Investigation of Deformation Analysis of Glass Fiber Reinforced Polymer Injection Molded Component

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ABSTRACT

Warpage is one of the most crucial problems in injection molded products. Factors affecting warpage include Material, Part geometry, gate location, Fiber content & orientation, temperature, etc. Since many factors cause shrinkage and warpage, it is very difficult to distinguish the predominant factor. In the present study, we have focused on contribution of fiber content on warpage of injection molded part. Basic requirement of the part is flatness at sealing area within given tolerance. The required flatness should be within a given tolerance for effective functioning of the component. Flow simulation software has been used to assess the effect of fiber content on warpage and in turn flatness of the component.

Keywords— Warpage, Fiber, Flatness

I. INTRODUCTION

The warpage is a critical quality issue in injection molded parts. It occurs when there is an uneven distribution of shrinkage throughout the product. It is the most common defect during production, and quite often this defect must be resolved in haste, relying mostly on experience of the skilled technician. While the designer is responsible for the functional and mechanical performance of a part, a molder is required to deliver the part with a good aesthetic quality and meeting the dimensional specifications. When a part fails in these requirements, it is necessary to find the causes and conduct molding process modifications. If simple process modifications cannot resolve the warpage problem, we must make a mold design change and possibly even extend the modifications to part design.¹⁰

The plastic material properties affecting shrinkage and warpage include plastic material type, degree of crystallization (crystallization rate), and filler properties. Shrinkage behavior varies between different plastic material types [2]. For example, polyoxymethylene (POM) is a highly crystallized material and presents considerable shrinkage after ejection. Polypropylene (PP), on the other hand, has a relatively less shrinkage. Amorphous polymers such as poly (methyl methacrylate) (PMMA) have the lowest shrinkage rates. The crystallization rate is related to cooling. Nylon is a material with a low crystallization rate related to the small injection filling time. The cooling is too fast for a high relative degree of crystallization, which leads to further shrinkage even after mold release. Also, non-Uniform shrinkage will cause warpage in injection molding part. The main reasons of this difference in shrinkage (resulting deformation) can be material properties, mold and part design or process settings. This distortion can be attached to three causes: anisotropic shrinkage, orientation effect and non-uniform cooling. Anisotropic shrinkage implies the presence of change in the shrinkage from region to region in the part. Orientation effect is the change in shrinkage parallel and perpendicular to the material orientation direction, largely happening in fiber reinforced thermoplastics. The third is affected by the temperature gradient through the thickness of the part caused by unequal core and cavity temperatures. This is called non-uniform cooling.

Fillers (inorganic elements) are basically rigid and do not shrink significantly, which makes them ideal for enhancing the mechanical properties and decreasing the shrinkage of the polymer matrix. However, the induced viscosity increase in the melt poses challenges to processing with high filler content. J.G. Kova’cs & B. Solymossy [3] researched the Effect of Glass Bead Content and Diameter on Shrinkage and Warpage of Injection-Molded PA. They concluded that the bead size did not have any effect on the near gate crossflow direction shrinkage but had a remarkable effect on the shrinkage at the end of the flow. Kikuchi and Koyama [4] studied the orientation of fiber reinforced polymer, being the main cause of the occurring warpage. They used glass reinforced polyamide in their analyses and made a conclusion that in a case of uniform orientation, there were not any deformation while non-uniform orientation caused warpage on the specimens. R. Y. Chang and B. D. Tsaur [5] did Experimental and Theoretical Studies of Shrinkage, Warpage, and Sink Marks of Crystalline Polymer Injection Moulded Parts. They concluded that several factors affect the shrinkage and warpage of molded parts, e.g., the...
crystallization, rheology, and equilibrium state of PVT behavior or the viscoelastic effect of polymer, and the variable mold temperature profile caused by nonuniform cooling, etc.. Which were considered to accurately describe the real conditions of injection molding as well as to predict the real shrinkage and warpage of molded parts. The other factors which also influence shrinkage and warpage of the final parts consist of molecular orientation & fiber orientation. Mlekusch [6] analyzed the effect of glass fiber on the warpage using polyamide as the matrix material. He concluded that the warpage difference between the reinforced and the non-reinforced polymer appeared due to the orthotropic caused by the fibers and their alignment. He also established that the distortion increased with increasing fiber volume fraction. C. S. Hindle and J. R. White [7] studied internal stress, molecular orientation, and distortion in injection moldings: polypropylene and glass-fiber filled polypropylene. They concluded that residual stress and molecular and glass fiber orientation all influence distortion in injection moldings. Also, they concluded that in newly molded parts, forces applied by the ejection system may cause distortion, although some of this distortion may be recovered. Recovery is less likely with filled polymer like GFPP. P. J. Hine and R. A. Duckett [8] studied Fiber Orientation Structures and Mechanical Properties of Injection Molded Short Glass Fiber Reinforced Ribbed Plates. They concluded that, thermal expansion anisotropy is more important than elastic anisotropy. The large temperature difference between solidification and room temperature on cooling (approx 160°C) and high thermal expansion anisotropy can make small differences important and can lead to significant warpage. Also, non-symmetric orientation layered structures lead to significant warpage on cooling. Takaaki Matsuok, [9] studied prediction of Fiber Orientation in Injection Molded Parts of Short-Fiber-Reinforced Thermoplastic. The linear relationship was obtained between computed orientation parameters and measured thermal expansion coefficients. It should be noted that this relationship can be used to estimate the thermal expansion coefficient of molded parts from the simulation of fiber orientation for predicting warpage of molded parts practically. Zhouhao Xie & Xianghong W, [10] has done an investigation on suppressing Shrinkage/Warpage of PBT Injection Molded Parts with Filler. They concluded that Glass fiber strongly influences PBT/GF composite shrinkage. Along the flow direction, the shrinkage decreases with glass fiber content; the shrinkage uniformity is improved with dry mixing over side feeding. Also, they concluded with side feeding, the tensile strength and bending strength of PBT/GF composite are improved with more glass fiber content, but decreased with dry mixing, because of the shear damage to the glass fiber. So, here we are trying to investigate the deformation of glass fiber reinforced polypropylene injection molded component by varying fiber content with the help of injection molding simulation software (Moldex3D).

II. EXPERIMENTAL WORK

2.1 Product Information

Intake of contaminated (dust and dirt) air affects engine wear, decreased performance, and costly maintenance. That is the reason why air filtration is a must amongst the most essential requirements for efficient engine functioning. Clean air is important for sustaining the health and long life of internal combustion engines, and the objective of an air filter is just so that – to provide clean air by keeping harmful dust, dirt, and moisture trapped and encourage increased engine life. Part Dimension: - 300mm x 300 mm x 25mm & 3mm Thickness

![Figure 1: Product Design](image1.png)

![Figure 2: Application](image2.png)

2.2 Product Functional Requirement

In air intake system, top cover and bottom cover is the outer body of the assembly. The top cover is going to be clamped to bottom cover as shown in the above picture. After clamping there should not be a gap between top cover & bottom cover, to prevent against water & dust particle entry. Otherwise, water or dust particle will damage the overall functionality of the assembly & engine of the vehicle. Due to this reason designer has introduce sealing in between these two components. But proper functionality of sealing is depending on flatness at the regain shown below, with the help of plotting no. of points in red colour. Min flatness required for proper sealing is 1mm.
Long glass fiber polypropylene (PP) were chosen as the injection materials to produce Top Cover part of automotive air intake system with injection-molding process. The PP is classified into two groups with different fiber percentage, PPLF30 & PPLF40, respectively. The properties of PP were obtained from the materials database of Moldex3D as shown in Table 1 & Table 2.

The Experimental work was divided into two steps. The first one is to the understanding of the rheologic difference in 3 grades, which have the same MFI 22g/10min (220,10), In the second step, an analysis of the product the experimental methodologies, exploring the main aspects to show the difference in result outcome of the product.

Table 1: PPLF30 Material

| Item Name      | Item Data            |
|----------------|----------------------|
| Material type  | Thermoplastic        |
| Generic name   | PP                   |
| Supplier       | AutoTech Polymer     |
| Trade name     | LFP3010              |
| Fiber percent  | 30.00 (%)            |
| Melt temperature range | 200 - 260 (°C) |
| Mold temperature range | 25 - 85 (°C) |
| Ejection temperature | 117 (°C) |

Table 2: PPLF40 Material

| Item Name      | Item Data            |
|----------------|----------------------|
| Material type  | Thermoplastic        |
| Generic name   | PP                   |
| Supplier       | AutoTech Polymer     |
| Trade name     | LFP4010              |
| Fiber percent  | 40.00 (%)            |
| Melt temperature range | 190 - 230 (°C) |
| Mold temperature range | 40 - 70 (°C) |
| Ejection temperature | 120 (°C) |

After comparing PVT of these materials, PPLF30 material is Shrink more than PPLF40. In Other word PPLF30 will show higher warpage than PPLF40.

Plastic generally undergoes a considerable volumetric change over temperature and pressure. It is therefore essential to characterize its Pressure-Volume-Temperature (PVT) relationship to calculate the compressibility of material during packing phase, and its final part shrinkage and warpage after ejection.
2.4.1 Process Setting
For understanding the effect of fibre content & orientation on the webpage we keep same process parameter for analysis.

Table 3: Process Parameters

| Parameter                      | Value  |
|--------------------------------|--------|
| Filling Time (s)               | 4      |
| Melt Temperature (°C)          | 230.0  |
| Mold Temperature (°C)          | 55.0   |
| Injection Volume (cm³)         | 570.724|
| Packing Time (s)               | 13.00  |
| VP Switch by filled volume (%) | 98.00  |
| Mold Opening Time (s)          | 5.00   |
| Air Temperature (°C)           | 25.0   |
| Cooling Time (s)               | 45.00  |
| Cycle Time (s)                 | 67     |

2.4.2 Feed System & Cooling Channel Layout
Here, as shown in fig.6, we used hot runner system design. Size of the gate is 3 mm dia. & Height of runner is 114 mm. Also tried to make an optimal cooling design as shown in fig.7, so that there will be less core side & cavity temperature differences achieved. The function of a cooling system is to remove the heat from the mold. Cooling channel diameter is 8 mm & Baffle diameter is 12 mm.

2.5 Result and Discussion
After both iterations we found below results. For better understanding we compare both results.

2.5.1 Filling Shears Stress

Shear stress at current instant is shown in different colour according to different stress level. Shear stress is one of cause of the moulded-in residual stress in moulded parts. If the shear stress is not spread evenly, it will cause some post warpage problems. Too high the shear stress level will result in stress-induced complications in the moulded part. From above result Fig. 8 & 9, we can see shear stress of PP40GF is more than PP30GF. This is due to increase in shear flow of material because of increase in fibre content. It will contribute to increase in shear heat to some extent. This may also affect on warpage of the component.
2.5.3 Melt Front Temperature

Melt front temperature is the temperature value of the plastic melt as it reaches the given point. This value shows how heat is conveyed and dissipated during the moulding stages. As earlier we have seen due to increase in shear heating there is an increase in shear stress of the component. This result also shows as fiber content increases melt temperature also increases. This will also impact on warpage.

2.5.4 Clamping Force

The clamping force of the injection molding machine is the crucial to the molding of injection products. If the clamping force is very less, it will affect the product to have flash or lack of material. An increase in fiber content by keeping same process parameter may reduce the packing pressure effect. Due to this volumetric shrinkage reduces. Ultimately, this will impact on warpage of the component.
Shows the Z-component of the total displacement (All effects are considered) after the part is ejected and cooled down to room temperature. The value is related to the model coordinate. Refer Fig 14 and 15. Due to the overall impact of increased shear stress, melt front temperature & reduced clamping force because of packing pressure impact we can see here total warpage in Z direction increases with increase in fiber content. But warpage at sealing area is decreased due to better fiber orientation & increase of fiber content. This results into improved flatness at sealing area. For us flatness is very important for effective functioning of the product.

2.5.5 Warpage Total Fiber Orientation Effect on Displacement

Refer Fig 16 and 17, As fibre content increases warpage of the part decrease. It shows the length of the fibre orientation effect displacement vector. The fibre orientation effect deformation is defined as the difference between the following two deformations: (1) Final deformation due to all factors. (2) Distortion due to the random orientation of fibre. It presents the anisotropic effect of fibre orientation.

Fig 18 & 19 shows fiber orientation at sealing area & away from sealing area. Fibre orientation at sealing area is showing better orientation due to this warpage at this section at z direction showing improvement as fiber content increases & also shrinkage decreases.

2.5.6 Flatness of Component

Refer Fig 20 and 21, Flatness of part for PP LF 30% and 40% respectively.
Refer Fig 20 and 21. As fibre content increases flatness of the part at sealing area decrease. It means with increase in fibre content flatness improves.

2.6 Result Summary

| Parameters                        | Units | LPFP3010 | LPFP4010 |
|-----------------------------------|-------|----------|----------|
| Shear Stress                      | MPa   | 3.2      | 3.6      |
| Melt front Temperature            | °C    | 212      | 215      |
| Clamping Force                    | Ton   | 640.16   | 590.56   |
| Warpage Z displacement            | mm    | 4.7      | 6.8      |
| Warpage, Total fiber Orientation  | mm    | 2.8      | 2.4      |
| Flatness at Sealing area          | mm    | 2.0      | 1.3      |

III. CONCLUSION

Second work focused on the warpage of an injection-molded automotive component made of PP with different fiber percentages from 30 to 40% weight. The warpage of component varied with fiber addition. Overall warpage of component is increased as the increase with fiber content. We used same process parameters for both materials. But by comparing viscosity graph ref Fig. No 4, we can see PP LF 40 is more viscous than PP LF 30% material. Due to this force required to fill & pack the part is more for PP LF 40% than PP LF 30% material. So, our result shows increase in warpage for PP LF 40%. For accurate warpage prediction for PP LF 40% we must increase filling and packing pressure. Also, fiber content increases shear flow, which increases some amount of heat; this also contributes to the increase of warpage of the component.

With the increase in fiber content shrinkage of the component, in the linear direction of fiber orientation decreases, this also affects warpage of the component. Due to this flatness at sealing area (ref Fig. no 20and 21) is showing better results as fiber content increases. With increase in fiber content fiber orientation also improves due to which warpage of the component decreases.

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