Decision-making on quality composition materials exposed to temperature differences

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Abstract. An approach is considered that allows one to make a decision on the choice of compositions of composite materials that have been exposed to temperature changes for a long time. The alternatives are considered – compositions of materials and special criteria, the analysis of which underlies the optimal choice of composition from the group under consideration. Proposed the formation of criteria by which the decision is made to assess the quality of building composite materials. In this article, the criteria are formed on the basis of such properties of building materials as hardness and modulus of elasticity on the surface of the test samples, which were subject to negative and positive temperature extremes. Criteria for each property of the sample are formed on the basis of the given values relative to the starting point of exposure. To make a decision about the quality of composite materials, it is proposed to form three criteria for each of the considered properties of materials. The first criterion is calculated as a change in the corresponding property relative to the initial exposure point. The second criterion is determined sequentially with respect to each exposure point by a change in each of the considered properties. The third criterion is represented as the sum of the first two criteria. After that, some provisions of the ELECTRE methods are applied for ranking the studied compositions of composite materials.

1. Introduction

The study of the characteristics of building materials and, in particular, cement composites is widely covered in scientific research [1–11]. Particular attention is paid to the operation of materials in extreme conditions. Such conditions can be sharp temperature changes at which a change in the properties of materials is possible, in particular, hardness and elastic modulus on the sample surface. An expandable assortment of building composite materials makes it necessary to solve the problem of choosing a composition that meets the specified boundaries of the permissible changes in certain properties. Here are certain scientific results in this direction, for example [4, 6–8, 11]. But a general analytical solution is difficult to obtain, and maybe impossible. Therefore, heuristic approaches to solving the problems of optimizing compositions, choosing the compositions of building materials are proposed. At the same time, a costly measure is to conduct an appropriate experiment to obtain data on changes in certain properties of building composite materials. Since the properties can have different
physical units of measurement, as well as a different range of changes, it is advisable to switch to relative units as a result of the ratio of the current value of the property to the control value recorded before the start of control tests. Then the nature of the change in properties will be enclosed within the boundaries [0; 1]. This paper analyzes the relative change in hardness and the relative change in modulus of elasticity on the surface of composite material samples.

2. Formulation of the problem
The results of the experiments were obtained with the following cyclic temperature differences [12]: from −50 °C to a positive temperature of +23 °C. During cyclic tests, various indicators of material properties are monitored, which can have different units of measurement and different absolute values. In this regard, it is advisable to analyze the relative change in the properties reduced to the values at the starting point of the exposure. Changes in the quality of building materials during the operating period in an unfavourable environment are due to changes in many of their physical and mechanical properties. Important indicators of composite materials include hardness and modulus of elasticity on the surface of the sample, which, as a rule, also vary during the exposure of materials. There are various approaches to optimizing building materials [12-19].

This article is based on some provisions of ELECTRE methods from the theory of decision making [20-23]. According to the terminology of decision theory, alternatives are compositions of building composites. For each of the properties of materials, it is proposed to form three criteria. The first criterion $K_{rv}$ is defined as the segments between the exposure points relative to the control point or the starting point of exposure (figure 1). The second criterion $H_{rv}$ is associated with changes in the properties of the material during exposure time at adjacent points of exposure (figure 2), and the third criterion $J_{rv}$ is the sum of $K_{rv}$ and $H_{rv}$.

![Figure 1. Definition of criterion $K_{rv}$.](image-url)
In the ideal case, when the properties of the composites do not change throughout the entire test period, the introduced criteria will tend to zero. Moreover, there is an obvious connection between the criteria $K_{rv}$ and $H_{rv}$. One complements the other with a shift of one step in the control test time. The third additive criterion $J_{rv}$ takes into account the values of two criteria. As a result, the resulting number of criteria is introduced into consideration, the number of which is a multiple of three and the number of control properties.

In accordance with the ELECTRE methods, the next step will be the formation of a matrix of alternatives and criteria. Moreover, this matrix should contain ranges of calculated values of each of the criteria with the assignment of prize points, which vary linearly from the maximum assigned value to the minimum. This assignment of prize points is relatively arbitrary in nature, since all alternatives will be ranked according to them – the studied compositions of the composites. To determine the total number of prize points for each alternative, various software algorithms in the selected programming language can be used. We note that to evaluate the value of the criterion, the results of processing the experimental data were used to determine half the category of significant digits of a real number. It is assumed that the experimental – data are recorded taking into account the fractional part of the numerical value. Formalization of the parametric optimization problem is expressed by the following relationships:

\[
K_{rvj} = \sum_{i=1}^{n} \frac{K_i}{K_0} \rightarrow \min, \quad H_{rvj} = \sum_{i=0}^{n-1} \frac{H_i}{H_{i+1}} \rightarrow \min, \quad J_{rvj} = K_{rvj} + H_{rvj}, \quad j = 1, 2, ..., m, \quad (1)
\]

where $n$ is the number of exposure points, $m$ is the number of investigated compositions.

In order to have a practical idea of the proposed approach for the optimal choice of compositions of cement composites, we used the experimental data from [12] (Table 1), from which compositions with a negative change in properties – hardness and elastic modulus on the sample surface were selected. They were designated A1, A3, A4, A5, A9, A11, which must be ranked in accordance with (1).
Table 1. Experimental data.

| Composition number, alternatives | Duration exposure, days | Hardness index, MPa | The modulus of elasticity, MPa |
|----------------------------------|------------------------|---------------------|-----------------------------|
| A1                               | 0                      | 4.010               | 92.914                      |
|                                  | 15                     | 2.037               | 33.545                      |
|                                  | 45                     | 1.349               | 18.225                      |
| A3                               | 0                      | 7.016               | 214.593                     |
|                                  | 15                     | 3.629               | 79.711                      |
|                                  | 45                     | 2.166               | 36.742                      |
| A4                               | 0                      | 54.770              | 147.694                     |
|                                  | 15                     | 3.966               | 91.025                      |
|                                  | 45                     | 3.194               | 66.153                      |
| A5                               | 0                      | 9.747               | 354.171                     |
|                                  | 15                     | 3.786               | 85.009                      |
|                                  | 45                     | 2.489               | 45.393                      |
| A9                               | 0                      | 3.503               | 75.640                      |
|                                  | 15                     | 2.729               | 51.977                      |
|                                  | 45                     | 2.442               | 44.019                      |
| A11                              | 0                      | 2.472               | 44.833                      |
|                                  | 15                     | 2.452               | 44.358                      |
|                                  | 45                     | 1.466               | 20.465                      |

3. Experimental results

The compositions of the investigated composites are formed on the basis of Portland cement PC500D0. In [7] these composites were exposed to high humidity and variable positive temperatures. Table 1 shows the results obtained by the following mode of exposure of cement composites.
1. Cooling samples from room temperature (+23 °C) to -50 °C for about an hour (50–55 min).
2. Exposure of samples at a temperature of -50 °C – 9 hours.
3. When the chamber is switched off, the samples are naturally heated to room temperature (+23 °C) for at least 5 hours.
4. Exposure of samples at room temperature (+23 °C) – 9 hours.

The basis of the investigated cement composites are cement stone and sandy concrete. The initial values of hardness and modulus of elasticity on the surface of the tested composites differ markedly from each other. In general, the properties of composites can have different units. The absolute values of the properties are shown in Table 1, where their properties are reflected: hardness (Hardness index) and modulus of elasticity on the surface of the samples (the modulus of elasticity). The next step is to translate the absolute values of hardness and modulus of elasticity (Table 1) to relative units, followed by the definition of criteria for each composition (Table 2).
Table 2. Matrix of alternatives and criteria

| Alternatives | $K_{rv1}$ | $K_{rv2}$ | $H_{rv1}$ | $H_{rv2}$ | $J_{rv1}$ | $J_{rv2}$ |
|--------------|-----------|-----------|-----------|-----------|-----------|-----------|
| A1           | 1.16      | 1.44      | 0.34      | 0.33      | 1.50      | 1.77      |
| A3           | 1.17      | 1.46      | 0.42      | 0.40      | 1.59      | 1.86      |
| A4           | 0.69      | 0.94      | 0.28      | 0.34      | 0.97      | 1.27      |
| A5           | 1.36      | 1.63      | 0.27      | 0.22      | 1.62      | 1.86      |
| A9           | 0.52      | 0.73      | 0.16      | 0.21      | 0.69      | 0.94      |
| A11          | 0.42      | 0.55      | 0.80      | 1.07      | 1.21      | 1.62      |

The expanded matrix of criteria with prize points in the right column is presented in Table 3.

Table 3. The expanded matrix of criteria with prize points

| $K_{rv1}$ | $K_{rv2}$ | $H_{rv1}$ | $H_{rv2}$ | $J_{rv1}$ | $J_{rv2}$ | $PB$ |
|-----------|-----------|-----------|-----------|-----------|-----------|-----|
| 0.415     | 0.554     | 0.164     | 0.210     | 0.688     | 0.941     | 12  |
| 0.501     | 0.652     | 0.221     | 0.288     | 0.773     | 1.025     | 11  |
| 0.586     | 0.750     | 0.279     | 0.366     | 0.858     | 1.108     | 10  |
| 0.672     | 0.848     | 0.337     | 0.444     | 0.943     | 1.191     | 9   |
| 0.757     | 0.946     | 0.394     | 0.521     | 1.028     | 1.275     | 8   |
| 0.843     | 1.044     | 0.452     | 0.599     | 1.113     | 1.358     | 7   |
| 0.929     | 1.142     | 0.509     | 0.677     | 1.198     | 1.441     | 6   |
| 1.014     | 1.240     | 0.567     | 0.755     | 1.283     | 1.525     | 5   |
| 1.100     | 1.338     | 0.625     | 0.833     | 1.368     | 1.608     | 4   |
| 1.185     | 1.436     | 0.682     | 0.910     | 1.453     | 1.691     | 3   |
| 1.271     | 1.534     | 0.740     | 0.988     | 1.538     | 1.774     | 2   |
| 1.356     | 1.632     | 0.799     | 1.066     | 1.623     | 1.858     | 1   |

As a result of processing the matrices of tables 1 and 2, the following optimal ranking of the studied compositions was obtained: A9, A4, A11, A1, A5, A3 (table 4).

Table 4. The result of optimal ranking of composites

| Sum of points | Compositions | Prize points |
|--------------|--------------|--------------|
|              | $K_{rv1}$ | $K_{rv2}$ | $H_{rv1}$ | $H_{rv2}$ | $J_{rv1}$ | $J_{rv2}$ |
| 63           | A9          | 10         | 9         | 12        | 12        | 10        | 10        |
| 48           | A4          | 8          | 7         | 10        | 10        | 7         | 6         |
| 30           | A11         | 11         | 11        | 1         | 1         | 4         | 2         |
| 26           | A1          | 3          | 2         | 9         | 10        | 1         | 1         |
| 26           | A5          | 1          | 1         | 10        | 12        | 1         | 1         |
| 22           | A3          | 2          | 2         | 7         | 9         | 1         | 1         |

4. Conclusion
The preference decision was made on the basis of a consideration of the relative change in such properties of composite materials as hardness and elastic modulus on the surface of samples. Perhaps, the final decision on the choice of materials will be made only taking into account all characteristics and properties of building materials. The proposed approach to determining the quality of composite materials can be implemented in almost any programming language with low computational costs and a
sufficiently high speed. At the same time, the authors believe that research is needed when changes in the properties of composite materials are not monotonically changing, when the index of properties can be increased in one area of exposure time and its reduction in the other.

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