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Simulation Study for the Compressed BMC Materials of Kenaf/Coir Reinforced Unsaturated Polyester: Flow Behaviour and the Effects of Charges Shapes Studies

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ABSTRACT

This study provides predictable flow behavior of a hybrid biocomposites made from kenaf/coir reinforced unsaturated polyester using the Moldflow software. A medium size electrical part has been chosen as a mold having multi-wall thicknesses and complex surfaces. Three different shapes of charges of the bulk molding materials were used and compressed into the mold part. The shapes of charges would be rectangular, cubic and cylindrical shapes. The results showed that rectangular charge took 0.2 seconds to fill up the part while the cubic and the cylindrical charges took 1.911 and 2.898 seconds respectively. After 70 seconds the conversion at nodes was more than 98% for all charges. On the other hand, the final densities were 1.88 ± 0.08 g/cm^3 for all charges. The cubic charges showed a better temperatures distribution at flow front followed by rectangular, the last being the cylindrical charge, and the average shrinkage was 5-7% for the charges. The cubic shape showed good fibers orientation to the flow direction of the bulk materials followed by cylindrical charge while the rectangular charge showed poor orientation of fibers affected on the deflections, weld lines and air traps in the internal part. For the rectangular, the charge showed more critical weld lines and more air traps especially on the surface of the molded part and more

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deflections on the corner edges. But, the cubic charge showed the lowest deflections rate, air traps and weld lines defects.

Keywords: Coir, compression molding, hybrid biocomposites, kenaf, moldflow simulation

INTRODUCTION

Favourable mechanical and thermal properties can be obtained from hybridizing the natural fibers to reinforce thermoset polymers, however designing hybrid composite for compression molding parts offers some challenges such as fiber orientation, mold shape, position and shape of charges which may leads to reduction in the mechanical and thermal properties and presents increase in the costs of manufacturing these parts. To overcome these challenges several simulation softwares and finite element models have been developed to reduce both time and cost of the design (Davis et al., 1997; Osswald et al., 1996; Rios et al., 2018).

The final structural performance of the part can be affected directly by molding process, and the location of gates and charges (Rosato & Rosato, 2000). In the molding process the flow pattern is considered complex due to the three dimensional flow of the molded materials and the effects of gravity on that materials (Mitani & Hamada, 2005).

Few reports in the literature employed simulation analysis to study hybrid composites curing behavior and temperature distribution of natural fiber composites during molding. Mitani et al. (2005) presented only a one-dimensional model using finite difference (FD) method to predict the temperature distribution and cure behavior of natural fiber composites in the RTM process. While A non-linear heat transfer analysis combined with a cure kinetic model based on finite element procedures was developed by Behzad (2007), using hemp fiber/thermoset composite, three-dimensional mode was developed for a simple block of the composite and compared with experimental results. Experimental data shows that the simulation procedure is numerically valid and stable (Behzad & Sain, 2007).

Practical observation was done by Sridhar and Kumar (2013) for the power box component with single gate and two gates and analyzed for mold flow using Pro/Engineer and Mould flow analysis Software. Original component die has single gate and two gates and by changing processing conditions in seven tests each. Surface temperature of 40ºC, Melt temperature of 240ºC, and Maximum machine injection pressure of 180 MPa were the optimum parameters for better quality products for both single and two gates designs.

MATERIALS AND METHODS

Part Selection and Drawings for Compression Molding

In this step the molded part was selected regarding to the availability of compression mold of this part in local company. For bulk molding compounds, the part were produced previously using BMC technique and the composites materials were glass fibers reinforced unsaturated polyester as shown in Figure 1. The part was considered as a medium size part and contains precise details with multi wall thickness which can give a good indicator of developed hybrid compounds ability to produce a complex small parts with precise details not only a simple products shapes.

The mold part and the materials charge were created using SOLIDWORK drawing software due to the good capability of this software in drawing of 3D objects. However, three shapes of charge materials were used to indicate the effect of the charge shape on the materials flow, temperature profile of the materials during the molding process, the defects that might occur such as (porosities, shrinkage and weldlines), and the pressure. The charge shapes were (rectangular, cubic and cylindrical), knowing that these three shapes were the easiest and fastest to be produced by the operator.

Figure 2 and 3 show 3D drawing of the part and the charges shapes respectively. From Figures 2 and 3 it can be seen that all the details of the part are reflected from the real part to the 3D drawing to give significance reliability for the simulation results.

Optimum charge weight was calculated by the simulation software after the first run. Charge weight optimization step is very important to avoid overloading materials into mold which might reduce the mold life time and mold efficiency. However, insufficient materials will give an incomplete shape and defected products. Knowing the required weight and the materials bulk density, the volume of the three charges shapes can be easily calculated from the density equation (density = mass / volume).

Figure 1. Shape of molded part

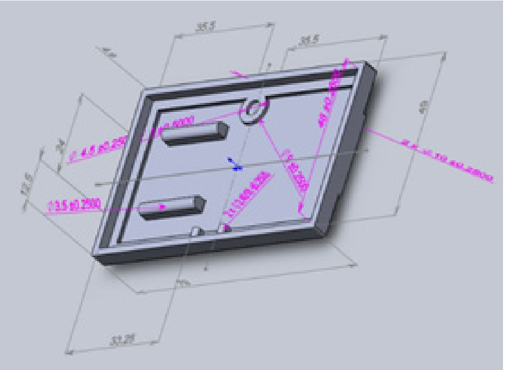


Figure 2. 3D drawing of molded part (measurements in mm)

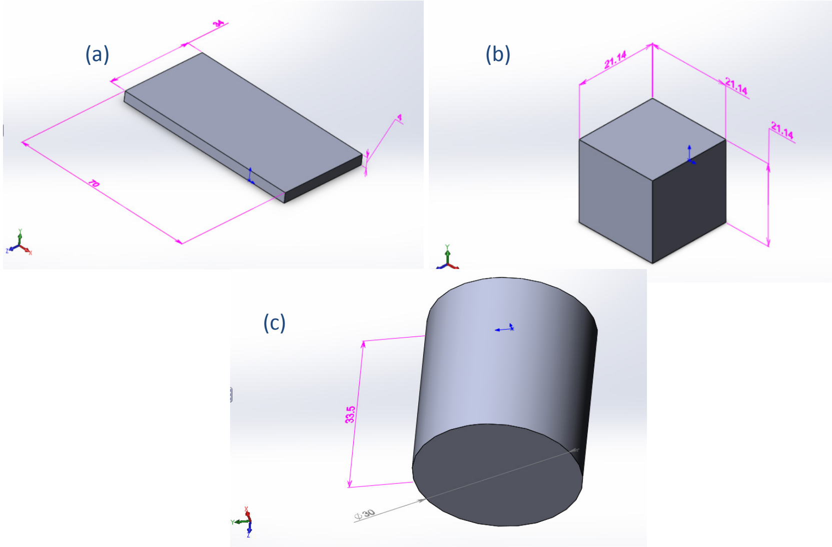


Figure 3. 3D Drawing of charges (Measurements in mm): (a) rectangular charge, (b) cubic charge (c) cylindrical charge

Simulation of Materials Flow

Autodesk® Simulation Moldflow® plastic injection molding simulation software was used to validate and optimise the design of plastic parts in compression molds by providing an actual prediction for the plastic compression molding process. Simulating the molding process reduces the need for costly physical prototypes, avoids manufacturing defects and assists delivering innovative products to market faster.

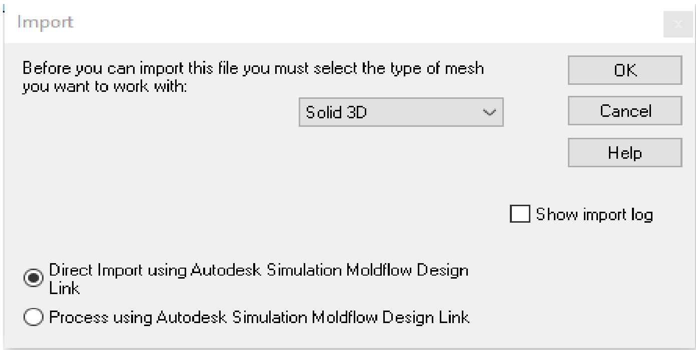
In order to run the software simulations, several procedures need to be set up to run the analysis of the simulation software.

Setting Up the Project Name and Importing the Drawing

After creating the new project 3D drawing for the mold part and the charge can be imported from the SOLIDWORK drawing software files with .SLDPRT extension and should import as Solid 3D as shown in Figure 4.

Selection the Molding Process

Several molding processes are available to be select such as (thermoplastics Overmolding, thermoplastics injection molding, Gas-assisted injection molding Reactive molding, Microchip Encapsulation, underfill Encapsulation, Reactive compression molding, etc). Reactive compression molding was selected for the bulk molding compounds materials.



Before you can import this file you must select the type of mesh you want to work with:

Solid 3D

☐ Show import log

● Direct Import using Autodesk Simulation Moldflow Design Link

○ Process using Autodesk Simulation Moldflow Design Link

Figure 4. Import of 3D drawing to autodesk simulation moldflow

Generate Mesh and Selecting the Analysis Sequence

In this procedure the mesh type was set as 3D Tetrahedra elements with global edge length of 0.5 mm and merge tolerance of 0.1 mm for both mold part and materials charge. After generating the meshed part and charge, the property of both of them should be identified as “compression element 3D” for the mold part, and as “initial charge” for the charge in order to be recognized by the software which one is 3D mold part and which one is the charge.

As analysis sequence, Fill + Pack + Warp was selected to present the sequence of analysis for the compression molding process, it has other available sequences which include the mold cooling analysis option which is not applicable to this study hence the real mold used was small and did not have a cooling system .

Materials Selections

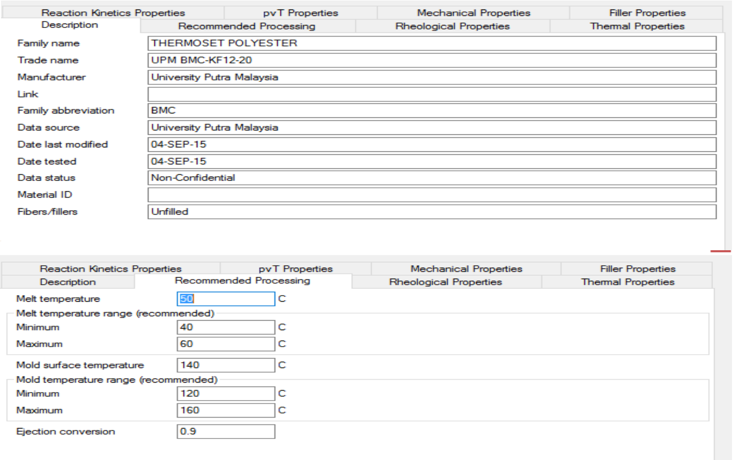
UPM BMC-KF12-20 trade name material had been selected from the materials library of the software, this reactive material consists of kenaf fibers with 12 mm length reinforced unsaturated polyester. Figure 5 shows material description and recommended processing. To modify the material properties and include the optimized hybrid premixed bulk compounds properties and reinforcements (Kenaf and Coir) properties in each single run this selected material (UPM BMC-KF12-20) was edited and some of the thermal and mechanical properties were changed to present the real hybrid premixed bulk compounds.

Process Settings

In this procedure several parameters were edited regarding to the process parameters, machine parameters, temperatures control and curing parameters, which can be illustrated as:

Machine parameters:

Maximum machine clamp force = 7.0002E+003 tonne



Family name: THERMOSET POLYESTER
Trade name: UPM BMC-KF12-20
Manufacturer: University Putra Malaysia
Link:
Family abbreviation: BMC
Data source: University Putra Malaysia
Date last modified: 04-SEP-15
Date tested: 04-SEP-15
Data status: Non-Confidential
Material ID:
Fibers/fillers: Unfilled

Melt temperature: 50 C
Melt temperature range (recommended)
Minimum: 40 C
Maximum: 60 C
Mold surface temperature: 140 C
Mold temperature range (recommended)
Minimum: 120 C
Maximum: 160 C
Ejection conversion: 0.9

Figure 5. UPM BMC-KF12-20

Machine hydraulic response time = 1.0000E-002 s
Temperature control:
Melt temperature = 50.00 C
Mold temperature = 180.00 C
Mold-melt heat transfer coefficients
Filling = 5000.0000 W/m^2-C
Packing = 2500.0000 W/m^2-C
Detached = 1250.0000 W/m^2-C
Atmospheric temperature = 25.00 C

Curing parameters:
Curing time = 60.00 s
Inlet melt conversion = 0.0000
Perform preconditioning analysis = No
Press compression direction = -Z
Pure compression press open distance option = Automatic
Press compression time = 10.0000 s
Compression speed cap = 1000.00000 mm/s
Press compression force = 150.0000 tonne
Press compression speed at incremental distances :
0.1000 mm 10.0000 mm/s
10.0000 mm 10.0000 mm/s
Switch to force control by % node volume filled = 99.00000 %

Final procedure was running the analysis to obtain the simulation results. The obtained simulation results includes the materials flow, temperature profile of the materials during the molding process, the defects that might occur such as porosities, shrinkage and weldlines, and the pressures. These results helped us to analysis and to compare the effects of the three charges shapes on the final products.

RESULTS AND DISCUSSION

Meshing Results for the Mold

Figure 6 shows mold after meshing process had been done, while Table 1 provides the information for the numbers of nodes and elements with acceptable aspect ratio, the element size was 2.11044 mm with 0.1055 mm of tolerance.

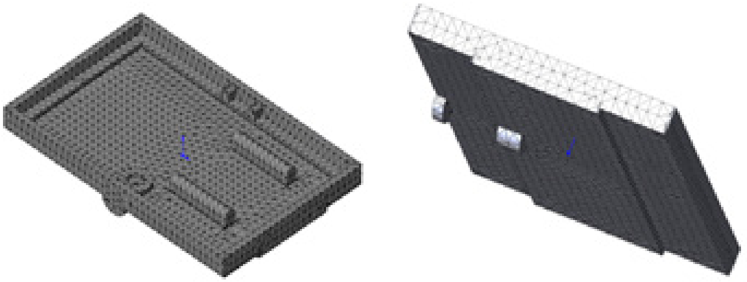


Figure 6. Mold after meshing process

Table 1

Meshing process results

Meshing Process	Results
Total Nodes	17967
Total Elements	9251
Maximum Aspect Ratio	18.053
% of elements with aspect ratio < 3	84.8
% of elements with aspect ratio > 10	0.389
% of distorted elements (Jacobian)	0

Materials Flow Results

Table 2 represent the comparison between the bulk molding materials flow results such as fill time, cavities volume, clamp forces and densities for the different charges shapes.

Table 2

Molding flow results for different charges types

Charge Shape	Fill Time (s)	Cavities Volume (cm^3)	Clamp Forces (tonne)	Densities (g/cm^3)
Rectangular	0.28	11.5	0.253	1.88 + - 0.08
Cubic	1.91	77.5	0.85	1.88 + - 0.08
Cylindrical	2.89	117.5	0.175	1.88 + - 0.08

The rectangular shape charge had the lowest cavities volume and took the shortest time to make the materials flow through the mold cavities, due to the distribution of the materials represented by rectangular shape and covered the large surface area of the mold. On the other hand the cylindrical shape charge covered a small surface area of the mold and left a much higher cavities volume at the beginning of the fill which took longer time to be filled.

Pressure at End of Fill

Figure 7 shows the pressure distribution at the end of fill for the three charges. It was obvious that the cylindrical and rectangular shapes needed less pressure and the distribution of the pressure was much uniform at the three dimensions than the cubic shapes. Thus, due to the higher compactness of the materials in the cubic shapes and much pressure was needed to fill up the edges of the mold.

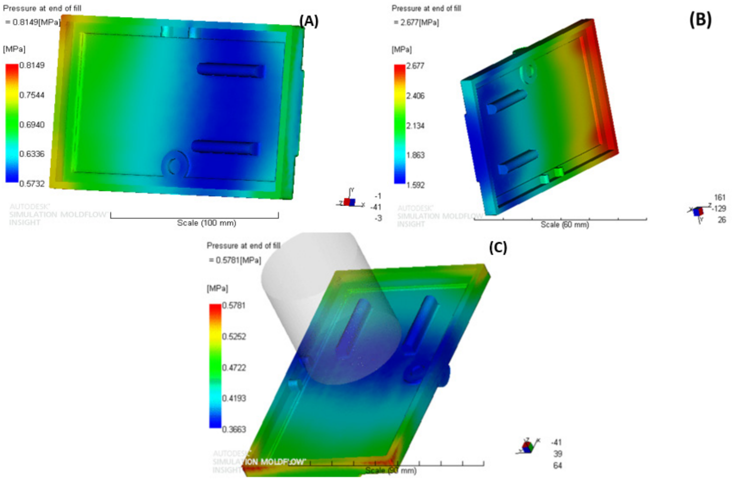


Figure 7. Pressures at end of fill (A) rectangular charge, (B) cubic charge, (C) cylindrical charge

Temperatures at Flow Front

As shown in Figure 8. temperature at flow front can be increased by increasing the filling time for the total cavities of the mold and also by reducing the thickness (the contact distance between the two parts of the mold and the surfaces of the charge). Thus, the cylindrical and the rectangular shape charge had more temperature at flow front than the cubic charge shape.

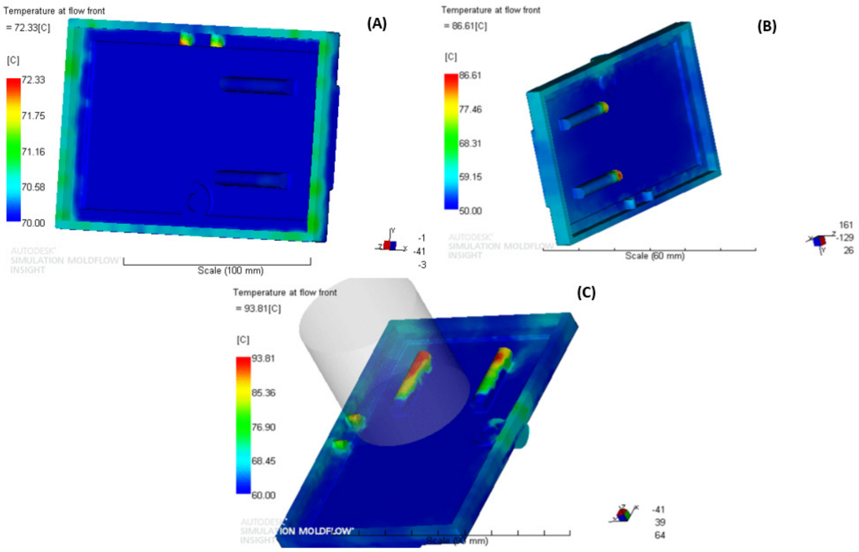


Figure 8. Temperatures at flow front (A) rectangular charge, (B) cubic charge, (C) cylindrical charge.

Average Volumetric Shrinkage

The cubic charge shape shows the lowest average volumetric shrinkage differences throughout the molded part of 5% as minimum and 7% as maximum with 2% differences approximately. This reflects the good temperature distribution in all direction for the materials while been pressed into the cavities of the mold. On the other hand, the cylindrical and the rectangular shape charges show more than 3.5% of differences in average volumetric shrinkage, as shown in Figure 9.

Fiber Orientation Tensor

The Fiber orientation tensor result shows the probability of fiber alignment in the specified principal direction. A high probability of fiber alignment in the specified principal direction is indicated by a value of close to 1 on the result scale, whereas a low probability is indicated by a value close to 0. The fiber orientation tensor in the first principal direction is the most useful result to view. Knowing that the first principal direction is close to the material flow direction in most cases, may not always coincide with the flow direction.

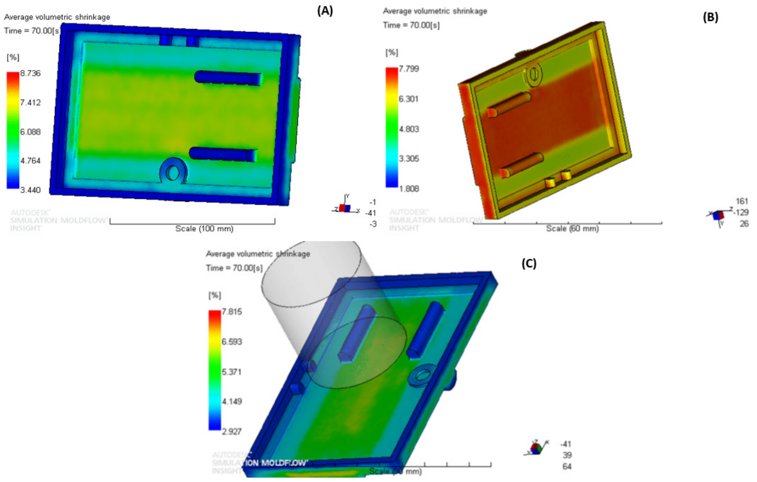


Figure 9. Average volumetric shrinkage (A) rectangular charge, (B) cubic charge, (C) cylindrical charge

Figure 10 shows fiber orientation tensor to the flow of the materials and the pressure applied on the charges. The cubic charge shape presents a good fiber orientation with range (0.66 – 0.99) over the mold cavities compared to the other two types of charges followed by cylindrical shape. This can be as result of the optimum time to fill to the volume of the cavities to the pressure applied which it can give the fibers to follow the flow of the matrix without any blockages from other fibers.

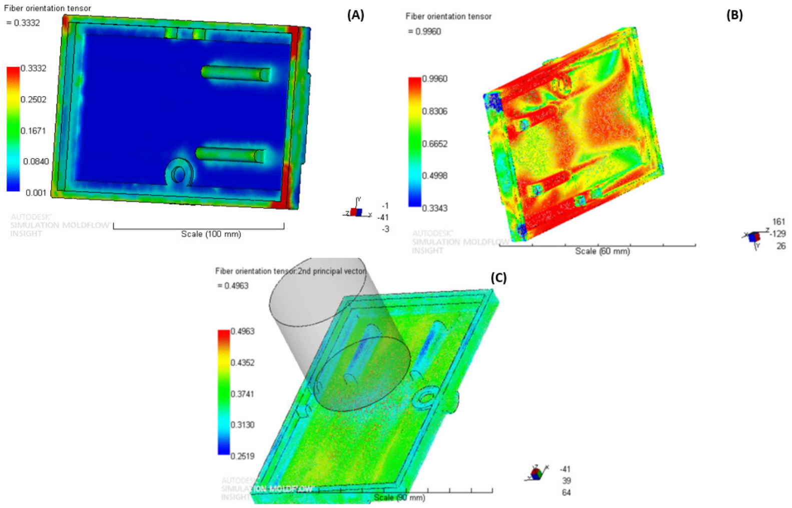


Figure 10. Fiber orientation tensor (A) rectangular charge, (B) cubic charge, (C) cylindrical charge

Predected Defects Results

Figures 11, 12 and 13 show the predicted defects (weld lines, air traps and deflections) respectively, for the weld lines the cubic shape charge shows less critical weld lines compared to the other two types and the higher critical weld lines presented by the rectangular charge shape. However, these critical weld lines were concentrated on the edges of the mold where the heat transfer was higher and the curing was faster.

The air traps formed by the rectangular shape charge were higher and concentrated in the middle of the molded part. This was due to the rectangular large surface area covered by this shape which trapped more air between the mold surface area and the charge.

Generally the deflections were concentrated on the edges of the part for all charges type, and the cubic charge shape had the lowest values for these deflections.

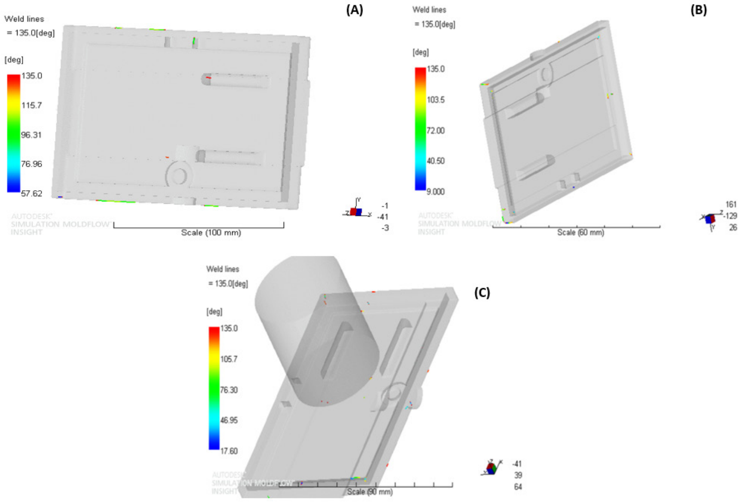


Figure 11. Weld lines (A) rectangular charge, (B) cubic charge, (C) cylindrical charge

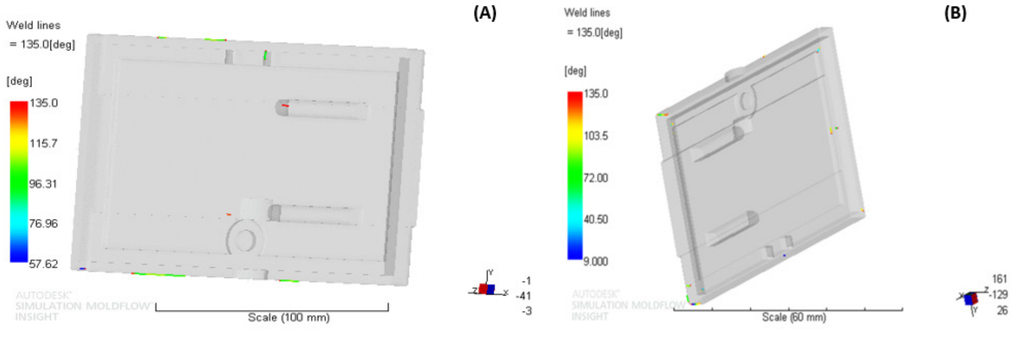


Figure 12. Air Traps (A) rectangular charge, (B) cubic charge

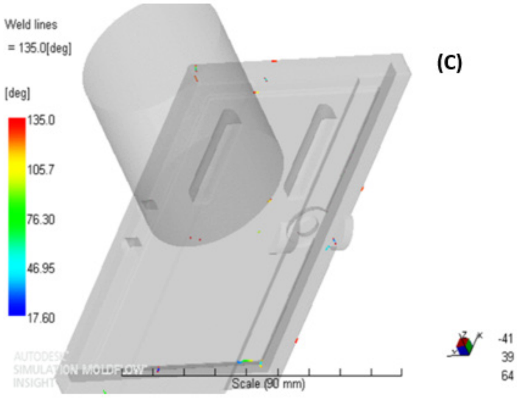


Figure 12. Air traps (C) cylindrical charge

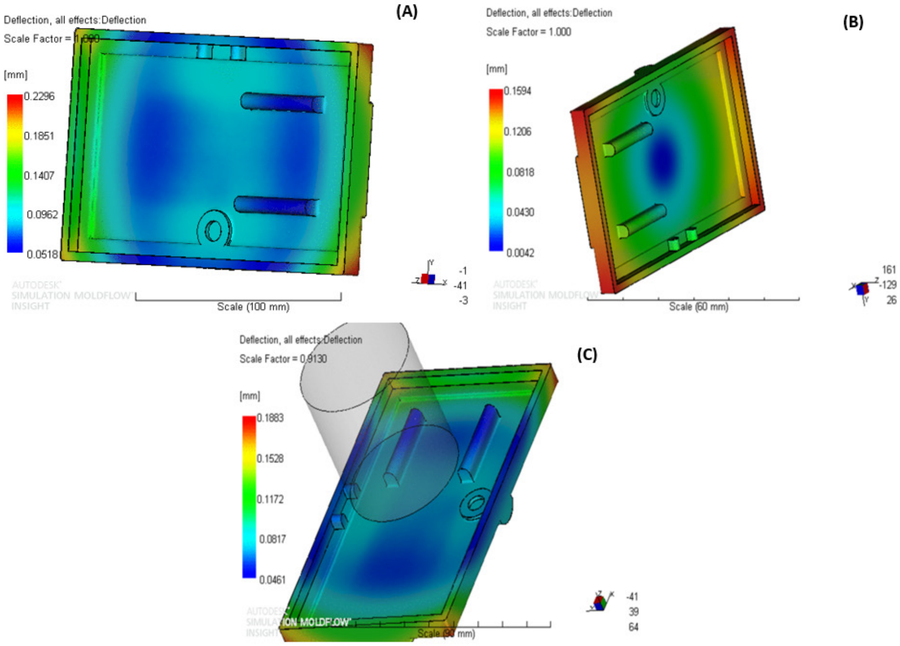


Figure 13. Deflection for (A) rectangular charge, (B) cubic charge, (C) cylindrical charge

CONCLUSIONS

It can be concluded that the shape of the charge had an effective effect on the molding parameters process and the final shape of the molded materials, and the developed materials approved that it can be implemented in complex shape parts and can flow smoothly to fill up all the cavities of the mold. The cubic charges showed lowest average shrinkage differences and a better temperatures distribution at flow front followed by rectangular while the last was the cylindrical charge. Due to the good fiber orientation for the cubic charge shape, the defects that accrued with this shape was the lowest compared to the other charges shapes, while the rectangular charge shape showed a critical air traps in the middle of the surface of molded part.

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