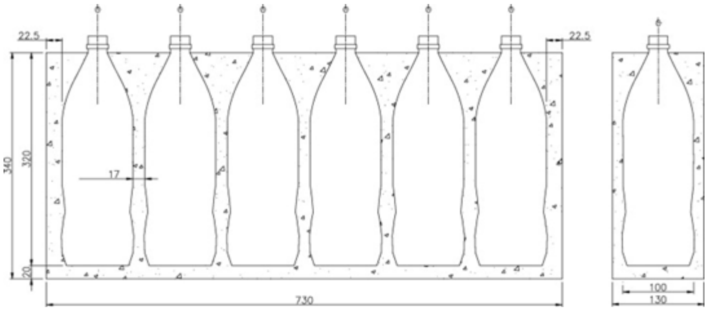

Figure 2. Dimensions of the block lightened with PET

The cylindrical and block specimens remained in their molds during the first 24 h to avoid the loss of humidity; they were subsequently standard cured until the age of testing. The mixing, casting and curing procedures were in accordance to ASTM C192.

Concrete panels

Two sets of thirty-two 960x560x50 mm panels reinforced with natural fiber grid were fabricated and to evaluate the compressive strength, three sets of 100-mm diameter concrete cylinders were tested. Two w/c ratios of 0.65 and 0.75, as well as FA in substitution at 20, 40 and 60% were used. The compositions of the concrete mixtures are shown in Table 5. The mixing procedure was performed in accordance with ASTM C192, and the slump test was performed according to ASTM C143. The panels were fabricated in wooden formworks. The mixture was placed in two layers of approximately 25 mm each, and each layer was compacted 15 times with a rubber mallet. The natural fiber-reinforced grid remained embedded in the middle part of the panel. A final compaction was performed using a vibrating table for 1 min.

3.3. Test methods

Concrete cylinders of all w/c ratios and FA percentages were tested for compression at all studied ages (1, 3, 7, 14, 28, 56 and 84 days) according to ASTM C 39. Concrete blocks were tested to determine their design compressive strength, using equation 1 from the current regulation [24].

$$fp^* = \frac{\overline{fp}}{1 + 2.5cp} \qquad (1)$$

Where

fp^* = Design compressive strength, (MPa).

$\overline{fp}$ = Mean compressive strength of the pieces; it refers to the gross surface, (MPa).

cp = Coefficient of variation for the compressive strength.

The fiber-reinforced concrete panels were tested for flexural strength, applying loads to a third of the panel. The span length was 900 mm; the strain was measured at the mid span using a transducer with a maximum range of 50 mm. Figure 3 shows the arrangement for the flexure test of the panels.

Figure 3. Arrangement for the flexure test of the fiber-reinforced panels.

4. Experimental results and discussion

4.1. Compressive strength of concrete

Figure 4 and 5 shows the compressive strength of the concrete cylinders obtained during the fabrication of the blocks and fiber-reinforced panels for all w/c ratios and different ages.

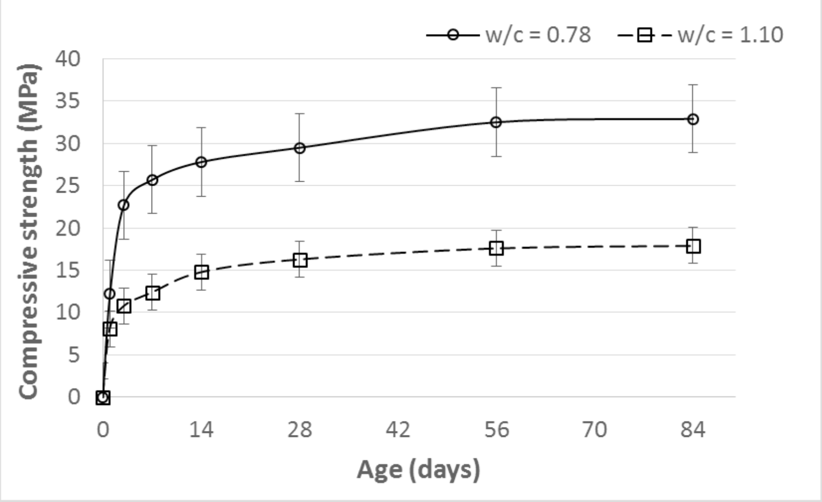

Figure 4 . Compressive strength of concrete cylinders used for the production of blocks.

Figure 5 shows that adding 20% of FA to both w/c ratios increase the compressive strength compared to the control specimens mainly an age of 120 days.

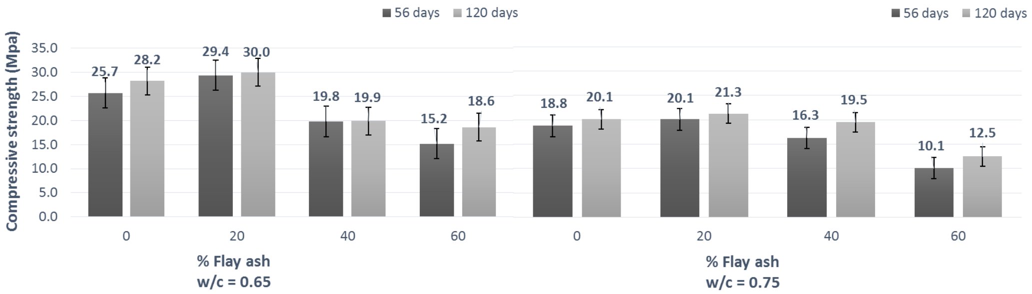

Figure 5 . Effect of FA percentage and age of concrete cylinders in the compressive strength, used for the production of panels.

4.2. Compressive strength of concrete blocks lightened with PET

The experimental results obtained for the compressive strengths of blocks are shown in Table 6. Figure 6 shows the load for the first crack and the maximum load at failure. For w/c ratios of 0.78 and 1.1, the loads of cracking were approximately 48% and 60% of the respective average load at failure. The ability to support more load once the blocks of the specimens with a w/c ratio of 0.78 cracked may be due to the increased density of the cementitious matrix, which allowed the block to distribute the compressive stresses where bottles were located to the lateral faces of the blocks, promoting a joint action on both sides. This action was less evident for a w/c ratio of 1.1, as shown in Figure 6 (a).

Table 6.
Compressive results obtained for blocks lightened with PET from mixtures with w/c ratios of 0.78 and 1.1 (Eq. 1)

Number of Block	Width (mm)	Length (mm)	First Crack Load (kN)	Maximum load (kN)	Compressive Strength (MPa)
			w/c ratio = 0.78		
1	129	730	123.9	312.4	2.0
2	130	729	180.9	292.0	1.8
3	131	728	143.3	301.4	1.9
4	130	729	119.6	291.7	1.8
5	130	728	172.8	321.8	2.0
			w/c ratio = 1.1		
1	131	729	64.7	206.4	1.4
2	130	729	109.3	201.4	1.3
3	130	728	117.4	183.7	1.2
4	130	731	106.0	152.8	1.1
5	129	730	173.0	199.2	1.3
6	131	730	94.6	173.9	1.1

(a) (b)

Figure 6. (a) Crack pattern of concrete masonry lightened with PET containers subjected to compressive strength. (b) Vertical crack in the plane of the PET containers.

According to the results observed during the uniaxial compressive tests, the failure of all blocks began with a vertical crack in the plane of the PET containers in response to a similar load for both w/c ratios, as shown in Figure 6 (b). The presence of the bottles created a stress concentration zone due to the lower concrete area in this plane. After the first vertical crack, other cracks appeared at the lateral sides of blocks, showing a pattern of diagonal cracks in the compression zones until failure due to concrete crushing.

Using equation (1) and considering ρ =0.35, the average design compressive strengths of concrete blocks lightened with PET for w/c ratios of 0.78 and 1.1 were fp^* = 1.9 and 1.2 MPa, respectively. As expected, a w/c ratio of 0.78 produced blocks with a higher uniaxial compressive strength. These data are similar to those reported in previous studies relative to natural fibers reinforced masonry, with respect to the blocks without fiber (1.93 MPa) [20]. Table 7 shows these results compared to those reported by the current regulations [24], and the recommended minimum unit weight and compressive strength limits are shown. The physical and mechanical properties of concrete blocks lightened with PET were similar to those typical masonry in accordance with the specifications established by the design and construction standards in Mexico.

Table 7

Unit weight and minimum compressive strength net design for different types of masonry [24].

Type of Construction	Unit Weight (kg/m^3)	Compressive Strength (MPa)
Annealed clay partition	1300	1.47
Hollow clay partition	1700	3.92
Concrete masonry	1700	1.96
Concrete partition	1500	1.96
Concrete masonry lightened with PET, w/c=0.78	1250	1.90
Concrete Masonry lightened with PET, w/c=1.1	1250	1.20

4.3. Flexural strength of fiber-reinforced concrete panels

The maximum load, the modulus of elasticity and the maximum mid span strain of the fiber-reinforced concrete panels are shown in Figures 7, 8 and 9, respectively. The reinforcement with the natural fiber grid was the same for all tested specimens; therefore, the main effect observed in the above mentioned figures is due to the FA content and age of the specimen.

Figure 7 shows that the age of the panels positively correlated with maximum load. Adding 20% of FA to both w/c ratios produced an approximately 25% load increase compared to the control specimens. The percentages of 40% and 60% for both w/c ratios, which are considered high FA consumption, did not favor the flexural strength gain; on the contrary, they decreased the maximum load compared to the control by approximately 25% and 40%, respectively, for an age of 120 days. The contribution of the natural fiber to the maximum flexural load was not evident; however, adding natural fiber grids into the rigid panels as reinforcement mainly contributed in two ways: preventing plastic shrinkage cracking and providing ductility to the concrete panel, which allowed larger strains after the concrete matrix cracking.

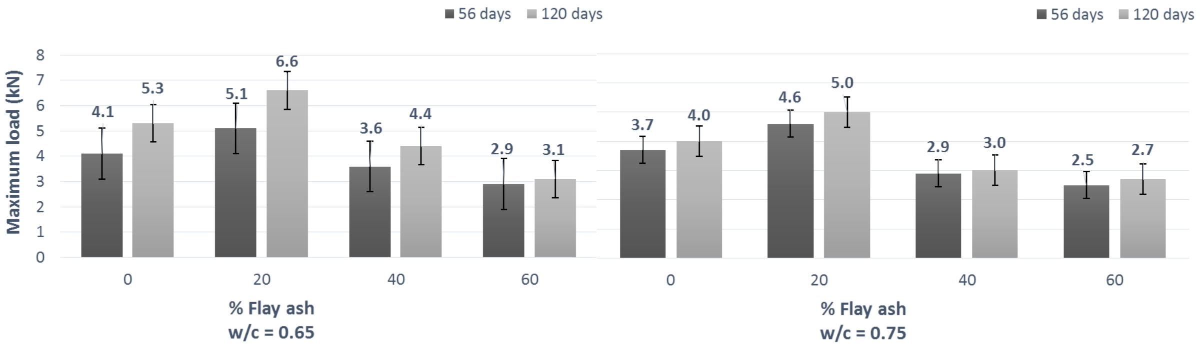

Figure 7. Effect of FA percentage and age of fiber-reinforced concrete panels in the flexural failure load.

Figure 8 shows that the modulus of elasticity did not significantly differ between 20% FA addition and the control sample, which only showed a 4% increase for both w/c ratios. For the maximum load, the addition of 60% FA decreased the modulus of elasticity by up to 25%, and the addition of 40% FA in decreased both values by only 8% compared to the control mixture.

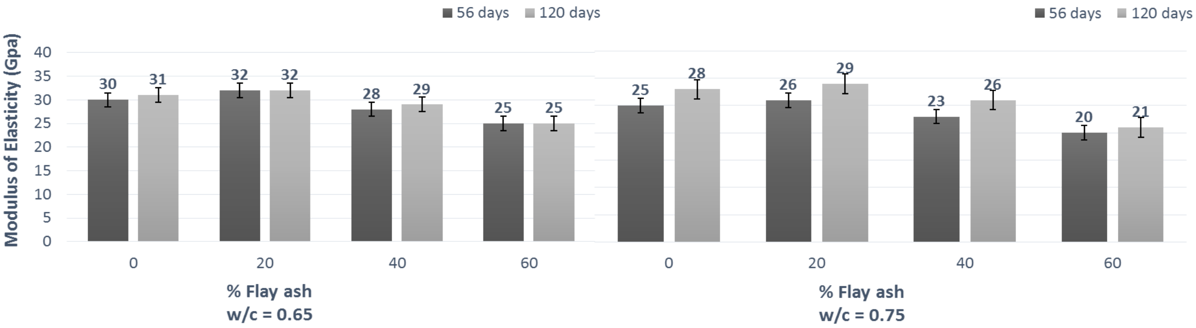

Figure 8. Effect of FA percentage and age of fiber-reinforced concrete panels in the modulus of elasticity.

Figure 9 shows the mid span strain of the panels, which corresponds to the maximum load reached during the flexural test. Figure 9 shows that the strain of the mixture containing 20% FA was less than those of the 40% and 60% FA mixtures as well that of the control mixture. This behavior may be due to the joint action of the fiber reinforcement and the cementitious matrix, which constituted the major stiffness and strength according to the previously discussed results. Furthermore, the strain was less for a w/c ratio of 0.75 than for a w/c ratio of 0.65, which is consistent with the maximum load values reached for those specimens.

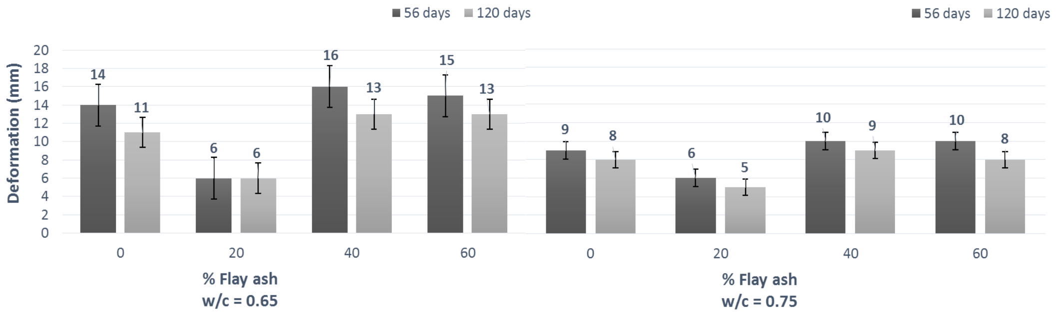

Figure 9. Effect of FA percentage and age of fiber-reinforced concrete panels in the maximum strain at the center of the span.

The experimental results obtained from the flexural performance of the fiber-reinforced concrete panels indicate that for both w/c ratios, 20% of FA in the concrete mixture and allowing sufficient time for the hydration reaction to take place (4 months minimum) increases the maximum load; furthermore, the modulus of elasticity does not decrease in relation to the values of the control specimens. Conversely, the reduction in the maximum strain corresponding to the maximum load for the 20% FA addition suggest a joint action of the FA with the reinforcement grid, which provided ductility after cracking due to the maximum load.

Performance tests related to the durability of the fiber-reinforced specimens were outside the scope of this study; however, degradation of the natural fiber grids caused by the concrete alkaline environment during the 120 days before the flexure test was not observed. The above was verified to the natural fiber grid, maintaining its reinforcement ability, and fragility signs were not observed due to alkaline attack in the concrete matrix.

5. Conclusions

The combination of alternative building materials made using by-products can be viable if the different requirements for each building element are identified, and these elements can be manufactured from common industrial by-products, which require minimum preparation for their use in the construction system.

The following can be highlighted based on the building elements developed in this research:

1. Concrete blocks lightened with PET can achieve compressive strengths similar to those reported for other building elements for related uses.
2. The failure mode presented is related to the setting of the elements lightened with PET, which simultaneously increased the performance to reduce the w/c ratio from 1.1 to 0.78.
3. The fracture at the plane of failure demonstrated an insufficient bond strength between the PET surface and the cementitious matrix.
4. The use of industrial by-products, such as PET, to manufacture building materials ensures that the proposal is sustainable, as it generates an ecological benefit to society.
5. The studied fiber-reinforced panels showed adequate mechanical behavior in response to flexure stress for the studied conditions. The compressive strength obtained for w/c ratios of 0.65 and 0.75 with 20% FA substitution could be considered adequate for the primary elements in a building because their mechanical behavior was acceptable, whereas the 40% and 60% FA substitution for both w/c ratios would be useful in secondary elements, such as dividing walls or non-structural elements.
6. The addition of natural fiber grid reinforcements to the rigid panels improved the ductility of the concrete panel because it allowed higher strains after the cracking of the concrete matrix.
7. The combination of the different building materials proposed could serve as an alternative in low-cost housing with a low environmental impact, even though the need to perform durability studies designed to investigate the performance of these elements in prolonged conditions of temperature and humidity should be emphasized.

6. References

1. Salas Serrano J., Oteiza San José I.: "Los materiales de construcción ante las ingentes necesidades de hábitat en el tercer mundo (Carencias de una investigación necesaria)". Instituto de Ciencias de la Construcción Eduardo Torroja, Consejo Superior de Investigaciones Científicas, II Jornada de Investigación en Construcción. Madrid, España, (2008), pp. 463.
2. Meyer C.: "The greening of the concrete industry", Cement & Concrete Composites, Vol. 31 (2009) 601-605.
3. Oikonomou N.D.: "Recycled concrete aggregates". Cement and Concrete Composites, Vol. 17 (2005) 315-318.
4. Khalifa S., Makoto H., Salem K., Abdullah H.: "Copper slag assandrepla cement for high performance concrete". Cement& Concrete Composites, Vol. 31 (2009) 483-488.
5. Arabani M., Azarhoosh A. R.: "The effect of recycled concrete aggregate and steel slag on the dynamic properties of asphalt mixtures". Construction and Building Materials, Vol. 35 (2012) 1-7.
6. Xiao-Yong W., Han-Seung L.: "Modeling the hydration of concrete incorporating fly ash or slag", Cement and Concrete Research, Vol. 40 (2010) 984-996.
7. Byung-Wan J., Seung-Kook P., Jong-Chil P.: "Mechanical properties of polymer concrete made with recycled PET and recycled concrete aggregates". Construction and Building Materials, Vol. 22 (2008) 2281-2291.
8. Graettinger A. J., Johnson P. W., Sunkari P., Duke M. C. and Effinger J.: "Recycling of plastic bottles for use as a light weight geotechnical material". Management of Environmental, Quality: An International Journal, Vol. 16, No. 6 (2005) 658 - 669.
9. Yazoghli M. O., Dheilly R.M., Queneudec M.: "Valorization of Post-Consumer Waste Plastic in Cementitious Concrete Composites". Waste Management, Vol. 2, No. 27 (2007) 310-318.
10. Mahdi F., Abbas H., Khan A.A.: "Strength characteristics of polymer mortar and concrete using different compositions of resins derived from post-consumer PET bottles". Construction and Building Materials, Vol. 24 (2010) 25-36.
11. Mahdi F., Khan A. A., Abbas H.: "Physiochemical properties of polymer mortar composites using resins derived from post-consumer PET bottles". Cement& Concrete Composites, Vol. 29 (2007) 241-248.
12. Byung-Wan J., Seung-Kook P., Jong-Chil P.: "Mechanical properties of polymer concrete made with recycled PET and recycled concrete aggregates". Construction and Building Materials, Vol. 22 (2008) 2281-2291.
13. Ochi T., Okubo S., Fukui K.: "Development of recycled PET fiber and its application as concrete-reinforcing fiber". Cement & Concrete Composites, Vol. 29 (2007) 448-455.
14. Foti D.: "Preliminary analysis of concrete reinforced with waste bottles PET fibers". Construction and Building Materials, Vol. 25 (2011) 1906-1915.
15. Silva D.A., Betioli A.M., Gleize P.J.P., Roman H.R., Gómez L.A., Ribeiro J.L.D.: "Degradation of recycled

PET fibers in Portland cement-based materials", Cement and Concrete Research, Vol. 35, Issue 9 (2005) 1741-1746.

16. Patrone J.C., García B., Nigro E., Mazzeo J.P.: "Sistema de Muro monolítico con suelo estabilizado, Buenos Aires, Argentina", Construcción con Tierra, Vol. 1 (2010) 60-65.

17. Roux R., Aranda Y.: "Desarrollo de Modelo de Edificación Sustentable de Tierra". Facultad de Arquitectura, Diseño y Urbanismo, UAT (2011) 4-6.

18. Pacheco-Torgal F., Jalali S.: "Cementitious building materials reinforced with vegetable fibres: A review". Construction and Building Materials, Vol. 25, No. 2 (2011) 575-581.

19. Jarabo R., Monte M. C., Blanco A., Negro C., Tijero J.: "Characterisation of agricultural residues used as a source of fibres for fibre-cement production". Industrial Crops and Products, Vol. 36 No. 1 (2012) 14-21.

20. Juárez C., Guevara B., Valdez P., Durán-Herrera A.: "Mechanical properties of natural fibers reinforced sustainable masonry". Construction and Building Materials, Vol. 24 (2010) 1536–1541.

21. Young R. J. and Lovell P. A.: "Introduction to Polymers", Chapman and Hall, 2nd ed. London, (1996) 241-424.

22. Young J. F., Mindess S., Gray R. J., Bentur A.: "The Science and Technology of Civil Engineering Materials", ed. by Prentice Hall Inc., (1998) 359 - 371.

23. Kinloch, A. J., Young, R. J., "Fracture Behavior of Polymers", London, England, Applied Science publisher, (1983) 18-371.

24. Gaceta Oficial del Distrito Federal, Normas técnicas Complementarias para Diseño y Construcción de Estructuras de Mampostería, Tomo I, No. 103-Bis (2004) 4-12.

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