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Thermal insulation products – the propensity to undergo continuous smouldering

Materiały termoizolacyjne – podatność na przechodzenie w proces ciągłego tlenia

DOI: 10.15199/33.2022.12.01

Abstract. Continuous smouldering process of thermal insulation materials is a significant issue of fire safety of buildings. Fourteen different materials were tested. The minimum temperature of 250°C at the fourth thermocouple (400 mm above the ignition source) was adopted as a criterion of smouldering. Based on the test results, it was concluded that glass wool and cement-bonded particle boards showed a tendency to self-heat, and the loose paper fibres and fibreboards are prone to self-heating and continuous smouldering.
Keywords: smouldering behaviour; thermal insulation materials; fire properties; fire safety of buildings.

Streszczenie. Podatność na ciągłe tlenie materiałów termoizolacyjnych jest istotnym czynnikiem bezpieczeństwa pożarowego budynków. Zbadano czternaście różnych materiałów. Jako kryterium występowania tlenia przyjęto minimalną temperaturę 250°C na czwartej termoparze (400 mm od źródła ognia). Na podstawie wyników badań stwierdzono, że wełna szklana i płyty włóknisto-cementowe wykazują tendencję do samonagrzewania się, a podatność na tlenie i samonagrzewanie się wykazują luźne włókna celulozowe i płyty z włókien drzewnych.
Słowa kluczowe: proces tlenia; materiały termoizolacyjne; właściwości ogniowe; bezpieczeństwo pożarowe budynków.

The process of smouldering itself can be initiated in different ways. Smouldering can be a consequence of an extinguished flame, involves slow thermal decomposition without flames. The thermal decomposition process may be induced by heat supplied externally or it may be self-sustaining [1, 2]. Smouldering combustion can be initiated with weaker ignition sources (radiant, conductive, embers and self-heating) and is more difficult to suppress than flaming combustion [3].

Smouldering (and glowing) has been proved to be the important issue in the case of fire safety of buildings. This process can occur in the area of thermal insulation of facades, upholstered furniture, electronic devices, etc. There can be recognised several ignition sources which can lead to smouldering by producing char and initiating its oxidation process: external fire source, such as burning cigarette; extinguished flames; short circuit in the electric installation; hot surfaces; light bulbs; electric radiators [4]. In general, smouldering, as opposed to flame combustion, is slow, low-temperatures, flameless form of combustion [5, 6] with the simultaneous generation of larger numbers of products of incomplete carbon oxidation. If the substance temperature is low, the oxidation reaction is slow; the oxygen concentration on the solid body surface does not differ from the oxygen concentration in the atmosphere. In such a case, the course of oxidation will depend on the kinetics of the chemical reaction (kinetics of combustion/decomposition). If the temperature of the solid body is high, the speed of the reaction increases; at the same time, the oxygen concentration on the surface decreases significantly. The oxidation process depends on the oxygen inflow from the environment. As a result, the speed of combustion will depend on the diffusion processes. In this case, we are dealing with diffusion combustion [6]. Also, the tendency of the material for self-heating may have a significant effect on smouldering. If the heat release rate inside the smouldering material is higher than that on the surface, the temperature inside this material increases leading to smouldering inside the product [5, 7].

Smouldering may occur in products with the following properties: organic components whose content is entirely or partly of a dry material, occurrence of pores containing air or being empty, which on the one hand causes the development of the surface, and on the other hampers heat outflow and adequate source (power) has an impact on the material [8].

Glass wool and mineral wool are classified in the reaction to fire class A1 or A2 according to EN 13501-1 standard [9] and it depends on the binder content [10]. However, some types of mineral wools insulation products contain organic material, which smoulders and generates heat at temperatures between 200÷500°C [11]. The foamed materials, such as expanded polystyrene and polyurethane foams, are organic polymer based, and depending on the fire conditions a significant part of their mass is lost as fuel, and may contribute to the overall size of the fire [9]. The current research works focuses on the smouldering behaviour of wood fi-

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breboards as the main reason why they do not comply with the requirements for application as a thermal insulations on façades as a part of External Thermal Insulation Cladding Systems (ETICS) [12, 13]. There was mentioned that commonly used flame-retardant additives for wood, such as boric acid, borax, ammonium polyphosphate, ammonium sulphate, some mineral fillers such as talc, kaolin and calcium carbonate, enhance wood fibreboards and other sustainable building materials. Another main parameter influencing the smouldering processes is the density of the wooden boards. As the density increases, the velocity of smouldering decreases. [12, 14, 15].

Fire safety regulations in Poland [16] recognize the danger of smouldering only for layer dust for which a specific smouldering temperature is determined.

Materials and test method

Fourteen different materials commonly used for thermal insulation of buildings of various chemical structure (stone, wood and polymeric materials) and physical parameters (density) were tested (Table) for determinations their tendency for smouldering. Three commercial mineral wool boards differ in the amount of resins in their structure, as well as glass and ceramic wool in form of boards were chosen for testing. Those materials are non-combustible. Also other thermal insulation materials used in buildings exhibiting fire properties. These are polymeric materials such as polystyrene, polyurethane, polyisocyanurate, crylamine in form of rigid or flexible boards. Finally, the wood based materials, such as fibreboards of different thickness and density and loose paper fibres, were tested to show the propensity to continuous smouldering. Thickness and density of tested insulation materials are presented in the Table.

The test specimens were prepared in accordance with requirements given in the standard [17]. The rectangular in shape boards with dimensions of (800 ±3) mm × (300 ±3) mm and original thickness given in Table were cut from the commercial products, whereas loose materials were fitted into the wire mesh box in order to achieve an approximate density in the end use application of this type of thermal insulation materials. The rigid specimens were placed in a handle for rigid samples, flexible products (flexible polyurethane foam) were installed in the frame. The mesh box for loose fill materials was 800 mm high, 300 mm wide and 100 mm deep. Test specimens were conditioned before testing at the temperature 23 ±2°C and relative humidity of 50 ±5% for about 48 hours in special conditioning chamber.

The test was performed by using the test stand equipped with a propane Teclu burner, mass flow controller and a specimen holder or frame. The equipment is described in the EN 16733 standard [17]. Before each test propane flow rate of the burner was established at 100 g/h ±5 g/h. (0.85 l/min ±0.05 l/min). The flame was applied to each specimen horizontally and perpendicular to their surfaces and 100 mm above the bottom edge of the specimen. Temperatures were measured during the test by six K type thermocouples 1.5 mm in diameter placed inside the specimens (Figure 1). Data were recorded every 3 s during the test. The location of the thermocouples is shown in Figure 1. After 15 min the burner was removed and if the flaming of specimens continuing then the fire extinguishing board (calcium silicate board, thickness of 10 mm) was placed on the face of the specimen for a period of 20 s. The fire behaviour of specimens was observed during each test. The temperature results are presented as temperature-time diagrams.

Each test specimen was exposed to the flame for 15 min. The following fire behaviours were observed: sustained

Thickness and density of tested products
Grubość i gęstość badanych wyrobów

No	Material	Thickness [cm]	Density [kg/m³]
1	Mineral wool 1	3	170
2	Mineral wool 2	5	114
3	Mineral wool 3	8	124
4	Glass wool	15	38
5	Ceramic wool	2.5	128
6	Crylamine foam	10	41
7	Cement-bonded particle board	2.5	244
8	Fibreboard 1	2.4	280
9	Fibreboard 2	10	53.5
10	Loose paper fibres	–	41.5
11	Expanded polystyrene	10	29
12	Rigid polyurethane foam	6.5	33
13	Rigid polyisocyanurate foam	10	40
14	Flexible polyurethane foam	7.5	56

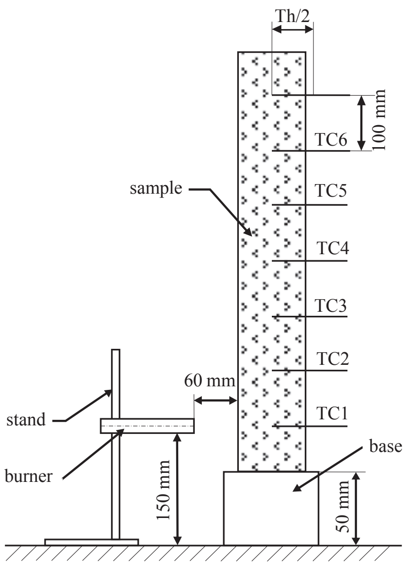

Fig. 1. Location of thermocouples on the test specimen (the end of thermocouple is positioned in the middle layer of each specimen)
Rys. 1. Rozmieszczenie termopar w obrębie próbki badawczej (zakończenie termopary jest umieszczone wewnątrz każdej próbki)

flaming, distance of flame spread, melting, spalling, charring, expansion, shrinkage, delamination or any other behaviour. The following criteria for assessing the tendency to smoulder have been taken into account:

- products, which during testing, show a temperature of 250°C, as measured by fourth thermocouple TC4, are considered to be prone to smouldering;
- products, which during testing, show an increase in temperature by 250°C above the temperature of the product after 15 min of testing, as measured by thermocouples TC1 or TC2, are considered to be prone to self-heating.

The temperature of 250°C on the fourth thermocouple (TC4) was selected as the smouldering criterion. This is a more sensitive criterion than those given in the EN 16733 standard [17] (exceeding the temperature of 250°C on the sixth thermocouple (TC6)). The obtained results and the analysis confirm that exceeding this criterion also means meeting the standard criterion.

Test results and discussion

In the Figure 2 there is shown the temperatures obtained during the three types of mineral wool (types 1, 2 and 3) tested under the same conditions. Between these materials no significant differences in fire behaviour were observed. However, the maximum temperature at TC1 point for the mineral wool 3 was equal to 374°C in 1800 s of test duration and decreases more slowly than for mineral wool 1 and 2.

The different burning behaviour of the mineral wool type 3 is shown on Figure 2c. This indicates a slow combustion process inside the sample, caused by likely differences in the amount of combustible additives of the mineral wool, and not due to differences in the density of the materials. The higher temperature at the thermocouple TC1 and a different temperature profile for mineral wool type 3 than for the others is due to the higher phenol-formaldehydes resin content between the mineral fibres, which seem to be better dispersed throughout the mass. In the case of mineral wool types 1 and 2 upon removal of the burner and extinguishing the specimen (900 s of test duration) the temperature quickly decreases, which indicates the rapid process of extinguishing for mineral wool types 1 and 2. The situation for mineral wool types 3 seems to be different, however, compared to the other materials for which the results are discussed below, does not seem to be significant.

In the case of glass wool (Figure 3a), the high temperature in the area of fire source were obtained during the test, about 700°C. The whole combustion process quickly terminated and declined completely about 3000 s after the beginning of the test. However,

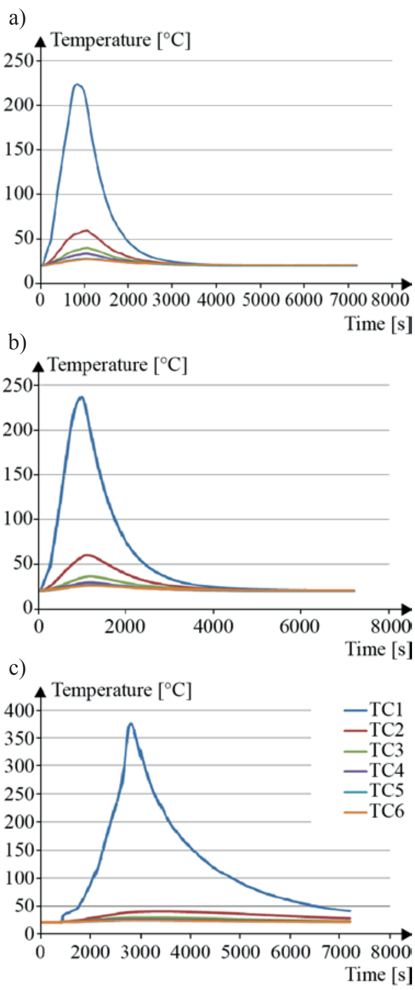

Fig. 2. Temperature during the test of three mineral wool types: a) type 1; b) type 2; c) type 3

Rys. 2. Temperatura w trakcie badania trzech rodzajów wełny mineralnej: a) typ 1; b) typ 2; c) typ 3

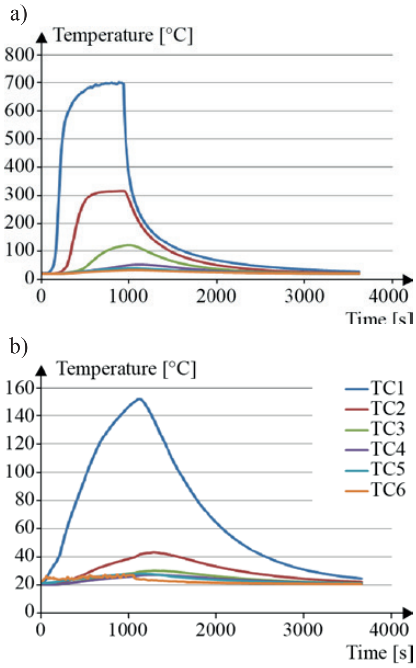

Fig. 3. Temperature during the test of: a) glass wool; b) ceramic wool

Rys. 3. Temperatura w trakcie badania: a) wełny szklanej; b) wełny ceramicznej

the temperature 307°C which has been observed on TC2 thermocouple. This allows us to state that self-heating process occurred. For ceramic wool (Figure 3b) and crylamine foam (Figure 4), the tendency of the specimens is similar in the case of flaming combustion within the fire source; however, temperatures for flaming conditions were significantly lower. The smouldering behaviour od ceramic wool is similar to mineral wool, which was presented on Figure 2.

For the expanded polystyrene, a quite high temperature was obtained on thermocouple TC2 equal to 226°C

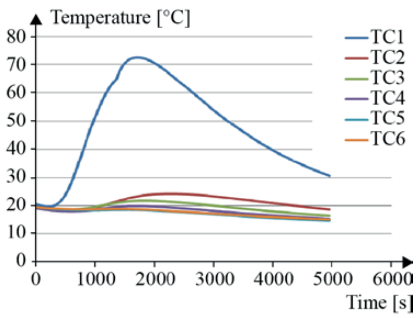

Fig. 4. Temperature during the test of crylamine foam

Rys. 4. Temperatura w trakcie badania pianki krylaminowej

(Figure 5) as a by-product of the self-heating process. No flame spread up the sample was observed. The test specimen self-extinguishing slowly even though the tendency for smouldering did not occur. However, the expanded polystyrene showed a tendency to melt at higher temperatures.

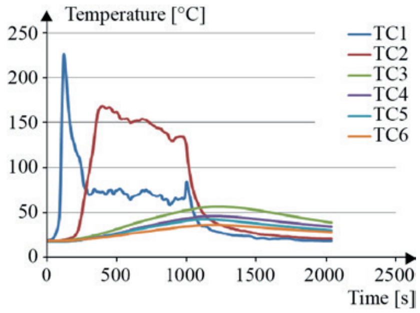

Fig. 5. Temperature during the test of expanded polystyrene
Rys. 5. Temperatura w trakcie badania polistyrenu ekspandowanego

For materials containing the urethane group, there are no significant differences in their burning/smouldering behaviour (Figures 6a, b, c). The smouldering and self-heating processes did not occurred, because the temperatures on the TC2 thermocouple did not exceed 250°C. Temperatures on TC1 thermocouple decreased slowly after they reached maximum until the ambient temperature. It shows the slowly self-extinguish process in the area of fire source.

For materials which contain combustible wood fibres distributed randomly in the mass (Figures 7, 8a, b), any tendency is shown as even between samples of the same material (Figures 8a,b). The same applies to loose paper fibres tested inside the wire box (Figure 8c). The spaces between organic fibres cause differences in ignition and flame propagation time, and influence the rest of the fire properties, especially the self-heating process, of this type of materials. The maximum temperature of the tested cement-bonded particle board is 500°C in 5210 s of test duration (thermocouple TC2), which could indicate non-homogeneous arrangement of wood fibres in the exposed part of the specimen. For fibreboards at two different densities and loose paper fibres (flame-retardant content) the highest temperatures were obtained on each thermocouple, especially for TC4 equal to 430°C for fibreboard, density of 280 kg/m^3, 616°C for fibreboard, density of 53.5 kg/m^3 and 584°C for loose paper fibres, respectively (Figures 8a,b,c).

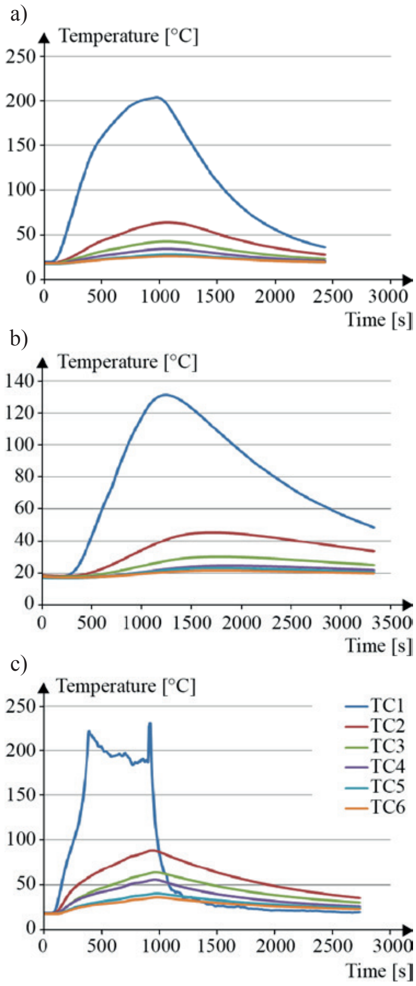

Fig. 6. Temperature during the test of: a) rigid polyurethane foam; b) polyisocyanurate foam; c) flexible polyurethane foam
Rys. 6. Temperatura w trakcie badania: a) sztywnej pianki poliuretanowej; b) pianki poliizocyjanurowej; c) elastycznej pianki poliuretanowej

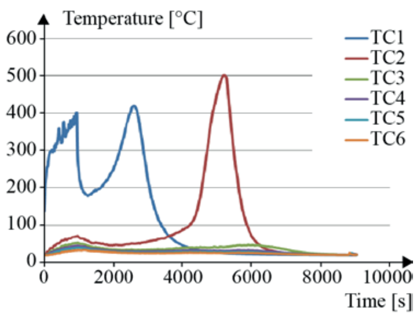

Fig. 7. Temperature during the test of cement-bonded particle board
Rys. 7. Temperatura w trakcie badania płyty włóknisto-cementowej

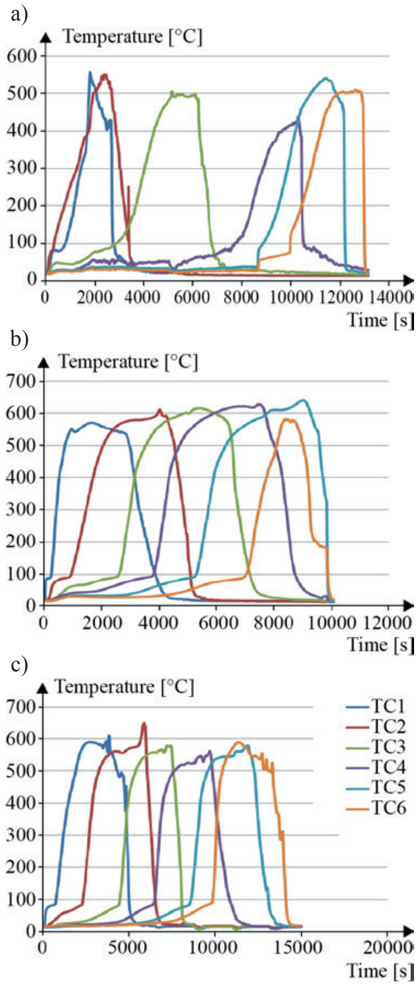

Fig. 8. Temperature during the test of: a) fibreboard, density of 280 kg/m^3; b) fibreboard, density of 53.5 kg/m^3; c) flame-retarded loose paper fibres
Rys. 8. Temperatura w trakcie badania: a) płyty wiórowej o gęstości 280 kg/m^3; b) płyty wiórowej o gęstości 53,5 kg/m^3; c) modyfikowanych ogniowo włókien celulozowych

The samples warmed up along their entire length, despite no visible flame, which is shown as deteriorations inside the specimen. The temperature results which far exceed 250°C on each thermocouple placed inside the specimens which indicates that smouldering occurred for those kind of products (Figures 8a,b,c). Those results are not compared with the cement-bonded particle board and mineral wool data. The graphs on Figure 8 also show how slowly the upward process took place by visible delays in the occurrence of maximum temperatures within individual thermocouples.

 ISSN 0137-2971, e-ISSN 2449-951X www.materialybudowlane.info.pl

Conclusions

On the basis of the obtained test results, it can be concluded mainly that cellulose insulations show a tendency to self-heating and continuous smouldering. The tests performed on each thermal insulation material showed that a significant increase in temperature occurred near the source of the fire, but this process did not lead to smouldering. This increased temperature was accompanied by self-heating processes, which occur spontaneously and depend on the nature of the material, i.e. the chemical composition. Glass wool showed a tendency to self-heating, and its occurrence depends of the dispersion of the loose fibres in the mass which are connected by combustible resins. Whereas, for cement-bonded particle boards the chemical composition of a material, based on small wood elements dispersed in the mass and poured with cement so that combustible fragments are present between the non-combustible spaces caused the effect of self-heating. Both in the glass wool board and in the cement-bonded particle boards, the combustion is extinguished, and then, when the heated non-combustible material comes into contact with the combustible material, it ignites again, caused self-heating of those building insulation materials.

Under real fire conditions for products with greater thickness or lover density, the temperature may exceed the ignition temperature of wood or various plastics. This means that there is the possibility of entering into a flame combustion process and the initiation of combustion. Thus, the propensity to smoulder and self-heat are fire properties of loose paper fibres and fibreboards, which increase the fire load of buildings.

It was observed that thermoplastic foams are not subject to smouldering. It might be explained by a tendency of material to soften, melt, scorch or sublimate under the influence of heat, and it is not susceptible to smouldering. The increase of temperatures causes melting and then smouldering is not possible. This applies to materials such as expanded polystyrene (EPS). The rigid closed-cell polyurethane foams (PUR) used as thermal insulation material might be taken into account for further research of the influence of the thickness and density of a analysed material on the process of continued smouldering. During the formulation of the foams, their density changes along with the height. The differences of smouldering behaviour in the vertical and horizontal configurations will be also analysed.

The propensity of smouldering of building materials still deserves more attention, because fires preceded by smouldering are among the most insidious. They develop unnoticed and then suddenly develop rapidly causing the loss of property and human life in the case of fire. Hence, further work should be focused on the release of toxic combustion products from thermal insulation under smouldering conditions, which undoubtedly have an impact on death in fires.

The conclusions presented in the article were based on the tested materials and the known fire source. However, depending on the nature of fire source (e.g. heated surface, light bulb), some polyurethane materials may smoulder, even if they showed no smouldering behaviour when the flame was applied. Therefore, it is necessary to carry out further investigation considering the density and thickness of the material and the type of fire source.

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The authors declare that they have no conflict of interest. This study was not founded.

Accepted for publication: 8.11.2022