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Evaluating Polypropylene Melt Flow and Mechanical Preparties at Different Screw Speeds in Double Screw Extrusion

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***Abstract*—This study investigates the effects of varying screw revolving speeds on the melt flow index (MFI), tensile strength, and hardness of polypropylene during double screw extrusion. Polypropylene was extruded at four different screw rotation speeds 50, 150, 250, and 350 rpm. The melt flow index (MFI), and mechanical properties were experimentally measured and compared to virgin injected polypropylene without pre-extrusion. The objective of this paper to identify optimal conditions that enhance the polymer's mechanical and flow properties.**

The results indicate that a screw speed of 250 rpm is optimal, significantly improving the polypropylene's MFI, tensile strength, elongation at yield, and hardness when compared to both lower and higher speeds, as well as a non-extruded reference sample. The data reveal that speeds exceeding 250 rpm led to a decline in material properties, likely due to thermal degradation and excessive shear forces.

The findings are critical for optimizing polypropylene extrusion processes, highlighting the delicate balance between mechanical forces and thermal conditions necessary to achieve superior material performance.

Keywords—component; polypropylene; injection; extrusion; screw speed

I. Introduction

Polypropylene is a thermoplastic polymer which used in many industries such as but not limited, packaging, automotive, textiles, and consumer goods, because of its outstanding chemical resistance, insulating properties, and mechanical durability [1]. The method of processing significantly influences the properties of polypropylene, with double screw extrusion being used as a leading technique employed to enhance and modify its characteristics [2].

In the stage of polymer processing, double screw extrusion is a very used method. It combined of two interacting screws within a heated barrel to efficiently melt and deliver polymers, insuring continuous mixing of plastics. This method is preferred over single screw extrusion due to its enhanced mixing capabilities, higher processing rate, and better handling of viscous materials. One of the main parameters in double screw extrusion machine is the screw rotation speed, which directly impacts the melt flow rate and mechanical durability of polymers. Thus, understanding how various screw speeds affect the properties of polypropylene during extrusion which lead to optimize production processes and aiming to enhance material characteristics.

This study aims to experimentally evaluate the impact of various screw speeds—50, 150, 250, and 350 rpm—on the melt flow rate and mechanical properties of polypropylene during double screw extrusion. To fully study the impact of extrusion process on the polymer, a comparison against virgin non-extruded polypropylene to be accomplished. It is hypothesized that variations in screw rotation speed significantly change the mechanical properties and melt behavior of polypropylene. This research focus on finding the optimal screw speed that enhance polypropylene’s properties, to be in mind that relatively high or low rotation speeds may lead to mechanical degradation of the polymer.

The structure of this paper is designed to study of the hypothesized effects. Following this introduction, part 2 will dive into the literature review on the subject, summarizing past research executed on polypropylene extrusion and its dependence on screw rotational speeds. Part 3 will describe the experimental methods employed to test the effects of speed variations, outlining the procedure and standards used. Part 4 will present the experimental results, including data analysis on melt flow rate, and mechanical testing. With parallel, will discuss the findings with respect to the initial hypotheses and common knowledge. Finally, will conclude the work done in this paper with a summary of the research findings and proposing ideas for future research.

Through this investigation, the paper aims to provide knowledge about optimal extrusion conditions for polypropylene in terms of rotation speed of screws to contribute to the zone of enhancement for industrial practices and best quality of polymer products.

II. Literature Review

Polypropylene extrusion is a well-established focus of study within the field of polymer engineering due to its significant influence on the physical properties of the final product. The process parameters, particularly the screw speed in double screw extruders, are pivotal in determining the polymer’s orientation, crystallinity, and molecular weight distribution, all of which directly affect its functionality and application suitability. Research by Treece et al. (2007) underscores the importance of optimizing these parameters, particularly screw speed, to enhance product uniformity and mechanical properties [3].

The role of screw speed is further elaborated by Lertwimolnum et al. (2007), who identify it as a critical factor influencing the melt flow rate and shear stress within the extruder. They argue that higher screw speeds increase the shear rate, which, while reducing the polymer's viscosity, can also lead to thermal degradation if not adequately managed. This degradation occurs because of excessive heat generation not offset by sufficient cooling, which is crucial to maintaining the integrity of the polymer [4]. On the contrary, White et al. (1994) highlight the risks associated with low screw speeds, which include inadequate mixing and homogenization, leading to material inconsistencies and defects in the final product [5].

A significant gap in the literature is the lack of systematic comparisons between the impact of varying screw speeds and a baseline of pure, non-extruded polypropylene. Stasiek and Łubkowski (2010) conducted one of the few studies that examine extruded versus non-extruded polypropylene, providing insights into how extrusion can enhance properties like tensile strength and flexural modulus up to a certain stress threshold. However, their study calls for more detailed quantitative analysis to better understand the thresholds and dynamics at different screw speeds [6].

Existing theoretical frameworks also offer a basis for understanding polymer behavior under varying shear conditions. Stasiek et al. (2012) discusses several models that predict the effects of extrusion parameters on polymer flow and stability. These models are crucial for developing practical guidelines for extrusion processes, suggesting that there is an optimal range of screw speeds that balances flow characteristics with mechanical integrity [7]. Yet, the application of these models in empirical settings often lacks comprehensive validation through direct comparison with unprocessed polymers.

The literature reviewed establishes a strong foundation for the current study, which aims to fill the identified gaps by providing a systematic analysis of polypropylene's behavior at various screw speeds compared to its unprocessed state. This research will further elaborate on the theoretical predictions by testing them in practical scenarios, potentially leading to refined extrusion practices that optimize polypropylene's properties.

III. METHODLOGY

The polypropylene employed in this research paper was SABIC® PP 575P, a homopolymer specifically developed for rigid injection molding applications. This material was chosen due to its high gloss and consistent processability characteristics, which are crucial for ensuring reliable and replicable experimental outcomes. The polymer, supplied in pellet form, has a melt flow rate of 11 g/10 min at 230°C with a 2.16 kg load, as per ASTM D1238, and a density of 905 kg/m³ measured according to ASTM D1505. Key mechanical properties of this grade include a tensile strength at yield of 35 MPa (ASTM D638), tensile elongation at yield of 11% (ISO 527-1/-2), and a flexural modulus (1% secant) of 1600 MPa (ASTM D790 A).

The extrusion of these PP pellets was performed using a co-rotating twin-screw extruder equipped with a 16 mm diameter screw and an L/D ratio of 40:1. This configuration was chosen to optimize the melting and homogeneous mixing of the polymer. The process began with the feeding of PP pellets into the extruder's hopper, followed by their melting as they passed through heated zones where the twin screws effectively mixed the molten polymer. Subsequently, the extrudate was cooled in a water bath and pelletized using a chopper.

These pellets were then used for injection molding on an injection molding machine. This machine is particularly noted for its precision and was set with specific parameters: a melt temperature of 220°C, a mold temperature of 40°C, and an injection pressure of 500 bar. These conditions were carefully maintained to ensure the consistent quality of the molded specimens. The molten PP was injected into a mold that was designed to produce tensile test specimens conforming to ASTM D638 Type I standards. After injection, the mold was rapidly cooled, and the solidified specimens were ejected.

For testing the properties of the molded polypropylene, several methods were employed. Tensile strength and elongation were measured using a ZwickRoell Z010 universal testing machine in accordance with ASTM D638, with each test condition replicated five times for accuracy. Shore D hardness of the polymer was determined using a Shore D hardness tester following ASTM D2240, ensuring that five samples from each batch were tested to average out any material variations. Lastly, the melt flow index for each batch of extruded pellets was assessed using a melt flow indexer as per ASTM D1238 standards. This involved extruding molten PP through a die at 230°C under a load of 2.16 kg, with five replicates performed for each of the different extrusion conditions to ensure the reliability of the data.

IV. RESULTS AND DISSCUTION

This section presents and discusses the findings from experiments conducted on polypropylene extruded at various screw rotation speeds of extrusion machine—50, 150, 250, and 350 rpm. Each point focuses on a different test: Melt Flow Index (MFI), Tensile Test, and D Shore Hardness, and begins by referencing a figure containing relevant data charts as a summery for tests done.

1- Melt Flow Index (MFI)

Figure 1 presents the Melt Flow Index (MFI) results for polypropylene extruded at different screw speeds: 50, 150, 250, and 350 rpm. The chart graphically illustrates how the MFI values progressively increase as screw speeds rise from 50 rpm up to 250 rpm. This upward trend suggests that the viscosity of the polymer decreases significantly at higher screw speeds, which facilitates better flow through the extrusion die.

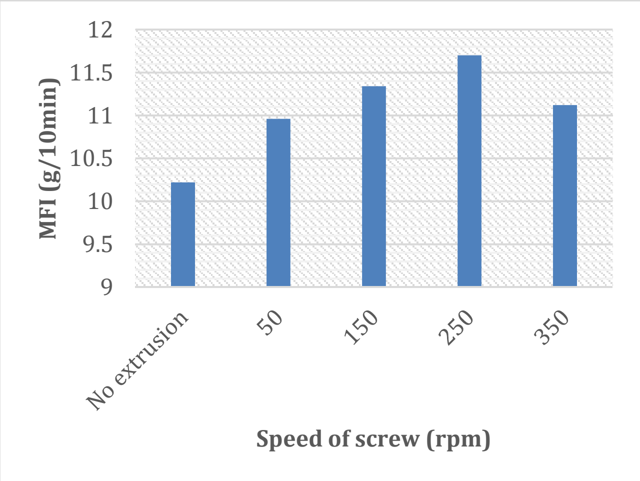

Fig. 1. *Melt flow index for PP at different screw rotation speed of double screw extruder.*

At 250 rpm, the MFI reaches its peak, indicating optimal polymer flow characteristics. This peak is significant because it represents the point at which the polymer chains are likely well-aligned and possibly undergo some level of crystallinity, leading to a reduction in molecular weight and, consequently, lower viscosity. Such conditions are ideal for injection molding applications where excellent flow properties are necessary for filling complex molds and achieving high-quality surface finishes.

However, beyond 250 rpm, the MFI demonstrates a slight decrease at 350 rpm. This reduction suggests the onset of thermal degradation, where excessive heat might be breaking down the polymer chains too much, leading to a loss of some desirable mechanical properties. This behavior underscores the delicate balance required in the extrusion process: too little shear and heat result in poor flow, while too much can degrade the material.

The results depicted in Figure 1 also include a comparison with a non-extruded direct injection reference sample of polypropylene, which consistently shows lower MFI values across all test conditions. This comparison starkly highlights the effectiveness of the extrusion process at enhancing the polymer's flow characteristics under controlled conditions. The non-extruded reference serves as a baseline to underline the substantial improvements in flowability achieved through extrusion at the correct screw speeds.

These findings are crucial for optimizing extrusion parameters, particularly for manufacturing processes that rely on precise control of polymer flow to achieve product consistency and quality. The optimal screw speed of 250 rpm provides a specific target for industrial settings, where maintaining this speed can lead to superior product characteristics and more efficient manufacturing operations.

2- Tensile Properties at Yield

In exploring the tensile properties of polypropylene at various screw speeds, Figure 2 presents the stress-strain curves for each sample, including the non-extruded reference. These curves provide a visual representation of the material's behavior under tensile loading, illustrating how the polymer stretches with load increment. The curve for the sample extruded at screw rotation of 250 rpm showcases a higher elongation and a delayed necking point, indicating superior toughness and strength. In contrast, the non-extruded sample demonstrates a stiffer behavior with less elongation, underscoring the beneficial effects of the extrusion process on the material’s ductility and resilience.

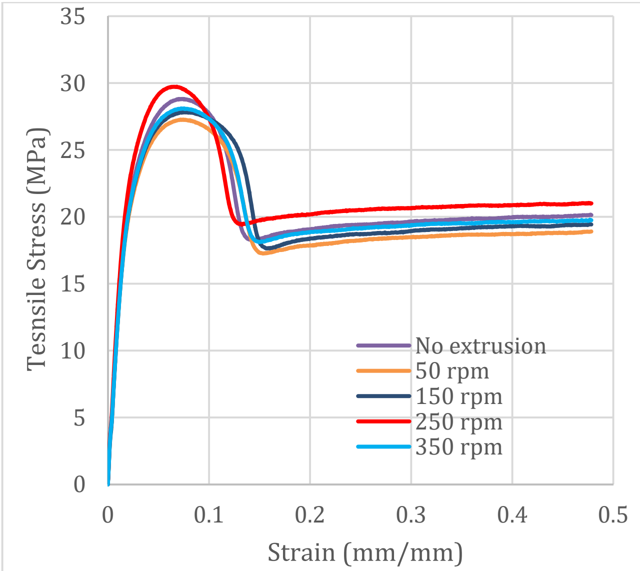

Fig. 2. *Stress-Strain curves for Polypropylene Across different processibility conditions.*

Figure 3 displays the yield stress for polypropylene at different screw speeds, providing a clear comparison of mechanical strength across the conditions tested. The yield stresses are as follows: non-extruded sample at 28.8 MPa, 50 rpm at 27.2 MPa, 150 rpm at 27.8 MPa, 250 rpm peaking at 29.7 MPa, and a slight decrease at 350 rpm to 28.1 MPa. This data confirms that 250 rpm is the optimal screw speed, as it results in the highest yield stress, indicating the strongest material performance under initial load. The lower yield stresses at 50 and 150 rpm suggest inadequate polymer alignment and insufficient heat application during processing, whereas the reduction at 350 rpm points to over-processing and potential thermal degradation of the polymer chains.

The graphical representation in Figure 3 also highlights the effectiveness of the extrusion process, particularly at 250 rpm, in enhancing polymer strength compared to the non-extruded baseline. This optimal speed enables the polymer to achieve better alignment and entanglement of chains, enhancing its load-bearing capabilities. The decline in yield stress beyond this point underscores the delicate balance required in extrusion settings to maximize mechanical properties without compromising the material's integrity.

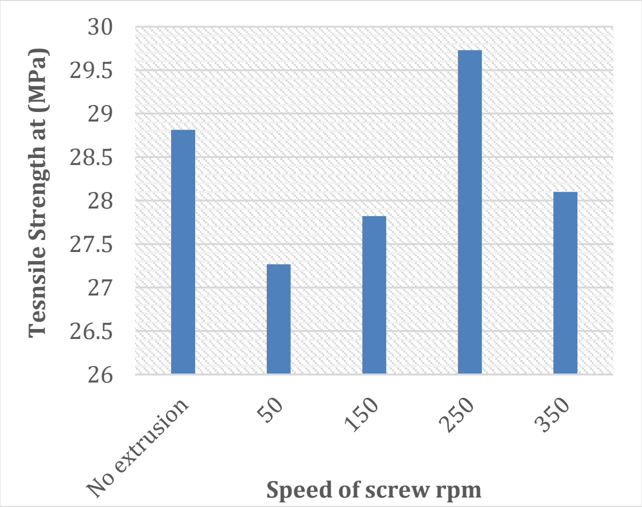

Fig. 3. *Yield stress of polypropylene at various screw speeds.*

Together, these figures illustrate the complex relationship between screw speed and polymer properties, emphasizing the need for precise control over extrusion parameters to achieve optimal material characteristics. The stress-strain curves and yield stress data provide compelling evidence for setting the screw speed at 250 rpm to optimize the tensile performance of polypropylene in industrial applications.

3- Hardness test

Figure 4 presents the D Shore hardness results for polypropylene samples extruded at screw speeds of 50, 150, 250, and 350 rpm, alongside a non-extruded reference sample. This figure provides a clear visualization of the impact of screw speed on the hardness of polypropylene, a critical property for applications requiring rigid and durable plastic components.

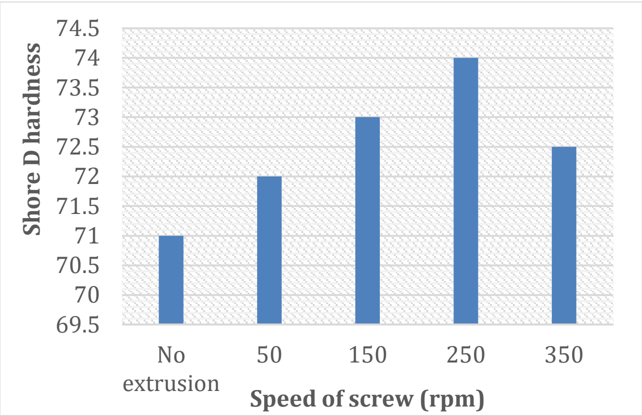

Fig. 4. *Results of D Shore Hardness for Polypropylene Extruded at Diverse Screw Speeds Ranging from 50 to 350 RPM.*

The hardness of the polypropylene increases steadily as the screw speed rises from 50 rpm to the optimal speed of 250 rpm. This increase suggests that the combination of thermal and mechanical conditions at 250 rpm is conducive to producing a polymer structure that is both tight and well-aligned, characteristics that contribute to increased hardness. The enhanced alignment and packing of the polymer chains at this speed likely result in a denser and stiffer material, which is reflected in the higher hardness values.

However, the trend reverses slightly at 350 rpm, where a decrease in hardness is observed. This decline can be attributed to the excessive shear and possibly higher temperatures that might degrade the polymer, leading to a loosening of the molecular structure, which reduces hardness. Such conditions can cause breakage in the polymer chains or create irregularities in the molecular alignment, adversely affecting the material's structural integrity and hence its hardness.

V. CONCLOUSION

This study systematically evaluated the impact of different screw speeds on the properties of polypropylene using SABIC® PP 575P. Through extensive testing, including tensile strength, D Shore hardness, and melt flow index (MFI), it was determined that the optimal screw speed for enhancing the properties of polypropylene during extrusion is 250 rpm. This speed provides a balance that maximizes mechanical properties and flow characteristics, significantly improving upon the baseline provided by non-extruded polypropylene. The findings underscore the critical influence of screw speed on polymer extrusion outcomes, demonstrating that precise control can significantly enhance product quality.

While this research provides foundational insights into the effects of screw speeds on polypropylene properties, several avenues remain open for further investigation. Future studies could explore:

1- Longer-Term Performance

Assessing the long-term durability and performance of polypropylene products produced at the identified optimal screw speed to understand the implications of these processing conditions over time.

2- Process Optimization

Exploring the interaction between screw speed and other extrusion parameters, such as barrel temperature, feed rate, and die geometry, to optimize further the extrusion process for quality and efficiency.

3- Environmental Impact Study

Investigating the environmental impacts of different extrusion speeds, particularly focusing on energy consumption and material waste, to promote sustainable manufacturing practices in the polymer industry.

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