HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

PREPARATION AND TENSILE STRENGTH INVESTIGATION OF POLYMER COMPOSITE GRANULES MODIFIED WITH MINERAL FILLERS

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Abstract. This study investigates the tensile strength of composite materials based on HDPE 7000F, LDPE L2102TX00, PPY130, PPJ150, and PPJ160 polymers modified with mineral fillers. Bentonite, kaolin, and calcium carbonate ($CaCO_3$) were used as fillers at concentrations of 5, 10, and 15 wt.%. The results demonstrated that the incorporation of mineral fillers improved the tensile strength of all polymer systems. The highest tensile strength was achieved for the PPJ160-B-10 composite, reaching 43 MPa. The reinforcing efficiency of fillers increased in the order $CaCO_3$ < Kaolin < Bentonite. The findings indicate that bentonite-modified polypropylene composites are promising materials for construction and engineering applications.

Keywords: HDPE, LDPE, polypropylene, bentonite, kaolin, calcium carbonate, composite materials, tensile strength, mineral fillers, polymer composites.

Introduction

Polymer composite materials are widely used in various sectors of modern industry, including construction, automotive manufacturing, electrical engineering, and the production of household goods. Their widespread application is primarily attributed to their low density, corrosion resistance, ease of processing, and high economic efficiency. However, in many cases, the mechanical properties of pure polymers do not fully satisfy practical requirements. Therefore, improving the physical and mechanical characteristics of polymers through the incorporation of various mineral fillers into the polymer matrix has become an important scientific and technological challenge.

In recent years, composite materials containing mineral fillers such as bentonite, kaolin, and calcium carbonate have attracted considerable research interest. These fillers interact with the polymer matrix, promoting more efficient stress distribution and enhancing the mechanical performance of the material. In particular, bentonite exhibits excellent reinforcing properties due to its layered structure and high specific surface area, making it an effective strengthening component in polymer composites.

The aim of this study is to evaluate the effect of bentonite, kaolin, and $CaCO_3$ on the tensile strength of composite materials based on HDPE 7000F, LDPE L2102TX00, PPY130, PPJ150, and PPJ160 polymers, and to determine the most effective composition. The obtained results provide a scientific basis for selecting the optimal type and concentration of mineral fillers in the production of polymer composite materials with enhanced mechanical properties.

Research Methods

Tensile strength (σt) is one of the most important mechanical characteristics of polymers and

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composite materials. This parameter describes the maximum stress that a material can withstand under an external load before failure. For polymer composites used in the production of construction materials, high tensile strength is essential for ensuring operational reliability, resistance to deformation, and long service life.

When mineral fillers are incorporated into a polymer matrix, interfacial interactions are formed between the polymer and mineral phases. As a result, the ability of the material to distribute stress under load is altered. Therefore, in this study, the effects of $CaCO_3$, bentonite, and kaolin fillers on the tensile strength of HDPE 7000F, LDPE L2102TX00, PPY130, PPJ150, and PPJ160 polymers were investigated. The tensile strength was determined using the following equation:

$$\sigma t=\frac{F_{max}}{A_0} \quad (1)$$

where: σ_t – tensile strength, MPa; F_{max} – maximum load applied before specimen failure, N; A_0 – initial cross-sectional area of the specimen, mm^2.

The initial cross-sectional area was calculated according to the following expression:

$$A_0=b\times h \quad (19)$$

where: b – specimen width, mm; h – specimen thickness, mm.

The tensile strength tests were carried out using standard tensile testing procedures. The obtained results were used to evaluate the reinforcing efficiency of different mineral fillers and to determine the optimum filler type and concentration for improving the mechanical performance of polymer composite granules.

Results and Discussion

For the HDPE-B-10 sample, the tensile strength was calculated using Equation. Given that F_{max} = 1550 N, b = 10 mm, and h = 5 mm, the initial cross-sectional area of the specimen was determined as: $A_0=10\times5=50\ mm^2$.

Substituting the obtained values into Equation, the tensile strength was calculated as: $\sigma t=\frac{1550}{31}=31\ MPa$.

To evaluate the degree of improvement in tensile strength resulting from mineral modification, the following equation was used:

$$\Delta\sigma_t=\frac{\sigma_{ti}-\sigma_{t0}}{\sigma_{t0}}x100 \quad (20)$$

where: $\Delta\sigma t$ – increase in tensile strength, %; σt_0 – tensile strength of the control sample, MPa; σti – tensile strength of the modified sample, MPa.

For example, for the PPJ160-B-10 composite: $\Delta\sigma_t=\frac{43-33}{33}x100 = 30{,}3\%$

Thus, the incorporation of 10 wt.% bentonite increased the tensile strength of PPJ160 by 30.3% compared with the unmodified polymer.

Tensile strength investigations were carried out for composite materials based on HDPE 7000F. The obtained results are presented in Figure 1.

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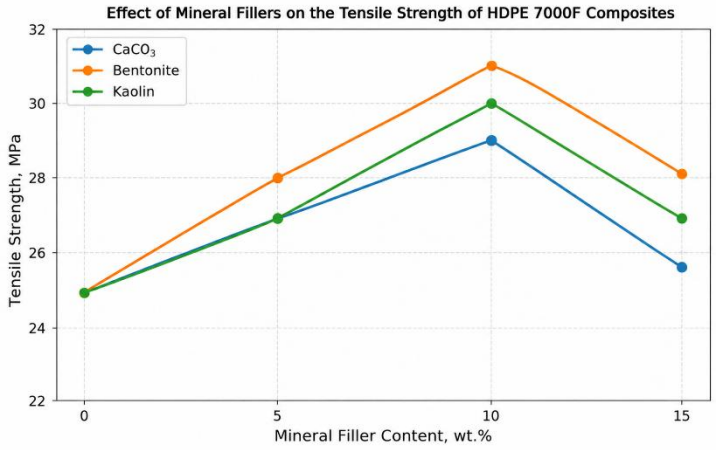


Figure 1. Effect of mineral fillers on the tensile strength of HDPE 7000F-based composites

The tensile strength of the neat HDPE sample was 25 MPa. The incorporation of mineral fillers resulted in a noticeable increase in tensile strength. In composites containing calcium carbonate, the tensile strength increased to 27–29 MPa, followed by a slight decrease to 26 MPa at a filler content of 15 wt.%. The highest value was observed for the HDPE-B-10 sample modified with bentonite, where the tensile strength reached 31 MPa. In kaolin-filled systems, the maximum tensile strength of 30 MPa was obtained for the HDPE-K-10 sample. The improvement in tensile strength up to 10 wt.% filler loading can be attributed to the reinforcing effect of mineral particles and the efficient transfer of applied stress from the polymer matrix to the dispersed mineral phase. However, at a filler concentration of 15 wt.%, partial aggregation of filler particles occurred, leading to the formation of stress concentration sites and a corresponding reduction in tensile strength. These results indicate that a filler concentration of approximately 10 wt.% provides the optimum balance between reinforcement efficiency and filler dispersion in HDPE-based composite materials.

Subsequent investigations were conducted to determine the tensile strength of LDPE L2102TX00-based composite materials. The obtained results are presented in Figure 2.

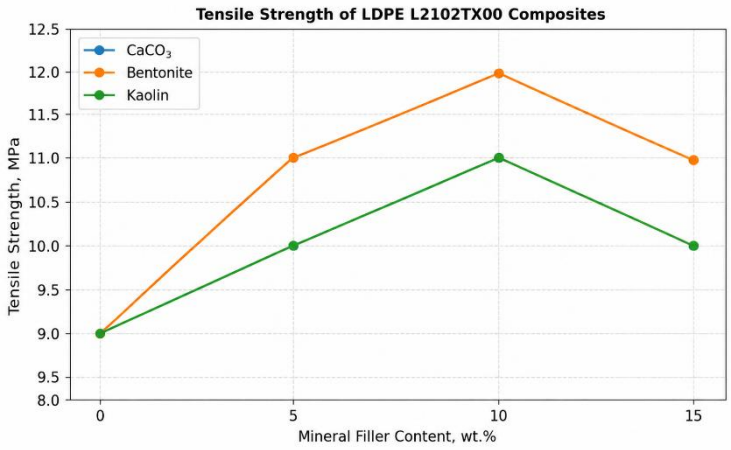


Figure 2. Effect of Mineral Fillers on the Tensile Strength of LDPE L2102TX00-Based Composites

In LDPE-based systems, the tensile strength of the control sample was 9 MPa. The incorporation

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of mineral fillers led to an increase in tensile strength; however, the degree of improvement was lower than that observed for HDPE and polypropylene-based systems. The highest tensile strength was achieved for the LDPE-B-10 sample modified with bentonite, reaching 12 MPa. The relatively limited reinforcing effect of mineral fillers in LDPE composites can be attributed to the branched molecular structure and lower degree of crystallinity of LDPE. These structural characteristics reduce the efficiency of stress transfer between the polymer matrix and the dispersed mineral particles. Nevertheless, all investigated fillers contributed positively to the mechanical performance of the material, resulting in improved tensile strength compared with the unmodified LDPE sample. Among the studied fillers, bentonite exhibited the most pronounced reinforcing effect, followed by kaolin and calcium carbonate. The results indicate that an optimum filler content of approximately 10 wt.% provides the best balance between particle dispersion and reinforcement efficiency in LDPE-based composite materials. Excessive filler loading may promote particle agglomeration, thereby reducing the effectiveness of stress distribution within the polymer matrix.

Further investigations were conducted on the tensile strength of PPY130-based composite materials. The obtained results are presented in Figure 3.

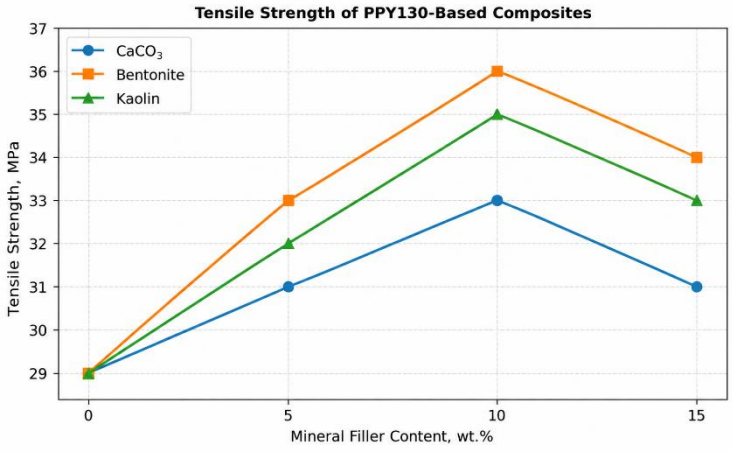


Figure 3. Effect of Mineral Fillers on the Tensile Strength of PPY130-Based Composites

For the control sample of the PPY130-based composites, the tensile strength (σt) was 29 MPa. A significant increase in tensile strength was observed after the incorporation of mineral fillers. The highest value was recorded for the PPY130-B-10 sample, reaching 36 MPa. The tensile strength of the PPY130-K-10 sample modified with kaolin was 35 MPa, while the PPY130-Ca-10 sample containing calcium carbonate exhibited a tensile strength of 33 MPa. The results indicate that the layered structure of bentonite provides an effective reinforcing effect within the polypropylene matrix, resulting in superior stress transfer and improved mechanical performance. Compared with kaolin and calcium carbonate, bentonite demonstrated the highest reinforcing efficiency, leading to the greatest enhancement in tensile strength. The observed improvement can be attributed to the large specific surface area and favorable interfacial interactions between bentonite particles and the polymer matrix. These findings confirm that mineral fillers can significantly improve the mechanical properties of polypropylene-based composites, with bentonite being the most effective filler among those investigated. The optimum filler content was found to be 10 wt.%, at which the maximum tensile strength was achieved.

Further investigations were carried out to evaluate the tensile strength of PPJ150-based

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composite materials, and the obtained results are presented in Figure 4.

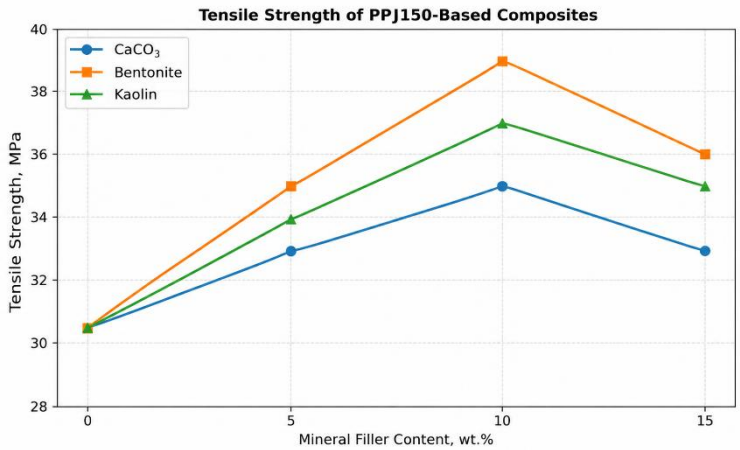
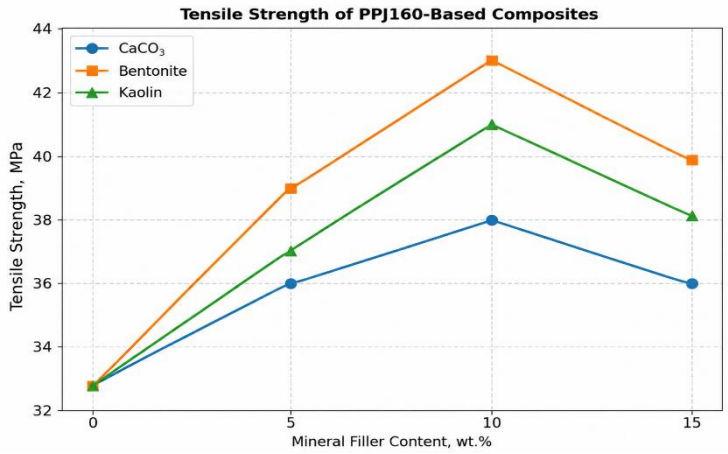


Figure 4. Effect of Mineral Fillers on the Tensile Strength of PPJ150-Based Composites

For the control sample of the PPJ150-based system, the tensile strength was 31 MPa. The highest tensile strength value of 39 MPa was recorded for the PPJ150-B-10 sample modified with bentonite. The PPJ150-K-10 sample containing kaolin exhibited a tensile strength of 37 MPa, while the PPJ150-Ca-10 sample filled with calcium carbonate reached 35 MPa. The results demonstrate that bentonite provided the most significant reinforcing effect among the investigated mineral fillers. Its high specific surface area and well-developed layered structure promoted efficient stress transfer between the polymer matrix and the filler particles, resulting in a substantial improvement in tensile strength. The enhanced interfacial interaction between bentonite and the polypropylene matrix contributed to improved load distribution and increased resistance to tensile deformation. Compared with calcium carbonate and kaolin, bentonite showed superior reinforcing efficiency, confirming its suitability as an effective mineral filler for polypropylene-based composites. The maximum tensile strength observed at 10 wt.% filler content indicates that this concentration provides the optimum balance between filler dispersion and reinforcement, while higher filler loadings may lead to particle agglomeration and a consequent reduction in mechanical performance.

Further investigations were carried out to evaluate the tensile strength of PPJ160-based composite materials, and the obtained results are presented in Figure 5.



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Figure 5. Effect of Mineral Fillers on the Tensile Strength of PPJ160-Based Composites

Among all the investigated systems, the PPJ160-based composites exhibited the highest mechanical performance. The tensile strength of the control sample was 33 MPa, whereas the incorporation of 10 wt.% bentonite increased this value to 43 MPa. The PPJ160-K-10 sample modified with kaolin exhibited a tensile strength of 41 MPa, while the PPJ160-Ca-10 sample containing calcium carbonate reached 38 MPa. The maximum tensile strength observed for the PPJ160-B-10 composite can be attributed to the high crystallinity of the polypropylene matrix and the excellent reinforcing efficiency of bentonite. The layered structure and high specific surface area of bentonite enhanced stress transfer within the composite, resulting in a substantial improvement in tensile properties. However, at a filler concentration of 15 wt.%, a slight reduction in tensile strength was observed due to particle agglomeration, which adversely affected filler dispersion and stress distribution. The overall results demonstrate that mineral fillers improve the tensile strength of all investigated polymer systems. A common trend was observed for all composites: tensile strength increased with filler content up to 10 wt.%, followed by a moderate decrease at 15 wt.%. This behavior can be explained by the dominance of the reinforcing effect at lower filler concentrations and the formation of particle agglomerates and stress concentration sites at higher filler loadings.

Conclusion

The reinforcing efficiency of the investigated mineral fillers increased in the following order: CaCO3<Kaolin<Bentonite. Among all studied composites, the highest tensile strength was achieved by the PPJ160-B-10 sample (43 MPa). Other high-performing composites included PPJ160-K-10 (41 MPa), PPJ150-B-10 (39 MPa), and PPJ160-Ca-10 (38 MPa).

Therefore, based on the tensile strength results, the bentonite-modified PPJ160-B-10 composite was selected as the most promising material for further mechanical and durability investigations. Its superior mechanical performance indicates significant potential for application in the production of high-performance polymer composite materials for engineering and construction purposes.

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