PROPERTIES OF CEMENT- BASED COMPOSITES WITH CHOPPED ELECTRICAL CABLES AND POLYURETHANE WASTES

Cristina DIMA (VĂDUVA)[1], Alina BĂDĂNOIU[2]*, Adrian Ionuţ NICOARĂ[3]

The paper presents the main properties (apparent density, thermal conductivity, mechanical strength and water absorption) of cement-based composites with various amounts (5-30%) of wastes – recycled polyurethane and chopped electrical cables. The presence of polyurethane waste determines an increase of the porosity due to its low density and high water to cement ratio (0.6) used for composites preparation. Due to the presence of aluminium, along with cooper, in chopped electrical cables waste, gas (hydrogen) is generated during the hydration and setting of cement composite; this process determines an important increase of porosity. The development of the porous structure (interconnected pores with large sizes) determines, as expected, an increase of water absorption as well as an important decrease of mechanical strengths. The increase of porosity also improves the thermal properties of these composites.

Keywords: recycling, industrial wastes, thermal insulation, cement, porosity

1. Introduction

Industrial wastes such as fly ash, blast furnace slag, polystyrene, polyurethane, polyethylene, rubber from used tires, glass, etc. are not biodegradable and may cause many environmental and storage problems.

One possible solution for their valorisation is to reintroduce them into the economic circuit as alternative raw materials, for the manufacture of construction materials.

Gadea *et al.* [1] studied the use of rigid polyurethane foam wastes in combination with cement to produce lightweight mortars. Polyurethane waste resulted by the processing of rigid panels used in the automotive industry. The polyurethane particles did not exceed a size of 4 mm and were used to substitute 25-100% (by volume) of the mineral aggregate (sand). The authors reported a 50% decrease of mechanical strength for mortars with polyurethane waste with reference to normal mortars [1].

[1] PhD, Student Dept. SIMONA, University POLITEHNICA of Bucharest, Romania,
[2] Professor, Dept. SIMONA, University POLITEHNICA of Bucharest, Romania,
*Corresponding author: e-mail: alina.badanoiu[at]upb.ro
[3] Assistant, Dept. SIMONA, University POLITEHNICA of Bucharest, Romania

Lanzón *et al.* [2] studied the possibility to reuse tire rubber and expanded polystyrene wastes in the manufacturing of rendering mortars. Physical and chemical tests performed on these materials proved that expanded polystyrene is more compatible with cement than tire rubber [2].

Previous results reported by our research group, pointed out as a possible valorisation method, the substitution of plaster with various types of wastes i.e. rubber, polyurethane foam and chopped electrical cables [3]. This type of plaster-based composites had better thermal properties as compared with plain plaster i.e. a decrease of thermal conductivity with 21-55% [3].

In this paper we present the main properties (density, thermal conductivity, mechanical strength and water absorption) of cement-based composites with various amounts (5-30%) of wastes – recycled polyurethane or/and chopped electrical cables.

2. Materials and methods

2.1. Materials

The materials used in this study were:

- Portland cement (C) - CEM I-42.5 R, with the main characteristics (as provided by the cement manufacturer) presented in Table 1;

Table 1

Physical and mechanical characteristics of the cement

Characteristic	Value
Initial setting time	> 60 min.
Stability	< 10 mm
Compression strength: -after 2 days -after 28 days	 > 20 MPa 42.5 - 62.5 MPa

- Recycled polyurethane foam (P) obtained from the shredding of insulation panels, with grain sizes comprised between 0.1- 2 mm;
- Electric cables waste (E) obtained from the chopping of electrical cables, with sizes comprised between 0.1- 1.5 mm.

The X ray diffraction analysis of chopped electric cables (Fig.1) shows the presence of copper and aluminium in this waste.

2.2. Specimens preparation

To assess the influence of these two wastes (E and P) on the main properties of cement composites, the mixtures presented in Table 2, were prepared and tested.

The cement and wastes were homogenized in dry state and subsequently mixed with water in a planetary mixer, in conformity to EN 1015-2:2001 [4]. The fresh paste was then poured in moulds (40x40x140 mm) and compacted by vibration for 2 minutes.

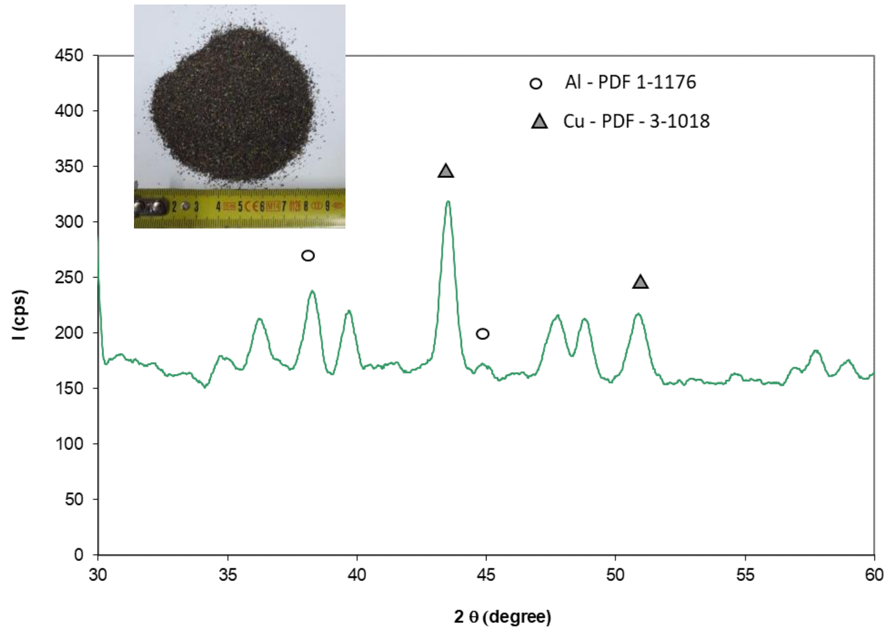


Fig.1. XRD patterns of choped electric cables waste (E) – see insert

The water to cement ratio of reference (C) and of the composition with 30% chopped electric cables (CE30) was 0.4, and for the compositions with polyurethane waste (P) the ratio increased to 0.6. This increase was necessary in order to achieve an adequate workability of the fresh mixture.

Table 2

Compositions of cement composites

Cod	Cement [%]	Waste		Water to cement ratio (wt.)
		Polyurethane foam [%]	Electric cable [%]	
C	100	0	0	0.4
CP5	95	5	0	0.6
CE30	70	0	30	0.4
CP5E25	70	5	25	0.6

2.3. Methods

The following tests were carried out on the cement composites:

- Apparent (geometrical) density, was assessed on prisms (40x40x160 mm) hardened for 28 days, dried in an oven at 60±5°C until constant mass was reached (two successive weighing undertaken twenty four hours apart give a mass variation smaller than 0.2% of the total mass).

- The bending and compressive strengths were determined according to the method presented in European Standard EN 1015-11:2002/A1:2007 [5]; the paste specimens were hardened for 28 days at 23 ± 2°C and 50 ± 5% R.H. The value of bending/compressive strength is the average of at least 3 values obtained on specimens cured in the same conditions.
- Water absorption coefficient due to capillary action was determined with the method presented in European Standard EN 1015-18:2003 [6]. Three specimens (40x40x160 mm) of each composition, hardened for 28 days were used. The long faces of specimens are sealed with synthetic reactive resin with a melting point above 60°C and then broken into half (after the completion of the resin curing). The samples are then dried in an oven at 60±5°C until constant mass is reached. The test specimens are immersed to a 10 mm depth in water and kept for 10 minutes removed and weighed (M1) reintroduced in water for 90 minutes, removed and weighed again (M2).The water absorption coefficient due to capillary action is calculated by the following formula:

$$C=0.1\ (M_2- M_1) \qquad [kg/\ (m^2\cdot min^{0,5})]$$

- Thermal conductivity was assessed with an equipment that measures the heat flow through a specimen placed between two plates with different temperatures; the measurement accuracy is ± 3%, in accordance with EN 12667:2002 [7].
- Scanning Electron Microscopy (SEM) analyses were performed on paste specimens coated with Ag, using a HITACHI S2600N microscope.
- X-ray diffraction (XRD) analysis was performed on a Shimadzu XRD 6000 diffractometer, using a monochromatic CuKα radiation (λ= 1.5406 Å).

3. Results and discussions

The visual aspect of cement composites with waste content (fracture surface), hardened for 28 days, is presented in Fig. 2. One can notice the high apparent porosity of specimens with waste content as opposed to the reference (C).

The high porosity observed for the specimen with polyurethane waste (CP5) is due to the specific shape (flakes and foam) and the low density of this waste, as well as to the high amount of water used for the preparation of this paste (water to binder ratio 0.6).

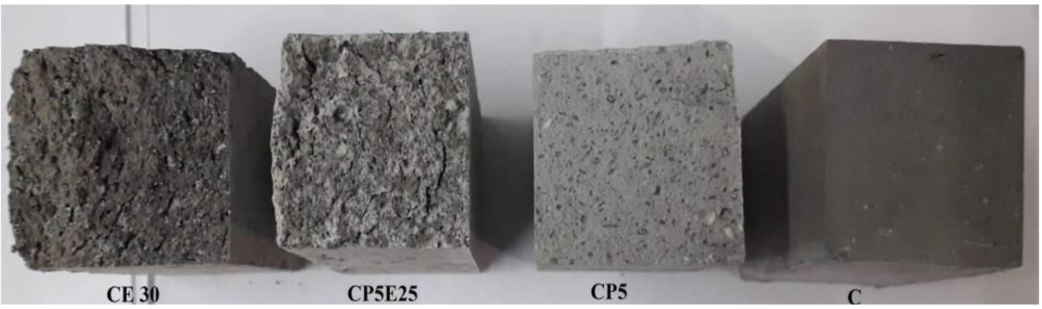


Fig.2. Transversal section (fracture) of specimens with/without waste content

The high porosity of the cement composites with chopped electric cables waste is due to the generation of gas during the setting of cement paste (Fig.3). The hydration of calcium silicates from portland cement leads to the formation of $Ca(OH)_2$ which reacts with aluminium (from E) and generate hydrogen (gas). This gas is entrapped in the cement matrix and forms closed pores (in the interior of the specimens) or/and cracks at the surface of the specimen (Fig. 3).

Top

Lateral view

a **b**

Fig.3. Cement composite with 30% E (CE30) after the pouring in the mould (a) and after 28 days of hardening (b)

The ***apparent density*** assessed on the composites, after 28 days of hardening at 23 ± 2°C and 50 ± 5% R.H. is shown in Table 3.

Table 3

Apparent density and thermal conductivity of cement composites

Composite	Apparent density (g/cm^3)	Thermal conductivity 10° C W/(m·K)
C	1.76	-
CP5	1.15	0.1787
CE30	1.23	0.1246
CP5E25	0.87	0.1146

The substitution of cement with 5% polyurethane waste results in a 35% decrease of apparent density (with reference to C) and 30% in the case of chopped electric cables. For the composition with both wastes (CP5E35), the apparent density decreases by about 50% with reference to cement paste (C). This decrease is explained by the high porosity assessed for the specimens with waste content.

The values of ***thermal conductivity*** are in good correlation with the values of apparent density and the porosity of these materials (Table 3 and Fig. 2). Thermal performance of cement composites increases after cement substitution with E or/and P waste.

Bending and compressive strengths were assessed on specimens hardened for 28 days (Fig. 4).

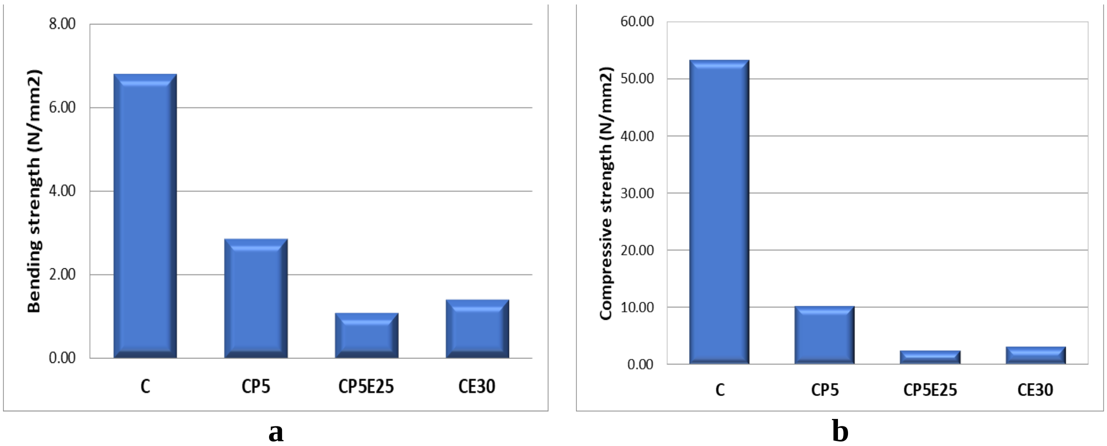


Fig.4. Mechanical properties of cement composites: a) bending strength; b) compressive strength

As expected, the incorporation of chopped electric cables waste or/and recycled polyurethane significantly reduced the mechanical properties of cement composites. This decrease of strength is due to the reduction of cement content (see Table 2) as well as to the increased porosity. With reference to cement paste (C), the bending and compressive strengths of composites with waste content decreased with 60% and 84% (bending strength) and 81% and 95.4% (compressive strength). These results are in good correlation with the data reported by Gadea *et al*. [1] i.e. a reduction of mechanical strength by 50% in lightweight mortars with recycled polyurethane foam.

The values of ***water absorption coefficient*** due to capillary action are presented in Fig. 5. The values of water absorption coefficient by partial immersion provide information about the capacity of the material to hold water while remaining in contact with it. This aspect is important for insulation materials because the thermal conductivity increases with the increase of moisture content [8]. Clearly, this coefficient increases with the increase of porosity (pores size and interconnectivity), as will be further presented (Figs. 6 and 7).

For cement composites with polyurethane waste (CP5), the water absorption coefficient increases by 48% as compared to reference (C). The compositions with chopped electric cables (CE30 and CP5E25) behaved similarly, the increase being of 57%, respectively 47%.

The ***microstructure*** of the studied materials was assessed by SEM analysis. The scanning electron microscopy (SEM) images of the cement paste and composites with waste content, hardened for 28 days, are shown in Figs. 6 and 7.

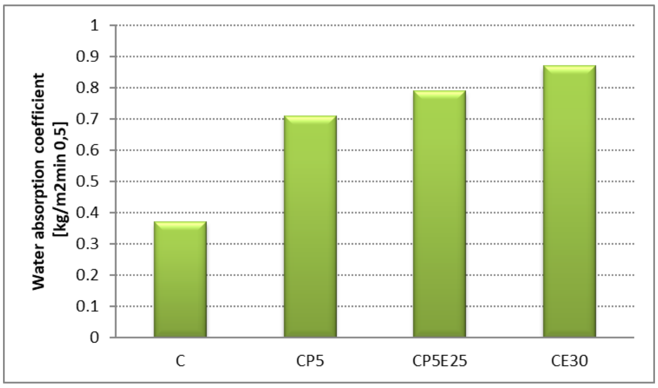
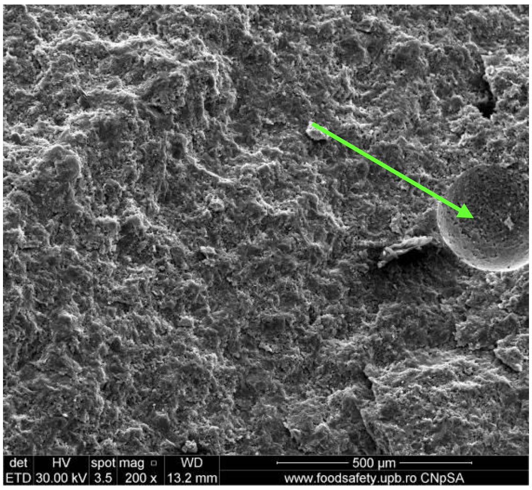
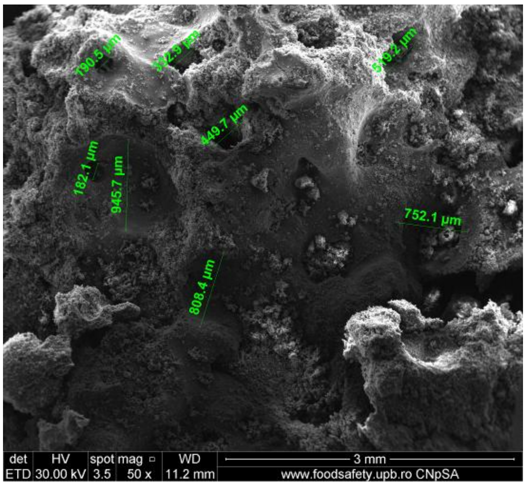


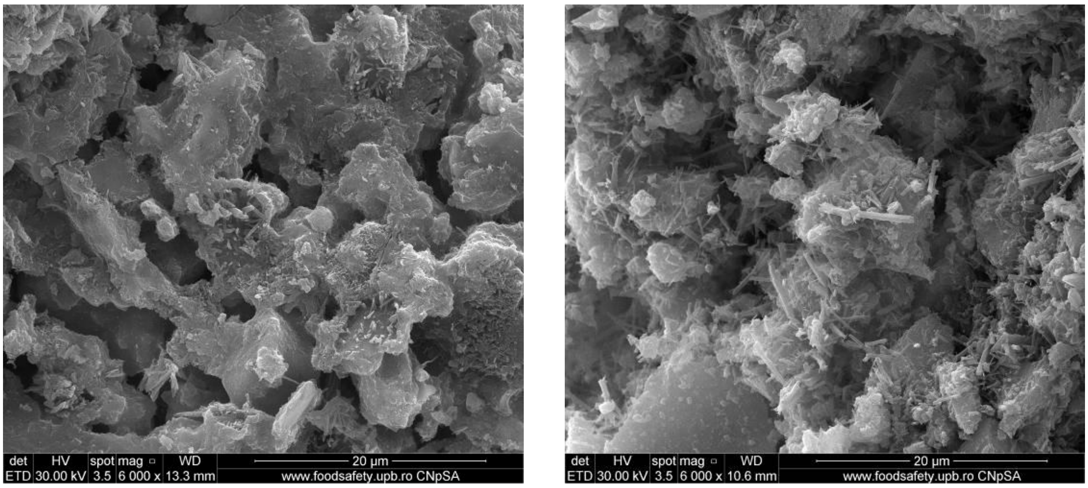
Fig.5. Water coefficient of cement composite with waste content



a



b

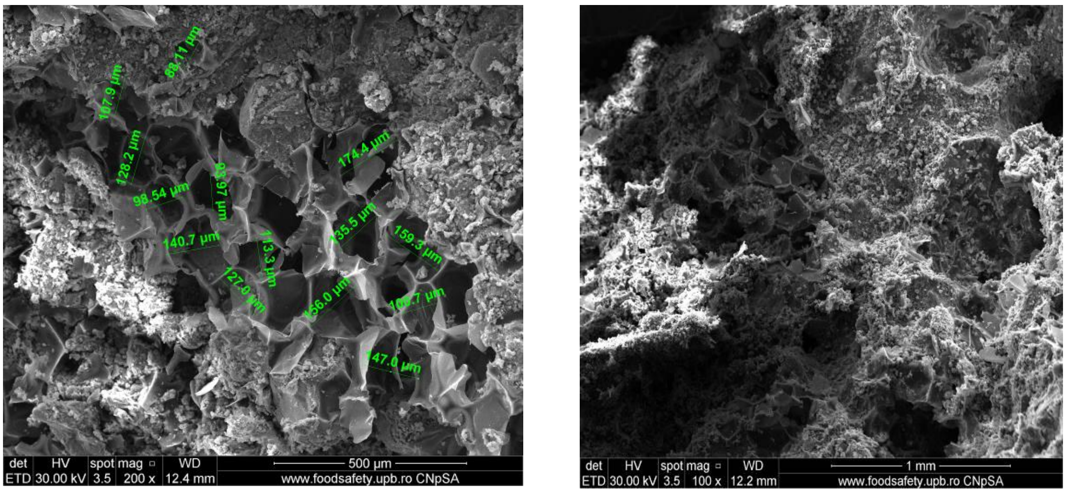


c d

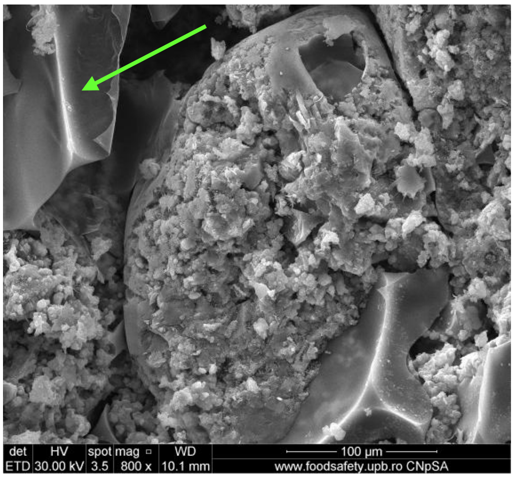
Fig.6. SEM images of cement paste (a and c) and CE30 (b and d)

On the SEM images of C specimen, one can assess the presence of large round pores (formed by the air entrained during the mixing of cement with water (arrow in Fig. 6a) as well as of smaller pores between the hydrates formed by cement hydration (Fig. 6c). When cement is substituted with 30% E waste (CE30) the number and sizes of pores increases (Fig. 6b) due to the entrapment of gas (hydrogen) in the binding matrix.

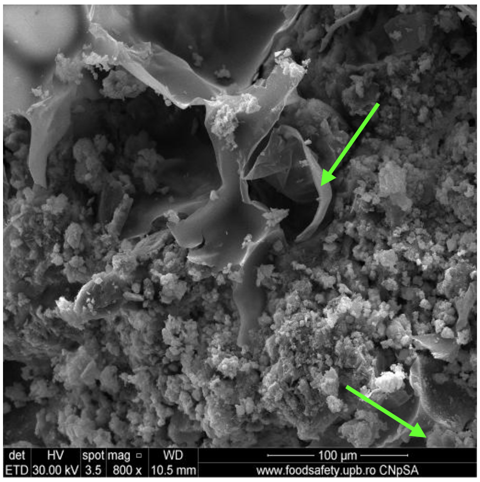
The polyurethane waste can be assessed in various areas of the CP5 and CP5E25 specimens; the honeycomb structure has pore size comprised between 100 – 200 µm (Fig. 7a, b).



a b



c



d

Fig.7. SEM image of CP5 (a and c) and CP5E25 (b and d)

Polyurethane particles (see arrows) are partially or totally embedded in the cement paste (Fig. 7c, d). The specimen which contains both wastes (CP5E25) have a much higher porosity due to entrapment of gas (hydrogen) in the hardened matrix. The development of such structures explains the increase of cement composites porosity as compared to that of cement paste, the reduction of mechanical strength and the increase of water absorption.

4. Conclusions

The results obtained in this paper can be summarized as follows:

- The cement substitution with polyurethane and chopped electric cables wastes determines an important decrease of the apparent density correlated with the increase of porosity.
- The increase of the porosity is due to several factors: i) the substitution of portland cement with a low density waste (recycled polyurethane) with high intrinsic porosity as well as the increase of water to binder ratio; ii) the generation of gas (hydrogen) in the composites with chopped electric cables (E), due to the interaction of aluminium from E with $Ca(OH)_2$ generated during portland cement hydration.
- The development of the porous structures (interconnected pores with high sizes) determines, as expected, an increase in water absorption as well as an important decrease of mechanical strengths.
- The increase of porosity decreases the thermal conductivity i.e. improves the thermal properties of cement-based composites with P or/and E wastes.

R E F E R E N C E S

[1]. *J. Gadea, A. Rodriguez, P.L. Campos, J. Garabito and V. Calderón* "Lightweight mortar made with recycled polyurethane foam", in Cement & Concrete Composites., no. 32, 2010, pp. 672-677.

[2]. *M. Lanzón, V. Cnudde, T. Kock, J. Dewanckele* "Microstructural examination and potential application of rendering mortars made of tire rubber and expanded polystyrene wastes" in Construction and Building Materials, no. 94, 2015, pp. 817- 925.

[3]. *C. Dima (Văduva), A. Bădănoiu, Ş. Stoleriu, C. Daneș* "Composite materials based on gypsum plaster and industrial wastes", in Romanian Journal of Materials, no. 48 (2), 2018, pp. 39-44

[4]. *** European Standard EN 1015-2:2001 - Methods of test for mortar for masonry. Part 2. Bulk sampling of mortars and preparation of test mortars

[5]. *** European Standard EN 1015-11:2002/A1:2007 - Methods of test for mortar for masonry. Part.11 Determination of flexural and compressive strength of hardened mortar

[6]. *** European Standard EN 1015-18:2003 - Methods of test for mortar for masonry. Part.18 Determination of water absorption coefficient due to capillary action of hardened Mortar

[7]. *** European Standard EN 12667:2002 – Thermal Performance of Building Materials and Products – Determination of Thermal Resistance by Means of Guarded Hot Plate and Heat Flow Meter Methods - Products of High and Medium Thermal Resistance.

[8]. *L. Ducoulombier, Z. Lafhaj* "Comparative study of hygrothermal properties of five thermal insulation materials" in, Case Studies in Thermal Engineering, Volume 10, 2017, pp 628-640.