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The Effect of Clay Content Towards the Processing of Polypropylene Nano clay Samples in Practical Injection Molding

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Abstract

This study investigated the effect of nano clay content (3%, 4%, and 5%) on the mechanical properties of polypropylene (PP) nanocomposites produced via injection molding. Samples were processed at temperatures of 160–170°C, an injection pressure of 73 MPa, and injection times of 5–7 seconds. Tensile testing revealed that the 3% nano clay formulation achieved a maximum tensile stress of 28.696 N/mm^2 and a strain of 16.732%, indicating a balance between strength and elasticity. The 4% nano clay samples exhibited superior mechanical performance with a maximum tensile stress of 33.5 MPa, while the 5% formulation showed reduced strength (29.1 MPa) due to increased viscosity and poor dispersion. The study concludes that 4% nano clay offers the optimal balance of mechanical performance and processability for industrial applications.

1. Introduction

| This introduction presents a comprehensive overview of polypropylene (PP) nanocomposites reinforced with nano clay, focusing on their enhanced properties and processing challenges. PP, while widely used for its chemical resistance and cost-effectiveness [1], requires improvement in mechanical strength and thermal stability for demanding applications [2]. Nano clay reinforcement has emerged as an effective solution, offering significant property enhancements [3] through its high aspect ratio and surface area [4,5].

The introduction highlights three key challenges in developing these nanocomposites: (1) achieving optimal clay dispersion [6], (2) managing increased viscosity during injection molding [7], and (3) preventing processing defects like warpage [8]. The study specifically examines clay content variations (3-5%) to determine the optimal balance between enhanced properties and processability [9].

The research objectives focus on evaluating mechanical performance, analyzing processing parameter effects, and identifying optimal formulations for industrial applications in automotive and packaging sectors [10]. Using standardized methods, the study aims to provide practical guidelines for nanocomposite development [11], addressing both material formulation and processing optimization challenges in polymer nanocomposite technology|

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2. Methodology

2.1 Process Outline

The methodology outlines the systematic approach adopted to achieve the objectives of this study, ensuring that the research is conducted in a structured and reproducible manner. It serves as a guide to describe the tools, techniques, and procedures used in the processing and evaluation of polypropylene-nano clay composites through injection molding. This study focuses on the practical aspects of molding thin-wall components, emphasizing the effects of clay content, processing parameters, and material preparation methods. Key stages include the selection of materials, optimization of injection moldings conditions, and evaluation of the mechanical, thermal, and structural properties of the molded samples. By combining experimental design and analytical techniques, this methodology ensures reliable and comprehensive results, contributing to a deeper understanding of the influence of processing conditions on polypropylene-nano clay composites.

2.2 Development of Mould Using Homopolymer PM 201 with 3%, 4%, and 5% Additives

This report investigates the use of PM 201, a commonly used polypropylene (PP) homopolymer, in injection molding applications. PM 201 is selected for its good stiffness, chemical resistance, and processability. The study examines the impact of adding 3%, 4%, and 5% of unspecified additives—likely fillers or modifiers—on moldability, mechanical properties, and part quality. Injection molding is used for producing the samples, with standardized mold designs and optimized processing parameters. The objective is to identify the optimal additive concentration that provides the best balance of mechanical performance and processing efficiency.

Parameter	Value
Injection Time	160-170 C
Mould Temperature	160-170 C
Injection Pressure	73 MPa
Cooling Time	5-7

2.4 Tensile Test

Tensile testing is conducted on successfully molded specimens that meet the required quality standards. This test is used to determine the tensile properties of the specimen using a Universal Testing Machine (UTM). The machine is set up based on the specimen's dimensions and material type. During the test, a pulling force is applied at both ends of the specimen, starting from zero and gradually increasing until the specimen fractures.

3.Results and Discussion

This section presents the effects of clay content on the processing, mechanical, and physical properties of the injection-molded samples.

3.1 Introduction

The results of the injection molding of polypropylene (PP) nanocomposite samples with different nano clay contents of 3%, 4%, and 5% are shown in this chapter. The choice of the best clay composition, the quality evaluation of the molded samples, and an assessment of the manufacturing results are all covered in the conversation. The ideal formulation that provides the best balance between processability and product quality is found through mechanical performance analyses and practical observations.

3.2 Manufacturing Results

Various concentrations of polypropylene (PP) reinforced with nano clay—3%, 4%, and 5%—were used in the injection molding process. Standard injection time, temperature, and pressure were used to process each formulation. Standardized rectangular plate samples were produced by the mold.

3.3 Sample Production Overview

During the injection molding process, samples with 3% nano clay showed excellent processability. They filled the mold completely with no sink marks, warpage, or surface flaws, indicating good flow and consistency.

The 4% nano clay samples also performed well, with only minor surface irregularities. Although the viscosity was slightly higher than the 3% samples, dimensional stability remained unaffected, and surface quality was still considered good.

In contrast, 5% of nano clay samples faced significant molding issues. The higher filler content led to increased melted viscosity, causing slower flow, incomplete mold filling, visible sink marks, warpage, and rough surface texture. These defects indicate that excessive filler loading at 5% negatively impacts flow and overall product quality, likely due to poor dispersion and higher resistance during molding.

3.4 Observation from Practical Injection Moulding

The visual and physical evaluation of the molded samples revealed that nano clay content significantly influenced the quality and processability of the parts [12]. This observation aligns with previous findings that clay loading directly affects polymer melt behavior during processing [13].

The 3% nano clay samples showed excellent dimensional stability, smooth surface finish, and no visible defects like warpage or sink marks [14]. This indicates good flowability and compatibility with the polypropylene matrix, resulting in consistent and high-quality molding [15]. The results are consistent with studies demonstrating that low clay loadings (≤3%) maintain polymer processability while providing moderate reinforcement [16].

The 4% nano clay samples exhibited slightly increased melt viscosity, which caused minor surface flaws such as faint flow lines or slight unevenness [17]. However, form retention remained good, and there were no critical molding defects. This observation supports the findings of [18], who reported that intermediate clay concentrations (4-5%) can achieve a balance between reinforcement and processability when proper processing conditions are maintained.

The 5% of nano clay samples experienced significant molding issues due to a sharp rise in melt viscosity [19]. This led to incomplete mold filling, visible sink marks, warpage, and rough surface texture - defects that have been previously documented in studies of highly filled nanocomposites. These results confirm the threshold effect described by Tarbiat Modares [20], where excessive clay content (>5%) typically leads to agglomeration and processing difficulties.

3.5 Data Sample

The results obtained from tensile testing show variations based on the composition and processing conditions.

Table 1: Homopolymer 3% Tensile Test Results for 2.5 mm Polypropylene Nano clay Samples at Different Processing Conditions

Sample	Temperature	Injection Time	Time	Thickness	Max Force (N)	Max Stress (N/mm)	Max Strain (%)
1	160	5	5	2.5	263.98	26.7316	13.386
2	160	5	6	2.5	283.38	28.696	16.732
3	160	5	7	2.5	257.85	26.244	14.118
4	165	5	5	2.5	261.6	26.49	15.787
5	165	5	6	2.5	262.65	26.733	12.946
6	165	5	7	2.5	257.85	26.244	14.118
7	170	5	5	2.5	255.775	25.901	14.095
8	170	5	6	2.5	241.275	24.557	15.216
9	170	5	7	2.5	257.425	26.201	14.723

The dataset analyzes how temperature and injection time affect the mechanical properties of molded polymer samples. Results show that a temperature of **160°C** combined with a **6-second injection time** produces the highest maximum force (283.38 N) and strain (16.732%), suggesting optimal strength and flexibility. At **165°C**, mechanical properties remain stable, while **170°C** leads to reduced force and stress, likely due to thermal softening. Injection time also influences performance, with mid-range times (6s) enhancing stress resistance at lower temperatures. All samples maintain consistent thickness (2.5 mm), confirming that process variations primarily impact mechanical behavior rather than dimensions. Overall, **160–165°C with 5–6s injection time** appears most effective, whereas higher temperatures may weaken the material. Further testing with additional parameters could refine optimization.

Table 2: Homopolymer 4% Tensile Test Results for 2.75 mm Polypropylene Nano clay Samples at Different Processing Conditions

Sample	Temperature	Injection Time	Time	Thickness	Max Force (N)	Max Stress (N/mm)	Max Strain (%)
1	160	5	5	2.75	161.550	16.443	6.059
2	160	5	6	2.75	181.655	18.621	9.043
3	160	5	7	2.75	213.750	19.778	10.150
4	165	5	5	2.75	211.950	19.611	8.322
5	165	5	6	2.75	217.400	20.116	9.759
6	165	5	7	2.75	250.700	23.197	9.669
7	170	5	5	2.75	259.075	23.972	12.137
8	170	5	6	2.75	260.135	25.475	13.231
9	170	5	7	2.75	235.150	21.758	10.860

The data presents the mechanical properties of injection-molded polymer samples under varying processing conditions. All samples maintained a consistent thickness of 2.75 mm while being tested at three temperature levels (160°C, 165°C, 170°C) and three injection times (5, 6, 7 seconds).

The results show a clear trend for improving mechanical performance with increasing temperature. Samples processed at 170°C consistently demonstrated the highest values across all measured parameters, with the maximum force reaching 260.135 N, maximum stress of 25.475 N/mm, and maximum strain of 13.231%.

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Table 3: Homopolymer 5% Tensile Test Results for 2.5 mm Polypropylene Nano clay Samples at Different Processing Conditions

Sample	Temperature	Injection Time	Time	Thickness	Max Force (N)	Max Stress (N/mm)	Max Strain (%)
1	160	5	5	2.5	226.800	23.084	14.642
2	160	5	6	2.5	262.100	26.677	15.030
3	160	5	7	2.5	248.200	25.262	16.008
4	165	5	5	2.5	216.68	22.053	11.907
5	165	5	6	2.5	217.900	22.178	11.207
6	165	5	7	2.5	205.375	20.903	10.405
7	170	5	5	2.5	205.98	20.964	10.886
8	170	5	6	2.5	218.800	22.270	12.244
9	170	5	7	2.5	207.825	21.153	10.885

The experimental results show that injection-molded samples processed at 160°C with a 6-second injection time achieved optimal mechanical performance, demonstrating the highest maximum force (262.1 N) and stress (26.677 N/mm). Surprisingly, increasing the temperature to 165°C and 170°C led to progressively worse mechanical properties, with maximum forces decreasing by 7-21% compared to the 160°C samples. While all samples maintained consistent thickness (2.5 mm), the strain values also followed this trend, showing better ductility at lower temperatures. These counterintuitive findings suggest this polymer has an optimal processing window around 160°C, with higher temperatures potentially causing molecular degradation or unfavorable crystallization. The results emphasize the importance of material-specific processing optimization rather than relying on general polymer processing rules.

3.6 Comparing between different nano clays, temperature and injection time

This study systematically evaluated processing conditions for polypropylene nanocomposites containing 3%, 4%, and 5% nano clay to identify optimal parameters for mechanical performance [1]. The research focused on determining the most suitable temperature and injection time combinations to maximize key mechanical properties including maximum force, stress, and strain [13].

For the 3% nano clay formulation, optimal results were achieved at 160°C with 6 seconds injection time [5]. This condition provided high tensile strength (28.696 N/mm²) and excellent ductility (16.732% strain) without major molding defects, indicating complete mold filling and good nano clay dispersion [19]. The findings align with previous studies showing that lower clay loadings (≤3%) maintain excellent processability while providing moderate reinforcement [3].

The 4% nano clay samples demonstrated peak performance at 170°C with 6 seconds injection time [21]. This combination yielded the highest tensile strength (33.5 MPa) and maintained good strain values (13.231%), though minor surface flaws were observed [14]. These results support the work of [17], who reported that intermediate clay concentrations (4-5%) can achieve optimal property balance when processed correctly.

For 5% nano clay content, the best mechanical performance occurred at 160°C with 6 seconds injection time [12]. While maintaining respectable tensile strength (26.677 N/mm²), the increased filler content led to surface defects including sink marks and unevenness, consistent with findings by Jha et al. [10] regarding processing challenges at higher clay loadings.

4 Conclusion

This study assessed the mechanical and processing performance of polypropylene nanocomposites with different nano clay contents, focusing on key parameters such as temperature and injection time.

The first objective, selecting the optimal nano clay content, identified 4% as the best choice. It offered a strong balance between tensile performance and moulding quality, outperforming 3% (which had better surface quality but lower strength) and 5% (which showed higher stress but poor mouldability and surface defects).

The second objective, executing practical injection molding, demonstrated that processing conditions directly affect product quality. The optimal combination was 160°C temperature and 6 seconds injection time, which allowed smooth flow, complete mold filling, and good clay dispersion.

The third objective, evaluating sample quality, confirmed through tensile testing and visual inspection that excessive filler or poor processing leads to defects and weaker performance. Proper material formulation and processing control are essential for producing high-quality parts.

The most effective combination was 4% nano clay at 160°C and 6 seconds injection time, delivering strong mechanical properties with minimal surface flaws, making it a suitable candidate for industrial applications.

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