New Method of Quality Control for Fire Protective Coatings

To cite this article: Dmitry Minailov et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 471 112016

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New Method of Quality Control for Fire Protective Coatings

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Abstract. This research highlights testing measurements for quality control of fire protective coating on the all life cycle services, which is aimed to improve the processing technology of product coatings, the quality of building and energy saving. Short-time experiments in resistance to climate factors were carried out in order to check the possibility of dielectric method appliance for quality control of fire protective coating during service life, with further measurement of dielectric and fire protective properties. This work analyses the thermal decomposition and fire-protective properties, based on visual inspection of surface appearance for all protected constructions at all protected area and criteria of coating surface appearance with the requirements of normative documents for its appliance. Thin-layer fire protective coatings were chosen for the experiments to appraisal fire protection quality control of steel constructions. Experiments were carried out for frequencies 100, 120, 1000, 10000 and 100000 Hz at temperature 26°C and relative humidity 45% within a week daily, for 30 min with a break 1 min. Obtained data array were processed statistically in order to determine mean root square deviation and confidence limits. Mean root square deviations were also calculated for the data obtained for 30 measurements within 24 hours.

1. Introduction

The new research methodology uses a highlights of fire retardant coating composition to improve the coating characteristics that affect its reliability, as well as to observe the coating conditions on the surface of unprotected steel constructions to be protected, fire protection becomes mandatory requirement for safe appliance with exclusive standards for fire resistance. This takes into account the regulatory requirements of fire safety in technological processes for various purposes in their design, construction, reconstruction and maintenance. Moreover, the control of protection facilities and developing of the technological projects are conducted in conditions, provided at the objects of significant importance, buildings with large places of assembly, such as night clubs, theatres, cinemas, educational institutions, buildings of federal, state and municipal entities, storage facilities, objects with fire protected area more 5000 sq.m. Thermal analysis is fulfilled, and thermal insulating properties of the coating are determined. Determination of properties of flammable materials and construction materials for quality control is conducted based on tests or calculations given state parameters - pressure, temperature, etc. Development batch of experiments for quality of thin-layer fire protective coating, based on dielectric property measurement, was carried out in order to check the functional abilities. According to Federal State Statistics Service data, since 2000 till 2016 3436,4
thousand of residential and non-residential buildings were taken into use in Russia. Around 412,368 thousands (~12%) of them are buildings with load-bearing framework produced with steel constructions; they are mainly industrial and agricultural objects.

Despite steel constructions are made of non-combustible materials, real fire resistance limit is 6-25 min in fire without protection, depending on cross-section thickness and effective stress value [2]. Necessary fire resistance limit is 15-120 min depending on fire resistance rating of the building and construction type [3-6]. These requirements essentially restrict area of appliance of unprotected steel constructions as loadbearing elements, and fire protection becomes mandatory requirement for safe appliance with exclusive standards for fire resistance.

The most popular method of fire protection for steel constructions is usage of thin-layer polymer coatings, which are able to increase in size much from heating. Intumescent coatings are composite materials, containing polymer binder coating and extenders (antipyrens, gas developing agents, heat-proof materials and stabilizers of foamed coal bed). Small-meshed layer is formed at intumescence and simultaneous coaling, this layer has low heat conduction, so metal construction heat up essentially decelerates.

According to p.21 [7-10] flameproofing (treatment) condition check should be fulfilled at least once a year, if there is no information in the guidance. Control of flameproofing condition (fire protective properties keeping) at maintenance is provided according to Guidance «Fire Protection Quality Control and identification of fire protective coating type at objects. FGBU VNIIPo EMERCOM of Russia».

2. Research Methods

According to the Guidance preventive check of fire protective properties keeping is fulfilled based on visual inspection of surface appearance for all protected constructions at all protected area. The main criterion is compatibility of coating surface appearance with the requirements of normative documents for its appliance. Simultaneously with surface appearance check, samples (discs) are selected from the surface of hardened coating, disc diameter is 3-5 mm, disc quantity is at least 3 per 200 sq.m. Then intumescence coefficient is determined in laboratory according to Annex F GOST R 12.3.3047-98, the value should be at least 10.

If the coefficient is less than 10, and also when control is provided at the objects of significant importance (buildings with large places of assembly (night clubs, theatres, cinemas, educational institutions, etc.), buildings of federal, state and municipal entities, storage facilities, objects with fire protected area more 5000 sq.m, etc.), thermal analysis is fulfilled, and thermal insulating properties of the coating are determined.

For thermal analysis point samples are selected from the surface of hardened coating per 200 sq.m. Mass, shape and sizes of the sample depend on the type of device used for test, and also on material type, density, and they are chosen according to conditions of primary test for check sample (identification), with account of recommendations for the device use. Conclusion of fire protective efficiency is based on comparing of thermoanalytic characteristics and parameters of the coating in the beginning and in service. In case of partial (acceptable) property loss the difference between means of thermoanalytic identification parameters shouldn’t exceed 25%.

Proceeding from the above, quality control of fire protective coating for all service life according to the Guidance «Fire Protection Quality Control and identification of fire protective coating type at objects. FGBU VNIIPo EMERCOM of Russia». is provided only based on visual inspection results, control with express-method (Annex F GOST R 12.3.3047-98) and thermal analysis methods, which, except for visual, are destructive and require repeating laboratory fire tests. Other methods, described in the Guidance, provide estimation of fire protective properties only at the stage of construction treatment, i.e. in the very beginning of service life (figure 1).
Besides this it’s necessary to take into account that fire protective property loss can go without observed occurrence, i.e. coating surface can stay unchanged [5], and this makes visual inspection ineffective and unable to detect fire protective property loss till limit value timely. Disadvantage of the method from Annex F GOST R 12.3.3047-98 is the impossibility to determine strict correlation between fire protective efficiency and intumescence coefficient. Thermal analysis methods are also not objective, because they should confirm some initial “identification” parameters of the sample by comparing. But these parameter values are not connected with fire protective efficiency directly, and their limit values are not determined. With account of difficult and often non-uniform structure of fire protective coating, it’s impossible to determine strict correlation between fire protective efficiency and such parameter values.

Therefore concept “working life of fire protective treatment” and its determination methods are often used for estimation of acceptable service life for the coating. These methods can’t be considered as control methods, because they don’t mean inspection of protected construction in use. Besides that, fire protective property loss can occur not only as a consequence of aging effect. This can be caused by unacceptable changes in composition, no observance of plating technology, departures from maintenance conditions. This emphasizes importance of fire protection quality control at painting and in use. It’s evident from the above that research for forecasting of service life for fire protective coatings are not alternative for control, but rather complete it, increasing degree of reliability in estimation of coating condition and investigation into the causes of non-compliance with fire safety requirements.

The most reasonable approach to confirm fire protective property keeping at maintenance is an approach using for control the same methods as were used for the certification of fire protective compound. But it’s in many cases impossible because of difficulties in sample selection for protected constructions in use. But development of control methods, which are aimed at high correlation with results of tests by certification methods, which at the same time control condition of protected constructions by dielectric power cubicles (figure 2), placed at the object with protective coating sample with repeating estimation of fire protective properties, seems to be solvable problem.
Figure 2. Dielectric power cubicle

Nowadays dielectric methods are widely used for solution of scientific and applied problems as well, due to their high sensibility to polymer composition and condition. This method determines dielectric properties of materials and researches the dependence on composition, temperature, frequency and other factor, and also researches kinetics of chemical and physical transformations of polymer compositions, molecular mobility changes in them; control environment composition in point of change of polymer dielectric properties. But dielectric methods haven’t been used for quality control of intumescent fire protective coatings so far.

Substance of the method of fire protective property control for coatings with the help of dielectric power cubicles is in control of coating dielectric property change (dielectric power cubicle capacity – C and tangent of an angle of dielectric losses – tgδ), which changes will allow to estimate changes in fire protective properties of the coating (figure 3). Correlation relationship between fire protective and dielectric property changes is determined in laboratory during short-time climatic tests (they determine coefficients of change of dielectric power cubicle capacity КС, of tangent of an angle of dielectric losses Кtgδ, which correspond decreasing of coating fire protective properties below required normative value). Temperature, humidity and UV sensors are applied, because values КС, Кtgδ depend on temperature, humidity and UV radiation. These values are also determined at short-time climatic tests. Coefficients КС, Кtgδ are determined by the formulas:

\[ K_C = \frac{dC}{dT} \times \frac{1}{C_0} \]  
\[ K_{tg\delta} = \frac{dtg\beta}{dt} \times \frac{1}{tg\delta_0} \]

where \( K_C \) – coefficient of change of dielectric power cubicle capacity,  
\( K_{tg\delta} \) – coefficients of change of tangent of an angle of dielectric losses,  
\( C_0 \) – initial value of dielectric power cubicle capacity;  
\( C \) – value of dielectric power cubicle capacity for service life of fire protective coating;  
\( tg\delta_0 \) – initial value of tangent of an angle of dielectric losses;  
\( tg\delta \) – value of tangent of an angle of dielectric losses for service life of fire protective coating.
Figure 3. Coating fire protective property control with the help of dielectric power cubicle

Values $K_C$, $K_{tg\delta}$ are equal to 1 in the beginning of service life. Further, for the whole service life of the coating, current values $C$ and $tg\delta$ are determined for each dielectric power cubicle, i.e current values $K_C$, $K_{tg\delta}$ are determined and compared with $K_C$, $K_{tg\delta}$, corresponding to decreasing of fire protective property below required normative value. If current values $K_C$, $K_{tg\delta}$ are in acceptable interval, fire protective coating quality is supposed to be compatible with normative requirements. If current values $K_C$, $K_{tg\delta}$ are not in acceptable interval, fire protective coating quality is supposed to be not compatible with normative requirements.

3. Results and discussion

At this point test installation for quality control of thin-layer fire protective coating, based on dielectric property measurement, has been developed (figure 4); dielectric power cubicle has been developed to measure dielectric properties of the coating; study has been undertaken to detect correlation between changes of dielectric and fire protective properties of thin-layer coating. Correlation between changes of dielectric and fire protective properties of thin-layer coating has been established. Developed test installation can be used for the evaluation of:

- values of dielectric power cubicle capacity and tangent of an angle of dielectric losses for fire protective coatings;
- temperature, humidity and UV radiation influence on values of dielectric properties for fire protective coatings.

Test installation consists of working unit and command console. Working unit consists of sensor units with 8 dielectric power cubicles, it's a container for fixing, transportation and exposure of samples. Command console is intended for operational management, automatic measurement of electric parameters for test samples, control of temperature, humidity and UV radiation, and also for measurement data transfer to PC. Measurement system of the installation is based on alternating current bridge. Samples (dielectric power cubicle) are put into one of branches of abridge, which allows to obtain values of capacity ($C$) and resistance $R$ (or its inverse value – conductivity $g$) at alternating electric field for frequencies 100, 120, 1000, 10000, 100000 Hz, which are transformed into electrical impulses with the help of variable pulse self-excited oscillator.
Development batch of experiments was carried out in order to check functional ability of the installation. Fire protective coatings «Terma», «Terma M», «Fenix STS», «Fenix STB» were chosen for the experiments. The main criterion for the choice was wide use of these coatings for fire protection of steel constructions.

Experiments were carried out for frequencies 100, 120, 1000, 10000 and 100000 Hz at temperature 26°C and relative humidity 45% within a week daily, for 30 min with a break 1 min. Obtained data array of Cₓ and tg δₓ were processed statistically in order to determine mean root square deviation and its confidence limits. Mean root square deviations were also calculated for the data obtained for 30 measurements within 24 hours. Mean random inaccuracies were calculated by Student criterion for measurements of dielectric power cubicle within a week. Random inaccuracies for C increase within frequency decrease and achieve maximum value 2,04% at frequency 100 Hz, and for tgδ conversely decrease and achieve maximum value 1,53% at frequency 100 kHz. Obtained values of inaccuracies for dielectric parameters are acceptable, because not exact values C and tgδ are important for control, but their changes during service life of fire protective coating. Development batch of experiments has confirmed functional ability of the installation and possibility of research of dielectric properties for fire protective coatings.

Temperature, humidity and UV radiation influence on dielectric properties of fire protective coatings was also determined in experiments. Temperature and humidity influence on dielectric parameters of power cubicles was established in these experiments, for reversible and irreversible transformations of content and structure of fire protective coating.

4. Conclusions

Short-time experiments in resistance to climate factors were carried out in order to check the possibility of dielectric method appliance to quality control of fire protective coating during service life (according to GOST 9.401-91 (industrial atmosphere type II according to GOST 15150-69, operation conditions according to GOST 9.104-79 – УХЛ 1, method 6)) with following measurement of dielectric and fire protective properties. 120 test cycles were carried out (4,5 months).
Change of intumescence rate and dielectric properties of fire protective coating were detected in the experiments. High statistically significant correlation between dielectric property change and coating intumescence rate was established (figure 5).

![Random inaccuracies for the mean of power cubicle data by Student criterion](image1)

![Characteristic curves for the change of intumescence frequency and dielectric properties of fire protective coating](image2)

**Figure 5.** Experimental results

Proceeding from the above, dielectric power cubicle appliance at construction service life allows to increase the efficiency of control for fire protective properties of intumescent coatings.

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