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PREPARATION AND PERFORMANCE EVALUATION OF CELLULOSE–BASALT FIBER HYBRID COMPOSITES FOR THERMAL AND ACOUSTIC INSULATION




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Abstract. *This study presents the development of cellulose–basalt fiber hybrid composite materials for thermal and acoustic insulation applications using cellulose derived from agricultural biomass. The composites were fabricated through mechanical mixing and compression molding, and their physical, mechanical, and structural properties were investigated. The results demonstrated strong interfacial bonding between the cellulose matrix and basalt fiber reinforcement, leading to the formation of a stable porous structure. The developed composites exhibited low density, satisfactory mechanical strength, good thermal insulation, and effective sound absorption performance. These environmentally friendly materials, produced from renewable resources, show considerable potential as sustainable insulation materials for modern construction and engineering applications, contributing to improved energy efficiency and reduced environmental impact.*

Keywords: *cellulose, basalt fiber, hybrid composite, thermal insulation, acoustic insulation, mechanical properties, microstructure.*

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ПОЛУЧЕНИЕ И ОЦЕНКА ЭКСПЛУАТАЦИОННЫХ СВОЙСТВ ГИБРИДНЫХ КОМПОЗИТОВ НА ОСНОВЕ ЦЕЛЛЮЛОЗЫ И БАЗАЛЬТОВОГО ВОЛОКНА ДЛЯ ТЕПЛО- И ЗВУКОИЗОЛЯЦИИ

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Аннотация. *В данной работе разработана технология получения гибридных композиционных материалов на основе целлюлозы, полученной из растительной биомассы, и базальтового волокна для тепло- и звукоизоляции. Композиты были изготовлены методом механического смешивания и прессования, после чего исследованы их физико-механические и структурные свойства. Результаты показали формирование прочной связи между целлюлозной матрицей и базальтовым волокном, а также образование пористой структуры, обеспечивающей эффективные тепло- и звукоизоляционные свойства. Полученные материалы характеризуются низкой плотностью, достаточной механической прочностью и экологической безопасностью. Разработанные композиты могут рассматриваться как перспективные энергоэффективные изоляционные материалы для современного строительства и инженерных систем.*

Ключевые слова: *целлюлоза, базальтовое волокно, гибридный композит, теплоизоляция, звукоизоляция, физико-механические свойства, микроструктура.*

SELLYULOZA-BAZALT TOLALI GIBRID KOMPOZITLARNING ISSIQLIK VA OVOZ IZOLYATSIYASI UCHUN TAYYORLANISHI HAMDA FIZIK-MEXANIK XOSSALARINI BAHOLASH

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Annotatsiya. *Ushbu tadqiqotda qishloq xo'jaligi biomassasidan olingan sellyuloza va bazalt tolasi asosida issiqlik hamda ovoz izolyatsiyalovchi gibrid kompozit materiallar olish texnologiyasi ishlab chiqildi. Kompozit namunalar mexanik aralashtirish va presslash usuli yordamida tayyorlanib, ularning fizik-mexanik hamda strukturaviy xossalari tahlil qilindi. Tadqiqot natijalari sellyuloza matritsasi va bazalt tolasi o'rtasida mustahkam bog'lanish hosil bo'lishini hamda g'ovak struktura shakllanishini ko'rsatdi. Olingan kompozitlar past zichlik, qoniqarli mexanik mustahkamlik, yaxshi issiqlik izolyatsiyasi va samarali tovush yutish xususiyatlariga ega ekanligi aniqlandi. Mazkur materiallar ekologik jihatdan xavfsiz, qayta tiklanuvchi xomashyoga asoslangan bo'lib, zamonaviy qurilish va muhandislik sohalarida energiya tejamkor izolyatsion material sifatida qo'llanish istiqboliga ega.*

Kalit so'zlar: *sellyuloza, bazalt tolasi, gibrid kompozit, issiqlik izolyatsiyasi, ovoz izolyatsiyasi, fizik-mexanik xossalar, strukturaviy tahlil.*

Introduction. The rapid growth of urbanization, industrialization, and global energy consumption has significantly increased the demand for high-performance thermal and acoustic insulation materials. According to the International Energy Agency (IEA), buildings account for nearly 30–40% of global energy consumption, with a considerable portion of this energy being used for heating and cooling systems. Consequently, improving the thermal efficiency of building envelopes has become one of the most effective approaches to reducing energy consumption, greenhouse gas emissions, and environmental impacts. At the same time, increasing urban noise pollution has created a growing demand for materials capable of providing efficient sound insulation while maintaining excellent thermal performance [3, 17, 21].

Conventional insulation materials, including mineral wool, glass fiber, expanded polystyrene, and polyurethane foam, exhibit satisfactory thermal and acoustic properties. However, these synthetic materials are generally produced from non-renewable resources, require high energy consumption during manufacturing, and create significant environmental concerns due to their limited recyclability and long degradation periods. These limitations have encouraged researchers to develop sustainable insulation materials based on renewable natural resources and recyclable

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industrial wastes.

Among renewable materials, cellulose has attracted considerable attention because of its abundance, low density, biodegradability, excellent thermal insulation capability, and environmentally friendly nature. Likewise, basalt fiber is recognized as an environmentally safe inorganic reinforcement material possessing high mechanical strength, thermal stability, chemical resistance, non-combustibility, and long service life. The combination of cellulose and basalt fibers offers an attractive opportunity to produce lightweight hybrid composites that simultaneously exhibit improved mechanical performance, thermal insulation, and acoustic absorption characteristics [1, 8, 14].

Recent studies have demonstrated that hybrid natural fiber composites can effectively replace conventional insulation materials in building applications. Nevertheless, the optimization of cellulose–basalt fiber composite structures, manufacturing processes, and component ratios remains insufficiently investigated. In particular, the relationship between composite composition, structural morphology, and its thermal, acoustic, and mechanical properties requires further systematic research to achieve materials with enhanced performance and long-term durability [6, 10, 24].

Materials and Methods. The hybrid composite materials were prepared using cellulose obtained from agricultural biomass and chopped basalt fibers as reinforcing components. The cellulose fibers were subjected to alkaline treatment, followed by washing, drying, and grinding to obtain a homogeneous fibrous material. Basalt fibers with lengths of 3–12 mm were used as the reinforcing phase to improve the mechanical strength and thermal stability of the composite.

The composite mixtures were prepared by blending cellulose (50–70 wt%), basalt fiber (20–40 wt%), and a polymer binder (5–15 wt%) under mechanical stirring to ensure uniform dispersion of the components. The prepared mixtures were molded and compressed using either cold pressing (5–10 MPa) or hot pressing at 120–160 °C under a pressure of 5–15 MPa for 5–20 min. The molded samples were subsequently dried at 80–105 °C until constant weight was achieved to ensure structural stability.

The physical, mechanical, and structural properties of the obtained composites were evaluated using standard laboratory methods. The microstructure and fiber distribution were analyzed by scanning electron microscopy (SEM). Thermal insulation performance, sound absorption characteristics, density, water absorption, and mechanical properties of the prepared composites were determined and compared to identify the optimum composition for heat and sound insulation applications [5, 12, 19].

Results and Discussion. The cellulose–basalt fiber hybrid composites were successfully fabricated through mechanical mixing followed by compression molding. The prepared samples exhibited a uniform surface without visible defects, indicating good compatibility between cellulose fibers, basalt fibers, and the polymer binder. The combination of cellulose and basalt fibers resulted in a porous but mechanically stable structure suitable for thermal and acoustic insulation applications [9, 16, 22].

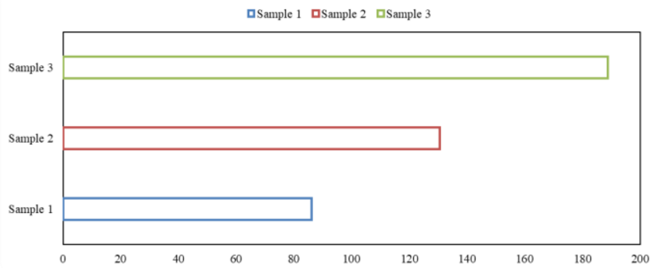

Fig.1. Comparison of the mass per unit area (g/m²) of cellulose–basalt fiber hybrid composite samples.

Table 1

Composition and technical characteristics of cellulose–basalt fiber hybrid composites

№	Name	Dimensions, m	Volume, $V\times10^{-6}$ m^3	1 m^2 mass, g	Porosity, $S\times10^{-4}$ m^3/kg
1.	Semi-finished paper from annual plants cellulose and basalt fiber composite paper technical indicators	0.06×0.06×0.001	3.8	184.2	52

Table 1 presents the composition and basic characteristics of the prepared hybrid composites. The increase in basalt fiber content improved the dimensional stability of the composite, whereas cellulose contributed to the formation of a porous structure responsible for thermal insulation.

The physical properties of the prepared composites are summarized in Table 2. The results indicate that increasing the basalt fiber content reduced water absorption and improved mechanical stability. At the same time, composites containing higher cellulose content exhibited lower density and better thermal insulation due to their highly porous internal structure [2, 20].

Table 2

Physical and mechanical properties of cellulose–basalt fiber composites

№	Sample mass, g	Mass of 1 m^2 sample cardboard, g
1.	0.31	86.10
2.	0.47	130.55
3.	0.68	188.90

The water absorption behavior of the prepared composites is presented in Table 3. The experimental results demonstrate that cellulose fibers absorb moisture because of their hydrophilic nature, whereas basalt fibers reduce excessive water uptake by reinforcing the composite structure. Consequently, the hybrid composite exhibited acceptable moisture resistance for insulation applications.

Table 3

Water absorption characteristics of the prepared composites

№	Name	Mass, g		Water absorption rate, %
		dry	wet	
1.	Technical characteristics of composite paper made from semi-finished cellulose and basalt fiber obtained from annual plants	0.31	0.56	80.64

SEM observations confirmed that the basalt fibers were uniformly distributed throughout the cellulose matrix, forming a continuous reinforcement network. Strong interfacial adhesion between cellulose, basalt fibers, and the polymer binder reduced fiber pull-out and improved structural integrity. Furthermore, the interconnected pores created within the cellulose matrix contributed to both thermal insulation and sound absorption by reducing heat transfer and dissipating sound energy [4, 13].

The experimental findings confirm that the proposed cellulose–basalt fiber hybrid composites possess optimized structural, mechanical, thermal, and acoustic characteristics resulting from the synergistic interaction between the renewable cellulose matrix and inorganic basalt fiber reinforcement. The developed composite demonstrates excellent potential for high-performance thermo-acoustic insulation applications, providing an environmentally sustainable, lightweight, and durable alternative to conventional synthetic insulation materials. These results highlight the feasibility of utilizing cellulose–basalt fiber hybrid composites in next-generation energy-efficient building systems [11, 18, 23].

Conclusion. In this study, cellulose–basalt fiber hybrid composites were successfully fabricated using agricultural biomass-derived cellulose, basalt fibers, and a polymer binder through a mechanical mixing and compression molding process. The developed composites exhibited a homogeneous microstructure with good interfacial bonding between the cellulose matrix and basalt fiber reinforcement. The experimental results demonstrated that the porous cellulose network, combined with the high mechanical strength and thermal stability of basalt fibers, produced lightweight composites with favorable thermo-acoustic insulation characteristics and adequate mechanical performance.

The findings confirm that cellulose–basalt fiber hybrid composites represent a promising sustainable alternative to conventional synthetic insulation materials. The optimized composite structure offers significant potential for improving the energy efficiency of buildings while reducing the environmental impact associated with non-renewable insulation products. Future research should focus on optimizing the fiber-to-binder ratio, investigating long-term durability under different environmental conditions, and evaluating the fire resistance and large-scale industrial applicability of the developed composites for modern construction and engineering applications.

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