Materials Science Innovations

RESEARCH PAPER

Research on the Preparation and Performance of Polypropylene-Based Composites

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Abstract: Polypropylene (PP) composites are often enhanced with fillers to meet industry demands and reduce costs, improving both mechanical properties and cost-effectiveness. This study explores a PP composite with a negative ion releasing agent, prepared in varying amounts. Tests revealed that increased agent content improved Young's modulus and yield strength but decreased elongation at break and impact toughness. Thermal stability was also significantly enhanced. The composite offers strong mechanical properties, improved conductivity, antioxidant capacity, and thermal stability, making it suitable for electronics, medical devices, and other industrial applications. These advantages highlight its potential for further development in high-performance PP composites.

Keywords: Polypropylene; Composite material; Thermal properties; Mechanical properties

1. Introduction

Polypropylene (PP) is a versatile thermoplastic with excellent properties such as high strength, toughness, heat resistance, and chemical stability. It is widely used in various industries, including furniture, automotive, medical instruments, and packaging materials [1-5]. However, PP has limitations, including susceptibility to UV radiation, flammability, and poor cold resistance, necessitating modifications to enhance its performance [6-8].

PP modifications aim to improve mechanical properties, heat resistance, corrosion resistance, and processability. Chemical modifications like copolymerization and grafting alter the molecular structure, while physical modifications such as blending and reinforcement improve material properties [9-14]. Inorganic fillers like calcium carbonate and talc increase hardness and wear resistance, while bio-based fillers enhance cost-effectiveness and environmental friendliness [15-20].

Adding fillers, toughening agents, and UV stabilizers significantly improves PP's performance [21-26]. Inorganic fillers enhance heat and chemical resistance, while reinforcing agents like glass fibers boost strength and stiffness. These modifications expand PP's application range, making it suitable for high-performance uses in various industries [17, 27-30].

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2. Experimental Part

2.1 Experimental Objective

The objective of this experiment was to prepare polypropylene (PP) composite materials using various additives to enhance their mechanical properties. The study aimed to examine the effects of different fillers, such as tourmaline powder, talc, calcium powder, and radium stone powder, on the material's properties, including antistatic ability, flowability, strength, wear resistance, and surface quality.

2.2 Experimental Materials

The primary materials used in this experiment were MM20S polypropylene, tourmaline powder, talc, calcium powder, and radium stone powder. Different formulations were created with varying proportions of these substances to investigate their effects on the composite properties. The equipment used included a vacuum hot press, an electronic universal testing machine, and a PP kneader.

Table 1. Proportioning ratios of the samples used in this experiment.

Nr.	PP	Tourmaline	Talcum	Calcium	Lanthanum
A0	100	-	-	-	-
A1	80	10	5	5	-
A2	70	20	5	5	-
A3	60	25	10	5	-
A4	70	5	15	10	-
A5	60	15	5	5	15

2.3 Sample Preparation

Samples were prepared by mixing the PP and additives in a kneader at 240°C for 15 min. The mixture was then molded using a vacuum hot press set at 200°C and 500 kg of pressure for 40 min. After molding, the samples were cooled and demolded, ensuring that the integrity of the samples was preserved for further testing.

2.4 Sensory Data Analysis

The mechanical properties of the composite materials were quantitatively evaluated using an electronic universal testing machine (Figure 1), which recorded data on tensile strength, elongation at break, and other key performance metrics. These results were used to analyze the effectiveness of the various additives in enhancing the PP's mechanical and surface properties, providing insights for further applications.

Figure 1. The electronic universal testing machine.

2.6 Chemical Analysis

The chemical composition of the polypropylene (PP) composites was indirectly influenced by the addition of various fillers, including tourmaline powder, talc, calcium powder, and radium stone powder. These additives were selected to modify the PP matrix's properties such as antistatic performance, flowability, strength, and wear resistance. However, the experiment focused primarily on the physical blending process, without direct chemical analysis of the resulting composites.

2.7 Chemical Analysis of Data Processing

Data processing primarily focused on the mechanical properties measured through tensile tests rather than chemical composition analysis. The data from the electronic universal testing machine included metrics such as tensile strength, yield strength, elongation at break, and elastic modulus. These mechanical properties were used to assess the impact of the different fillers on the PP composite's performance, providing quantitative insights into how the chemical additives affected the material's overall behavior.

3. Results and Discussion

3.1 Mechanical Results Analysis

The mechanical performance of polypropylene composite materials was analyzed through tensile fracture testing using an electronic universal testing machine. Key parameters, including stress, strain, and Young's modulus, were calculated for samples with varying compositions.

Stress-Strain Behavior, Figure 2: The stress-strain curves for the samples showed a gradual increase in stress up to a peak, followed by a sharp drop upon fracture. Samples with modifying substances, such as tourmaline powder and talc, exhibited higher Young's modulus and tensile strength but lower elongation at break, indicating enhanced stiffness but reduced toughness.

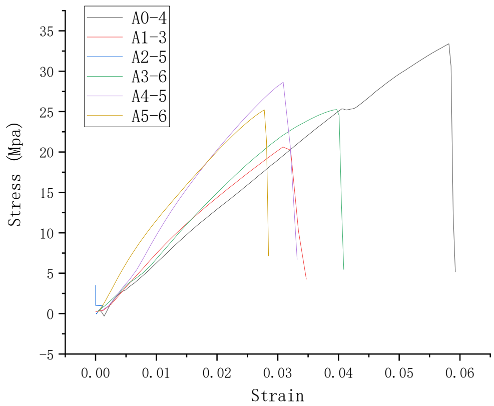


Figure 2. Stress-Strain Graph of the Highest Young's Modulus Among Each Group.

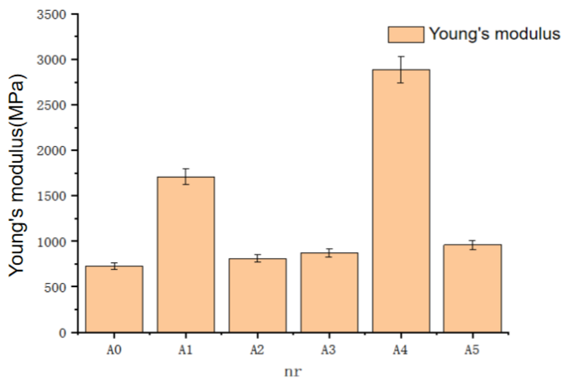


Figure 3. Average Young's Modulus of Various Samples.

Young's Modulus, Figure 3: Samples with added fillers displayed a significant increase in Young's modulus, with the highest value recorded for sample A5 (maximum 1475 MPa, average 1291 MPa). Sample A4, which combined enhancers and fillers, showed a balanced improvement in rigidity, strength, and toughness, demonstrating optimal mechanical performance.

Impact of Modifying Substances, Figure 3: The addition of fillers such as tourmaline and talc improved the material's rigidity and strength. However, it also reduced the elongation at break, highlighting a trade-off between strength and toughness. Among all the samples, A4 exhibited the best overall mechanical properties, with enhanced modulus, ultimate strength, and toughness, making it suitable for high-demand applications where both rigidity and durability are essential.

The analysis concludes that while modifying substances significantly enhance mechanical properties, a careful balance is required to maintain sufficient material toughness.

3.2 Morphology of Polypropylene Composite with Ion Releaser

The surface and internal structures of polypropylene composite materials containing negative oxygen ion releasers were examined using Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). As seen in Figure 4, SEM images revealed typical ductile fracture characteristics, including cracks along grain boundaries and voids in sample A0. The composite material's cross-section showed an even distribution of the negative oxygen ion releaser within the polypropylene matrix, creating a denser structure with fewer pores and defects.

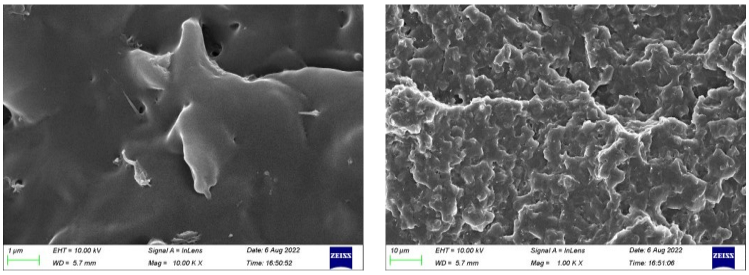


Figure 4. SEM Image of A0.

The addition of the negative oxygen ion releaser also promoted crystallization in the polypropylene matrix, resulting in small crystalline areas, which improved the material's hardness and strength. This enhanced structure and mechanical performance make the composite material suitable for various applications, providing improved durability and strength (Figure 5).

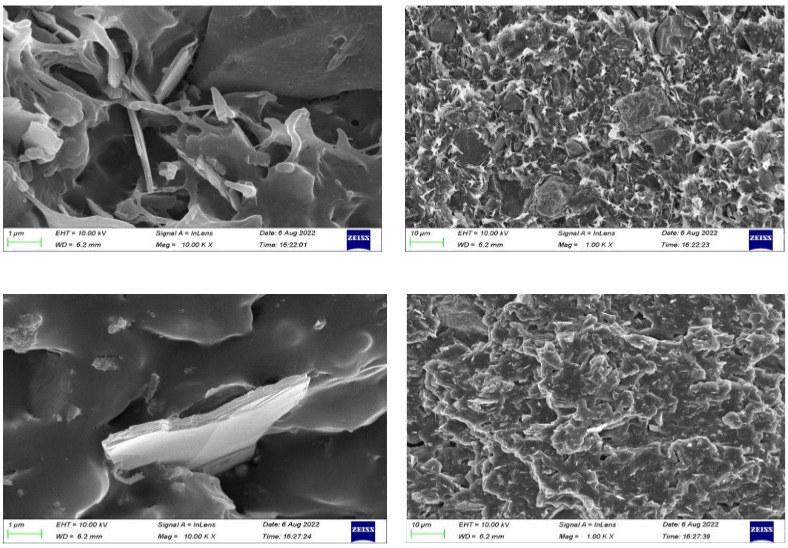


Figure 5. SEM Image - A3 (Top) and A5 (Bottom).

3.3 Thermal Performance of Polypropylene Composite with Ion Releaser

Thermal Gravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC) showed that polypropylene composites with negative oxygen ion releasers exhibited good thermal stability. All samples underwent two stages of mass loss: in Figure 6, a slight first loss around 160-200°C due to partial thermal degradation of the PP resin, and a strong second loss between 390-506°C, indicating complete carbonization of the PP resin. The remaining mass consisted of carbonized resin and unaffected modifying substances. These results suggest that the composites possess excellent resistance to high-temperature degradation, making them suitable for high-temperature applications.

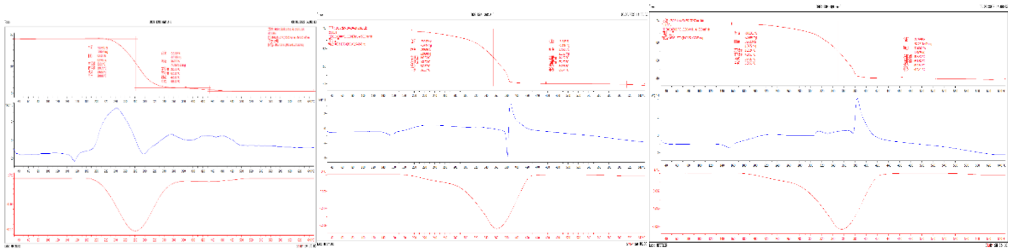
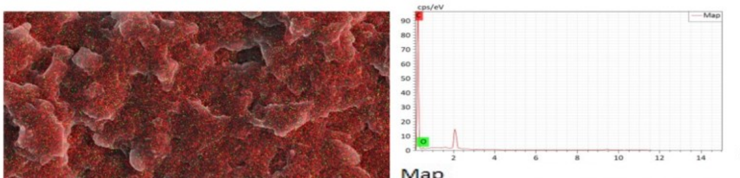


Figure 6. TGA Curve - A0 (Left), A3 (Mid) and A5 (Right).

3.4 Elemental Analysis of Polypropylene Composite with Ion Releaser

Elemental mapping of polypropylene composites revealed that carbon (C) and oxygen (O) were the predominant elements across all samples. In the blank group in Figure 7, C accounted for 93.91%, while O was 6.09%, consistent with the carbon-based composition.

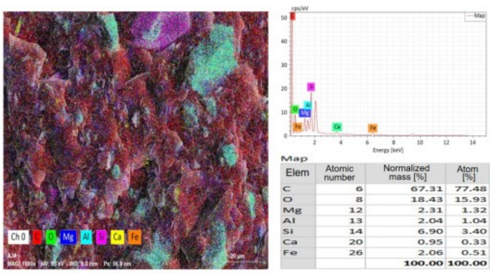


Map

Elem	Atomic number	Normalized mass [%]	Atom [%]
C	6	93.91	95.36
O	8	6.09	4.64
		100.00	100.00

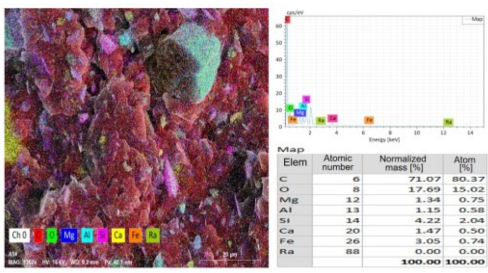
Figure 7. Elemental Analysis of A0.

In samples with added modifiers (A1-A5), other elements like magnesium (Mg), aluminum (Al), silicon (Si), calcium (Ca), and iron (Fe) were detected, Figure 8, contributing to enhanced material properties such as hardness and strength. The distribution of these elements varied across samples, with A5 showing the most uniform elemental distribution, improving material stability and performance.



Map

Elem	Atomic number	Normalized mass [%]	Atom [%]
C	6	67.31	77.48
O	8	18.43	15.93
Mg	12	2.31	1.32
Al	13	2.04	1.04
Si	14	6.90	3.40
Ca	20	0.95	0.33
Fe	26	2.06	0.51
		100.00	100.00



Map

Elem	Atomic number	Normalized mass [%]	Atom [%]
C	6	71.07	80.37
O	8	17.69	15.02
Mg	12	1.34	0.75
Al	13	1.15	0.58
Si	14	4.22	2.04
Ca	20	1.47	0.50
Fe	26	3.05	0.74
Ra	88	0.00	0.00
		100.00	100.00

Figure 8. Elemental Analysis - A3 (Left) and A5 (Right).

4. Conclusion

This study focused on the effects of adding negative oxygen ion releasers to polypropylene composite materials. Through mechanical testing, including tensile and bending tests, it was found that the addition of these releasers significantly improved the material's strength, stiffness, and overall mechanical performance. The experimental results demonstrated that the modified composites exhibited superior stability and residual strength compared to those without the releasers. In conclusion, incorporating negative oxygen ion releasers into polypropylene composites enhances their mechanical properties, making them more suitable for use in demanding environments.

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Conflicts of Interest: The authors declare no conflict of interest.

References

[1] Ling Yun. New Trends in Blister Packaging: The Challenges and Responses of Polypropylene Application. Process Industry, 2022(9): 46-48.

[2] He Ping, Peng Zonglin, Ren Wentan, Zhang Yong, Zhang Yinx. In situ synthesis of zinc methacrylate modified EPDM/PP thermoplastic elastomer. Synthetic Rubber Industry, 2006, 29(6): 435-438.

[3] Jin Riya, He Zengdi. Modification of Polypropylene. Modern Plastics Processing and Applications, 2001, 13(1): 62-64.

[4] Lu Yongsheng, Jia Yi. Modification of Polypropylene and Its Application. Plastics Processing and Application, 2002, 24(3): 58-60.

[5] Jiang Shan, Li Xiaqian, Wang Kemin, Yu Qiang. Methyl methacrylate/divinylbenzene grafting crosslinked modified polypropylene separator. Functional Materials, 2014, 45(20): 20020-20023.

[6] Li Shushu, Ma Yingxia, Li Guangquan, Liu Xiaoyan. Research Progress on Physical Toughening Modified Polypropylene .. Plastics Industry, 2022, 50(8): 9-14.

[7] Li Henan, Xu Shijie, Teng Wenpeng. Research on Blended Modification of Polypropylene. Refining and Chemical Industry, 2003, 14(4): 8-10.

[8] Liu Jun, Li Jiangping. Research Progress on Modification of Polypropylene. Guangdong Chemical, 2010(1): 66-67.

[9] Ma Yurong, Zhang Zhen, Su Qing, Liu Zhen, Yan Xixi, Zhang Suna, Ying Sibin, Wang Lijun. Preparation and Mechanical Property Improvement of Waste Sulfonic Acid Resin Modified Polypropylene Composite Material. Journal of Shanghai Second Polytechnic University, 2022, 39(1): 30-35.

[10] Xu Yaohui, Liu Tao, Meng Xiuqing, Guo Peng, Lv Mingfu. The Effect of High Concentration Glass Fiber Reinforcement on the Viscoelasticity of Polypropylene. Plastics Industry, 2022, 50(8): 74-79.

[11] Wei Yuyong, Zhang Qingfa, Sheng Kuichuan. The Effect of Biochar on the Mechanical Properties of Corn Zein/Polypropylene Composite Material. China Agricultural Science and Technology Guide, 2022, 24(10): 161-168. DOI: 10.13304/j.nykjdb.2022.0572.

[12] Duan Huande. Research on Mechanical Properties of Microcellular Polypropylene Composite Material. Guizhou University, 2015.

[13] Jin Yuehong, Sun Changhong, Liu Shufeng. The Effect of Boron Nitride on the Properties of Polypropylene Composite Material. Henan Chemical Industry, 2023, 40(02): 22-25. DOI: 10.14173/j.cnki.hnhg.2023.02.015.

[14] Chen Houzhen, Wang Yanzhi, Zhang Yanli, et al. The Effect of Different Sizes of Aluminum Oxide on the Properties of Polypropylene Composite Material and Numerical Simulation. Plastics Technology, 2022, 50(11): 24-29. DOI: 10.15925/j.cnki.issn1005-3360.2022.11.005.

[15] Chen Rongyuan, Zhao Lingfeng, Liu Xin, et al. Preparation and Property Study of Glass Fiber Reinforced Toughened Recycled Polypropylene Composite Material. Plastics Technology, 2022, 50(09): 20-24. DOI: 10.15925/j.cnki.issn1005-3360.2022.09.005.

[16] Hao Yatun. Study on Mechanical Properties of Carbon Fiber/Basalt Fiber/Polypropylene Composite Material .. Chemical Propellants & Polymeric Materials, 2022, 20(02): 60-63. DOI: 10.16572/j.issn1672-2191.202209016.

[17] Chen Binghua, Zheng Gang, Nan Yu, et al. Mechanical Properties of Hexagonal Boron Nitride Filled Polypropylene Composite Material. Plastics Industry, 2022, 50(07): 47-51+96.

[18] Wang Yuan. Study on Mechanical and Sound Absorption Properties of Modified Jute Fiber Polypropylene Composite Material. Hunan University, 2020. DOI: 10.27135/d.cnki.ghudu.2020.004269.

[19] Zheng Gang, Nan Yu, Qin Zehua, et al. The Effect of Compatibilizer on the Mechanical Properties of Boron Nitride Filled Polypropylene Composite Material. Journal of Zhongyuan University of Technology, 2022, 33(02): 13-18

[20] Souza Milena Chanes, Moroz Ivan, Cesarino Ivana, Bronzato Giovana Roberta Francisco, Reis Victor Angelo Cavalari Arantes dos, Carvalho Brito Lucas Balieiro, Zanzini Murilo Gibbin, Leão Alcides Lopes. Influence of Moisture and Hydrogen Peroxide Fiber Treatment on the Flexural Properties of Polypropylene Composites Reinforced with Unsmoked Cigarette Butts. Macromolecular Symposia,2022,406(1).

[21] Parida Malaya Ranjan, Mohanty Smita, Biswal Manoranjan, Nayak Sanjay K., Rai Suchita. Influence of aluminum trihydrate (ATH) particle size on mechanical, thermal, flame retardancy and combustion behavior of polypropylene composites. Journal of Thermal Analysis and Calorimetry,2022,148(3).

[22] Zhou H, Zhang X, Chen X, et al. Study on Mechanical Properties of Flake Graphite Filled Polypropylene Composites[C]//Wuhan Zhicheng Times Cultural Development Co., Ltd. Proceedings of 4th International Conference on Materials Science, Resource and Environmental Engineering (MSREE 2022). 2022:98-102.DOI:10.26914/c.cnkihy.2022.066260.

[23] Yun JongHwan, Jeon YuJae, Kang MinSoo. Prediction of Elastic Properties Using Micromechanics of Polypropylene Composites Mixed with Ultrahigh-Molecular-Weight Polyethylene Fibers. Molecules,2022,27(18).

[24] Yu Shuxian, Zhao Changjun, Wei Jie, Jia Shuai, Chen Pan, Shao Ziqiang, Lyu Shaoyi. Preparation of BTCA-esterified cellulose nanocrystals and effects on mechanical and thermal properties of polypropylene composites. Journal of Applied Polymer Science,2022,139(42).

[25] Hong-jun Liang, Qiu-shi Sun, Xiao-huai Hou Institute of Chemistry, Chinese Academy of Sciences, Beijing, 100080, China.SURFACE MODIFICATION OF POLYPROPYLENE MICROFIBRE BY PLASMA-INDUCED VAPOR GRAFTING WITH ACRYLIC ACID. Polymer Science,1999,0(3):221-229

[26] Benzeggagh M L, Benmedakhene S. Residual strength of a glass/polypropylene composite material subjected to impact. Composites Science & Technology, 1995, 55(1):1-11.

[27] Li J. Multiwalled Carbon Nanotubes Reinforced Polypropylene Composite Material. Journal of Nanomaterials, 2017, 2017(2):1-5.

[28] Sardar J, Bandopadhya D. Development and fabrication of cement reinforced polypropylene composite material spur gear. Journal of Polymer Engineering, 2014, 34(8):775-786.

[29] Tang Y, Huang X, Ye N, et al. PREPARATION METHOD FOR TOUGHENED AND REINFORCED POLYPROPYLENE COMPOSITE MATERIAL, WO2022110656A1. 2022.

[30] Fan W, Zhang T, Meng X, et al. METHOD FOR PREPARING DENIM FIBER-REINFORCED POLYPROPYLENE COMPOSITE MATERIAL FROM DENIM FABRIC WASTES AND POLYPROPYLENE FIBER, AU2020102106A4. 2020.