SCIENTIFIC RESEARCH OF THE SCO COUNTRIES: SYNERGY AND INTEGRATION

上合组织国家的科学研究：协同和一体化

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TECHNICAL SCIENCES

ARCHITECTURE

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矿棉节能产品性能与结构研究

STUDY OF PROPERTIES AND STRUCTURE OF MINERAL WOOL ENERGY EFFICIENT PRODUCTS

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摘要。在现代世界中，提高能源效率和降低能源强度对于建筑行业尤其重要，这在很大程度上决定了整个生产的发展。可以通过使用高效的隔热材料和基于它们的产品，特别是矿物纤维产品（基于玻璃或岩棉）来降低能源强度。这些产品的性能受粘合剂的类型和引入方法的显着影响，降低其生产能源强度的方法之一是降低这些产品的热处理温度。

本科学论文中提出的研究目的是分析现有的粘合剂类型和引入方法，旨在降低基于岩棉的产品制造的能源强度。

结果，获得了将固化接触强度与各种因素联系起来的数字模型，并开发了用于解决数字建模正向和逆问题的列线图，并确定了最重要因素的最佳值区间：粘合剂消耗量3.75%;热处理温度为 120-140 oC 时，潜在组分含量在粘结剂质量的3.6% 至 4.0% 范围内。

关键词：岩棉、合成粘结剂、潜在组分、数值模型、分析优化、

Abstract. *In the modern world, increased energy efficiency and reduction of energy intensity are especially important in the construction industry, which largely determines the development of production as a whole. Reduction of energy intensity can be achieved through the use of efficient thermal insulation materials and products based on them and, in particular, mineral fiber products: based on glass or rock wool. The properties of these products are significantly influenced by the type and method of introduction of binder, and one of the ways to reduce the energy intensity of their production is to reduce the temperature of heat treatment of these products.*

The purpose of the research presented in this scientific paper is to analyze the existing types and methods of introduction of binders, aimed at reducing the energy intensity of the manufacture of products based on stone wool.

As a result, a digital model linking the strength of cured contact with varying factors is obtained and a nomogram for solving the forward and inverse problem of digital modeling is developed, as well as optimal intervals of values of the most significant factors are determined: binder consumption 3.75%; content of latent component in the range from 3.6 to 4.0% of the binder mass at the temperature of heat treatment 120-140 ^{o}C.

Keywords: *stone wool, synthetic binder, latent component, numerical model, analytical optimization,*

Introduction

As technological development progresses, environmental and sustainable development issues are becoming increasingly important, and energy efficiency and energy intensity play a key role in various sectors of the economy. In the Russian Federation, measures aimed at increasing energy efficiency and reducing energy intensity in various sectors of the economy are being actively developed and implemented. The application of these measures in construction and the production of building materials is especially important. This is due to the fact that the construction industry is one of the most energy-intensive and at the same time is the locomotive of economic development [1-3].

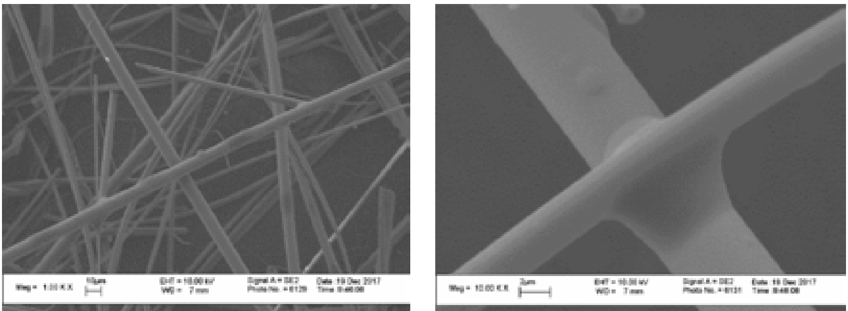
The multi-stage process of producing fibrous thermal insulation materials, including high-temperature melting of mineral components to obtain a mobile melt and its spraying using centrifuges, is completed by mechanical molding of mineral wool products with the introduction of a binder and heat treatment of the mineral wool carpet in a polymerization chamber. These processes are characterized by significant energy costs.

Despite the availability of scientific research in this area, the topic of mineral wool products with reduced technological energy intensity remains insufficiently developed. Existing research and development do not always take into account all aspects related to the production, operation and disposal of such products. In this regard, there is a need for additional research aimed at optimizing technological processes and improving the performance characteristics of mineral wool products [4, 5].

In the context of building insulation technologies, it is important to reduce operating costs and develop new efficient thermal insulation materials with lower energy consumption.

Experiment and results

The properties of mineral wool products and their operational durability depend on three main factors: the properties of mineral fibers, the interweaving of these fibers in the product and the type of synthetic binder. The operational characteristics of fiber from rocks (stone wool) are quite high, during technological processing a volumetric interwoven structure is formed in the product, therefore the most important component in the overall strength structure is the type and properties of the synthetic binder. Mineral wool carpet is a typical example of a chaotic structure stabilized both in time and relative to characteristic parameters. The structure of the fibrous base of the mineral wool carpet is characterized by a significant length of fibers and their intensive interweaving (Fig. 1). The main properties (strength, average density and thermal conductivity) of a mineral wool product depend on the strength of the fiber in the product, on the properties of the fibers (diameter and length), on the number of contacts and the distance between the points of contact of the fibers, the strength of the monolithic contacts (the strength of the carpet). The smaller the fiber diameter, the more fibers are contained per unit volume, and the more points of contact between fibers and the higher the strength of the interwoven structure.



a ***б***

Figure 1. *Structure of the mineral wool layer: a – general plan; b – close-up of the contact of the expected case*

The research was based on the hypothesis that an increase in the strength and operational durability of mineral wool products can be achieved through the use of a low-toxic heat-curing epoxy binder containing latent components (enhancing the adhesion of the binder to the fiber, regulating the curing temperature) under the conditions of forming a cohesive multilayer structure of the mineral wool product.

In the process of implementing the general research plan, an experiment was conducted to determine the dependence of the shear strength of the adhesive joint (U) on the formulation and process parameters. The following were adopted as variable factors: the consumption of the binder X1 (2–4%), the content of the latent component in the composite binder X2 (0.5–5.5%) and the curing temperature of the composite binder X3 (80–140 °C).

Conducting an active experiment, statistical processing of its results and testing statistical hypotheses made it possible to obtain a regression equation (algebraic polynomial) of the following type:

$$У = 7{,}2 + 0{,}6X_1 + 3{,}2X_2 + 1{,}2X_3 + 1{,}0X_2X_3 – 0{,}4X_1^2 – 0{,}5X_3^2 \quad (1)$$

An analysis of the coefficients of the algebraic polynomial allows us to draw a number of conclusions. Firstly, the greatest influence on the strength of the adhesive joint is exerted by the content of the latent component and the temperature of heat treatment. Secondly, the consumption of the binder in the range established by the experimental conditions has the least influence on the strength. Thirdly, there is an optimum for factor X1, which can be determined by the analytical optimization method.

We carry out analytical optimization in several stages:

1). Considering the algebraic polynomial (1) as an algebraic function of three variables, we can find the partial derivative of this function with respect to factor X1:

$$\partial y / \partial X_1 = 0.6 - 0.8X_1 = 0 \rightarrow X_1 = \frac{0.6}{0.8} = 0.75 \quad (2)$$

2). We substitute the optimal value X1 = 0.75 into the algebraic polynomial (1) and obtain the optimized strength function:

$$У = 7{,}4 + 3{,}2X_2 + 1{,}2X_3 + 1{,}0X_2X_3 – 0{,}5X_3^2 \quad (3)$$

3). We determine the natural value of the binder consumption: Bc = 3 + 0,75 = 3,75%

4). We carry out a graphical interpretation of function (3) with an optimal binder consumption of 3.75% (Fig. 2)

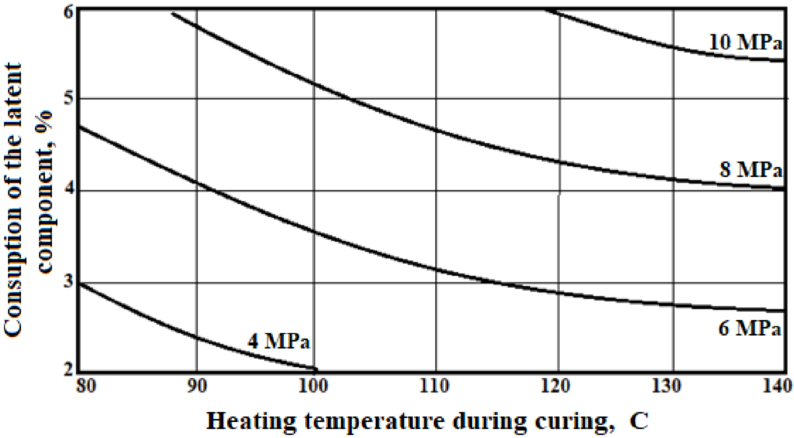


Figure 2. *Dependence of the shear strength of the adhesive joint (at the optimal binder consumption of 3.75%) on the consumption of the latent component in the composite binder and the heating temperature during curing*

The nomogram of the dependence of the adhesive joint shear strength on the latent component consumption in the composite binder and the heating temperature during curing (Fig. 1) allows solving the direct and inverse problems of mathematical modeling. As applied to the experimental conditions, the direct problem consists in determining the strength values based on the values of the variable factors, and the inverse problem consists in determining the values of the variable factors corresponding to the specified strength. As a result of the experiment, it was found that with a low content of the latent component (in the considered biss-phenol technology) in the composite binder, that is, with compositions close to pure epoxy, the shear strength of the adhesive joint is significantly reduced. The combined effect of the latent component consumption and the heating temperature on the contact strength is significant and has a synergistic effect, i.e. it is enhanced with a simultaneous increase in the latent component consumption and an increase in temperature in the intervals established by the experimental conditions. The optimal content of the latent component is in the range from 3.6 to 4.0%, at a heat treatment temperature of 120-140 °C.

Conclusion

The properties of mineral wool products and their operational durability depend on three main factors: the properties of mineral fibers, the interweaving of these fibers in the product, and the type of synthetic binder. The operational characteristics of fiber from rocks (stone wool) are quite high; during technological processing, a volumetric interwoven structure is formed in the product, therefore, the most important component in the overall strength structure is the type and properties of the synthetic binder.

Reducing the energy intensity of manufacturing products based on mineral (including stone wool) is possible both by optimizing the processes of obtaining the mineral fiber itself, and by introducing innovative types of binders that monolithize these fibers during the curing process as a result of polycondensation of these binders. In this regard, the use of synthetic resins that harden at temperatures up to 160 ° C is promising, including with the use of latent components as a catalyst and plasticizer. The studies used a latex binder with a curing temperature of 120 °C.

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