Lightweight Aggregated Foam Plaster for Thermal Insulation in Buildings

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Abstract- *R*ecently, searching devoted to the alternative energy sources increases in our country having limited energy sources based on fossils, important steps were extended to save energy by applying the effective precautions. Hence, the thermal insulation applications have speed up especially in new constructions.

Thermal insulation products such as EPS and XPS polystyrene foam, glass wool and rock wool etc. are commonly used in our country. In addition to this, European Community Directives were become valid and the new arrangements were made in our relevant national laws based on these directives. After these arrangements, thermal insulation performances of these types of materials gain much more important. This case caused acceleration to new investigations for both improving the current thermal insulation product properties and developing new insulation materials.

In this paper, pre-inventions of a thermal insulation material with high performance, long service life, economic and easily applicable carried out in SDU Pumice Research and Application Centre are discussed in detail. This research material is actually an inorganic based plaster. This plaster proves the suggested technical properties in TS EN 998-1 and is a lightweight aggregated plaster in “T Category” according to this standard. Physico-mechanical analysis results of samples casting in laboratory conditions were evaluated according to TS EN 998-1. Developed plaster indicates these technical properties; T1 category thermal insulation class, A·1 class of fire resistance and non-combustible, CS·I - CS·II class compressive strength, W·0 class capillary water permeability, low water vapor diffusion resistance, high adhesive strength and easily applicable any type of surfaces.

Key Words- Lightweight aggregate, inorganic binding, high thermal insulation, foam plaster

Binalarda Isı Yalıtımı İçin Hafif Agregalı Köpük Sıva

Özet- Son yıllarda, fosil kökenli enerji kaynakları kısıtlı ülkemizde, alternative enerji kaynaklarına yönelik araştırmalar artmakta ve enerji tasarrufunun etkin biçimde uygulanmasıyla ilgili önemli adımlar atılmaktadır. Bunun sonucu olarak özellikle yeni yapılarda ısı yalıtımı uygulamaları hız kazanmıştır

Ülkemizde EPS ve XPS polisitren köpük, cam yünü ve kaya yünü gibi ısı yalıtım ürünleri yaygın olarak kullanılmaktadır. Bununla birlikte, Avrupa Birliği Direktifleri geçerlilik kazanmış ve bu direktifler esas alınarak ilgili ulusal yönetmeliklerimizde yeni düzenlemeler yapılmıştır. Bu düzenlemeler sonrasında bu tip ısı yalıtım malzemelerinin ısı yalıtım performansları daha çok önem kazanmaya başlamıştır. Bu durum hem mevcut ısı yalıtım ürün özelliklerini iyileştirme ve geliştirme de hemde yeni yalıtım malzemeleri için yeni araştırmaların ivme kazanmasına neden olur.

Bu makalede, yüksek performanslı, uzun ömürlü, kolay uygulanabilir ve ekonomik bir ısı yalıtım malzemesinin ön-çalışmaları SDÜ Pomza Araştırma ve Uygulama Merkezi'nde ayrıntılı olarak gerçekleştirilmiştir. Bu araştırma malzemesi aslında bir inorganik esaslı sıvadır. Bu sıva TS EN 998-1 standardında önerilen teknik özellikleri kanıtlayan ve bu standarda göre "T Kategori"sinde yer alan hafif köpük sıvadır. Laboratuvar şartlarında hazırlanan örneklerin fiziko-mekanik analiz sonuçları TS EN 998-1 göre değerlendirildi. Geliştirilmiş sıva, T1 kategori ısı yalıtım sınıfı, yangın dayanımı ve yanıcı olmayan A 1 sınıfı, CS I-CS II sınıfı basınç dayanımı, W 0 sınıfı kılcal su geçirgenliği düşük, su buharı difüzyon direnci yüksek, yapışma gücü iyi ve yüzeye kolay uygulanabilirlik gibi teknik özelliklere sahiptir.

Anahtar Kelimeler- Hafif agrega, inorganik bağlayıcı, yüksek ısı yalıtımı, köpük sıva

1. INTRODUCTION

Nowadays against the gradually run out of energy resources (especially fossil), the need of energy are increased and unit energy price are rapidly advanced. This situation causes the searching new applications devoted to productive energy consumption in many countries having limited energy resources.

Although investigations on alternative energy resources are recently getting improve in our country having limited fossil based energy resources, the important steps were began to apply effective precautions for energy saving. Specially, related legal laws were changed at 2008 year and existing "Thermal Insulation Regulation" was revised and new regulations are brought into force to increase the productivity in energy consumption and in energy resources, too. In this parallel, the effective thermal insulation applications are gain acceleration especially in new constructions.

Products such as EPS and XPS polystyrene foam plates, glass wool, rock wool etc. are very often used as thermal insulations materials. In addition to this, new arrangements in our related legal laws were made according to the European Community Directives. After arrangements, such technical properties of fire resistance, compressive strength, capillarity, water vapor transmission and sound absorption in parallel of the thermal insulations characteristics are started very important gain. This status is accelerated to improve the new researches on both reform to some technical properties of present thermal insulation materials and develop the new insulation materials (inorganic binding composites etc.).

In this paper, the initial research findings of a new thermal insulation material having high performance, long service life, economic and easy application were discussed. This research work was carried out in Pumice Research and Application Centre of Süleyman Demirel University. Four different lightweight aggregate types (perlite, micronised Nevşehir, Kayseri and Isparta pumice aggregates with < 1mm size) are used in ready mix foam plaster mixtures at laboratory conditions. Other components (cement, slaked lime, water etc.) of the mixture were kept as constant.

The physico-mechanical property findings of foam plaster (FP) after 28 days curing time were evaluated according to TS EN 998-1 standard. The research results were compared with equivalent EPS and XPS application thicknesses.

2. MATERIAL AND METHODS

Four different plaster mortars were prepared by using expanded perlite (EP), Nevşehir pumice (NP), Kayseri pumice (KP) and Isparta (Karakaya) pumice (IP) as lightweight aggregates (LWA) in this research work. CEM 42.5 R type Portland cement was used as a main binder. Slaked lime, polypropylene fiber, adhesive polymers and foam agent were also used in the mortar mixtures. Water/binders (w/b) ratios and proportions by weight of other whole of mixtures components in all FP groups were constant except for LWAs. Water absorption ratios of LWAs by 24 hour suction were calculated and were added to the mixing water. Physical properties of LWAs used in FP mortars were determined according to TS EN 1097-6 standard and the research findings are given in Table 1.

Table 1. Physical properties of LWAs [1]

LWA Types	ρ_s (g/cm^3)	ρ_a (g/cm^3)	ρ_{rd} (g/cm^3)	ρ_{ssd} (g/cm^3)	WA_{24h} (%)
NP	2.311	1.574	0.857	1.313	53.217
KP	2.407	2.113	0.820	1.432	74.595
IP	2.477	2.237	1.000	1.553	55.257
EP	2.390	2.219	0.292	1.161	297.052

NP : Nevşehir Pumice **KP:** Kayseri Pumice
IKP: Isparta Karakaya Pumice **EP:** Expanded Perlite
ρ_s : Specific density, g/cm^3
ρ_a : Apparent density, g/cm^3
ρ_{rd} : Oven-dried grain density, g/cm^3
ρ_{ssd} : Saturated-Dry surface density, g/cm^3
WA_{24h} : Water absorption at 24 hours

Properties of CEM I 42.5 R type Portland cement used in FP mortars are given in Table 2 and mortar mixture parameters are also given in Table 3.

Table 2. Results of suitability analyses according to TS EN 197-1 standard of cement used in mortar mixtures [2,3]

Blaine(1) (cm^2/g)	Specific gravity (g/cm^3)	Initial Set (min.)	Final Set (min.)	Exp. (mm)	Compressive Strength (MPa)			SO_3 (%)	L.O.I(3) (%)	I.R.(4) (%)	Cl^- (%)	C_3S
					B2	B7	B28					
3340	3.120	185	240	1	27.1	39.3	51.0	2.53	2.72	0.29	0.006	56.66

(1) Blaine : Cement fineness **(2) Exp. :** Expansion **(3) L.O.I. :** Loss on ignition **(4) I.R. :** Insoluble residue

Table 3. Mix designs of FP mortars with NP

FP with NP						
Ingredients	**ρ_{real} (g/cm^3)**	**ρ_a (g/cm^3)**	**ρ_{ssd} (g/cm^3)**	**ρ (g/cm^3)**	**W (kg)**	**V (m^3)**
Cement (CEM I 42.5 R)	3.12	-	-	-	200.000	64.103
Water	1.00	-	-	-	110.000	110.000
Slaked Lime	2.45	-	-	-	80.000	32.633
Pumice (<1mm)	-	-	0.857	-	168.500	196.616
Foam	-	-	-	0.080	47.600	595.000
Fiber (PP)	1.150	-	-	-	2.000	1.729
Viscosity Agent	-	-	-	-	1.500	-
Water absorption (%) of LWA	0.532	**%V_{LWA}**	19.659		609.600	1000.000
Addition mixing water[1] (kg)	89.642	**w_t/c^2**	0.998		**Unit weight [3]**	**610 kg/m^3**
1. Water amount (by weight) of LWA at saturated-dry surface condition 2. Total water amount of mortar mixture / cement ratio. 3.Theorical density of fresh mortar (kg/m^3)				ρ: Bulk density (g/cm^3)		

Energy saving, thermal conductance (U) and the energy requirement (P) which is given in Table 6 were calculated according to following equations:

Energy saving (according to TP)

$$(P_{TP} - P_{FP/XPS/EPS}) * 100 / P_{TP}$$

Where;

P_{TP} : The energy requirement for brick-wall covered with traditional plaster, %

$P_{FP\text{-}XPS\text{-}EPS}$: The energy requirement for brick-wall covered with foam plaster, XPS or EPS, %

Thermal conductance (U value)

$$R_T = (d_1/\lambda_1) + (d_1/\lambda_1) + \ldots + (d_n/\lambda_n)$$
$$U = (1/R_i) + (1/R_T) + (1/R_e)$$

Where;

R_T : Total thermal resistance of building component, m^2.K/W

R_i : The thermal resistance of internal surface of wall, m^2.K/W

R_e : The thermal resistance of outside surface of wall, m^2.K/W

U : The overall heat transfer coefficient of wall, W/m^2.K

λ : The thermal conductivity of material, W/m.K

Energy requirement (P)

$$P = A.\ U.\ dT \ldots (W)$$

Where;

P : Energy requirement of building, W

A : The surface area of wall, m^2

dT : The temperature difference between inside and outside surface of wall, K

These calculations were based on the wall section given in Figure 1.

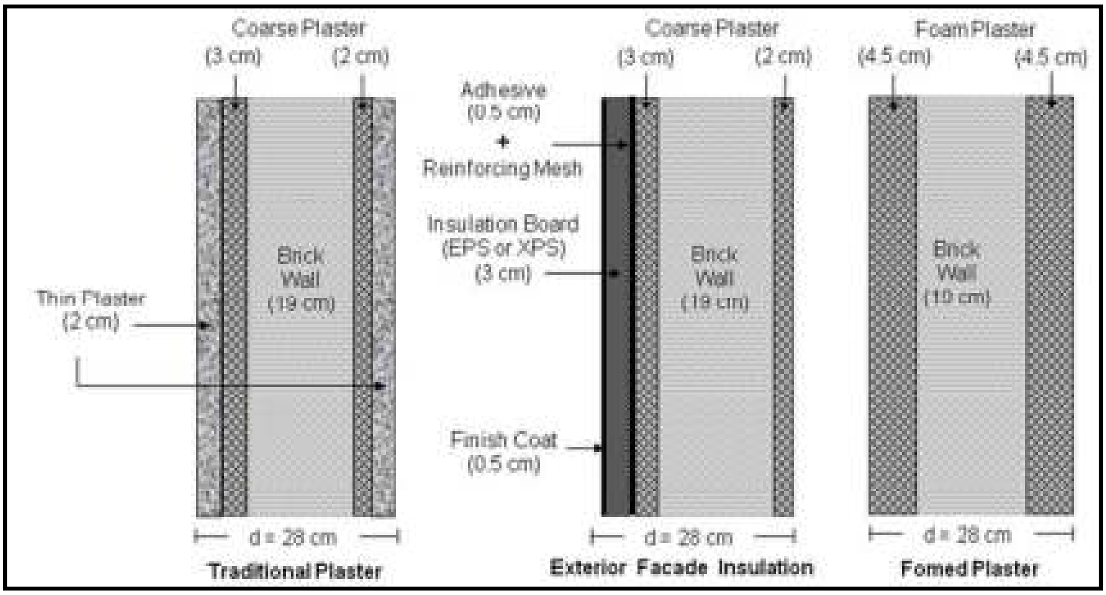

Figure 1. Thickness of wall components based on the calculation of thermal insulation performance

3. RESULTS AND DISCUSSIONS

Thermal conductivity values of traditional plaster, foam plaster, XPS and EPS were measured according to DIN EN 1602:199701 standard with Holometrix Rapid K-30 device. Thermal conductivity coefficients of these materials are given in Table 4 [13].

Table 4. Thermal conductivity coefficients of EPS, XPS, traditional plaster (TP)

Materials	Thermal Conductivity Coefficient (λ, W/m.K)
XPS	0.032
EPS	0.040
TP	0.870
FP-EP	0.068
FP-NP	0.081
FP-KP	0,079
FP-IP	0.085
Brick (19 cm)	0.452

Values for the initial setting ad final setting times of fresh FP plasters are given in Table 5. It is possible to state that workability time of FP based on their LWA types are between 500 and 600 minutes.

Table 5. Initial setting and final setting times of fresh FP according to LWA types

Sample	Initial Setting (min.)	Final Setting (min.)
EP	585	865
NP	495	735
KP	565	820
IP	535	775

The densities of oven-dry FP samples after curing at 28 days time are given in Figure 2a. Also, the compressive strength of these samples at 7, 14 and 28 days curing are given in Figure 2b.

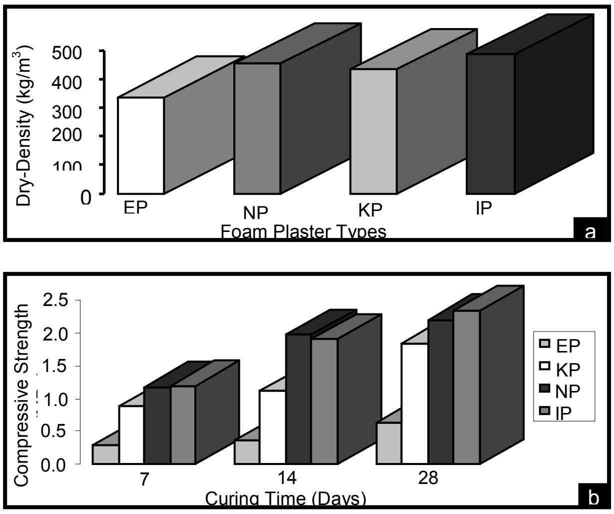

Figure 2. Dry-density (a) and compressive strength (b) according to curing times of FP samples

It was observed that matrix structure of FP samples are formed approximately 60% micro pores (except for LWA's porosity) and it is a cement binding composite including 0.5% polypropylene fiber by volume. In this respect, its mechanical behavior under the load is very different compared to other cement based products. Stress–deformation relations of four different types of FP samples including LWA were analysed (Figure 3). All of the FP samples show "constipated plastic" mechanical behavior

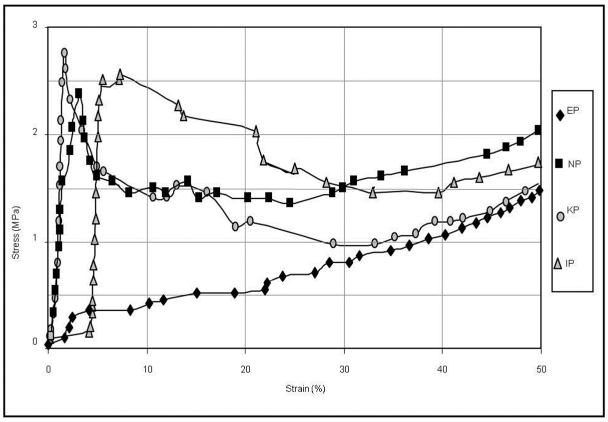

Figure 3. Stress-strain curves of FP samples at the curing on the 28th day according to LWA types.

Furthermore, tangent modulus of elasticity, (one point loading) bending strength, mass loss after thaw-freezing cycles, fire resistance, capillarity, water vapor transmission coefficient and thermal conductivity of all FP samples are determined and listed in Table 6.

Table 6. Physical and mechanical properties of FP samples

Physical or Mechanical Testing	FP Type			
	EP	NP	KP	IP
Density (oven-dry, kg/m^3)	338	455	435	487
Compressive Strength (at 28th days, MPa)	0.638	2.206	1.845	2.337
Tangent Modulus of Elasticity of FP (MPa)	25	82	190	280
Bending Strength (N/mm^2)	0.080	0.100	0.110	0.071
Loss of Mass in Frezee-Thaw (by weight, %)	3.74	1.69	2.35	1.20
Capillarity (kg/m^2.min$^{0.5}$)	1.815	0.615	0.785	0.615
Water Vapor Transmission Coefficient	5.10	7.57	7.13	8.29
Thermal Conductivity (W/m.K)	0.068	0.081	0.079	0.085
Organic material content (by weight, %)[1]	0.402	0.329	0.333	0.314
Fire Retardant Class [2]	A·1	A·1	A·1	A·1

[1,2] Because of organic material content less than 1% by weight, foam plaster groups were described as "non-combustible and no contain any organic material" according to TS EN 998-1 [12]

The thermal insulation performance of FP developed in this research was compared with EPS and XPS insulation material performances in a same wall situation according to the calculation methodology of Turkish Thermal Insulation Regulations [11]. Also the same comparison was followed to the traditional plaster (TP) work in this wall situation as well. The wall conditions to be used in these analyses were as follows: The masonry unit is brick with 19 cm thickness having the thermal conductivity of 0.26 W/mK. Insulation area of the wall is 100 m^2 in all analyses. The insulation was applied at outer surface of the wall with the thickness of 2 cm. Energy saving percentage of FP against EPS, XPS and TP applications were evaluated. Also, thermal conductance (U value) and the need of energy value (P) were determined in the analyses. The research findings are all given in Table 7.

Table 7. Thermal insulation performances comparison of EPS, XPS, TP and FP.

Thermal Insulation Material	EPS	XPS	TP	FP
FP Type : EP				
Energy Saving of FP against others (%)	2.40	-2.08	36.68	-
Thermal Conductance (U, W/m^{2}K)	0.713	0.654	1.054	0.668
The need of Energy (P, Watt)	2283	2093	3372	2137
FP Type : NP				
Energy Saving of FP against others (%)	0.10	-8.95	32.37	-
Thermal Conductance (U, W/m^{2}K)	0.713	0.654	1.054	0.713
The need of Energy (P, Watt)	2283	2093	3372	2281
FP Type : KP				
Energy Saving of FP against others (%)	0.98	-7.99	32.96	-
Thermal Conductance (U, W/m^{2}K)	0.713	0.654	1.054	0.706
The need of Energy (P, Watt)	2283	2093	3372	2260
FP Type : IP				
Energy Saving of FP against others (%)	-1.58	- 10.79	31.23	-
Thermal Conductance (U, W/m^{2}K)	0.713	0.654	1.054	0.725
The need of Energy (P, Watt)	2283	2093	3372	2319

The research was showed that the highest thermal insulation performance of foam plaster is EP type with the energy saving percentage of 2.40 against EPS insulation, 36.68 of against traditional plaster application. Based on energy saving values, the thermal insulation performance of foam plasters are arranged in order of EP, KP, NP and IP type plasters. All types in actual case have a good thermal insulation performance and they could use as an insulation purposes according to the analyses results.

4. CONCLUSIONS

The FP types are all suitable products in accordance with requirements of TS EN 998-1 standard. All FP types are in class of T·1 for thermal insulation and are in class of W·0 for capillarity. However, EP type of FP is taken part of CS I class for the compressive strength; the other types (NP, KP and IP) are taken part of CS II class based on the standard requirements. Evaluating the whole properties of the FPs, EP type is most suitable mixture combination for thermal insulation capability in a wall condition.

The basic advantage of these plaster works are easy to apply in any wall surfaces. The cost of application is very low compared with the other type of insulation materials. Because of their natural manner, the durability of the foam plasters is also higher than the other insulation material applications.

Important disadvantages of these plaster types are described as follows. Plaster could be applied by hand or plaster machine. However, all of the solid components of FP mortars could be obtained as craft bag. Besides, foam generator must be ready in application area. Mixing water, foam amount and mixing time must be followed according to the instructions. The surface should be saturated before application. The mortar mixture amount should be defined for a condition of 30 minutes application time. After initial strength of plaster, waterproof material should be applied on surface.

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