

Research Article

Investigation of the Large-Scale Pallet by Recycled Polypropylene and the Sequential Valve Gate System during the Injection Molding

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Plastic pallets are essential devices for the transport of industrial products within containers and can be made from recycled plastics to be more environmentally friendly. However, numerous thin reinforcing ribs are required to mold such large-size pallets, thereby requiring a large-scale injection-molding machine. Many filling gates can reduce the welding lines to enhance the structural strength of the pallet to achieve injection molding using a lower locking force machine. This study simulated the production of recycled polypropylene plastic pellets using a 3500-ton super-large injection-molding machine and the Moldex3D package to derive the flow analysis of the moldability. The PTC Creo software is used to construct plastic pallets (1100 mm × 1100 mm × 140 mm), filled by twelve gates using a baffle cooling system. During the four-stage filling of the sequential valve gate system, the flow front spreads from the central gate to the four corners of the pallet, decreasing the number of welding lines, with an average filling pressure of 19.23 MPa by a sequential valve gate scheme which is approximately 65% of the concurrent valve gate opening scheme. The maximum clamping force by this sequential valve gate opening scheme in the molding of plastic pallet is 874.6 tons, only half of the one by concurrent valve gate opening scheme. The average welding angle was 85.7° in the concurrent valve gate opening scheme, with smaller angles than that of the sequential gates controlled scheme. The maximum temperatures during the filling by the two schemes with the concurrent valve gates opened and the sequential gates controlled were 230.5 and 232.5°C, respectively. The sequential valve gate opening scheme's warpages are smaller than the ones by the concurrent valve gate opening scheme. The warpages of the pallet by the sequential valve gate system are smaller than the ones by the concurrent valve gate system. A higher temperature of the cooling channel and a medium level of cooling time result in lower warpage of the pallet.

1. Introduction

Plastic components with thin-wall features in injection molding have become a major manufacturing technology for the modern plastic industry in recent decades. During thin-wall injection molding, the melted material under high pressure flows into the mold cavity by the screw and barrel to overcome the melt-flow resistance within the thin-wall mold cavity. This process must avoid freezing the melted material during the flowing; hence, the flowing length is limited to each filling gate due to the variety of the connection features in the thin wall and ribs within the mold cavity. Kashyap and

Datta [1] indicated that the injection-molding process incurs considerable changes in rheological and thermomechanical properties of polymeric materials and their composites due to highly varying stresses at various points of the process, material processing at melt temperatures, and high cooling rates of the final product. The modern computational techniques consist of hard computing and soft computing that may confront the challenges posed by MIMO parameters, requirement of huge experimental analysis, and limited knowledge about the intra- and inter-relationships between input and output parameters of the injection molding.

Fernandes et al. [2] also revealed that to find the optimal process parameters for improvement of quality of molded parts is to decrease the production cost. There are four approaches to solve the nonlinear governing equations of the multiphysical process to optimize process parameters in the injection molding which are the error-and-trial approach, process window, design of experiments, and numerical simulation. The numerical simulation of the multidirectional flow and the heat transfer through complex-shaped cavities of the mold are more convenient and efficient because of the complexities of the analytical models concerning the previous multiphysical matters. The moldability of a mold is usually defined by the molding abilities, including the materials, mold, and processing parameters. Moayyedean and Mamedov [3] constructed a quality evaluation model combining the Taguchi fuzzy process and order performance to determine the configuration of the process parameters for the highest moldability index and eliminating manufacturing defects in the conventional injection-molding process. Their simulation results showed that the proposed quality evaluation model is an efficient way of setting process parameters for injection moldability. Yang and Liou [4] used a moldability diagram to identify the relative importance of process parameters for gas-assisted injection molding and found that the melt temperature and short shot were most significant. The moldability analysis parameters should also include the mold temperature, packing pressure, packing time, cooling time, and the filling rate of injection. The polymer interaction with the mold under specific processing parameters is also important as the cavity pressures of filling and packing may affect the molding quality.

Huang [5] used a cavity pressure sensor to measure the pressure history of the melted material during the injection-molding process and found that the cavity pressure is the major parameter that affects the molding repeatability. Zhou et al. [6] utilized pressure and temperature sensors and applied injection parameters to construct an injection-molding physical model to numerically interpret via a neural network. Subsequently, a well-empirical neuron network was then trained for injection-molding quality by Zhou et al. [7].

Zhang et al. [8] proposed a statistical quality-monitoring method using only hydraulic pressure and screw position data obtained from built-in machine sensors. Experimental results showed that the rate of fault detection reached 91.48% at a confidence level of 99%. Gordon et al. [9] indicated that multiple orthogonal streams of process data yield higher-fidelity models with coefficients of determination approaching one. Furthermore, the best subset analysis indicated that the most important process data are gathered from in-mold sensors, where the acquired information is closest to the state of the polymer forming the final product. Thus, multiple filling gates are essential for large molding components to meet each gate flow length. Besides, the melted plastic material from the injection gate flows into two or more filling approaches behind the feature variation, which may meet each other to form the welding line, the strength of which is less than the general molding plastic material because the temperature of the meeting approaches is decreased. Furthermore, the air between these approaches is

molded as the welding line bubble, yielding lower strength heterogeneous plastic. The meeting angle between the two flow fronts is the welding angle. Fellahi et al. [10] differed the two filling approaches meeting formations by the welding angle into two regions, including the welding angle smaller than 135° marking a welding line and greater than 135° meld line, showing that the strength of the welding line was greater than the meld line.

It is inevitable that in single-gate molding, an insufficient filling may occur, and/or a relatively high injection pressure is required to mold thin-wall parts, particularly in large plastic pallets to accommodate high loads for the transport of stacked products by a forklift. The large plastic pallet with several thin walls and rib features can be molded using multiple injection gates for simultaneous filling of the melted materials during injection with a high injection speed and pressure. The presence of weld and meld lines in the molded component is one of the most significant structural application problems since the potential failure near the welding line area is very high. The hot runner system is commonly used for thin-wall injection molding to meet the high molding pressure requirement. In the injection molding of plastic pallets by multiple gates associated with hot runners, the melted plastic could be filled at the same time by the molding machine, which requires an accumulator capable of supplying instantaneous high boosting pressure. However, the prediction of the generated welding lines by the previous gates is more than that of a single gate in the molding part.

The concurrent filling of multiple gates enhances the filling pressure, which is required for a larger injection-molding machine to clamp and pack the mold during the filling and packing processes. A sequential valve gate system can be used to decrease the clamping and packing forces, dividing the gates into several groups. Fang [11] investigated the injection molding of ASTM-D638 standard specimens of 200 mm in length, 20 mm in width, and 2 mm in thickness from acrylonitrile butadiene styrene (ABS), showing that by setting the on/off time of these filling gates sequentially, the sequential valve gate system eliminated the welding line and increased the tensile strength. Furthermore, Wu [12] used the sequential valve gate system to control the filling gate opening and closing in the molding of ASTM-D638 specimens under different flow front temperatures before welding in the cavity of the mold. The different levels of the melted materials' flow front temperature give various tensile strengths, and the melt polyamide flow front temperature (PA6) was positively correlated with the strength of the welding line, with the average tensile strength only 90% of the tensile strength of the component without a welding line.

The delay in the sequential valve gate system is critical to control the filling time during plastic injection molding. Chen et al. [13] found that the commercially sequential valve gate system delay time is from 0.3 to 0.5 seconds and most affected by the pneumatic control system air pressure responding to the valve opening and closing. Larger air pressure of 100 bars may give a shorter delay time of fewer than 15 milliseconds, and this more accurate control of the on/off switch valve helps connect the flow fronts to reduce the filling pressure loss.

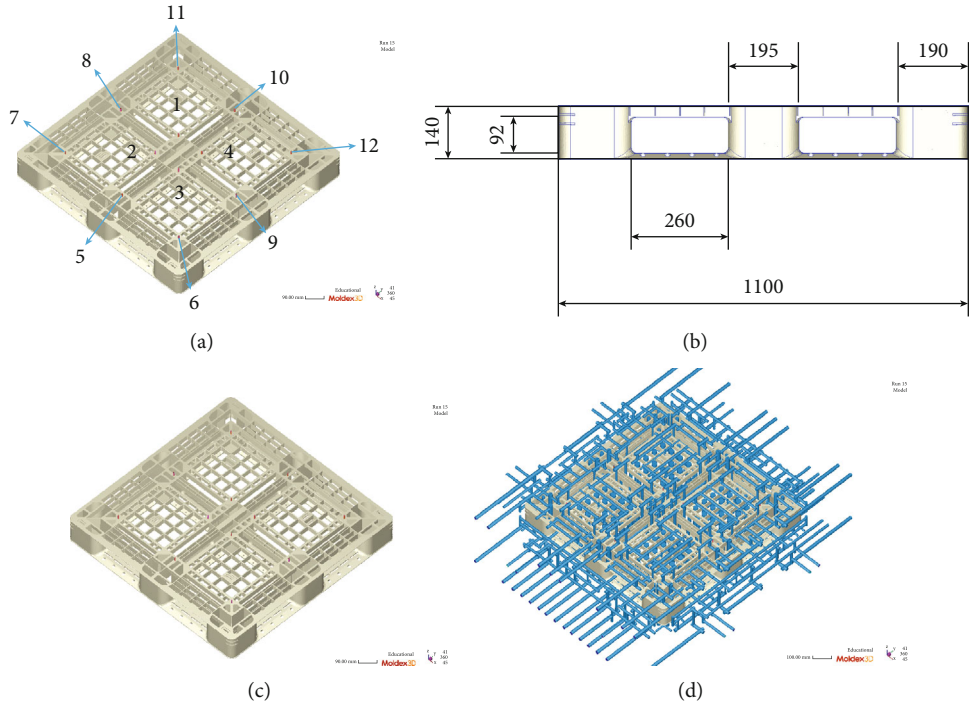


FIGURE 1: Injection-molded pallet. (a) Twelve filling gates in the pallet. (b) The dimensions of the pallet in front view. (c) Isometric view of the top side of the pallet. (d) Isometric view of cooling flow system on the top side of the pallet.

Cardozo [14] reviewed studies concerning the simulation of the filling process in plastic injection molding and showed that the simulation methods were based on three models as the midplane model, the surface model, and the solid model. The midplane model is constructed by the assumption of the quasi-steady-state flow and neglecting of the inertia terms due to the low Reynolds numbers encountered in the flow of molten polymers. The arbitrary planar midplane with a defined thickness is used to represent the three-dimensional geometry of the part, and the midplane models are 2.5D models. The surface model represents a three-dimensional part with a boundary or skin mesh on the outside surfaces of a solid geometric part. Great benefits from the surface model-based simulation of injection molding are gained, and the surface model has thus become the mainstream of injection-molding simulation in commercial CAE systems. The third one of the previous models is the solid model, which is a true three-dimensional simulation performed on geometries. Cardozo [14] especially indicated that Chang and Yang [15] developed a numerical simulation program for mold filling based on an implicit finite volume approach. Their approach was later commercialized as the Moldex3D software and then extended to cover various stages in injection molding. By acrylonitrile butadiene styrene (ABS) and polycarbonate (PC), Guerrier et al. [16, 17] use a glass mold to get a direct visual comparison of injection-molded parts with simulations, where the simulations are performed by the Moldex3D Solid R13. They found the pressure levels from the sensors agree very well for ABS, and for PC, there is a slight deviation, mostly in the timings, since the curvature and

TABLE 1: Material properties of recycled polypropylene.

Solid density (g/cm ³)	1.026
Ultimate strength (MPa)	45.2
Thermal conductivity (W/(m°C))	0.228
Material characteristics	Crystalline
Eject temperature (°C)	91
Melt temperature (°C)	240–260
Recommended mold temperature (°C)	35–55

the levels of the pressure profiles are in fairly good agreement with the experiments.

By the previous literature, one finds that the Moldex3D solid is performing well in the simulation of the injection molding. The quality and process parameters of the plastic pallet are the fundamental investigations for optimization of the injection-molding process. The injection process using a sequential valve gate system for molding of the pallet should firstly determine the welding angle and temperature to identify any weaknesses in the molded components. It has been established that the sequential valve gate system should be applied to control the filling gates for the injection molding of large plastic components and that as the number of welding lines decreased, the injection machine clamping force is reduced. The purpose of this study was to illustrate the applicability of the sequential valve gate system. The Moldex3D solid 2020 package software was used to numerically simulate the injection molding of a plastic pallet (1100 mm × 1100 mm × 140 mm) with thin walls and ribs

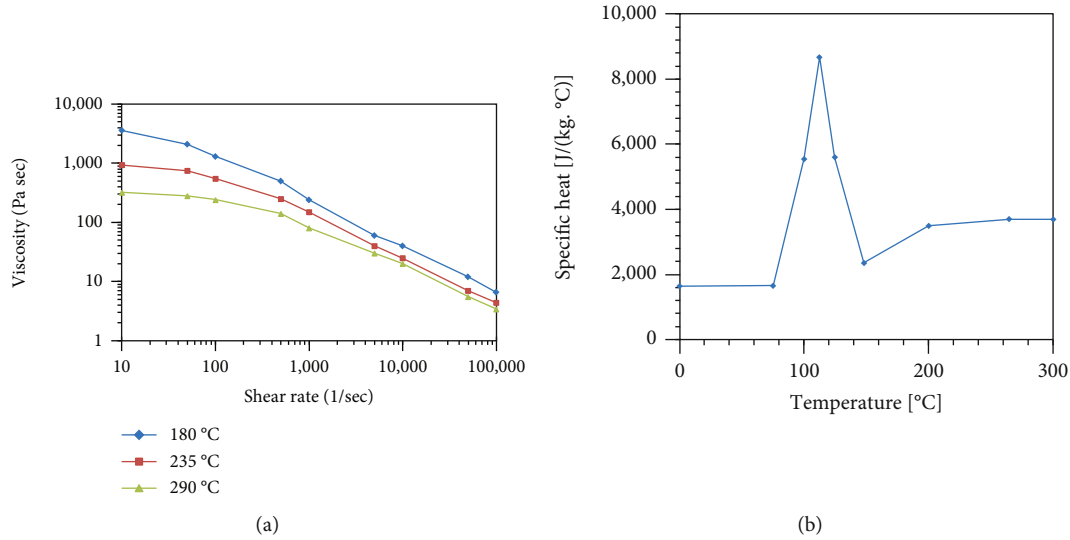


FIGURE 2: Recycled polypropylene viscosity and specific heat. (a) Viscosity versus temperature and shear rate. (b) Specific heat versus temperature.

filled by twelve gates using two different gate designs: a sequential opening of twelve-valve gates and a concurrent opening of valve gates. The maximum pressure and average mold cavity were calculated to determine the effect of the different gate designs on the molding pressure.

2. Numerical Setup

The plastic pallet dimensions used in this study are shown in Figure 1, with a reinforcing rib thickness of 3.4 mm, which was changed according to the draft angle. There were twelve filling gates 7.0 mm in diameter and 20 mm in height as shown in Figure 1(a). Recycled polypropylene (PP) was used as the injection-molding plastic material. An isometric view of the pallet's top side in Figure 1(c) shows the complex features that should be cooled during the molding by the baffle cooling flow system as in Figure 1(d). The molding experiments included a sequential gate opening and the concurrent valve gate opening for the melt-filling process using the Moldex3D package to analyze the mold flow. During melt filling, the gate opening and closing are controlled sequentially by a pneumatic system so that the previous gates are closed by relay filling, and the following gates are opened at the same time during the filling; this assumes that the melted material starts to fill the mold cavity once the valve gate is completely open.

For the concurrent valve gate opening condition, the Moldex3D package was used to open the twelve gates simultaneously to fill the melted material into the mold cavity and determine the distribution of the welding lines, filling pressure, and the estimated clamping force. Then, the molding analysis was conducted with the same injection filling time via the sequential gate opening operation for the melt-filling process. The associated molding pressure within the mold cavity was measured numerically using the same injection parameters to set the timing control of the twelve gates.

TABLE 2: Injection-molding parameters of recycled polypropylene.

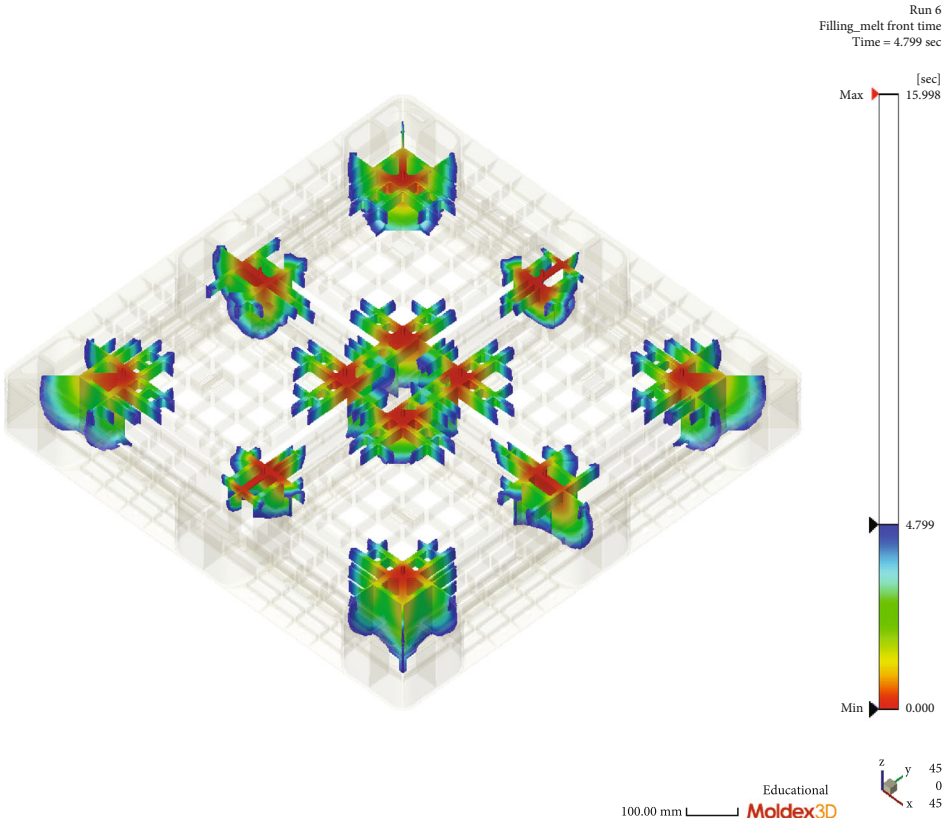
Melt temperature (°C)	250
Curing temperature (°C)	117
Mold temperature (°C)	45
Fill rate (%)	72
Filling pressure (max) (MPa)	40
Filling time (sec)	15
Packing time (sec)	15.5
Packing pressure (%)	70
Cooling time (sec)	53
Mold opening time (sec)	20

TABLE 3: Chen Hsong Supermaster 3600E1 specifications.

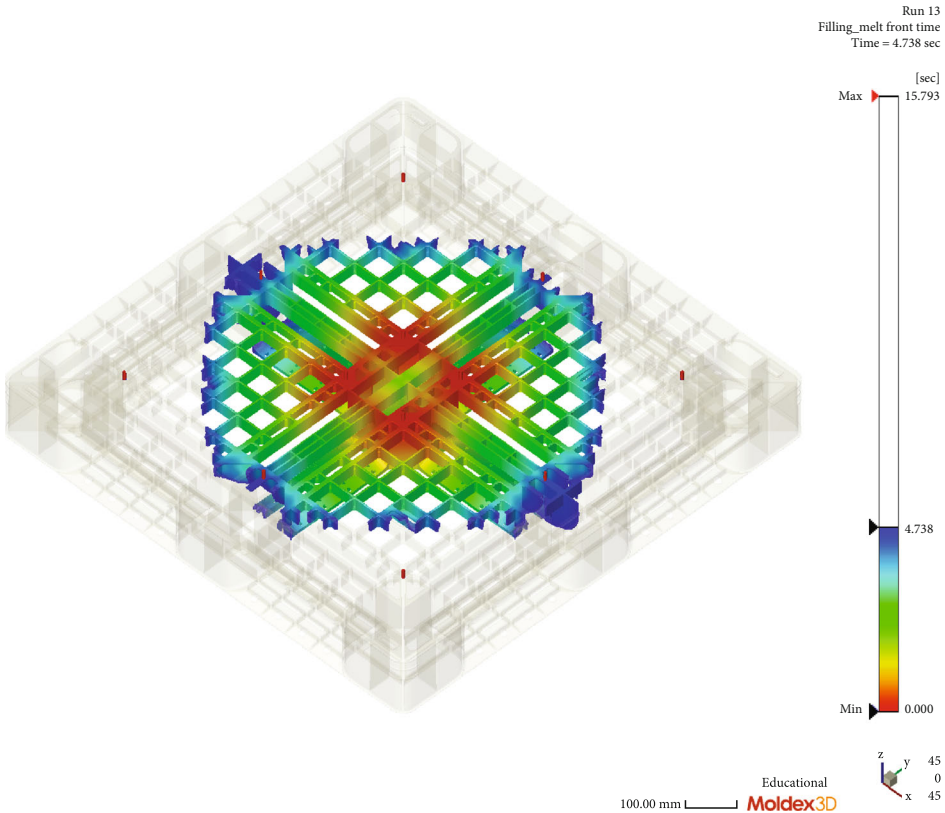
Clamping force (max) (ton)	3600
Screw diameter (mm)	225
Screw stroke (mm)	1100
Injection pressure (max) (MPa)	159.7
Swept volume (max) (cm ³)	49,278
Injection rate (max) (g/sec)	2475

The hot runners were opened at different time points to fill the molten material. The filling pressure, temperature distribution, deformation, and thermal stresses, as well as the shrinkages, were then compared for the sequential gate opening and the concurrent valve gate opening.

In the design phase, the volume of the plastic pallet was 13,160 mm³, and the mesh of the plastic pallet without cooling geometry contains 2,775,565 elements. During the filling stage, the fill flow front of the molten material is closely related to the viscosity, material temperature, and the runner



(a)



(b)

FIGURE 3: The flow front at 30% of the filling process in short shot testing. (a) Concurrent valve gate opening scheme. (b) Sequential valve gate opening scheme.

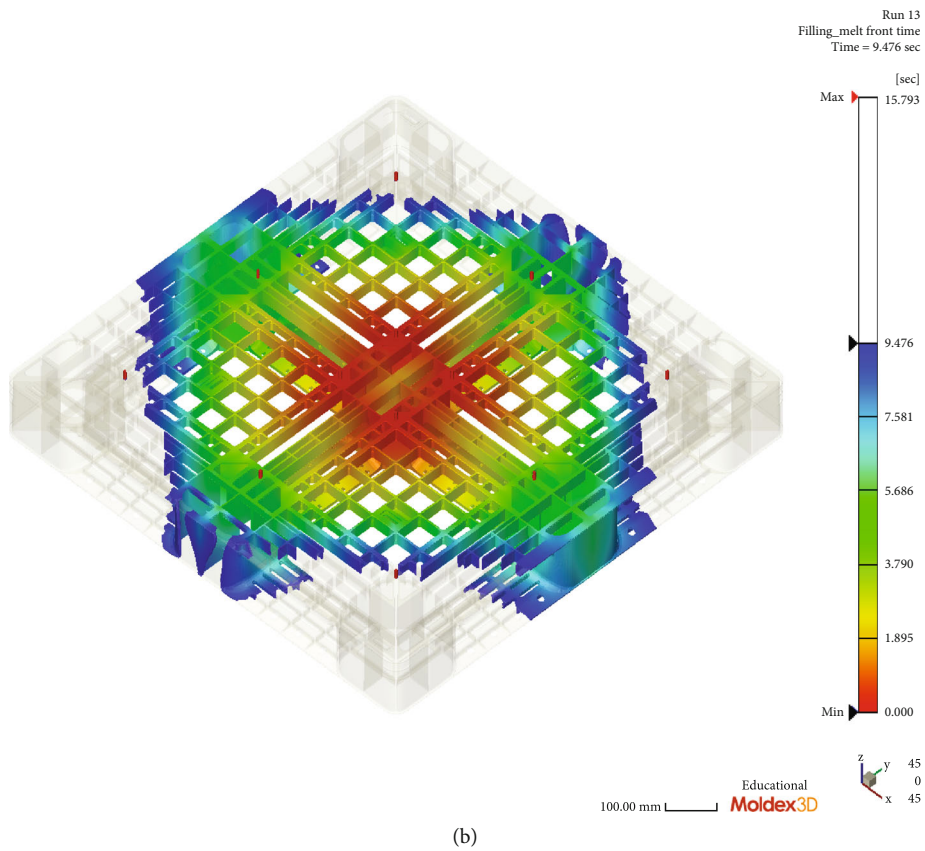
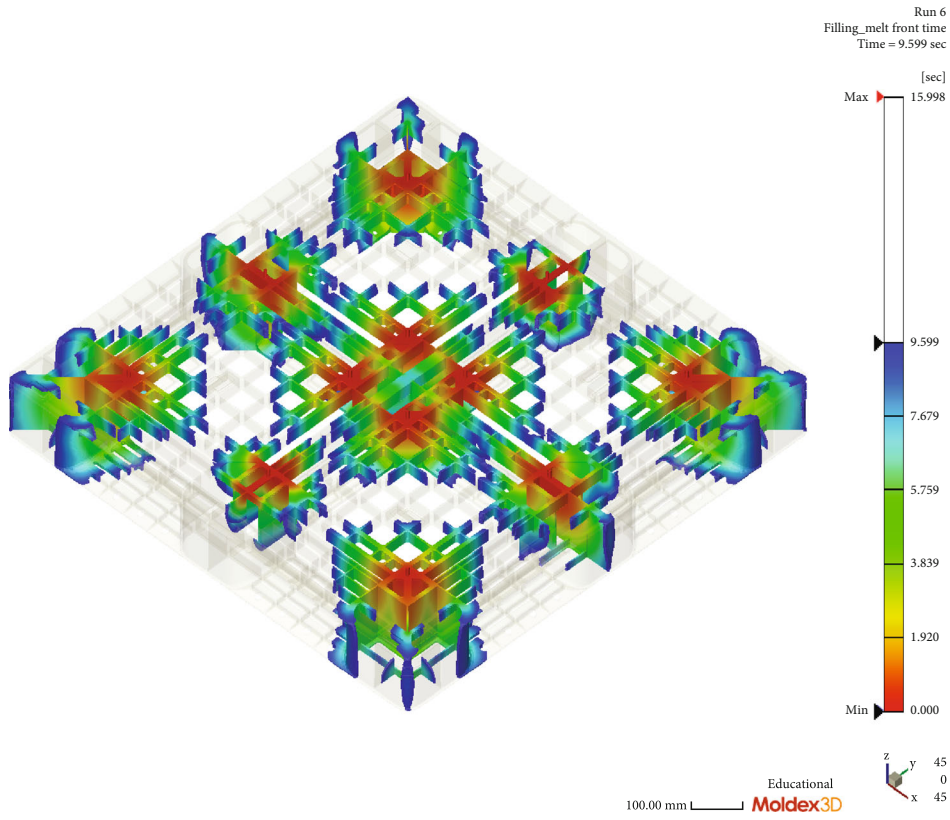


FIGURE 4: The flow front at 60% of the filling process in short shot testing. (a) Concurrent valve gate opening scheme. (b) Sequential valve gate opening scheme.

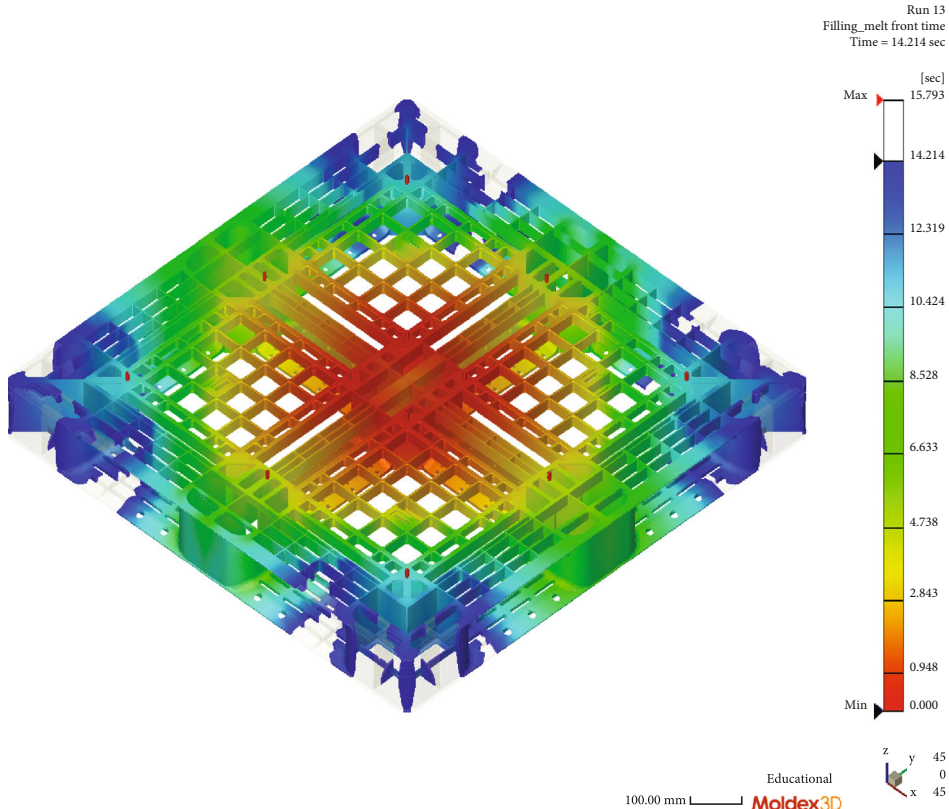
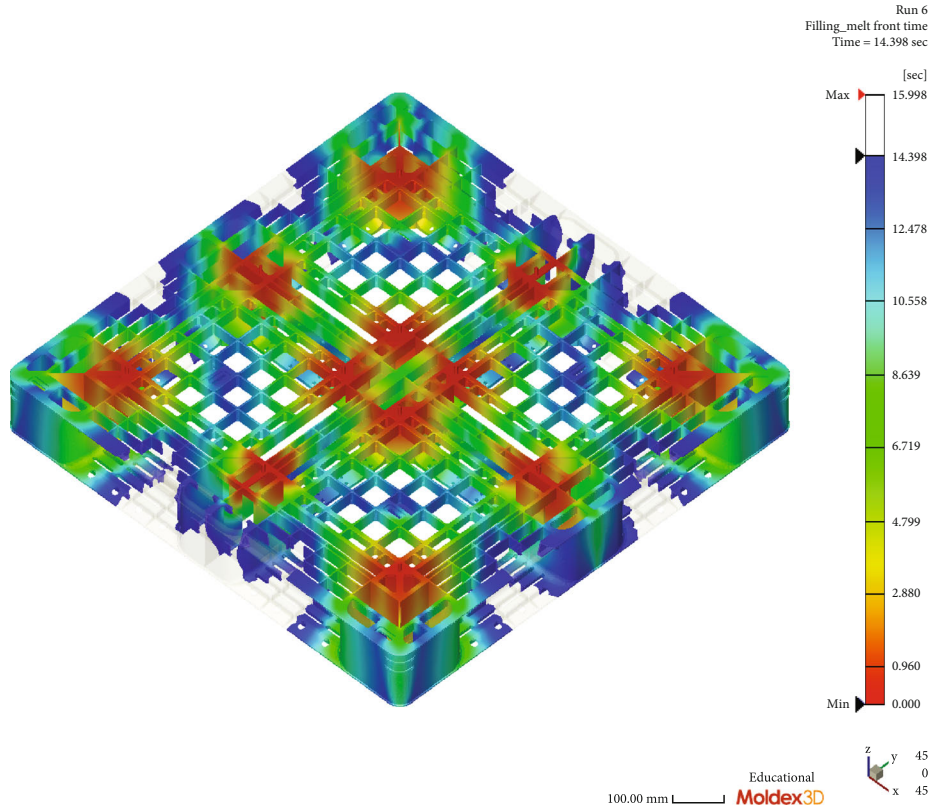


FIGURE 5: The flow front at 90% of the filling process in short shot testing. (a) Concurrent valve gate opening scheme. (b) Sequential valve gate opening scheme.

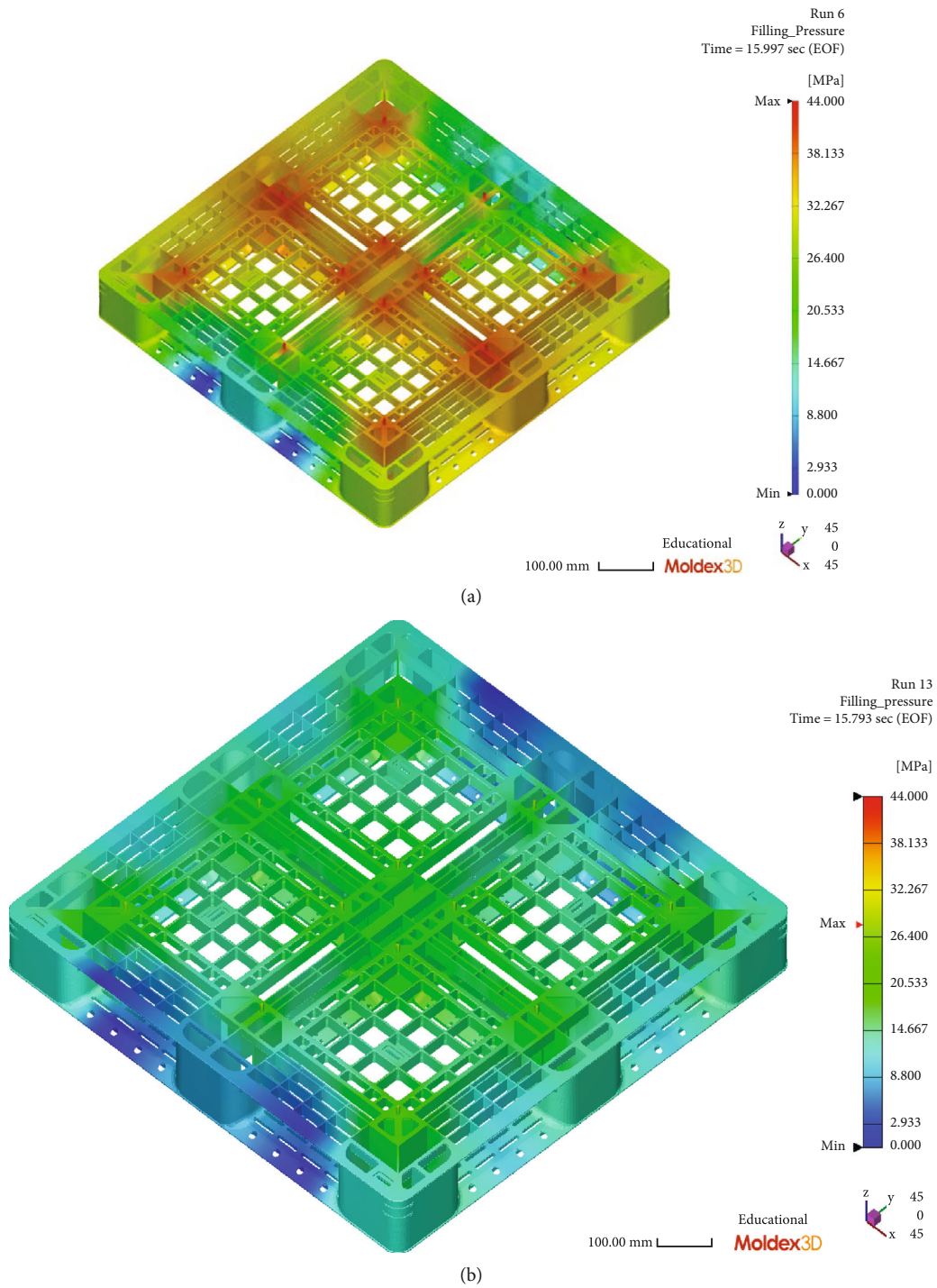


FIGURE 6: Filling pressure distribution within the mold cavity. (a) Concurrent valve gate opening. (b) Sequential gate opening.

and gate of the mold. Pressure of the molten material is a consequence of the viscosity, typically. The flow front is controlled by the flow rate during the filling of the injection-molding process. The material properties of the recycled PP are shown in Table 1, with the density of recycled PP being 1.026 g/cm^3 , more than raw PP. Figure 2(a) shows that the shear rate and temperature of the recycled melt PP resin are negatively proportional to their viscosity. The Carreras

Yasuda model is used to describe the viscous behavior of the molten material [18] for the simulations in this study. Figure 2(b) is the measured specific heat of the recycled PP. The melt and recycled PP curing temperatures are 250°C and 117°C , respectively, the temperature of the mold is 45°C , and the ejected molded component is 97°C . The fill time was 15 seconds, the packing time was 15.5 seconds at the packing pressure of 102.2 MPa, the cooling time was 53

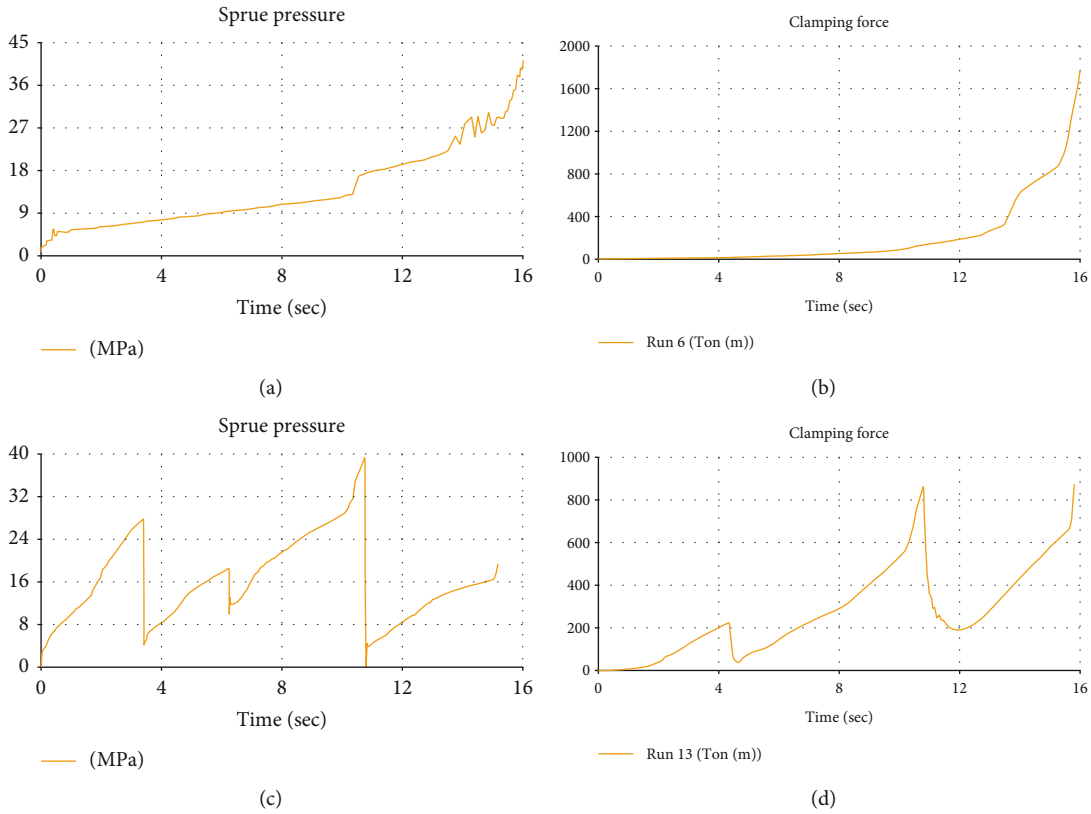


FIGURE 7: Filling pressure and clamping force history. (a) Filling pressure by concurrent valve gate opening scheme. (b) Clamping force by concurrent valve gate opening scheme. (c) Filling pressure by sequential valve gate opening scheme. (d) Clamping force by sequential valve gate opening scheme.

seconds, and the mold opening time was 20 seconds, giving a total cycle time of 103.5 seconds. The other molding parameters are shown in Table 2.

Within the simulation, the 3600-ton injection of Supermaster 3600E1 molding machine by Chen Hsong Group is modeled. This molding machine has a screw diameter of 225 mm, a maximum screw stroke of 4400 mm, a maximum injection pressure of 159.7 MPa, and a maximum injection volume of 49,278 cm³ (Table 3). The simulation analysis was performed by Moldex3D. First, the concurrent opening of the valve gates allowed the molten material to fill with a hot runner to determine the filling flow front, the clamping force, temperature distribution, thermal stress, and deformation; then, the twelve gates were opened and closed in a controlled sequence.

As shown in Figure 1(a), gates 1 to 4 open to fill the molten material into the mold cavity, gates 8 and 9 are opened at the 3rd second, then gates 5 and 10 are opened to fill at the 6th second, and finally, gates 6, 7, 11, and 12 are opened at 10.7 seconds to finish the filling process.

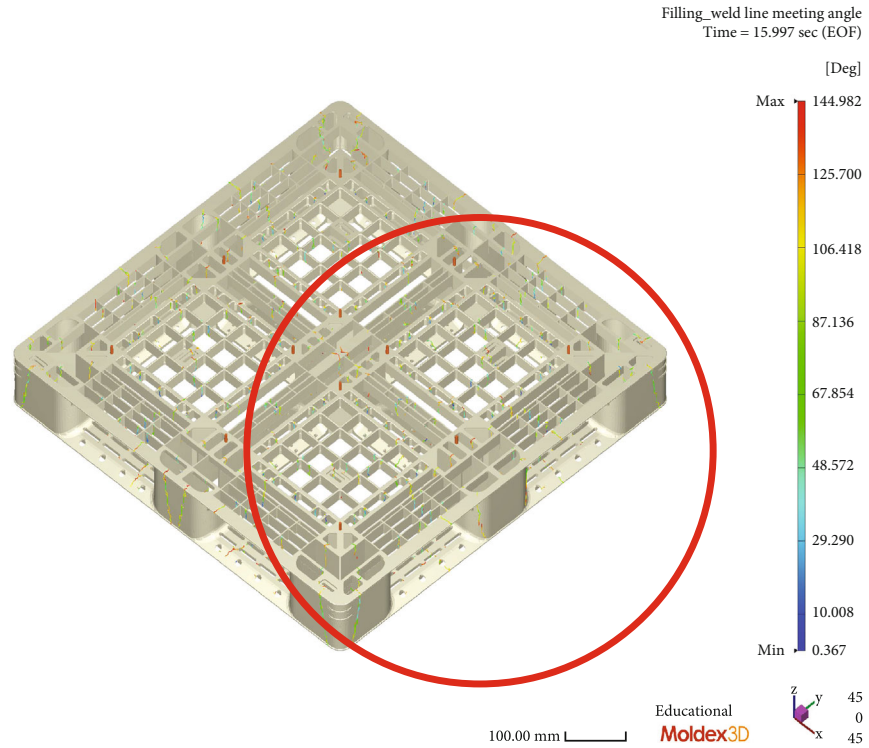
3. Results and Discussion

3.1. Flow Front of Short Shot Testing. The numerical results of the 30% filling process short shot testing are shown in Figure 3, with Figure 3(a) showing the flow front with the

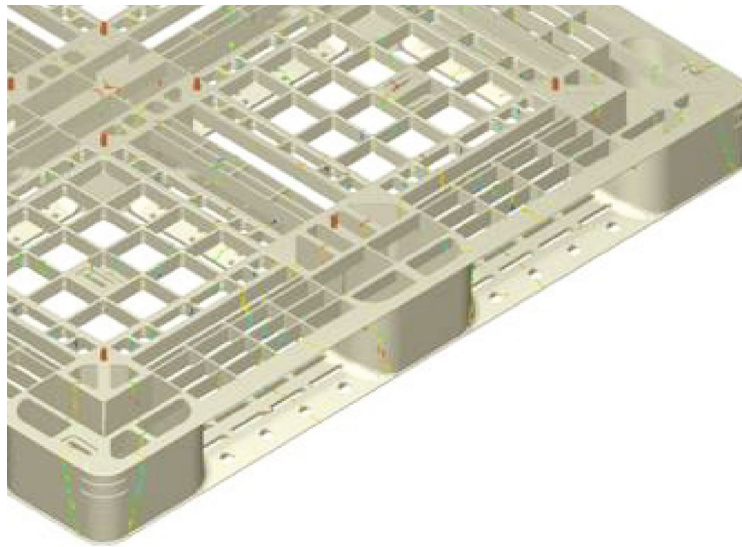
twelve gates concurrently opened at the same time and a fill time of 4.35 seconds. The fill flow fronts form around each gate, with gates 1 to 4 having flow fronts stitched at the center of the plastic pallet. Figure 3(b) shows that the twelve gates are controlled in a four-stage sequence. In the short shot testing, the flow front distribution propagates from the four central gates with a fill time of 4.35 seconds. In the first stage, gates 1 to 4 are opened for 3 seconds and then turned off, and gates 8 and 9 are turned on for 1.35 seconds. During this stage, the flow fronts of gates 3 and 4 extend to gate 9, then gates 3 and 4 are turned off, and gate 9 is turned on to extend the flow front continuously. Similarly, the flow front from gate 1 and 2 extends to gate 8.

Figure 4(a) shows the flow front distribution in the short shot testing during concurrent valve gate opening when the filling time is 8.7 seconds. The flow fronts of adjacent gates contact and weld, with the welding lines of neighboring gates on thin ribs. Figure 4(b) shows the flow front distribution of the timed control gate at 60% of the total fill, that is, gates 8 and 9 are turned off in the second stage. The third stage involves the turning on of gates 5 and 10 for 2.7 seconds. During this fill, the fill flow front gradually extends, with only the four corners of the plastic pallet remaining to be filled.

The flow front distribution of the concurrent valve opening of the twelve gates is filled to 90% in the short shot testing of 13.05 seconds (Figure 5). The filling contribution of gates 1



(a)



(b)

FIGURE 8: Continued.

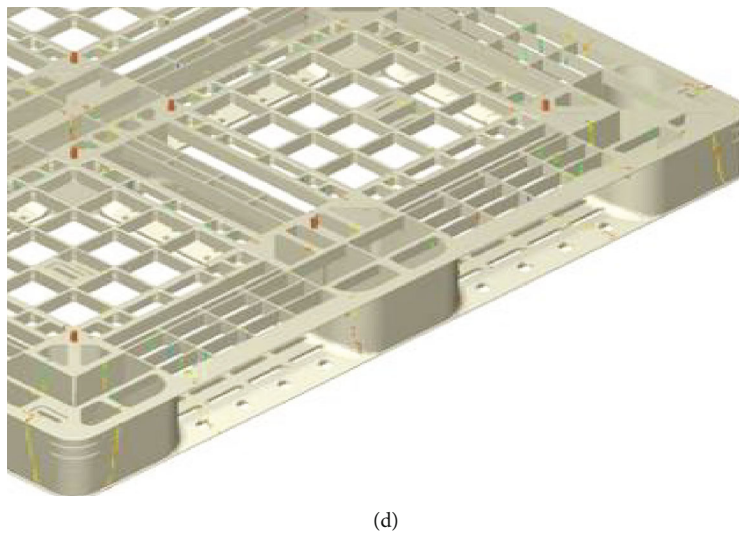
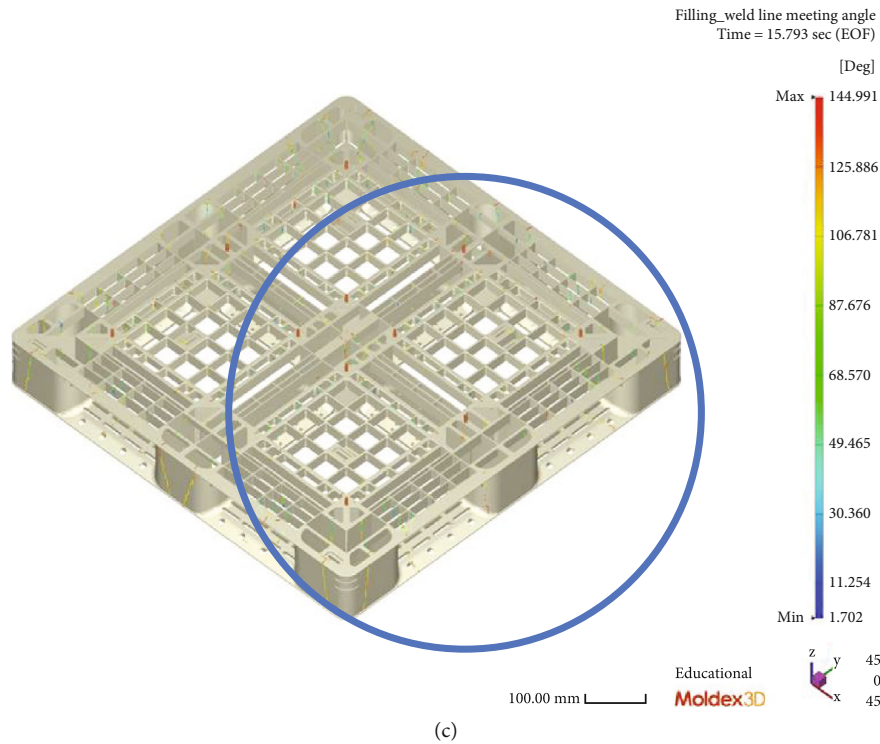
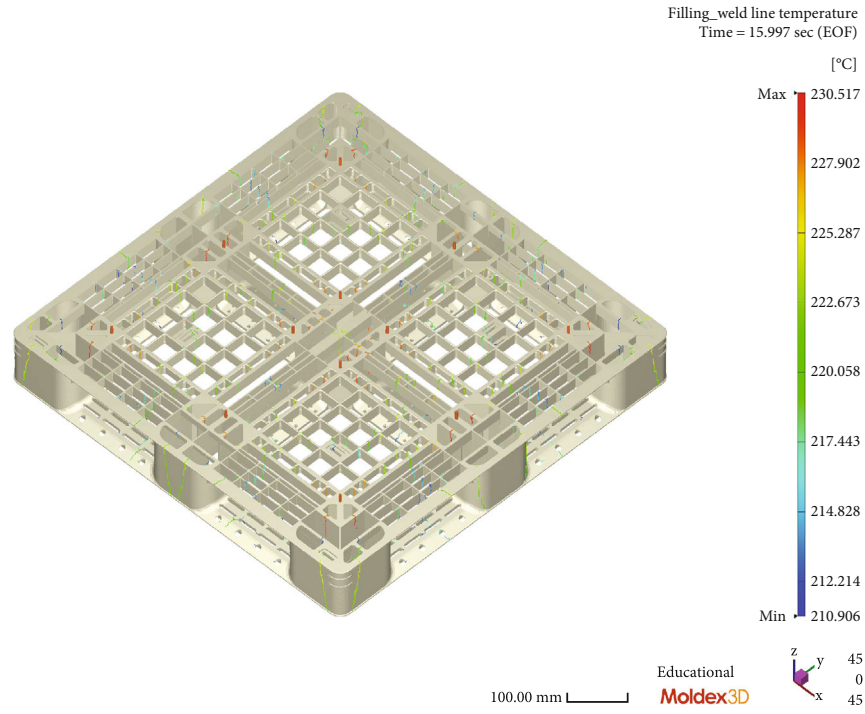


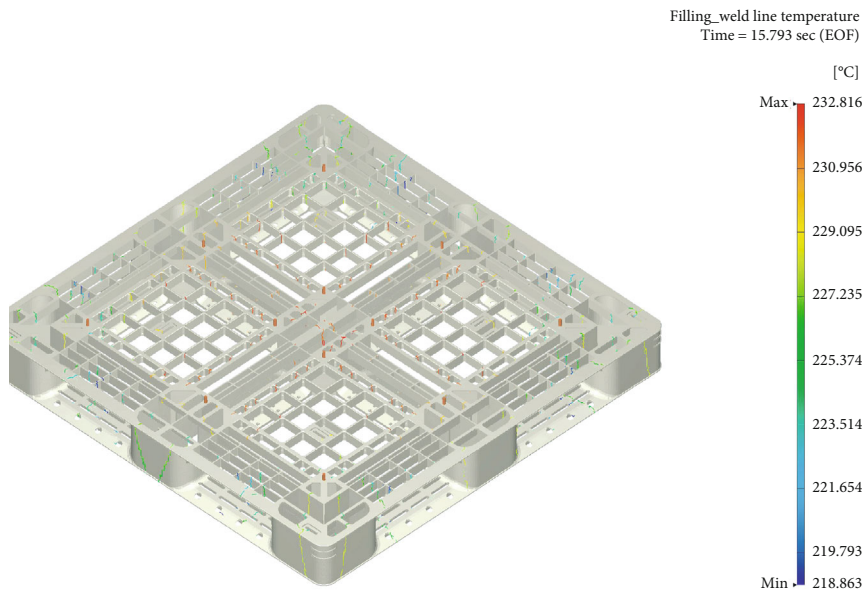
FIGURE 8: Welding angle. (a) Concurrent valve gate opening scheme (avg. angle = 85.7°). (b) Meeting angle of weld line of pallet by concurrent valve gate opening scheme. (c) Sequential gate opening scheme (avg. angle = 92.6°). (d) Meeting angle of weld line of pallet by sequential gate opening scheme.

to 4 in the center of the pallet can be neglected at this time. The welding lines are clustered at the eight contact portions of the fork/pallet, the weakest part of the plastic pallet. Regarding the flow front distribution, the final stage involving gates 6, 7, 11, and 12 are turned on to fill to 90% of the short shot testing, as shown in Figure 5(b) with a fill time of 13.05 seconds. During filling in stage one to three, gates 6, 7, 11, and 12 fill the mold cavity; then in the fourth stage, these gates fill the four corners of the pallet. The welding lines on the ribs between gates 7, 5, and 6 and 11, 10, and 12 occur near the two forks and pallet contact points.

Figure 6(a) shows the filling pressure distribution when the twelve gates are filled concurrently without timing control, with a maximum and average pressure at the end of the filling process of 44 and 29.7 MPa, respectively. The pressures near gates 5 and 10 are lower than in other areas. The short shot of molding is found occasionally around these two gates, with the pressure being significantly higher than that in other areas. Figure 6(b) shows the filling pressure distribution of the mold cavity under time sequence control, with maximum and average filling pressures of 24.39 and 19.23 MPa, respectively. This



(a)



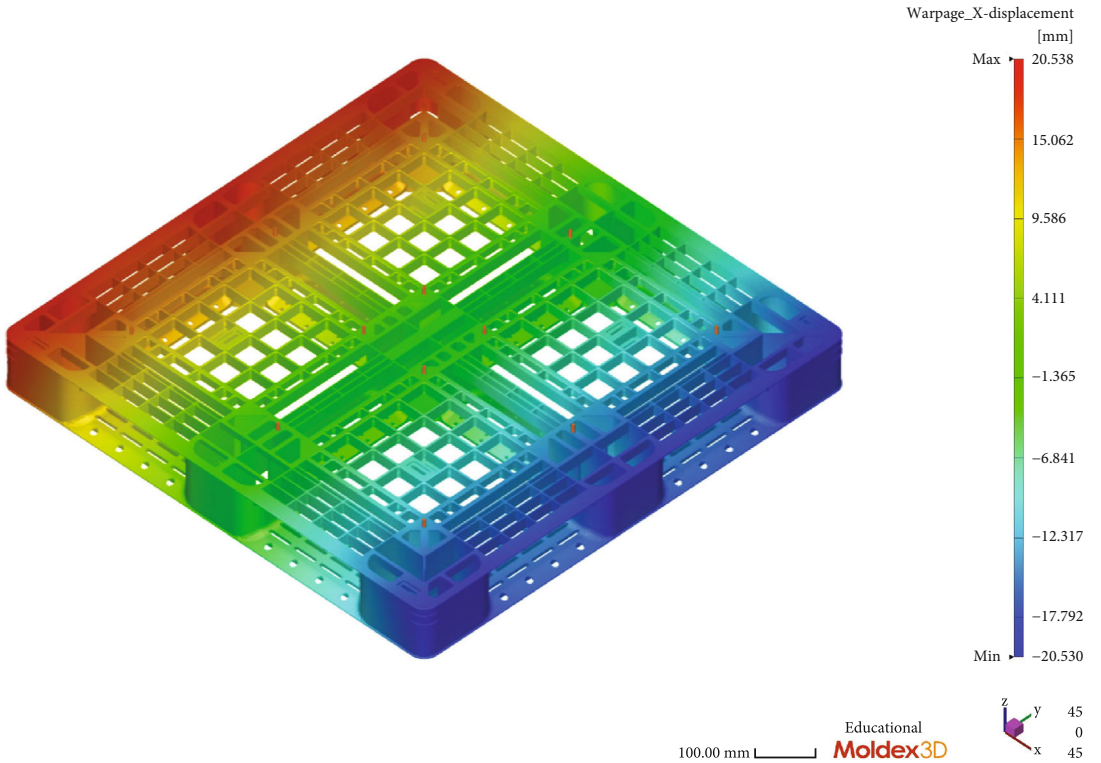
(b)

FIGURE 9: Temperatures of the weld lines. (a) Concurrent valve gate opening scheme (avg. $T = 219.8^{\circ}\text{C}$, min. $T = 210.9^{\circ}\text{C}$). (b) Sequential gate opening scheme (avg. $T = 227.3^{\circ}\text{C}$, min. $T = 221.3^{\circ}\text{C}$).

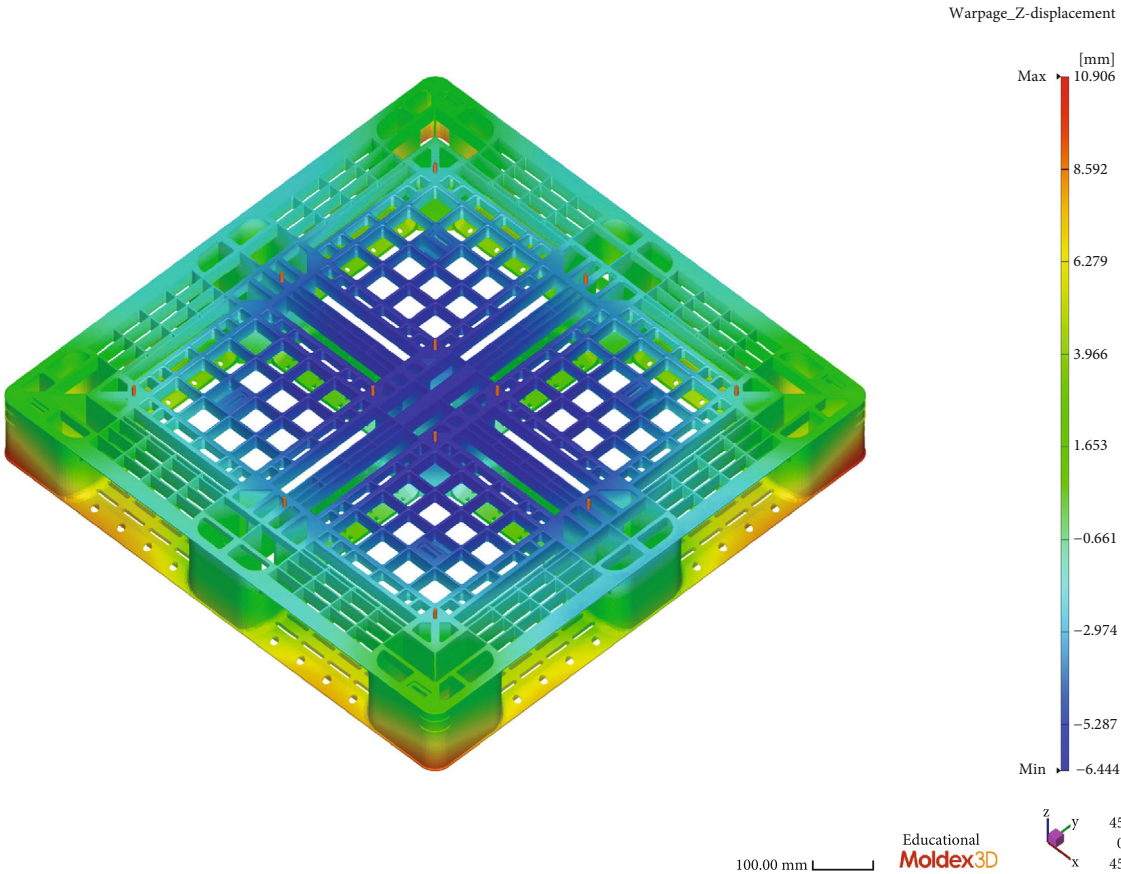
average filling pressure is about 65% of the concurrent valve gate opening schemes, thus decreasing the clamping force on the mold during the filling process.

Figure 7(a) shows the pressure history versus filling time, with the filling pressure increasing rapidly due to the unbalanced flow between gates 1 to 4 and the others.

Also, the filling force is drastically increased from the twelfth second to the end of the filling process, with a similar filling pressure variation in the last three seconds as in the previous twelve seconds. The maximum clamping force by this concurrent valve gate opening scheme in the molding of plastic pallet is 1771.3 tons in Figure 7(b).

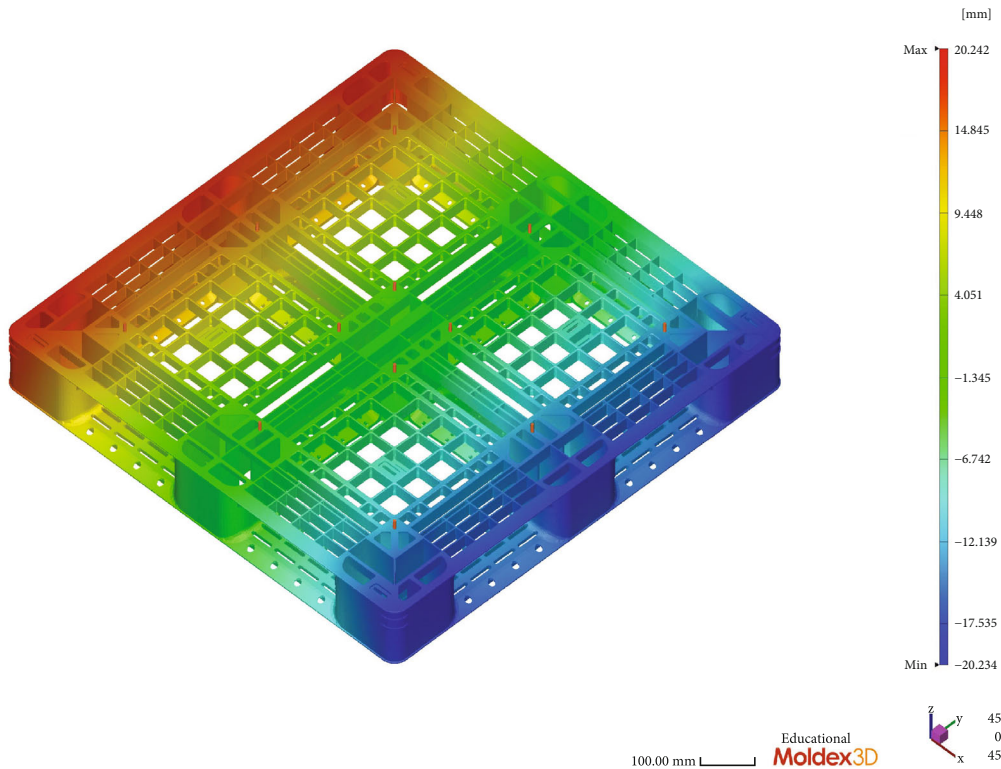


(a)

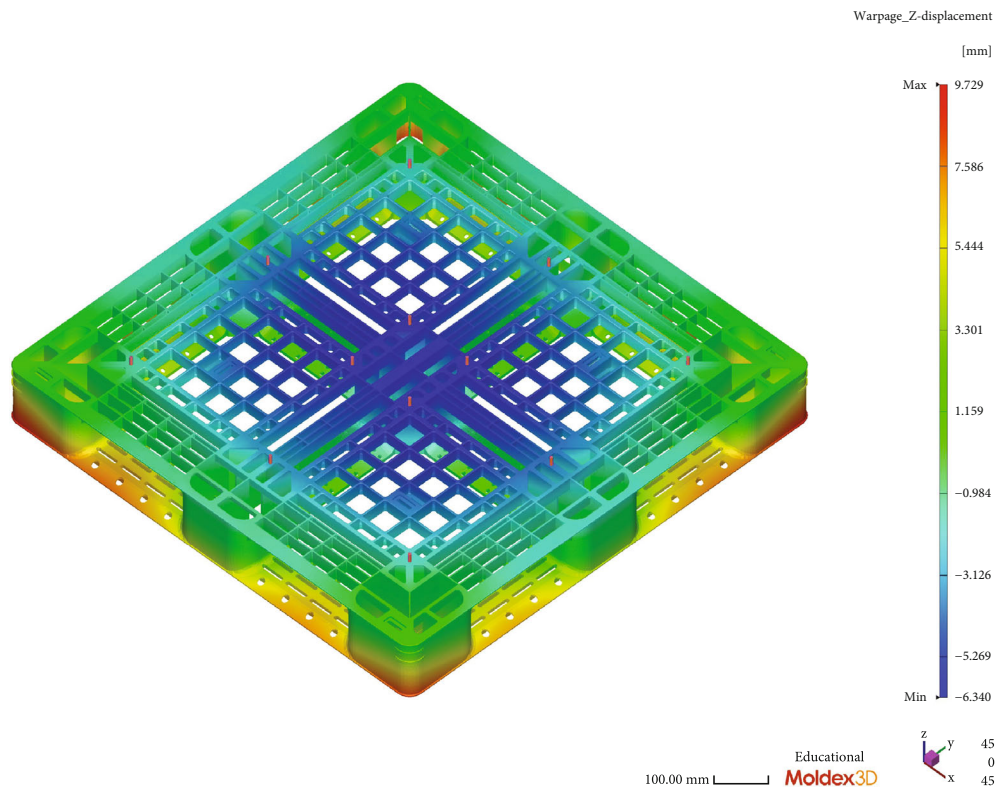


(b)

FIGURE 10: Continued.

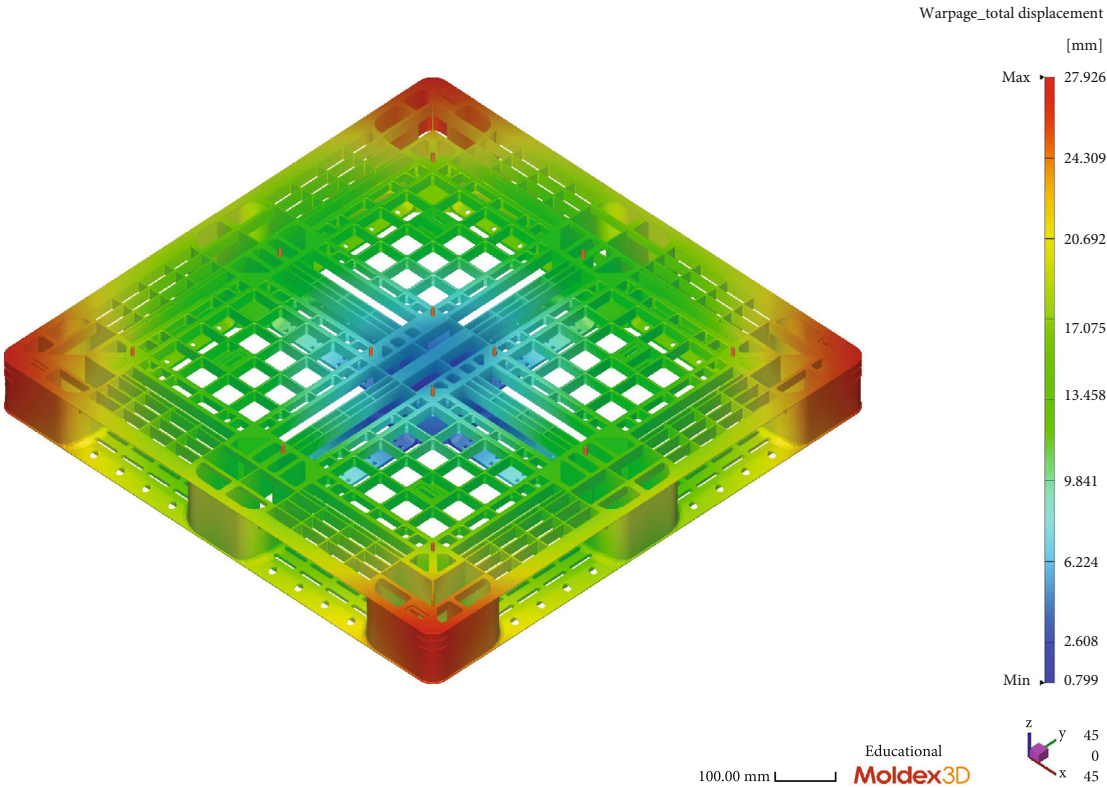


(c)

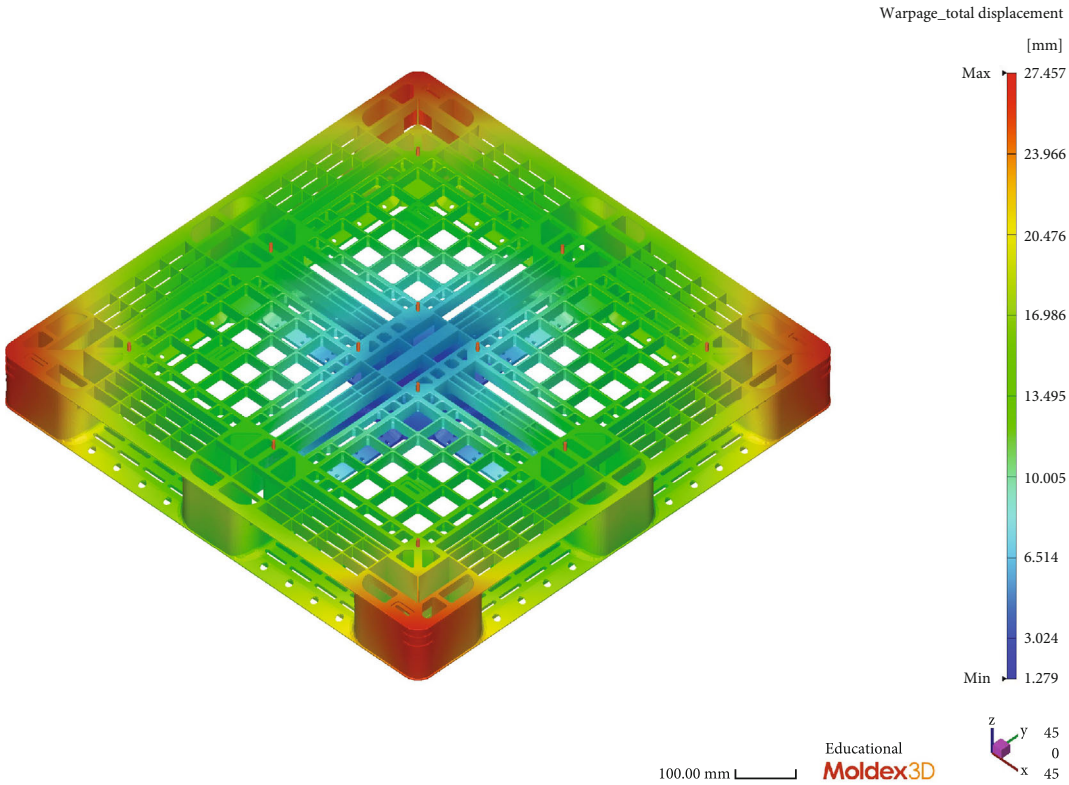


(d)

FIGURE 10: Warpage deformations of plastic pallet. (a) *x*-axial deformation by concurrent valve gate opening scheme (-20.530~20.538 mm). (b) *z*-axial deformation by concurrent valve gate opening scheme (-6.444~10.906 mm). (c) *x*-axial deformation by sequential valve gate opening scheme (-20.234~20.242 mm). (d) *z*-axial deformation by sequential valve gate opening scheme (-6.34~9.729 mm).



(a)



(b)

FIGURE 11: Warpage total deformation. (a) Concurrent valve gate opening scheme (0.799~27.926 mm). (b) Sequential valve gate opening scheme (1.279~27.457 mm).

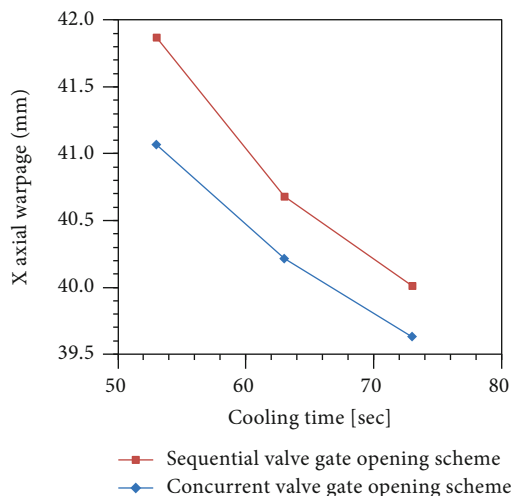


FIGURE 12: Warpage total deformation respect to the cooling time.

The pressure variation in the four-stage sequential gate filling is shown in Figure 7(c), with the filling pressure fluctuating at each on/off switching point. In the first stage, the filling pressure increases from zero to about 30 MPa, from 4 to 16 MPa in the second stage. The filling pressure in the third stage ranges from 10 to 39.5 MPa, and the final stage indicates the pressure from about zero to 22 MPa. The large variation in pressure means that the filling time of each stage is unsuitable due to the large loss in filling pressure during the switching points, that is, the filling pressure must be controlled by sequential gate opening. The maximum clamping force by this sequential valve gate opening scheme in the molding of plastic pallet is 874.6 tons, only half of the one by concurrent valve gate opening scheme as shown in Figure 7(d).

3.2. Welding Angle and Temperature. Welding lines are formed where the flow fronts meet, with the meeting angle between the two flow fronts being the welding angle. Also, a welding line is more likely to form when the welding angle is smaller than 135° ([4]), and the temperature of the flow fronts is higher than the temperature of the injection material. Figure 8(a) shows the maximum and average welding angles of 145° and 85.7° in the concurrent valve gate opening scheme. All twelve gates fill the molten material into the mold cavity simultaneously, so resulting welding angles are unavoidably larger than 135° , but the average welding angle is only 85.7° in this case. In Figure 8(c), both the welding angle and position of the nine column legs are almost identical, with a major change in the rib area between the legs of Figures 8(b) and 8(d) where fewer welding lines are located in comparison to Figure 8(a). The average welding angle is 92.6° in the pallet in the sequential gates controlled scheme, larger than in the concurrent valve gates opening scheme, although the welding angles in both schemes are smaller than 135° .

Figure 9 displays the temperature distribution on the potential welding lines of the plastic pallets. Although

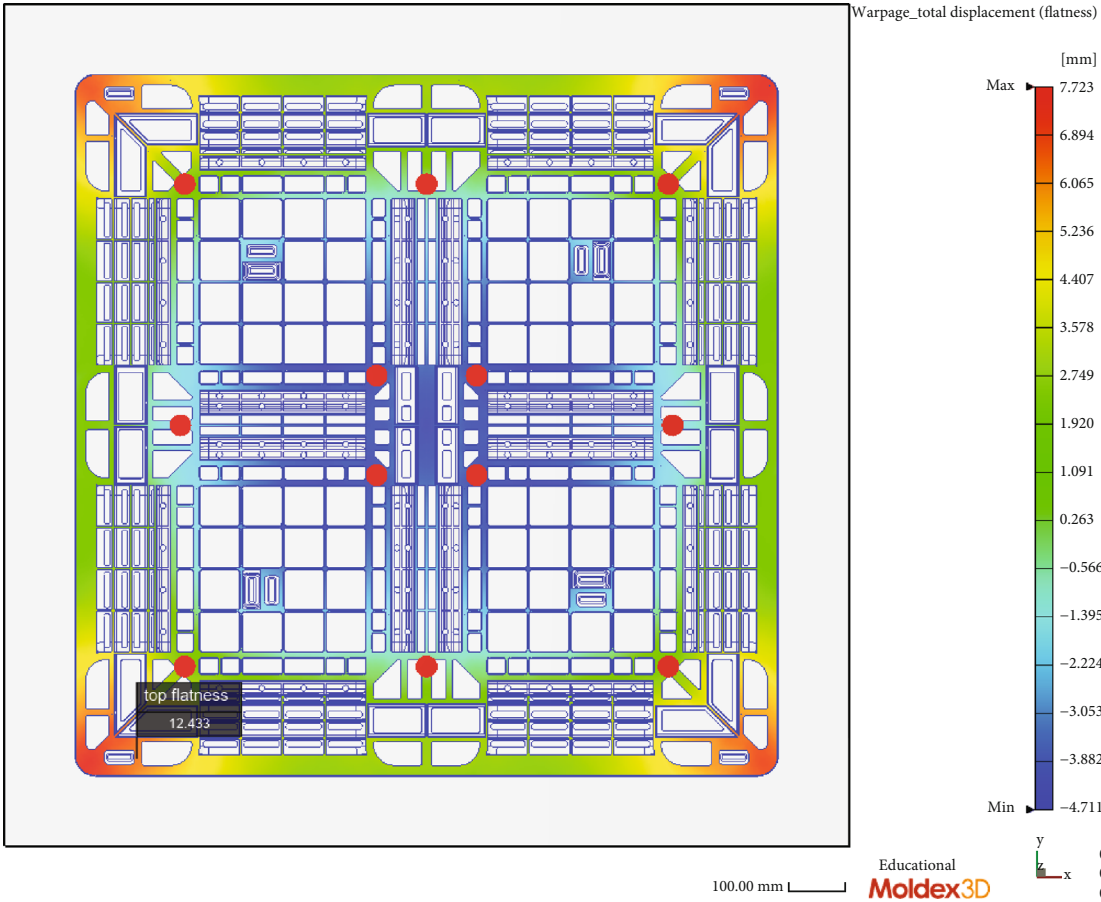
increasing the melting temperature of the injected materials to elevate the welding line temperatures may diminish their appearance, it is recommended to hold this scheme due to the increased melting temperature that may aggravate the molded parts' warpage.

The temperatures of the melted material and mold are 230 and 40°C , respectively. The shear rate of the injection material enhances the melting temperature near the gates, as shown in Figures 9(a) and 9(b). The maximum temperatures of the two schemes with the concurrent valve gate opening and sequential gate control are 230.5°C and 232.5°C , respectively. The maximum temperature in the concurrent valve gate opening scheme is near the pallet gates, whereas in the sequential gate opening scheme, the maximum temperature is located in the central portion near gates 1 to 4 of the pallet. The temperature distribution indicates that the sequential gate opening leads to a higher average temperature during the filling process, which would diminish the appearance of welding lines by increasing the strength of the welding lines.

3.3. Warpage Displacement. During the packing and cooling process, the acting pressure and temperature cause differences in the orientation and density of the cross-section, leading to shrinkage in the molded component. Asymmetric shrinkage and unequal contraction in any section may yield a net force causing warpage. Figures 10(a) and 10(c) show the warpage deformations in the x -axis during the two schemes of the concurrent valve gate opening, and the sequential gate opening of 41.068 mm and 40.476 mm, respectively. The sequential gate opening scheme results in lower warpage in the x -axial direction of the molded pallet. Figures 10(b) and 10(d) show the z -axial warpage of the pallets by the two schemes of the concurrent valve gate system and the sequential valve gate system. One finds that the top surface of the pallet has a concave profile where the sequential valve gate system gives a slight concave.

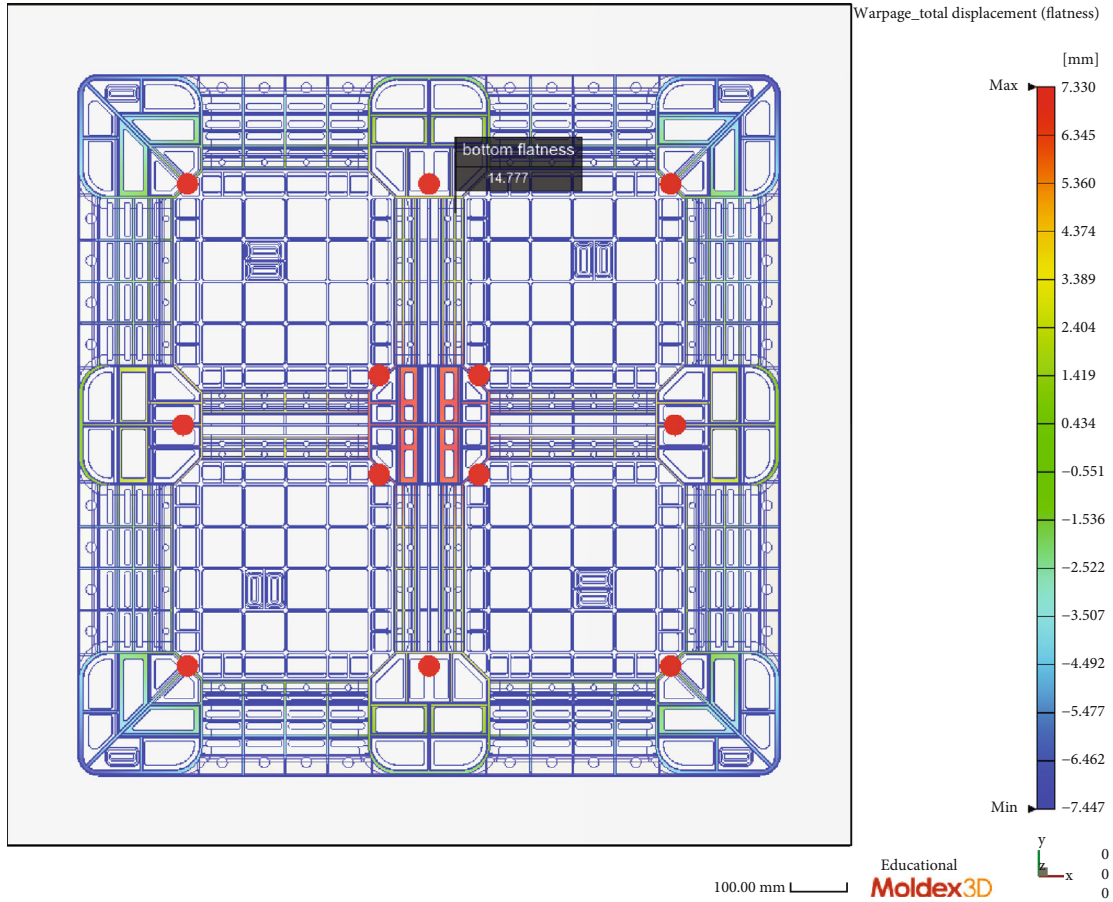
The axial warpages was transformed by the least square root method to derive the total warpage of pallet. As shown in Figure 11(a), the concurrent valve gate opening scheme's total deformation is 27.926 mm; however, the one by the sequential valve gate opening scheme is 27.457 mm. The x -axial warpage is decreased by increasing the cooling time to 63 seconds and 73 seconds, as shown in Figure 12. The sequential valve gate opening scheme gives a larger x -axial warpage of the pallet, although it has fewer weld lines.

Under the cooling time 48 seconds, mold temperature 40°C , cooling channel 20°C , Figures 13(a) and 13(b) reveal the flatnesses 12.433 mm and 14.777 mm of the top and bottom of the pallet, respectively. The flatness means the difference between the highest and the lowest levels of the pallet surfaces. By optimization of the molding parameters, one finds that the flatness decreased with respect to a higher temperature of the cooling channel. Under the cooling channel temperature on 60°C and varying the cooling time from 8 to 58 seconds, the flatnesses of the top and bottom surfaces of the pallet is shown in Figure 13(c). A cooling time of 28 seconds gives minimal flatness which differs from the empirical prediction.

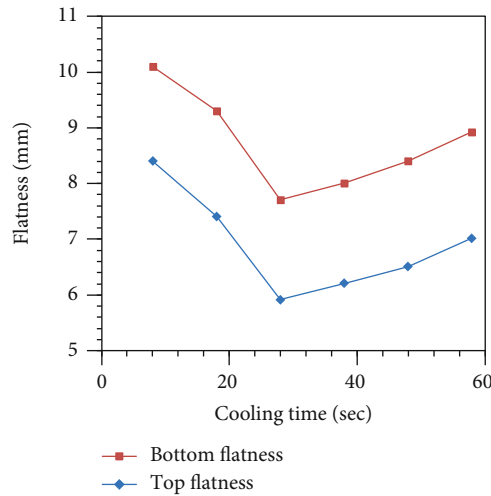


(a)

FIGURE 13: Continued.



(b)



(c)

FIGURE 13: Flatness of the pallet. (a) The flatness of the top plane of the pallet (cooling time 48 sec, mold temperature 40° Celsius, cooling channel 20° Celsius) (flatness 12.433 mm). (b) The flatness of the bottom plane of the pallet (cooling time 48 sec, mold temperature 40° Celsius, cooling channel 20° Celsius) (flatness 14.777 mm). (c) Flatness with respect to cooling time under mold temperature 40° Celsius, cooling channel 60° Celsius.

4. Conclusions

The moldability of a polypropylene pallet using a sequential valve gate system in injection molding was investigated, with

short shot testing analysis performed to determine the flow phenomenon in the mold cavity for two filling schemes, the concurrent valve gate opening, and sequential gate opening. The flow fronts from the twelve gates propagate to fill the

pallet mold when all twelve gates are opened and closed concurrently, then make contact to form welding lines on the thin ribs. The four-stage sequential opening of the gates propagates the flow front from the central gate to the four corners of the pallet, with fewer welding lines formed between every four legs located at the rib portions than the concurrent valve gate opening scheme. The sequential opening valve gate system has a lower average filling pressure than the concurrent valve gate opening scheme. The filling pressure in the sequential gate-controlled scheme fluctuates at each on/off switching point; hence, further analysis is required to reduce this pressure fluctuation. The average welding angle of the plastic pallet by the concurrent valve gate system is smaller than the one by the sequential valve gate system. The warpages of the pallet by the sequential valve gate system are smaller than the ones by the concurrent valve gate system. A higher temperature of the cooling channel and a medium level of cooling time may derive the smallest flatness of both sides of the pallet.

Data Availability

Data are available from the Lab. of Molding Flow Analysis in Ming Chi U. of Technology, Taiwan. Data can be made publicly available. Requests for data can be sent as a formal proposal to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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