ARCENG
INTERNATIONAL JOURNAL OF ARCHITECTURE AND ENGINEERING

ISSN 2822-6895

Article Arrival Date 13.11.2024 | **Article Type** Research Article | **Article Published Date** 20.12.2024

EFFECT OF POLYPROPYLENE FIBER ON THE TENSILE PROPERTIES AND MICROSTRUCTURAL BEHAVIOR OF POLYESTER COMPOSITES

Assist. Prof. İbrahim DEMİRCİ

Selcuk University, Technology Faculty, Department of Mechatronics Engineering

ORCID: 0000-0002-6808-8550

ABSTRACT

In this study, polypropylene (PP) was added to polyester material, which is widely used in the industry and can also be utilized as a matrix material, in chopped weight fractions of 0%, 0.25%, 0.5%, and 0.75% to improve its mechanical performance. Tensile tests were conducted to determine the optimal additive ratio. The experimental results revealed that the best additive ratio was 0.5% by weight of PP in the polyester material. This ratio formed a good interface with the polyester matrix, thereby enhancing its tensile strength. On the other hand, the 0.75% additive ratio caused significant agglomeration issues in the polyester material, leading to a reduction in its mechanical strength.

Experimental analyses were extended by obtaining microscopic images after the tensile tests, and damage analyses were performed based on these images. The microscopy results showed a detailed examination of the distribution of chopped PP additives within the polyester matrix. It was determined that the most homogeneous structure was achieved in polyester composites with 0.5% by weight PP.

This study demonstrates that low-cost and lightweight additive materials like polypropylene can enhance the performance of thermoplastic matrices such as polyester when used in appropriate ratios. However, it highlights that microstructural issues like agglomeration observed at higher additive ratios can adversely affect material performance.

Keywords: Polypropylene Fiber, Polyester Composites, Tensile Properties

1. INTRODUCTION

Polypropylene (PP) materials are the most widely used among polyolefins and are the most produced materials globally on an annual basis. PPs are highly versatile due to their chemical properties, such as polymerization, copolymerization, and grafting, as well as physical modifications like blending and the addition of fillers. With these modifications, the properties of PPs can be enhanced for use as engineering thermoplastics. Engineering-grade PPs, with improved mechanical properties through the addition of fillers, are extensively used in industries such as automotive, household appliances, and home goods[1-8]

Tang et al. conducted a study to enhance the mechanical properties of cemented and non-cemented clay soils using short polypropylene (PP) fibers. PPs were added in weight fractions of 0.05%, 0.15%, and 0.25%. The curing periods were set at 7, 14, and 28 days, followed by unconfined compression and shear tests. The test results showed that the addition of PPs to both cemented and non-cemented soils led to an increase in shear strength and axial stress. Additionally, it was observed that the cemented soil transitioned from a brittle behavior to a more ductile behavior with the inclusion of PPsb [8]. Fu et al. investigated polypropylene (PP) composites reinforced with short glass fibers (SGF) and short carbon fibers (SCF) produced through extrusion compounding and injection molding techniques, focusing on their tensile strengths. They explored the relationship between average fiber length and fiber volume fraction. The tensile strength and modulus of SGF/PP and SCF/PP composites were evaluated by considering the combined influence of fiber volume fraction and average fiber length. The results showed that fiber efficiency factors decreased as fiber volume fraction increased. Furthermore, the inherently more brittle nature of carbon fibers led to lower fiber efficiency factors compared to glass fibers[9].

Unterweger et al. studied the mechanical and electrical properties of composites made with short carbon fibers and short polypropylene (PP) fibers, using injection and compression molding, to evaluate the effects of fiber length and content. The results showed a strong linear correlation between weight-average fiber length and properties such as tensile strength, tensile modulus, notched impact strength, and electrical conductivity. Additionally, tensile strength and modulus exhibited a highly consistent linear relationship with fiber volume fraction. The composite containing 15% carbon fiber by volume demonstrated the best performance, achieving a tensile strength of 98 MPa, a tensile modulus of 14.4 GPa, and an electrical conductivity of 102 S/cm10^2 \text{S/cm}102S/cm.[10]

In this study, polypropylene (PP) was added to polyester material in weight fractions of 0%, 0.25%, 0.5%, and 0.75%, and their tensile strengths were examined. The optimal additive ratio among these weight fractions was determined. After the tensile tests, microscopic images of the fracture regions were obtained, and the fracture points and the distribution of PPs were analyzed in detail.

ISSN
2822-6895

2. MATERIALS and METHODS

2.1. Preparation of PP/Polyester Material

To prepare the composite materials, polypropylene (PP) was added to polyester in weight fractions of 0%, 0.25%, 0.5%, and 0.75% using manual mixing. The mixing process was extended to approximately 20 minutes to ensure a homogeneous distribution of PP within the polyester matrix.

Following the mixing process, 2% by weight of a curing agent was added to the mixture, in accordance with the manufacturer's recommendations, and the mixture was stirred again.

The prepared mixture was poured into tensile test molds and allowed to cure at room temperature for approximately 24 hours. The tensile test molds were designed according to the ASTM D638 standard, ensuring that the test specimens were produced in compliance with this standard.

Figure 1. Chopped Polypropylene Material

2.2. Tensile Test

Tensile tests were conducted to determine the tensile strengths of the prepared composite samples. The tests were performed using a Shimadzu 100 kN universal testing machine at a tensile speed of 5 mm/min. During the tensile tests, stress-strain values, average stress, and standard deviation values were obtained. Each parameter was tested with a minimum of three repetitions to ensure accuracy.

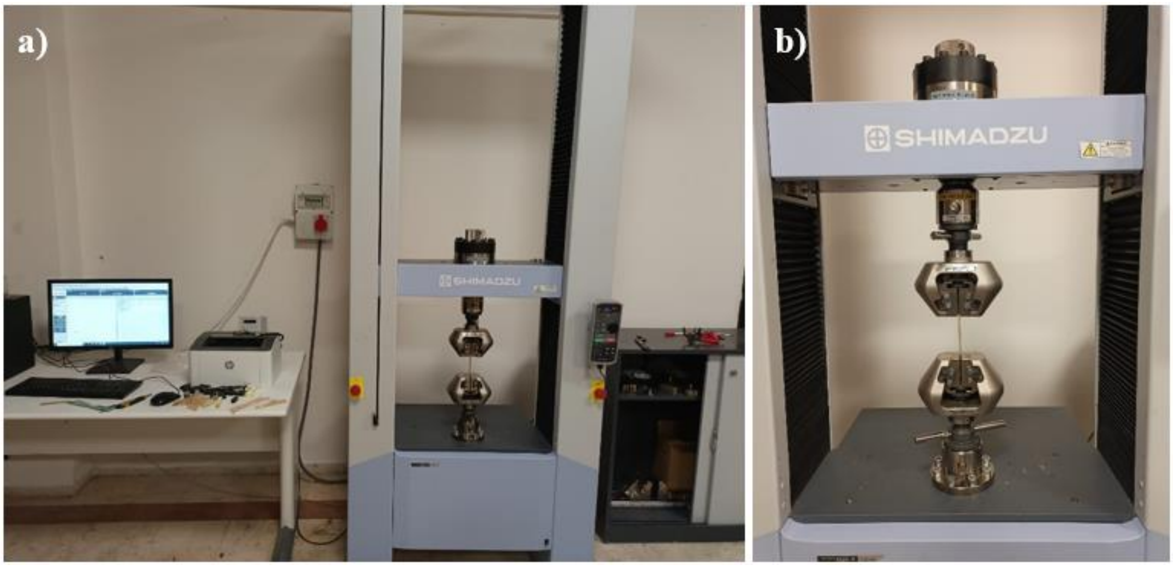


Figure 2. a) Test device and setup b) Tensile test specimen

2.3. Microscopic Analysis

Microscopic images obtained from the fracture regions after the tensile tests were analyzed to observe the effects of PP within the polyester matrix. These images were used to examine the distribution of PPs within the matrix, damage mechanisms, and the presence of agglomeration.

Microscopic analysis is an effective method for understanding the impact of PP additives on the mechanical properties of the polyester matrix and for revealing the relationship between the additive ratio and material performance.

3. RESULTS and DISCUSSION

3.1. Tensile Test

In this study, the tensile performance of composites prepared by adding chopped polypropylene (PP) to a polyester matrix at weight fractions of 0.25%, 0.5%, and 0.75% was investigated. Figure 3 shows the stress-strain graph.

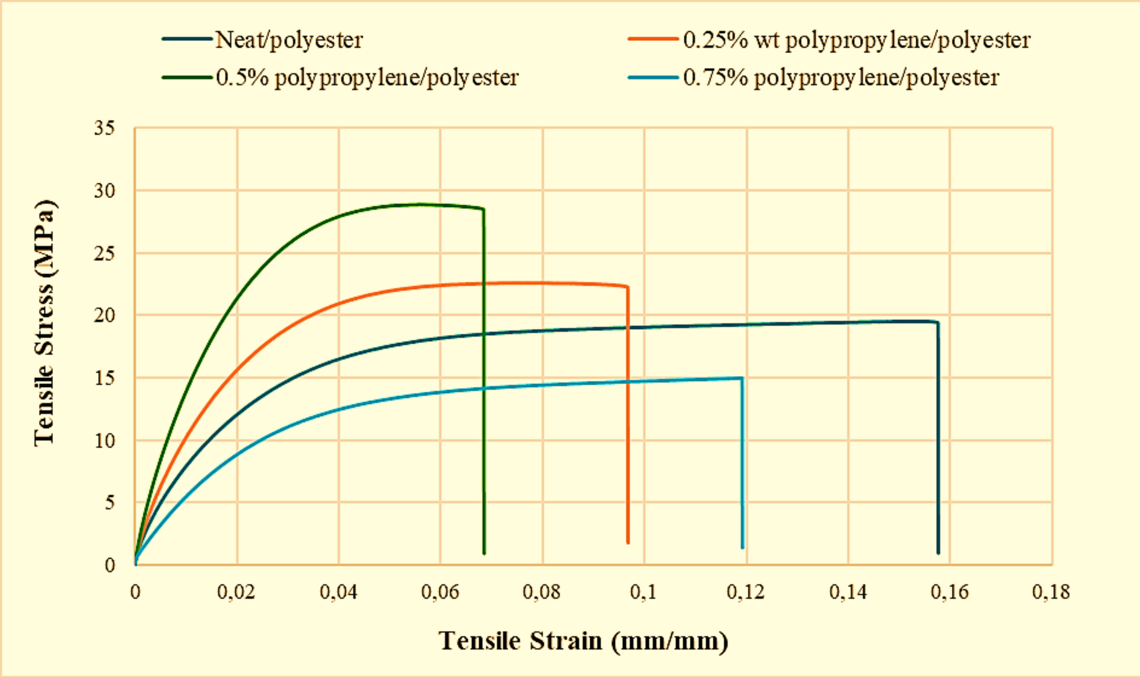


Figure 3. Stress-Strain Graph of Neat/Polyester, 0.25% PP/Polyester, 0.5% PP/Polyester, and 0.75% PP/Polyester Materials

In Figure 3, PP was added to the polyester material in weight fractions of 0%, 0.25%, 0.5%, and 0.75%, and their tensile strengths were analyzed. The 0.5% PP/Polyester material demonstrated the best tensile performance. This was followed by 0.25% PP/Polyester and Neat/Polyester materials, respectively. The lowest tensile strength was observed in the 0.75% PP/Polyester material.

The primary factor contributing to the superior tensile performance of the 0.5% PP/Polyester material is the homogeneous distribution of PPs at this ratio, which formed a strong interface with the polyester matrix. The PPs distributed tensile loads evenly across the sample, enhancing the structural strength of the polyester material.

Figure 4 illustrates the maximum stress and standard deviations for Neat/Polyester, 0.25% PP/Polyester, 0.5% PP/Polyester, and 0.75% PP/Polyester materials.

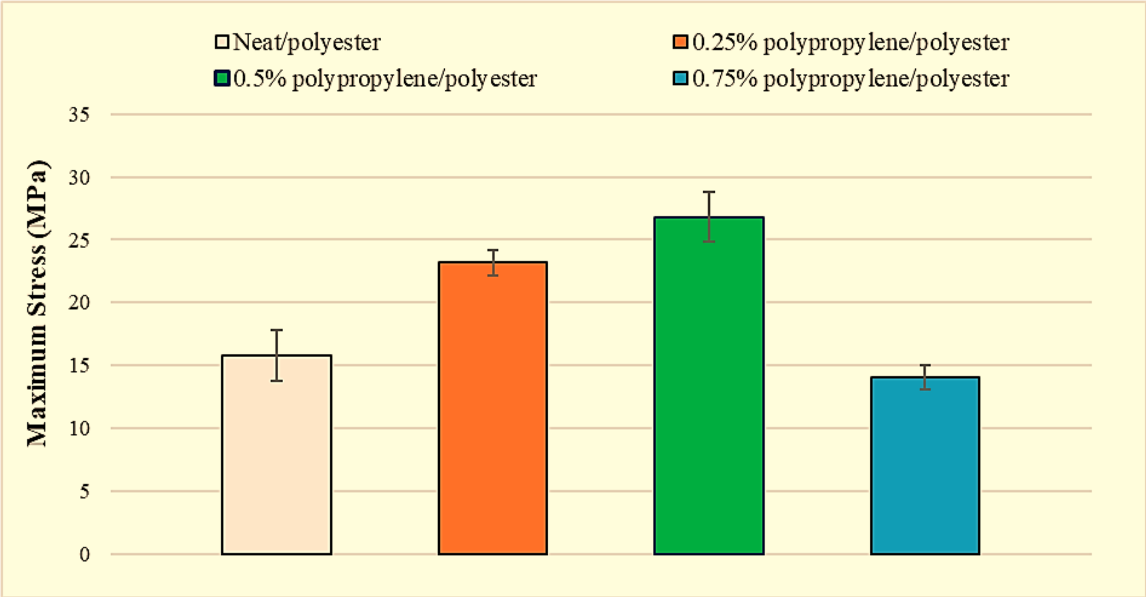


Figure 4. Maximum Stress Graph of Neat/Polyester, 0.25% PP/Polyester, 0.5% PP/Polyester, and 0.75% PP/Polyester Materials

In Figure 4, the maximum stress value of the Neat/Polyester composite is approximately 15.8 MPa. For the 0.25% PP/Polyester composite, the maximum stress reached approximately 23.1 MPa. Although the tensile strength showed a noticeable increase with 0.25% PP addition, this improvement was not as significant as that observed with the 0.5% PP addition. While the distribution of PPs in the 0.25% PP/Polyester composite appeared homogeneous, the amount of PP was insufficient to achieve optimal tensile strength.

The maximum tensile strength of the 0.5% PP/Polyester composite was measured at 26.8 MPa, representing an approximate increase of 16%, demonstrating the best mechanical performance.

In contrast, the tensile strength of the 0.75% PP/Polyester composite was approximately 14.06 MPa, the lowest among all tested composites. This value was even lower than that of the unreinforced Neat/Polyester composite. The primary reason for this low strength is agglomeration.

Strong interfacial bonds between the polyester matrix and the reinforcement material are critical for efficient load transfer. Agglomeration adversely affects the mechanical behavior of polyester composites by disrupting these bonds. In the agglomerated regions, insufficient bonding occurred between the polyester matrix and the PP fibers, leading to the formation of microcracks under tensile loads. These microcracks significantly reduced the mechanical performance of the polyester structure.

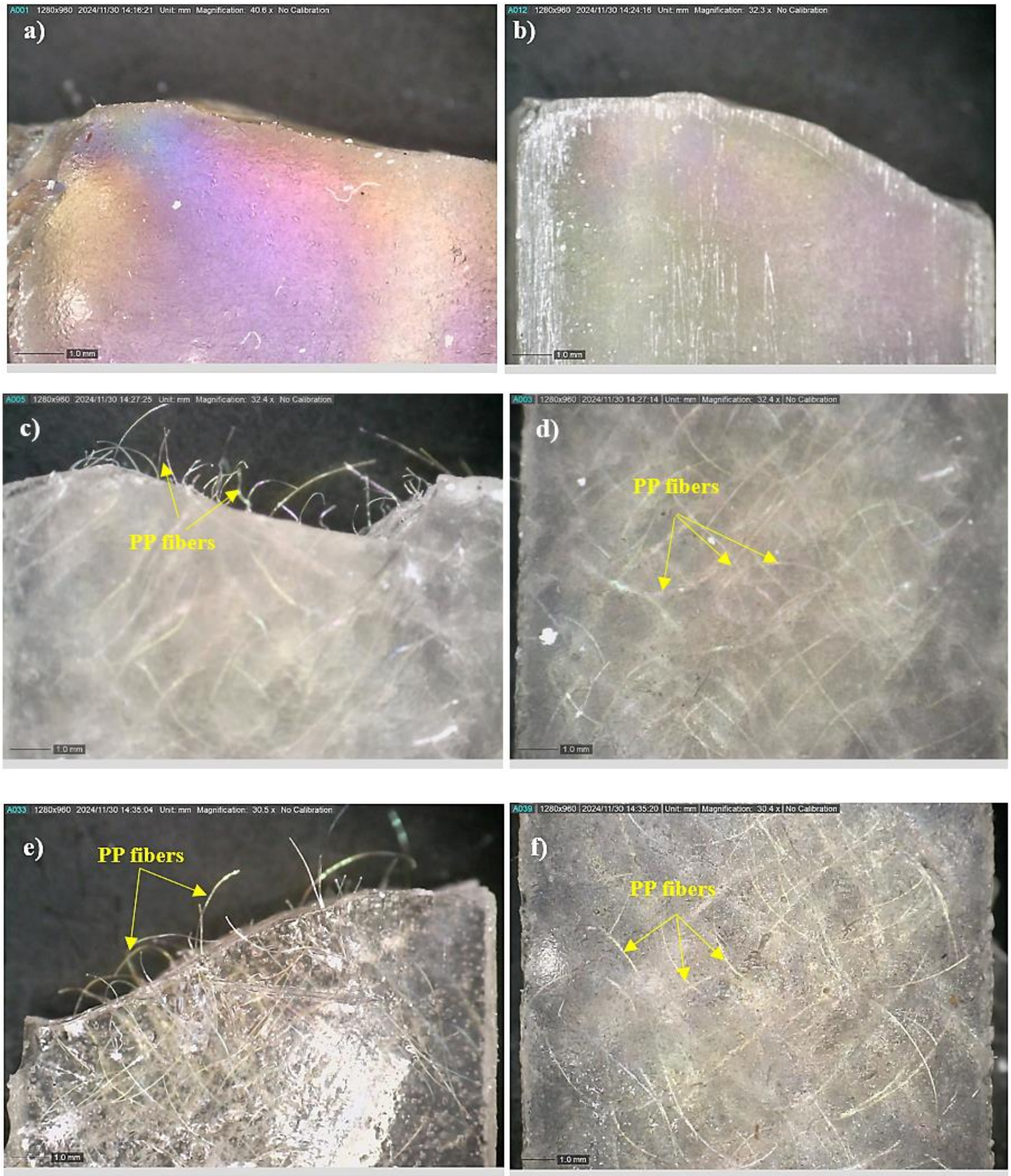
3.2. Microscopic Analysis

Microscopic imaging of composite materials subjected to tensile tests with varying PP additive ratios is an essential method for understanding fracture mechanics. The microscopic images of Neat/Polyester composites are shown in Figures 5a and 5b. The images of 0.25% PP/Polyester composites are presented in Figures 5c and 5d. Examination of the fracture surfaces in these composites revealed visible PP fibers within the fracture surfaces. The PP fibers were evenly distributed within the polyester matrix, with no signs of agglomeration. This uniform distribution positively contributed to the tensile strength of the neat polyester matrix material, resulting in an increase in performance.

The 0.5% PP/Polyester composites are shown in Figures 5e and 5f. Microscopic examination of these composites indicated that the PP fibers were homogeneously distributed within the matrix, with no signs of agglomeration. The interface strength between the PP fibers and the matrix appeared to be strong, as evidenced by the attachment of PP fibers to the matrix on the fracture surfaces. The PP fibers effectively distributed tensile loads evenly across the material, significantly enhancing its tensile strength. The 0.5% PP addition was identified as the optimal additive ratio, and this finding was validated by both stress-strain graphs and microscopic images.

In the case of 0.75% PP/Polyester composites, a high tendency for agglomeration was observed, as shown in Figures 4g and 4h. In these agglomerated regions, PP fibers were found to be clumped together, while voids were observed in other areas. The weak interface formed between the PP fibers and the matrix in agglomerated regions significantly reduced tensile strength. Due to agglomeration, the tensile loads were not distributed effectively, leading to poor mechanical performance.

Microscopic analyses clearly demonstrated that achieving a homogeneous distribution of polypropylene within the polyester matrix is a critical factor. The optimal additive ratio was determined to be 0.5% by weight of PP, ensuring the best balance of mechanical performance and fiber distribution.


A001 1280x960 2024/11/30 14:16:21 Unit: mm Magnification: 40.6 x No Calibration
a)
1.0 mm
A012 1280x960 2024/11/30 14:24:16 Unit: mm Magnification: 32.3 x No Calibration
b)
1.0 mm
A005 1280x960 2024/11/30 14:27:25 Unit: mm Magnification: 32.4 x No Calibration
c)
PP fibers
1.0 mm
A003 1280x960 2024/11/30 14:27:14 Unit: mm Magnification: 32.4 x No Calibration
d)
PP fibers
1.0 mm
A033 1280x960 2024/11/30 14:35:04 Unit: mm Magnification: 30.5 x No Calibration
e)
PP fibers
1.0 mm
A039 1280x960 2024/11/30 14:35:20 Unit: mm Magnification: 30.4 x No Calibration
f)
PP fibers
1.0 mm

ISSN
2822-6895

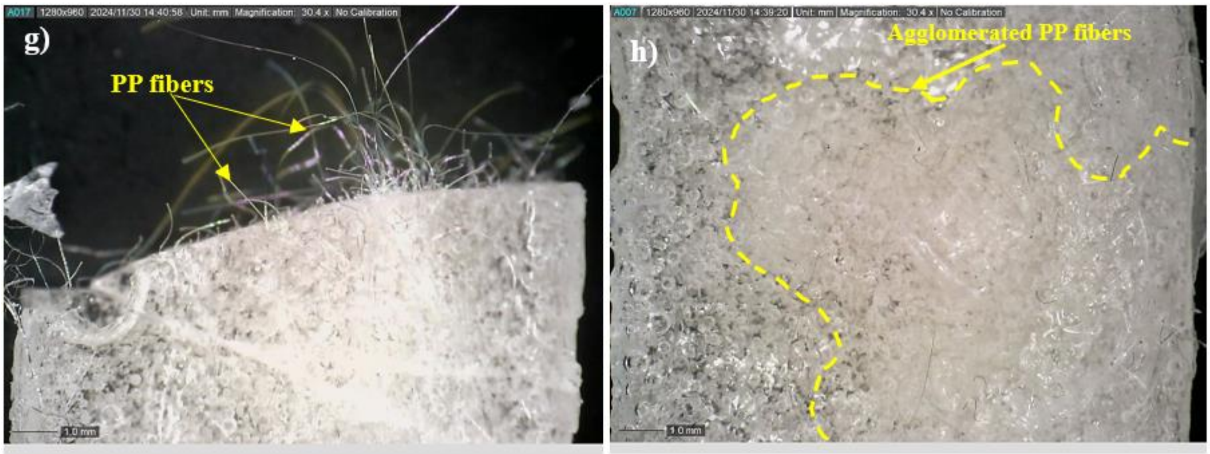


Figure 5. Microscopic Images of Neat/Polyester, 0.25% PP/Polyester, 0.5% PP/Polyester, and 0.75% PP/Polyester Composites

4. CONCLUSIONS

In this study, composites with weight fractions of 0%, 0.25%, 0.5%, and 0.75% polypropylene (PP) were added to a polyester matrix material, and their tensile strengths were examined. Microscopic images of the fracture points were obtained after tensile tests to determine the optimal additive ratio.

The best stress values were observed in composites with 0.5% PP by weight. Microscopic images also confirmed that at this ratio, the PP fibers were homogeneously distributed within the matrix material.

The lowest mechanical performance was found in composites with 0.75% PP by weight. Microscopic images of these composites revealed significant agglomeration, which severely reduced the tensile strength of the polyester matrix.

Composites with 0.25% PP by weight showed improved tensile strength and homogeneous fiber distribution within the matrix. However, the additive ratio was insufficient to achieve optimal tensile strength.

The study identified agglomeration as the most significant issue reducing tensile strength. To address this problem, it is recommended to explore alternative production methods that ensure a more homogeneous distribution of PP fibers within the polyester matrix.

ISSN
2822-6895

5. REFERENCES

1. Hertzberg, R.W. and J.A. Manson, *Fatigue of engineering plastics.* 1980.

2. Kinloch, A.J., S.J. Shaw, and D.L. Hunston, *Deformation and fracture behaviour of a rubber-toughened epoxy: 2. Failure criteria.* Polymer, 1983. **24**(10): p. 1355-1363.

3. Williams, J.G., *Fracture mechanics of polymers.* (No Title), 1984.

4. Kausch, H.-H., *Polymer fracture*. Vol. 2. 2012: Springer Science & Business Media.

5. Atkins, A.G., *Scaling in combined plastic flow and fracture.* International Journal of Mechanical Sciences, 1988. **30**(3-4): p. 173-191.

6. Friedrich, K., *Application of fracture mechanics to composite materials*. 2012: Elsevier.

7. Karger-Kocsis, J., *Microstructural aspects of fracture in polypropylene and in its filled, chopped fiber and fiber mat reinforced composites*, in *Polypropylene Structure, blends and Composites: Volume 3 Composites*. 1995, Springer. p. 142-201.

8. Tang, C., et al., *Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil.* Geotextiles and Geomembranes, 2007. **25**(3): p. 194-202.

9. Fu, S.Y., et al., *Tensile properties of short-glass-fiber-and short-carbon-fiber-reinforced polypropylene composites.* Composites Part A: Applied Science and Manufacturing, 2000. **31**(10): p. 1117-1125.

10. Unterweger, C., et al., *Characterization of carbon fiber surfaces and their impact on the mechanical properties of short carbon fiber reinforced polypropylene composites.* Composites Science and Technology, 2015. **108**: p. 41-47.