

# Injection Molding Parameters Optimization for Polymer Matrix Composite Polypropylene Reinforced Wood Fiber

Muhd Hasanul Isyraf Mat Junoh

Department of Mechanical Engineering  
Politeknik Sultan Mizan Zainal Abidin, Dungun, Terengganu, Malaysia

*Received: April 23, 2015*

*Accepted: July 11, 2015*

## ABSTRACT

This study presents the method of injection molding parameter optimization of polymer matrix composite reinforced natural materials for automotive component by software simulation. In this research, a timing belt cover Cam Profile Switching Cam Profiling system (CamPro CPS) Proton engine was selected as a component of the study. The component was modeled in three dimensional (3D) by using Computer Aided Three-dimensional Interactive Application version 5 (CATIA V5) software. The 3D model components translated into STereoLithography (STL) format and transferred it into the Moldflow Plastics Insight (MPI) 6.1 software for feedstock moldability analysis. The feedstock used in this study is polymer matrix composite (PMC) PPLiWo60 types which consisting of 40% polypropylene (PP) and 60% wood fiber. MPI software able to analyze and predict the results of molding quality with shows the defects in products, and also shows a pattern of the injected material flow fill in designing mold. Simulation is carried out based on the material of the feedstock and the four parameters of the injection molding process, there is injection temperature, mold temperature, injection pressure and flow rate. The results of injection molding simulation were analyzed by using the design of experiment (DOE) with three levels of experiment design through the response surface method (RSM) and analysis of variance (ANOVA) analysis to obtain the optimal parameters of the injection molding process. The most optimal parameters of PMC PPLiWo60 for this study are 40°C of mold temperature, 170°C of injection temperature, 180MPa of injection pressure and 50cm<sup>3</sup>/s of flow rate. From the comparison of simulation result found that these parameters are suitable for PMC PPLiWo60 and natural PP.

**KEYWORDS:** Parameters Optimization, Injection Molding, Simulation, Polymer Matrix Composite, Natural Fiber.

## INTRODUCTION

In this work, numerical simulation study is carried out to obtain the optimum injection parameters polymer matrix composite (PMC) with natural material to reduce physical disability in the product. Timing belt cover for the CamPro CPS engine as shown in Figure 1 has been selected as research products by using a simulation of injection molding process with polymer polypropylene (PP) composite and natural fiber materials. The flow properties of composite PP with natural material in the mold will be reviewed and analyzed based on the pressure volume temperature (PVT) properties of materials for optimum injection molding parameters. Four main parameters were considered in this study such as mold temperature, injection temperature, injection pressure and flow rate with five types of response namely fill time, average velocity, pressure, sink index and volume shrinkage.

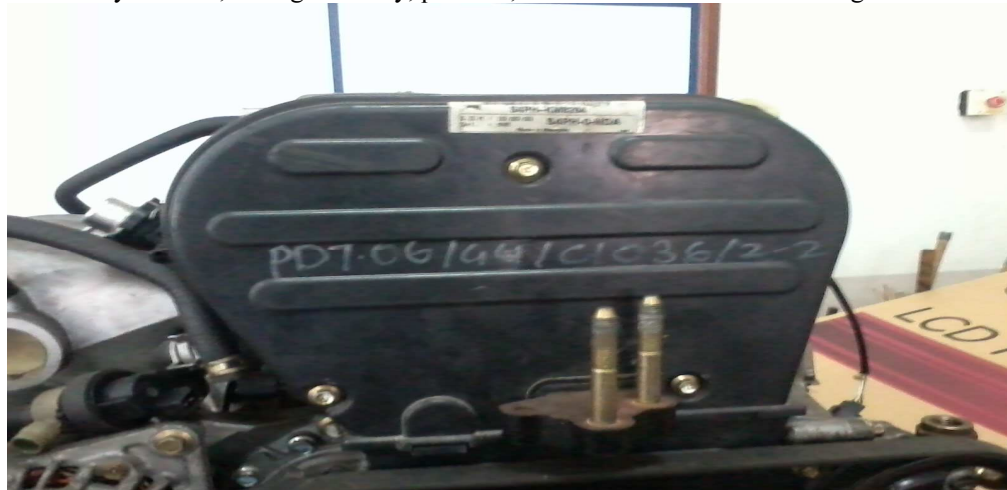


Figure 1: Timing belt cover for CamPro CPS engine

## PROBLEM STATEMENT

Various experimental studies have been conducted on composite polymer. But still less simulation study has been conducted for the injection molding of polymer composites, especially natural fiber polymer composites such as wood which for a product to review the flow of composite material in the mold and injection molding parameters as appropriate. In the injection molding process, a problem that is common in the resultant product which does not meet the design specifications and dimensions that are required due to defects such as short shot, weld lines, air trapped, dents and other blemishes. This problem can be reduced by identifying the parameters that are appropriate to use simulation software.

### Objectives

- i. To optimize the injection molding parameters for the best moldability of components.
- ii. To compare the value of responses for PMC and natural PP molding by using the most optimize parameters.

## LITERATURE REVIEW

Composite is a combination of two or more substances in which one of the components function as an anchor material in the form of fibers, flakes or particles and the other is the phase matrix whether polymer, metal or ceramic. Composite materials are classified according to the type of main material such as polymer matrix composite (PMC), ceramic matrix composite (CMC) and metal matrix composites (MMC). Polymers (resins) are classified into two types of thermoplastic and thermoset, which are reinforced with natural fibers and man-made fibers for different applications [2]. Due to the increase in population, natural resources are being exploited significantly as an alternative to synthetic materials. Therefore, the use of natural fibers for composite reinforcement has gained attention. Natural fibers have many advantages than their exceptional synthetic fibers. Now, various types of natural fibers have been studied for use in composites including flax, jute straw, wood, hemp, grass, rice husk, barley, oats, wheat, rye, sugarcane, bamboo, kenaf, hemp, palm oil, hemp, mulberry, papyrus leaves, banana fiber and pineapple fiber. Natural fibers are largely divided into three categories which depends on their origin such as mineral, plants and animals based [5]. Application of natural fibers in plastic products as composite filler material can reduce the use of synthetic polymers and also reduces environmental pollution. A natural fiber that is capable of self-biodegradable can help the decomposition process of disposal of synthetic polymer-based products in a shorter time. Product from this composite can be produced by a variety of processes such as injection molding, compression molding and etc. Numerical simulations by using computer software which capable predicting a quality of molding products which will be produced. Information from the simulation carried out is very important to avoid defects that are likely to occur in the resulting product. Designers can identify any eventuality in the product that is designed and molding process at an early stage in computerized simulations before the actual mold is produced in order to produce the optimum quality. PMC is usually composed of a matrix reinforced with synthetic or natural fibers. Matrix acts as an intermediary with the externally applied loads which are distributed to the stronger and harder fibers to support the composite structure. It protects the outer fibers of chemical attack or atmosphere wheather and abrasion. Matrix plasticity acts as a barrier to nucleation or crack propagation, and to prevent rupture of the destroyed [4]. Extensive study of the preparation and properties of PMC replace synthetic fibers with natural fibers such as jute, sisal, pineapples, bamboo, kenaf and bagasse was carried out. Fibers from plant have many advantages over glass fiber or carbon fiber such as a renewable, environmentally friendly, low cost, light weight and high mechanical properties' performance [1]. Polymer reinforced with wood fibers is a type of PMC. It consists of wood fibers and plastic granules such as PP and polyethylene. PMC properties are dependent on the properties of fibers and plastics. It has many applications in broad areas such as aviation, automobile, interior and exterior furniture and others which require different strengths of the board for specific applications [3].

## METHODOLOGY

Design of timing belt cover for Cam Profile Switching Cam Profiling system (CamPro CPS) Proton engine remodel in three dimensional computer-aided design (3D CAD) systems by using Computer Aided Three-dimensional Interactive Application version 5 (CATIA V5) software based on the original design as shown in Figure 2. This model is then translated in STereoLithography (STL) or Initial Graphics Exchange Specification (IGES) files before be transferred into the Moldflow Plastics Insight (MPI) software. Simulations of feedstock flow of the model will be carried out in accordance with MPI software parameters which have been set. Feedstock which had been used in this study is PMC PPLiWo60 that be selected by the Fraunhofer Institute for MPI material list. The material consists a mixture of 40% of thermoplastic PP and 60% of wood fibers.

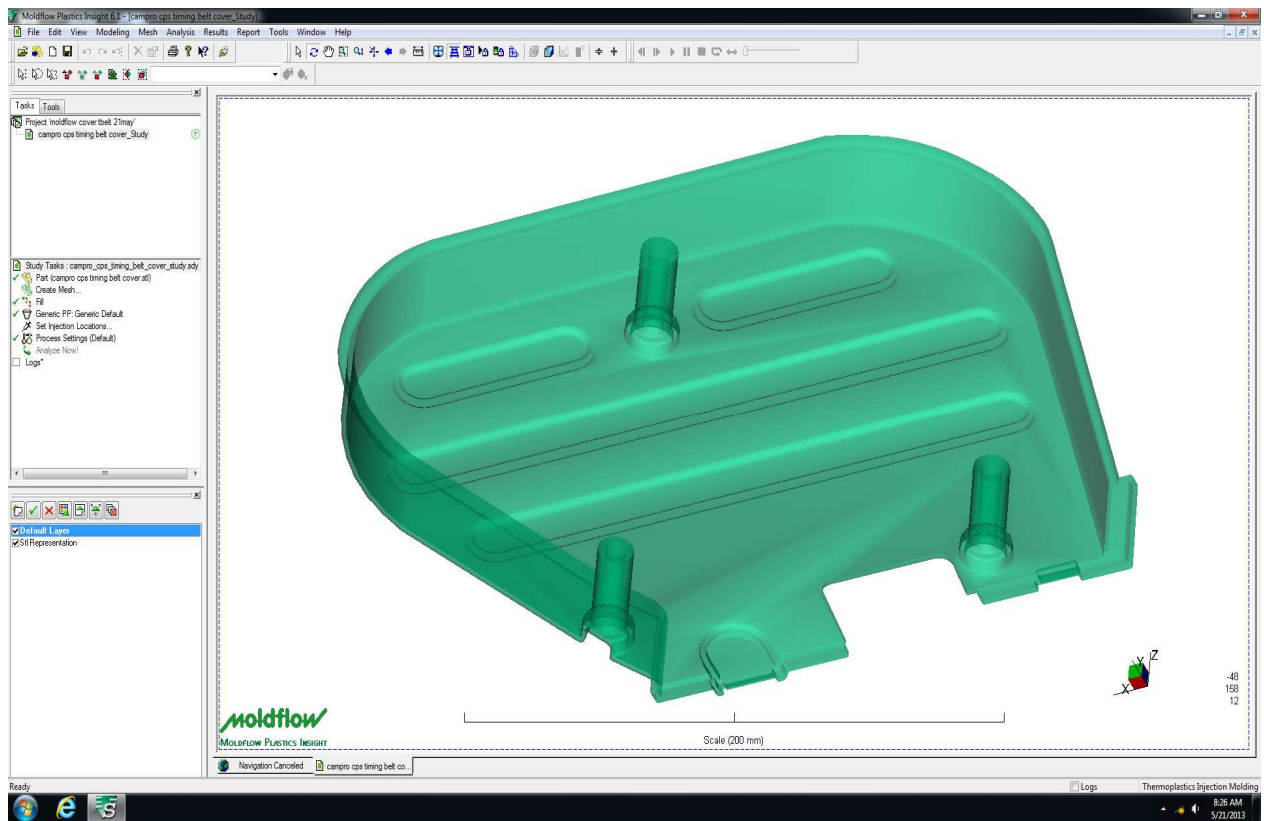


Figure 2: Component designed by CATIA V5

Referring to Table 1, the studied experimental arrangement consists of 3 levels and 4 different factors. Levels are determined based on preliminary simulations and molding conditions which are selected to suit the material.

Table 1: Factors and experimental design levels

| Factor | Parameter                  | Level 1 (–) | Level 2 (0) | Level 3 (+) |
|--------|----------------------------|-------------|-------------|-------------|
| A      | Injection temperature (°C) | 180         | 190         | 200         |
| B      | Mold temperature (°C)      | 40          | 50          | 60          |
| C      | Melt flow rate (g/10min)   | 50          | 60          | 70          |
| D      | Injection pressure (MPa)   | 180         | 190         | 200         |

The results obtained from simulation MPI will analyze by using Minitab 16. This analysis process was run by using experimental design Response Surface Method (RSM) by order of Box-Behnken design and analysis of variance (ANOVA) to obtain the optimal parameters for injection molding process.

## RESULTS AND DISCUSSION

From the analysis are made for the five responses, the optimal value of the parameters are identified with regard to the frequency of the values which obtained from the analysis as shown in Table 2.

Table 2: Optimize parameter for 5 responses

|                         | Mold temperature (°C) | Injection temperature (°C) | Injection pressure (MPa) | Flow rate (cm <sup>3</sup> /s) | Response value |
|-------------------------|-----------------------|----------------------------|--------------------------|--------------------------------|----------------|
| Fill time (s)           | 40                    | 170                        | 200                      | 70                             | 2.3585         |
| Average velocity (cm/s) | 40                    | 190                        | 180                      | 50                             | 831.1026       |
| Pressure (MPa)          | 45                    | 185                        | 181                      | 62                             | 69.9903        |
| Sink index (%)          | 60                    | 171                        | 180                      | 50                             | 1.9999         |
| Volume shrinkage (%)    | 60                    | 170                        | 200                      | 50                             | 11.2788        |

Combination of optimum parameters which tabulated in Table 2 was analyzed through parameter optimization step in MPI software to obtain the most optimal parameter injection molding for timing belt cover CamPro CPS engine. The result is shown in Table 3.

Table 3: The most optimize parameters

| Mold temperature (°C) | Injection temperature (°C) | Injection pressure (MPa) | Flow rate (cm <sup>3</sup> /s) |
|-----------------------|----------------------------|--------------------------|--------------------------------|
| 40                    | 170                        | 180                      | 50                             |

By using the most optimal parameters obtained, MPI simulation is run again on the components to analyze whether the results of molding process become more better or otherwise. Simulation is carried out by using two types of feedstock PMC polymer composite material PP with wood fiber (PPlWo60) and natural PP material (PP-7533: TaiwanPP) which intended to compare the results. Figures 3 (a)-(e) and Figure 4 (a)-(e) show a graphical summary of components simulation by using injection molding PMC (PPlWo60) and natural polypropylene (PP-7533: TaiwanPP).

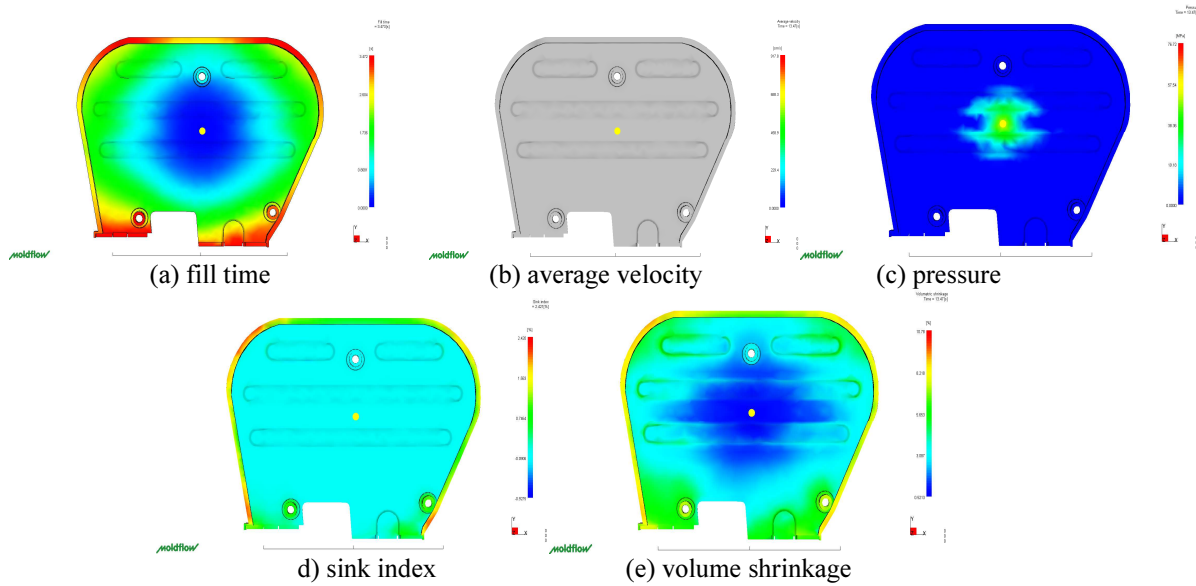


Figure 3: Simulation of most optimum parameters of injection molding PMC (PPlWo60)

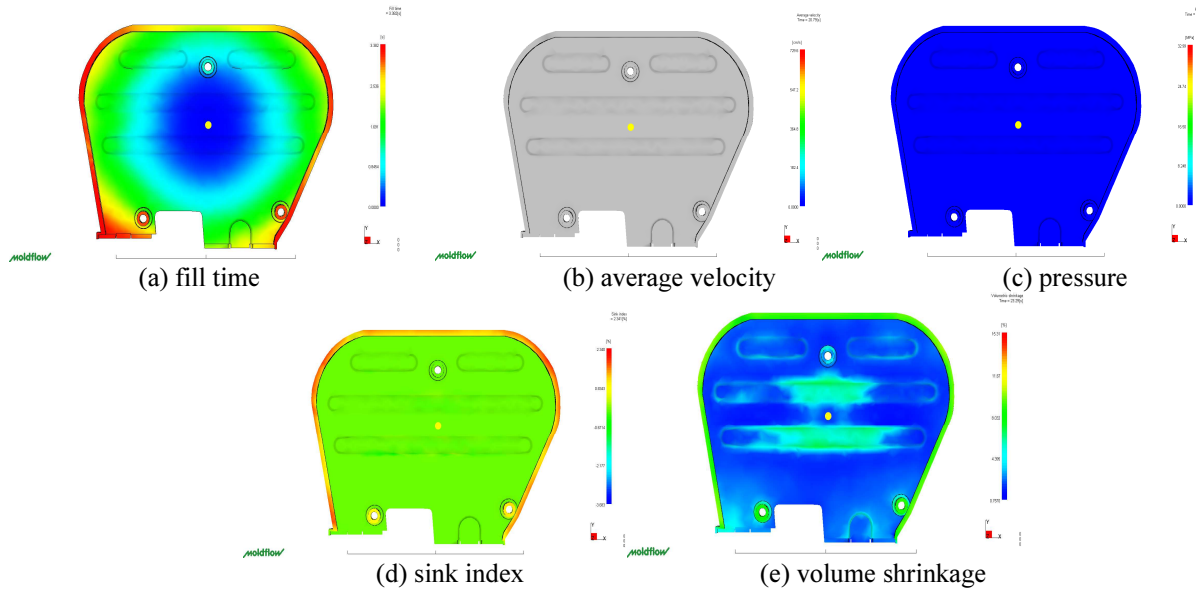


Figure 4: Simulation of most optimum parameters for natural PP injection molding

The result of injection molding MPI simulation for both feedstocks is listed in Table 4. The fill time for original PP is a little shorter than the PMC, but still can be considered which almost equal around 3.4 seconds. However, filling time actually does not influence the quality of the product but it still has to do with other parameters such as pressure and injection velocity.

Table 4: Simulation results of optimum parameters of injection molding

| Feedstock Response      | PMC (PPLiWo60) | PP (PP-7533; TaiwanPP) |
|-------------------------|----------------|------------------------|
| Fill time (s)           | 3.473          | 3.387                  |
| Average velocity (cm/s) | 917.8          | 797.5                  |
| Pressure (MPa)          | 76.72          | 50.33                  |
| Sink index (%)          | 2.421          | 0.812                  |
| Volume shrinkage (%)    | 10.78          | 12.51                  |

For the size of the average velocity readings for PMC materials (PPLiWo60) is 917.8cm/s. It is higher than the average velocity of the PP-7533 material. This is due to the PMC material (PPLiWo60) containing 40% PP and 60% wood fiber, while the PP-7533 is a 100% PP. So, PMC requires a higher velocity to fill the mold cavity. Similarly, the percentage of the sink index and groove pressure, the pressure of PMC was higher compared to the PP-7533. Wood polymer composite required a higher pressure to bring the material into the mold compared to the original PP readings. Percentage of sink index for natural PP was very small compared with the PMC. While analyzing the percentage of volume shrinkage, the value of PMC material is much lower than the PP-7533. This is due to the presence of wood fibers in the composite to reduce the percentage of volume shrinkage. The optimum parameters which obtained from this study can be applied to real injection molding for components PMC timing belt cover CamPro CPS. The reading of the simulation results by using the optimal parameters is not much different than the PP-7533. Most important is the percentage of shrinkage defects index and volume fossa is very small and acceptable. The presence of wood fiber can reduce the defects in molding results.

## CONCLUSION

In conclusion, the most optimal parameters of the injection molding process for timing belt cover CamPro CPS component by using PMC PPLiWo60 are 40°C of mold temperature, 170°C of injection temperature, 180MPa of injection pressure and flow rate at 50cm<sup>3</sup>/s. The most optimal parameter value can be used for the PMC PPLiWo60 and PP-7533 injection molding process. The comparison has been done to the simulation result which found that the values of response for both feedstocks still in range and suitable to use. But, it can be improved to obtain a better result. The study also shows that this software can predict and provide adequate decision between filling time, the average velocity, pressure, sink index and volumetric shrinkage groove. Through these results, it can help to reduce defect products in the injection molding process of polymer composite reinforced natural material as a sign of a real sink mark, trapped air and welding line. Through this analysis, it also can assist in the design of the mold so that the mold can be designed with high accuracy. This condition is not only save cost and time, but also can improve the quality and dimensional accuracy for the production of a product.

## ACKNOWLEDGEMENT

The authors would like to thank Mr Zairi Ismael Rizman for his guidance and assistance in getting this paper published.

## REFERENCES

1. Deo, C.R., 2010. Polymer matrix composite using natural fiber Lantana-Camara, Phd thesis, National Institute of Technology Rourkela.
2. Saxena, M., A. Pappu, A. Sharma, R. Haque and S. Wankhede, 2011. Composite materials from natural resources: Recent trends and future potentials. In: *Advances in Composite Materials-Analysis of Natural and Man-Made Materials* (eds P. Tesinova) pp. 121-162. InTech, Rijeka.
3. Gupta, R., N. Sulaiman, A. Gupta and M.D.H. Beg, 2013. A Simulation Software for the Prediction of Thermal and Mechanical Properties of Wood Plastic Composites. *Computer Technology and Application*, 4 (1): 1-5.
4. Monteiro, S.N., 2009. Polymer-Matrix Composites: New Fibers Offer New Possibilities. *Journal of the Minerals, Metals and Materials Society*, 61 (1): 16.
5. Taj, S., M.A. Munawar and S. Khan, 2007. Natural Fiber-Reinforced Polymer Composites. *Proceedings-Pakistan Academy of Sciences*, 44 (2): 129-144.