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Thermo-physical characteristics of acrylic-based building external isolation panels produced from different geological materials

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Abstract

Here we describe a new type of environmentally sensitive insulation panels which can be used on exterior wall surfaces to minimize all the negative aspects of existing coating materials by taking advantage of natural rock properties. We investigate the decorative characteristics and insulation performance of this new product, obtained by applying materials from different lithologies to Expanded Polystyrene Surfaces (EPS). First, a mortar with 25% acrylic and 75% sand was applied to the EPS by a stripping method using sand size materials from various lithologies (granite, micaschist, basalt, quartzite, and pumice). To determine the optimum thickness, insulation panels containing plaster of 2, 4, 6, and 8 mm thickness were prepared for each lithology. Their thermal conductivity coefficient, bending and compressive strength were tested. Predictably, thermal conductivity coefficient yielded lowest values in 2 mm panels and highest in 8 mm panels for all lithologies. The bending strength also increased proportionaly with thickness. In the compressive strength tests, the highest values were measured for the 2 mm panels while relatively low values were obtained for the 4, 6 and 8 mm panels, except for the micaschist and basalt-based panels. As a result, basalt and pumice offer superior features in the three measured parameters, so, it is expected that different combinations of these two lithologies would offer positive features. In this context, considering its high fire resistance and low thermal conductivity coefficient perpendicular to the planar surface of muscovites, micaschist is the third lithology that can be utilized with the two materials mentioned above. Compared with previous materials, the products investigated in this study are cost effective because they reduce paint costs, application time and total building load. The geomaterials also have aesthetic appeal.

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1. Introduction

With rising cost of energy, heat insulation of residential and industrial buildings has become an increasingly important topic. Despite increasing interest, buildings that follow regulations of TS825 standard (TS-825, 1998) are rare. The increase in awareness on this issue in Turkey suggests that rapid developments, opportunities and regulations on the subject should be anticipated. For that reason, many researchers have been working on the development and research of building envelope materials. Some researchers have investigated the thermal comfort and performances of the well-known insulation materials such as mineral wool, expanded polystyrene (EPS), extruded polystyrene (XPS) foam, foamed polyurethane, fiberglass, etc. (Al-Homoud, 2005; Dombaycı, 2007; Özel, 2011; Jelle, 2011; Korjenic et al., 2011; Ekici et al., 2012; Kaynaklı, 2012). Another group of researchers have concentrated on the compositions of the mortar for decreasing the thermal conductivity of the building walls by using some materials such as perlite aggregate, silica fume, fly ash, pumice, blast furnace slag, etc. (Gül et al., 1997; Demirboga, 2003; Demirboga and Gül, 2003; Uysal et al 2004). The thickness of the wall and plaster are also play an important role on thermal isolation (Özel, 2011; Ekici et al., 2012; Kaynaklı, 2012). On the other hand, other investigations focused on the behavior of the different building envelope materials in time (Jelle, 2011; Papadopoulos, 2005; Cabeza et al., 2010). Although the development of insulation elements using natural materials to ensure thermal comfort to the expected levels and the analysis of the economic gain have been an important subject, the modest usage of natural materials for insulation purposes is noteworthy. Natural materials that can be used for the building external cover are divided into two groups as organic and inorganic materials. In this context, some organic materials such as jute, flax, hemp, cotton stalk fibers, sugar cane, bagasse fibers, bamboo, etc. were used as members of composites for both internal and external covering material (Korjenic et al., 2011; Reis, 2006; Zhou et al., 2010; Onésippe et al., 2010). The inorganic exterior cover materials are widely used in the world, but the movement against the production and development of new brand materials produced from various geological units are not sufficient. Most research actually concentrated on the production of concrete and thermal isolation panels with thermally superior characteristics (Gül et al., 1997; Demirboğa, 2003; Demirboğa and Gül, 2003). The authors of this papers investigated the technical characteristics of thermal isolation plates coated by cement-based plasters produced from same geomaterials (Karataş and Rızaoğlu, 2017).

Efforts to increase the durability of insulation and structures in buildings are not a universal concern. If buildings are to be built with heat insulation, a correlative advantage will be a reduction of the total load of the structure including the carrier loads and the natural loads of the structures. In this case, earthquake load will be reduced and such structures could be designed with advantageous direction in terms of earthquake due to less load on the nodal points of the structures (Taşdemir, 2003). Other similar products used for decoration and insulation are very costly options such as composite and wood coating, as well as requiring considerable time. Applications such as composite and wood coating have a big impact on the building's handling load at the same time. As is known, the earthquake resistance of buildings is directly proportional to the loads. Because of this reason, the selection of low density exterior material significantly reduces the damage to the building during an earthquake.

When taking this information into consideration, it will have a considerably positive effect in terms of both strength and reduction of building load by developing new material which can be used in exterior and interior by minimizing all the negative aspects mentioned above. Producing thermal insulation panels by taking advantage of the characteristics of natural rocks will be alternative to many similar materials used at present. Thus, the decorative insulation panels obtained will have versatile application areas and can be integrated into many areas such as exterior covering, inside the building for decoration purposes and on the inner walls where the heat loss is maximum.

Obtained panels reveal that this is an innovative work. When we look at the currently used applications, they are completed in 4-5 steps. However, the material to be obtained within the scope of this study will be completed in a very short time compared to the existing application by subjecting it to a single treatment, and it will reduce the period of its finalization to half and a profit of about 50% in terms of cost. In this respect, it brings an innovative perspective to all the materials used for insulation in the buildings.

2. Materials and Methods

2.1. Materials

The natural geomaterials that we used for building exterior insulation panels include micaschist, pumice, quartzite, basalt and arenitized granite. The granitic arenites come from the Late Cretaceous Esence granitoids located between Esence and Deveboynu villages in Afşin-Kahramanmaraş, Turkey. The granite samples consist of quartz, plagioclase, K-feldspar, biotite, horn- blende and secondary minerals (Rızaoğlu et al., 2005). The micaschists samples come from the Paleozoic Malatya metamorphic units of the northern part of Kahramanmaraş city. These rocks consist of quartz, muscovite, biotite and secondary alteration minerals (epidote, chlorite and calcite). The basalt samples come from the Aydınlar Mining plant located in İzmir and were extracted from an open pit in Aliağa county. The basalt samples consist of plagioclase, pyroxene, olivine and iron oxide minerals. The quartz sand samples also originates from quarries in the Aydın-Çine district. These samples were micronized at the Aydınlar plant. The acidic pumice samples originate from the Pliocene Cappadocian Volcanic Province (CVP) in Kaymaklı county, Cappadocia. These samples have a high porosity (75-80%) and a glassy texture. Another insulation material, colorless expanded polystyrene (EPS) with a density of 16 kg/m3 and thermal conductivity of 0.037 W/mK was used for comparison. In the coating of the insulation material, an acrylic mixture is used with the five geological materials above.

2.2. Methods

2.2.1. Preparation of materials

Before testing the physical properties of the thermal insulation panels, we prepared mortars for each rock type by homogeneously mixing 75% of rock with 25% of acrylic as binder.

2.2.2. Sample preparation

Acrylic-based isolation panels were prepared using granite, micaschist, basalt, quartzite, and pumice (Figure 1a). The mortar was applied on EPS (Figure 1b). We used two different methods: stripping and spraying (Figure 1c,d). The spraying method involves a higher amount of acrylic in the fabrication because the method requires a mortar of lower viscosity. This approach negatively affects both the cost and fabrication time (Figure 1c,e). This approach also has thedisadvantage of higher use of a chemical substance know to be potentially harmful to human health. The stripping method is preferred because it uses less acrylic, is faster and more environmentally sensitive (Figure 1d). In order to investigate the effect of plaster thickness on the insulation performance of the panels we produced panels of 2, 4, 6 and 8 mm thickness for each of the materials (Figure 1f).

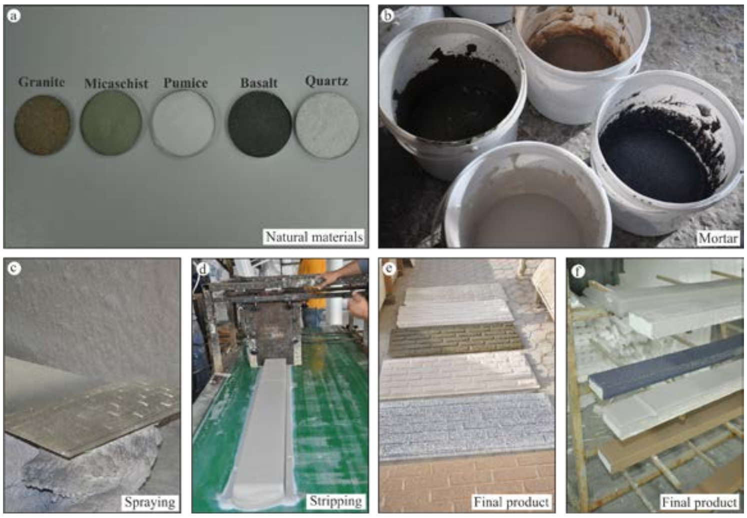

Fig. 1. Sample preparation: a) geological materials b) mortar preparation c) spraying method d)stripping method e) final product from spraying method f) final product from stripping method

2.2.3. Bending resistance

Before performing mechanical tests, we cut samples of 50 x 50 x 100 mm size from the final products (Figure 2a). The bending resistance was tested using a "Zwick/ 2010 Universal Test" machine with 20 kN capacity and capable of making bending, compressive and tensile strength tests at the laboratory of ÜSKİM (University-Industry-Government Cooperation Center) at Kahramanmaraş Sütçü İmam University, Turkey. A 50 N load was applied in a second with a 85 mm span (1.5-2 times of the sample height) on all the samples of various thicknesses (Figure 2a,b)

2.2.4. Compressive strength

The compressive strength tests were performed at the laboratory of ÜSKİM (University - Industry - Government Cooperation Center) at Kahramanmaraş Sütçü İmam University, Turkey using the same instrument as for bending tests (Figure 2c).

2.2.5. Thermal conductivity

The thermal conductivity was measured, using the Lasercomp-Fox 314 heat flow meter following the protocol and standards of (ASTM C, 518; ISO, 8301) at the Department of Forestry Engineering Kahramanmaraş Sütçü İmam University, Turkey. The sample sizes were 300-300 mm (Figure 2d).

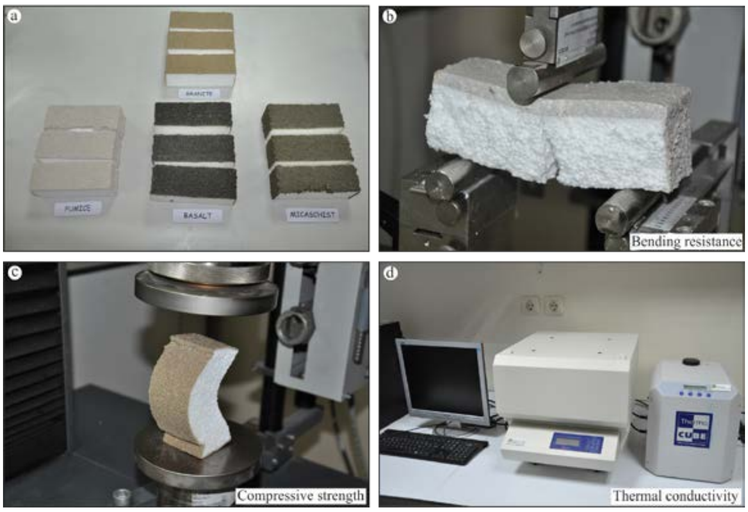

Fig. 2. Thermo-physical tests a) samples b) bending resistance test c) compressive strength test d) thermal conductivity test

3. Results and Discussion

Here we discuss the results of thermo-physical tests on acrylic based thermal insulation boards obtained from different lithologies, as well as the causes of variations caused by different lithologies and thickness of the plaster. In this context, the test results of the thermal insulation materials produced from each geological material will be given separately and finally the advantages, weaknesses and different behavioral patterns of the mentioned materials will be discussed. In order to determine the optimum values, insulation panels containing plaster of 2, 4, 6 and 8 mm thickness were prepared for each lithologic and thermal conductivity coefficient, bending and compressive strength tests were performed with three sets on each panel. The average values of bending resistance and compressive strength for the acrylic based thermal isolation panels from the different lithological units with four different plaster thicknesses are given in Table 1.

In the compressive strength tests, the highest values were found for granite (0.399 MPa), quartzite (0.420 MPa) and pumice (0.438 MPa) in 2 mm panels and relatively low values in 4, 6, and 8mm panels (Table 1). In the micaschist, the thickness and compressive strength values are positively correlated (0.260- 0.307-0.388-0.434 MPa on 2, 4, 6, and 8 mm panels respectively) due to the parallel alignment of the planar surfaces of the mica minerals (Table 1). On the panels obtained from basalt, the compressive strength has a positive correlation with the thickness of 2, 4, and 6 mm (0.420-0.424-0.432 MPa respectively) and only a slight decrease in thickness of 8 mm (0.326 MPa) (Table 1). This can be interpreted as the fact that at high thickness and critical value, acrylic and basalt cause a sudden loss of resistance due to the porous structure of the basalt. As a result, basalt and pumice offer superior performance in the three measured parameters, so, it is expected that different combinations of these two lithologies would offer positive characteristics. In this context, considering the high fire resistance and low thermal conductivity coefficient perpendicular to the planar surface of micaschist, this material would constitute a good alternative to the two previous materials.

The bending resistance values increase in proportion to the thickness and the values for granite (0.255-0.350 MPa), micaschist (0.236-0.457 MPa), basalt (0.245-0.305 MPa), quartzite (0.237-0.418 MPa) and pumice (0.234-0.377 MPa) were obtained (Table 1).

Figure 3 shows deformation styles and Figure 4 presents the styles and percentages of deformation against both under compressive and bending stress. Deformation in 2 and 4 mm thicknesses in both granite and basalt were concave in both EPS and plaster, and fracture occurred in both parts, considering the compressive strength behavior according to the thicknesses (Figure 3a,f) (Figure 4f,h). However, in the 6 and 8 mm specimens, the fracture occurs in EPS, no fracture is observed in the plastic, and it exhibits a completely elastic behavior (Figure 3b,c,g) (Figure 4f,h). In micaschist, fracture occurs by showing plastic deformation both in EPS and in plaster, which is very visible in 2 and 4 mm plaster thickness and decreasing to 6 and 8 mm thicknesses (Figure 3d,e) (Figure 4g). The general deformation is seen as concave swelling but the outer plaster shows brittle behavior.

Table 1. Bending resistance and compressive strength tests results of the samples (Fc:Maximum Load Rc: Compressive Strength SM: Bending strength rmax:Maximum Flexure strain)

Sample & Unit	Plaster Thickness	Compressive Strength		Bending resistance	
	(mm)	Fc (N)	Rc (MPa)	SM (MPa)	Rmax (%)
Granite	2	993	0.399	0.255	34.6
	4	769	0.310	0.290	34.8
	6	783	0.315	0.290	35.2
	8	849	0.342	0.350	29.0
Micaschist	2	646	0.260	0.236	27.0
	4	764	0.307	0.314	32.5
	6	965	0.388	0.347	37.2
	8	1078	0.434	0.457	51.4
Basalt	2	1043	0.420	0.245	33.8
	4	1053	0.424	0.288	38.0
	6	1073	0.432	0.291	37.6
	8	810	0.326	0.305	33.7
Quartz	2	1046	0.421	0.238	25.9
	4	847	0.341	0.257	28.0
	6	905	0.364	0.373	40.2
	8	952	0.383	0.418	48.5
Pumice	2	1085	0.438	0.234	31.6
	4	844	0.340	0.321	35.3
	6	1003	0.403	0.324	51.1
	8	1051	0.423	0.377	32.6

This is a consequence of the transmission of tensile stresses from the planar surfaces as a result of the inability of the micas (muscovite-biotite) to exhibit complete bonding with the acrylic (Figure 3d,e) (Figure 4g). The panels made of quartz sand show concave deformation similar to granite and basalt with plaster thicknesses of 2 and 4 mm (Figure 3h) (Figure 4i). The panels have 6 and 8 mm thick plaster show elastic behavior independently of EPS and no fracture occurs in EPS, but it separates from adhesion surface by fracture and bending (Figure 3i) (Figure 4i).

This suggests that the feldspar minerals in the granite are unstable against the alteration and that the adherence potential of the secondary minerals in the basalt with EPS is higher than the quartz. On the other hand, in the pumice, the compressive strength is low and consequently shrinkage and S-shaped deformation occur in 2 and 4 mm plasters (Figure 3j) (Figure 4j), and they present a concave elastic deformation similar to granite and basalt in 6 and 8 mm thickness (Figure 3k) (Figure 4j). Due to the pore structure of the pumice and the low pressure resistance, each pumice particle in thin plaster presses against the adjacent pumice and undergoes shrinkage. As the thickness increases, this situation causes elastic deformation with increasing strength.

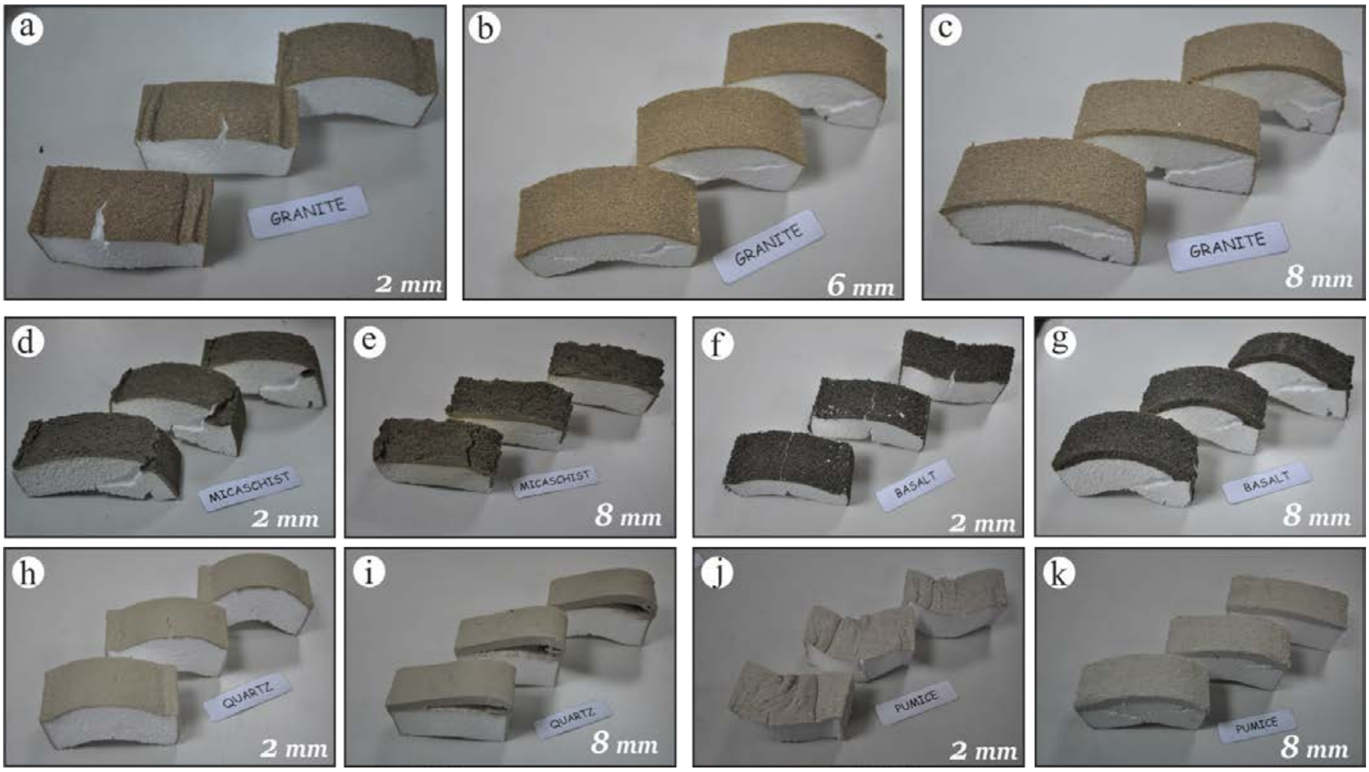

Fig. 3. Deformation styles of the test samples under compressive stress

Granite, quartz and pumice samples show similar characteristics as the highest values on bending resistance in 2 mm plasters. On the other hand, the bending resistance values of same samples increase with the increasing thickness from 4, 6 and 8 mm thicknesses respectively. Because of the granular structure of those samples, 2 mm plasters have the highest values (Table 1) (Figure 4a,d,e). Due to their elastic characteristics of the mica minerals, the bending resistance values of micaschist show more rapid rise than the other four components with the increasing plaster thickness (Figure 4b). On the basalt sample, the positive correlation of thickness and bending resitance reversed with the 8 mm thick plaster due to its granule shapes (Figure 4c).

Thermal conductivity coefficient values for the isolation plates are listed in Table 2. The values are indicating the average of three measurements for each sample. The values of thermal conductivity coefficient values yielded lowest in 2 mm panels and highest in 8 mm panels for all lithologies and the values 195 ranges from 0.0461 to 0.0525 W/mK for granite, from 0.0552 to 0.0650 W/mK for micaschist, from 0.0413 to 0.0502 W/mK for basalt, from 0.0581 to 0.0681 W/mK for quartz and from 0.0401 to 0.0499 W/mK for pumice (Figure 5).

Table 2. Thermal conductivity results of the samples

Sample / Thickness	Thermal conductivity Coefficient (W/mK)			
	2 mm	**4 mm**	**6 mm**	**8 mm**
Granite	0.0461	0.0471	0.0502	0.0525
Micaschist	0.0552	0.0582	0.0621	0.0650
Basalt	0.0413	0.0443	0.0489	0.0502
Quartz	0.0581	0.0611	0.0631	0.0681
Pumice	0.0401	0.0423	0.0476	0.0499

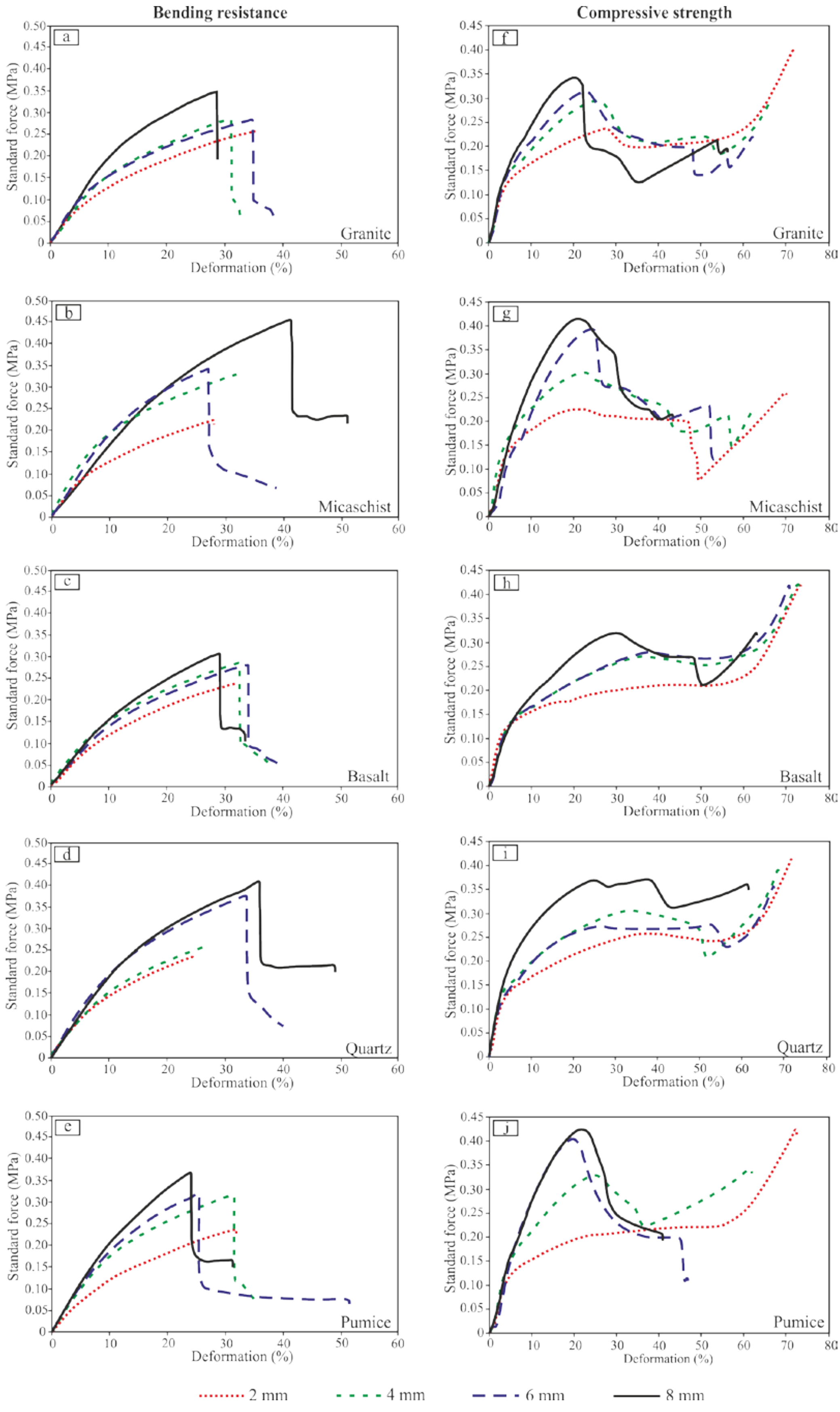

Fig. 4. Deformation graphics of the test samples

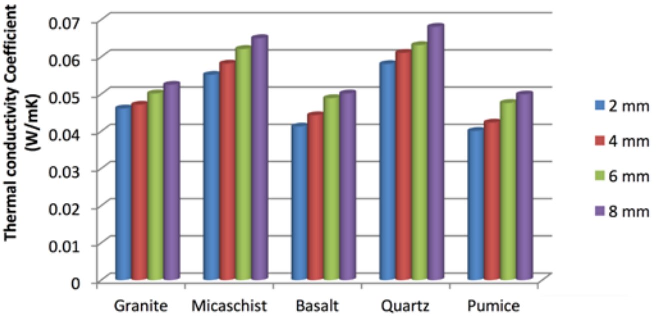

Fig. 5. Thermal conductivity values of the samples with different thicknesses

4. Conclusions

Thermo-physical tests performed on the thermal isolation panels produced from the combination of acrylic and five different lithologies suggest the following:

(1) Because of the granular structure of the samples, 2 mm plasters have the highest bending resistance values for granite, quartz and pumice. The values of same samples increase with increasing thickness from 4, 6 and 8 mm thicknesses respectively. Due to their elastic characteristics of the mica minerals, the bending resistance values of micaschist show superior characteristics than the other lithologies given with the increasing plaster thickness. On the basalt plaster, a reverse trend is observed on the 8 mm thick plaster due to its granule shapes.

(2) Granite and basalt show similar behavior in compressive strength tests. In both natural materials, a decrease in the plastic deformation under the compressive load is observed as the thickness increases, which can be expressed as an increase in strength. The biotite and muscovite minerals in the micaschists are less integrated than the granular minerals due to their acrylic platelet structure. For this reason, the plasters from micaschist exhibit brittle behavior under compressive pressure. The strength against pressure increases with increasing thickness on micaschist plasters. It is observed that quartz plaster is separated from EPS under pressure. This situation does not show a complete adhesion surface with EPS because of the absence of secondary minerals (calcite, chlorite, epidote) and feldspar minerals in quartz sand which provide good bonding and adhesion proper- ties in granite and basalt. When the compression was applied on the pumice samples in the pumice, they exhibit shrinkage and S-shaped deformation in relatively thinner plasters (2 and 4 mm in thickness), and they present a concave elastic deformation similar to granite and basalt thicker plasters (6 and 8 mm thickness).

(3) The thermal conductivity coefficient yielded lowest values in the 2 mm panels and highest in the 8 mm panels for all lithologies. The pumice and basalt panels yielded the lowest values of thermal conductivity coefficient and the third material is micaschist.

(4) Although pumice, a well-known thermal isolation material, gives positive result in terms of thermal conductivity (Çelik et al., 2016), the combination of this material with micaschist can possibly give similar results. Also as a fire resistant and retardant mineral (Hanu et al., 2006), mica minerals in micaschist will add positive characteristics to this material. Granite and basalt are prone to good adhesion and elastic deformation, so it is believed that it is possible to produce higher performance exterior insulation panels as a result of the use of these two materials together with pumice and micaschist.

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基于丙烯酸的建筑外部隔离板的热物理特性由不同的地质材料制成

關鍵詞
土工材料
天然岩石
外墙涂料
丙烯酸树脂
隔离

摘要
在这里，我们描述了一种新型的环境敏感隔热板，可用于外墙表面，通过利用天然岩石特性，最大限度地减少现有涂层材料的所有负面影响。我们研究了这种新产品的装饰特性和绝缘性能，这是通过将不同岩性材料应用于膨胀聚苯乙烯表面（EPS）而获得的。首先，使用来自各种岩性（花岗岩，云母，玄武岩，石英岩和浮石）的砂粒材料，通过剥离方法将具有25％丙烯酸和75％砂的砂浆施加到EPS上。为了确定最佳厚度，为每种岩性制备含有厚度为2,4,6和8mm的石膏的隔热板。测试了它们的导热系数，弯曲和抗压强度。可以预见，导热系数在2 mm面板中产生最低值，在所有岩性中在8 mm面板中产生最高值。弯曲强度也随厚度成比例增加。在抗压强度测试中，对于2mm面板测量最高值，而对于4,6和8mm面板获得相对低的值，除了基于云母和玄武岩的面板。因此，玄武岩和浮石在三个测量参数中提供了优越的特征，因此，预计这两种岩性的不同组合将提供积极的特征。在这种情况下，考虑到其垂直于白云母平面表面的高耐火性和低导热系数，micaschist是可以与上述两种材料一起使用的第三种岩性。与以前的材料相比，本研究中调查的产品具有成本效益，因为它们可以降低涂料成本，施工时间和总建筑负荷。岩土材料也具有美学吸引力。