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PRODUCTION OF ECO-FRIENDLY AND SUSTAINABLE COMPOSITE MATERIALS FROM CELLULOSE-BASED WASTE

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Abstract. Solid municipal waste management has become a major global environmental issue due to the accumulation and decomposition of organic materials, which can lead to soil, water, and air pollution. This study focuses on the sustainable utilization of municipal waste through the production of wood-plastic composites (WPCs) using locally available wood and plastic waste. Waste materials, including polyethylene bags, branches, twigs, and leaves, collected from landfills in Tashkent Region were processed through washing, extrusion, and hot pressing to produce WPC samples. The effects of different types and compositions of wood waste on the physical and mechanical properties of WPCs were investigated under natural weathering conditions in the Gazalkent district for six months. The experimental results showed that increasing the amount of walnut wood flour and adding 6% MAPPS (maleic anhydride-grafted polypropylene) improved the interfacial adhesion, tensile strength, and hardness of the composites. However, prolonged exposure to natural weathering led to the formation of microcracks, resulting in a gradual decrease in the modulus of rupture and elasticity. Overall, the study confirms that solid municipal waste can serve as a valuable raw material for the production of environmentally friendly WPCs, offering a promising solution for reducing landfill accumulation and providing durable materials for outdoor construction applications such as decking, fencing, and cladding.

Keywords: wood-plastic composites (WPCs), cellulose-based waste, solid municipal waste, wood waste.

Annotatsiya. Qattiq maishiy chiqindilarni boshqarish organik materiallarning to'planishi va parchalanishi natijasida tuproq, suv va havoning ifloslanishiga olib kelishi mumkinligi sababli global ekologik muammolardan biriga aylangan. Ushbu tadqiqot mahalliy yog'och va plastmassa chiqindilaridan foydalanib, yog'och-polimer kompozitlar (WPC) ishlab chiqarish orqali maishiy chiqindilardan barqaror foydalanishga qaratilgan. Toshkent viloyatidagi chiqindi poligonlaridan yig'ilgan polietilen paketlar, shoxlar, novdalar va barglardan iborat chiqindilar yuvish, ekstruziya va issiq presslash jarayonlari orqali qayta ishlanib, WPC namunalari tayyorlandi. Tabiiy ob-havo sharoitida olti oy davomida Gazalkent tumanida yog'och chiqindilarining turli turlari va tarkiblarining WPC materiallarining fizik-mexanik xususiyatlariga ta'siri o'rganildi. Tajriba natijalari yong'oq yog'ochi uning miqdorini oshirish va 6% MAPPS (malein angidrid bilan payvandlangan polipropilen) qo'shish kompozitlarning fazalararo yopishishini, cho'zilishdagi mustahkamligini va qattiqligini yaxshilaganini ko'rsatdi. Biroq tabiiy ob-havo ta'sirining uzoq davom etishi mikrodarzlarning hosil bo'lishiga olib kelib, egilishdagi mustahkamlik moduli va elastiklik modulining asta-sekin pasayishiga sabab bo'ldi. Umuman olganda, tadqiqot qattiq maishiy chiqindilar ekologik toza WPC materiallarini ishlab chiqarish uchun qimmatli xomashyo bo'lib xizmat qilishi mumkinligini tasdiqlaydi. Bu esa chiqindi poligonlarida to'planishni kamaytirish hamda decking, to'siqlar va qoplama kabi tashqi qurilish sohalari uchun mustahkam materiallar olishning istiqbolli yechimini taklif etadi.

Kalit so'zlar: yog'och-polimer kompozitlar (WPC), selluloza asosidagi chiqindilar, qattiq maishiy chiqindilar, yog'och chiqindilari.

Аннотация. Управление твёрдыми бытовыми отходами стало одной из важнейших глобальных экологических проблем, поскольку накопление и разложение органических материалов может приводить к загрязнению

почвы, воды и воздуха. Настоящее исследование посвящено устойчивому использованию бытовых отходов посредством производства древесно-полимерных композитов (WPC) из местных древесных и пластиковых отходов. Отходы, включая полиэтиленовые пакеты, ветви, прутья и листья, собранные на полигонах Ташкентской области, были переработаны с применением мойки, экструзии и горячего прессования для получения образцов WPC. В течение шести месяцев в условиях естественного атмосферного воздействия в Газалкентском районе исследовалось влияние различных видов и составов древесных отходов на физико-механические свойства WPC. Экспериментальные результаты показали, что увеличение содержания муки из древесины грецкого ореха и добавление 6% MAPPs (полипропилена, привитого малеиновым ангидридом) способствовали улучшению межфазной адгезии, прочности при растяжении и твёрдости композитов. Однако длительное воздействие естественных погодных условий привело к образованию микротрещин, что вызвало постепенное снижение модуля прочности при изгибе и модуля упругости. В целом исследование подтверждает, что твёрдые бытовые отходы могут служить ценным сырьём для производства экологически безопасных WPC, предлагая перспективное решение для сокращения накопления отходов на полигонах и получения долговечных материалов для наружных строительных применений, таких как настилы, ограждения и облицовка.

Ключевые слова: древесно-полимерные композиты (WPC), отходы на основе целлюлозы, твёрдые бытовые отходы, древесные отходы.

INTRODUCTION

Solid municipal waste (SMW) is one of the most pressing environmental problems associated with modern urbanization. It is generated daily in residential areas, workplaces, and public facilities and, when improperly managed, poses serious risks to the environment and human health. Accumulated waste that remains stagnant in landfills or permanent storage sites undergoes biological and chemical decomposition under the influence of external factors such as temperature, moisture, and microbial activity. During this decomposition process, various by-products, including greenhouse gases, volatile organic compounds, and leachates, are released into the environment, resulting in soil, water, and atmospheric pollution.

Worldwide, the disposal and recycling of SMW remain serious challenges, and different regions are adopting various strategies to address them. For example, Japan has implemented advanced waste-to-energy approaches in which accumulated waste is incinerated under controlled conditions, and the resulting heat energy is converted into steam and subsequently into electricity while minimizing environmental impacts. In contrast, many developing countries continue to rely on landfills, leading to increased environmental stress and inefficient utilization of valuable waste resources [1-2].

In recent years, increasing attention has been given to converting waste into value-added materials, particularly through the production of wood-plastic composites (WPCs). These composites, produced from mixtures of wood fibers and thermoplastic polymers, offer a sustainable and economically efficient approach to recycling plastic and lignocellulosic waste. Landfills commonly contain large quantities of wood residues such as branches, leaves, and twigs, which can significantly affect the physical and mechanical properties of WPCs due to their surface morphology and chemical composition [3].

Therefore, this study aims to investigate the effects of different types and compositions of wood waste on the properties of wood-plastic composites produced from locally available municipal waste. The research focuses on developing environmentally friendly WPCs that can be used in construction and infrastructure, particularly in applications such as cladding, fencing, roofing, and wall panels, where high resistance to natural weathering and mechanical durability are required. Furthermore, the results may contribute to promoting circular economy principles by reducing waste accumulation in landfills and supporting the sustainable utilization of waste in industrial production [4-5].

LITERATURE REVIEW

Wood-plastic composites have attracted considerable attention as materials capable of combining the advantages of thermoplastic polymers with renewable lignocellulosic resources. Craig M. Clemons described wood-plastic composites as materials containing wood in different forms combined with thermoplastic or thermosetting polymers and emphasized their growing importance in industrial applications.

Daniel F. Caulfield, Craig M. Clemons, Rodney E. Jacobson, and Roger M. Rowell investigated wood-thermoplastic composites and noted that polyethylene (PE), polypropylene (PP), and polyvinyl chloride (PVC) are among the principal thermoplastic matrices used in such materials. Their work also highlighted the use of wood fibers and wood flour as lignocellulosic components in composite production.

Similarly, Craig M. Clemons, Roger M. Rowell, David Plackett, and B. Kristoffer Segerholm examined wood and nonwood thermoplastic composites and emphasized the importance of combining biomass-derived reinforcement with polymer matrices to obtain materials with useful physical and mechanical properties.

RESEARCH METHODOLOGY

The experimental methodology was developed to investigate the possibility of producing wood-plastic composites from locally available municipal plastic and lignocellulosic waste and to evaluate their mechanical performance under natural weathering conditions. The overall experimental procedure consisted of waste collection and preparation, polymer processing, wood-fiber preparation, composite formulation, extrusion, hot pressing, mechanical characterization, and outdoor weathering.

The plastic and lignocellulosic materials used in this study were collected from municipal solid-waste disposal areas in the Tashkent Region. Used polyethylene bags were selected as the primary thermoplastic component, while branches, twigs, leaves, and wood residues were used as lignocellulosic reinforcement. Walnut wood was additionally processed into wood flour for comparison with the mixed plant-waste fraction.

The collected materials were initially sorted manually to remove foreign materials and visible contaminants. The plastic waste was washed thoroughly with water to remove soil, dust, and other surface impurities and was subsequently dried before further processing. The branches and twigs were similarly cleaned and reduced in size to facilitate mechanical processing. The prepared lignocellulosic material was converted into smaller particles and subsequently used as reinforcement in the composite formulation.

Experimental Studies. For the experimental studies, waste materials, including polyethylene bags, wooden branches, twigs, and leaves, were collected from a landfill in Tashkent Region. Before processing, the polyethylene bags were washed with a liquid cleaning solution to remove surface contaminants and rinsed three times with water. After cleaning, the plastic materials were cut into small pieces measuring 0.5-1.5 cm using a cutting machine. These pieces were then processed into granules using an extruder operating at a temperature of 200-225°C. The prepared plastic granules served as the polymer matrix for the production of wood-plastic composites.

Different types of collected wood waste, including branches, leaves, and twigs, were initially dried and converted into wood flour. The plastic granules and wood flour were mixed with pigment additives in a twin-screw extruder. During the extrusion process, the temperature was maintained at 165-185°C, while the screw speed was set at 60 rpm to ensure complete and uniform mixing of the components [6]. The extruded material was prepared for compression molding. For this purpose, the mixture was heated in a hydraulic compression machine at 300-350°C under a pressure of 3.55 MPa for 5-7 minutes. Following the initial heating, the material was molded under a pressure of 6.90 MPa for 15 minutes to ensure densification and uniform density. The molded material was then cooled under the same pressure for an additional 15 minutes to stabilize the structure of the samples. The resulting WPC panels were cut into specimens for the evaluation of their physical and mechanical properties [7].

To evaluate the durability of the composites under outdoor environmental conditions, a natural weathering test was conducted in the Gazalkent district near the Chirchiq River. The prepared samples were placed outdoors around a swimming pool and exposed directly to sunlight, rainfall, and the characteristic humidity of the area. The natural weathering test lasted six months and covered the rainy season from July to December 2024. During the testing period, the average relative humidity (RH) was 82.03%, the total precipitation was 2366.8 mm, and the air temperature ranged from 22.8°C to 34.8°C [8]. The composite samples were analyzed after two, four, and six months of exposure to determine changes in their mechanical and physical properties.

Based on the experimental results, the study demonstrated that solid municipal waste, particularly plastic and wood residues, can be effectively used as raw materials for producing environmentally friendly and durable wood-plastic composites. The composites developed in this study are suitable for outdoor construction applications such as flooring, fencing, roofing, and wall panels due to their resistance to natural weathering and their contribution to waste reduction and environmental sustainability.

ANALYSIS AND RESULTS

The experimental study demonstrated that the physical and mechanical properties of the obtained wood-plastic composites (WPCs) depend significantly on the type and composition of the wood waste used, as well as the concentration of the MAPPS coupling agent. The test results showed that the incorporation of wood flour obtained from walnut waste significantly improved the mechanical strength and elasticity of the composites. Among all the samples, those containing a higher proportion of walnut wood flour exhibited the highest values of tensile strength and modulus of elasticity [9].

The incorporation of 6% MAPPS into the mixture increased the adhesion strength between the polymer matrix and wood particles, resulting in stronger interfacial bonding and improved mechanical stability. At the same time, increasing the MAPPS content enhanced the hardness of the composites, confirming that the coupling agent improved compatibility between the hydrophobic polymer and hydrophilic wood flour. In contrast,

samples containing lower amounts of MAPPS exhibited weaker interfacial adhesion, which resulted in reduced modulus of elasticity and resistance to deformation, demonstrating the importance of the coupling agent in the composite structure.

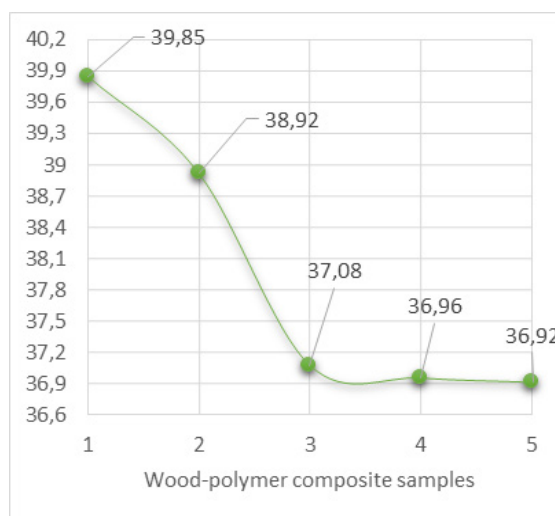


Figure 1. Physical and Mechanical Properties of Wood-Plastic Composites

During the six-month natural weathering test conducted outdoors, gradual changes in the physical and mechanical properties of the composites were observed. Exposure to sunlight, moisture, and precipitation led to the formation of microcracks on the surface of the WPC samples. This resulted in a slight decrease in the modulus of rupture (MOR), modulus of elasticity (MOE), and surface wear strength (SWS). However, the hardness of the composites tended to increase after weathering, which may be associated with surface densification and polymer interlocking under prolonged exposure to environmental conditions [10].

Overall, the results confirmed that increasing the wood flour content from 30% to 60% improves the structural strength of the composites, while also slightly increasing the rate of surface deterioration due to the formation of microcracks. Despite these effects, all WPC samples retained sufficient mechanical strength and durability for outdoor applications. The experimental results indicate that wood-plastic composites produced from solid municipal waste, particularly with optimal ratios of wood flour and MAPPS, can serve as sustainable and weather-resistant materials suitable for construction purposes such as flooring, cladding, fencing, and roofing [11].

These results also demonstrate the practical feasibility of reusing plastic and wood waste to produce new composite materials with high mechanical performance and long-term environmental durability. Thus, the use of solid municipal waste for WPC production represents an effective solution for reducing the accumulation of waste in landfills and supports the development of environmentally friendly materials for the construction industry.

CONCLUSION AND SUGGESTIONS

The experimental studies confirmed that solid municipal waste, particularly plastic and wood residues such as branches and leaves, can be effectively used as raw materials for the production of wood-plastic composites (WPCs). The obtained results showed that the type and amount of wood waste, as well as the concentration of the coupling agent MAPPS, play a decisive role in determining the physical and mechanical properties of the composites. Samples containing a higher proportion of walnut wood flour demonstrated the best overall performance in terms of tensile strength, modulus of elasticity, and hardness. The addition of 6% MAPPS significantly improved adhesion at the interface between the polymer and wood particles, resulting in increased mechanical stability and durability.

Natural weathering tests conducted under actual outdoor conditions for six months showed that although prolonged exposure led to the formation of surface microcracks and a slight decrease in the modulus of rupture and modulus of elasticity, the composites retained sufficient hardness and strength for construction applications. These results indicate that WPCs derived from solid municipal waste possess both mechanical reliability and environmental durability, making them suitable for outdoor applications such as flooring, fencing, roofing, and wall cladding.

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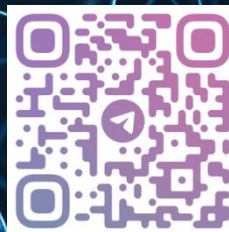
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