Processability Assessment of HDPE/UHMWPE Blends for Fused Deposition Modeling Applications

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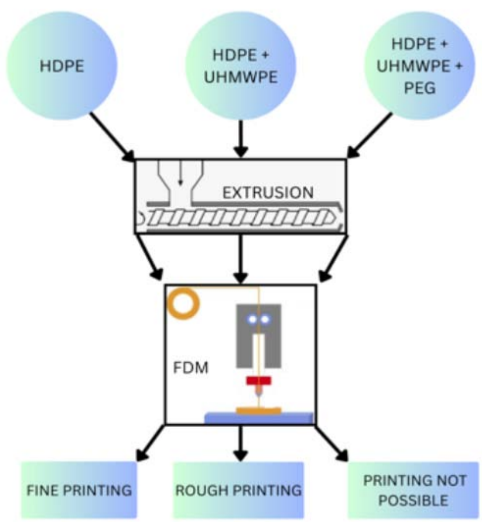
Abstract: Ultra-high molecular weight polyethylene (UHMWPE) is highly regarded for its superior mechanical properties, chemical resistance, and biocompatibility. However, its extremely high melt viscosity inhibits direct use in extrusion-based additive manufacturing techniques like fused deposition modeling (FDM). This study explores enhancing the processability and FDM compatibility of UHMWPE by blending it with high-density polyethylene (HDPE) and polyethylene glycol (PEG). Three formulations were assessed: neat HDPE, a 70:30 (w/w) binary HDPE/UHMWPE blend, and a ternary blend of HDPE/UHMWPE/PEG at 60:30:10 (w/w/w). Consistent with prior literature, pure HDPE displayed stable extrusion and excellent filament quality facilitating high-fidelity prints. The binary blend allowed filament formation but showed rough surface morphology and compromised print quality due to poor miscibility, echoing similar challenges reported in polymer blend studies. The ternary blend, intended to improve melt flow via PEG plasticization, resulted in erratic filament diameter and unreliable extrusion, highlighting the delicate balance needed in additive incorporation. These outcomes confirm that HDPE incorporation improves UHMWPE extrusion capabilities; however, advanced compatibilization techniques and refined processing, such as twin-screw extrusion, remain essential for achieving dependable FDM performance. The findings offer critical insights for designing UHMWPE-based filaments tailored for biomedical and industrial additive manufacturing applications.

Keywords: Ultra-High Molecular Weight Polyethylene (UHMWPE), High-Density Polyethylene (HDPE), Polyethylene Glycol (PEG), Polymer Blends, Additive Manufacturing, Fused Deposition Modeling (FDM).



Blending strategies to enhance UHMWPE processability and FDM compatibility.

HIGHLIGHTS

- HDPE enhances UHMWPE extrusion for FDM.
- PEG aids flow but compromises stability.
- Poor miscibility hinders print quality.
- Direct HDPE-UHMWPE filament is viable.
- Shear mixing affects blend uniformity.

1. INTRODUCTION

Additive manufacturing (AM), particularly fused deposition modeling (FDM), has gained substantial attention for its ability to produce customized, complex polymer structures with minimal material waste. Among the wide array of thermoplastics used in FDM, polyolefins such as polyethylene (PE) have shown promise due to their chemical resistance, durability, and biocompatibility. However, their widespread use in 3D printing is limited, primarily due to challenges related to melt processability and interfacial adhesion during layer-by-layer deposition [1,2].

Ultra-high molecular weight polyethylene (UHMWPE) is a high-performance thermoplastic known for its exceptional mechanical strength, outstanding abrasion resistance, and very low coefficient of friction. With molecular weights typically exceeding 3×10^6 g/mol, UHMWPE offers superior impact resistance and chemical inertness compared to conventional PE grades [3,4]. These properties make it ideal for demanding biomedical and engineering applications. However, its extremely high melt viscosity results in negligible melt flow, preventing direct use in conventional extrusion and FDM techniques [5,6].

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Recent advancements in polymer processing and additive manufacturing have renewed interest in developing novel polyethylene-based blends that combine functional performance with printability. To overcome UHMWPE's melt-flow limitations, blending it with more processable polymers such as high-density polyethylene (HDPE) has been widely explored. HDPE-a linear, semicrystalline polymer-offers good melt flow and thermal stability, making it suitable for conventional processing methods [7,8]. Blends with UHMWPE have demonstrated synergistic improvements in processability and mechanical properties when compared to neat components [9,10]. By leveraging synergistic effects among constituent polymers, such as UHMWPE's strength and HDPE's processability, researchers aim to engineer composite materials tailored for high-performance 3D printing.

Integrating a plasticizer like polyethylene glycol (PEG) into UHMWPE/HDPE blends has shown promise. PEG acts as a melt-flow enhancer and compatibilizer, reducing viscosity and improving dispersion of UHMWPE particles in the HDPE matrix [11,12]. Moreover, the incorporation of PEG facilitates polymer chain mobility during melt flow, which is critical for achieving smooth extrusion and interlayer fusion in FDM. However, its effect must be carefully balanced to prevent mechanical strength degradation at higher concentrations [13].

Despite this progress, controlling interfacial adhesion and minimizing void formation during printing remain significant challenges. Furthermore, the thermomechanical behaviour and print fidelity of these blends under FDM-specific thermal gradients are still not well understood. Previous studies have investigated extrusion-based processing and melt rheology of HDPE/UHMWPE blends [5,9,14,15], yet limited research exists on FDM-specific compatibility. Understanding the interplay between blend composition, extrusion stability, and print quality is essential for optimizing such systems for practical deployment. Additionally, material compatibility with commercial FDM hardware—especially nozzle tolerance, temperature control, and feeding consistency—warrants further investigation.

This study addresses these gaps by evaluating three formulations—neat HDPE, a 70:30 HDPE:UHMWPE blend, and a ternary 60:40:10 HDPE:UHMWPE:PEG blend—focusing on extrusion behaviour, filament quality, and print performance for FDM-based applications. As industries increasingly seek sustainable and functional polymer systems for additive manufacturing, developing FDM-compatible UHMWPE-based blends could significantly expand their applications in biomedicine, packaging, and structural components.

2. MATERIALS

Three different materials were utilized in this study to develop blend-based filaments aimed at improving the processability of ultra-high molecular weight polyethylene (UHMWPE) for fused deposition modeling (FDM).

2.1. High-Density Polyethylene (HDPE Grade HD50MA180)

This material, obtained from Reliance Industries under the brand name Relene® HD50MA180, is a high-flow HDPE grade designed specifically for intricate, thin-walled injection-moulded products. It was supplied in the form of uniform granules (Figure **1a**). The grade features a melt flow index (MFI) of 20 g/10 min (ASTM D1238, 190°C/2.16 kg), a density of 0.950 g/cm³ (ASTM D1505), and a Vicat softening point of 123°C (ASTM D1525) [16]. It exhibits good stiffness (flexural modulus ≈ 900 MPa) and moderate tensile strength (~22 MPa) [16,17]. The narrow molecular weight distribution facilitates smooth extrusion and contributes to better dimensional stability of extruded filaments [16,18].

2.2. Ultra-High Molecular Weight Polyethylene (UHMWPE–POLIMAXX)

UHMWPE fine powder, acquired under the trade name POLIMAXX U311, is characterized by an average molecular weight of approximately 3 × 10^6 g/mol (Figure **1b**). It offers exceptional wear resistance, high impact strength, and chemical inertness, aligned with its design as a specialist resin for demanding applications [19]. However, its extremely high viscosity and near-zero melt flow index (<0.01 g/10 min) severely limit its standalone processability in thermal extrusion processes [20]. Consequently, it was utilized as a reinforcing phase in blend formulations to enhance mechanical performance while maintaining processability.

2.3. Polyethylene Glycol (PEG 4000)

Polyethylene glycol (PEG 4000), used as a plasticizer and compatibilizer, was supplied in the form of semi-crystalline flakes (Figure **1c**). With an average

Figure 1: Photographs of raw materials used for blend preparation: (**a**) high-density polyethylene (HDPE) granules displaying uniform, rounded morphology and smooth surface; (**b**) ultra-high molecular weight polyethylene (UHMWPE) in fine powder form; and (**c**) polyethylene glycol (PEG) flakes exhibiting irregular, crystalline structure.

molecular weight of 4000 g/mol, PEG was incorporated to improve melt compatibility and blend processability. It was expected to enhance interfacial adhesion between HDPE and UHMWPE and assist in reducing blend viscosity during extrusion [21].

All materials were used without further modification or chemical treatment.

3. LITERATURE REVIEW: BLEND PREPARATION AND EXTRUSION

Blending ultra-high molecular weight polyethylene (UHMWPE) with high-density polyethylene (HDPE) is a widely adopted strategy to overcome UHMWPE's extremely high melt viscosity, which limits its processability in extrusion-based applications such as fused deposition modeling (FDM). HDPE, being a melt-processable thermoplastic with moderate viscosity and good flow properties, acts as a carrier matrix that facilitates the extrusion of UHMWPE when used in binary blends. A 70:30 HDPE:UHMWPE composition has previously demonstrated improved processability while retaining some of UHMWPE's desirable mechanical and wear-resistant properties [22-27].

To further tailor the melt rheology and enhance printability, low-molecular-weight poly-ethylene glycol, (PEG 4000) is often introduced as a plasticizer or processing aid. PEG can reduce melt viscosity, enhance interfacial compatibility, and improve the dispersion of UHMWPE particles within the HDPE matrix [28-30,33,34]. A ternary blend ratio such as 60:40:10 (HDPE:UHMWPE:PEG) is rational, as it maintains the structural backbone from HDPE while allowing UHMWPE to contribute strength and PEG to modulate flow [31,32,35].

The blends are typically processed through melt extrusion, where parameters such as temperature profile, screw speed, and residence time significantly affect homogeneity. While single-screw extruders are often used for simplicity, twin-screw extrusion is recommended in literature for better distributive and dispersive mixing of high-viscosity polymers like UHMWPE [38-43]. Proper screw configuration and control of shear zones are essential to achieving blend uniformity and avoiding degradation or phase separation [44-48].

Rationale for selected ratios. The decision to employ a 70:30 HDPE:UHMWPE composition is supported by literature identifying this range (20–35 wt% UHMWPE) as a practical limit for extrusion-based processing. Within this window, UHMWPE contributes its well-known strength and abrasion resistance, while HDPE ensures adequate melt flow. Higher UHMWPE contents typically raise the melt viscosity beyond the extrusion capability of conventional setups, producing unstable filaments and processing defects [22-27].

For ternary blends, PEG has been widely reported as a low-molecular-weight additive that reduces melt viscosity, enhances wetting of UHMWPE within the HDPE matrix, and stabilizes flow. Studies indicate that small additions of PEG (≈5–10 wt%) are sufficient to achieve noticeable improvements in processability, while larger amounts can compromise mechanical integrity and lead to strand softening. Consequently, the 60:40:10 formulation was selected to balance the backbone strength from HDPE, the reinforcing effect of UHMWPE, and the rheological tuning provided by PEG [31,32,35].

These blend ratios therefore reflect well-documented processing boundaries rather than trial-and-error selection, aligning with previously reported findings on HDPE/UHMWPE and HDPE/UHMWPE/PEG systems [22-35].

3.1. Blend Preparation and Extrusion

Three different formulations were investigated to evaluate the extrusion behaviour and FDM compatibility of UHMWPE-based blends: (i) 100% HDPE (HD50MA180), (ii) 70:30 HDPE:UHMWPE, and (iii) 60:40:10 HDPE:UHMWPE:PEG 4000 (all by weight). The individual components were directly weighed and fed into a single-screw extruder without any prior dry mixing or melt pre-processing. The extrusion experiments were carried out using laboratory-scale equipment at the Indian Institute of Technology (IIT) Bombay).

Single-screw extrusion is a widely adopted method for processing thermoplastics due to its operational simplicity, cost-effectiveness, and ability to handle moderate-viscosity polymers [49]. The extruder used in this study consisted of a horizontally mounted barrel with three independent heating zones, allowing for precise temperature control across the length of the barrel. Temperature settings were adjusted between 160°C and 200°C, depending on the blend formulation and its flow behaviour. The screw, typically designed with feed, compression, and metering sections, facilitated the conveyance, melting, and pressurization of the polymer blend toward the die [50].

The screw speed was maintained between 40–50 rpm, which ensured a steady throughput and minimized surging. Based on the throughput rate and barrel length, the average residence time was approximately 2–3 minutes, sufficient for complete melting and homogenization of the HDPE/UHMWPE/PEG blends. The die at the end of the extruder was a circular nozzle with a diameter of 1.75 mm, chosen to match standard filament dimensions used in fused deposition modeling (FDM) printers. The extruder also featured a gravity feed hopper for loading raw materials directly without pre-mixing.

Although twin-screw extruders are generally preferred for enhanced distributive and dispersive mixing of high-viscosity or immiscible systems [38-43], a single-screw extruder was deliberately chosen here to reflect the kind of equipment most accessible in laboratories and small-scale filament development setups. Prior reports confirm that single-screw machines, when operated under carefully controlled parameters, can produce sufficiently homogeneous HDPE/UHMWPE blends for processing studies [49,50]. Our use of single-screw extrusion therefore provides a realistic baseline for assessing the FDM compatibility of UHMWPE-based blends, while acknowledging that future optimization using twin-screw systems may further improve dispersion.

Filament uniformity was influenced by the shear profile and residence time within the extruder, highlighting the importance of thermal and mechanical tuning when working with high-viscosity or multi-component systems such as HDPE/UHMWPE/PEG blends [51,52]. Initially, a water bath cooling system was attempted to stabilize the extruded filament. However, in the case of neat HDPE, the sudden temperature drop caused warping and distortion of the filament due to thermal shock and uneven shrinkage. As a result, air cooling at ambient room temperature was adopted for all formulations, allowing the filament to solidify gradually. The extruded wire was then manually wound onto a take-up reel and inspected for surface quality and dimensional consistency prior to FDM trials.

4. FILAMENT FEEDING AND FDM PRINTING ON ENDER-SERIES DESKTOP 3D PRINTER

To evaluate the printability of the extruded filaments, both neat HDPE and HDPE: UHMWPE (70:30) blend filaments were tested using a commercial Ender-series desktop FDM printer. The printer was equipped with a 0.4 mm brass nozzle, heated bed, and direct-drive extrusion system. The nozzle temperature was maintained at 230°C, and the bed temperature was set to 90°C, optimized for HDPE-based materials to minimize warping and promote adhesion.

4.1. Neat HDPE Filament Printing

The filament derived from 100% HDPE (HD50MA180) exhibited excellent feeding characteristics. The filament maintained a consistent diameter close to 1.75 mm, enabling smooth passage through the extruder gear and hot end. No jamming or skipping of the feeder motor was observed. During printing, melt flow was stable, and layer deposition was continuous, resulting in parts with clear perimeters, minimal stringing, and good inter-layer adhesion. The bed adhesion was also satisfactory when used with a suitable build surface (e.g., PEI or lightly sanded masking tape).

The printed parts showed uniform texture and dimensional accuracy, with no signs of delamination or distortion. These results confirm that virgin HDPE is fully compatible with desktop FDM setups, provided optimized thermal and mechanical settings are used.

In contrast, the HDPE: UHMWPE (70:30) blend filament posed several challenges during feeding and printing. Although the filament could be manually fed into the extruder, intermittent variations in diameter (~1.65 mm) and surface roughness led to occasional resistance at the feeder and nozzle entry. This caused inconsistent extrusion, and the stepper motor occasionally skipped or under-extruded material during printing.

During actual deposition, the printed tracks were visibly uneven, with poor surface finish, irregular bead widths, and signs of under-extrusion and clogging. These issues stem from incomplete melting of UHMWPE particles, poor interfacial adhesion within the blend, and lack of flow uniformity. The nozzle experienced partial blockage at times, likely due to agglomerated UHMWPE, which has negligible melt flow under the applied conditions.

Despite the partial compatibility of HDPE with the printing setup, the incorporation of UHMWPE in significant proportion without proper compatibilization or twin-screw blending led to sub-optimal printing performance, rendering the part structurally and visually deficient.

5. RESULTS AND DISCUSSION

5.1. Morphological and Dimensional Analysis of Extruded Filaments

The visual and dimensional characteristics of the extruded filaments from the three formulations-neat HDPE, HDPE:UHMWPE(70:30), and HDPE:UHMWPE: PEG (60:40:10)-were evaluated to assess extrusion quality, filament uniformity, and suitability for FDM printing.

The filament on the right, composed of neat HDPE (HD50MA180), shows a smooth, uniform, and glossy appearance, indicating consistent extrusion, homogeneous melt flow, and good cooling behaviour. In contrast, the left filament, representing the HDPE: UHMWPE (70:30) blend, displays a rough, matte surface with visible irregularities, highlighting incomplete mixing and morphological incompatibility between the two polymers. These differences directly impacted feedability and print quality during FDM, with the neat HDPE filament producing high-quality prints, while the blend led to under-extrusion and poor surface finish.

The neat HDPE filament exhibited excellent surface finish, a uniform and glossy appearance, and consistent diameter (~1.75 mm) across the entire spool (Figure **2**). These traits indicate stable melt flow, good thermal response, and compatibility with the single-screw extrusion setup [53]. The filament maintained structural integrity and was easily wound without warping, making it fully compatible with FDM printers.

In contrast, the HDPE:UHMWPE (70:30) blend filament demonstrated visible surface roughness, a matte finish, and occasional diameter fluctuations (~1.65 mm average, Figure **2**). The inclusion of UHMWPE introduced interfacial incompatibility and incomplete dispersion, leading to uneven extrusion and reduced dimensional stability. Though filament formation was successful, the feeding process during FDM was impaired by inconsistent layer deposition and poor print finish.

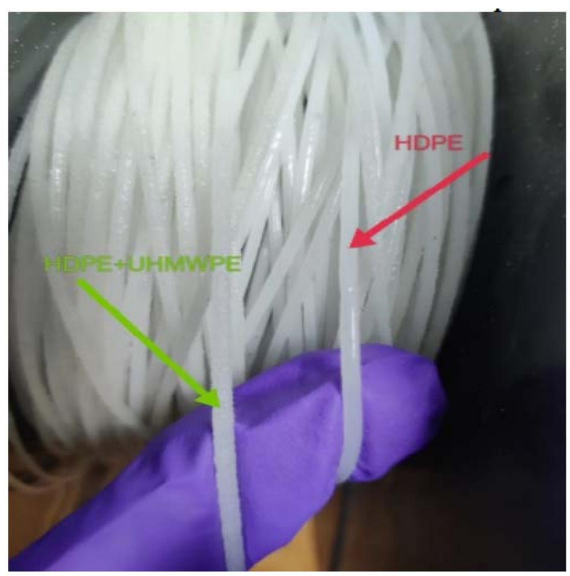

Figure 2: Visual comparison of extruded filaments: neat HDPE (right) and HDPE: UHMWPE (70:30) blend (left).

The filament shows (Figure **3**) a measurable diameter close to 1.65 mm, slightly below the standard 1.75 mm typically required for FDM printing. While the filament was extrudable and generally feedable, the deviation from the ideal diameter and the surface roughness observed in this blend led to inconsistent material flow during printing. Although the extruded filament had a slightly reduced diameter of approximately 1.65 mm, it exhibited continuous and uniform extrusion, indicating acceptable throughput behaviour. However, these dimensional variations, combined with surface irregularities, are attributed to melt incompatibility, poor dispersion of UHMWPE, and lack of interfacial adhesion, which ultimately affected strand uniformity and print quality [54].

Figure 3: Digital caliper measurement of HDPE:UHMWPE (70:30) extruded filament showing a diameter of approximately 1.65 mm.

Figure 4: Extruded filament of HDPE:UHMWPE:PEG (60:40:10) showing severe non-uniformity and curling.

The filament produced from the ternary blend of HDPE, UHMWPE, and PEG exhibited significant diameter fluctuations, ranging from as low as 0.88 mm to as high as 2.43 mm, as observed during measurement as seen in Figure **4**. The strand appears visibly distorted, curled, and structurally unstable, indicating poor melt strength and flow control during extrusion. The addition of PEG 4000, while intended to enhance blend fluidity, resulted in over-plasticization of the matrix, reducing viscosity to the point of melt instability. Furthermore, inadequate compatibility and insufficient shear mixing likely contributed to poor dispersion and localized phase separation [55]. As a result, the filament could not be consistently fed into the FDM printer and was unsuitable for printing applications.

These findings clearly indicate that while HDPE serves as a suitable base for filament formation, the inclusion of UHMWPE requires improved blending strategies or compatibilizers. PEG addition, without adequate formulation control, compromises filament stability due to excessive softening.

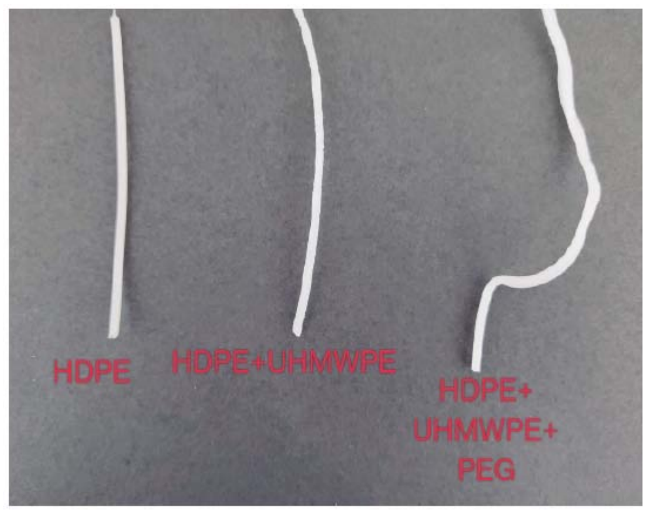

Figure 5: Visual comparison of extruded filament samples from the three formulations:100% HDPE, 70:30 HDPE:UHMWPE, and 60:40:10 HDPE:UHMWPE:PEG.

The neat HDPE filament on the far left appears straight, smooth, and consistent in diameter, indicating stable extrusion and a high-quality product suitable for FDM as shown in Figure **5**. The HDPE+UHMWPE filament in the middle shows a rough, matte surface with slight curvature, which is indicative of poor miscibility between the two polymers. Finally, the HDPE+UHMWPE+PEG filament on the right is highly irregular, displaying severe diameter fluctuations and significant curling, a result of over-plasticization and poor melt stability caused by the addition of PEG. This side-by-side comparison clearly illustrates the direct impact of different blend compositions on filament quality and, consequently, on their suitability for 3D printing applications.

5.2. Phase Separation and Compatibilization Strategies

The extrusion and FDM results highlight the inherent immiscibility between HDPE and UHMWPE, manifested in filament diameter fluctuations, rough surface morphology, and inconsistent print quality. This behavior is attributed to limited chain entanglement and the large disparity in molecular weights, which promote phase separation during melt flow [22-27]. Such separation reduces interfacial adhesion and hinders the formation of a homogeneous filament structure, as also noted in related extrusion-based processing studies [13,15].

To address these issues, various compatibilization strategies have been reported. One common approach is the addition of reactive compatibilizers, such as maleic anhydride-grafted polyethylene (PE-g-MA), which can chemically interact at the interface and enhance adhesion [29,30]. Alternatively, physical processing methods such as twin-screw extrusion or high-shear mixing are effective in improving the dispersion of UHMWPE particles by promoting better distributive and dispersive mixing [38-43]. Another promising route is the use of nanoparticle fillers (e.g., silica, clay, graphene oxide), which can act as interfacial bridges, reducing phase separation and contributing to mechanical reinforcement [31,32,35].

While the present study did not employ compatibilizers, recognizing these established strategies underscores the path forward for optimizing HDPE/UHMWPE/PEG blends for reliable FDM use. Future work will incorporate such modifications to evaluate their impact on filament homogeneity, interfacial strength, and overall printability.

5.3. FDM Printability of Virgin HDPE Filament

The filament prepared from 100% HDPE (HD50MA180) was successfully used in a fused deposition modeling (FDM) setup to fabricate a test geometry, as shown in Figure **6**. The printed part demonstrated excellent layer definition, minimal warping, and uniform line deposition. The clean edges and smooth surface finish are indicative of consistent melt flow, proper filament feeding, and good interlayer adhesion.

Figure 6: 3D printed part using neat HDPE (HD50MA180) filament showing excellent surface finish and dimensional accuracy.

The success of this print validates the suitability of HD50MA180-grade HDPE for direct extrusion-based 3D printing applications. Its high melt flow index (20 g/10 min) and narrow molecular weight distribution likely contributed to steady extrusion and reliable deposition during printing. Furthermore, the part did not exhibit common polyolefin issues such as delamination or shrinkage, confirming the dimensional stability of the filament during thermal cycling.

This outcome establishes virgin HDPE as a viable baseline material for filament fabrication and FDM printing. It also provides a critical reference for comparing the effects of UHMWPE and PEG inclusion in subsequent blend formulations.

5.4. FDM Performance of HDPE:UHMWPE (70:30) Blend Filament

The FDM process using the HDPE:UHMWPE (70:30) blend filament was attempted on an Ender-series desktop 3D printer, as shown in Figure **7**. During printing, the filament could be manually fed into the extruder; however, the printed part exhibited significant surface irregularities, including incomplete deposition, inconsistent layer width, and weak interfacial bonding.

These issues primarily stem from poor miscibility between HDPE and UHMWPE, resulting in non-uniform melt behaviour and erratic flow through the nozzle. Additionally, localized unmelted UHMWPE particles may have blocked the nozzle intermittently, further disrupting deposition. Although filament formation was successful, the dimensional instability (as previously observed around 1.65 mm diameter) and poor interfacial adhesion limited its printability.

Figure 7: 3D printed part using HDPE:UHMWPE (70:30) blend filament showing poor surface finish and inconsistent deposition.

Despite partial material compatibility, the blend's high viscosity and phase separation led to poor layer definition and rough print finish, making the printed geometry unsuitable for functional applications without further process or material optimization.

The HDPE:UHMWPE:PEG (60:40:10) ternary blend introduced PEG 4000 as a plasticizer to enhance melt flow. However, the resulting filament exhibited severe diameter fluctuations, ranging from 0.88 mm to 2.43 mm, as confirmed by digital caliper measurements. These variations disrupted the feeding process, resulting in unstable extrusion, filament curling, and nozzle clogging. Consequently, this filament failed to print reliably, and no functional part could be produced using standard FDM settings. The excessive plasticization likely led to melt instability, causing poor strand formation and structural collapse during extrusion.

These findings highlight the critical role of blend compatibility, molecular architecture, and flow behaviour in determining the FDM suitability of UHMWPE-containing systems.

5.5. Key Findings and Literature Validation

This study systematically examined the potential of HDPE/UHMWPE and HDPE/UHMWPE/PEG blends as feedstock for FDM filament fabrication. Neat HDPE exhibited consistent extrusion behavior and produced filaments with stable diameters, resulting in successful 3D printing runs with strong layer adhesion and satisfactory surface finish [11]. When 30% UHMWPE was incorporated into the HDPE matrix, filament formation remained possible, but pronounced surface irregularities and reduced diameter uniformity were observed. These characteristics were linked to phase separation and incomplete mixing, severely impacting print quality due to inconsistent material feed and nozzle blockages [3,7,8]. The inclusion of PEG as a processing aid further reduced melt viscosity, but also destabilized strand formation, leading to filaments with large diameter fluctuations, curling, and poor feedability [23-27].

These findings are solidly substantiated by contemporary literature. For instance, Wang *et al*. demonstrated that increasing HDPE content in UHMWPE blends improves processability, though phase incompatibility persists at higher UHMWPE fractions [56]. Similarly, Hortencio *et al*. reported that PEG additions can reduce viscosity and enhance dispersion in UHMWPE/HDPE blends, but excess PEG content compromises filament stability and mechanical performance [3,7,8,15-17,57]. A recent review by Banhegyi *et al*. highlighted that compatibilization and advanced processing strategies, particularly twin-screw extrusion, are critical for achieving uniform dispersion and strong interfacial adhesion in extrusion-based additive manufacturing [58]. Additionally, Zhang *et al*. confirmed that flow modifiers enhance the melt processability of UHMWPE/HDPE systems but can induce instability when not optimized [59].

Thus, the experimental observations in this work find strong validation in the scientific community's collective experience, underscoring the importance of blend optimization and processing controls for the successful application of UHMWPE-based materials in additive manufacturing.

6. CONCLUSION

This study evaluated the extrusion behavior and FDM suitability of HDPE-based blends incorporating ultra-high molecular weight polyethylene (UHMWPE) and polyethylene glycol (PEG). Virgin HDPE (HD50MA180) exhibited stable extrusion, dimensional uniformity, and consistent printability, reaffirming its reliability for additive manufacturing applications. The binary 70:30 HDPE:UHMWPE blend demonstrated partial filament formation but suffered from rough surface morphology and poor interlayer adhesion, reflecting the inherent immiscibility and weak interfacial bonding of the system. The ternary 60:40:10 HDPE:UHMWPE:PEG blend modified the melt rheology but introduced filament instability and erratic feeding behavior, underscoring the limitations of processing UHMWPE-rich formulations without compatibilization.

Overall, the findings emphasize that improving interfacial adhesion and achieving uniform melt flow are critical to enabling reliable use of UHMWPE in FDM. The integration of compatibilizers, such as maleic anhydride-grafted polyethylene, together with advanced processing strategies like twin-screw extrusion, is expected to mitigate phase separation and enhance blend uniformity. These approaches represent key pathways for unlocking the full potential of UHMWPE-based systems in additive manufacturing.

7. FUTURE DIRECTIONS

Future research should prioritize the incorporation of compatibilizers, including maleated polyethylene, grafted HDPE, or other functional copolymers, to strengthen interfacial adhesion and promote phase compatibility in HDPE/UHMWPE blends. The adoption of twin-screw extrusion is strongly recommended due to its superior distributive and dispersive mixing, which can significantly reduce phase separation and generate filaments with more consistent morphology. Complementary rheological and thermal analyses will be required to establish optimized processing conditions and to correlate melt behavior with FDM performance.

Additionally, integrating post-processing techniques such as annealing or solvent vapor smoothing may further improve surface finish and reduce internal stresses in printed parts. Collectively, these strategies will broaden the practical applications of UHMWPE-based filaments and enhance their structural and functional performance in additive manufacturing contexts.

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