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Evaluation of The Influence of Talc Properties on The Physic Mechanical Characteristics of Polypropylene Block Copolymer

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Abstract: This study investigates the effect of talc particle size on the structure–property relationships and physicomechanical performance of polypropylene block copolymer (PP-BC) composites. Particular attention is given to the role of talc as a mineral filler in modifying intermolecular interactions within the polymer matrix and interfacial adhesion between the filler and matrix phases. Composite samples containing talc with different particle size distributions were prepared and evaluated in terms of elastic modulus, yield strength, hardness, Izod impact strength, heat deflection temperature (HDT), and melt flow index (MFI). The results demonstrate that decreasing talc particle size leads to a significant improvement in stiffness and thermal resistance due to enhanced dispersion and increased interfacial surface area. Fine talc particles promote stronger filler–matrix interactions, resulting in improved load transfer efficiency and restriction of polymer chain mobility. As a consequence, the elastic modulus and HDT increase, while the melt flow index decreases, indicating higher melt viscosity. However, excessive reduction in particle size may adversely affect impact strength due to stress concentration effects. Overall, the study confirms that optimizing talc particle size is a key factor in tailoring the balance between stiffness, strength, and toughness in polypropylene-based composites. The findings provide practical guidance for the development of high-performance polymer composites for industrial applications.

Keywords: Polypropylene, talc, elastic modulus, Izod impact strength, heat deflection temperature, interfacial interactions.

Introduction: The rapid development of the modern automotive industry imposes increasingly stringent requirements on materials, particularly in terms of strength-to-weight ratio, durability, thermal stability, and cost efficiency. In this context, polymer composite materials have gained significant attention as alternatives to traditional metals due to their lightweight nature, design flexibility, and ease of processing [1]. Advances in polymer science and materials engineering have enabled the development of high-performance composites through the incorporation of micro- and nanoscale fillers into polymer matrices [2].

The addition of mineral fillers, even in relatively small quantities, can significantly improve the mechanical, thermal, and rheological properties of polymer systems [3]. Among various fillers, talc is widely recognized as one of the most effective and economically viable reinforcing agents for thermoplastic polymers, particularly polypropylene (PP) [4]. Talc possesses a lamellar (plate-like) structure, high aspect ratio, and good thermal stability, which contribute to improved stiffness, dimensional stability, and heat resistance of composite materials [5].

Polypropylene block copolymers (PP-BC) are especially suitable for modification with talc due to their balanced combination of impact resistance and rigidity [6]. These materials are extensively used in automotive applications such as interior panels, dashboards, bumpers, and under-the-hood components, where both mechanical performance and processability are critical [7]. The incorporation of talc into PP-BC matrices leads to reduced shrinkage, enhanced heat deflection temperature (HDT), and improved elastic modulus, making these composites competitive engineering materials [8].

A key factor determining the performance of talc-filled polypropylene composites is the nature of interfacial interactions between the filler and the polymer matrix [9]. Strong interfacial adhesion facilitates efficient stress transfer from the matrix to the filler, thereby enhancing stiffness and strength. At the same time, the dispersion quality and particle size of talc play a crucial role in defining the overall composite behavior [10]. Fine particles increase the specific surface area and improve filler–matrix interaction, whereas coarse particles may lead to stress concentration and reduced impact resistance [11].

Despite extensive studies on talc-filled polypropylene systems, the relationship between talc particle size, interfacial interaction mechanisms, and the resulting physicomechanical properties remains insufficiently clarified. In particular, there is a need for systematic evaluation of how variations in filler characteristics influence both mechanical performance and processing behavior, such as melt flow index [12].

Therefore, the present study aims to investigate the interaction mechanisms between talc filler and polypropylene block copolymer matrix, as well as to evaluate the dependence of physicomechanical properties on talc particle size and content. In addition, potential application areas of such composites in the automotive industry are considered, highlighting their practical relevance and industrial applicability.

Experimental Part

A highly dispersed talc grade with an average particle size in the range of 1–10 µm was used as the mineral filler. The talc was selected due to its lamellar morphology, high aspect ratio, and well-known reinforcing effect in polyolefin matrices. Prior to processing, the filler was dried at 105 °C for 2 h to remove moisture and ensure stable processing conditions.

As the polymer matrix, a propylene–ethylene block copolymer (PP-BC), grade J-350 (JV Uz-Kor Gas Chemical, Uzbekistan), was employed. This grade was selected due to its optimal balance between melt flowability and physicomechanical performance, which makes it suitable for injection molding applications and industrial-scale processing.

Composite materials were prepared by melt compounding using a laboratory twin-screw extruder. The processing temperature profile was maintained within the range of 180–220 °C, depending on the zone, to ensure homogeneous dispersion of the filler within the polymer matrix. The screw speed was kept at 100–150 rpm to achieve effective mixing without thermal degradation of the polymer.

The obtained гранules were subsequently molded into standard test specimens using injection molding in accordance with relevant international standards. The molding temperature was set at 200–220 °C, with a mold temperature of 40–60 °C.

The physicomechanical properties of the prepared composites were evaluated using standard methods. Tensile properties (elastic modulus and yield strength) were determined according to ISO 527, impact strength (Izod) according to ISO 180, hardness according to ISO 868 (Shore D), and heat deflection temperature (HDT) according to ISO 75. The melt flow index (MFI) was measured following ISO 1133 at a temperature of 230 °C under a load of 2.16 kg.

In addition, the dispersion quality of talc particles within the polypropylene matrix and the nature of filler–matrix interaction were analyzed using optical microscopy and indirect structural interpretation based on mechanical behavior.

RESULTS AND DISCUSSION

Filled polymer composites represent colloidal dispersed systems in which the dispersed phase (mineral filler) is distributed within a continuous polymer matrix. The performance of such systems is primarily governed by interfacial interactions, dispersion quality, and the geometric characteristics of the filler, particularly particle size and aspect ratio. These factors determine the efficiency of stress transfer, restriction of polymer chain mobility, and the overall structural organization of the composite.

In the present study, the physicomechanical properties of two-phase talc–polypropylene block copolymer (PP-BC) composites were evaluated, and the results are summarized in Table 1.

Table 1. Physicomechanical properties of talc–polypropylene compositions

Talc Type	Content, wt.%	Indicators					
		Melt Flow Index (230°C), g/10min	Flexural Modulus, MPa	Flexural Modulus, MPa	Izod Impact Strength (unnotched), kJ/m² (+23°C)	Molding Shrinkage, %	Heat Deflection Temp (1.8 MPa), °C
PP J350	0	10	1240	23	6,5	1,1	45
TM (1 µm)	5	9,0	1390	24	6,4	0,95	50
	10	8,0	1480	27	6,2	0,90	53
	20	7,0	1530	28	5,2	0,81	55
TM (5 µm)	5	9,0	1385	24	6,3	0,97	49
	10	8,2	1450	27	6,0	0,94	53
	20	7,3	1510	28	5,0	0,86	55
TM (10 µm)	5	9,3	1340	24	5,8	0,98	47
	10	8,5	1400	26	5,3	0,95	52
	20	7,5	1460	27	4,8	0,88	54

The analysis of the obtained data shows that the incorporation of talc into the polypropylene matrix leads to a noticeable increase in stiffness-related properties. In particular, the elastic modulus and hardness increase with increasing talc content and decreasing particle size. This behavior can be attributed to the reinforcing effect of talc particles, which restrict the mobility of polymer chains and enhance the rigidity of the composite structure. Fine talc particles, due to their larger specific surface area, provide more effective interfacial contact with the polymer matrix, resulting in improved load transfer efficiency.

At the same time, an increase in yield strength is observed, although its growth is less pronounced compared to the elastic modulus. This indicates that while the filler enhances resistance to deformation, the ultimate strength is still influenced by the intrinsic properties of the polymer matrix and the quality of interfacial adhesion.

The heat deflection temperature (HDT) also increases with the addition of talc, which is associated with the reduced mobility of macromolecular chains and the formation of a more thermally stable structure. This effect is particularly significant for compositions containing finely dispersed talc, where the uniform distribution of particles contributes to improved thermal resistance.

In contrast, the impact strength (Izod) tends to decrease with increasing filler content, especially when coarse talc particles are used. This phenomenon can be explained by the formation of stress concentration zones around poorly dispersed or larger particles, which facilitate crack initiation and propagation under dynamic loading. However, when finer particles are used and good dispersion is achieved, the reduction in impact strength is less significant.

The melt flow index (MFI) decreases with increasing talc content, indicating an increase in melt viscosity. This behavior is typical for filled polymer systems and is related to the hindrance of polymer chain movement caused by the presence of solid particles. Nevertheless, compositions with optimized particle size distribution maintain sufficient processability for injection molding applications.

Overall, the results confirm that talc particle size plays a critical role in determining the balance between stiffness, strength, toughness, and processability of polypropylene-based composites. Fine talc particles provide superior reinforcement due to enhanced interfacial interactions, whereas coarse particles may negatively affect impact performance. Therefore, controlling the dispersion and particle size of the filler is essential for achieving optimal composite properties.

The colloidal-chemical characteristics of talc-filled polypropylene composites are primarily defined by their heterogeneity (multiphase nature) and degree of dispersity. The heterogeneity reflects the existence of a well-developed interfacial surface between the polymer matrix and the filler particles, which plays a decisive role in determining the overall behavior of the system. As the degree of dispersity increases, the contribution of surface phenomena becomes more significant, leading to a more pronounced manifestation of the specific features inherent to heterogeneous dispersed systems. In this context, any multiphase polymer composite can be regarded as an object of colloidal chemistry due to the dominant role of interfacial interactions.

From a practical standpoint, the variation of talc particle size (1, 5, and 10 µm) provides an effective approach for tailoring composite materials to meet specific performance requirements. However, it should be emphasized that simple mechanical grinding of talc to particle sizes below 5 µm, while preserving its reinforcing efficiency, is not feasible. During conventional grinding processes (e.g., in rotary mills), when particle sizes are reduced below approximately 30–40 µm, talc flakes tend to fracture across their basal planes. This leads to the destruction of their lamellar morphology, which is essential for imparting elasticity, dimensional stability, and barrier properties to polypropylene-based composites.

To achieve the required particle size distribution while partially preserving the lamellar structure, a two-stage grinding process is typically employed. In the first stage, talc is ground to a size of 30–40 µm using conventional milling techniques. In the second stage, fine grinding is carried out to obtain particles with an average size of approximately 5 µm. Nevertheless, even with this approach, there are technological limitations beyond which the lamellar structure cannot be maintained, thereby reducing the effectiveness of talc as a reinforcing filler.

The experimental results presented in Table 1 indicate that the use of ultrafine talc particles (≤1 µm) allows for maintaining high levels of stiffness, heat resistance, and impact strength simultaneously. This behavior can be explained by the increased interfacial surface area and the formation of interphase regions with unique physicochemical properties. The interfacial layers, with a characteristic thickness on the order of ~0.5 nm, exist under the influence of intermolecular forces from both phases and contribute significantly to the mechanical performance of the composite. However, the industrial production of talc with particle sizes below 1 µm remains economically impractical, which limits its widespread application.

Therefore, from both technological and economic perspectives, an average talc particle size of approximately 5 µm can be considered optimal. At this scale, a favorable balance is achieved between stiffness, strength, impact resistance, and processability, making such composites suitable for industrial applications, particularly in the automotive sector.

Two key factors govern the colloidal-chemical and physicomechanical behavior of talc-filled polyolefin systems: the initial particle size and the degree of particle aggregation. Analysis of impact strength data indicates that at a talc concentration of approximately 20 wt%, particle aggregation occurs irrespective of particle size (1, 5, or 10 µm). The formation of aggregates increases the effective structural dimensionality of the filler network and leads to an increase in the fractal dimension of the composite. As a consequence, stress concentration sites are formed, which facilitate crack initiation and propagation, resulting in a decrease in impact strength.

This phenomenon can be interpreted in terms of the so-called "barrier effect." The lamellar morphology and micron-scale dimensions of talc particles, combined with their uniform dispersion within the polymer matrix, create a system of physical barriers that hinder particle coalescence and restrict crack propagation. When dispersion is optimal, these barriers enhance the structural integrity of the composite. However, when aggregation occurs, the barrier system becomes less effective, and the mechanical performance, particularly impact resistance, deteriorates.

CONCLUSION

In conclusion, the results of the present study demonstrate that the incorporation of talc into polypropylene block copolymer leads to the formation of an effective interfacial interaction between the filler and the polymer matrix, which governs the overall performance of the composite system. The mechanochemical compatibility between talc particles and the polypropylene matrix ensures efficient stress transfer and contributes to the enhancement of physicomechanical properties.

It has been established that the introduction of finely dispersed talc significantly broadens the application potential of polypropylene by improving stiffness, heat resistance, and dimensional stability while maintaining acceptable impact performance. Among the investigated systems, an average talc particle size of approximately 5 µm at a concentration of 10–20 wt.% was identified as optimal, providing a balanced combination of mechanical strength, toughness, and processability.

The achieved high physicomechanical characteristics confirm the formation of a well-developed interphase region and strong adhesion between the organic (polymer) and inorganic (talc) components. At the same time, it was shown that excessive filler dispersion or increased aggregation may adversely affect impact resistance, highlighting the importance of controlling both particle size and dispersion quality.

The findings of this work can be effectively applied in the development of high-performance polypropylene-based composites for automotive and engineering applications, where a combination of lightweight, durability, and cost-efficiency is required.

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