Contemporary Engineering Sciences, Vol. 7, 2014, no. 28, 1555 - 1563
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2014.410188

Method of Building Optimization of Composites Based on the Criterion Analysis

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Abstract

A new approach to optimize the composition of dry mixes with the relationship "composition-structure-property-value", which is based on the parameterization of the quality criteria for the unit cost of the compositions, mathematical formulation and computer solution of the optimization problem with constraints.

Keywords: dry mixes, finishing compositions, unit cost, the generalized criterion of quality, numerical methods for solving optimization problems

1 Introduction

In this paper, we propose a method to optimize the formulation of building composites based on their cost, while maintaining a given level of quality. This problem is solved by choosing the optimal ratio of the components, which allows to formulate a set of criteria values of physical, mechanical, technological and aesthetic properties subject to the minimum value of. For this purpose, it is necessary to find a set of components of the mixture with the given specific cost (DC), which provides the solution of the optimization problem:

$$\max Z(x_1,..,x_n)$$
$$\min x_i \le x_i \le \max x_i,\ i = 1,\dots,n \qquad (1)$$
$$0 \le K_j(k_1,..,k_p) \le 1,\ j = 1,\dots,l$$

$$\min k_q \le k_q \le \max k_q,\ q = 1,\dots,p$$
$$\min S(x_1,..,x_n) = \min(c_1x_1 + \dots + c_nx_n)$$

where $Z \ge 0$ - the selected generalized criterion of quality (GCQ),
x_i - weight fraction of the i-th component, n - number of the components.
K_j -shkalirovannye coefficients j-th material properties depending on partial criteria quality

$$k_q = k_q(x_1,\dots,x_n),\ q = 1,\dots,p.$$

To determine the GCQ in paper proposes to use the following expression:

$$Z = \sum_j^m \alpha_j K_j \qquad (2)$$

wherein α_i – the weights of the *i*-th private factor. This should satisfy the following conditions $Z_i \ge 0$ and $\sum_i^m \alpha_i = 1$ Each of K_j numerically characterizing the value of the scale factor may be different, selected within the meaning of the functional relationship between the quality criteria kq, while large values of GCQ characterize the best condition. The quality of construction of the composite in accordance with the decomposition of the system of quality criteria kq, is evaluated by experimental results or the method of expert estimates [1].

2 Experimental Study

The investigations have used a dry building mixtures (DBM) for performing restoration and finishing works [2]. During the experimental studies were used formulations shown in Table 1. To improve the durability of coatings in their formulation administered filler based on calcium hydrosilicates (HSCs) obtained in the synthesis of sodium waterglass addition in the presence of precipitants, followed by drying the precipitate at a temperature 105-300°C and grinding. As the precipitant used calcium chloride in an amount of 30-50% by weight of sodium silicate in the form of 7.5-15% solution [3].

The quality of the DBM and the coatings on their basis was estimated in terms of physical and mechanical (group 1), the technological properties (group 2) and the properties that characterize the quality class appearance coatings (group 3).

Table 1: Quality indicators and the unit cost of finishing compositions

№	The ratio of main components	Physical and mechanical properties			Technological properties			Aesthetic properties	The unit cost of, rub./ 100 g
		Compressive strength MPa	Adhesion strength, MPa	Coefficient of permeability, mg / (m • h • Pa)	Water-holding capacity. %	Drying time to degree 5 min	Viability hour	Grade quality appearance coatings	
1	Lime - 18.9%, calcium hydrosilicates - 0.95%, quartz sand - 59.53%, C-3 - 0,14%, Neolith - 0,63%, water - 19.85%	3,05	0,72	0,05	98,2	15	1,5	V	0.19

2	Lime – 17,26%, calcium hydrosilicates - 2,59%, quartz sand - 59,53%, C-3 - 0,14%, Neolith – 0,63%, water – 19,85%	4,12	0,86	0,05	98,5	15	1,4	V	0.203
3	Lime – 15,26%, calcium hydrosilicates - 4,58%, quartz sand - 59,54%, C-3 - 0,14%, Neolith – 0,64%, water – 19,84%	3,86	0,91	0,063	98,7	15	1,1	V	0.219
4	Lime – 15,24%, calcium hydrosilicates - 4,57%, quartz sand - 59,45%, C-3 - 0,14%, Neolith – 0,64%, water – 19,81% Pigment Yellow fast light - 0,15%	3,82	0,86	0,06	98,6	15	1,1	V	0.245
5	Lime – 15,14%, calcium hydrosilicates - 4,54%, quartz sand - 59,11%, C-3 - 0,14%, Neolith – 0,63%, water – 19,68%, Pigment Yellow fast light -0,76%	3,76	0,73	0,059	98,5	15	1,2	V	0.254

6	Lime – 15,24%, calcium hydrosilicates - 4,57%, quartz sand - 59,45%, C-3 - 0,14%, Neolith – 0,64%, water – 19,81%, phthalocyanine pigment depths - 0,15%	3,46	0,67	0,06	98,3	15	1,2	V	0.35
7	Lime – 15,14%, calcium hydrosilicates - 4,54%, quartz sand - 59,11%, C-3 - 0,14%, Neolith – 0,63%, water – 19,68%, phthalocyanine pigment depths - 0,76%	3,32	0,53	0,058	98,2	15	1,3	V	0.392

Dedicated criteria (properties) are grouped in the GCQ to the following:

$$Z = \alpha_1 \cdot K_{фм} + \alpha_2 \cdot K_{тех} + \alpha_3 \cdot K_{эст} = \alpha_1 \sqrt[3]{k_{пр} k_{п} k_{адг}} + \alpha_2 \sqrt[3]{k_{в} k_{ж} k_{w}} + \alpha_3 k_k \quad (3)$$

where $K_{фм}$ - coefficient characterizing the physical and mechanical properties (compressive strength, adhesive strength, water vapor transmission rate), calculated by the formula $K_{фм} = \sqrt[3]{k_{пр} k_{п} k_{адг}}$

$K_{тех}$ - coefficient characterizing the technological properties (drying time of the material to the point of "5" at (20 ± 2) ° C and the viability of the finish coat material, water-holding capacity), which is calculated by the formula $K_{тех} = \sqrt[3]{k_{в} k_{ж} k_{w}}$

$K_{эст}$ - coefficient characterizing the quality grade appearance;

$\alpha_1, \alpha_2, \alpha_3$ - weighting coefficients

$k_{пр}$ - weighting coefficients

$k_{п}$ -	criterion of compressive strength
$\text{k}_{адг}$ -	criterion vapor permeability
$\text{k}_{адг}$ -	adhesive strength test
$k_{в}$ -	criterion drying time to degree 5;
$k_{ж}$ -	criterion of viability when stored in open containers;
k_{w} -	criterion of water-holding capacity
k_{k} -	criterion-class quality appearance

Establishment of weights for each of this group of criteria was performed by expert judgment. As a measure of the consistency of experts used the coefficient of concordance W. As a result of calculations the following values of the weighting coefficients physico-mechanical (α_1), technological properties (α_2) and properties that characterize the quality class appearance coatings (α_3): $\alpha_1 = 0{,}5, \alpha_2 = 0{,}25, \alpha_3 = 0{,}25$ The coefficient of concordance was W = 0 94 that allows you to mark a sufficiently high consistency of expert opinion and proceed to further calculations. Here n=7, l=3, p=7, m=3.

To transfer performance properties DBM adopted the method of scaling using Harrington function [4, 5]. Value was calculated for all compositions indicated in table 1.

We introduce a parameterization of the coefficients $K_j = K_j(x_1,...,x_n)$ that depend on the compositions of the unit cost of compositions:

$$S = \sum_{i}^{n} c_i x_i \tag{4}$$

Then $K_j = K_j(S)$ and $Z = Z(K_1(S),...,K_l(S))$.

Thus, all expressions will depend on the value of the parameter S. We solve the optimization problem of the generalized criterion of quality, taking into account cost, determining the value of S_0 by the formula (4), in which Z has a maximum value Z_0. The corresponding structure is considered optimal.

3 Results

Figure 1 shows the values of quality DBM, where the x-axis indicates the number of compositions in accordance with Table 1 for the coefficients Kj, and the ordinate shows the scale of values for the corresponding CSS.

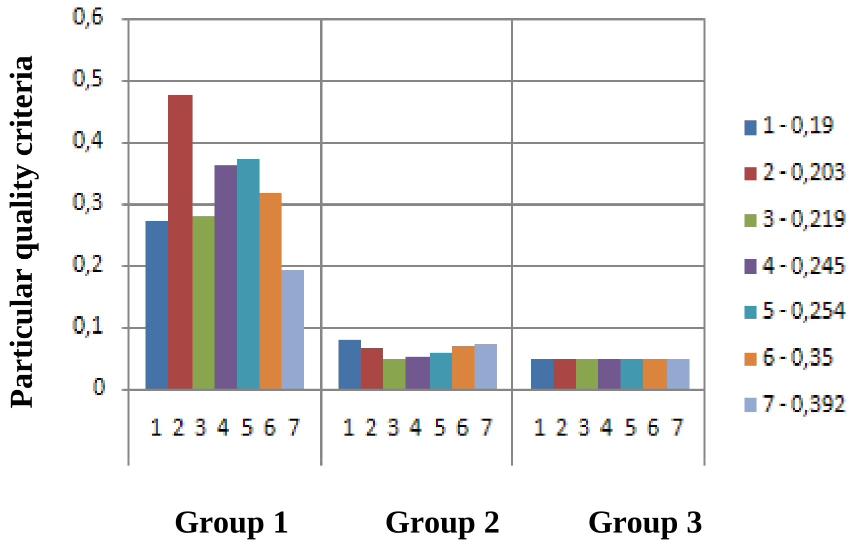

Figure 1: Dependence of coefficient groups K of the cost will be

Figure 2 presents the GCQ calculated by formula (3) with the CB. As might be expected, the main contribution to the JCC make the physical and mechanical properties of $(k_{адг}, k_{пр}, k_{п})$.Maximum values correspond to the composition of the GCQ (without pigment) with a specific value component 0.206. When administering the formulation to the maximum value of the GCQ pigment is characteristic for CS formulations with equal 0.249.

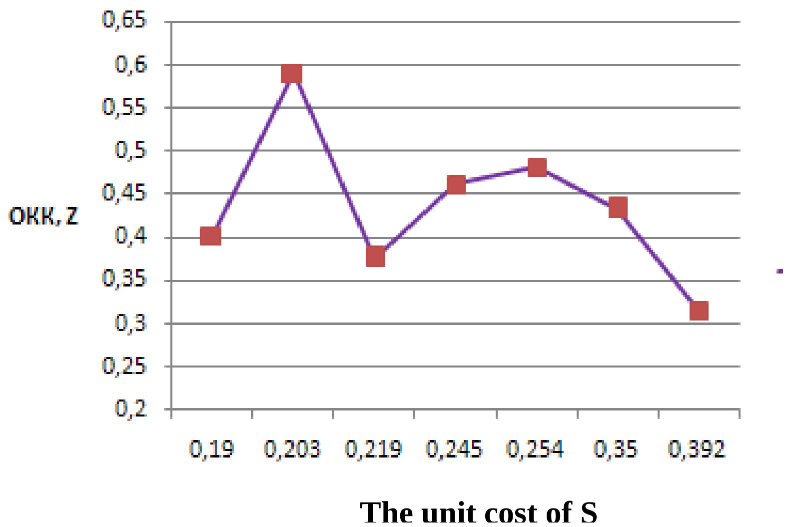

Figure 2: Generalized criterion of the quality of the DBM with regard to the share of the cost of composition.

To find the optimal composition on the requirements of "price-quality" consistently solved two problems:
- Finding the price range within which sought value S_0, corresponding to the maximum GCQ;
- The found value of S_0 are the corresponding values of components, the solution of the linear equation (4) with the restrictions (in this case used or regulatory requirements or the results of experimental studies) methods of quadratic programming. Numerical solution to both problems was in MathCad environment function Minimize [6, 7].

To find the maximum GCQ each of the coefficients K_j from the experimental data was approximated by a quadratic trinomial by the method of least squares (OLS) and the function is used to minimize MathCad environment for finding optimal values of the components. In this case, the optimal composition was obtained with the following contents of the initial components (x_i^0): lime - 15%, calcium hydrosilicates -4,185%, sand - 59,982%, C-3 - 0,136%, Neolith - 0,64%, water - 19.9% , pigment-0.157% and unit cost of 0.*2*49.

4 Discussion

Note that the chosen parameterization OCC CM allows you to get from the expression (3) the formula for the calculation of the increment of the JCC at any selected point in the unit cost of So

$$Z - Z_0 = \left(\frac{\partial Z}{\partial K_1}\right)_0 (K_1 - K_1^0) + ... + \left(\frac{\partial Z}{\partial K_l}\right)_0 (K_l - K_l^0) =$$
$$= \left[\left(\frac{\partial Z}{\partial K_1}\right)_0 \left(\frac{\partial K_1}{\partial S}\right)_0 + ... + \frac{\partial Z}{\partial K_l}\left(\frac{\partial K_l}{\partial S}\right)_0\right] \cdot (S - S_0) =$$
$$= \left[\left(\frac{\partial Z}{\partial K_1}\right)_0 \sum_i^n \left(\cdot \left(\frac{\partial K_1}{\partial X_i}\right)_0 / C_i\right) + ... + \frac{\partial Z}{\partial K_l} \sum_i^n \left(\cdot \left(\frac{\partial K_l}{\partial X_i}\right)_0 / C_i\right)\right] \cdot (S - S_0) \quad (5)$$

Expression (5) allows us to analyze the impact of each factor on the change in the GCQ when changing the unit cost on the size and assess its value to the overall meaning of the GCQ, that is to control the means of achieving conditions - increasing the quality criterion - and thus the quality of the DBM.

Thus, in this paper we propose a new approach to optimize the system "composition-structure-property-value" based on the parameterization of the quality criteria for the unit cost of the compositions, as a solution to an optimization problem with constraints and the possibility of economic optimization.

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Received: October 15, 2014; Published: November 19, 2014