International Journal of Engineering & Technology, 7 (3.17) (2018) 15-20

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Numerical Simulation Analysis of Wood/PP Composites for Injection-Moulded Car Battery Trays

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Abstract

This research focused on the simulation analysis of wood polymer composites (WPCs) based on polypropylene (PP) for the injection moulding of automotive parts, namely car battery trays (CBTs). A plastic CBT, which is commonly used to support the battery in a car engine, is manufactured completely through the injection moulding process. The conventional design method is clearly unable to satisfy production requirements; however, with the application of the Moldflow software rational production process parameters, the filling time, injection pressure, clamping force, and others, can be formulated. A moulded CBT was designed using a computer-aided design tool, namely CatiaV5R20, before being imported to the finite element analysis tool, Moldflow. The use of the Moldflow software enabled a full analysis to be conducted of the material flow inside the mould cavity for the moulded CBT. Two types of gates, namely, the sprue and pinpoint gates, were used, through which the analyses were carried out by the Moldflow software to check the filling time, injection pressure, clamping force and warpage, by simulation in the sequential trials. The data on the wood fibre/PP composite, where 40 wt% of wood fibre loading was used. Finally, the use of the Moldflow simulation software was presented.

Keywords: *Wood fibre; Car Battery Tray; Injection Moulding; Moldflow*

1. Introduction

The first generation of composites with wood-based reinforcement have been on the market for some 20 years now, and the market is expected to grow. These materials are used mainly in structural, building and automotive parts. Wood flour is used as the reinforcement in WPCs. WPCs were developed in Italy and gradually gained popularity in other parts of the world [1]. Most polymer composites can be processed using injection moulding. Injection moulding is one of the most common and versatile operations for the mass production of complex plastic components with perfect dimensional tolerances. This is because the process requires only minimal operations without finishing. Injection moulding is the process of recycling plastic in order to form a desired shape by means of pressing molten plastic into a cavity [2].

Injection moulding is the most generally utilised process for the manufacture of plastic parts. Many kinds of plastic items, which differ significantly in terms of their size, complexity and application, are produced by means of injection moulding. The process of injection moulding requires the use of an injection moulding machine, plastic resin, and a mould. The plastic is melted in the injection moulding machine and then injected into the mould, where it cools and solidifies into the final part. Many years ago, before the plastic injection moulding industry possessed all the finite element analysis software, most injection mould makers used the old style and experience of the trial and error approach. This approach, which is required at the try-out stage, can be decreased through CAE by simulating the resin flow pattern and predicting the defects, which can then be avoided by improving the flow balance [3]. The Moldflow software can be used to simulate the injection moulding of fibre-reinforced thermoplastics [4]. The use of simulation software is crucial in the moulding industry to predict the quality and processability of a product, and, most importantly, to save money [5, 6]. The mould-filling process in the injection moulding of WPCs was carried out with the use of the commercial software package, Autodesk® Moldflow® Insight 2016 (AMI) [7]. The concept of modern plastics manufacturing emphasizes computer-aided engineering (CAE) technology to predict the number or types of defects and errors in the products that are produced before the injection process is carried out by plastic injection machines. The CAE results will be very useful as the data will help to minimize defects during production, provide a guide for the mould maker in designing the mould, and set the process parameters in the machine so as to accelerate the process of trial and error performed on the plastic injection machines.

Computer software can be used for the initial design of plastic material products in the injection moulding process. One computer program that is able to apply the design to injection moulding is CATIA (computer-aided three-dimensional interactive application). CATIA is a three-dimensional graphic design program that is able to feature a product or result that is similar to the real thing before the object creation process is carried out, so that the shape and strength of the product are known before the goods are produced. The moulding of the products designed with the

CATIA program can then be simulated by a computer program, which will run the injection moulding process. One such computer software program that can be applied to simulate the injection moulding process or the charging of the plastic material into the cavity of the mould is the Moldflow Plastics Insight 5.0R1 [8].
The main focus of this study was to find a way to minimize moulding defects in plastic products so as to meet the demands of customers for quality. This was achieved by obtaining the optimum injection process parameters by applying the concept of modern plastics manufacturing-based CAE. For this study, a car battery tray made of wood/PP composite was selected as the object for the application of this concept. Most car battery trays are made of aluminium alloy, high strength steel and composite materials [9].

2. Methodology

The Computer-aided Three-dimensional Interactive Application version 5 (CATIA V5R20) software was used to create a three-dimensional computer-aided design (3D CAD) of a model of the plastic part for this research based on the original design, as shown in Figure 1. The selected model for this research was a battery tray for the national car, as shown in Figure 2. Once the part had been designed in Catia V5R20, it was saved in the .stl format. The model was imported into the Moldflow analysis software to become the mesh model [10]. Next, NCell 40, which is a 40-wt% wood/PP composite, was selected as the material for this research.

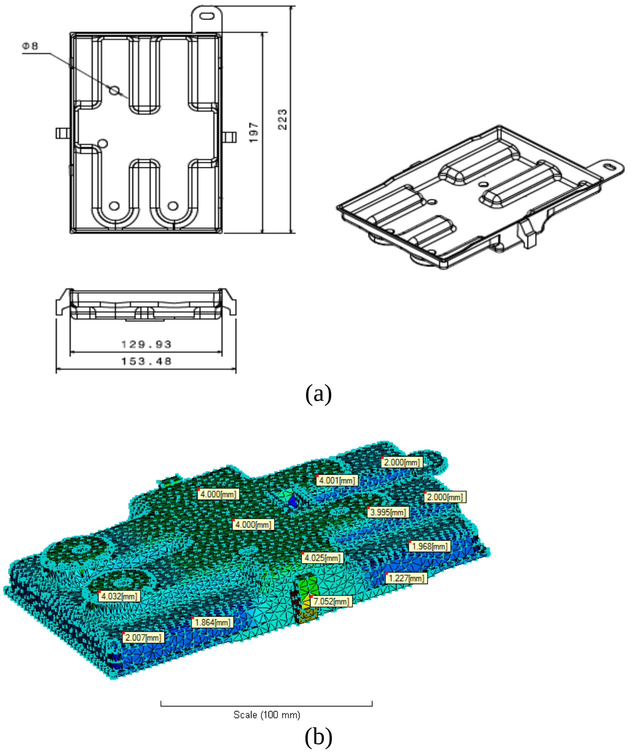


Fig. 1: Product appearance. (a) Dimensions of car battery tray, (b) Checking of variable wall thickness in Moldflow

Figure-2. Actual battery tray part

The Moldflow methodology that was followed is shown below in Figure 3.

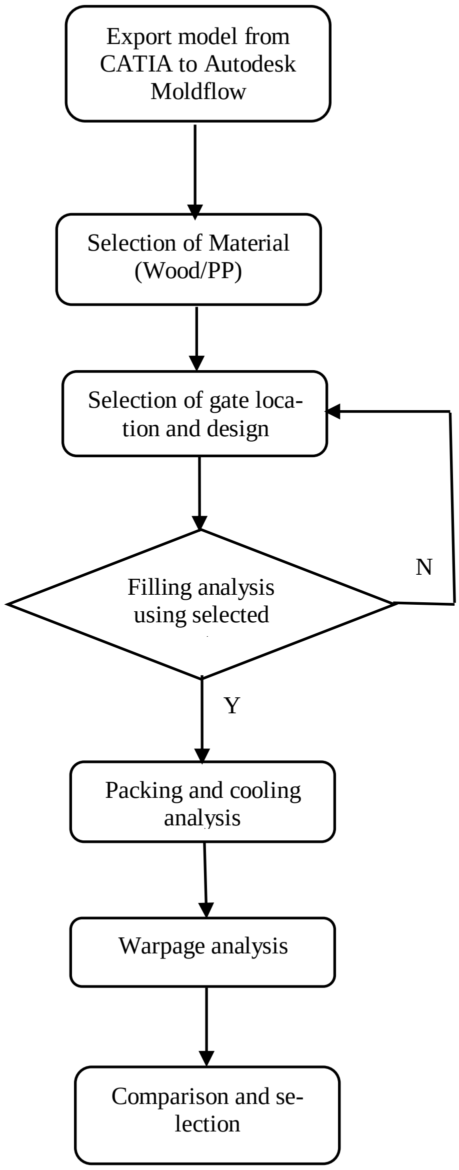


Fig. 3: Flow diagram of the adopted analysis

The material for the plastic car battery was produced by Green Core Composites, and the properties of the material are shown in Table 1 and Table 2. The injection moulding machine used in the simulation adhered to the specifications: Arburg Allrounder 420S 110 Tons injection moulding machine (35mm).

Table 1: Product specifications

Property	Value
Weight of the part	105.722 g
Elastic modulus	4172 MPa
Poisson's ratio (v12)	0.36
Shear modulus	1297 MPa
Projected area	262.107 cm^2
Wall thickness	1.8 mm

Table 2: Input details for Moldflow Plastic Insight 2012

Property	Value
Melt density	0.92585g/cm^3
Solid density	1.0746g/cm^3
Ejection temperature	114^{o}C
Melt temperature (min)	170^{o}C
Mould temperature (min)	35^{o}C
Mould temperature (max)	70^{o}C
Max. shear stress	0.25 MPa
Max. shear rate	100000/s
Absolute max. melt temp.	205^{o}C

3. Results and Discussion

The mould filling results obtained from this project methodology were used to investigate and verify the benchmarking analysis. The common method for performing the mould filling analysis was only suitable for determining the proper part and mould geometry during the initial stages of the product development and mould design. For this reason, the results obtained from this project methodology were suitable for benchmarking against the AMI 2012 analysis, as shown in Table 3.

Table 3: Flow analysis results

Result	PP/40 wt% Wood
Melting temperature (°C)	190
Filling time (s)	2.678
Projected area (cm^2)	262.118
Volume (cm^3)	106.137
Weight of part (g)	110.456
Weld line	Exist
Air trap	Exist
Freeze time (s)	30
Max. clamping force (tonne)	92.319
Volumetric shrinkage (%)	4.177
Max. injection pressure (MPa)	75.065
Mesh match percentage	90.8

3.1 Moldflow Analysis Results

3.1.1 Mesh Analysis

After meshing the model, it was necessary to perform a series of diagnostic checks to ensure that the mesh was suitable for analysis. In this project, the dual domain and meshing model was developed as shown in Figure 4. The mesh match ratio must be above 85% for a flow analysis and above 90% for a warpage analysis. In this research, the mesh match ratio was 90.8%, as can be seen in Figure 5.

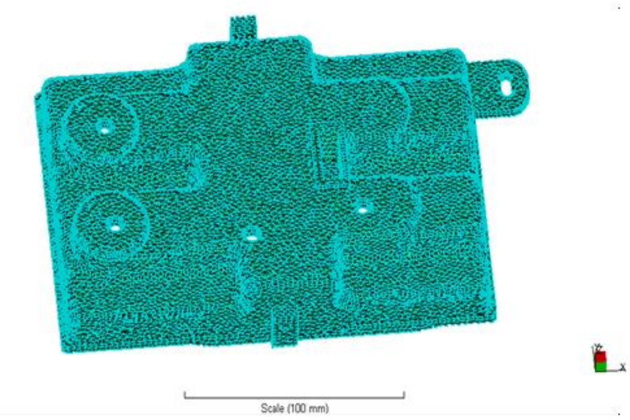


Figure-4. Dual domain mesh

```
Entity counts:
    Triangles:        53840
    Connected Nodes:          26912
    Connectivity regions          1

Area:
    Surface Area:       840.143 cm^2

Volume:
    Triangle:   105.545 cm^3

Aspect Ratio:
                Max     Average    Min
               112.9     2.10      1.16

Edge details:
    Free edges                  0
    Manifold edges              80760
    Non-manifold edges          0

Orientation details:
    Elements not oriented       0

Intersection details:
    Element intersections       23
    Fully overlapping elements  0

Match percentage:
    Match percentage            87.4%
    Reciprocal percentage       81.6%
```

Fig. 5: The mesh statistics results

3.1.2 Gate Location Analysis Results

The Autodesk Moldflow Insight 2012 software was used to perform an analysis in order to detect a suitable gate location. The most challenging factor was the insertion into the best gate while filling the resin in the cavity so as to obtain an excellent and high-quality product of moulding. As shown in Figure 6, the gate analysis indicated that the best injection location was at the centre of the model (blue area) and the worst injection location (red area) was located slightly below the centre, where the thickness of the model was less in comparison to the top of the model. The upper part of the model was selected for the injection location to facilitate the ejection of the moulding from the core and for measuring the ejection force. The reasons for choosing the gate location were to ensure uniform flow paths in the cavity fill and to complete the filling as rapidly as possible without any problems [11, 12]. Two different gates were used in this research, namely, the direct sprue gate and pinpoint gate. The direct sprue gate requires an operator to separate the parts from the runners manually after each cycle, while the pinpoint gate is broken or sheared when the mould opens to eject the part. Manually-trimmed gates are chosen for several reasons; the gates are too bulky to be automatically sheared by the machine, and the flow distribution for certain designs requires a simultaneous flow distribution across a wide front. Meanwhile, automatically-trimmed gates are used for several reasons: to avoid the removal of the gates as a secondary operation, reduce the cost, maintain consistent cycle times for all parts, and minimize gate scars on the parts.

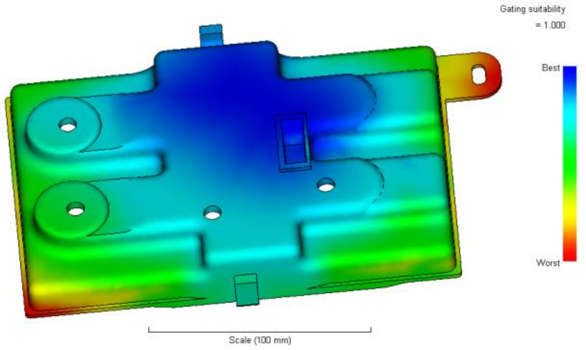
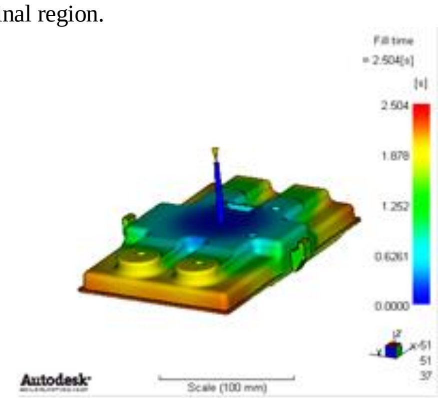


Fig. 6: Best gate location

3.1.3 Filling Analysis

Figure 7 depicts the filling time for the wood/PP composite CBT with different gates. In the injection moulding process, the mould filling analysis plays a significant role in determining the quality of the moulded CBT part. Moulding defects like short shots can be avoided by a precise forecast of the filling time. A short shot is the part of the model that is not filled. A short shot has no shading and shows up as translucent. In the modelling, the acquired outcomes of the filling time for the plastic material flow path through the sections used contours to connect the areas that were being filled at the same time. The contours appeared to change hues from blue to red; where blue indicated the first areas to be filled, and red indicated the final region.



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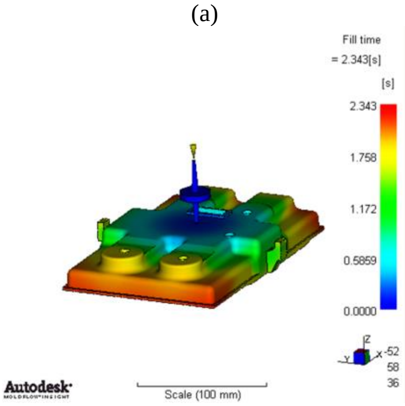
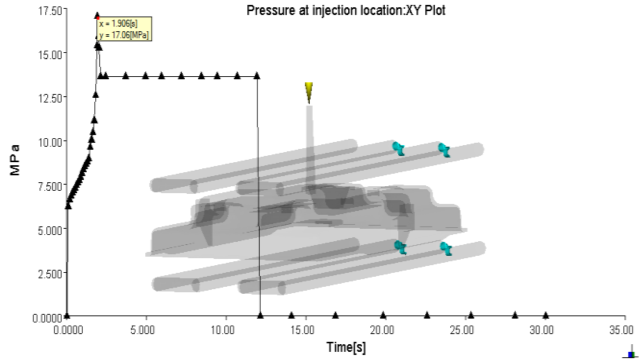


(b)

Fig. 7: Filling time of CBT: (a) using a direct sprue gate with a diameter of 6.2 mm, and (b) using a pinpoint gate with a diameter of 1.8 mm.

The result predicted the filling pattern of the plastic material inside the mould. Each colour band indicated the regions in the cavity that were filled at the same time. An unbalanced flow occurred when the extremities of the cavity were filled at different times. Figure 8 shows the filling analysis results for the best gate location. As shown, the expected filling times for the CBT part via the sprue gate and the pinpoint gate were 2.504s and 2.343s, respectively.

Figure 8 displays the injection pressure for the different gate designs. The injection pressures using the sprue gate and the pinpoint gate were 17.06 MPa and 89.54 Mpa, respectively. This was due to the different gate areas; a smaller area produced a higher injection pressure.



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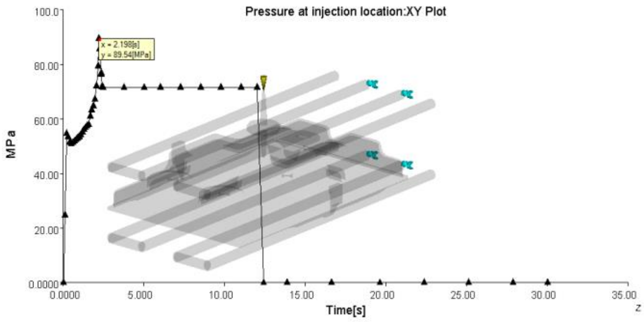


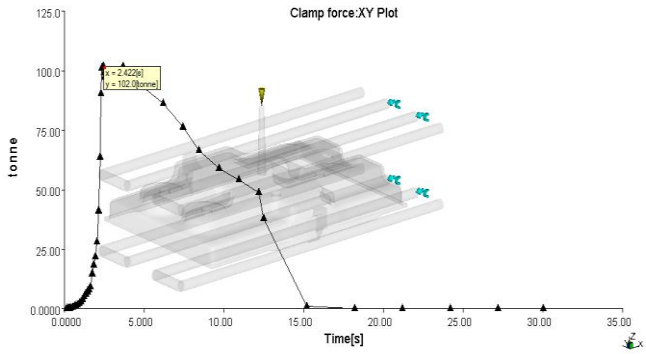
(b)

Fig. 8: Injection pressure for the two different gates: (a) Direct sprue gate, and (b) Pinpoint gate

Figure 9 shows that the clamping forces for the direct sprue gate and the pinpoint gate were 102 tonnes and 134 tonnes, respectively. This statement can be explained by the following equation:

$$F = P \times A \quad (1)$$

where F is the clamping force, P is the injection pressure and A is the projected area of the product.



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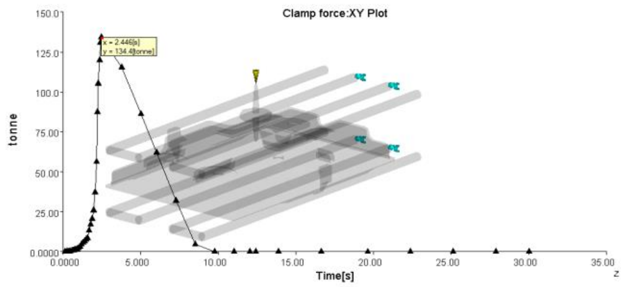
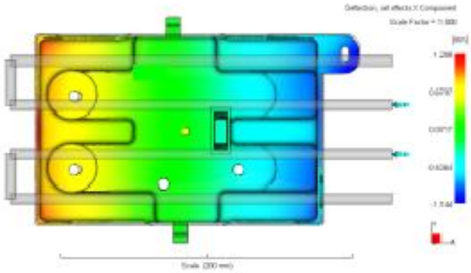


(b)

Fig. 9: Clamping force for the two different gates: (a) Direct sprue gate, and (b) Pinpoint gate

3.1.4 Warpage Analysis

Figures 10 and 11 display the warpage of the product in three directions (X, Y and Z). Figure 10 represents the warpage from using the direct sprue gate, while Figure 11 represents the warpage from using the pinpoint gate. It can be seen that the warpage in the direction of X, Y and Z for the direct sprue gate was 1.288 mm, 1.795 mm and 0.713 mm, respectively, as shown in Figure 11. Meanwhile, the warpage in the direction of X, Y and Z for the pinpoint gate was, 1.402 mm, 1.889 mm and 0.730 mm, respectively, as indicated in Figure 12. The results showed that the pinpoint gate provided more warpage compared to the direct sprue gate.



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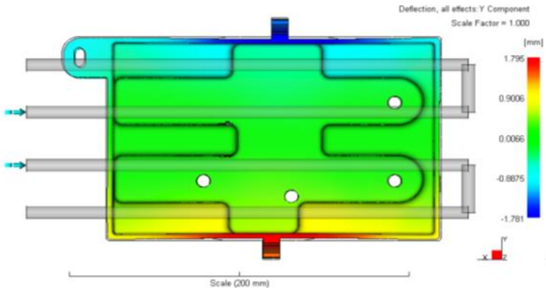

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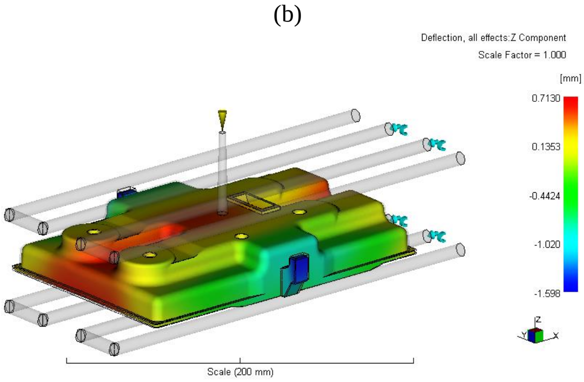
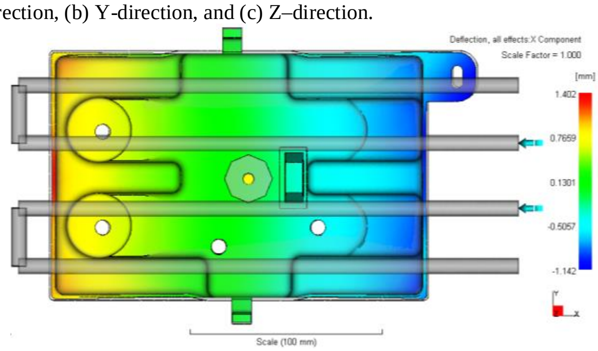


(c)

Fig. 10: Deflection in warpage analysis for the direct sprue gate in the (a) X-direction, (b) Y-direction, and (c) Z–direction.



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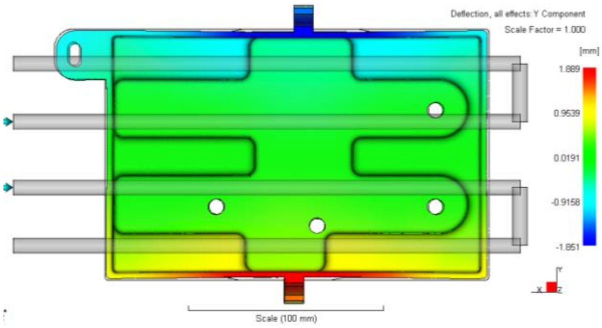

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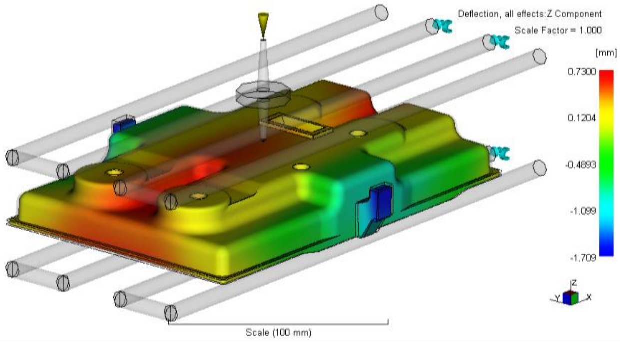
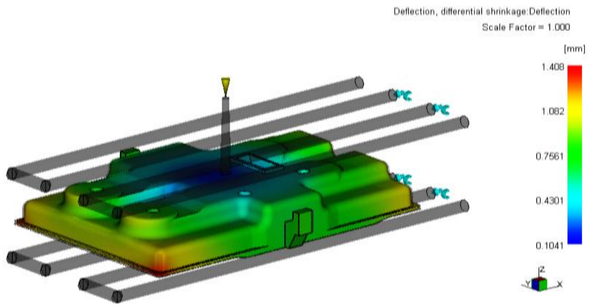


(c)

Fig. 11: Deflection in warpage analysis for the pinpoint gate in the (a) X-direction, (b) Y-direction, and (c) Z–direction.

According to Figures 10 and 11, the total product deformation was in the three directions of X, Y, Z, with the Y direction accounting for the biggest proportion [13]. Hence, it could be concluded that the product warpage was principally in the X and Y directions. Therefore, controlling the X and Y directions was the key to the resolution of the warpage defect in the product. Next, the elements that caused the warpage of the product were analysed to seek the primary factors affecting the product. Three primary factors were influencing the warpage of the product: uneven volume shrinkage, uneven cooling, and uneven orientation (refer to Figures 12 and 13). The most influential parameter on warpage was the injection pressure, while it was slightly influenced by the gate dimensions and the filling time [14].



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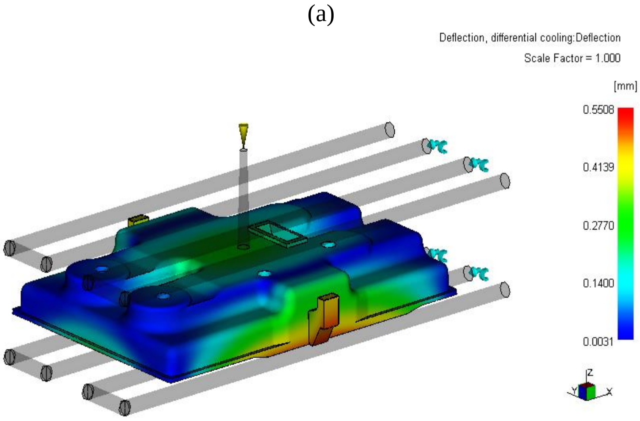

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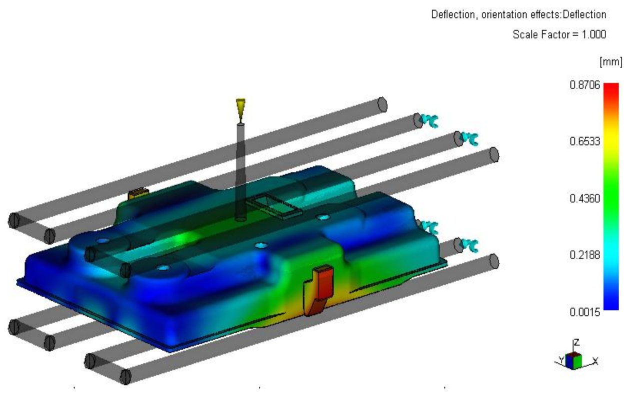
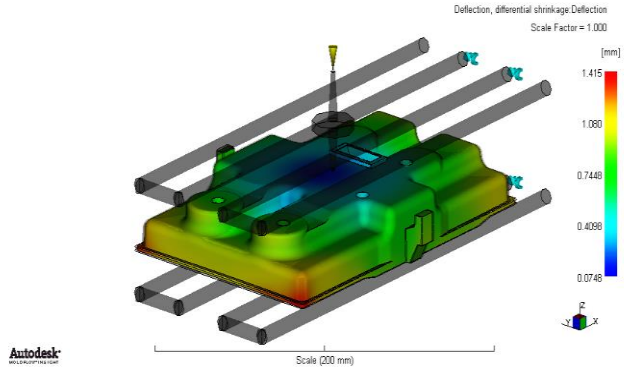


(c)

Fig. 12: Factors influencing the warpage of the product for the direct sprue gate. (a) Deflection, differential shrinkage, (b) Deflection, differential cooling, and (c) Deflection, differential orientation.



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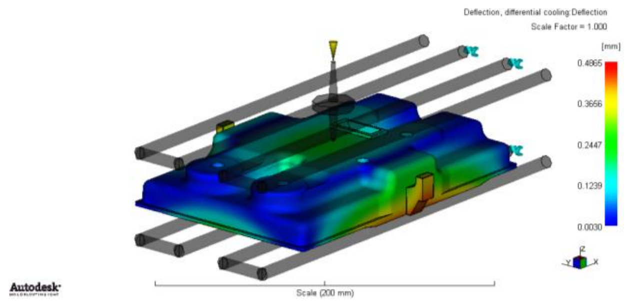

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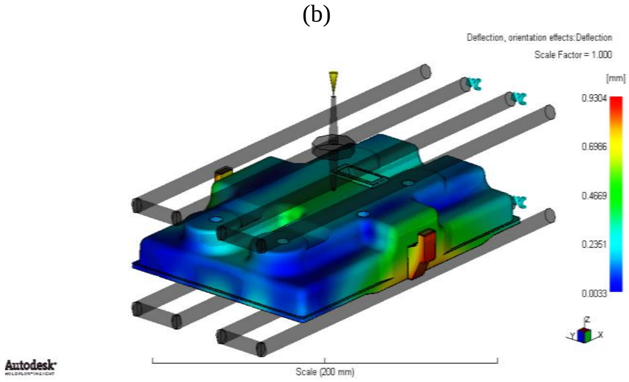

(c)

Fig. 13: Factors influencing the warpage of the product for the pinpoint gate. (a) Deflection, differential shrinkage, (b) Deflection, differential cooling, and (c) Deflection, differential orientation.

Figures 12 and 13 show that the largest amount of deformation, which was shrinkage deformation, was 0.0748 – 1.415 mm; deformation caused by cooling was 0.003 – 0.4865 mm; and the total deformation orientation factor was 0.0015 – 0.8706 mm. It can be summarised that the deflection caused by shrinkage accounted for the largest part of the total deflection in the moulding process [15].

4. Conclusion

Referring to the numerical simulation analysis with the Moldflow software, it can be concluded that the wood/PP composite CBT can be moulded through the injection moulding process. This method can effectively improve the lead time of manufacturing, shorten the production cycle, and result in the effective production of quality products. Thus, with the help of the Moldflow software, the gate location and the filling time can be predicted, while keeping all the parameters in mind for plastic injection-moulded components, and hence, the use of such types of tools for analyses has been proven to be helpful. The analysis also showed the mouldability of the battery tray using the direct sprue and pinpoint gates. For the direct sprue gate, it was necessary to use a secondary process for the cutting of the sprue and a low machine capacity was required, while the pinpoint gate was considered to be an auto-degating mould with a high machine capacity. This research can be extended to determine the usability of components at locations where they are exposed to high temperatures, such as the battery tray, which is located adjacent to the engine compartment.

Acknowledgements

The researchers wish to thank the Ministry of Higher Education, Malaysia and Universiti Kebangsaan Malaysia for the financial support under grant LRGS/TD/2012/USM-UKM/P1/05.

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