VÉDELEM TUDOMÁNY
KATASZTRÓFAVÉDELMI ONLINE TUDOMÁNYOS FOLYÓIRAT

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EFFECT OF THICKNESS OF POLYSTYRENE INSULATION AGAINST RADIANT HEAT

Abstract

Thermal insulation of buildings is not only important to the owners, but also mandatory due to legal requirements. Energy certificates are also a part of these. For correspondence various thermal insulation materials are used. The authors selected two common and cheap insulating materials for the test, such as polystyrene EPS and XPS types. These are commercially available in different thicknesses. The objective of the article is to examine what thickness can be considered optimal, above which the already increased costs should be taken into account. During our research, we exposed the materials to radiant heat. The authors measured the temperature evolution of the interior of the samples after a heat load of around 100 C. The measurement results showed that above 5 cm thickness a steady state is already established, so the temperature rise stops at a constant value. From the fire protection point of view, it is important to know the thermal properties of insulating materials, as the ignition process is always preceded by warming.

Keywords: polystyrene insulation, radiant heat, test, specimen

POLISZTIROL SZIGETELŐK VASTAGSÁGÁNAK HATÁSOSSÁGA SUGÁRZŐ HŐVEL SZEMBEN

Absztrakt

Épületek hőszigetelése már nemcsak az építtetőnek fontos, hanem a jogszabályi előírások miatt kötelező is. Ezt a célt szolgálják az energia tanúsítványok. Ennek a megfelelésére legkülönbözőbb hőszigetelő anyagokat használnak. A mi vizsgálatunkban két gyakori és legolcsóbb szigetelő anyagot választottunk ki az a polisztirol EPS és XPS típusokat. Kereskedelemben különböző vastagságokban lehet kapni. Vizsgálatunk célja, hogy megvizsgáljuk milyen vastagság tekinthető optimálisnak, ami felett már a megnövekedett költségek számítanak. Jelen munkánkban a hőszigetelés a fő vizsgálat és nem a tűzzel szembeni viselkedés, így az anyagokat sugárzó hőnek tettük ki. A minták egyik oldalát 100 C körüli hőterhelés érte és mértük a minták belsejének hőmérséklet alakulását. A mérési eredmények azt mutatták, hogy 5 cm vastagság felett már beáll egy stacionárius állapot, azaz a hőmérsékletemelkedés leáll és beáll egy állandó értékre. Fontos megjegyezni, hogy tűzvédelmi szemponttól is fontos a szigetelő anyagok termikus tulajdonságaik megismerése, mert a gyulladási folyamatot mindig felmelegedés előzi meg.

Kulcsszavak: polisztirol szigetelők, hősugárzás, mérés, minta

1. INTRODUCTION

It is important to know the thermal properties of insulating materials, as the ignition process is always preceded by warming [1] [2] [3]. Thermal insulation of buildings is not only important to the owners, but also mandatory due to legal requirements. Energy certificates serve this purpose. The first legislation in connection with energy was published in 2006 in Hungary. It was followed by a government decree in 2009 that already regulates when the Energy Certificate is mandatory. Over the years, the number of those who are required to certify has steadily extended. From the 1st of January 2016, the preparation of the certificate is obligatory when selling and renting the buildings (flat, independent unit). Naturally, energy is secondary viewpoint after the safety of life in case of buildings [4].

The first Hungarian standards were issued in 1980 under the name "Fire resistance tests". Its sub-standards include for example ‘Non-combustibility testing of building materials’, ‘Testing the spread of fire on the facade of a building’, ’ Determination of the ignition temperature of solids ’ [5]. It is not mandatory in case of building materials, but in the opinion of the authors, the behaviour of the materials against radiant heat plays an important role. They would like to prove in this in their study [6].

Sustainability benefits associated with EPS are:

- EPS manufacturing does not involve the use of ozone-layer-depleting CFCs and HCFCs
- No residual solid waste is generated during its manufacturing
- It aids energy savings as it is an effecting thermal insulation material which helps reduced CO_2 emissions
- EPS is recyclable at many stages of its life cycle

2. SPECIMENS

EPS is widely used in building and construction industry thanks to its insulation properties, chemical inertness, bacterial & pest resistance, etc. Its closed cell structure allows only little water absorption. It is durable, strong and can be used as insulated panel systems for facades, walls, roofs and floors in buildings, as flotation material in the construction of marinas and pontoons and as a lightweight fill in road and railway construction [7] [8].

We selected two common and cheap insulating materials for the test, such as polystyrene EPS and XPS types [9] [10].

2.1. Extruded Polystyrene vs. Expanded Polystyrene

XPS is often confused with EPS. **EPS (expanded)** and **XPS (extruded)** are both closed-cell rigid insulation made from the same base polystyrene resins. However, difference lies in their manufacturing process [11].

Table 1 – Expanded polystyrene (EPS) and extruded polystyrene (XPS). Created by the Authors.

Expanded Polystyrene (EPS)	Extruded Polystyrene (XPS)
• EPS is manufactured by expanding spherical beads in a mould, using heat and pressure to fuse the beads together. While each individual bead is a closed cell environment, there are significant open spaces between each bead • EPS beads are moulded in large blocks that are subsequently cut by hot-wire machines into sheets or any special shape or form by computer-driven systems • EPS's blowing agent leaves the beads rather quickly creating thousands of tiny cells full of air • EPS absorbs more water than XPS resulting in reduced performance and lost insulation power (R-value)	• XPS is manufactured in a continuous extrusion process that produces a homogeneous "closed cell" matrix with each cell fully enclosed by polystyrene walls • XPS is "extruded" into sheets. Polystyrene is mixed with additives and a blowing agent – which is then melted together through a dye • XPS's blowing agent stays embedded in the material for years • XPS is often selected over EPS for wetter environments that require a higher water vapour diffusion resistance value • The compressive strength of XPS is greater than that of EPS

EPS has very low thermal conductivity due to its closed cell structure consisting of 98% air. This air trapped within the cells is a very poor heat conductor and hence provide the foam with its excellent thermal insulation properties. The thermal conductivity of expanded polystyrene foam of density 20 kg/m^3 is 0.035 – 0.037 W/ (m·K) at 10 °C. Fire Resistance – EPS is flammable. Modification with flame retardants significantly minimize the ignitability of the foam and the spread of flames [12] [13] [14].

The tests were performed on EPS80, EPS100, Graphite, Flame Retardant Graphite, XPS, XPS expert materials.

3. TEST METHOD

The test is based on ISO 6941, 2nd Edition, 2003 - Textile fabrics Burning behaviour Measurement of flame spread properties of vertically oriented specimens and EN 13 772: EN13772: Textile and textile products-burning behaviour curtains and drapes measurement of flame spread of vertically oriented specimens with large ignition source.

A flame is applied to a vertically oriented test fabric to determine the burning behaviour. The test specimen is placed in a vertical metal frame. A propane gas flame is applied to the test sample. The test is pursued according to a predefined scheme. A heat source with defined energy is applied to the back of a vertical specimen. After exposure a small flame is applied to a piece of cotton fabric wrapped around the bottom of the specimen. Flame spread is measured by determining the time taken to reach reference points on the specimen.

The test device, layout, this was done according to the standard.

There was a difference in sample size. Size of our sample: 10 x 10 cm, thickness:15-25 cm

The duration of the study was 10 and 12 minutes.

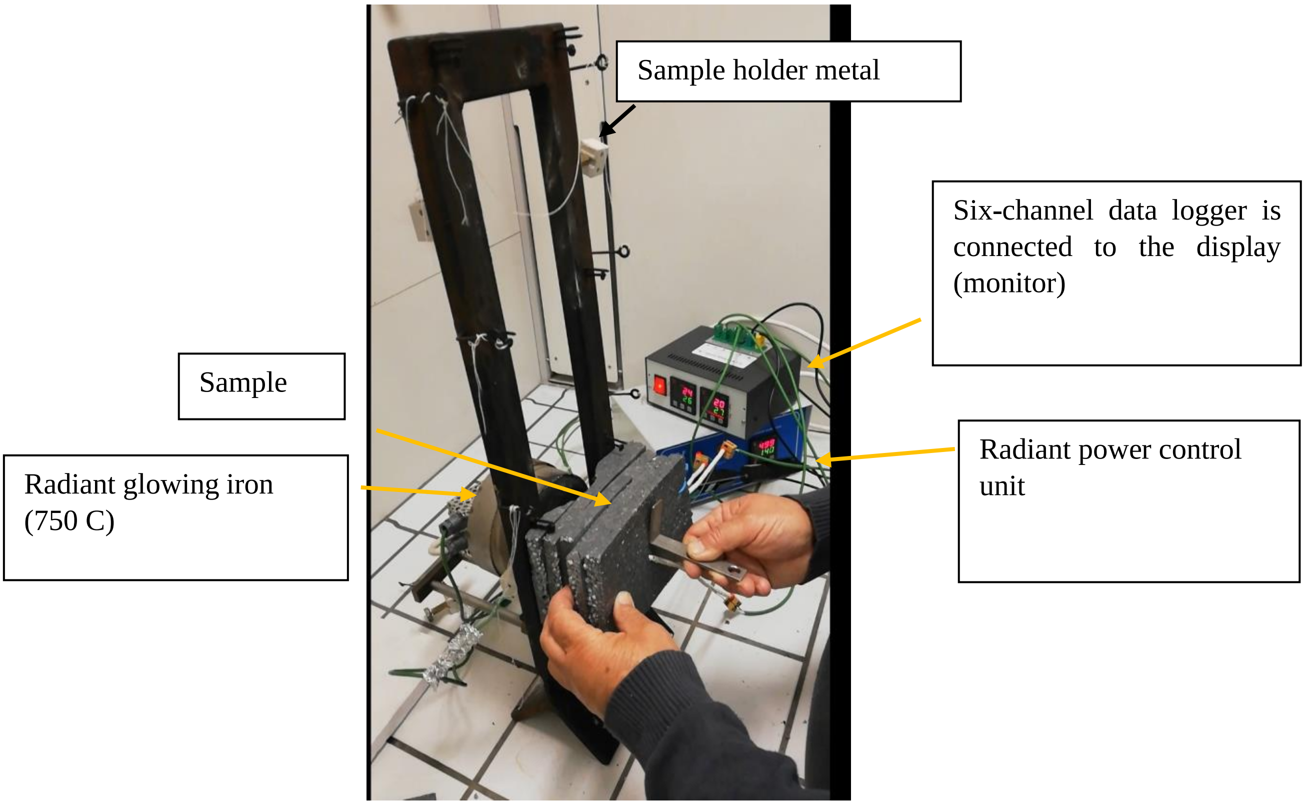


Figure1 - Radiant power control unit. Source: Authors.

The size of the test specimens is 10 x 10 cm, ranging in thickness from 15 cm to 25 cm. Thermo elements are inserted into the specimens in every 3 centimetres. The specimens are pre-drilled so that the thermo element sticks can be inserted. The thermocouple continuously measures the temperature of the surface.

The setting of the electric heater varies between 500-600 °C. However, during pre-measurements, it was determined that its positioning from the frame changes the amount of heat radiation reaching the samples from the heat dissipation surface. Due to the thermal insulating effect of the room temperature, removing 1 cm from the emitter results in a 100 °C temperature decrease on the surface of the sample.

Data recording:

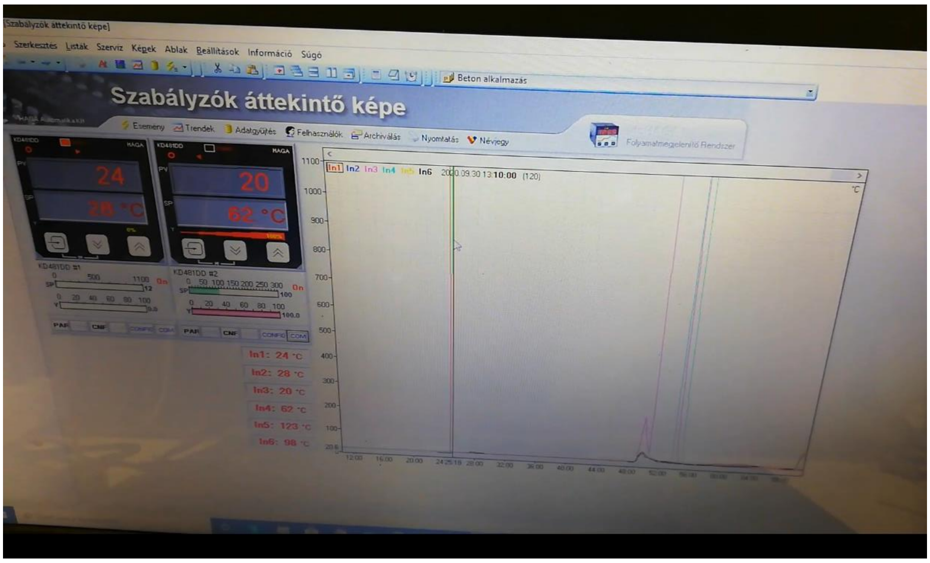


Figure 2 - Radiant heat testing – Operation of the recording program. Source: Authors.

Figure 3 - Thermo elements in the specimen. Source: Authors.

4. TEST RESULTS

The temperature of the specimens is 100°C. During the test, thermocouple 1 was placed 3 cm , thermocouple 2 to 6 cm, thermocouple 3 to 9 cm, thermocouple 4 to 12 cm, thermocouple 5 to 15 cm and thermocouple 6 to 18 cm inwards from the surface. In case of all samples, the temperature of the surface increased in all cases due to exothermic processes. It heated to a temperature higher than the heat reached the surface, so that exothermic processes were started in all specimens under the influence of heat. The extent of this depends on the type of examined material. The smallest temperature rise was observed in case of white EPS 80 and 100, while the largest temperature rise was observed for XPS products. Here the heat could reach an excess temperature of + 43 °C. All in all a surface temperature increase can be observed in all cases. The interior of the specimens shrinks in all cases. We cannot talk about combustion, because the loss of matter (as it will be seen) is related to a minimum mass.

In case of the examinations, after 12 cm of thickness, the temperature change could no longer be measured with a thermocouple.

Table 2 - Radiant heat test - Data in case of uncoated specimens

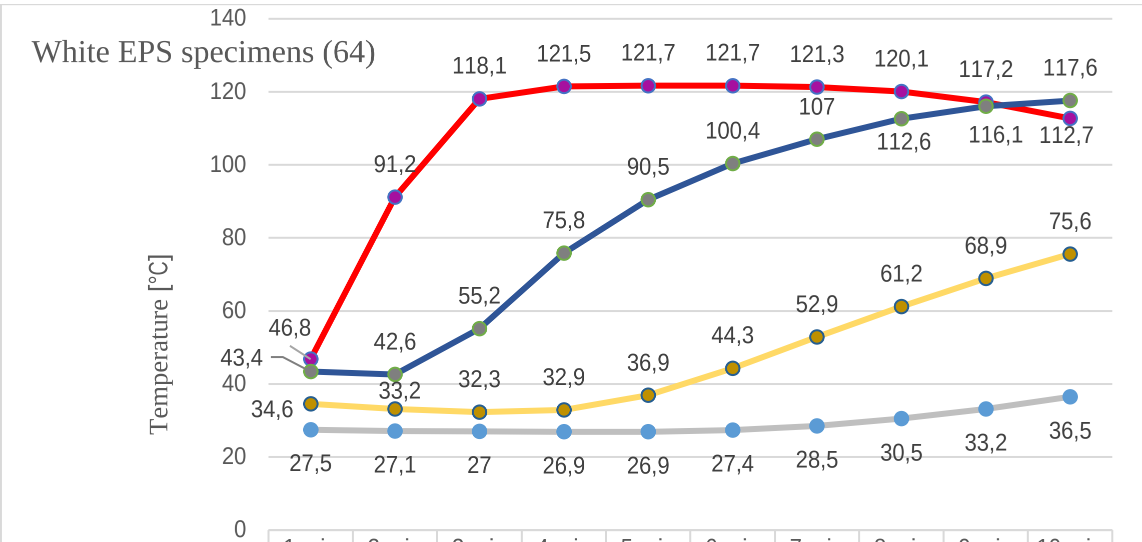
Examination of the of uncoated specimens												
Basic data										Results		
Date	No.	Type	Type	Width [mm]	Length [mm]	Thickness [mm]	Volume [cm3]	Weight [g]	Density [g/cm3]	Max. temp.	Weight after test [g]	Weight loss [g]
2020.10.20	71	bevonat nélküli	XPS TOP 30	100	100	140	1400	46,09	0,033	139	45,79	0,3
2020.10.27	72	bevonat nélküli	XPS TOP 31	100	100	140	1400	46,19	0,033	142	45,86	0,33
2020.11.10	27	bevonat nélküli	XPS GF	99	90	99	882,09	28,69	0,033	143	28,21	0,48
2020.11.10	67	bevonat nélküli	Expert fix	100	100	100	1000,00	28,14	0,028	138	27,74	0,4
2020.11.10	70	bevonat nélküli	XPS TOP-P	100	100	120	1200	37,87	0,032	139	37,64	0,23
2020.11.10	29	bevonat nélküli	XPS GF	98	88	120	1034,88	32,62	0,032	144	32,15	0,47
2020.11.10	30	bevonat nélküli	XPS GF	99	89	149	1312,84	41,87	0,032	138	41,37	0,5
2020.10.20	64	bevonat nélküli	AT-H80	100	100	150	1500	24,29	0,016	123	24,03	0,26
2020.10.27	63	bevonat nélküli	AT-H80	100	100	150	1500	24,98	0,017	113	24,72	0,26
2020.10.27	65	bevonat nélküli	AT-H80	100	100	200	2000	30,05	0,015	114	29,81	0,24
2020.10.27	74	bevonat nélküli	AT-H80	100	100	120	1200	18,22	0,015	122	18,08	0,14
2020.11.10	5	bevonat nélküli	JC-80	100	98	100	980	14,57	0,015	126	14,48	0,09
2020.11.10	7	bevonat nélküli	JC-80	101	99	120	1199,88	17,56	0,015	128	17,43	0,13
2020.11.10	20	bevonat nélküli	EPS	100	99	100	990	17,16	0,017	140	16,98	0,18
2020.10.20	58	bevonat nélküli	GRAFIT REFL	100	100	140	1400	21,11	0,015	136	20,92	0,19
2020.10.27	55	bevonat nélküli	GRAFIT REFL	100	100	160	1600	25,27	0,016	120	25,07	0,2
2020.10.27	57	bevonat nélküli	GRAFIT REFL	100	100	140	1400	21,89	0,016	122	21,8	0,09
2020.10.27	60	bevonat nélküli	GRAFIT REFL	100	100	100	1000	16,23	0,016	115	16,09	0,14
2020.10.27	62	bevonat nélküli	GRAFIT 80	100	100	140	1400	21,74	0,016	115	21,56	0,18
2020.10.27	73	bevonat nélküli	GRAFIT 80	100	100	80	800	12,52	0,016	114	12,45	0,07
2020.11.10	1	bevonat nélküli	Grafit	71	100	100	710	16,86	0,024	135	16,75	0,11

Now we compare the changes in the heat radiation of the samples in time under the influence of heat. For simpler understanding, we examine the white EPS graphite and the XPS materials separately. Below we can see the development of internal temperatures over time. The colour of the lines indicates the location of each thermocouple in the thickness of the specimen.

4.1. White EPS specimens

In case of white EPS specimens it can be observed that in 7-8 minutes each thermocouple which is 3 cm from the surface already shows a decrease in temperature. This was established after the test because there was no material in the vicinity of the measuring element and the temperature produced inside could only leave in advance by touching this thermocouple. As the rate of internal heat production decreased, a decrease in temperature was observed in case of the thermocouple 1.

In contrast, because the material started to react at thermocouple 2, the increased suddenly in the second period of the test. Furthermore, it can be observed in half of the examined cases that, based on the test data in case of thermocouple 2, the increase in the inner temperature in the interior enclosed from 3 sides at **6 cm depth gives the maximum inner temperature value**.



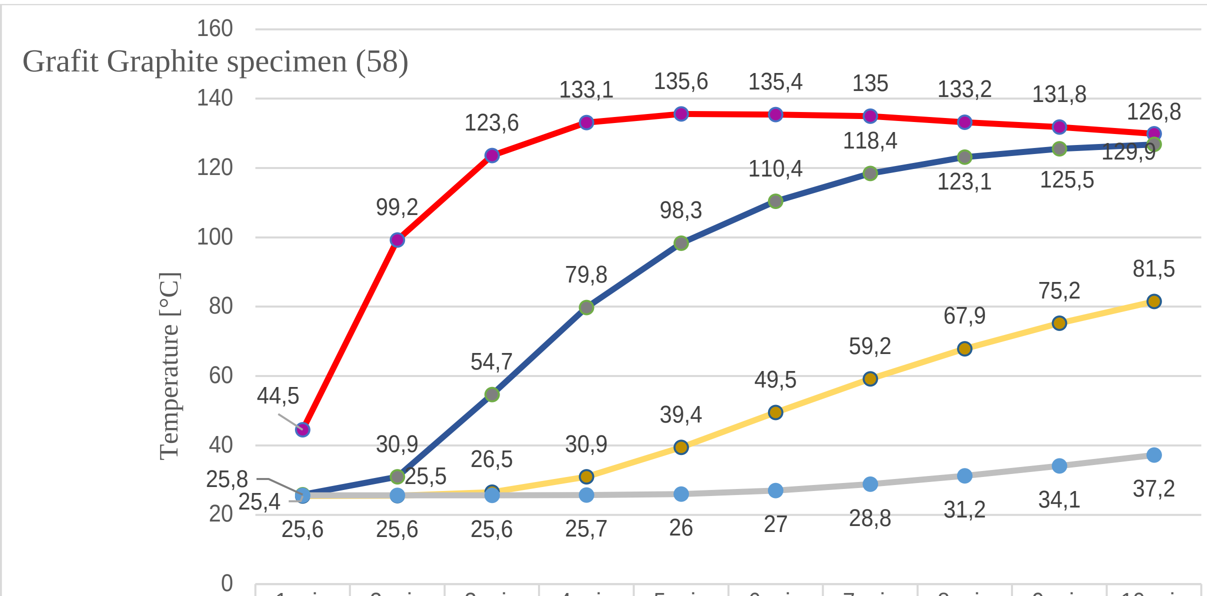
	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min
1. thermo elem	46,8	91,2	118,1	121,5	121,7	121,7	121,3	120,1	117,2	112,7
2. thermo elem	43,4	42,6	55,2	75,8	90,5	100,4	107	112,6	116,1	117,6
3. thermo elem	34,6	33,2	32,3	32,9	36,9	44,3	52,9	61,2	68,9	75,6
4. thermo elem	27,5	27,1	27	26,9	26,9	27,4	28,5	30,5	33,2	36,5

Figure 4 - White EPS specimens on graphs. Created by the Authors.

4.2. Examination of the graphite specimens

In case of graphite specimens, it can also have observed that the values measured at thermocouple 2 exceed the values measured at element 1. However, it cannot be stated from the amount of the test that this is a feature of a particular product. However, in case of graphite material treated with a flame retardant, it can be stated that the maximum value could be measured at thermocouple 1. In contrast, for the other test specimens (except specimen 1), the maximum value was measured at thermocouple 2 (see Figure 5).

The lowest temperature was basically at the smooth graphite specimens. During the test, it can be observed that the change of the inner temperature is more intense than the graphite material. This means that it reaches the higher temperatures earlier in time than the flame retardant materials.



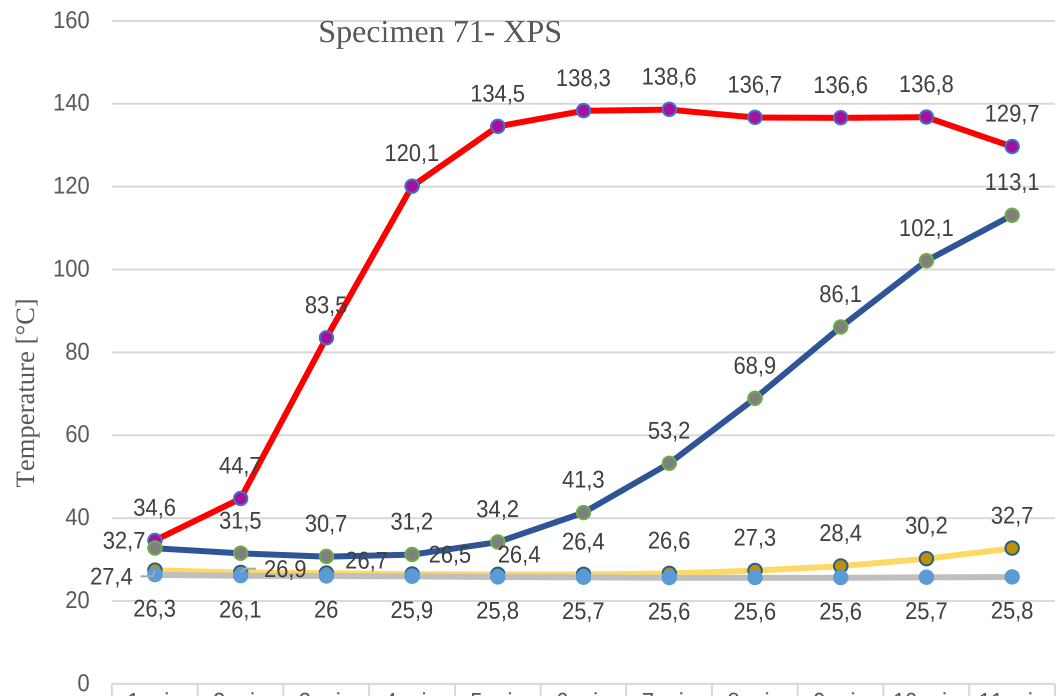
	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min
1. thermo elem	44,5	99,2	123,6	133,1	135,6	135,4	135	133,2	131,8	129,9
2. thermo elem	25,8	30,9	54,7	79,8	98,3	110,4	118,4	123,1	125,5	126,8
3. thermo elem	25,4	25,5	26,5	30,9	39,4	49,5	59,2	67,9	75,2	81,5
4. thermo elem	25,6	25,6	25,6	25,7	26	27	28,8	31,2	34,1	37,2

Figure 5 - EPS graphite specimens. Created by the Authors.

4.3. Examination of XPS specimens

In case of XPS-based samples, it can generally be stated that they have a much better insulating ability. This conclusion can be based on the measurements of thermocouple 2 placed at a thickness of 6 cm. In case of thermocouple 1, a quicker temperature rise can be observed, and in each case the maximum inner temperature can also be measured here. However, a very slow temperature change can observed at thermocouple 2, so we should extend the test time to 10 minutes.

The temperature rise at thermocouple 2: The curve can be described by a polynomial equation in each case.



	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min	11 min
1. thermo elem	34,6	44,7	83,5	120,1	134,5	138,3	138,6	136,7	136,6	136,8	129,7
2. thermo elem	32,7	31,5	30,7	31,2	34,2	41,3	53,2	68,9	86,1	102,1	113,1
3. thermo elem	27,4	26,9	26,7	26,5	26,4	26,4	26,6	27,3	28,4	30,2	32,7
4. thermo elem	26,3	26,1	26	25,9	25,8	25,7	25,6	25,6	25,6	25,7	25,8

Figure 6 - XPS specimens. Created by the Authors

5. SUMMARY

The 3 different types of thermal insulation are compared below. Among the specimens examined above, we highlighted the number 65 for white EPS, number 57 for graphite, and number 72 for XPS specimens (see Table 2). It can be observed that the more heat additives are added to the material, the more intense is the surface heating.

In the first two minutes, because of the first heat, the white EPS without additive reacts worse. However, as the time progresses, chemical reactions affecting the additive begin, which turns to exothermic processes, thus starting to produce of the heat generation. As a result of it, the generated heat will continue to be added as a catalyst to the processes.

As can be seen from the thermal insulation capacity of the inner layers, it is strongly related to the additives and the density of the materials. Much slower heating is observed in case of graphitic and XPS materials.

Examining the thermal insulation materials without a coating, it can be concluded that XPS-materials perform best under short-term radiant heat at 100 °C. The measurements explicitly support the need for radiant heat testing. This is only true for thermoplastic PS materials, a PUR foam or rock wool will definitely perform better.

Combined with the diversity of the materials sold, the differences arising from the production technology, the variety of different application areas and coating systems, completely new properties appear.

When non-flammability, fire propagation limit, chemical composition, tensile strength, thermal conductivity value are given in the qualification, heat radiation properties are not. Heat resistance is also important, because a possible fire next to the facade wall can cause invisible damage inside the insulation in just a few minutes. Laboratory experiments also prove that within a few minutes, significant deformation can occur inside the insulations. In case of external fire it is not only dangerous that deformations may generate inside the insulation, but also that it ignites and spreads to the rest of the façade.

Overall, fire prevention is an important area of the research, which includes not only outdoor fires [15] [16] [17] but also building fires.

REFERENCES

[1] Érces Gergő- Ambrusz József: A katasztrófák építésügyi vonatkozásai Magyarországon. *Védelem Tudomány*, IV.2. (2019), pp. 45-83.

[2] Érces Gergő - Vass Gyula: Okos épületek, okos városok tűzvédelmének alapjai I. *Védelem Tudomány*, VI. 1. (2021), pp. 1-21.

[3] Érces Gergő - Vass Gyula: Veszélyes ipari üzemek tűzvédelme ipari üzemek fenntartható tűzbiztonságának fejlesztési lehetőségei a komplex tűzvédelem tekintetében. *Műszaki Katonai Közlöny*, XXVIII. 4. (2018), pp. 2-22.

[4] Ragács Nikoletta - Nagyné Kovács Teodóra - Szilágyi Imre Miklós - Kerekes Zsuzsanna: Hőszigetelők termoanalitikai vizsgálata a környezetszennyezés szempontjából. *Védelem Tudomány*, III. 2. (2018), pp. 35-50.

[5] Csoknyai Tamás - Szalay Zsuzsa - Stefler-Hess Nóra: *Energiatudatos családi ház tervezése, építészeti és gépészeti optimalizációval*. http://e4haz.hu/files/1427991340.pdf Download: 10.03.2021.

[6] Kerekes Zsuzsa: Az oxigén index (LOI) jelentősége a textíliák tűzvédelmi minősítésében *Magyar Textiltechnika*, I. 3. (2019), pp. 1-11

[7] Szép János - Horváth Antal - Kerekes, Zsuzsanna: Hőszigetelős hatása a faházak elektromos tüzeire. Védelem Tudomány, III. 3. (2018), pp. 23-49.

[8] Kerekes Zsuzsanna - Reich Kristóf - Lublóy Éva: Sugárzó hőnek kitett tűzvédelmi habok viselkedése tűzgátló tömítések alkalmazása esetén, *Védelem Tudomány*, II. 4. (2017), pp. 1-18.

[9] https://omnexus.specialchem.com/selection-guide/expanded-polystyrene-eps-

foam-insulation (03, 2021. EPS,XPS) Download: 10.03.2021.

[10] *https://omnexus.specialchem.com/selection-guide/expanded-polystyrene-eps-foam-insulation* Download: 10.03.2021.

[11] Tóth Péter - Wagner Károly: Építményszerkezetek tűzvédelmi jellemzői I., *Védelem Katasztrófavédelmi Szemle* – XXII. 5. (2016), pp. 5-11

[12] Nagy László - Érces Gergő - Kiss Péter - Márton Ferenc - Kiss Róbert - Király András - Hajósi Péter - Szilágyi Csaba: Alkalmazott tűzvizsgálat. Fővárosi Főfelügyelőség. Budapest. 2014. p. 364.

[13] Műanyaghab anyagú hőszigetelések: extrudált, expandált polisztirol https://kreativlakas.com/tobblakasos-hazak/muanyaghab-anyagu-hoszigetelesek-extrudalt-expandalt-polisztirol/ Download: 10.03.2021.

[14] Kerekes Zsuzsanna - Restás Ágoston - Lublóy Éva: The effects causing the burning of plastic coatings of fire-resistant cables and its consequences. *Journal of Thermal and Calorimetry*, 139. 2. (2020), pp. 775-787.

[15] Bodnár László - Pántya Péter: The Threat of Forest and Vegetation Fires and the Possibilities of Intervention in Hungary. *Academic and Applied Research in Military and Public Management Science*, XVIII. 3. (2019), pp. 21-31.

[16] Debreceni Péter - Pántya Péter: A fokozottan tűzveszélyes időszakok meghatározásának lehetőségei. *Műszaki Katonai Közlöny*, XXIX. 1. (2019), pp. 243-260

[17] Rácz Sándor: Firefighting problems in case of large outdoor fires. *Műszaki Katonai Közlöny*, XXVIII. 4. (2018), pp. 23-32.

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