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Single burning item test for timber with fire protection

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Abstract. Fire protection of timber structures and finishing structural materials is actual due to the high combustibility of these materials. The technical characteristics for protected timber structures in case of fire, determined by the single burning item test (SBI), are considered in the paper. Nine thin-layered lacquers and paints fire protections, which were differed by the type of fire resistance and chemical contents, were analyzed. The timber specimens treated by such fire protections as the paints, impregnations, lacquers and water glass were tested by SBI method. It was shown, that the lacquer on the base of the acryl resin has a significant influence on the fire growth rate indices FIGRA and smoke growth rate SMOGRA on the initial stage of combustion (FIGRA – 2948.78 W/s, SMOGRA – 101.28 m^2/s^2). Traditional fire protection by the water glass shows the high fire growth rate indices FIGRA (268.63 W/s) and total smoke production TSP600s (163.13 m^2). The low levels of the both values did not confirm a classic consideration of the water glass as effective fire protection of timber members. Type of timber base and assembling method (with or without air gap) has a significant influence on the effectiveness of fire protection. Analogous results obtained for the intumescent paint and two types of lacquers. The modern water impregnations that contains phosphoric acids characterized by the low expenditure (mean value 250 g/m^2) and low values of smoke growth rate and total smoke production in 3MJ and 33 m^2, correspondingly. These impregnations provides a class Bs1d0 of fire protection by the European classification.

1. Introduction

The methods for determination of technical characteristics of finishing structural materials in case of fire actions and it classification by the fire hazard are differed in Russian Federation and Europe at the present moment [1]. A lack of direct correlation of European and Russian codes regulating determination of fire hazard of structural materials is the major difficulty in the harmonization of the methods [1–4].

European method Single Burning Item (SBI) [5] is used for determination of technical characteristics of structural materials in case of fire and class of fire-resistance [6].

Two sub-systems (structural and finishing materials so as ceiling coverings) includes the seven classes of the fire hazard starting from the class A (noncombustible materials) until the class F (highly combustible materials).

The SBI method is considered in current work for the determination of technical characteristics of timber structures in case of fire action because timber is a structural material, which is characterized by the variety of shapes and dimensions and widely used for the structural purposes now [7–10]. The low fire resistance and high ability for ignition are the critical disadvantages of the timber as a structural material. The timber member treated by the fire protective agents, including fire-retardant treatment, must strongly corresponds to the requirements of standards by the heat and smoke growth rate so as the fire protective agents can increase the fume developing ability of the base. It is very significant in the cases, if the timber member is placed in the probable ways of the evaquation. So, structural products are classified basing on the determined class and additional class by the smoke growth rate [6]. The SBI method cannot be considered as an etalon in some

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unstandardized cases, when the national standards enables to obtain the results with the increased precision [11–19].

A special attention should be payed to assembling process and fasteners so as both the factors have the significant influence on the obtained results. The methods of fastening should be reflected in the specifications. Assembling in accordance with the standard provides determination of fire hazard class with the increased precision. Several deviations during the assembling leads to misrepresentation of the classification [18, 19]. Results of the classification can be differed dependently from the type of the base. Therefore, the results obtained in the case of the gypsum boards base without air gap can be different from the results obtained in the case of clearances existence between the specimen and noncombustible base. Conditions of the test will be more rigid in the second variant with the air gap. The timber, non-treated by the fire protective agents, products with the minimum thickness in 22 mm and minimum density in 350 kg/m^2, are classified without the further testing in accordance [20]. Structural timber relates to the class D-s2, d0 in accordance with [20]. The class of fire hazard of the timber increases until the B2 by the using of fire protective agents [21]. The unprotected timber structures are related in Russian Federation to 5th class of fire hazard (strongly combustible materials with the highest rates of ability to ignition, combustibility, total smoke production, gase toxicity rate and fire growth rate) [1–4]. Intermediate variants from class A to class F are characterized by the lack of correlation with the adopted in Russia classification and methods of confirmation of the classification. Toxicity of buring products is determined by the laboratorian mouses in Russia and by the gas analysers in SBI method, for example [1, 2].

The target of current paper is to analyses the technical characteristics of the fire protected timber structures by the SBI method. Nine different fire protection agents for wood and plywood with different chemical nature are considered in order to understand the best fire-technical characteristics.

2. Methods

The SBI method suppose fire action from one side on the external surface of the whole specimen of the structure (Fig. 1 and 2). A chamber for the tests is the closed space (room) with the single source of ignition (gas burner) in one of the corners and air hole system with sensors for taking the indications. The material is subjected by the flame with the exposure rate in 100 kW in course of the first ten minutes and in 300 kWt in course of the next ten minutes [5]. The indications of materials behavior (expenditure of oxygen, output of carbon dioxide, and values of temperatures) are determined. The behavior than can be used for the determination of parameters for the classification of materials. The parameters give the full-scale information about the dynamic of the fire development including the heat emission and capability of the smoke production.

- THR – total heat release (MJ) from the specimen in the first 600 seconds of exposure to the main (primary) burner flames.

- HRR – heat release rate (kW/m^2) – velocity of heat emission from the combustion of specimen and gas in the burner.

- FIGRA – fire growth rate indices (W/s) – maximum of the quotient of heat release rate from the specimen and the time of its occurrence.

- TSP – total smoke production from the specimen (m^2) – the value, which characterize the total smoke production from the specimen in the first 600 seconds of exposure to the main (primary) burner flames.

- SMOGRA – smoke growth rate (m^2/s^2) – maximum of the quotient of smoke production rate from the specimen and the time of its occurrence.

- LFS – lateral flame spread on the long specimen wing – the length of the flame spread on the long specimen wing.

The results enables to evaluate the fire growth rate indices and critical heat emission. The values enables to classify the material in accordance with the standard EN 13501-1 and to determine a class of the fire hazard of the structural material. The algorithm of the classification of structural material is consists from three components:

1. Classification on the base of the total heat release and fire growth rate indices. Class A-F is determined on the base of the values of parameters FIGRA and THR.
2. Additional classification by the smoke growth rate. Class s1-3 is determined on the base of the values of parameters SMOGRA and TSP.
3. Additional classification by the development of firing drops/particles. Class d0-2 is determined dependently on the development of the firing drops/particles in course of the 600 s during the test.

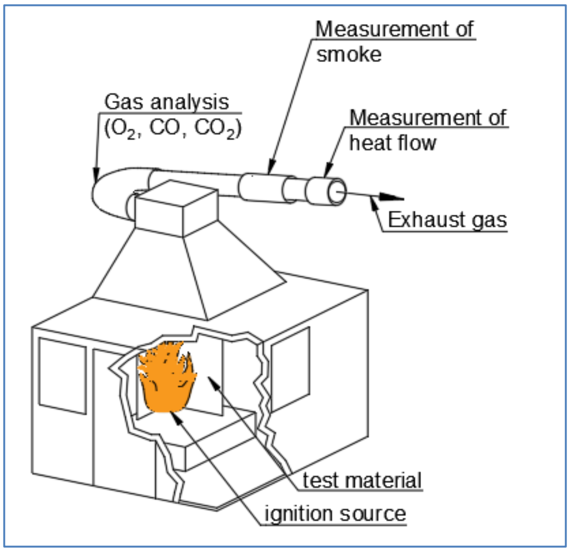

Figure 1. Scheme of the chamber for the tests.

Figure 2. Process of the samples testing.

Timber or plywood boards made of such spieces as a pine, spruce or a larch with moisture 8–10 %. The small board with dimensions 1.5×0.5 m and big board with dimensions 1.5×1.0 m developing the direct angle.

Products perfomance determinned on gypsum plasterboard substrate A2-s-1-d0 reaction to fire class and classification is valid for product mounting on substrates at least reaction to fire class A2-s-1-d0.

Figure 3. Sample 1 before the test.

Figure 4. Sample 1 at the tenth minute of the test.

Plywood and timber of such spices as a larch and spruce were used as the materials of the samples. The spices of timber were indicated in the laboratorian protocols. Thickness of the samples changes within the limits from 17 to 19 mm. The following types of the fire protection were considered:

1. Aqueous alkaline solution of sodium silicate Na2O(SiO2)n is a viscous substance of the grey colour without admixtures. It decrease the fire hazard of timber and it efficiency depends on the amount of the borrowed layers. The samples shown on Fig. 3-5 were treated by three layers.
2. Priming on the base of water glass in two layers and lacquer on the base of stirol-acryl resin, melamin and paraffin chlorine (three layers).
3. Lacquer with the decreased combustability consisting from the stirol-acryl resin, ammonoum poliphosphat melamin and paraffin chlorine (three layers). The lacquer is analogous to the same for the sample 2.
4. Lacquer on the base of carbomideformaldehyde resin with the admixture of classic fire retardants (three layers) [22]. A homogeneous suspension with the colours from white to pale yellow without external admixtures. The completed finishing has a lustre and is turbid. The charing of the fire-protective layer occours under the fire action. The fire protective layer gat a structure of the foamed

coil and the surface of the material is protected from the influence of oxygen (Fig. 6). So, process of combustion is retarded.

Figure 5. Sample 1 at the end of the test.

Figure 6. Sample 4 – bloating of the lacquer.

5. Intumescent water based paint (two layers). The high porous foamed coil is developed at the tempherature in 300°C and it protect the structure from the further heat action.The paint is a white color finedispersion suspension of functional admixtures and a pigment in the polivinilacetate dispersion or an acryle latex with admixture of several additional agents [22].
6. Traditional impergnation on the base of the soluble salts which are based on the roasted carbonate of potassium. The fire retardant is a color-less liquid with non-sufficient precipitate. The fire retardant is applied on the surface or the protected material is deeply impergnated under pressure. It fire retarding action is joined with ability of the fire retardants to develop the protective layer on the surface of the timber and to produce non-combustable gases which prevents expansion of the fire and it penetration in the protected material. The effect is obtained by the retarding if the fire expansion by the surface of protected material in the case if surface impergnation.
7. Impergnation «NEOHIM», produced by the Russian company «NEOHIM» LTD, is the water based solution with the fire retardants. Impergnation «NEOHIM» possess an effect of intumescention (Fig. 7). The samples shown on the Fig. 7 are made of the larche.

Figure 7. Development of foamed coil after the testing of sample 7.

8. Impergnation Palonot. The content is patented [23], it includes the water based solution of the fire retarding material «PALONOT F1», which is produced by the company Palonot, Finland. It contains

acids with the high content of phosphorus (30.1 %). Using of the ethanolamine as the nitrogen containing compounds is in the base impergnation Palonot application. The components are used in the proportion which possess a synerhism in case of the fire protective action.The specimens treated by the fire retardant Palonot F1 were produced of the birch plywwood FSF. Peculiarities of assembling in accordance with the protocol of the test: valid for product mounting with air gap between product and substrate. Valid also product mounting on substrates without air gap.

9. Water based impergnation Flamex, which is produced by the Norvegian company Thermax as. The water based impergnation Flamex contains amino phosphates (30–60) %, amino chlorides (1–5) %, carbomide (5–10)%, glycerine (1–5)% and other admixtures. The specimens with the thickness in 21 mm were made from the spruce timber. Peculiarities of assembling in accordance with the protocol of the test: valid for product mounting with or without air gap between product and substrate, for ventilated and unventilateted applications.

The authors possess the following information about group of combustability for the tested specimens [23]. One of the targets for the test was determination of one of the four group of combustability. The groups were determined as follows:

- Group of combustability 1 – slightly combustable materials, which are not burning without source of fire. The materials produce the smoke gases with the temperature up till the 135°C in case of burning. The length of the damaged area does not exceeds the 65 %. Only 20% of the material mass can be destroyed by the fire action.
- Group of combustability 2 – medium combustable materials, which are burning without source of fire not longer, than half of the minute. The nominal tempherature of the developed smoke gases is equal to 235°C. The length of the damaged area does not exceeds the 85 %. Only 50 % of the material mass can be destroyed by the fire action.
- Group of combustability 3 – normally combustable materials, which are burning without source of fire not longer, than five minutes. The nominal tempherature of the developed smoke gases is equal to 450°C. The length of the damaged area does not exceeds the 85%. Only 50 % of the material mass can be destroyed by the fire action.
- Group of combustability 4 – strongly combustable materials, which are burning without source of fire not longer, than five minutes. The nominal tempherature of the developed smoke gases exceeds 450°C. The length of the damaged area does not exceeds the 85 %. Only 50 % of the material mass can be destroyed by the fire action.

Unfortunately, such parameters as a combustability, total smoke production, fire growth rate and gase toxicity rate (on the combustible timber and noncombustible asbestos plates) are unknown. So the class of the fire hazard from 0 to 5 in accordance with the Russian classification can not be determined. The tests for the determination of the group of combustability should be conducted for the structural materials exclude the finiching coverings of the ceilings and carpet coverings in the case if the material should be certified in the field of the fire safety.

The considered in the course of current study samples related to 1–2 groups of combustability. It is slighty combustable materials on the noncombustable base.

The parameters determined by the SBI method and by the method of determination of combustability groups [23] are shown in the Table 1. Several parameters determined by the SBI method are shown on the Fig. 8–13 dependently from the duration of the tests.

3. Results and Discussion

Table 1. Results of the specimens testing by the method SBI and it comparison with the group of combustability [23].

Investigated parameters and classification in EN and Russia	Sample 1.	Sample 2.	Sample 3.	Sample 4.	Sample 5.	Sample 6.	Sample 7.	Sample 8.	Sample 9.
Expenditure on the board (g/m^2) big / small	336 / 346	252+542 / 261+486	410 / 400	486 / 393	691 / 533	303 / 253	250 / 250	240 / 240	200
FIGRA $_{0.2}$ - fire growth rate indices (W/s)	268.63	2948.78	2729.07	76.40	49.78	200.83	31.6	21.9	95.0
FIGRA $_{0.4}$ (THR(t) threshold of 0.4MJ)	268.63	2659.13	2729.07	74.76	30.41	186.35	30.5	21.9	66.7
THR$_{600}$ - total heat production (MJ)	20.101	13.997	6.531	11.70	2.602	21.483	3.8	3.0	5.4
SMOGRA - smoke growth rate (m^2/s^2)	15.82	101.28	88.28	32.93	13.58	9.94	-	1.4	7.9
TSP$_{600s}$ - total smoke production (m^2)	163.13	60.88	79.89	152.91	48.66	97.33	33.0	34.9	41.9
Group of combustibility GOST 32244 [24]	1	2	2	1	1	2	-	-	1
Supposed class EN 13501-1	D s2 d0	E s2 d0	E s2 d0	C s2 d0	A2/B s1 do	D s2 do	A2/B s1 do	A2/B s1 do	B s1 d0

Note. The results for the sample 9 were absent in the protocol of the tests; «-» – results are unknown; FIGRA – maximum relation HRRcp.(t)/(t – 300), multiplied by 1000. The maximum relation should be determined when the threshold levels of HRRcp. and THR were exceeded only. Indice of FIGRA is equal to zero if one or the both of it threshold levels were not exceeded during the time of action. Two different THR threshold values are used, which give finally FIGRA 0,2MJ and FIGRA 0,4MJ.

Basing on the results shown in Table 1, three types of fire protection are strongly differed: the water glass (nonorganic material), lacquers with the decreased combustibility and paints, which are close to water impregnations so as water impregnations.

Traditional impergnation on the base of the soluble salts which are based on the roasted carbonate of potassium (sample 6) possess the worst fire protective properties among the recently developed impregnations. The maximum smoke growing rate (SMOGRA), as it was expected, was observed for the fire protections with the organic components. The water glass also shows high maximum smoke growing rate (sample 1), what can be explained by the rapid combustion of the specimen made of pine wood.

The specimens 2, 3 and 6 are related to the medium combustable materials of group of combustibility 2 and possess the enough high fire rate growth indexes FIGRA $_{0.4}$. But the specimen 1 also possess the fire rate growth index equal to 268.63 W/s. Foamed paint containing the organic combustible components, which was used for treatment of the sample 5, have the low values of all the parameters due to the bloating effect.

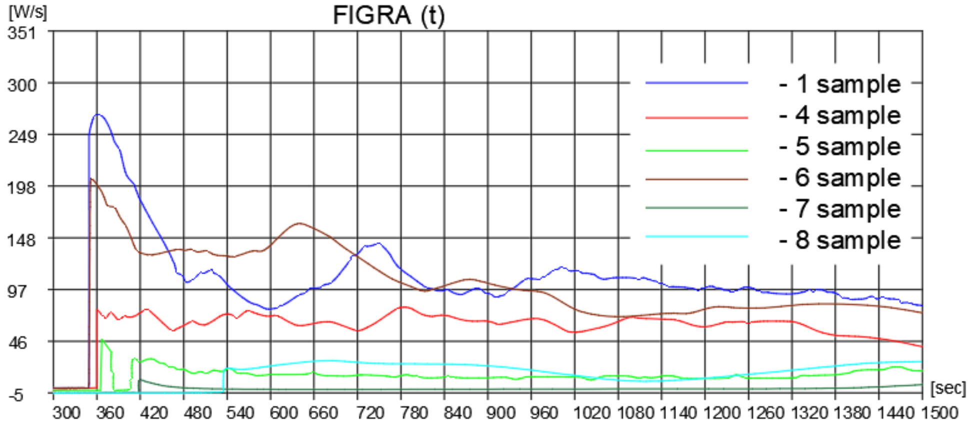

Figure 8. Fire growth rate indices FIGRA as a function of the time for the samples 1 and 4-8.

The fire growth rate indices FIGRA as a function of the time has a shock type shape for all the samples. The sample 1 is characterized by the highest fire growth rate indices probably due to the combustibility of the pinewood, which was used as a base material.

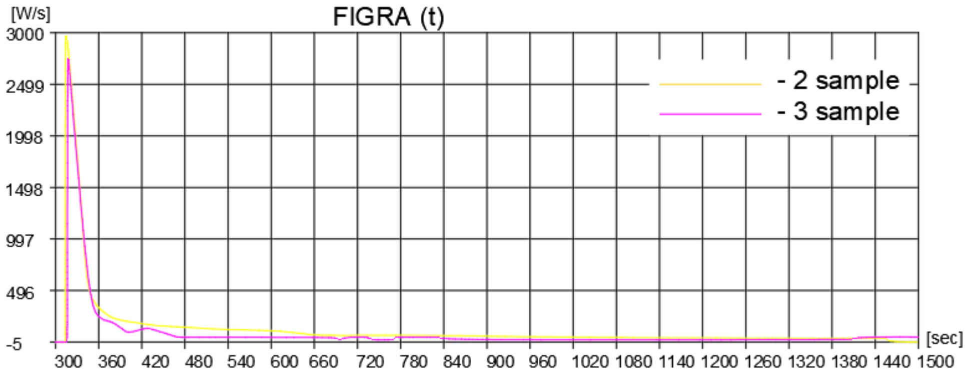

Figure 9. Fire growth rate indices FIGRA as a function of the time for the samples 2 and 3.

The base of the water glass does not have a significant influence on the fire growth rate indices FIGRA. The rapid shock in 300-540 s corresponding to the heat emission in 2.5–3 kW/s was observed at the initial stage. Than the fire growth rate indice tends to zero due to the fusion of the top layer and development of noncombustible gases. The water glass protective layer did not allows the heat emission. The small shock in 360 s than slightly decreased 2 times with the small oscilations, as it is shown on the chart. The similar character of the chart with the shock in 350 swas observed for the sample 6. The chart of the sample 4 has the shock starting from zero on the 360-th second and than it developed with the small oscilations from 46 to 97 Wt/s. The chart of the sample 8 has the similar shape with the shock on the 540-th second up to 22 W/s and than the value of the fire growth rate was stable. The graph for the sample 5 has two shocks at 360-th and 420-th seconds and than it has the shape similar to the grapf for the sample 4 with the mean value of the fire growth rate indices FIGRA equal to 30 W/s.

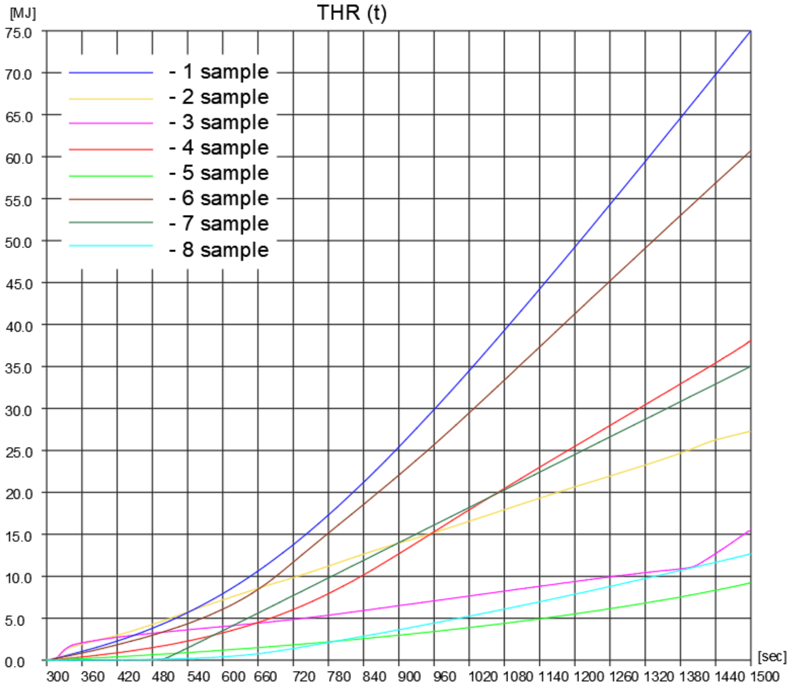

Figure 10. Total heat release THR as the function from the time.

All the charts shown on the Fig. 10 shows that the totel heat releases are the directly proportional to the time. The maximum heat release was observed for the sample 1 and sample 6 with the fire protection of the water glass and salt impregnation due to the constant heat release. The least heat release and least temperature of combustion were observed for the sample 4.

The fire growth rate indices quickly decreases and process of combustion developed more slowly for the samples 2 and 3. The samples 5 and 8 have the minimum fire growth rate indices and, correspondingly, minimum total heat releases.

The direct dependence between the fire growth rate indices and total heat release was not observed for the sample 7. The mean value of the total heat release corresponds to the minimum value of the fire growth rate indices.

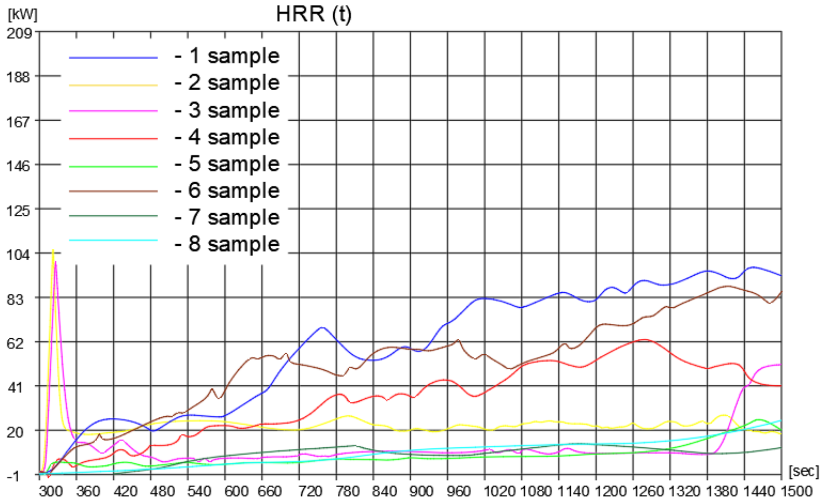

Figure 11. Total heat release rate HRR as the function from the time.

The total heat release rate for the samples 1, 6 and 8 is growing gradually with the time due to warming and damages of the protective layer. The charts for the samples 2 and 3 repeat the dependences of FIGRA on the time, which are shown on the Fig. 9. The shock in 300-360 s was observed at combustion and then the fire growth rate indices rapidly decreases due to the limiting of the oxygen level due to the changing of the structure of the protective layer.

The rapid increase of the fire growth rate indices was observed at the final stage of the testing of sample 3 (1380–1500 s), which is based by the charring of the protective layer and ending of it functions.

The dependence obtained for the sample 4 shows that the total heat release rate id directly proportional to the time until the 1260-th second and start to decrease than.

The sample 5 was characterized by the constant in the time total heat release rate with the slight increase starting from the 1320-th second. The total heat release rate for the sample 7 is growing till the 700-th second and then was constant with the non-sufficient oscillations.

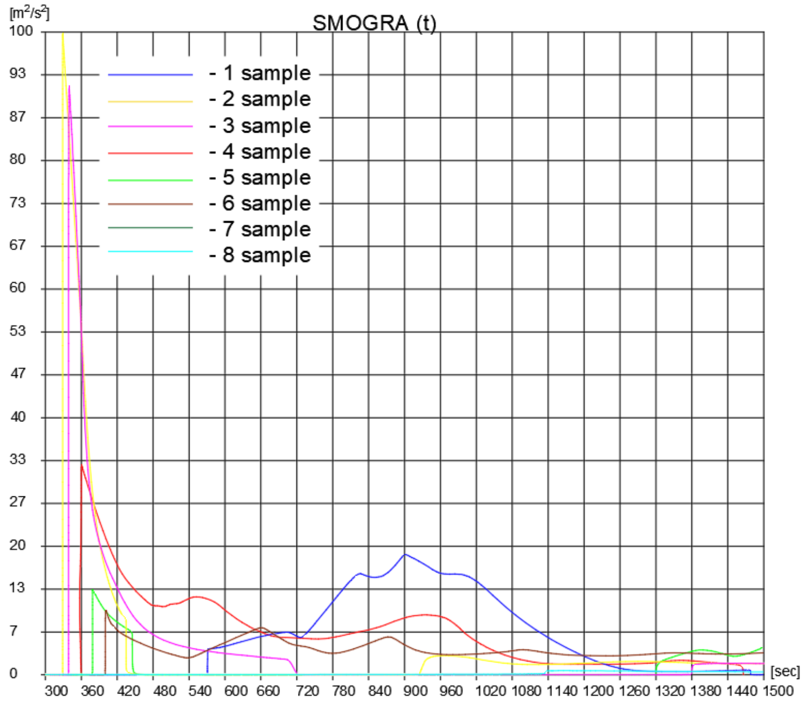

Figure 12. Smoke growth rate SMOGRA as the function from the time.

The smoke growth rate as a function from the time for the samples from 1 to 8 are shown on the Fig. 12. The dependences obtained for the samples 2 and 3 repeat the shape of the dependences obtained for the fire growth rate indices due to the charring of the upper layer and decrease the amount of the oxygen on the surface of the protected material. The smoke growth rate impetuously decreases in the case.

The dependence obtained for the sample 1 shows the slight increase of the smoke growing rate due to the surface warming with the further decrease. The dependences obtained for the samples 4, 5 and 6 have the shocks from 360 to 420 s. The smoke growth rate is slightly decrease until zero at the 1500-th second for the sample 4. The smoke growth rate is equal to zero starting from the 420-th second and slightly increase from 1340-th second for the specimen 5. The dependence of the smoke growth rate is slightly decreases with the no significant oscillations for the sample 6. The dependence obtained for the sample 8 is characterized by the small shock on the 1100-th second. It reaches a maximum in 1.8 m^2/s^2, what is the minimum value of the smoke growth rate in comparison with the other tested specimens.

The dependence for the sample 7 was not shown, so as smoke growth rate is insufficient and threshold sensitivity was not obtained.

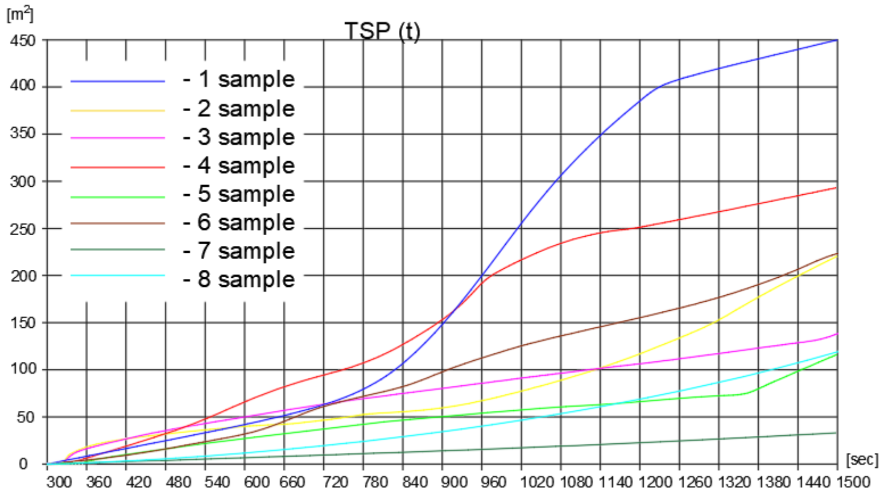

Figure 13. Total smoke production TSP as the function from the time.

The maximum total smoke production observed for the sample 4 due to the existence of the organic substances in the content of the fire protective material. The rapid increase of the total smoke production for the sample 1, which was treated by the water glass, on the 540-th second can be explained by the charring of the protective layer and firing of the base made of the pine wood with the high content of the resin.

Investigations conducted by the SBI method of the timber samples of the same type and assembling scheme probably, will enebles to identify the content of fire protective impergnations (paints and lacquers) at the same methods of the specimens treatment. Research on fire retardants for wood–plastic composites has been attracting more attention in recent years; however, most results are preliminary because of the difficulty in identifying or formulating a fire-retardant system that is effective for both wood and plastics [25–29].

4. Conclusions

1. Correlation between the parameters determined by the European and Russian standards for classification of the fire hazard of the structural materials is difficult for evaluation due to the difference in the choice of the values of the criterias, which are necessary for the classification. The additional data characterizing combustibility, smoke growth rate, fire growth rate indices and materials toxicity are necessary. Additional tests should be conducted at the similar conditions to get the information for the more precise comparison of the materials. The type of base, existence or absence of the air gap, spice of timber, it treatment should be considered as the conditions for the test.

2. Composition on the base of the acryl resin has a significant influence at the fire growth rate indices FIGRA (W/s) and the smoke growth rate SMOGRA (m^2/s^2) at the initial stage of fire. The maximum values of the FIGRA and SMOGRA observed for the nine specimens differed by the base materials and fire protection, were equal to 2948.78 W/s and 101.28 m^2/s^2, correspondingly.

3. The minimum values of the parameters were obtained for the water based bloated paint used as the fire protection. The paint expenditure which is necessary for the treatment of the board was the maximum at the same time and equal to 691 and 533 g/m^2 for the big and small boards, correspondingly.

4. The impregnations NEOMID 450-1 and Palonot have enough high characteristics as the fire protection which is characterized by the minimum smoke growth rate. It was equal to 1.4 m^2/s^2 for the Palonot and low undetermined on the chart value of smoke growth rate for the NEOMID 450-1.

5. The further investigations are necessary for the determination of fire protective materials consumption, defining of their types by the development of protective films and influence of the content on the technical characteristics of protected timber structures in case of fire, getted by the SBI method.

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