Methodology for optimizing the study of fire-retardant compositions for building materials and structures

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Abstract. In Russia, a large number of domestic and foreign fire-retardant materials are used to reduce fire danger when using metal and wooden structures in construction, as well as cable products. Regulatory instruments are used to assess these properties of fire-retardant materials, which do not allow for sufficient performance assessment. In this regard, the use of interdisciplinary research methods is proposed. The authors propose a wide range of research methods, as well as a methodological approach based on the separation of interdisciplinary methods into groups by scale of the research object (material). Based on the level-based division of the study, as well as an analysis of possible experimental methods at each level, it is proposed to optimize the study of the operational properties of building materials and fire retardants through the use of a compatibility chart. A practical example of how to use a compatibility chart is shown.

1. Introduction

One of the most pressing issues in science and education is the conduct of interdisciplinary research. In the Russian Federation, this area has recently received special attention at the highest level of state scientific and technical policy formation. The main goal of the development of interdisciplinary research in international practice is recognized as the integration of intellectual resources and scientific and production infrastructure.

In our country, a large number of domestic and foreign fire-retardant materials are used to reduce fire danger when using metal and wooden structures in construction, as well as cable products. These materials have both organic and inorganic bases, have passed the necessary fire tests to standards and have received a certificate for practical use in construction. In this regard, there are no special requirements, regulated by fire safety standards and regulations, for fire retardant materials for their use in normal conditions. To assess these properties of fire-retardant materials are used regulatory documents intended for the products of paint industry - varnishes, paints. In the development of fire-retardant materials, these requirements should be taken into account with a fairly large specificity of interdisciplinary methods of researching mechanochemical construction of materials with specified structure parameters and operational properties. These requirements are related to chemical and physical aggression caused by both the external environment and the material elements directly. In addition, the adhesion of materials (from the compatibility diagram) of fire retardant compositions to metal, wood and cables, technological factors when applied to the structure, depending on the physical and chemical processes in various fire retardant materials, should be investigated.
The methodology of interdisciplinary research involves several stages of scientific research, the development of which is one of the most difficult tasks, uniting scientists of different specialties in modeling block schemes of research.

The choice of interdisciplinary research methods for mechanochemical construction of materials with specified structure parameters and operational properties consists of several stages:

- Methods of mechanochemical creation of materials,
- physics and chemical research methods,
- programs of fire and other tests.

It is known that for the study for mechanochemical construction of materials with specified parameters of structure and operational properties are used methods of thermogravimetric analysis of the structure, X-ray spectroscopy, chromato-mass spectrogram, elemental analysis, IR spectroscopy, pH-metrics.

The authors propose the following methodological approach to the study, based on the division of interdisciplinary methods into groups by the scale of the research object (material). In this case, the studies are divided into the following levels:

- Micro level;
- supramolecular level;
- Research on the material;
- Design research.

Table 1 presents the methods used in micro-level and supramolecular research:

| Physical and chemical characteristics | Assessment of the porous structure: |
|--------------------------------------|------------------------------------|
| Heat conductivity assessment         | Specific surface                   |
| Temperature assessment               | Porosity                           |
| Heat-intensity assessment            | Distribution of pores by size      |
| Thermo-gravimetric analysis          | Assessment of surface structure:   |
| Isothermic calorimetry               | Electronic microscopy              |
| Determining Gibbs Energy             | The edge of wetting                 |

| High-quality elemental analysis:     |
|-------------------------------------|
| X-ray spectroscopy                  |
| Chromato-mass-spectrogram           |
| Elemental analysis                  |
| IR-spectroscopy                     |
| pH-metro                            |

Choosing methods to study structural processes under the influence of man-made factors (fire), including emergencies, due to factors that can affect the reduction of fire retardant coating efficiency: adhesion, its strength characteristics, resistance to the effects of aggressive environments (including moisture), shelf life before application to the design, etc.

The conditions in which the structures are operated have a great impact on the quality and durability of fire retardant treatment. In this regard, for example, in the development of fire retardant compositions for wood it is necessary to assess their properties in the influence of high and negative temperatures, different humidity, aggressive vapors and gases, precipitation. It is necessary to have data on the expiration date, time and degree of drying, strength on bend, strength on impact, biological durability.
In accordance with this, from the micro-level and supramolecular level of research we move to the study of materials and structures with the preservation of the physical and chemical characteristics of the object studied (table 2).

Table 2. Interdisciplinary methods of research at the level of materials and designs.

| Material-level research methods | Design-level research |
|--------------------------------|-----------------------|
| **Performance:**              | **Performance:**      |
| Assessment of water absorption| Assessment toorrosional durability |
| Assessment of water resistance| Evaluation erosie     |
| Assessment of hydrophobic     | Assessment of bio resilience |
| Assessment of permeability    | Assessment of UV sustainability |
| Definition of adhesion        | Assessment of heat resistance |
| Assessment of heat resistance | **Fire hazards:**     |
| Assessment of thermal aging   | Assessment of the fire resistance limit |
| **Fire retardant characteristics:** | **Mechanical test:** |
| Assessment of fire hazards    | Large-scale trials   |
| Assessment of fire retardant efficiency |
| **Mechanical characteristics:** |
| Strength assessment           |
| Stretching score              |
| Evaluation of the shift       |
| Bend assessment               |
| **Methods to control the quality of the material structure** |
| Obtain data on the characteristics of the surface of compositions (electron microscopy) |
| Assess the edge angle of wetting |
| Ir-spectroscopy               |
| Study of fire retardants by pH-marker (complex study of the chemical composition of water solutions (rigidity, anion chromatography, pH-metro)) |

In order to assess and predict the behavior of a fire retardant material (used in practice or re-developed) with the expiration of a specific lifespan, Effective methods are methods of control of the quality of the structure of the material (receiving data on the characteristics of the surface of compositions (electron microscopy), assessment of the regional angle of wetting, conducting IR-spectroscopy, examination of fire retardant compositions by pH-marker (complex study of the chemical composition of water solutions (rigidity, anion chromatography, pH-metro)), data differential-thermal analysis (DTA) and X-ray analysis (XRA), values of effective thermal conductivity factor ($\lambda_{\text{eff}}$), chromato-mass spectograms, etc.).

All of the above indicators are determined by selecting a certain amount of fire retardant material directly from the object (from the substrate of the material) where the fire retardant was carried out, and comparing them with the indicators obtained in the study of properties on models (after conducting studies on the technique of artificial aging).

Based on the level-based division of the study, as well as an analysis of possible experimental methods at each level, it is proposed to optimize the study of the operational properties of building materials and fire retardants through the use of a compatibility chart. (Figure 1.)
2. Using a compatibility chart
The proposed diagram allows a comprehensive study of the properties of the object under study, followed by the exception of intermediate methods to predict the performance of the typical groups of materials.

An example is the study of wood fire danger. A number of papers provide examples of research into the various factors that influence these characteristics. In most cases, a wide range of methods are used, which fits into the proposed compatibility chart. At the same time, several types of elemental analysis, thermal research methods and methods for determining fire hazard characteristics can be used, as well as detailed structural analysis for a large list of similar properties of samples. It should be taken into account that such groups of samples may have a similar functional criterion (e.g., functional chemical link), the change of which in different samples can lead to a change in performance. Therefore, in such cases, one micro-level method of research, such as X-ray analysis, can be selected to predict performance characteristics that relate to the level of the structure (figure 2).

**Figure 1.** Study compatibility chart.
There are significant drawbacks to using many experimental methods:
- Large financial investments and labor costs;
- Negative impact on the environment (e.g. in on-the-day trials).

It is obvious that targeted experimental methods should be chosen to predict the characteristics of building materials and fire-retardant materials. Such methods must meet the functional criteria of the study group of materials.

3. Conclusions
For the first time, an algorithm is proposed to summarize empirical data on the mechanochemical characteristics of materials using interdisciplinary methods in the form of a compatibility diagram;

Shows a practical example of how to use a compatibility chart.

Figure 2. Example of using study compatibility chart.
This methodology optimizes research for any composite materials, preserving targeted research methods and eliminating impractical and related experimental studies with reduced labor costs and, as a result, environmental impact.

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