

PVT RELATIONSHIP OF POLYMER MATERIAL IN INJECTION MOLDING PROCESS

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ABSTRACT

Injection molding process is the mass manufacturing process of plastic material via using a mold to form the product with complex shapes and high quality. PVT relationship represents the relationship of pressure-temperature-specific volume of polymer material that it is crucial data for processing plastic product and setting up PVT feature for new plastic material. The relationship of pressure-temperature-volume (PVT) is one of the most important relation of polymer material for its processing in polymer industry such as injection molding process. The PVT behavior is the crucial data source for simulation of injection molding process to control the quality of product and predict the defects such as shrinkage, short-shot, warpage, and weldlines. The PVT database is effectively used in the fabrication of plastic product for many practical applications. This paper demonstrates the PVT relationship for polymer processing applications of injection molding process. The PVT equations are important for developing of simulation tools to aim engineers and researchers used to develop their new products with cost effective, rapid cycle time and high product quality. The HDPE material was used to analyze the injection molding process. The EasyFill simulation tool was used to perform the simulation process of injection molding. The results are crucial for designing and manufacturing industry of plastic product by using injection molding process.

Keywords: *PVT behavior, injection molding, polymer processing, processing parameters.*

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1. INTRODUCTION

Injection molding process is the mass manufacturing process of plastic material via using a mold to form the product with complex shapes and high quality [1].

Injection molding is used to fabricate many plastic parts for practical applications such as automotive [2], electrical equipment [3], household wares [4], and industrial applications [5]. PVT relationship represents the relationship of pressure-temperature-specific volume of polymer material that it is crucial data for processing plastic product and controlling product quality [6]. The relationship of pressure-temperature-volume (PVT) is one of the most important relation of polymer material for its processing in polymer industry such as injection molding process. The PVT behavior is the crucial data source for simulation of injection molding process to control the quality of product and predict the defects such as shrinkage, short-shot, warpage, and weldlines [7]. The PVT database is effectively used in the fabrication of plastic product for many practical applications [8]. PVT behavior is proven as a crucial database of injection molding process for smart technologies and emerging technologies [9]. PVT relationship has received many concerns from research groups to develop database for manufacturing industry such as detecting specific volume of material during injection molding process via using artificial intelligence technique [10]. There are many defects appeared on the plastic product that can be detected by using digital software with PVT databases such as using Moldex3D software to detect warpage of product during injection molding process [11], analyzing warpage deformation by using Moldflow software [12], using digital tool of EasyFill to simulate the filling process of plastic product [13], and using Solidworks plastic tool to analyze warpage of plastic product [14]. High density polyethylene (HDPE) is a plastic material with characteristics of high strength and low friction coefficient [15]. HDPE has been used to fabricate plastic product for many applications such as pipe [16], industrial, medical and biomedical applications [17]. This paper demonstrates the PVT relationship for polymer

processing applications of injection molding process. The PVT equations are important for developing of simulation tools to aim engineers and researchers used to develop their new products with cost effective, rapid cycle time and high product quality. The simulation and analysis procedures of injection molding process were conducted with HDPE material and EasyFill software. The results are crucial for designing and manufacturing industry of plastic product by using injection molding process.

2. MATERIALS AND METHODS

2.1. PVT measurement method

The common technique has been used to measure PVT relationship as piston-die mechanism. Figure 1 shows the testing equipment of PVT behavior with basic components including a die to store workpiece, a piston to set up pressure on the sample, a heater to heat up the die and sample, thermocouples to measure temperature of the system [18]. The working mechanism of the measuring process can be briefly explained as following steps. In the initial state, the die will be heat to the required temperature, the capillary is sealed to the lever at the bottom hole position of the capillary. Next, the plastic sample is put to the die. Then, the piston is pressed to the pellets and that it removes bubbles. As the plastic material fills full into the die, the piston is pressed again. As the sample temperature equals the required temperature that it is set up at the initial stage, the capillary's bottom hole is opened. The 2nd piston compresses the melt material out of die and stops at the measurement position.

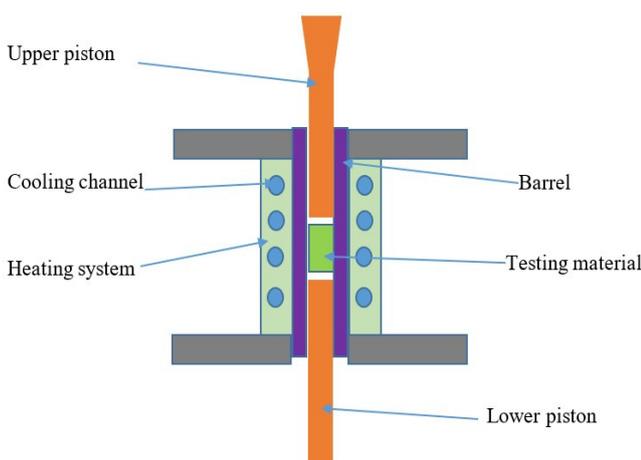


Figure 1. The PVT measurement mechanism

2.2. Material for injection molding

Table 1 shows the mechanical properties of HDPE material with basic index of melt density of 0.738g/cm³,

elastic modulus of 911MPa, and transition temperature of 112°C, respectively [19].

Table 1. The mechanical properties of HDPE material

| Mechanical properties | Unit | Value |
|------------------------|-------------------|-------|
| Melt density | g/cm ³ | 0.738 |
| Elastic modulus | MPa | 911 |
| Specific heat capacity | J/(Kg-C) | 3000 |
| Transition temperature | °C | 112 |
| Poission's ratio (ν) | | 0.426 |

3. RESULTS AND DISCUSSION

3.1. PVT governances

PVT is tight relationship of pressure-volume-temperature in presenting of deformation of plastic deformation under conditions of polymer processing [20]. Figure 2 shows PVT curve of the material that it is used in computer to analyze material processing during injection molding [21]. Two domains are completely divided by the transition temperature. The PVT data can be expressed by mathematical relationships of following two-phases Tait equations [22, 23]:

$$v(p, T, q) = v_0(p_0, T, q) \left\{ 1 - C \cdot \ln \left[1 + \frac{p}{B(T)} \right] \right\} + v_t(p, T) \tag{1}$$

Where: *v* is the specific volume of material; *p* is the pressure; *T* is temperature; *q* presents the cooling rate of material. *C* denotes the universal constant (*C* = 0.0894); *v*₀ is specific volume at the pressure of zero.

$$T_t(p, q) = b'_5 - b''_5 \ln(q) + b'_6 p - b''_6 p^2 \tag{2}$$

Where: *b*₅ and *b*₆ represent variations of the *T*_t by pressure.

$$\bar{T} = T - T_t \tag{3}$$

With

$$\bar{T} > T_t(p, q)$$

$$v_0(p_0, T, q) = b'_{1m} - b''_1 \ln(q) + b_{2m} \bar{T} \tag{4}$$

Where: *b*_{1m} and *b*_{2m} present variations of the *v*₀ by the pressure and the temperature.

$$B(T) = b_{3m} \exp(-b_{4m} \bar{T}) \tag{5}$$

Where: *b*_{3m} and *b*_{4m} represent material constants that has sensitivity to the pressure.

$$v_t(p, T) = 0 \tag{6}$$

With

$$\bar{T} < T_t(p, q)$$

$$v_0(p_0, T, q) = b'_{1s} + b''_1 \ln(q) + b_{2s} \bar{T} \tag{7}$$

$$B(T) = b_{3s} \exp(-b_{4s} \bar{T}) \tag{8}$$

$$v_t(p, T) = \exp(b_8 \bar{T}) \left\{ \begin{array}{l} \left[-b''_{1m} \ln(q) \right] \left[-C \cdot \ln \left(1 + \frac{p}{b_{3m}} \right) \right] \\ \left[-(b'_{1s} + b''_{1m} \ln(q)) \right] \left[-C \cdot \ln \left(1 + \frac{p}{b_{3s}} \right) \right] \end{array} \right\} \tag{9}$$

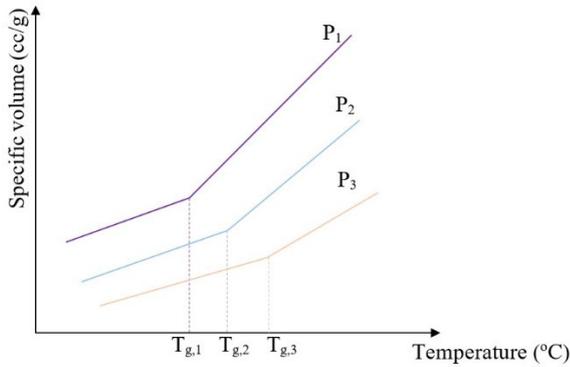


Figure 2. The PVT relationship of polymer material

3.2. Analysis and simulation results

The injection molding process was performed by using EasyFill software. The material is HDPE. Figure 3 shows the image of plastic part with dimensions including biggest length of 40.8 mm, biggest thickness of 2.6mm, and biggest width of 11.5mm, respectively. Table 2 shows the processing parameters that it need for the injection molding process with basic parameters of injection pressure of 12.54MPa, mold temperature of 37.5°C, melt temperature of 210°C, and filling time of 0.1 sec, respectively. The processing parameters are referenced from previous works and experienced manufacturers [19]. Figure 4 shows the analysis result of volume shrinkage with maximum volume shrinkage of 2.157%. Figure 5 shows the analysis result of warpage with maximum warpage of 0.116mm. Figure 6 shows the analysis result of density with maximum density of 9.605E-7kg/cm³. Table 3 shows the summary results of injection molding process as using PVT data base of HDPE with the help of EasyFill simulation tool.

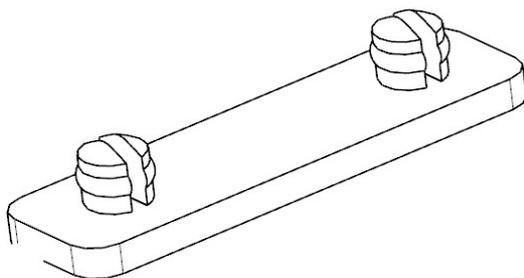


Figure 3. The image of plastic part

Table 2. The processing parameters for injection molding process

| Processing parameters | Unit | Value |
|-----------------------|------|-------|
| Injection pressure | MPa | 12.54 |
| Melt temperature | °C | 210 |
| Filling time | sec | 0.1 |
| Mold temperatuer | °C | 37.5 |

Table 3. The summary results of injection molding process as using PVT data base of HDPE

| Molding results | Unit | Value |
|-----------------|--------------------|-----------|
| Moldability | | Good |
| Filling time | sec | 0.1 |
| Shrinkage | % | 2.157 |
| Density | kg/mm ³ | 9.605E-07 |
| Warpage | mm | 0.12 |

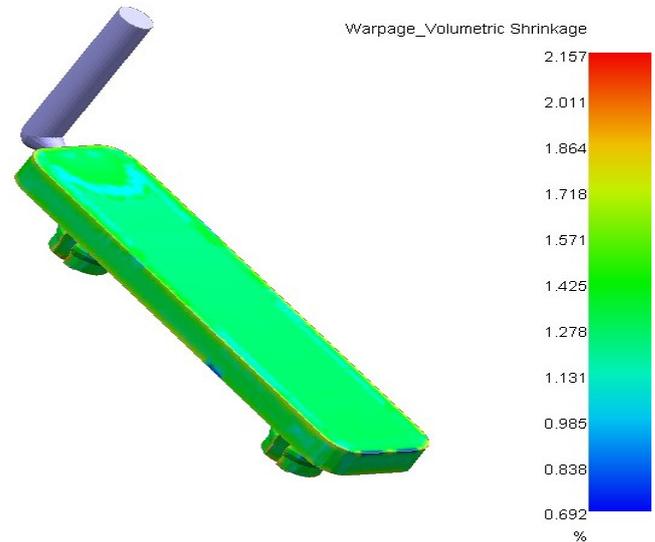


Figure 4. The analysis result of volume shrinkage

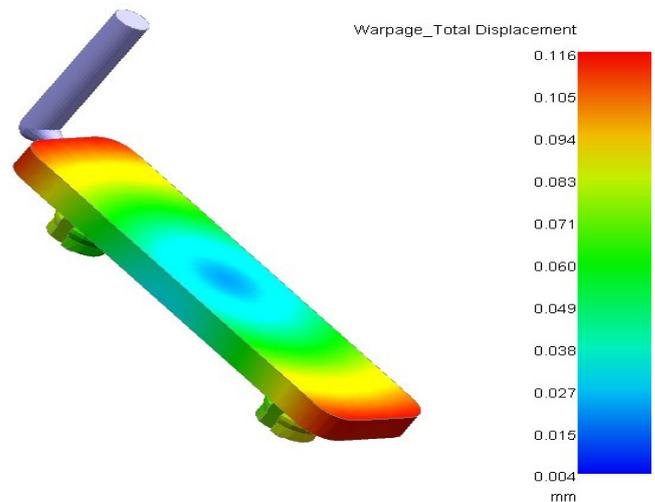


Figure 5. The analysis result of warpage

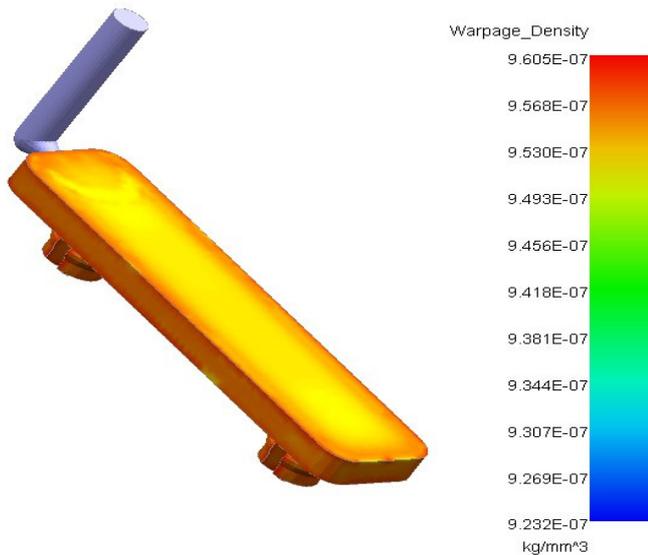


Figure 6. The analysis result of density

In brief, the PVT relationship is crucial data for controlling the injection molding to produce the plastic parts. The defects of the molded parts can be predicted by using a simulation tool as mentioned above. The PVT relationship is a solid platform to build new plastic materials such as composite materials and biopolymer materials.

4. CONCLUSION

The relationship of pressure-temperature-volume (PVT) is one of the most important relations of polymer material for its processing in the polymer industry such as injection molding process. The PVT behavior is the crucial data source for simulation of injection molding process to control the quality of product and predict the defects such as shrinkage, short-shot, warpage, and weldlines. The PVT database is effectively used in the fabrication of plastic products for many practical applications. This paper demonstrates the PVT relationship for polymer processing applications of injection molding process. The PVT equations are important for developing simulation tools to aid engineers and researchers used to develop their new products with cost-effective, rapid cycle time and high product quality. The results are crucial for designing and manufacturing industry of plastic products by using injection molding process.

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