New flame-retardant composition for lowering contribution of expanded poly styrene to the propagation of fire

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Abstract. Despite the major advances in ensuring fire safety of buildings and structures, fire risks still represent the serious issue not only on the territory of the Russian Federation but on the global basis. Presently, while erecting buildings and structures focused attention is given to lowering material consumption and reducing construction time. This is achieved by means of application of lightweight building envelopes with efficient insulators. For the most part, foam poly styrene plates are used as an insulator. Expanded or foam poly styrene has low coefficient of heat conductivity, high acoustic isolation, long-term durability, moisture resistance, and is characterized by ease of installation. However, application of foam poly styrene has constrains due to its high contribution to the propagation of fire.

In the present paper, the authors proposed new flame-retardant composition on the base of organo-siloxanes, which inhibits combustion initiating of foam poly styrene and constrains fire propagation when applied on the surface of foam poly styrene plates.

1. Introduction

Nowadays, when erecting buildings and structures thorough attention is paid to reduction of building materials consumption and cutting construction time. The desired outcome could be reached by means of lightweight envelope structures with efficient insulating materials. In the majority of cases, foam poly styrene plates are used as insulators. However, foam or expanded poly styrene is a combustible and highly flammable material forming burning melting drops [1, 2]. Contribution of foam poly styrene to the propagation of fire is assessed on two principal directions: fire hazard of a material itself (the effect of temperature and flame) and the hazard of thermal decomposition and oxidation products.

When having effect on human bodies at elevated temperatures and lowered oxygen concentration, various clinical implications could be observed that reflect, most notably, the state of oxygen deprivation of human tissues and organs.

On average, only 18% of people die of skin burns in fire condition, the remainder represents the victims of fumes poisoning combined with the effect of stress, heat and other kill effects. Statistics shows that if a relatively small fire breaks out in the premises saturated with combustion products of
polymer materials, there takes place uncontrollable life loss of the people inside the premises mainly due to volatile products poisoning.

All foam poly styrene plates are regarded as flammable and combustible building materials [3]. Thus, speed of flame propagation on the surface of foam poly styrene accounts for 1 meter per second that predetermines extremely high speed of flame propagation in the buildings and structures insulated with this material. Specific mass burning rate of foam poly styrene of the PSB grade is 2.19 kg/min·m². Due to high speed of flame propagation of foam poly styrene and increased specific heating value, the heat is released at the peak temperature of 1500°C within relatively limited time.

Initiating combustion of foam poly styrene occurs at the temperature range 220÷380°C while spontaneous combustion corresponds to the temperature range 460÷480°C [4].

2. Materials and methods
In the present paper, the authors proposed new flame-retardant composition on the base of organo-siloxanes, which inhibits combustion initiating of foam poly styrene and constrains fire propagation when applied on the surface of foam poly styrene plates.

The paper methodology is based on the All-Union Standard GOST 30402-96 “Building materials. Ignitability Test Method”, the section related to assessing ignitability of combustible buildings materials.

The object of study was presented by foam cellular plastics used in construction industry as insulators, enclosure structures of buildings such as foam poly styrene of the types RAVATHERM XPS STANDARD (Technical regulations 2244-002-00259620-2013, «NISKO Industry» plc, village Kryukovo, Moscow region) and PSB-S 15U (Technical regulations 2244-007-04001508-96, Joint-venture «TIGI KNAUF», Krasnogorsk, Moscow region) manufactured in compliance with the All-Union Standard GOST 15588 [5].

As the objects of research, the authors have chosen the compositions on the base of ethylene-siloxane, water-glass and sulfanol. The present substances have high thermal resistance and are used in various spheres of development and protection of buildings materials. Thus, organo-siloxanes and silicones present the most important polymer group, with the main chain formed by other elements in place of carbon [6]. Organo-siloxanes could be of linear, ring and branched structure. Their common features include increased flexibility and rotational freedom of atomic groups around bonds Si-C and Si-O. When rotating around bonds, the sections of diverse polarity of discrete siloxane groups of linear siloxane chains tend to arrange themselves in space in such an order that dipolar moments of different groups are compensated when possible [7-9]. In the result, linear organo-siloxanes form supramolecular structure. The present property is of utmost importance when applied in practice as it leads to the fact that the properties of organo-siloxanes are not much affected by the temperature.

In the present study, the following compositions have been used:
- composition No. 1 (5% organo-siloxane, 1% sulfanol solution);
- composition No. 2 (5% water-glass, 1% sulfanol solution);
- composition No. 3 (10% organo-siloxane, 1% sulfanol solution);
- composition No. 4 (10% water-glass, 1% sulfanol solution);
- composition No. 5 (2.5% organo-siloxane, 2.5 water-glass, 1% sulfanol solution);
- composition No. 6 (10% organo-siloxane, 30% aluminium flake, 5% soap stone, 30% water-glass);
- composition No. 7 (10% organo-siloxane, 30% aluminium flake, 5% soap stone, 30% water-glass, 5% carbamide).

3. Results and discussion
In the research, the authors have determined the parameters of material’s ignitability at the given standard levels of radiant heat flux impact and ignition source flame on the specimen’s surface. These parameters comprise critical area heat flow density (henceforth referred to as CAHFD) [10] and ignition time. Having implemented the tests, the authors applied CAHFD for subsumption of the material to a certain group.
Flame-retardant coats have been applied to the specimens (figure 1) on all sides.

![Figure 1. The tested specimens.](image1)

Figure 2 is thus a representation of the general drawing of the machine designated for ignitability testing.

![Figure 2. Ignitability testing machine.](image2)

The test results and their analysis are given in the tables 1 and 2.
Table 1. Dependence of ignition time of foam poly styrene on the type of coat. The tests results have been analyzed under Cochran’s test.

| Composition number applied for foam poly styrene’s treatment | Ignition time, seconds | \( y^* \) (point estimation) | \( S_x \) (mean square deviation) | \( \delta \) (half of the additional interval) | \( y^* \pm \delta \) (interval estimation) |
|-------------------------------------------------------------|------------------------|-------------------------------|-----------------------------------|---------------------------------|----------------------------------|
| Non-treated                                                 | 186                    | 179.6667                     | 6.506407                         | 16.15285                        | 179.6667 ± 16.15285              |
|                                                             | 173                    |                               |                                  |                                 |                                  |
|                                                             | 180                    |                               |                                  |                                 |                                  |
| Composition 1                                               | 244                    | 246.6667                     | 3.05505                          | 7.584487                        | 246.6667 ± 7.584487              |
|                                                             | 246                    |                               |                                  |                                 |                                  |
|                                                             | 250                    |                               |                                  |                                 |                                  |
| Composition 2                                               | 210                    | 205.3333                     | 5.033223                         | 12.49551                        | 205.3333 ± 12.49551              |
|                                                             | 206                    |                               |                                  |                                 |                                  |
| Composition 3                                               | 286                    | 284.6667                     | 4.163332                         | 10.33591                        | 284.6667 ± 10.33591              |
|                                                             | 280                    |                               |                                  |                                 |                                  |
|                                                             | 288                    |                               |                                  |                                 |                                  |
| Composition 4                                               | 230                    | 235.3333                     | 5.033223                         | 12.49551                        | 235.3333 ± 12.49551              |
|                                                             | 236                    |                               |                                  |                                 |                                  |
|                                                             | 240                    |                               |                                  |                                 |                                  |
| Composition 5                                               | 242                    | 241                          |                                  | 2.482606                        | 241 ± 2.482606                   |
|                                                             | 240                    |                               |                                  |                                 |                                  |
|                                                             | 241                    |                               |                                  |                                 |                                  |
| Composition 6                                               | 241                    | 243.3333                     | 3.21455                          | 7.980462                        | 243.3333 ± 7.980462              |
|                                                             | 247                    |                               |                                  |                                 |                                  |
|                                                             | 242                    |                               |                                  |                                 |                                  |
| Composition 7                                               | 231                    | 232.3333                     | 3.21455                          | 7.980462                        | 232.3333 ± 7.980462              |
|                                                             | 236                    |                               |                                  |                                 |                                  |
|                                                             | 230                    |                               |                                  |                                 |                                  |

where:
- \( y^* \) - arithmetic mean for each series of tests (the formula 3.5 page 47 [1])
- \( S_x \) - estimated by the formula 3.6 on the page 48 [1]
- \( y^* \pm \delta \) – estimated by the formula 3.31 on the page 65 [1].

When implemented few series of tests, check on compliance of results’ resettability (check of homogeneity of variance) was done under Cochran’s criterion (the formula 3.47 on the page 94 [1]): - statistics calculated under the present criterion turned out to be equal 0.299528 at the significance point 0.5157, as 0.299528 < 0.5157, then the condition of results’ resettability is complied with (variances are homogeneous).

Check of significance of variances of mean values obtained in the result of discrete series of implemented tests was done under the Student’s t-test (formula 3.50 on the page 100 [1]): - with the help of the mentioned criterion, pair-wise comparison of the results of test 1-7 has been done with the results of “Non-treated” experiment.

The results are presented in the table 2.
Table 2. Test results’ analysis (under Student’s t-test).

| Compared tests | Estimated statistics of t-criterion |
|----------------|------------------------------------|
| 0 – 1          | 16.1                               |
| 0 – 2          | 5.4                                |
| 0 – 3          | 23.5                               |
| 0 – 4          | 11.7                               |
| 0 – 5          | 16.1                               |
| 0 – 6          | 15.2                               |
| 0 – 7          | 12.6                               |

Significance point $t$ (significance level 0.05, number of degrees of freedom 4) = 2.776.

As the calculated values of t-criterion are higher than significance point, we can draw a conclusion that the observed differences between fixed parameters in the experiments 1-7 are statistically significant if compared to the zero-experiment.

Having analyzed the results of carried out research, the authors found out that the composition 3 (10% organo-siloxane, 1% sulfanol solution) is proven to be the most efficient one. As the table data demonstrate the average ignition time of foam poly styrene plates treated with the composition 3h as accounted for 219 seconds, i.e. it has increased by the factor 1.5 when compared with the check sample.

4. Conclusions

Thus, the authors have conducted research of the impact of new flame-retardant compositions on fire engineering characteristic of foam poly styrene. The specimens with applied coats are considered less hazardous. The composition containing 10% organo-siloxane and 1% sulfanol solution is proven to be the most efficient one. Time to reach maximum temperature has increased nearly by factor of 2, maximum temperature increment has lowered by 25.3%, when the reduction of specimen’s mass loss is observed (~17.9%).

References

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