Prospects for utilizing secondary resources in the construction of facilities for various purposes

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Abstract. The objective of this research is to explore potential opportunities for utilizing secondary resources in the road construction, and construction of agricultural facilities, considering the changes in their technical and consumer attributes over the lifespan of used materials and their ecological impact. This study examines the challenges associated with implementing innovative materials, such as fiber-reinforced concrete and low carbon materials in the road and agricultural industry. Taking into account generally accepted indicators for assessing the properties of materials, a method based on a separate analysis of regulatory and methodological support for the construction preparation process was applied. The main tool for influencing the design process is the formalization of requirements for preparing design documentation, which involves the use of innovative building materials. These requirements need to be consolidated in the form of an improved mechanism for introducing innovations, providing for the expansion of possible areas of application of innovative materials, taking into account their technical and cost characteristics. The article is recommended to a wide range of specialists in civil, agricultural and road construction, as well as environmental engineering.

1 Introduction

In recent years, there has been an active update and improvement of designs and technologies for the construction of transport infrastructure facilities. This allows us to simultaneously reduce labor intensity, shorten construction time, improve the quality, reliability and durability of structures, which is indirectly confirmed by various types of analysis [1,2]. This is facilitated by the production of modernized and efficient building materials and the introduction of technological innovations. Considerable experience has been accumulated indicating that secondary materials and accumulated industrial by-products can also be effectively used in the road sector with appropriate feasibility studies (slag, plastic, polymers, rubber) [3].

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It is known that the leading material in the construction of almost any type of real estate, regardless of its purpose, size, shape and type, is concrete. The use of production waste in effective building materials, such as concrete, solves the issue of reducing construction costs and provides standard indicators for the level of quality of manufactured products. Among the concretes that belong to new types and are actively being introduced in the construction of transport infrastructure, it is worth highlighting fiber-reinforced concrete, the composition of which includes fibrous materials of various types (steel or non-metallic) [4,5,6]. The use of fiber in concrete provides concrete with higher performance in such characteristics as tensile strength, bending, shear, impact and fatigue strength, crack resistance, frost resistance, water resistance, heat resistance and fire resistance. In addition, the distinctive features of fiber-reinforced concrete are high levels of anisotropy and discreteness. The effectiveness of fiber-reinforced concrete is achieved both by the correct combination of the properties of its constituent components, and by the correct company policy on the use of innovative materials [7].

Research activities focusing on a comprehensive investigation of the properties of dispersed reinforced concrete are being actively pursued in many countries [8]. By studying international practices, taking inspiration from the methods described in references [9-11], it is evident that fiber-reinforced concrete is commonly employed in various practical applications. These include the construction of equipment foundations that experience dynamic loads, road construction for bridges, roads, and tunnels, the development of offshore platforms, the construction of industrial building floors, and tunnel linings [12,13].

The use of fiber-reinforced concrete in Russia is not currently as widespread as abroad, but potentially has great prospects. In industrial and civil construction, polymers reinforced with various types of fiber are used in enclosing elements of buildings and structures. The cluster use of fiber-reinforced concrete in structures such as walls, partitions, ceilings, coatings, floors, special-purpose structures, pipes, channels, trays, tongues, rings and tubings has good performance properties [12]. New materials have proven themselves positively in road construction during the implementation of large projects. They are used as permanent formwork in the construction of bridges, which can significantly simplify and speed up the process of pouring structures. In addition, for bridge deck slabs of different thicknesses and different spans between the main beam trusses, the supporting part can be formwork made of fiber-reinforced concrete. The formwork has good compatibility with concrete, thanks to which it is an integral part of monolithic concrete structures. The degree of strength when exposed to chemicals is also high, which facilitates the possibility of using this material in the construction of waterproof coatings, drainage trays and local treatment facilities [14,15].

2 Materials and methods

In the road sector, self-compacting and fine-grained fiber-reinforced concrete based on metal, polypropylene fiber and industrial waste have wide application prospects. They have the ability to fill the mold even in densely reinforced structures and are compacted under the influence of their own weight, without the use of vibration compaction. This type of concrete reduces construction time, while ensuring high quality surfaces of products, reducing noise levels and additional processing.

The quality indicators of fiber-reinforced concrete depend on the structure and shape of the grains, density, hardness and strength, and depend on both the chemical composition and the mineralogical composition of the filler. The prospect and effectiveness of improving the structure of fiber-reinforced concrete lies in the widespread use of various organic and inorganic additives. Modifying additives affect the processes of hydration and crystallization, i.e., the structure of solid cement stone and change the properties of concrete. The range of additives used is very extensive. The most common are fly ash (ash and slag material - a byproduct of coal combustion), microsilica, metakaolin, which bind calcium oxide hydrate into calcium hydrosilicates during cement hardening. Due to this, the strength and durability of concrete increases significantly. The use of these additives is effective in combination with hyperplasticizers and fibrous materials [16-18].

Experimental studies are necessary to understand the properties of self-compacting fine-grained concrete reinforced with metal, polypropylene fibers, and production waste. These studies help determine the fundamental laws and processes involved in forming the structure of fiber-reinforced concrete using these materials. Along with this, it is considered highly effective to develop a fiber-reinforced concrete composition with the inclusion of production waste, which has high physical and mechanical characteristics, and to obtain a composition that has mass demand and consumption in the construction market due to the high homogenization of the mixture components [19].

Analysis of data in accordance with technical literature and data obtained as a result of experiments makes it possible to formulate the following conclusions:

– the disadvantages of concrete are low tensile strength and crack resistance, which leads to brittle failure of structures under loads;

– dispersed reinforcement with fibrous materials of various types and sizes helps to improve the strength and deformation characteristics. It is important to take into account that the properties of concrete depend on the length and the length-to-diameter ratio of fibrous materials. The theory is that long fibers with a high length-to-diameter ratio are better than short ones. With increasing fiber length, the effect on the strength properties of concrete as a whole increases. However, with long fibers, the conditions for preparing fiber-reinforced concrete worsen as they are less well distributed in the concrete. In this regard, the condition must be met – the length of the fiber must exceed the double diameter of the largest aggregate. These material properties are often considered not only from the point of view of the design solution effectiveness, but also as part of determining the effectiveness of concluded design and construction contracts [13, 14].

3 Results

A comparison of the cost of manufacturing fiber-reinforced concrete based on metal, polypropylene fiber and fiber from production waste shows that the most economical is fiber-reinforced concrete with production waste – polyamide fiber. In terms of its properties, this fiber-reinforced concrete is not inferior to, and even exceeds, the strength characteristics of fiber-reinforced concrete samples with polypropylene fiber (on average by 5 - 8%) and, according to cost calculations, is cost-effective, since its cost is 30-35% lower than the cost of fiber-reinforced concrete with polypropylene fiber given composition, all other conditions being equal. Fiber-reinforced concrete with metal fibrous materials has high strength characteristics and high cost compared to conventional concrete. Despite the high cost of this type of fiber-reinforced concrete, it will be in demand due to its high physical and mechanical properties. And the high cost of such fiber-reinforced concrete is compensated by the durability of the material. Based on research findings, it has been demonstrated that utilizing industrial waste in the production of fiber-reinforced concrete can lead to cost savings without compromising the material's strength properties (as shown in Table 1).

An analysis of foreign and domestic experience has shown that road construction is one of the promising areas for recycling ash and slag waste. The fiber-reinforced concrete obtained with their help can be used in the design of not only various service facilities and road infrastructure, but also in the design and selection of road pavement structures with cement concrete pavements or asphalt concrete pavements on a concrete base.

Table 1. Comparative characteristics of the material

No.	Fiber quantity, kg/m^3	Tensile strength, MPa		Cost, RUB
		When compressed	When bending	
C:S= 1:2				
Metal fiber				
1	80	46.8	7.3	14884.2
2	110	47.4	7.7	17162.4
3	150	50.1	7.9	20390.5
Polypropylene fiber				
4	8	46.1	7.1	10178.6
5	10	45.3	7.0	10939.5
Polyamide fiber				
6	7	50.3	7.5	7050.2

We believe that the feasibility and effectiveness of the decisions made should be assessed by technical and economic comparison of design solutions for given conditions of work only taking into account their compliance with current regulatory documents.

To ensure widespread introduction of innovative building materials in the field of road construction, it is necessary:

- create and subsequently promptly update their register, including secondary materials and industrial by-products;
- create a complete information base of suppliers and manufacturing (receipt) technologies;
- update regulatory documents regulating the processes of introducing innovations in the road industry;
- obtain certificates of compliance with the requirements of technical regulations, standards, codes of practice and international treaties.

A thorough analysis of industry investment project audits indicates a positive trend in the implementation of a diverse range of innovative construction resources. This trend emerged following the introduction of standardized requirements for innovative materials, including secondary and by-products of industry, as well as the incorporation of fundamental principles of materials science into methodological documents. The decrease in inaccurately determined building material requirements suggests that cost justifications have become more transparent and readily available to developers.

4 Conclusion

Continuous monitoring of the innovation implementation processes in the road industry highlights the urgent need to expand the utilization of new construction materials on a larger scale. However, the current volume of innovation is hindered by the inadequacy of existing regulatory documents and bureaucratic restrictions.

The utilization of secondary materials derived from recycling industrial waste extends beyond the mere conservation of material resources, including non-renewable ones. It is driven by the imperative to address environmental safety concerns for the population, particularly during the transition from a traditional linear economic model to a more sustainable circular economy model. In the road sector, there are several promising areas for the application of secondary resources. These include the production of concrete and concrete products, aggregates, construction of road base layers, soil stabilization, incorporation of additives in asphalt concrete mixtures, and manufacturing of de-icing materials to combat winter slipperiness.

Continued systematic enhancement of the innovation management mechanism, enabling the implementation of new design solutions with utmost efficiency, will facilitate the optimal utilization of available construction resources not only during the construction phase but also throughout the entire life cycle of the built facility. It is evident that the early stages of project development bear the greatest responsibility for the effectiveness of the construction resources employed. The endeavors undertaken by industry experts in this regard are driving positive transformations, ultimately representing a pivotal characteristic of the ongoing stage of project management evolution in the road industry.

Proposals for systematizing the content of design materials during the pre-design stage, especially regarding the incorporation of innovative materials, aim to enhance the rationality of design decisions, decrease construction costs, and ultimately elevate overall project quality. By including resource support sections, construction timeframe descriptions, and considerations of the commercial environment as mandatory components, the foundation for precise cost calculations in future construction projects is established. Improving the quality of investment project justifications is key to achieving success in expanding the scope and scale of implementing industry innovations.

References

1. Lie-Jane Kao, Cheng-Few Lee, Tzu Tai, Handbook of Financial Econometrics and Statistics, pp. 2461-2476 (2014) https://doi.org/10.1007/978-1-4614-7750-1_89
2. Shea D. Chen, E. B. Andrew, A Generalized Black–Litterman Model (Taiwan, National University of Singapore, 2020) https://doi.org/10.1287/opre.2019.1893
3. V.V. Soloviev, A.P. Korchagin, Vestnik MGSU **15(4),** 605-616 (2020)
4. R. Prakash, N. Divyah, S. Srividhya, S. Avudaiappan, M. Amran, S. Naidu Raman, P. Guindos, N.I. Vatin, R. Fediuk, Materials **15(12),** 4272 (2022). DOI: 10.3390/ma15124272
5. S.V. Klyuev, A.V., Klyuev N.I. Vatin, Magazine of Civil Engineering, **84 (8),** 41 – 47 (2018). DOI: 10.18720/MCE.84.4
6. G., Murali S.R. Abid, M. Amran, R. Fediuk, N. Vatin, M. Karelina, Crystals, **11 (7),** 720 (2021). DOI: 10.3390/cryst11070720.
7. P. Adamko, Jan Chutka, SHS Web of Conferences Globalization and its Socio-Economic Consequences, Zilina, Slovak Republic (2020) https://doi.org/10.1051/shsconf/20207405002
8. Yu. Cheng, Hai Hu, Open Journal of Business and Management **08(02),** 32-44 (2020) https://doi.org/10.4236/ojbm.2020.82025
9. S. Donnelly, Jay Verkuilen, Journal of Memory and Language **94,** 28-42 (2017) https://doi.org/10.1016/j.jml.2016.10.005
10. H. Mathar, et.al, Built Environment Project and Asset Management **9(5),** 29-33 (2020) https://doi.org/10.1108/BEPAM-07-2019-0057
11. S. Khandelwal, Dh. Kumar, CoDS Proceedings of the 7th ACM IKDD CoDS and 25th COMAD, pp. 204–208 (2020) https://doi.org/10.1145/3371158.3371187
12. Acta Obstet, Gynecol Scand 99, 145–146 (2020) https://doi.org/10.1111/aogs.13776
13. A. Charehzehi, et.al, International Journal of Engineering Business Management **9,** 184797901774625 (2019) https://doi.org/10.1177/1847979017746257

14. Yu Zhang, et.al, Journal of Oil and Gas Technology **41(06),** 39-47 (2019) https://doi.org/10.1007/978-981-13-0107-0_109
15. B. Aarup, *Fibre Reinforced High Performance Concrete for Precast Applications*, in Proceedings of the Second International Symposium on Prefabrication, 17 – 19 May 2000, Helsinki, Finland, Concrete Association of Finland, pp. 173 – 178
16. V. Bindiganvile, et.al, ACI Materials Journal **99(6),** 543 – 548 (2002)
17. T. Uzawa, et al, Proceedings of the First FIB Congress, Osaka, 2002
18. K. Wille, et.al, Concrete International **33(9),** 35 – 41 (2011)
19. K. Wille, G. Parra – Montesinos, ACI Materials Journal **109(3),** 379 – 388 (2012)