



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

Proceedings of the
International Conference

Date:
December 4

Beijing, China 2024

上合组织国家的科学研究：协同和一体化
国际会议

参与者的英文报告

International Conference
“Scientific research of the SCO
countries: synergy and integration”

Part 2

2024 年 12 月 4 日，中国北京
December 4, 2024. Beijing, PRC

Proceedings of the International Conference
**“Scientific research of the SCO countries: synergy
and integration”** - Reports in English

(December 4, 2024. Beijing, PRC)

ISBN 978-5-905695-82-7

这些会议文结合了会议的材料 – 研究论文和科学工作者的论文报告。它考察了职业化人格的技术和社会学问题。一些文章涉及人格职业化研究问题的理论和方法论方法和原则。

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ISBN 978-5-905695-82-7

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CONTENTS

ECONOMIC SCIENCES

欧亚铁路主要性能特征比较分析

Comparative analysis of key performance characteristics of Eurasian railways
Anufrieva Yulia Valerievna, Antoshkin Anton Alekseevich8

多功能商品与耐用品消费质量的比较定量评估方法（以无人设备为例）

The methodology of comparative quantitative assessment of consumer quality of multifunctional goods and durable goods (using the example of unmanned devices)
Khubaev Georgy Nikolaevich, Poluyanov Evgeniy Vladimirovich, Rodina Olga Valerievna, Streltsova Elena Dmitrievna13

区域均衡发展研究的理论方法

Theoretical approaches to research balanced development of territories
Trofimova N.V......28

区域社会经济体系现代增长点

Modern growth points of the regional socio-economic system
Trofimova N.V......33

区域社会经济发展管理基础

Fundamentals of management of socio-economic development of territories
Trofimova N.V., Mamleeva E.R., Sazykina M.Y......39

海关和交通基础设施是区域发展的一个因素

Customs and transport infrastructure as a factor in regional development
Chapkina Nadezhda Anatolyevna, Razmakhova Sofia Denisovna45

HISTORICAL SCIENCES

论二十世纪五六十年代苏联批发贸易的组织

On the organization of wholesale trade in the USSR in the 50s and 60s of the XX century
Moroz Irina Anatolyevna56

ART HISTORY

从 2D 到 3D——平面设计和品牌塑造的新发展

From 2D to 3D - the new evolution of graphic design and branding
Yaguzina Inna Alexandrovna, Han Bo63

标志的数字化转型：从静态符号到交互式媒体

Digital transformation of signs: from static symbols to interactive media
Yaguzina Inna Alexandrovna, Yang Chenyi69

文化传承与空间设计：传统文化元素在室内设计中的创新运用 Cultural heritage and space design: innovative use of traditional cultural elements in interior design <i>Buchaka Anatoly Nikolaevich, Cui Yiyao, Huang Yuwen</i>	75
平山书光玉堂社区活动中心重新设计（中国安徽省） Redesign of Pingshan Shu Kwong Yutang community activity center (Anhui province, China) <i>Huang Xuanhui, Abbasov Iftikhar Balakishievich</i>	80
苗族文化符号在品牌设计中的运用及形成 Utilization and formation of Miao culture symbols in brand design <i>Wang Wenxuan, Kuleshova Anna Alexandrovna</i>	84
虚拟博物馆作为对幼儿园教师进行方法支持的手段 Miao creativity as a unique art form <i>Wang Wenxuan, Kuleshova Anna Alexandrovna</i>	90
学校人格发展教育环境是初中生成功人格发展的一个因素 Investigating the communication effectiveness of brand design based on elements of clay sculptures of Chinese intangible cultural heritage <i>Zhao Chaobo</i>	95
中国非遗泥塑数字设计转化与品牌视觉形象创新 Digital design translation and visual brand identity innovation for Chinese non-heritage clay sculptures <i>Zhao Chaobo</i>	100
在传统皮影戏基础上的现代装置 Modern installations on the basis of traditional shadow theatre <i>Ouyang Decao</i>	105
现代服装中的中国青铜文化 Chinese bronze culture in modern garments <i>Yang Lidong</i>	109
BIOLOGICAL SCIENCES	
小剂量辐射暴露对公众健康的风险评估 Assessment of the risk to public health of radiation exposure in small doses <i>Rakhimova Natalia Nikolaevna, Zorin Aleksandr Sergeevich, Deligirova Victoria Viktorovna, Ivanova Anastasia Petrovna</i>	112
植物源场化感作用的时空动态 Temporal and spatial dynamics of allelopathic effects of phytogenic fields <i>Scherbina Vitaliy Georgiyvich</i>	119
MEDICAL SCIENCES	
神经网络算法在牙科实践中的应用 Application of a neural network algorithm in dental practice <i>Makedonova Yuliya Alekseevna, Dyachenko Denis Yurievich, Gavrikova Ludmila Mihailovna</i>	126

具有预测咬合关系违规风险的专家系统的开发和应用经验

Experience in the development and application of an expert system for predicting the risk of violations of occlusive relationships

Makedonova Yuliya Alekseevna, Yarygina Elena Nikolaevna,

Dyachenko Denis Yurievich, Gavrikova Ludmila Mihailovna.....134

结节病患者外周血细胞毒性T淋巴细胞亚群组成

Subpopulation composition of cytotoxic T lymphocytes in peripheral blood of sarcoidosis patients

Leushina Polina Alexandrovna, Ses' Tatiana Pavlovna, Baranova Olga Petrovna,

Kudryavtsev Igor Vladimirovich139

TECHNICAL SCIENCES

使用 Flutter 开发用于 RC 管理的跨平台应用程序的方法

Methodology for developing a cross-platform application for RC management using Flutter

Koltygin Dmitry Stanislavovich, Sedelnikov Ilya Andreevich143

矿棉节能制品性能与结构研究

Studies of the properties and structure of mineral wool energy-efficient products

Artemenko Savely Olegovich, Bobrova Ekaterina Yuryevna,

Zhukov Aleksey Dmitrievich.....152

ARCHITECTURE

移动结构的工程支持（来自海运集装箱）：补给帐篷、垃圾、电气套件、隔热材料

Engineering support for mobile structures (from sea containers): water supply, sewerage, electricity, thermal insulation

Yaguzha Inna Alexandrovna, Al'kova Diana Anvarovna,

Smelyansky Maxim Alexandrovich.....158

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著影响，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 °C 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 °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.

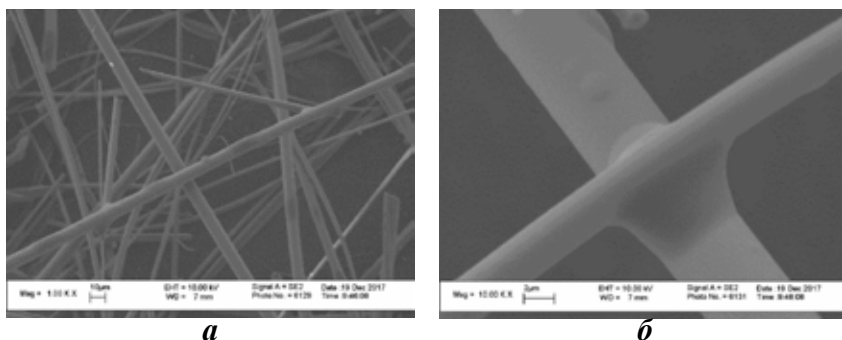


Figure 1. Structure of the mineral wool layer: a – general plan; b – close-up of the contact of the expected case

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:

$$Y = 7,2 + 0,6X_1 + 3,2X_2 + 1,2X_3 + 1,0X_2X_3 - 0,4X_1^2 - 0,5X_3^2 \quad (1)$$

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:

$$\frac{\partial Y}{\partial X_1} = 0,6 - 0,8X_1 = 0 \rightarrow X_1 = \frac{0,6}{0,8} = 0,75 \quad (2)$$

2). We substitute the optimal value $X_1 = 0,75$ into the algebraic polynomial (1) and obtain the optimized strength function:

$$Y = 7,4 + 3,2X_2 + 1,2X_3 + 1,0X_2X_3 - 0,5X_3^2 \quad (3)$$

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)

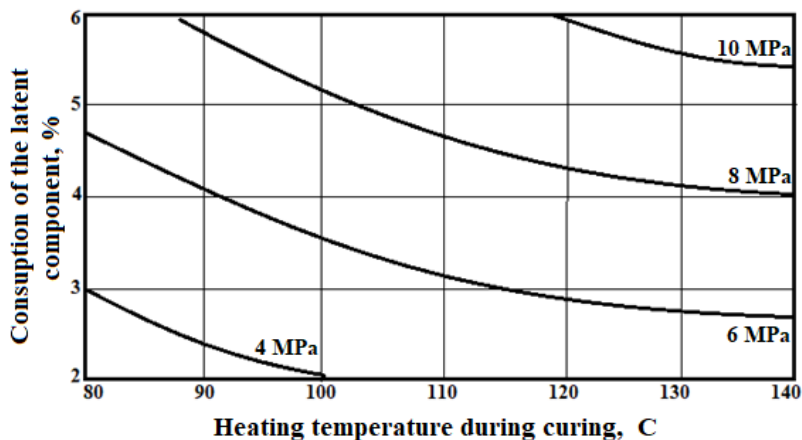


Figure 2. Dependence of the shear strength of the adhesive joint (at the optimal binder consumption of 3.75%) on the consumption of the latent component in the composite binder and the heating temperature during curing

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 bisphenol 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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科学出版物

上合组织国家的科学研究：协同和一体化

国际科学大会的材料

2024 年 12 月 4 日，中国北京

编辑 A. A. Siliverstova

校正 A. I. 尼古拉耶夫

2024 年 12 月 4 日，中国北京
USL。沸点：98.7。 订单253. 流通500份。

在编辑和出版中心印制
无限出版社



