Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 161 (2016) 660 – 665

Procedia Engineering

www.elsevier.com/locate/procedia

World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium 2016, WMCAUS 2016

Effect of Using Recycled instead of Virgin EPS in Lightweight Mortars

Francesca Tittarelli[a], Chiara Giosuè[a,*], Alessandra Mobili[a], Costanzo di Perna[b], Saveria Monosi[a]

[a]Department of Materials, Environmental Sciences and Urban Planning-SIMAU, Università Politecnica delle Marche, 60131 Ancona, Italy
[b]Industrial Engineering and Mathematical Sciences-DIISM, Università Politecnica delle Marche, 60131 Ancona, Italy

Abstract

Performances of structural, moderate and heat insulating lightweight mortars manufactured by replacing sand volume with virgin or recycled expanded polystyrene (EPS) are compared. At the same dosage, replacing virgin EPS with recycled one improves the mechanical performance of mortars without a significant variation in capillary water absorption and water vapour permeability. Recycled EPS mortars have lower thermal insulation properties than those manufactured with a virgin one, but this can be counteracted by increasing the percentage of EPS. To obtain mortars with a certain thermal insulating capacity, an economical saving over than 25% can be reached by using recycled EPS.

Peer-review under responsibility of the organizing committee of WMCAUS 2016

Keywords: EPS; recycling; lightweight mortar; cement, hydrophobic admixture;

1. Introduction

EPS is extensively used in food packaging where EPS waste, 0.1% of total municipal solid waste, is ground into small fragments to reduce volumetric bulk before disposal. In buildings, lightweight mortars manufactured with expanded polystyrene (EPS) pearls are used thanks to their thermal insulation properties. A possible way of recycling EPS waste is the substitution of commercial virgin EPS with recycled one in mortars, decreasing also the resource

* Corresponding author. Tel.: +39 071 220 4726; fax: +39 071 220 4729.
E-mail address: c.giosue@univpm.it

Peer-review under responsibility of the organizing committee of WMCAUS 2016
doi:10.1016/j.proeng.2016.08.728

consumption in building sector. Literature still reports a limited amount of research on recycling of EPS waste in cement mortars.

In particular, only few authors [1, 2] compared the properties of mortars manufactured with commercial and recycled EPS at the same volume dosage: the first with EPS grain size less than 1 mm, up to 70% sand volume replacement; the second with 2-4 mm EPS grain size and 100% sand volume replacement.

The aim of this study is to compare the properties of lightweight structural mortars (ρ = 1400 - 2000 kg/m^3 and Rc ⩾18 MPa), lightweight mortars with moderate strength (ρ = 800 - 1400 kg/m^3 and Rc = 7 - 18 MPa) and thermo-insulation mortars (ρ = 300 - 800 kg/m^3 and Rc = 0.5 - 7 MPa) manufactured with virgin or recycled EPS at the same volume dosage. In this paper, the EPS grain average diameter is about 4 mm for both, replacing 33%, 66% and 100% of sand volume. In order to improve the durability, the effect of adding a hydrophobic admixture in recycled EPS mortar is also investigated.

2. Experimental

2.1. Materials

Lightweight mortars, with water to cement ratio (w/c) equal to 0.55 by weight and aggregate to cement ratio (a/c) equal to 6 by volume, are manufactured by using Portland cement type CEM II/A-L 42.5 R. As common and lightweight aggregates, a calcareous natural sand, with 6 mm maximum size and virgin EPS pearls commercially available with specific gravity of 0.018 g/cm^3 are used, respectively. Recycled EPS granules with the specific gravity of 0.018 g/cm^3 coming directly from a local industry of food packaging that grinds the EPS waste into granules before its disposal is used as a comparison. The visual observation and the grain size analysis show that the virgin EPS pearls are almost mono-granular with more than 90% of granules size between 2 and 8 mm. Recycled EPS granules have a rougher and less regular surface with a more distributed grain size between 1 and 10 mm (Figure 1).

Lightweight mortars are manufactured by replacing the 33%, 66% and 100% of sand volume with virgin (V33, V66, V100) and recycled EPS (R33, R66, R100) in order to obtain lightweight structural mortars, lightweight mortars with moderate strength and thermo-insulation mortars, respectively (Table 1). An Air-Entraining Admixtures (AEA) is added in mortars with 66% and 100% of EPS, at the dosage of 0.1% and 0.3% by cement weight, respectively, to inhibit segregation. In the case of mortars manufactured with recycled EPS, the addition of a hydrophobic admixture (H) in the form of a 45% aqueous emulsion of butyl-ethoxy-silane at the dosage rate of 0.5% of active ingredient by cement weight is considered (HR33, HR66, HR100).

Table 1. Mixes of different mortars and fresh state properties. (kg/m^2).

	Cement	Water	Sand	Virgin EPS	Recycled EPS	Slump (mm)	Density (kg/m^3)
V33	357	196	1224	4.10	-	120	1812
V66	357	196	621	8.19	-	116	930
V100	357	196	-	12.41	-	110	290
R33	357	196	1224	-	4.10	120	1900
R66	357	196	621	-	8.19	118	1370
R100	357	196	-	-	12.41	115	600
HR33	357	196	1224	-	4.10	125	1770
HR66	357	196	621	-	8.19	120	1320
HR100	357	196	-	-	12.41	118	680

2.2. Tests

Tests were carried out according to the standards: Workability-UNI EN 1015-3:2007; bulk density -UNI EN 1015-10:2007.

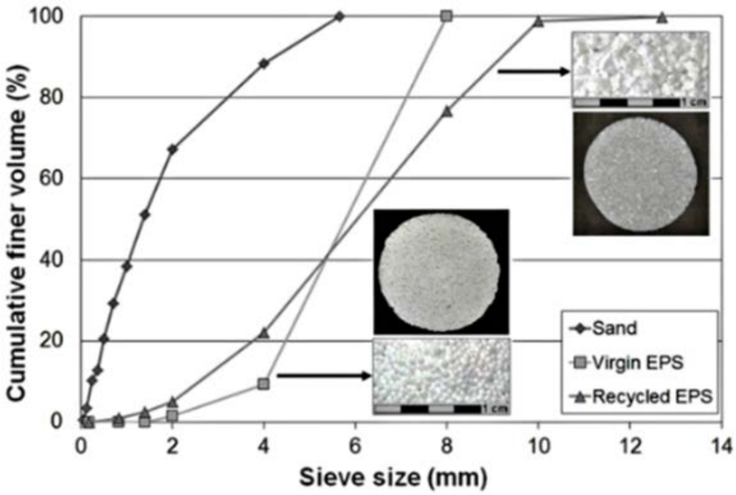


Fig. 1. Particle size distribution of virgin and recycled EPS compared with sand. Images of recycled (R100) and virgin (V100) EPS mortars are also reported.

Compressive and flexural strength and dynamic modulus of elasticity (Ed) were evaluated according to UNI EN 1015-11:2007 and UNI EN 12504-4:2005, respectively. Capillary water absorption (UNI EN 15801:2010) and water vapour permeability (UNI EN 1015-19: 2008) measurements were performed according to the current standards Thermal conductivity was evaluated according to UNI EN 12664: 2002.

3. Results and discussion

3.1. Workability and mortar density

Even if workability of mortars decreases with increasing the dosage of EPS due to the lower density, all mortars are classified as stiff mortars (slump value ≤ 140 mm) (Table 1). Replacing round virgin EPS pearls with recycled EPS granules does not affect the workability of mixes. At the same volume dosage, the density of recycled EPS mortars is always higher than that of virgin ones: the better grain size distribution and rougher surface of recycled EPS with respect to the commercial one help to manufacture a more resistant and compact mortar with less macro-porosities, especially when higher dosages of EPS are added. Moreover, in structural mortars (HR33), the hydrophobic admixture slightly decreases the density, since it increases the capillary porosity of the cement paste [3]. When higher dosages of EPS are added (HR66-HR100%) this trend is not evident because there is less cement paste. Moreover, in these cases, the effect of silane addition on increasing capillary porosity of cement paste is partially compensated by the positive effect on macro-porosity due to a certain plasticizing effect of silane which improves the low compactibility of the fresh material (Table 1) [4, 5].

3.2. Mechanical strength

As expected, the substitution of calcareous sand with EPS leads to a decrease in mechanical properties (Figure 2), due to the zero EPS strength and the low adhesive strength between the cement paste and smooth surface of EPS [6]. However, at the same sand replacement with EPS, *Rc* of mortars prepared with recycled EPS is increased up to four times (100% sand volume replacement) with respect to the value measured in mortars prepared with virgin one due to the same reasons already discussed in section 3.1. The addition of the hydrophobic admixture implies a slight reduction in compressive strength in lightweight structural mortars and in lightweight mortars with a moderate strength, as already observed in traditional concretes [3]. It is not evident in thermal insulation mortars since again the effect of silane addition on increasing capillary porosity of cement paste is partially compensated by the decrease of macro-porosity due to the plasticizing effect. The earlier strength gaining increases with the EPS dosage confirming the results obtained by Kan and Demirboga [7] in modified EPS waste. This is not true in the presence of silane admixture that delays the mechanical strength development.

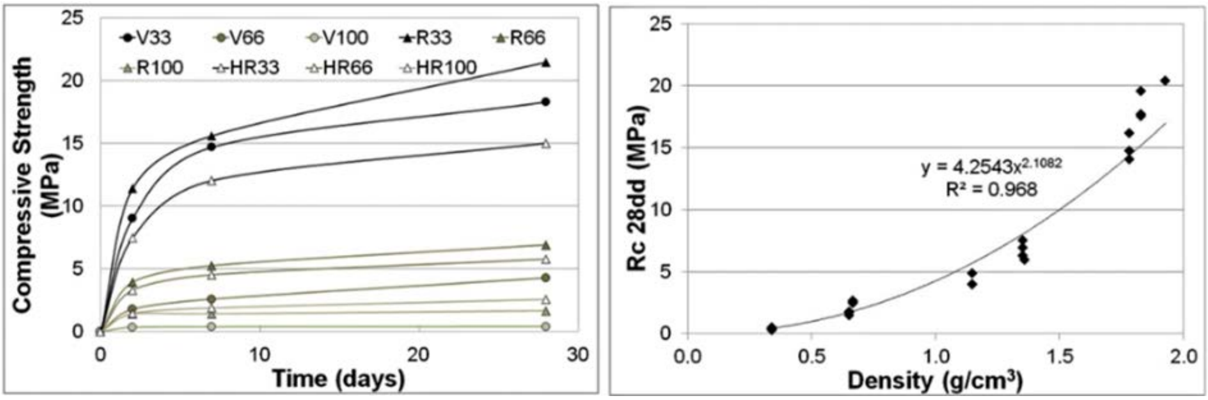


Fig. 2. (a) Compressive strength development with time and (b) variation of compressive strength with EPS mortar density.

Only at very early age of curing (2dd), the use of recycled EPS instead of virgin one increases slightly the compressive strength development. Even with the use of recycled EPS, the enhancement of the compressive strength at 28 days with density (Figure 2 b) and of flexural with compressive strength (Figure 3 a) follow similar exponential relationships found in EPS beads concretes containing fly ash [8]. The relation between the cylinder compressive strength and UPV (V) suggested by Sri Ravindrarajah and Tuck [9], even if developed for EPS concretes made with BST coated aggregates, well estimates the pulse velocity values for a given strength for the EPS mortars tested in this study. The effect of hydrophobic admixture and recycled EPS instead of the virgin one on the dynamic elastic modulus follows the same trend already discussed for compressive strength (Figure 3).

3.3. Capillary water absorption and water vapour permeability

The study of water absorption is fundamental to stand the durability of a construction material. Moreover, absorbed water decreases the insulation properties of materials. The capillary water absorption coefficient (*CA*) decreases with increasing the dosage of EPS, due to the hydrophobic nature of EPS (Figure 4). At 33% of EPS, *CA* is lower in recycled than in virgin EPS mortar due to the irregular shape of the recycled EPS that, as a not absorbent material, increases the tortuosity of the water path [10, 11]. At a higher level of EPS, the trend is the opposite because in virgin EPS mortars there are more macro-porosities than in recycled ones due to the regular spherical shape of grains. There is no cement paste in the pores where water moves by capillarity, so the continuity of the capillarity network is interrupted. The hydrophobic admixture reduces *CA* of 50%, at least, for all EPS dosages, improving the durability of mortars.

Reduced water vapour permeability is a negative factor in mortars. The addition of EPS as aggregate does not significantly affect the water vapour permeability. There is no significant variation in the water vapour resistance μ by replacing virgin with recycled EPS (Figure 4). Again, only in V100 mortar there is a decrease in μ due to the high presence of macro-porosities. Silane admixture, increasing the micro-porosity of cement paste, slightly decreases μ.

3.4. Thermal conductivity

When the percentage of EPS increases, the thermal conductivity of mortars decreases as expected with an exponential trend correlation between density and thermal conductivity (λ) (Figure 5). At the same dosage of EPS, the thermal insulation performance decreases when recycled EPS is used.

The addition of the hydrophobic admixture partially recovers this penalization due to the increase of cement paste porosity. In all cases, a good linear correlation is found between λ and percentage of EPS (Figure 5) useful to know the percentage of virgin or recycled EPS to be added in mortars to obtain a certain λ value.

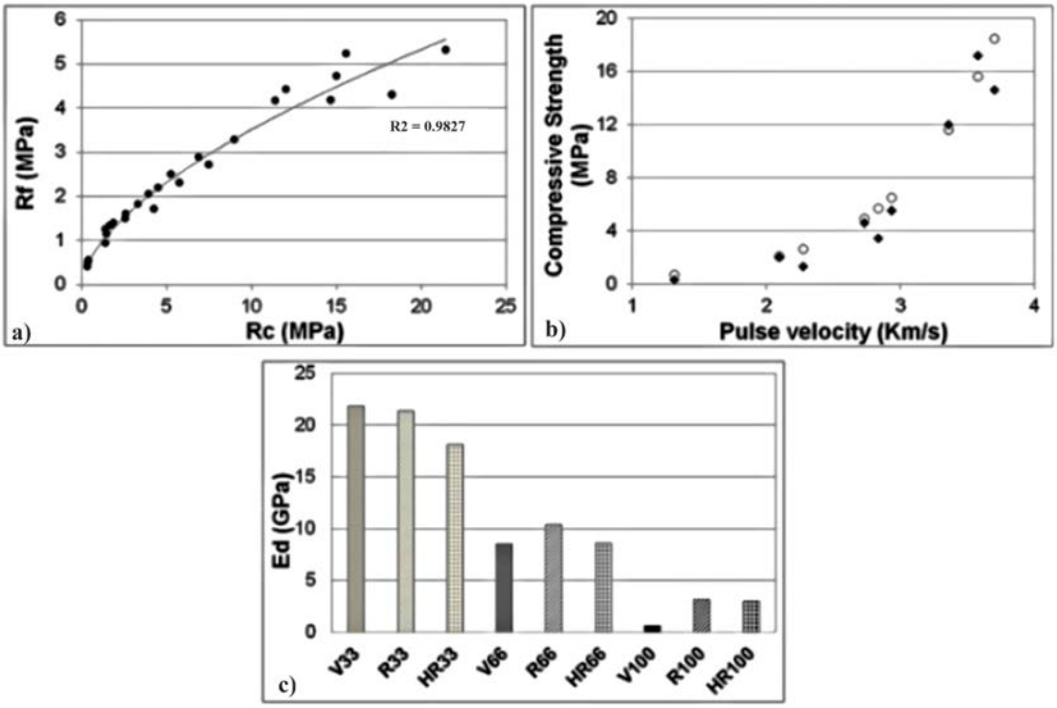
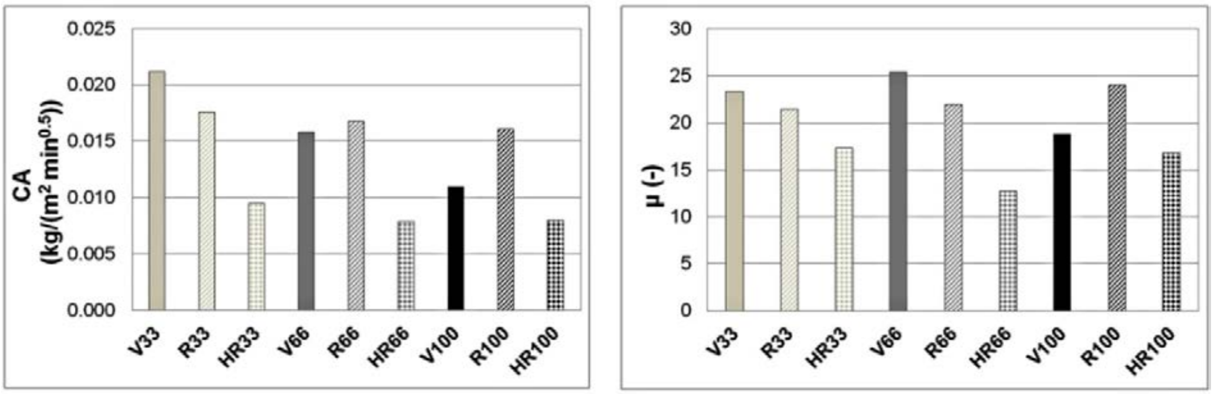


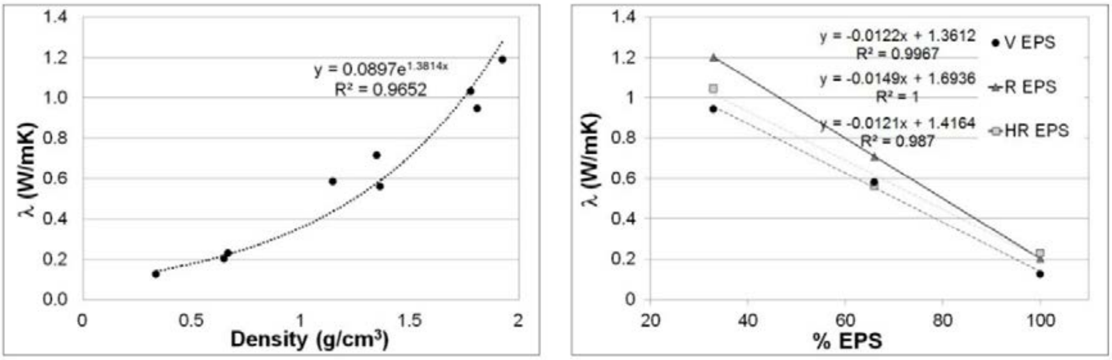
Fig. 3. (a)Variation of flexural strength with compressive strength, (b) variation of cylinder compressive strength with ultrasonic pulse velocity of experimental data (dark circles) and literature data, representing the relation between the cylinder compressive strength and UPV (V) suggested by Sri Ravindrarajah and Tuck (empty circles) [9] and (c) dynamic elastic modulus.

For example, to manufacture a mortar with a thermal conductivity value of 0.4 W/mK, 78% and 85% of virgin or recycled EPS as sand volume replacement should be added, respectively, according to the shown trend line. Knowing that cost of recycled EPS is about 8 €/m^3 while that of virgin EPS is 25 €/m^3, with recycled EPS instead of virgin one an economical saving over than 25% can be reached.



a) b)

Fig. 4. (a) Capillary water absorption coefficient (CA) and (b) water vapour resistance μ.



a) b)

Fig. 5. (a) Exponential correlation between thermal conductivity and hardened density and (b) linear correlation between thermal conductivity and percentage of EPS.

4. Conclusions

At the same dosage, the use of recycled EPS instead of virgin one in cement mortars: does not affect workability; increases density and mechanical properties of mortars; increases the capillary water absorption in thermo-insulation mortars (100% EPS by sand volume) that can be decreased with an hydrophobic admixture; does not change significantly the permeability of water vapour and decreases the thermal insulation performance of mortars, but this penalization can be recovered by increasing the dosage of EPS. To obtain mortar with a certain thermal insulating capacity, using recycled EPS allows an economical saving over than 25%.

References

[1] V. Ferrándiz-Mas, T. Bond, E. García-Alcocel, C.R. Cheeseman, Lightweight mortars containing expanded polystyrene and paper sludge ash, Constr. Build. Mater. 61 (2014) 285-292.

[2] C. Aciu, L.M. Manea, L.M. Molnar, E. Jumate, Recycling of polystyrene waste in the composition of ecological mortars, Procedia Technol. 19 (2015) 498-505.

[3] G. Moriconi, F. Tittarelli, V. Corinaldesi, Review of silicone-based hydrophobic treatment and admixtures for concrete, Indian Concr. J. 76(10) (2002) 637-642.

[4] M. Carsana, F, Tittarelli, L. Bertolini, Use of no-fines concrete as a building material: Strength, durability properties and corrosion protection of embedded steel, Cem. Concr. Res. 48 (2013) 64-73.

[5] F. Tittarelli, M. Carsana, M.L. Ruello, Effect of hydrophobic admixture and recycled aggregate on physical-mechanical properties and durability aspects of no-fines concrete, Constr. Build. Mater. 66 (2014) 30-37.

[6] F. Iucolano, B. Liguori, D. Caputo, F. Colangelo, R. Cioffi, Recycled plastic aggregate in mortars composition: Effect on physical and mechanical properties, Mater. Des. 52 (2013) 916-922.

[7] A. Kan, R. Demirboga, A novel material for lightweight concrete production, Cem. Concr. Compos. 31(7) (2009) 489-495.

[8] D. Saradhi Babu, K. Ganesh Babu, T.H. Weea, Properties of lightweight expanded polystyrene aggregate concretes, containing fly ash, Cem. Concr. Res. 35(6) (2005) 1218-1223.

[9] R. Sri Ravindrarajah, A.J. Tuck, Properties of hardened concrete, containing treated expanded polystyrene beads, Cem. Concr. Compos. 16(4) (1994) 273-277.

[10] F. Tittarelli, P.S. Shah, Effect of low dosages of waste GRP dust on fresh and hardened properties of mortars: Part 1, Constr. Build. Mater. 47 (2013) 1532-1538.

[11] F. Tittarelli F, Effect of low dosages of waste GRP dust on fresh and hardened properties of mortars: Part 2, Constr. Build. Mater. 47 (2013) 1539-1543.