Advanced and Sustainable Technologies (ASET) eISSN 2976-2294
Volume 2, No 1, June 2023 [30-37]

Simulation Analysis of Injection Moulding Process for Fidget Spinner

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Received 30 March 2023, Revised 20 May 2023, Accepted 21 May 2023

ABSTRACT

The injection moulding process is a widely adopted manufacturing method for producing parts using thermoplastic and thermosetting plastic materials. This investigation focuses on the moulding process of a fidget spinner. It aims to analyse the gate location to minimise defects in the final product. Simulation analysis using Autodesk Moldflow 2012 software is employed to achieve this objective. The 3-dimensional model of the fidget spinner is constructed using Solidwork. High Impact Polystyrene (HIPS) was selected as the moulding material. Various aspects, including the volume shrinkage, air trap, sink marks and weld lines within the Moldflow software, visualise the results obtained. Through this investigation, valuable insights can be gained regarding the parameter settings for reducing defects and improving the overall quality of the fidget spinner during the injection moulding process.

Keywords: Injection moulding, Fidget spinner, Moldflow, High Impact Polystyrene

1. INTRODUCTION

Injection moulding has become a prominent method for producing various plastic products using powdered thermoplastics [1]. The process involves feeding the material through a hopper into a heated chamber, which is melted and injected into a mould using a screw mechanism. Consistent pressure is maintained throughout the process until the material solidifies and is extracted from the mould. This technique is highly favoured due to its simplicity and efficiency in manufacturing plastic products of varying complexity and size. Notably, injection moulding enables mass production of high-precision, three-dimensional plastic parts, making it an ideal choice for net shape manufacturing [2].

The introduction of software tools has revolutionised the analysis of new part designs for manufacturing [3]. In the past, there was a risk that flaws in the design phase would go unnoticed until a mould tool was produced. Modifying a part or moulding design at that stage would be costly and time-consuming. However, with the advent of Moldflow Plastic Insight software [4], it is now possible to predict potential quality issues in part early on, including volume shrinkage, weld lines, sink marks, warpage, and more. This capability allows immediate adjustments to the part design to address these issues with minimal time and cost investment. Injection moulding designs can also be analysed for potential flaws before moulding [5]. For instance, moulds are optimised by sizing the runners to achieve balanced filling, eliminating quality issues that may arise from uneven or improper fill times. Manufacturers can proactively identify and rectify design flaws by utilising these software tools, ensuring a smoother and more efficient manufacturing process. The ability to analyse part designs and injection moulding processes in advance significantly reduces the risk of defects, enhances product quality, and minimises costly iterations in the production cycle [6].

Moldflow Plastic Insight is a valuable tool usually applied to new and existing part designs. While it is commonly used for complex 3D product designs and for simpler components like round lids

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to predict the impact of changes in wall thickness on part quality and moulding conditions. In today's injection moulding industry, a trend is growing towards making products lighter and thinner to reduce material costs [7]. However, this poses challenges in maintaining moulding standards and producing high-quality components. By using Moldflow Plastic Insight, manufacturers assess the potential effects of such design changes before costly modifications to existing part designs, mould designs, or machine requirements [8]. This application saves significant time and minimises stress by providing insights into the anticipated outcomes. Furthermore, predicting the requirements of the moulding machine in advance allows for accurate cost calculations, as larger machines tend to have higher operating costs than smaller ones. This information is also beneficial for machine scheduling and planning purposes. Moldflow analysis software is also utilised to identify alternative solutions for existing components that exhibit issues such as warpage [9]. Manufacturers can optimise the part design and minimise problematic outcomes by exploring different design and process parameters. In summary, Moldflow Plastic Insight is valuable for assessing part quality, optimising moulding conditions, and making informed decisions regarding part design, mould design, and machine requirements. By leveraging this software, manufacturers streamline their processes, save costs, and enhance the overall quality of their injection-moulded components.

In recent times, fidget spinners have gained popularity as stress-relieving toys for individuals of all ages, ranging from children to adults [10]. These toys typically consist of a bearing at the centre. They are available in various materials, including brass, stainless steel, titanium, copper, and plastics. Fidget spinners have been marketed as tools that can aid individuals who struggle with focus or have a tendency to fidget, serving as a stress and anxiety relief mechanism. They have particularly benefited individuals with attention-deficit/hyperactivity disorder (ADHD), autism, or nervousness. Although fidget spinners were initially invented in the 1990s, they gained significant traction and demand in the manufacturing industry in 2017. These toys were often marketed with claims of various health benefits, and they became prevalent among school children. The widespread appeal of fidget spinners is attributed to their effectiveness in providing a tactile and calming experience. The repetitive motion and tactile feedback offered by these toys have been found to promote relaxation and focus [11]. As a result, fidget spinners have become widely recognised as tools for stress relief and concentration enhancement [12]. Fidget spinners have emerged as popular stress-relieving toys with a broad demographic appeal. They have been embraced as tools for managing stress and anxiety and improving focus, particularly by individuals with conditions such as ADHD, autism, or nervousness [13]. Despite being invented in the 1990s, their surge in popularity and demand in the manufacturing industry occurred in 2017. The widespread adoption of fidget spinners is a testament to their effectiveness in providing a calming and sensory experience.

The primary objective of this investigation is to analyse the injection moulding process of fidget spinners using simulation analysis. The focus is on reducing defects in the final product. Two critical aspects of the analysis were the gate location analysis and the defect analysis. The gate location analysis involves determining the optimal position for the gate through which the molten plastic enters the mould cavity. The choice of gate location plays a crucial role in achieving uniform filling, minimising flow-related defects, and ensuring proper material distribution. By conducting a detailed analysis, the researchers aimed to identify the most suitable gate location that would result in a successful injection moulding process with minimal defects. In addition to the gate location analysis, the defect analysis was essential to the investigation. This analysis aimed to identify and understand the potential defects that could occur during the injection moulding process. Common defects include sink marks, warpage, weld lines, and volumetric shrinkage. By analysing these defects, the researchers sought to determine the root causes and develop strategies to mitigate or eliminate them. The findings from the simulation analysis would provide valuable insights into the process parameters, such as the gate location, melt temperature, and injection speed, which could be adjusted to achieve a successful and defect-free production. Overall, the investigation focused on using simulation analysis to enhance understanding of the injection moulding process for fidget spinners.

2. MATERIAL AND METHODS

The current methodology employed for this investigation involved utilising Autodesk Moldflow 2012 software [14] to simulate and analyse the moulding process of the fidget spinner. Several challenges were encountered during the study, highlighting the need for proper parameter settings to reduce defects in the final product. While the software provides suitable settings and parameters, certain adjustments were necessary to ensure the success of the simulation.

The first step involved importing the CAD model of the fidget spinner into the Moldflow Plastic Insight software. Prior to this, the CAD model was saved in the IGS/STL file format from SolidWorks software. Confirming and rechecking the model in SolidWorks was essential to minimise potential issues during the simulation and analysis process. The flow domain was divided to facilitate the simulation and analysis, and meshing was applied. Geometric primitives such as hexahedra and tetrahedra were used for 3D models, while quadrilaterals and triangles were employed for 2D models. In this work, the chosen mesh type was the Dual Domain Mesh, a common mesh type. This type of mesh, including midplane elements and outer shell elements, is particularly suitable when the part design includes many thin regions. Opting for this mesh type balanced accuracy and efficiency, as it did not require an extensive time commitment while still offering reliable results. The average aspect ratio is 1.82, and 90% of the match and reciprocal percentage.

The material chosen for the simulation and analysis of the fidget spinner was High Impact Polystyrene (HIPS). HIPS was selected due to its versatility, economical nature, and impact resistance properties (Table 1). It is known for being easy to fabricate and machine, making it a suitable choice for this study [15]. HIPS is preferred for low-strength structural applications, readily available, and relatively cheap. Its ease of machining enables efficient production processes. HIPS's physical and general properties were considered during the simulation and analysis. These properties include its impact resistance, which ensures the durability of the fidget spinner. HIPS is widely used in various applications [16], such as manufacturing toys, televisions, audio-visual equipment, bicycle components, etc. By utilising HIPS as the material for the simulation, this study aimed to evaluate the performance and behaviour of the fidget spinner during the moulding process. The material's specific properties and characteristics were considered to ensure a realistic and accurate representation of the final product.

Table 1: Recommended moulding properties of High Impact Polystyrene (HIPS).

Manufacturer		STRYRENICS
Family abbreviation		HIPS
Material structure		Amorphous
Recommended melt temperature (°C)		235 °C
Recommended mould surface temperature (°C)		65 °C
Mould temperature (°C):	Minimum	60°C
	Maximum	70 °C
Melt temperature (°C):	Minimum	230 °C
	Maximum	240 °C
Ejection temperature (°C)		98 °C
Max. shear stress (MPa)		0.3 MPa
Max. shear rate (1/s)		40000 [1/s]
Maximum design clamp force (tonne)		7000.22 tonne
Maximum design injection pressure (MPa)		180.00MPa
Best recommended gate location, Near node		N3368

The fill time setting parameters for the simulation and analysis of the fidget spinner was determined based on a comprehensive literature review. The recommended values for the mould surface temperature, melt temperature, maximum machine clamp force, filling control, and velocity/pressure switchover were identified through this investigation. A recommended value of 66 ^{o}C was selected for the mould surface temperature. This temperature setting ensures proper material flow and cooling during the moulding process. The melt temperature, which refers to the temperature at which the plastic material reaches a molten state, was set to 235 ^{o}C. The maximum machine clamp force, measured in tonnes, was determined to be 7000.22 tonnes. This parameter represents the maximum force the moulding machine exerts to keep the mould closed during the injection process. The recommended value was established to ensure proper mould clamping and prevent any potential issues during production. In filling control, it was determined that automatic adjustment would be the most suitable option. This setting allows for dynamic control of the filling process, ensuring consistent and efficient material distribution within the mould cavity. Similarly, the velocity/pressure switchover was also set to automatic mode. This parameter determines the point at which the injection speed transitions to pressure control during the filling stage.

2.1 Gate Location Analysis

In order to determine the optimal injection location for the selected part, a gate location analysis was conducted. The analysis was performed using the Advanced Gate Locator and the Gate Region Locator algorithms, with the former being the default choice. This analysis recommended the most suitable position for the injection gate, which is crucial in the overall moulding process. During the gate location analysis, excluding certain areas as potential gate locations were possible by utilising prohibited gate nodes. These nodes allowed for specifying areas where the gate should not be placed. Considering these constraints, the analysis aimed to identify the most appropriate gate location that would result in an effective and defect-free injection moulding process. After running the gate location analysis, the recommended injection location was automatically displayed in the subsequent duplicate study. The intensity of the blue colour at the centre indicated the suitability of the gate location (Figure 1). This visualisation indicated the gate's effectiveness and allowed easy suitability assessment. The recommended injection location, determined through this analysis, would contribute to achieving a successful and high-quality production of the chosen part.

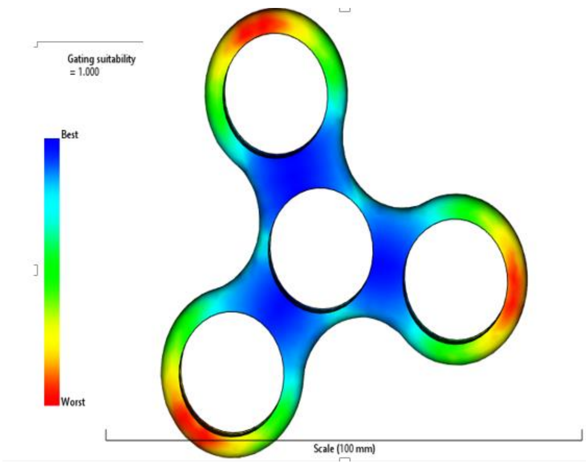

Figure 1: Recommended gate location on the fidget spinner.

3. RESULTS AND DISCUSSION

The observed volume shrinkage at the top of the blade in the fidget spinner (Figure 2) may be attributed to using low-stress injection during the moulding process. Analysis indicates that the estimated parallel shrinkage within the part is influenced by the calculated contribution from crystallisation, which exceeds the measured limits obtained during the shrinkage testing of the material. It is important to note that the reliability of the shrink analysis results may be compromised if the part's volume is high, as the process conditions employed in this study significantly differ from those used in the shrinkage testing.

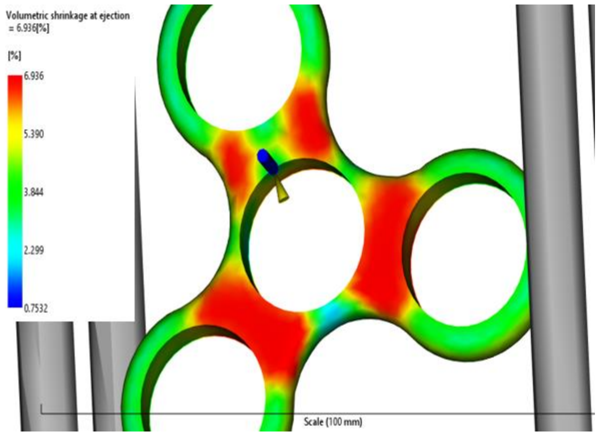

Figure 2: Possible volume shrinkage on the injected part.

Air traps are a common issue that can occur at the sides and ends of the spinner's circles during the injection moulding process. These air traps are typically caused by converging flow fronts resulting from the race track or hesitation effects and non-uniform or non-linear fill patterns [17]. Even if the part has balanced flow paths, inadequate venting can contribute to the occurrence of air traps at the ends of these flow paths. Different visualisation techniques are employed depending on the modelling approach used to address and analyse the likelihood of air traps. In the case of Midplane or Dual Domain models, the Air traps result is represented as a thin, continuous line indicating the potential locations where air traps are likely to occur (Figure 3). For 3D models, a contour plot is utilised to represent the probability of air traps appearing visually. The Fill time result is utilised in conjunction with the Air traps result to validate the filling behaviour and assess the probability of air traps appearing.

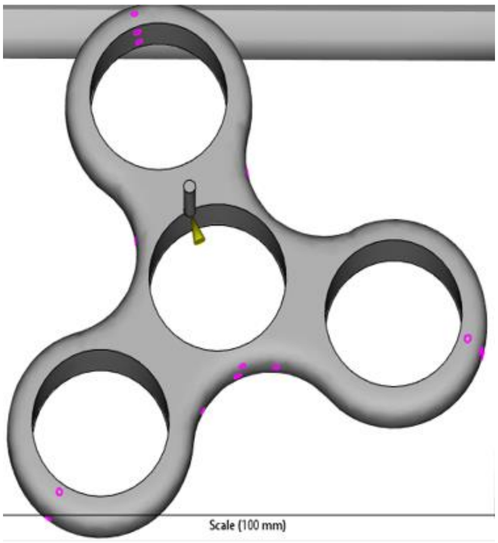

Figure 3: Air trap on the injected part.

Sink marks at the spinner's centre (Figure 4) indicate that depressions and voids are likely to occur due to features on the opposite side of the surface. Sink marks commonly occur in areas with thicker sections or locations opposite ribs, bosses, or internal fillets [18]. However, the analysis does not identify sink marks caused by locally thick regions. To address this issue, it is recommended to make adjustments to the part design to avoid thick sections and minimise the thickness of any features that intersect with the main surface. Relocating the gate to or near the problematic areas allows for properly packing these sections before the thinner sections between the gate and the trouble spots solidify. Increasing the size of gates and runners can prolong the gate freeze-off time, allowing more material to be packed into the cavity and reducing sink marks [19]. Additionally, reducing the melt and moulding temperature may effectively mitigate the issue. Another approach is using a less viscous melt, which can help alleviate sink marks. By implementing these recommendations, the goal is to minimise sink marks and achieve a more uniform surface finish on the spinner. It is crucial to consider the factors contributing to sink marks, such as thick sections and the positioning of features, and apply appropriate design modifications and process adjustments to overcome these challenges in the injection moulding process.

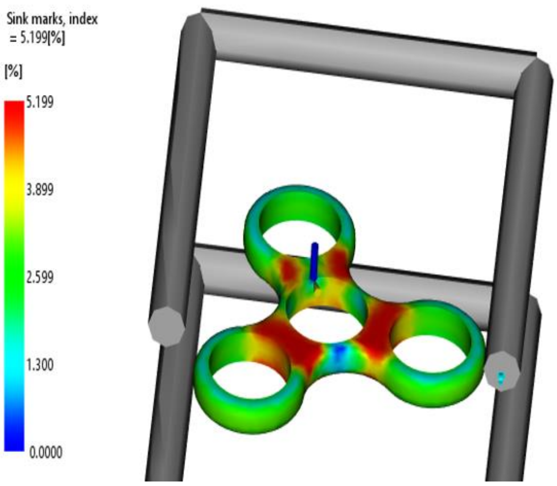

Figure 4: Sink mark.

Weld lines are observed at the sides of the fidget spinner (Figure 5), representing a significant yet relatively straightforward defect commonly found in many parts. These lines occur when two melt fronts meet in an opposing manner. The formation and severity of weld lines depend on the meeting point's angle, force, and temperature [20]. In simulation analysis, weld lines are identified at specific nodes. When two or more connected nodes indicate the presence of a weld line, a line is drawn to represent it. It is important to note that predicting weld lines is sensitive to mesh density. Thus, a finer mesh is necessary to accurately capture the presence of weld lines, as a coarse mesh may not always indicate their occurrence. Determining the location of weld lines is relatively straightforward, often based on critical indicators such as the fill time of the moulding process. By closely observing the flow of molten material around features and components, one can determine the probable locations of weld lines. However, analysing weld lines in Moldflow extends beyond mere location determination. The outcome of the weld line analysis in Moldflow provides more than just the location information. It offers valuable insights into the severity, strength, and overall impact of the weld lines on the part's quality and performance. Understanding these factors aids in making informed decisions regarding part design modifications, material selection, and process optimisation to minimise the occurrence and effects of weld lines.

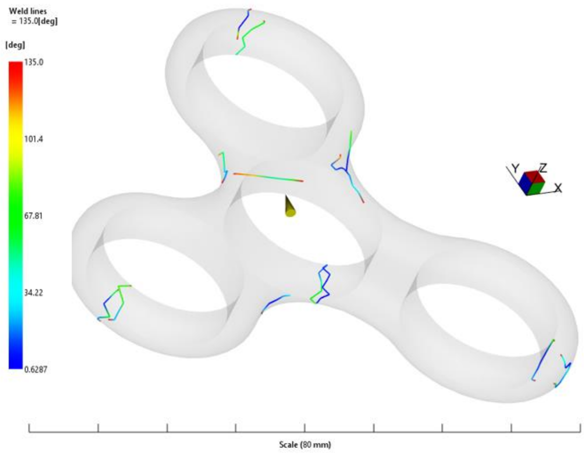

Figure 5: Weld lines on the fidget spinner.

4. CONCLUSION

This investigation focused on the design of a mould for a fidget spinner gadget using Moldflow software. The utilisation of Moldflow software proved to be vital in designing all the required components of the mould. The manufacturing process taught us the importance of selecting materials that can effectively cope with the properties required for the simulation and analysis of the project. By employing Solidworks software, the product design of the fidget spinner was successfully achieved within the Moldflow software. However, it is essential to note that this phase presented numerous challenges and obstacles in creating a successful fidget spinner design in the simulation and analysis. Through the iterative process of simulation and analysis, the investigation aimed to attain the best possible product design for the fidget spinner. The simulations and analyses provided valuable insights into optimising the mould design and process parameters. These insights aided in the identification and mitigation of potential defects, ensuring a higher-quality final product. In conclusion, this investigation demonstrated the significance of utilising Moldflow software and integrating Solidworks software for effective product design and simulation analysis. The combination of these tools proved instrumental in optimising the mould design and refining the manufacturing process for the fidget spinner gadget. The knowledge gained from this investigation can be applied to future projects involving injection moulding processes and enhance the overall efficiency and quality of the manufacturing process.

ACKNOWLEDGEMENTS

The author expresses sincere gratitude to the Faculty of Mechanical Engineering & Technology, Universiti Malaysia Perlis (UniMAP) staff for their invaluable technical support.

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