GENERAL SYMPOSIA | INJECTION MOLDING

Impact of Glass Fiber Content and Packing Pressure on Weld Line Integrity in Injection Molded Short Glass Fibre Reinforced Polyamide

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Abstract: Managing the challenge of weld lines of short-fiber reinforced polymers (SFRPs) in injection molding is crucial for enhancing the mechanical performance of these composites. This study evaluates the impact of various glass fiber contents (0 to 50 wt%) within a polyamide 6 (PA6) matrix on the tensile and flexural properties at weld lines, comparing each sample to its counterpart without a weld line. Our findings indicate that weld lines have minimal impact on the mechanical properties of composites with low fiber content (10 wt%). However, at higher fiber contents, the strength, modulus, and strain at fracture are significantly reduced due to unfavorable fiber orientations at the weld lines. Increasing the packing pressure during injection molding can partially recover these properties by promoting favorable fiber orientation at the weld line. This signifies the importance of carefully controlling processing parameters to optimize the mechanical performance of SFRPs at weld lines.

Keywords: Injection Molding, Short-Fiber Reinforced Polymers, Weld Lines, Fiber Orientation

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Introduction

Injection molding is a widely used process for producing thermoplastic polymers and composites. A significant challenge in this process is the formation of weld lines, which occur when multiple flow fronts merge within the mold cavity. These weld lines can significantly deteriorate the mechanical properties of the finished product, particularly in short-fiber reinforced polymers (SFRPs). Stagnating weld lines, formed by the direct collision of flow fronts, are especially problematic as they restrict polymer flow and result in poor interface bonding [1].

In unfilled polymers, the mechanical properties at weld lines are degraded due to insufficient molecular diffusion and the presence of voids and V-notches, which create localized stress points. The reduction of mechanical performance is more severe in SFRPs featuring stagnating weld lines, where unfavorable fiber orientation at the weld line can lead to a reduction in mechanical properties of up to 50% . Near the weld line, fibers are oriented perpendicular to the flow direction as a result of elongational flow, whereas fibers near the mold walls outside the weld region align parallel to the flow direction due to the high shear stress. The perpendicular fiber alignment at the weld line disrupts the load transfer efficiency and creates weak points in the composite, thereby significantly diminishing its mechanical properties [2].

Extensive research has been conducted on how injection molding parameters affect weld line strength. For non-reinforced polymers, increasing the melt and mold temperatures generally improves weld line strength by promoting better polymer chain interdiffusion [3]. However, the effect of packing pressure remains debated. For reinforced polymers, fiber orientation at the weld line is a critical factor, and the literature presents conflicting views on how processing parameters influence this orientation [4].

Our previous study investigated the effects of weld lines on the mechanical properties of unfilled and glass fiber-reinforced PA6 [4]. We found that weld lines minimally impacted the mechanical properties of unfilled PA6 due to the matrix's high healing capability, as confirmed by DSC and oscillatory shear measurements. In contrast, glass fiber-reinforced PA6 composite showed significant reductions in mechanical performance at the weld lines due to unfavorable fiber orientation, with fractures primarily occurring at the weld line. We identified a bell-shaped fracture surface structure linked to the 'underflow' phenomenon caused by flow imbalances during injection molding, which affects fiber orientation. Processing parameters such as melt and mold temperatures had negligible effects on weld line strength, while increased packing pressures improved mechanical properties by intensifying the underflow and promoting more favorable fiber orientation at the weld line.

Building on our previous research, which focused solely on pure PA6 and its composite reinforced with 50 weight percent (wt%) glass fiber, the current study aims to investigate the impact of varying fiber content on the mechanical behavior of composites featuring stagnating weld lines. Specifically, we examined composites incorporating 0, 10, 20, 30, 40, and 50 wt% glass fibers within a PA6 matrix. This investigation seeks to clarify how different fiber contents affect the tensile and

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flexural properties of the composites. We have extended our analysis by incorporating both tensile and flexural tests, thereby providing a more comprehensive evaluation of the mechanical behavior of these materials.

Materials and Methods

Materials

For this study, a PA6 matrix equivalent to the one used in DOMAMID 6LVG50H2BK was used to compound various composites with different glass fiber content. This particular PA6 matrix is not commercially available and was thus supplied directly by Domo Chemicals. Composites containing 0, 10, 20, 30, 40, and 50 weight percent (wt%) of glass fibers were compounded using the supplied PA6 matrix. Advantex® chopped glass fibers, measuring 4 mm in length and 10 μm in diameter, were used in the compounding process. Tensile bars with and without weld lines were molded from each composite pellet. Prior to injection molding, both the PA6 matrix and glass fibers were dried for a minimum of 4 hours at 80°C.

Sample Preparation

To investigate the impact of fiber content on weld line strength, composites were produced using a two-step manufacturing process. Initially, chopped glass fibers were blended into virgin PA6 through compounding with a Leistritz ZSE18MAXX corotating twin-screw laboratory extruder. This process produced composites containing varying glass fiber content from 0 to 50 wt%. Following this, dog-bone-shaped tensile samples were produced via injection molding using an Arburg 320S machine. The mold cavity, designed with a cold sprue and runners, adheres to the ISO 527 standard and can produce two samples simultaneously. Dual gates positioned at opposite ends of each sample facilitate the formation of weld lines at the midpoint of each tensile bar. Filling the cavity from one side with the opposite gates closed results in samples without weld lines. The details and dimensional specifications of the mold cavity are shown in Figure 1. The packing pressure was systematically varied across three levels (40, 60, and 80% of the maximum injection pressure) to examine its effect on weld line strength.

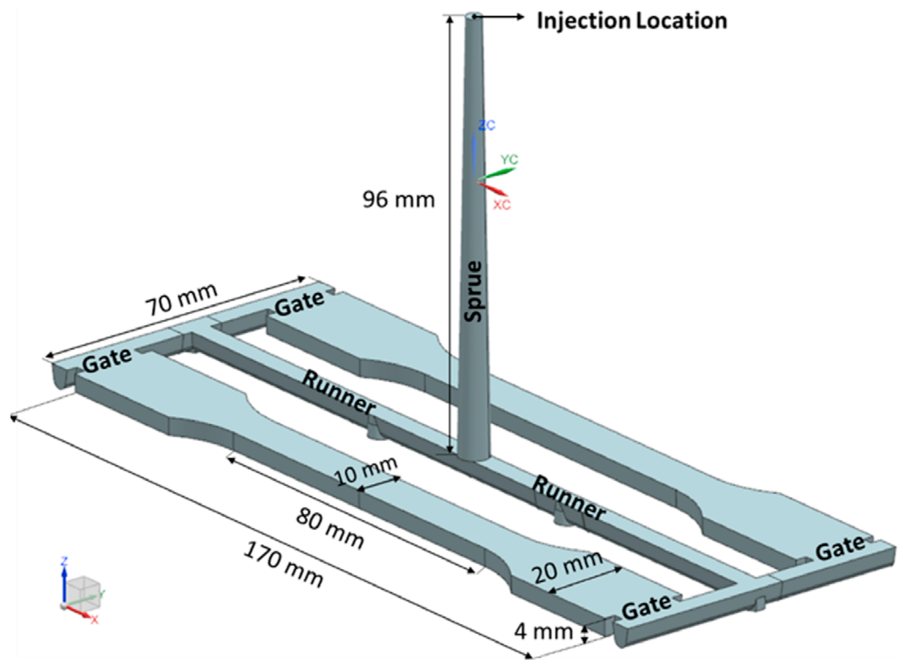

Figure 1. Details of the mold cavity used for producing dog-bone-shaped samples.

Tensile and Flexural Testing

Tensile tests were conducted on specimens with varying fiber content processed at different levels of packing pressure to measure tensile properties of samples, both with and without weld lines. Using an Instron 3367 two-column tensile bench equipped with a 30 kN load cell, and an extensometer for precise strain measurements, samples were tested at a crosshead speed of 1 mm/min following the ISO 527 standard. Mechanical properties such as maximum tensile stress, strain at fracture, and tensile modulus were recorded. Each category was tested with three specimens and the average results were reported. For flexural testing, three-point bending tests were performed according to the ISO 178 standard using an Instron 3345 single-column tensile bench with a 1 kN load cell. Samples were tested at a crosshead speed of 2 mm/min, and properties such as maximum flexural stress, strain at fracture, and flexural modulus were evaluated. To prevent moisture absorption, the injection molded samples were sealed immediately after injection molding.

Results and Discussions

In this section, we analyze the mechanical properties of PA6 composites reinforced with varying percentages of glass fibers to investigate the impact of weld lines and injection molding processing parameters on their tensile and flexural performance. Our previous research demonstrated that while melt and mold temperatures have minimal influence on weld line strength, packing pressure does play a critical role. By examining various fiber contents and adjusting packing pressures to 40%, 60%, and 80% of the maximum injection pressure during the molding process, we aim to clarify the complex interactions among mechanical properties at the weld lines, fiber content, and packing pressure.

Tensile and Flexural Strength

The effect of fiber content and packing pressure on the tensile and flexural strength of composites with stagnating weld lines is shown in Figure 2. Initial observations show minimal impact of weld lines on the tensile and flexural strength of pure PA6 and PA6 composite reinforced with 10 wt% glass fiber. This can be attributed to the lower fiber content, which does not significantly disturb the polymer matrix healing at the weld lines. As the glass fiber content increases to 20 wt% and beyond, a noticeable reduction in both tensile and flexural strength in samples with weld lines is evident, compared to their counterparts without weld lines. This reduction is more pronounced with increasing fiber content. Increased packing pressures show a mitigating effect on this strength reduction. For composites with 20 wt% or higher glass fiber content, higher packing pressures help improve the tensile and flexural strength, thereby partially restoring the mechanical properties. This suggests that the application of higher packing pressures facilitates better distribution and orientation of fibers at the weld lines, as shown in our previous study [4], contributing to a more effective fiber role in carrying tensile and flexural stresses.

It is also observed that flexural strength generally surpasses tensile strength across all composites. This phenomenon can be explained by the nature of the loading conditions during the tests. Flexural tests involve both tension and compression within the material, allowing the composites to better distribute and withstand stresses. In contrast, during tensile tests, the composite is subjected to a unidirectional force, which can lead to earlier failure due to the lack of fiber reinforcement, as many fibers are aligned perpendicular to the force direction at the weld line.

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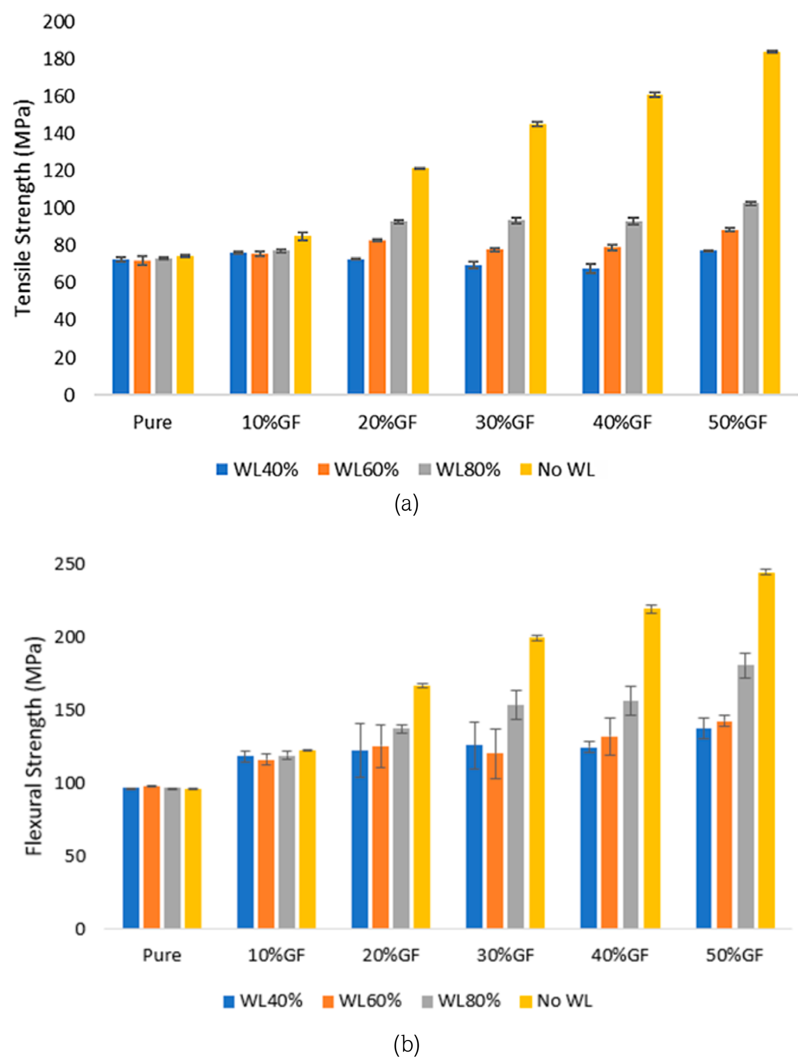

Figure 2. The effects of fiber content and packing pressure on the strength of composites with and without weld lines in (a) tension and (b) bending modes.

Tensile and Flexural Modulus

Similar trends in the influence of fiber content and packing pressure on the tensile and flexural modulus of composites with stagnating weld lines are observed, mirroring those seen in tensile and flexural strength. The presence of weld lines in pure and 10 wt% glass fiber composites shows minimal impact on their modulus, suggesting that the material's stiffness is predominantly governed by

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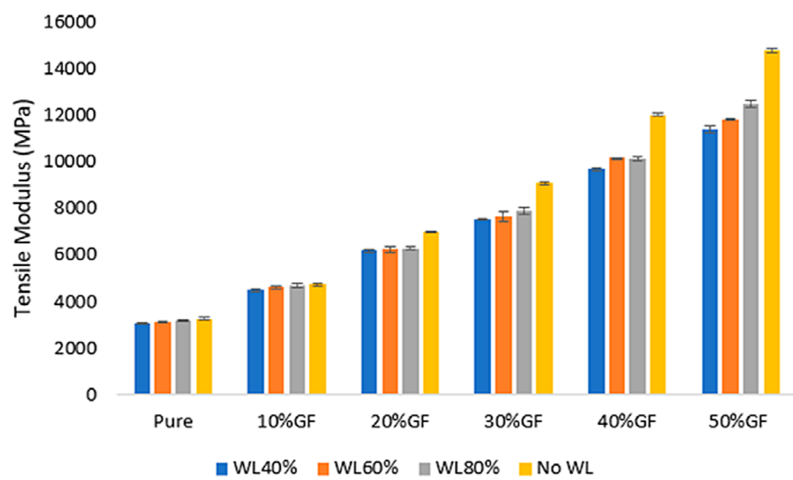
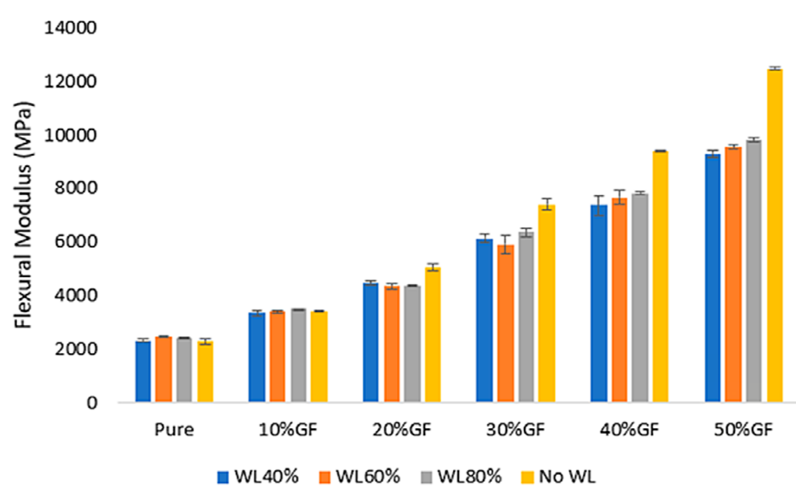
the polymer matrix in these lower fiber content composites. However, as the fiber content increases to 20 wt% and above, a significant reduction in both tensile and flexural modulus is observed at the weld lines. This reduction is primarily due to unfavorable fiber orientation at the weld line and the resulting inefficiency in load transfer capabilities within the composite.

The recovery of modulus with increased packing pressure further supports the concept that the fiber orientation at the weld lines is improved by increasing the packing pressure. The lack of a deflectometer during bending tests prevents a direct comparison between tensile and flexural modulus, highlighting a potential area for methodological improvement in future studies.



(a)



(b)

Figure 3. The effects of fiber content and packing pressure on the modulus of composites with and without weld lines in (a) tension and (b) bending modes.

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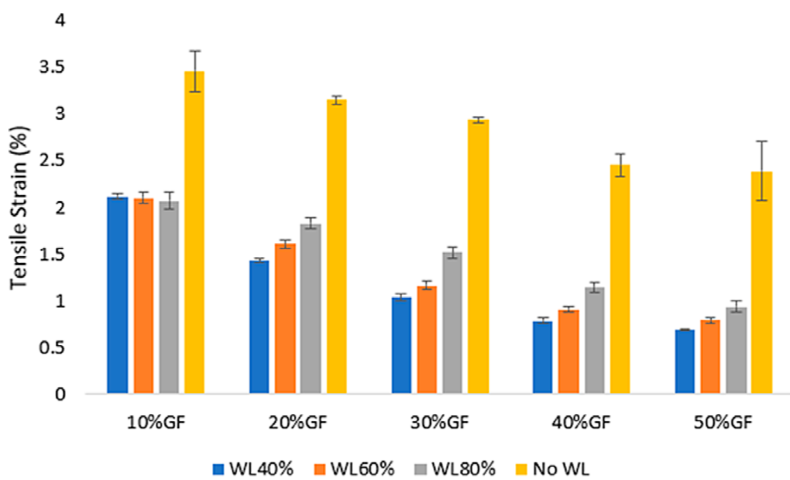
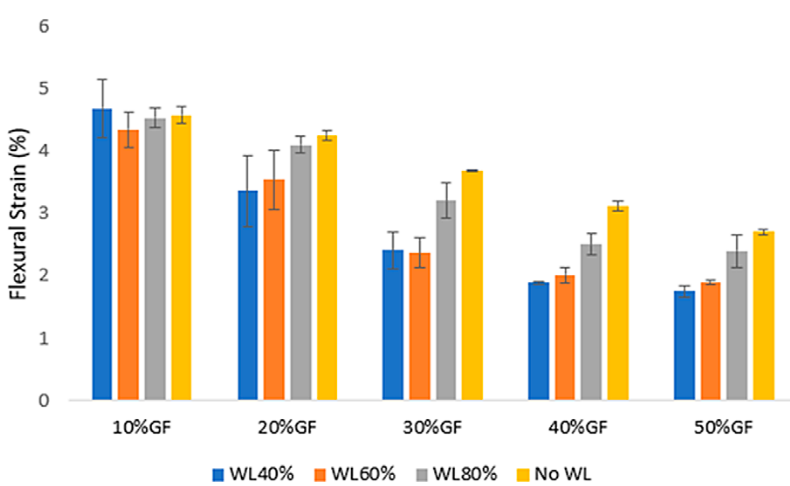
Strain at Fracture

The strain at fracture in tension and bending modes provides further insights into the ductility of the composites (Figure 4). Pure PA6 samples exhibit relatively high strains (>10%) in tensile tests. This property is maintained in bending tests, where no fractures were observed, suggesting an inherent ductility in the material, which is not affected by the presence of weld lines. However, in composites with 10 wt% or more glass fibers, significant reductions in tensile fracture strains are evident at weld lines. The reductions in flexural fracture strains are less pronounced than in tensile tests. This could be due to the triaxial stress state in bending, which may allow the material to sustain higher deformations before fracture, compared to the uniaxial tension where stress concentration at weld lines leads to earlier failure.



(a)



(b)

Figure 4. The effects of fiber content and packing pressure on the strain at fracture for composites with and without weld lines in (a) tension and (b) bending modes.

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Conclusion

This study highlights the significant impact of weld lines on the mechanical properties of PA6 composites with varying glass fiber contents. While pure PA6 and low fiber content composites (10 wt%) are minimally affected by weld lines, composites with ≥20 wt% glass fiber exhibit substantial reductions in tensile and flexural strength, modulus and fracture strain due to weld lines. However, increased packing pressure can partially mitigate these reductions by promoting a more favorable fiber orientation at the weld line. These findings underscore the importance of optimizing processing parameters to enhance the mechanical performance of fiber-reinforced composites in the presence of weld lines.

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