Safety Engineering Series DOI 10.1515/tvsbses-2016-0013

THE REACTION TO FIRE TEST FOR FIRE RETARDANT AND FOR COMBUSTIBLE MATERIAL

Adelaida FANFAROVÁ[1], Ladislav MARIŠ[2]

Research article

Abstract: Currently the natural materials become popular building material for houses, buildings and recreational property. The risk of fires in residential timber construction or eco houses cannot be completely ruled out, therefore there is a need for proper and correct implementing preventive measures and application of all available solutions, which may reduce the risk of fire as far as possible, to slow down the combustion process, to protect the life of people, animals and also the building itself until arrival members of the Fire and Rescue Services. Fireproofing of combustible materials is a specific area of fire protection. For scientific research as well as for real-life practice, not only their structural and physical properties, but also fire-technical characteristics are really important. The present researchers mostly focus on fire-retardant treatment of wood that is why the authors of this contribution focused on a different combustible material. This research article presents the experimental testing and examination of the reaction to fire test of the selected thermal insulation of hemp fiber that was impregnated by the selected fire retardant in laboratory conditions.

Keywords: The reaction to fire test, fire retardant, combustible material, hemp, experiment.

Introduction

The target of fire-technical engineering and fire science is also the improvement and development of test methods for the examination and evaluation of materials. It also helps to make the pressure for scientist, academics and people from practice to trying to find different ways and opportunities for fire protection and complete fire prevention. In the field of fire science is the way how to make the combustible materials noncombustible the ambitious and challenging destination. One possible proceeding of the wide and various spectrums of possibilities of fire prevention measures against fires and combustion is the correct application of fire retardants. The reaction to fire is not a term related only to construction materials and substances but also construction products. The reaction to fire tests are fire tests that further specify the specific methodological and testing procedures to determine the behavior of a respective subject of testing in case of fire. The objective of these tests is to define the reaction to fire of a tested material or a product. The testing experiment of reaction to fire of a combustible product was realized using the methodology for testing fire retardants and fire-retardant treatments of materials - reaction to fire tests - test for limited flame spread (Fanfarová, 2014). This method was developed in the Fire-chemical laboratory of the Department of Fire Engineering, Faculty of Security Engineering, University of Žilina as an internal document within the institutional grant project. The methodology specifies the fire test focused on evaluation of the specimen combustion behavior when exposed to a direct mid-height flame for a longer time period. It describes and specifies the fire test for testing retardant treatments of combustible materials exposed to a mid-height flame, with the surface exposure angle of 45° to the vertical axis. This angle is the angle of the product used in real-life practice.

Materials and methods

Fire retardants are chemical impregnating substances which can in chemical, physical or combined way to manage to protect and prevent the ignition, slowing down the process of combustion and eliminate the inception of fire and conflagration.

[1] University of Žilina, Faculty of Security Engineering, Žilina, Slovak Republic, Adelaida.Fanfarova@fbi.uniza.sk

[2] University of Žilina, Faculty of Security Engineering, Žilina, Slovak Republic, Ladislav.Maris@fbi.uniza.sk

Safety Engineering Series DOI 10.1515/tvsbses-2016-0013

The principle of the process of retardation is the continuation of the specific retardation element to the surface and structure of combustible materials. Most retardants works by preventing the access of oxidizing agent (e.g. air), but they are also able to affect the ratio of flammability or to upgrade flammability parameters and characteristics of impregnated material which is protected. Fire retardants have the ability to improve the fire-technical characteristics and fire resistance of the impregnated material and as well they protect materials and products against from direct flame contact, spontaneous combustion, flameless combustion (smoldering) and before higher temperatures of fire (Drysdale, 1999, Osvaldová, 2005).

Classification of fire retardants depending on the principle of retardation (Osvald, 1997):

1. Fire retardants that release and emit non-combustible gases in the heat interval, when the combustible gases generated by thermal decomposition of the combustible material, which leads to dilution and decompression of concentration of flammable gases and then is difficult to ignite them.
2. Fire retardants that accumulate heat from the heat of source, which leads to cooling the heat of source and to slowing the process of combustion.
3. Fire retardants that create on surface of impregnated combustible material the protective intumescing layer of foam (few centimeter foam) that separate the surface of combustible material from the heat of source and simultaneous with the chemical reactions slow down the process of combustion.
4. Fire retardants that represent mechanical type (for example various building film and cladding made of non-combustible materials).

Classification of fire retardants depending on the way of application:

a) Application of coating (e.g. building constructions, metals).

b) Application of impregnation (e.g. wood products, textile).

c) Application of soaking (e.g. plastics, thermal insulation).

In current engineering technical practice already exists a number of different types of fire retardants and retarder modifications, which are used primarily to achieve a reduction of the flammability of most and commonly used substances. They can be applied to finished products or added during the technological process of materials processing. Application methods and mechanism of action of fire retardants depends on the characteristics of the fire retardant and the properties of the treated material that we want to protect against the negative effects of fire. Fire retardants can be applied to various types of materials: the construction and design elements, coverings of wall and ceilings, flooring, insulation materials, electrical appliances, electronic equipment, cable bundles, wood, furniture, plastics, metals, indoor and outdoor paints, textiles, toys and more. The careful choice of fire retardant, the correct way of application and professional appraise of conditions and surroundings which will affect to combustible material represent the functional and qualitative system of retardation proceedings (Mikkola, 2000). Mechanism of action of fire retardants usually depends on their chemical characteristics and properties of material that we want to protect against the negative effects of fire (Vandlíčková, 2008). The system of retardation and fire retardants are in present considered by the methods of testing, which for the purposes of fire protection assess used flammable materials, their surface modifications and comparison of effects of retardation on the materials and environs.

The subject of testing was the building material of plant origin named Canabest Basic - natural thermal and sound insulation made of hemp fiber (see Figure 1). It is normally used as a filler in roof construction, between the rafters or beamed ceilings. Hemp fiber insulation can be characterized by specific properties such as: high moisture resistance, ability to dry quickly, insulation stability in extreme conditions and creation of natural microclimate. Due to the natural content of bitter substances, it does not support fungal growth and has a certain resistance against rodents. Manipulation with this material is without health risks, such as skin damage, eye and airways irritation. It is also important to point out that hemp as a pure natural material is environmentally friendly, with no adverse health effects, recyclable and renewable. There was applied the fire retardant Ohnostop Special - a colorless watery substance of inorganic salts, 100% ecological, naturally recyclable, environmental and health friendly (see Figure 1). It is hygroscopic - it is able to bind water molecules and absorb moisture from the air or water vapor from the surrounding environment. This retardant was invented to decrease the combustibility and to improve the fire resistance of building products in interior spaces. It works on the principle of releasing non-combustible gases in the heat interval when the combustible gases are generated by thermal decomposition of the combustible material. This leads to dilution and decompression of concentration of flammable gases and, in this way, their ignition is impeded. In case of long-time exposure to direct flame it significantly impedes the spread of fire. We can apply it by soaking, coating, spray application or by the vacuum - pressure method.

Fig. 1 The representative picture of thermal insulation product Canabest Basic and the representative picture of fire retardant Ohnostop Special

The test specimens for the experiment comprised 18 specimens which were cut from a piece of thermal hemp insulation product Canabest Basic. Each specimen had dimensions of 200 x 100 x 30 mm (± 1 mm). All the specimens were divided into three sets. The first set of the tested specimens (marked X1 » X6) was not impregnated or modified in any way. The second set of the tested specimens (marked 1 » 6) was impregnated by soaking in the fire retardant Ohnostop Special. The third set of the tested specimens (marked 1B » 6B) was similarly impregnated by soaking in the fire retardant Ohnostop Special but with addition of another effective chemical element in order to increase its fire protection.

The experiment presented experimental and scientific testing method of fire retardants through the test for limited flame spread on the test specimens in the test device under laboratory conditions. This laboratory method consists of direct exposure to the gas burner to test specimens for a period of time. The testing device used for the reaction to fire test is a complex device, constructed according to the scheme adopted from an older standard (STN 73 0862 - supplement b) (Fanfarová, 2015). It is formed by a structure of materials resistant to the adverse effects of heat and combustion products released during the test. This device (see Figure 2 and Figure 3) consists of the following parts: a test specimen holder of non-combustible material, gas burner, flow meter with fuel flow regulation and the fuel source - technical propane butane mixture cylinder. The fuel source is a pressure cylinder with a technical propane-butane mixture with purity of at least 95%. The test specimen was placed in to the holder device at angle 45° and it was exposed to impact of flame for 5 minutes. For each individual measurement was accurately defined distance from the center of the test specimen to the mouth of the gas burner 50 mm (± 1 mm) and also the defined height of flame 40 mm (± 2 mm). In every single testing was followed the united technological testing procedure (Fanfarová, 2013).

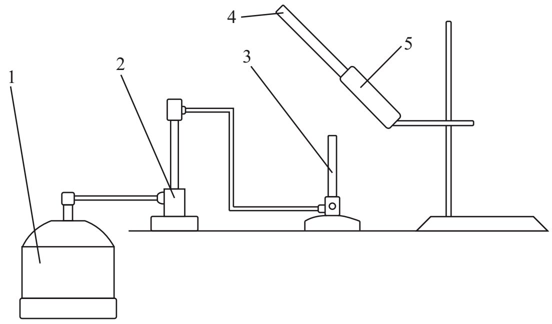

Fig. 2 The schematic of test device for fire tests: 1 - propane gas cylinder, 2 - flow meter, 3 - gas burner, 4 - test specimen, 5 - holder for test specimen (Fanfarová, 2014)

Fig. 3 The testing device for fire tests constructed and located in the Fire-chemical laboratory of the Department of Fire Engineering, FBI, University of Žilina

The testing device also includes laboratory scales Mettler Toledo - model MS1602S (see Figure 4). They are specifically designed to be used in laboratories. They are protected against dust and water, resistant to most chemicals including acetone, have a protective cover to protect them against stains and scratches, the maximum weighing capacity of 1 620 g and readability of 0.01 mg. The fast and error-free data transfer is provided via the USB computer connection. These analytical and calibrated scales combine a lot of weighing alternatives that can be adjusted with the help of properly set software. It is also possible to set the measurement in various time intervals - as little as 1 second.

Fig. 4 The laboratory scales Mettler Toledo - model MS-S located in the Fire-chemical laboratory of the Department of Fire Engineering, FBI, University of Žilina

The preparation for realization of testing by reactions to fire test included mixing of Ohnostop Special fire retardant solutions in accordance with the producer's instructions. The specimens of hemp insulations were impregnated by soaking in duration of 5 minutes, whereby 350 ml of fire retardant solution was used for each two specimens. Subsequently, the specimens were weighted in regular intervals until completely dry, which meant complete evaporation of water, bounded during the retardation proceedings. When the weight of all test specimens became stable (with 1g deviation), the testing devices were prepared and required ambient laboratory conditions.

The testing procedure according to the methodology for testing the fire retardants (Fanfarová, 2014), necessary for determination of fire-technical characteristics of combustible materials, consisted of the following steps: before the test was conducted each specimen was weighed and the weight was recorded; then each test specimen was placed in the test device holder under the angle of 45° and was exposed to the effects of an open mid-height flame for 5 minutes. The flame height was set according to the methodology to 100 mm (± 1 mm). During the exposure of the specimen to the effects of flame the weight loss of the specimen was recorded using the laboratory scales in the set time interval of 10 seconds. During this experiment there were recorded further evaluation criteria that reflected the behavior of the tested specimen (time of ignition, time of spontaneous combustion, time of smoldering, burning process etc.). This data is necessary for evaluation of the fire protection efficacy of the tested product. Each specimen test adhered to the unified test methodology and fire safety measures for laboratory work.

Results

The main evaluation criterion in this experiment was the weight loss of the tested specimens. This value represents the difference between the weight loss before the testing, the weight change during the testing (10-second interval), and the weight after the testing. All the weight values were measured using the laboratory scales Mettler Toledo. The results of the reaction to fire tests - weight losses - according to the sets of the tested specimens are initiated in following table for each set of test specimens. In figures 5 - 8 are processed graphs with the results of experimental method of reaction to fire test.

Table 1 The values of the main evaluation criterion of tested specimens

Time of experiment [s]	**Weight of specimens X1 » X6 (average values) [g]**	**Weight of loss (average values) [g]**	**Weight of specimens 1 » 6 (average values) [g]**	**Weight of loss (average values) [g]**	**Weight of specimens 1B » 6B (average values) [g]**	**Weight of loss (average values) [g]**
0	31,16	0,00	35,10	0,00	32,43	0,00
10	29,78	1,38	34,96	0,14	32,30	0,13
20	28,53	2,63	34,87	0,24	32,29	0,14
30	27,15	4,01	34,75	0,35	32,18	0,24
40	25,49	5,67	34,61	0,49	32,06	0,36
50	23,56	7,60	34,49	0,61	31,96	0,46
60	20,97	10,19	34,36	0,74	31,85	0,58
70	18,17	12,99	34,20	0,91	31,74	0,69
80	15,44	15,72	34,09	1,01	31,61	0,82
90	12,66	18,50	33,94	1,17	31,49	0,93
100	10,35	20,81	33,73	1,37	31,43	1,00

Time of experiment [s]	Weight of specimens X1 » X6 (average values) [g]	Weight of loss (average values) [g]	Weight of specimens 1 » 6 (average values) [g]	Weight of loss (average values) [g]	Weight of specimens 1B » 6B (average values) [g]	Weight of loss (average values) [g]
110	8,47	22,69	33,53	1,57	31,28	1,15
120	6,91	24,25	33,36	1,74	31,16	1,27
130	5,86	25,30	33,16	1,94	31,05	1,38
140	5,16	26,00	32,91	2,20	30,93	1,49
150	4,80	26,36	32,62	2,48	30,74	1,69
160	4,60	26,56	32,31	2,80	30,52	1,91
170	4,47	26,69	31,99	3,11	30,27	2,15
180	4,29	26,87	31,68	3,43	30,05	2,38
190	4,11	27,05	31,35	3,75	29,69	2,73
200	3,99	27,17	30,97	4,13	29,34	3,08
210	3,87	27,29	30,41	4,69	28,98	3,45
220	3,79	27,37	29,95	5,16	28,55	3,88
230	3,10	28,06	29,31	5,79	28,01	4,41
240	3,01	28,15	28,73	6,37	27,59	4,83
250	2,94	28,22	28,05	7,05	27,14	5,28
260	2,84	28,32	27,31	7,79	26,78	5,65
270	2,74	28,42	26,63	8,47	26,28	6,15
280	2,69	28,47	25,75	9,36	25,84	6,58
290	2,34	28,82	25,03	10,07	25,48	6,95
300	2,27	28,89	24,27	10,83	24,91	7,52

Weight loss of the tested specimens X1 » X6 - average values

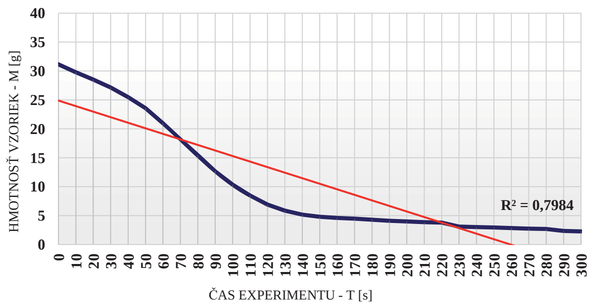

Fig. 5 Weight loss of the tested specimens X1 » X6 (not impregnated)

The first graph (see Figure 5) presents the continuous weight loss of the first set of the tested specimens (marked X1 » X6), that were not modified or impregnated with a fire retardant. The curve presents the average values of the total weight loss of each specimen in the set. All the tested specimens behaved in a similar way, they participated in the process of combustion, ignited, and there was spontaneous combustion, considerable smoldering and smoking. Some specimens were dripping flaming particles. Each specimen reacted to the flame exposure and in 2 minutes it lost more than 2/3 of its original weight. The average weight loss calculated with regard to the original weight (the weight before the experiment) in this set was more than 90%. One specimen even burnt completely in the 4th minute and did not withstand the given time of the fire exposure. We can thus conclude that this set of specimens achieved the worst results in our experiment.

Weight loss of the tested specimens 1 » 6 - average values

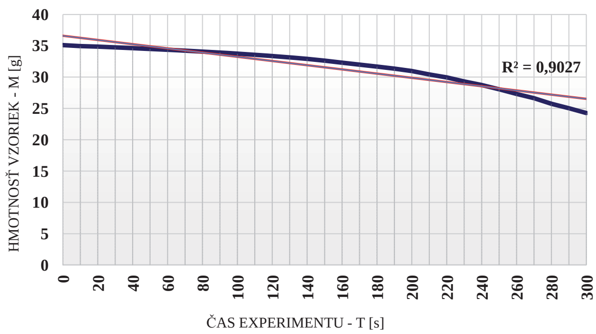

Fig. 6 Weight loss of the tested specimens 1 » 6 (impregnated with the fire retardant Ohnostop Special)

The second graph (see Figure 6) presents the average weight loss values of the second set of the tested specimens (marked 1 » 6). These specimens were impregnated with the fire retardant Ohnostop Special and due to this impregnation their results were better compared to the first set of the tested specimens. Even after the given time of the experiment expired (5 minutes), all the tested specimens were able to retain more than 1/2 of their original weight. The average weight loss in this set of specimens was approximately 30%, which is 2/3 less than the first set of specimens. The behavior of the impregnated specimens during the testing procedure: they resisted the effects of flame better, they did not ignite, there was no spontaneous combustion or smoldering, the specimens emitted smoke only.

The third graph (see Figure 7) shows the curve of the average weight loss values of the third set of the tested specimens (marked 1B » 6B). Similarly as with the second set of specimens, these specimens were impregnated with the fire retardant Ohnostop Special, but there was also a new chemical element added to the fire retardant solution. The aim of this modification was the improvement of fire-technical properties of the tested combustible product. We were able to meet this goal as this set of the tested specimens showed the lowest weight loss as well as the best behavior during all the experiment. The average weight loss in this set is 25%.

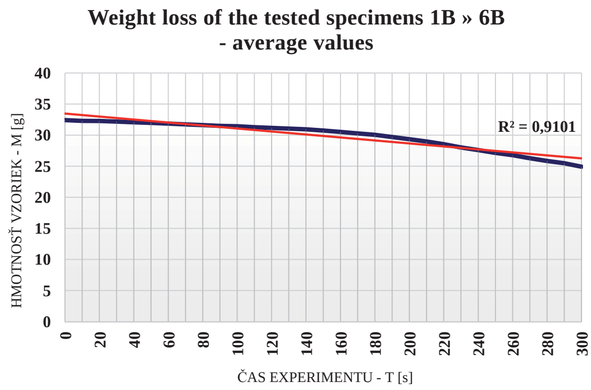

Fig. 7 Weight loss of the tested specimens 1B » 6B (impregnated by the fire retardant Ohnostop Special with a chemical additive)

The final graph (see Figure 8) presents the comparison of average weight loss values of all the tested specimens as divided into sets. It also interprets the behavior of all three sets of the tested specimens during the laboratory experiment focused on the testing of reaction to fire.

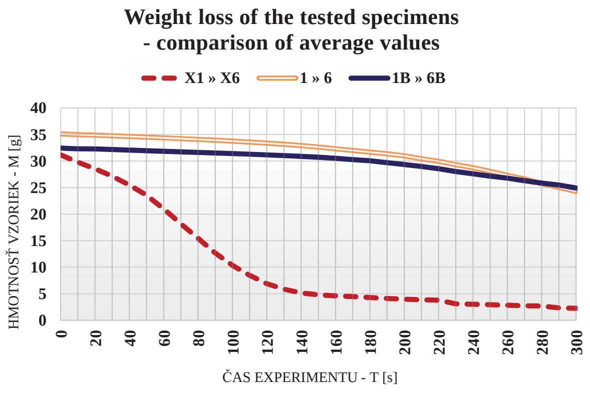

Fig. 8 The comparison of average weight loss values of the tested specimens according to the specimen sets

Discussion

The experiment results confirmed that the impregnation of the tested combustible product with the fire retardant improved positively its reaction to fire. The applied fire retardant Ohnostop Special was able to improve the fire-technical characteristics of the thermal insulation product, especially its combustibility. From the point of view of weight loss, when the effective chemical element was added the improvement was more than 65%, compared to the unimpregnated material. The linear trend line with the level of confidence R2 was added to the individual graphs (Figures 4 - 6). This value of the coefficient of determination states that more than 90% of the weight loss of specimens impregnated with the fire retardant depends on the time of flame exposure. In actual standard practice these discovery can mean for example the possibly deceleration of time of completing burn up in the case of fire building, which can help to save human lives, to reduce property damages or to defuse the negative impacts on environmental components (Kavický, 2014). The team of authors aim to point out to the use of fire retardants in standard practice and underline the importance of fire protection and fire-fighting qualities of retardant modifications of combustible materials and products. This particular piece of information can be found helpful by improving the quality of fire protection, security and safety. The experiment was conducted with maximum effort to approximate the laboratory conditions to real-life environment.

Conclusion

The active interaction with fire-fighting equipment, signaling and alarming equipment, software or other tools (Mariš, 2013) and fire prevention inspections, which be in the service of fire protection and to protect against fire, fire retardants are one of the most affordable and effective system to protect the life and health of people, animals, property and components of the environment from potential fire hazard. Various statistical studies and scientific research has repeatedly demonstrated the importance of fire retardants for the whole society. The need to anticipate the future must be an essential feature of any study of this type given the external pressures in, for example, the increased environmental sustainability of all materials. Therefore, novel methods of rendering materials fire retardant are explored as well as the anticipated changes for performance-based test regimes. However, the increasing costs of developing new fire retardant materials is such that mathematical modelling and simulation are increasingly becoming a part of underpinning science. It is very important to test behavior and function of interaction new materials and new fire retardants for comprehensive fire protection.

References

DRYSDALE, D. (1999).: *An Introduction to Fire Dynamics*. 2nd edit. University of Edinburg, West Sussex, England: John Wiley & Sons Ltd, 1999. 576 p. ISBN 0 471 97290 8.

FANFAROVÁ, A.; MARIŠ, L.; OSVALD, A.; MIKKOLA, E. (2015).: The reaction to fire tests for natural thermal insulation of hemp material modified by fire retardant ohnostop special. In *Communications*, volume 17, issue 1, pages 15-21, 2015. ISSN 13354205.

FANFAROVÁ, A. (2014).: *Methodology for testing the fire retardants and retardant modifications of materials - Reaction to fire tests*. Internal document. University of Žilina, Žilina: Department of Fire Engineering, Faculty of Security Engineering, 2014. Verified by: mjr. Ing. Štefan Galla, PhD., managing director of the Fire-fighting, technical and expertise institute of the Ministry of Interior seat in Bratislava, Slovak republic. (in Slovak)

FANFAROVÁ, A. (2013).: The testing of surface fire retardants. In *Transactions of the VŠB - Technical University of Ostrava: safety engineering series*, Vol. 8, no. 2, pages 6-9, 2013. ISSN 1801-1764. Online ISSN 1805-3238.

KAVICKÝ, V.; FIGULI, L.; JANGL, Š.; ZVAKOVÁ, Z. (2014).: Analysis of the field test results of ammonium nitrate: fuel oil explosives as improvised explosive device charges. In *Structures under shock and impact XIII: 13th international conference*, susi 2014: New Forest, United Kingdom, Southampton, Boston: WITpress - WIT transactions on the built environment, vol. 141, pages 297-309, 2014. ISBN 978-1-84564-796-4. ISSN 1746-4498. Online ISBN 978-1-84564-797-1.

MARIŠ, L.; VEĽAS, A. (2013).: Possibilities of using of software tools in the security projects. In *Securitologia = Securitology = Sekjuritologija: czasopismo nauk o bezpieczeństwie*, Nr. 1 (17), pages 144-152, 2013. ISSN 1898-4509.

MIKKOLA, E. (2000).: Fire retardant and Product Behavior in Fire Tests. In *Polymer International, special issue: Fire retardant polymers*, volume 49, no. 10, pages 1222-1225, October 2000. ISSN 1097-0126.

OSVALD, A. (1997).: *Evaluation of fire safety materials and products of wood and based on wood*. Textbook. Zvolen: Technical University in Zvolen, 1997. 104 p. ISBN 80-228-0595-5. (in Slovak)

OSVALDOVÁ, L. (2005).: Fire retardants. *Arpos*, 18-19, 2005. ISSN 1335-5910. (in Slovak)

VANDLÍČKOVÁ, M.; JANČÚCH, M. (2008).: Fire retardants and their toxicity. In *Young science - Science and crisis situations*. Žilina: University of Žilina, 2008. ISBN 978-80-8070-896-2.