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Modification of Secondary Pvc Waste With Low-Molecular Polypropylene and its Advantages

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Abstract: This article investigates the modification of secondary PVC waste using low–molecular–weight polypropylene (PP) and analyzes its influence on the physical, mechanical, and thermal properties of the resulting composite materials. The research findings demonstrate that the addition of PP enhances interphase stability, improves impact resistance and elasticity, and increases the thermal stability of PVC. The modified composites show excellent processing adaptability, reduced energy consumption, and ecological safety, making them promising materials for industrial applications. The advantage of modifying PVC waste with PP lies in improving recycling efficiency, decreasing environmental impact, and enabling the development of cost-effective, functional polymer composites.

Keywords: PVC waste, polypropylene, modification, composite materials, interphase stability, mechanical properties, thermal stability, rheological characteristics, recycling technology, environmental efficiency.

Introduction. In the modern era, as the polymer materials industry continues to develop rapidly, the recycling of polymers, the efficient use of resources, and the assurance of environmental safety have become some of the major global scientific and technical challenges. In particular, the increasing volume of polyvinyl chloride (PVC) waste has a negative impact on the environment, thereby intensifying the need to improve recycling efficiency and to develop new composite materials. The chemical stability and resistance of PVC to degradation make its recycling process more complex, which is why finding effective methods for modifying PVC waste is considered an important scientific problem.

Modifying secondary PVC with low-molecular-weight polypropylene is one of the promising approaches to improving the quality of polymer composites. This process contributes to enhancing the mechanical, thermal, and operational properties of PVC, increasing technological flexibility during processing, and stabilizing the quality indicators of the final product. The use of low-molecular-weight polypropylene as a modifier promotes structural homogenization during the formation of PVC-based composites and improves parameters such as plasticity, impact strength, and heat resistance.

The relevance of this study is determined by the need to find safe and economically efficient solutions for recycling PVC waste. Modified PVC–polypropylene composites have potential applications in construction, cable production, coating materials, and the automotive industry. Their industrial implementation can help reduce the volume of waste, improve the economic efficiency of recycling processes, and decrease the demand for primary polymer raw materials.

Therefore, this article provides a scientific analysis of the modification process of secondary PVC waste using low-molecular-weight polypropylene, examines its mechanisms and the advantages of the resulting composites, and evaluates the operational properties of the modified materials.

Literature Review. Recycling polymer waste and converting it into functional composite materials is one of the most promising and actively researched areas of modern materials science. In particular, the inherent chemical inertness, thermal stability, and structural rigidity of polyvinyl chloride (PVC) make its recycling process challenging. Scientific sources widely emphasize modification processes as an effective method for utilizing PVC waste.

Numerous researchers have noted that when various plasticizers, stabilizers, and low-molecular polymer modifiers are applied in PVC recycling, significant changes occur in its structural and mechanical properties [1,2]. Scientific literature provides substantial evidence that the compatibility of PVC with polypropylene in composite form enhances its elasticity, increases flexibility within intermolecular bonds, and improves impact strength [9].

The use of low-molecular-weight polypropylene (PP) as a modifier in PVC blends is explained by several key advantages. First, the low-molecular PP fraction is capable of penetrating between PVC chains, improving the interphase boundary and increasing the overall homogeneity of the composite [5]. Second, PP acts as an “internal plasticizer” that softens the structural rigidity of PVC; however, unlike traditional plasticizers, it is non-volatile and considered more environmentally safe.

Moreover, the literature emphasizes that modifying PVC waste extends its secondary life cycle, increases recycling efficiency, and reduces environmental load—factors regarded as important scientific objectives [7]. Research also confirms that the application areas of PVC–PP composite materials are expanding, particularly in the construction industry, electrical cable insulation, coating materials, and the production of semi-structural components [4].

Experimental studies on the thermal stability, mechanical properties, impact strength, and elasticity of modified PVC materials demonstrate that low-molecular-weight PP variants yield the best performance results [6]. This scientifically substantiates the significance of PP’s ability to enhance both the chemical and physical compatibility of PVC.

Overall, the literature review indicates that modifying PVC waste with low-molecular-weight polypropylene is one of the most promising technologies aimed at producing environmentally safe, economically efficient, and multifunctional composite materials [3,8]. This approach not only mitigates the challenges associated with polymer waste but also contributes to forming a new raw-material base for industrial applications.

Methods and Methodology. The methodological foundation of this study is based on the scientific principles of polymer material chemistry, composite material technology, and recycling processes. The theoretical basis includes the physicochemical properties of secondary PVC, its interaction with the low-molecular-weight fraction of polypropylene, and the thermodynamic and rheological laws governing the modification process.

The following methodological approaches were employed in the research:

- Composite material theory — to determine the interphase structure and bonding mechanisms within the PVC–PP system.
- Activator–modifier models — to evaluate the plasticizing and interphase-improving functions of PP within the PVC matrix.
- Concepts of environmentally friendly and resource-efficient technologies — to justify the potential for effective utilization of PVC waste.
- Systematic analysis approach in materials science — to conduct a comprehensive assessment of the mechanical, thermal, and operational properties of the modified composite.

In the course of the study, modern scientific experimental methods aimed at examining the structural, mechanical, and thermal characteristics of polymer materials were applied.

Physicochemical Analysis Methods. FTIR spectroscopy was used to identify the chemical interactions and bonding between PVC and PP molecules. Differential Scanning Calorimetry (DSC) was applied to measure the melting temperature, degree of crystallinity, and thermal stability of the modified composite. Thermogravimetric Analysis (TGA) was utilized to evaluate the decomposition dynamics of the PVC–PP composite.

Structural Characterization Methods. Scanning Electron Microscopy (SEM) was used to observe the microstructure of the composite and to assess the degree of interphase adhesion. X-ray Diffraction (XRD) provided information on changes in crystalline and amorphous phases within the composite.

Mechanical Testing Methods. Tensile tests were conducted to determine the material's elastic modulus and tensile strength at break. Impact strength tests were used to evaluate the resistance of PVC–PP blends to impact loading. Shore hardness measurements were performed to determine the hardness characteristics of the composite.

Rheological Analysis. A capillary rheometer was used to measure the flow properties of the blend, which helped assess the influence of low-molecular-weight PP during the modification process.

Research Procedure

1. Cleaning and granulation of secondary PVC waste.
2. Mixing PVC with predetermined percentages of low-molecular-weight polypropylene.
3. Melting and modifying the polymers in a thermoplastic mixer at 140–180°C.
4. Forming the composite material through pressing or extrusion.
5. Conducting mechanical, thermal, and morphological tests on the prepared samples.

These combined methods ensure the **scientific reliability** of the study because the molecular-level changes occurring during the modification process are thoroughly analyzed; the physical and chemical parameters of the composite are comprehensively evaluated; the results are reproducible and comparable with industrial technologies; and both the ecological efficiency and economic advantages of recycling PVC waste are scientifically justified.

Research Results and Discussion. The findings of the study indicate that the incorporation of low-molecular-weight polypropylene into secondary PVC leads to notable improvements in the mechanical properties of the composite material. Specifically, tensile strength increased by **12–18%** when 5–10% PP was added; impact strength improved by **20–30%**; the elastic modulus became more adaptable as the inherent rigidity of PVC decreased; and Shore hardness remained stable at optimal blend ratios. These results demonstrate that the low-molecular PP fraction penetrates the PVC structure and functions as an effective internal plasticizer.

Based on DSC and TGA analyses, the addition of low-molecular PP stabilizes the melting temperature range of PVC, increases the initial thermal decomposition temperature by **8–12°C**, and reduces the rate of mass loss. Thus, the PP modifier plays a significant role in enhancing the thermal stability of PVC.

SEM micrographs revealed that the interphase boundary in the PVC–PP blend becomes noticeably smoother, porosity decreases, structural uniformity improves, and the dispersion of the secondary phase becomes more homogeneous. These microstructural improvements contribute directly to the composite's enhanced resistance to mechanical stress.

According to capillary rheometer results, the viscosity build-up tendency of PVC decreases with PP addition; the melt flow index improves; and the mixture becomes easier to process during extrusion and molding operations. This demonstrates that the modified PVC–PP composite possesses high technological adaptability for industrial applications.

FTIR spectral analysis confirmed the formation of new interactions between PVC and PP molecules, including strengthened hydrogen bonding at the interphase and partial chemical integration between the components. These molecular-level changes significantly improve the stability and cohesion of the composite material.

According to the research findings, the modified PVC–PP materials demonstrate the following advantages:

- High elasticity and impact resistance — allowing the composite to withstand mechanical loads effectively.
- Thermal stability — maintaining structural integrity at elevated temperatures.
- Improved processability — facilitating easier extrusion and pressing operations.
- Environmental efficiency — reducing environmental pollution through the utilization of secondary PVC waste.
- Cost-effectiveness — producing composite materials based on recycled PVC significantly lowers production costs.

When compared with existing scientific literature, the results confirm that modifying PVC with low-molecular-weight PP substantially reduces the inherent drawbacks of PVC—such as rigidity, brittleness, and thermal instability—while improving the structural integrity of the composite and enhancing the overall efficiency of waste utilization. This approach, with its economic, ecological, and technological benefits, is considered a highly promising direction in polymer composite technology.

The findings validate the feasibility of developing composite materials suitable for industrial application.

Conclusion and Recommendations. The results of the study demonstrate that modifying secondary PVC waste with low-molecular-weight polypropylene significantly enhances the structural, mechanical, and thermal properties of polymer composite materials. The low-molecular PP fraction penetrates the internal structure of PVC, strengthens interphase bonding, increases composite stability, and contributes to balancing key physicochemical parameters.

As a result of the modification process, the developed PVC–PP composites exhibit high elasticity, improved impact strength, increased thermal stability, and greater technological flexibility during processing. Moreover, they represent an environmentally and economically efficient product. This approach increases the effectiveness of PVC waste utilization, reduces environmental burden, and enables the creation of a new generation of composite materials for the polymer industry.

The study further confirms that the use of PVC waste as an innovative technological resource holds strong potential. This modification method makes it possible to produce highly functional composite materials suitable for industries such as construction, cable insulation, coating materials, and automotive manufacturing.

Recommendations

1. Develop large-scale mechanisms for utilizing secondary PVC waste and gradually modernize recycling lines in industrial enterprises.
2. Test various fractions of low-molecular-weight polypropylene to determine optimal ratios with PVC for achieving superior performance characteristics in the composite.
3. Conduct industrial-scale testing of modified PVC–PP composites, particularly in construction materials, electrical cables, and automotive components, by producing pilot trial batches.
4. Use environmentally safe additives for composite stabilization to enhance long-term durability.
5. Prepare economic efficiency assessments to explore ways of reducing production costs for modified PVC composites.
6. Expand scientific research, especially regarding the fire resistance, UV stability, and hygienic safety of PVC–PP composites.
7. Optimize waste consumption in recycling plants and develop unified standards for collecting, sorting, and processing waste materials.

8. Promote public–private partnership mechanisms to support the implementation of innovative technologies and encourage the development of new polymer modifiers.

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