

Die Build-Up Generation and Improvement in a Case of Polypropylene Film Extrusion Process

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Abstract

Die build-up is a persistent issue in plastic film extrusion, causing surface defects, product inconsistencies, and increased machine downtime. The use of Polymer Processing Aids (PPAs) is used in industry to reduce Die build-up. The aim of this study is to investigate the effect of PPA to reduce DBU during polypropylene (PP) cast film extrusion. In a first step, four different PP formulations with three manufacturing conditions are evaluated in order to get DBU. Then, in a second step, reduction of DBU is performed using the formulation with the highest DBU tendency with 1 phr and 3 phr PPA additives. Experimental results, observed over 30 minutes, indicate that the incorporation of 3 phr PPA significantly reduces DBU, improves film surface quality, and reduces the need for frequent equipment cleaning. The findings demonstrate the potential of PPA as a practical solution to enhance extrusion process stability and operational efficiency.

Keywords: Polypropylene, Die build-up, Cast film extrusion, and Processing aid.

1. Introduction

One of the essential qualities of film production is its ability to protect products from air exposure, thereby preventing rapid deterioration. These protective films are manufactured using extrusion machines, a widely used polymer processing technique for producing thin plastic films essential in packaging, agriculture, construction, and consumer goods industries. This process enables the continuous production of uniform films with excellent mechanical, thermal, and barrier properties.

Sheet/Film extrusion can be performed using different methods, including blown film

extrusion and cast film extrusion, depending on the desired film properties and applications. However, one of the major challenges in this process is "Die Build-Up", which accumulates on the die surface and necessitates frequent cleaning, often on a weekly basis [1]. This build-up compromises film quality, leading to imperfections such as die lines [2], particularly when the machine operates continuously for extended periods.

Die build-up (DBU) refers to the continuous accumulation of polymer resin on the die surface during the extrusion process [3]. This phenomenon occurs when the polymer resin

comes into contacting with the outer mold surface, where a thermal oxidation reaction takes place (Figure 1). When processing the velocity profile exhibits a steep gradient across the flow channel, particularly under high output rates (Figure 2). This results in elevated shear rates near the die wall, which in conventional polymers leads to pronounced die-swell, a phenomenon where the extrudate expands upon exiting the die. Over time, this reaction leads to the deposition of degraded material along the die exit, resulting in the formation of die lines on the extruded film. These imperfections can compromise product quality, leading to surface defects, variations in thickness, and potential production inefficiencies. Die build-up is a complex issue influenced by a combination of physical, chemical, and environmental factors, which interact to determine the extent and severity of the accumulation.

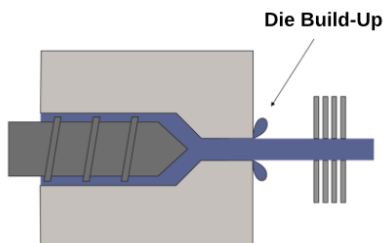


Figure 1 Die build-up concept

To address this issue, Polymer Processing Additives (PPA) are frequently employed to modify polymer flow behavior and reduce surface adhesion. PPAs, typically fluorinated or silicone-based compounds, migrate to the polymer-metal interface during processing, forming a lubricating layer that minimizes polymer sticking and delays surface build-up. PPA effectively address two key challenges in polypropylene extrusion: excessive die-swell and die build-up. When added to the polymer melt, PPA modifies the flow behavior by

reducing shear stress and creating a lubricating layer at the polymer-metal interface (Figure 2). This dual action leads to smoother material flow through the die. The reduced shear stress minimizes the elastic recovery of the polymer as it exits the die, resulting in less die-swell and better dimensional accuracy of the extruded product. Simultaneously, the lubricating effect prevents molten polymer from adhering to the die surface, significantly reducing material accumulation. These improvements allow for longer production runs with more consistent output quality and fewer interruptions for die cleaning. The effectiveness of PPA depends on using the proper concentration. Insufficient amounts may not provide full benefits, while excessive amounts could potentially affect other material properties. The experimental results presented in later sections demonstrate how different PPA loadings influence these extrusion characteristics, helping identify optimal formulations for industrial applications. This practical solution offers manufacturers a reliable way to enhance process efficiency while maintaining product quality in polypropylene extrusion operations.

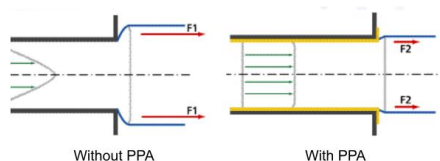


Figure 2 Effect of PPA on flow behavior [3]

This research employs an experimental approach to investigate the factors affecting DBU in polymer extrusion processes. The study first identifies processing conditions that promote DBU formation to enable systematic analysis, with particular focus on temperature parameters and material formulations. Subsequently, the

investigation examines DBU reduction strategies through the incorporation of polymer processing additives (PPAs) in polypropylene systems.

The study aims to identify critical DBU-inducing factors and develop effective solutions to minimize this phenomenon, thereby improving final product quality while reducing operational downtime. Following a detailed presentation of materials and processing methods, the work analyzes key factors influencing DBU formation before experimentally evaluating PPA effectiveness in DBU mitigation.

2. Materials and methods

2.1 Materials

2.1.1 Polypropylene

For this experiment, the primary material used was Polypropylene (PP), and its properties are provided in Table 1, and different composition of PP has been used and the Table 2 categorizes the three formulas (PP-11, PP-15, and PP-20).

Table 1. Properties of the polypropylene (PP).

Property	Value	Unit
Density	0.91-0.94	g/cm ³
Tensile strength	3200-5000	Psi
Water absorption	0.01	%
Elongation	3-770	%
Softening point, T _g	140-150	°C
Melting point, T _m	160-166	°C
Thermal expansion	5.8-10	°C
Specific volume	30.4-30.8	cm ³ /lb

Table 2. Data of Polypropylene grades.

PP Grade	PP-11	PP-15	PP-20
Type	Homo	Homo	Homo
Melt flow index D1238	11	15	20

Melt flow rate	230°C (2.16 kg)	230°C (2.16 kg)	230°C (2.16 kg)
Process temperature (°C)	Injection 200-240 / extrusion 240-280	Injection 160-240	Injection 200-250 / extrusion 188-220

2.1.2 Compositions

In order to create die built-up, experiments were conducted by mixing different grades of Polypropylene, labeled as 1, 2, 3, and 4 where their respective compositions are given into the Table 3.

The formula 1 blend (50% PP-11 + 50% PP-20) combines a low and high MFI material, creating a balanced system where the PP-11 contributes melt strength while the PP-20 enhances flow, potentially reducing die build-up by minimizing shear-induced degradation. In contrast, the formula 2 blend (70% PP-15 + 30% PP-20) is dominated by the medium-flow PP-15, which may offer moderate processability but could still lead to some die build-up due to insufficient flow optimization from the lower PP-20 content. The formula 3 blend (50% PP-15 + 50% PP-20) contains equal parts of medium and high MFI polymers, which might lower viscosity but risk flow instability due to the high proportion of PP-20, possibly worsening build-up. Meanwhile, the formula 4 blend (60% PP-15 + 40% PP-20) strikes a middle ground between C2 and C3, slightly improving flow over C2 but potentially still facing challenges if the PP-15's intermediate viscosity doesn't sufficiently counteract shear stress.

Table 3. the ratio for the experiment to generate die build-up.

Sample	Ratio (%)			
Formula	C1	C2	C3	C4
PP-11	50			
PP-15		70	50	60
PP-20	50	30	50	40

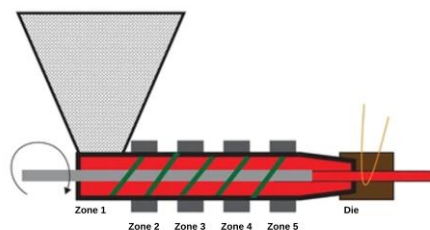


Figure 3 Process description

2.1.3 PPA additive

Processing Aid Additives (PPA) assist in high heat dissipation and thermal stability, which can contribute to die build-up during polymer processing. To reduce die build-up phenomena, PPA was incorporated into formula at concentrations of 1 phr and 3 phr (Table 4). This experiment will allow us to assess the effect of PPA on die build-up duration, providing insights into its effectiveness in reducing accumulation over time.

2.2 Extrusion process

The experimental conditions were optimized by our anonymous industrial partners, who reported this problem. The manufacturing process begins with the weighing of 5 kilograms of each formula. The weighed materials are then introduced into the cast film extrusion system, where processing conditions are carefully controlled. The extrusion process is conducted at a screw speed of 190 rpm, with temperature settings in different zones to ensure proper material flow and thermal stability (Figure 3).

Table 5 process condition.

Condition	Temperature profile (zone) (°T)					Die (°T)	Color Master Batch (white)
	1	2	3	4	5		
A	180	200	240	260	260	200	No
B	180	200	240	260	260	200	10 phr
C	290	295	300	300	300	280	10 phr

For each formula (Table 3), three process conditions (A, B, and C) were investigated (Table 5). The temperature in Zone 1 is set to 190°C for conditions A and B, while it is increased to 290°C for condition C. A temperature of 200°C is used in Zone 2 for conditions A and B, and a higher value of 295°C is applied for condition C. In conditions A and B, the temperature of Zone 3 is maintained at 240°C, while Zones 4 and 5 are kept at 260°C. For condition C, Zones 3 to 5 are held at a constant temperature of 300°C. The material then reaches the die zone, where the temperature is reduced to 200°C for conditions A and B and 280°C for condition C. To facilitate the understanding composition 1 under condition A will be noted A1 as example.

To analyze die build-up, time checks are performed at 0, 5, 15, and 30 minutes, allowing for a systematic evaluation of material behavior over time. Die build-up has been quantified using visual inspection following the industrial process.

3. Result and discussion

3.1 Effect of composition

Under Condition A (Table 5), the polymer melt could not be differentiated (Figure 4). Moreover, no die build-up (DBU) was observed after 30 minutes, regardless of the formulation (Table 3).

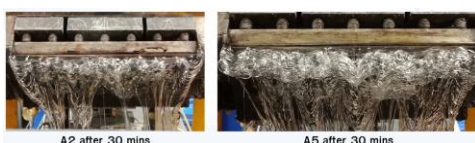


Figure 4 Die build-up observed from the die surface in cast film extrusion formula A2 and A5 at 30 minutes.

To facilitate the observation of DBU, color was added (Condition B, Table 5). However, experimental observations showed that no DBU was detected after 30 minutes (Figure 5), for any of the formulations (Table 3).



Figure 5 Die build-up observed from the die surface in cast film extrusion formula B1 and B3 at 30 minutes.

Finally, Condition C (higher temperature, Table 5) was investigated. DBU was observed within 5 minutes of extrusion. In the initial stage, the effect of time was examined. After 5 minutes of extrusion, significant DBU was visible. Thus, increasing the temperature promoted polymer degradation, leading to DBU formation (Figures 6-8). Among Conditions C1–C4, the C1 formulation exhibited the most severe DBU. As a result, C1 was selected for further modification with a polymer processing aid (PPA) to mitigate DBU.

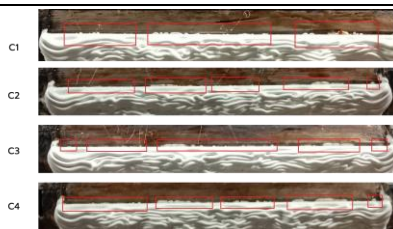


Figure 6 Die build-up observed from the die surface in cast film extrusion formula C1 at 5 minutes.

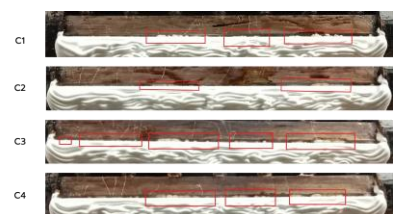


Figure 7 Die build-up observed from the die surface in cast film extrusion formula C1 at 15 minutes.

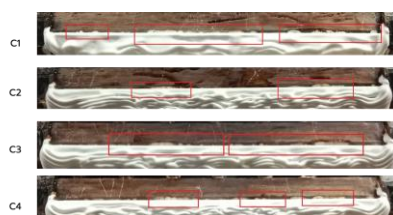


Figure 8 Die build-up observed from the die surface in cast film extrusion formula C1 at 30 minutes.

The analysis of Figure 9 reveals clear differences in build-up length among the four untreated conditions (C1–C4). Sample C2 demonstrates the lowest accumulation, suggesting it may represent either a more stable configuration or one with inherent resistance to the build-up process. In contrast, samples C1 and C4 exhibit significantly higher build-up values, indicating these conditions are more prone to material accumulation. The intermediate position of C3 suggests a gradation in build-up propensity across the tested conditions. These baseline measurements provide crucial reference points for evaluating the effects of subsequent treatments,

particularly the PPA light intervention shown in later figures.

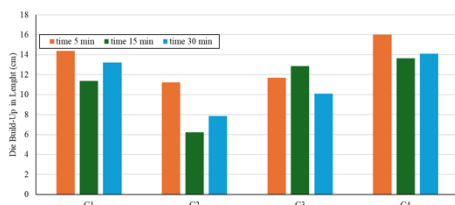


Figure 9 Build Up in Length (cm) for Untreated Conditions (C1-C4), compared to the die-lip total length of 30 cm.

3.2 Effect of PPA

From the experimental results, it was observed that all formulas (C1 to C4) exhibited varying degrees of die build-up in the absence of additives. Among these, Formula C1 showed the highest severity of build-up, making it a critical candidate for additive testing. Upon incorporating PPA into C1 at 1 phr and 3 phr concentrations (Table 4), a progressive reduction in die build-up was observed (Figure 8-10). Notably, the formulation C1 + PPA (3 phr) demonstrated the most effective reduction, with significantly less residue at all time intervals (5, 15, and 30 minutes), as shown in Figures 10 and 12.

This result confirms that Formula C1 with 3 phr of PPA offers the best performance, improving surface cleanliness and reducing the potential for film defects and machine downtime. It is therefore identified as the most desired configuration among those tested for enhancing extrusion efficiency and maintaining film quality.

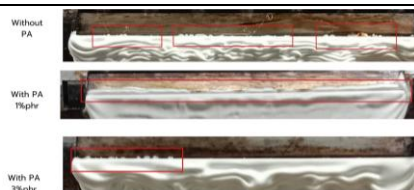


Figure 10 Die build-up from the die surface in cast film extrusion formula C1, C1+PA 1 phr and C1+PA 3 phr and at 5 minutes.

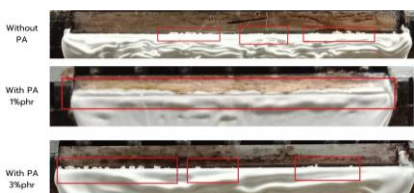


Figure 11 Die build-up observed from the die surface in cast film extrusion formula C1, C1+PA 1 phr and C1+PA 3 phr and at 15 minutes.

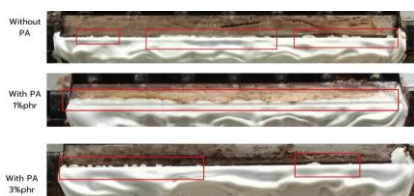


Figure 12 Die build-up observed from the die surface in cast film extrusion formula C1, C1+PA 1 phr and C1+PA 3 phr and at 30 minutes.

The analysis of Figure 13 reveals significant trends in die build-up (DBU) behavior for the tested formulations over time. The graph illustrates material accumulation on the die surface during cast film extrusion for the base composition (C1), C1+PPA 1 phr, and C1+PPA 3 phr, measured at intervals of 5, 15, and 30 minutes. The total die-lip length (30 cm) serves as a reference.

The base composition, C1, exhibits a DBU ranging between approximately 10 and 15 cm, indicating moderate but consistent material accumulation. In contrast, the addition of 1 phr

PPA results in a significantly higher DBU, reaching the maximum reference value of 30 cm across all time intervals. This suggests that the lower PPA concentration exacerbates build-up without showing a time-dependent effect.

At the higher PPA concentration (3 phr), DBU is markedly reduced compared to both C1 and C1+PPA 1 phr, with values ranging between 2.5 and 10 cm. Furthermore, a clear time effect is observed: DBU increases linearly with extrusion time, though it remains well below the levels seen in the other formulations. By the 30-minute mark, DBU for C1+PPA 3 phr reaches approximately 10 cm, still significantly lower than the 30 cm observed for C1+PPA 1 phr.

The 3 phr PPA concentration demonstrates the best performance in terms of DBU reduction, despite the gradual increase over time. These results highlight the concentration-dependent role of PPA in mitigating die build-up, with the higher concentration (3 phr) offering the most effective suppression of material accumulation under the tested conditions. Further investigation could explore the mechanisms behind PPA's dual effects and optimize its use for industrial applications.

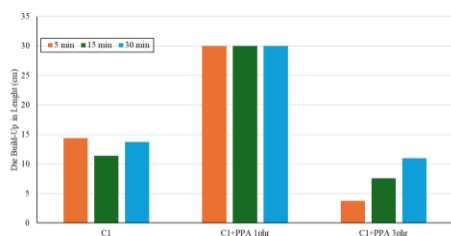


Figure 13 Die build-up observed from the die surface in cast film extrusion formula C1, C1+PA 1 phr and C1+PA 3 phr at 5, 15 and 30 minutes, compared to the die-lip total length of 30 cm.

4. Conclusion

In this study, reduction of DBU has been studied by analyzing the effect of PPA additive addition. In a first step, effect of injection temperature and PP concentration have been investigated in order to create DBU. Then, using the worst case, DBU reduction has been studied by adding into the polypropylene composition different PPA percentage. The experimental results confirm that die build-up is influenced obviously by the introduction of PPA additives. PPA significantly mitigates die build-up, with 3 phr showing the most effective reduction. These findings suggest that incorporating PPAs into PP polymer formulations can be a practical strategy for enhancing the extrusion process by reducing surface defects, minimizing equipment downtime, and improving overall product quality.

However, the future research should focus on optimizing PPA formulations and investigating their long-term effects on die performance and film extrusion stability. Future studies will extend PPA testing to generalize the additive's effectiveness across a broader range of polypropylene blends. Moreover, long-term effects such as PPA residue formation, aging behavior of the films, and potential impact on equipment maintenance will be evaluated to ensure sustainable adoption in industrial settings.

5. Acknowledgments

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