OVERMOLDING INJECTION MOLDING SIMULATION OF TENSILE TEST SPECIMEN

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Abstract: Multicomponent injection molding is gaining popularity due to its potential to produce multifunctional parts at low costs. Autodesk Moldflow Insight injection molding simulation software is providing in-depth analysis and optimization of plastic parts and their associated molds which further reduces the production cost of parts. In this paper is presented a study of injection molding optimization process of bi-component tensile test specimens using different materials. The main concern of this optimization is to establish the optimal condition and material combinations for the tensile specimens' injection molding. Also it is very important to study the effects of the interface geometry between the two materials on the strength adhesion.

Key words: bi-component injection molding, simulation, process optimization.

1. INTRODUCTION

Bi-component injection molding is a sequential molding process in which one plastic material (overmold) is molded (partially molded) onto a previously filled and solidified part from a different plastic material (substrate). This process is a special case of multi-component injection molding and extends the capability of conventional injection molding process to produce finished assemblies and multifunctional parts [20, 13, 2, 3, 4]. Multi-component injection molding requires that these two materials are chemically and rheologically compatible [14, 15]. Currently, this process is widely accepted and extensively used in the plastic industry. Typical examples are car bumpers, toothbrush handles and mobile phone case.

The introduction of simulation software has made a significant impact in the industry where in the past much was unknown about the injection process itself [18, 19]. However, with the increasing use of computers in design engineering, the amount of commercially available software on the market has also increased. Autodesk Moldflow Insight is one of much software available on the market that helps to simulate the filling and packing phases of the injection molding process, so you can better predict the flow behavior of plastic melts and achieve higher-quality manufacturing [21, 22, 24, 26].

This paper studies the bi-material injection molding process optimization for tensile test specimens molding that will be further used in experimental analysis of the mechanical properties of bi-material components and the influence of the two-material interface bonding on the parts properties. For the considered part we have selected a particular interface surface geometry between the two materials which has a rectangular shape with 60 mm in length and 10 mm wide (see fig. 2). The interface surface will be analysed for the influence of this feature on the shapeand mechanical properties on overmolded tensile test specimen.

2. BI-MATERIAL INJECTION MOLDING

The advantages of multicomponent injection molding encouraged researchers to extend their research form conventional injection molding to the multicomponent injection molding which was studied by means of both numerical simulation and laboratory experiments [5, 6, 17, 21]. Chen et. al. [1] studied the polymer melt flow in co-injection molding process using clear PMMA for the skin material and colored PMMA for the core observing the polymer melt flow and material distribution on both skin and core materials. Palluch and Isayev [16] obtained a approach for the physical modeling and simulation of multi-component injection molding which takes into account the transient interface movement during co-injection, the stress-induced crystallization and the effect of elasticity on the interface development.

Lee, Isayev and White [11], based on the Hele Saw approximation they calculate the interface evolution between two phases during the cavity filling in simulataneous sandwich injection molding taking account of the viscosity ration melt temperature and injection rate effects. Harte and Namara [7, 8] studied the overinjection molding of a short fibre thermoplastic onto a long fibre thermoplastic base. They studied the deformation of the considered part and also the adhesion between the two materials. Liu et. al. [12] used C-Mold and Fortran software to simulate the overinjection molding process compared the obtained results with the conventional injection molding. They concluded that in the case of overmolding process the pressure required to fill the overmold is about 20% less than what is required for a conventional part and also the

Table 1. Material properties used on the study

Property / Material	Specific heat (J/kg-C)	Elastic moduls (MPa)	Poisson ratio	Melt temperature range (ºC)	Melt density (g/cm^3)
Generic HDPE (Eltex)	2859	911	0.426	180-240	0.74381
LDPE 4012	3400	124	0.41	180-280	0.73537
Hostalen PPU 1780 S5	1800	1340	0.392	200-280	0.75277

shorter the filling tim, the less difference of flow patern exist between two-material injection molding and conventional injection molding.

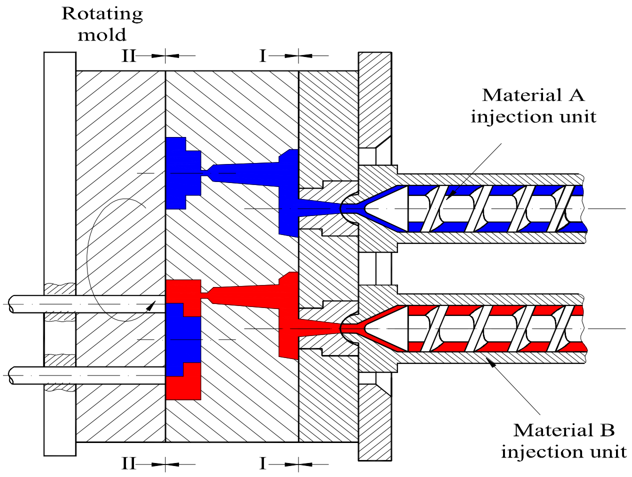


Figure 1. Two material mold for overinjection molding

The bi-material injection molding process can be divided into the following stages (see figure 1):

Stage 1: Filling and Post-filling of first component (substrate) which in fact is the same as conventional injection molding;

Stage 2: Core switchover. During this stage the core is rotated or the insert is retracted to create a cavity for the overmold;

Stage 3: Filling and Post-filling of Overmold. During stage 3, melt polymer fills up the cavity of the overmold and solidifies. Because part of the cavity wall of the overmold is made up by the substrate, the overmolding analysis has to take account the boundary condition of the substrate. The different boundary condition distinguishes the bi-component injection molding process form the conventional injection molding process.

2.1 Simulation of bi-material injection molding

The generalized Hele-Saw flow model provides simplified governing equations for non-isothermal and non-Newtonian viscous fluid [7, 9, 10].

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0\,, \tag{1}$$

Momentum equation

$$\frac{\partial p}{\partial x}=\frac{\partial}{\partial z}\left(\eta\frac{\partial u}{\partial z}\right), \tag{2}$$

$$\frac{\partial p}{\partial y}=\frac{\partial}{\partial z}\left(\eta\frac{\partial v}{\partial z}\right), \tag{3}$$

$$\frac{\partial p}{\partial z}=0 \tag{4}$$

Energy equation

$$\rho C_p\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\eta\dot{\gamma}^2+k\frac{\partial^2 T}{\partial z^2} \tag{5}$$

Boundary conditions:

$$u=v=0 \text{ at } z=b \text{ and } z=-b \tag{6}$$

$$T=T_{overmold}=T_{substrate} \tag{7}$$

where b is the half-gap thickness, $\dot{\gamma}$ is the shear rate, η is the shear viscosity, ρ is the density, C_p is the specific heat, k is the thermal conductivity, (x,y,z) are the Cartesian coordinates, (u,v,w) are the velocity components and T is the temperature.

Table 2. Cross-WLF viscosity model coefficients

Material / Coefficients	HDPE	LDPE 4012	Hostalen PPU 1780 S5
n	0.3417	0.3145	0.2879
τ^*, [Pa]	75700	34515	210090
D_1, [Pa-s]	7×10^{12}	310×10^{12}	251×10^{17}
D_2, [K]	153.15	233.15	263.15
D_3, [K/Pa]	0	0	0
A_1	26.3	34.602	42.877
$\tilde{A}_2$, [K]	51.6	51.6	51.6

The viscosity is modeled using the Cross-WLF model.

$$\eta = \frac{\eta_0}{\left(1 + \frac{\eta_0 \dot{\gamma}}{\tau^*}\right)^{1-n}} \quad (8)$$

with

$$\eta_0 = D_1 \exp\left\{ -\frac{A_1 [T - (D_2 + D_3 p)]}{\tilde{A}_2 + D_3 p + [T - (D_2 + D_3 p)]} \right\} \quad (9)$$

where $n, \tau^*, D_1, D_2, D_3, A_1$ and $\tilde{A}_2$ are the seven constants of the model.

2.2. Moldflow simulation setup

The part subjected to this study is a tensile test specimen according to SR EN ISO 527-2 standard. Figure 2 illustrates the geometry of the specimen and the particular geometry of the two materials interface. For this study the material combinations were obtained using three plastic materials such as, LDPE 4012, Generic HDPE (Eltex), and Hostalen PPU 1780 S5 (PP). Table 1 presents some of the properties for the considered materials. The material selection for the two component part injection molding was made according to literature specifications [5]. The adhesion between the two components is one of most important factors influencing material combinations used in the simulation of the overmolding injection process. The rheological coefficients of Cross-WLF model for the considered materials are presented in table 2. There were considered two material combinations for simulation of the injection molding process: LDPE/HDPE, LDPE/PP.
For this study an overmolding analysis is used to analyse two shot sequentially overmolded parts.

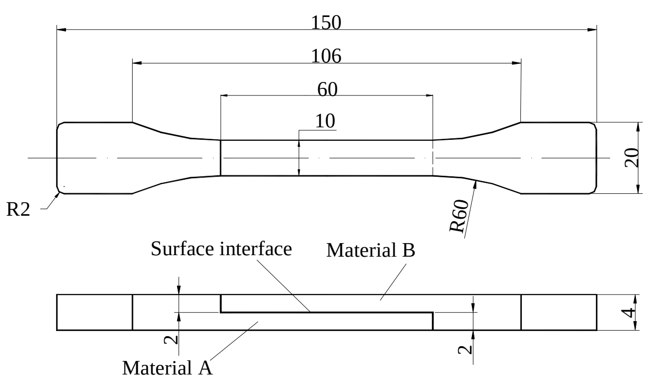


Fig. 2. Standard tensile test specimen according to SR EN ISO 527-2

Overmolding analysis consist of a two step process, where a Fill+Pack analysis is performed on the first cavity (first component stage), and then a Fill+Pack analysis or a Fill+Pack+Warp analysis is performed on the overmolding cavity (overmolding stage). The overmolding stage on the second cavity uses a different material from the first component stage. As the temperature of the insert, injected in the first component stage, is not uniform, mold and melt temperatures used in the overmolding stage are initialized by the temperatures recorded at the end of the first component stage.

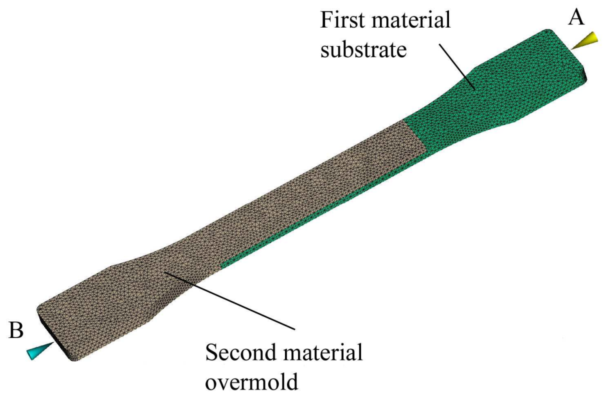


Fig. 3. 3D mesh of the two material tensile test specimen with the considered injection points. Substrate injection location (A) and overinjection(B) location and material combinations [23]

The part mesh (see figure 3) was realized with a number of 119113 3D tetrahedral elements from wich the substrate part has a number of 59398 3D tetrahedral elements and the insert a number of 59715 3D tetrahedral elements. The injection location for both materials can be observed in figure 3. The simulation was made using the Autodesk Moldflow Insight thermoplastic overmolding module. The materials were imported from the material database of the software.

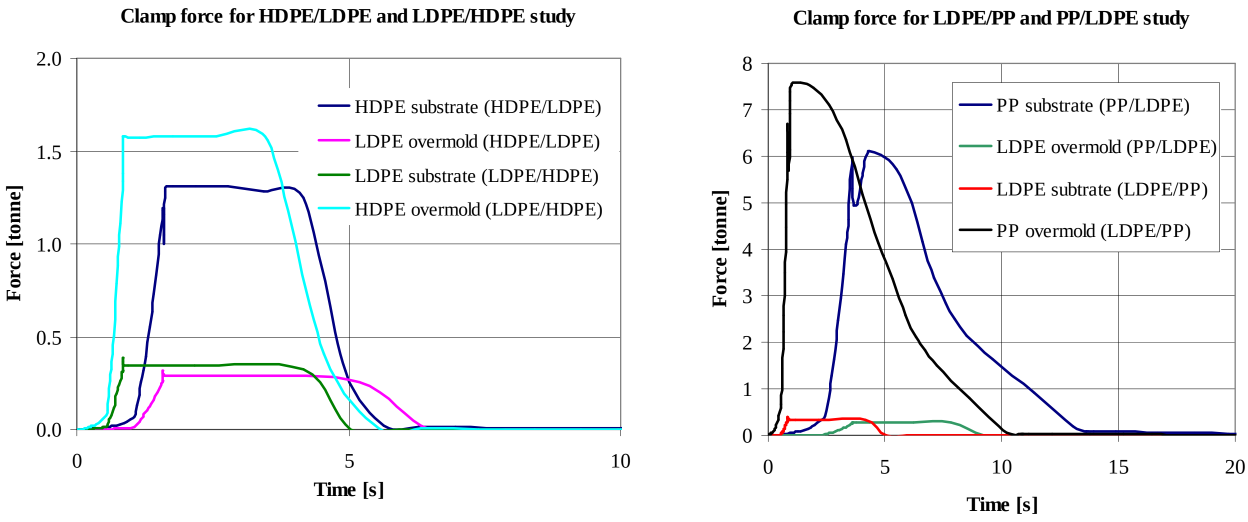
Table 3. Simulation setup combination

Nr.	Substrate material	Overmold material
1.	LDPE	HDPE
2.	HDPE	LDPE
3.	LDPE	PP
4.	PP	LDPE

For this study, a fill-pack-warp analysis was submitted for all the material combinations.
One main objective of the study is to determine the order on the material injection on the process. In this case we realized four simulations using both possibilities for the order of the injection.
Table 3 presents the studies programmed to be realized and the order of the polymeric materials injection for each study.

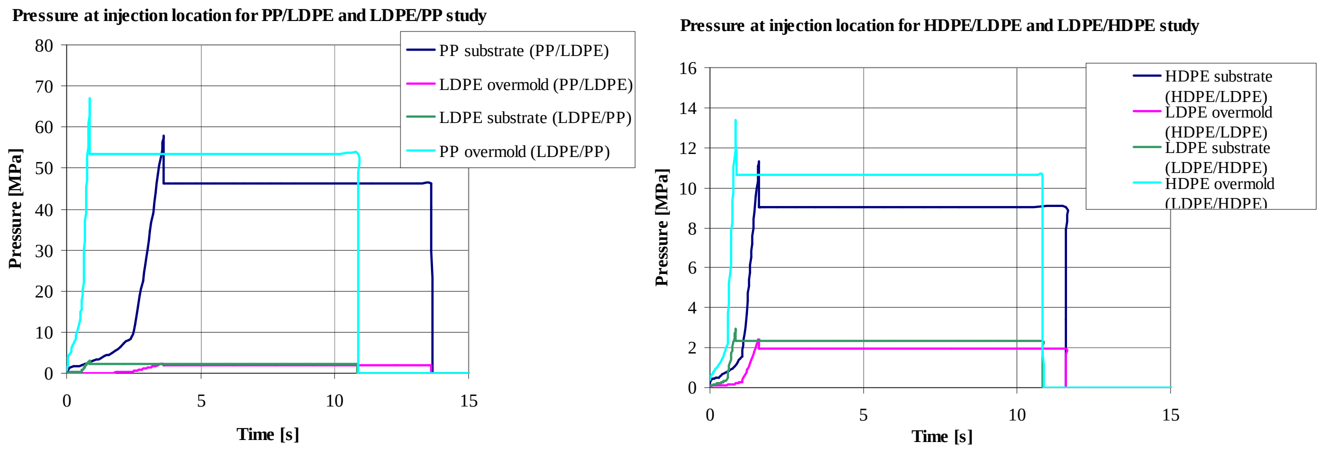
3. SIMULATION RESULTS

The analysis of the simulation results will indicate the proper combination for each particular case study. The results will be further used on the injection molding process setup for the two-material tensile test specimen injection.



a) b)

Fig.4. Clamp force results XY plot



a) b)

Fig. 5. Pressure at injection location XY plot

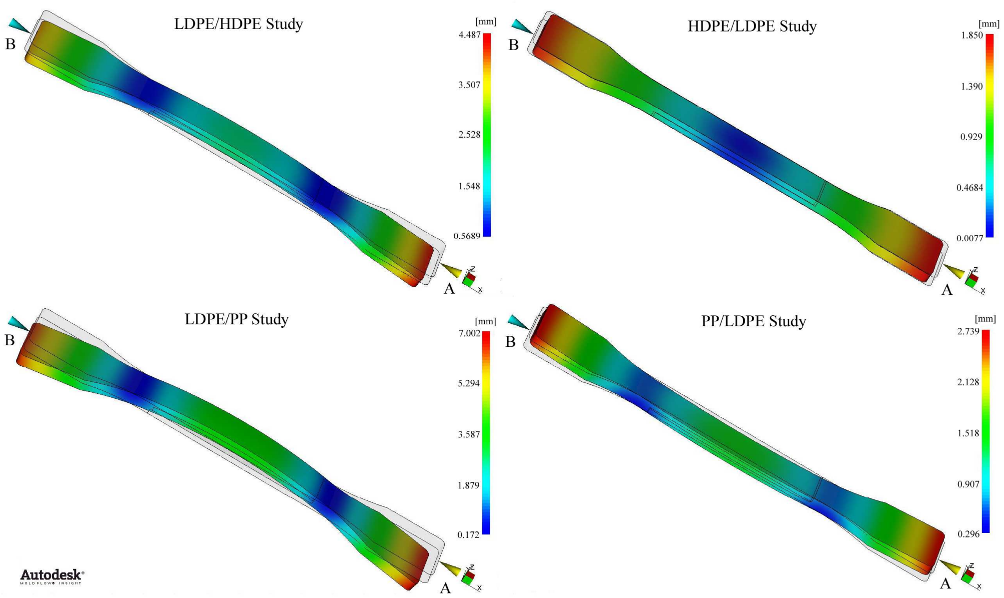


Fig. 6. Deflection all efects results for two-component injection molding [23]

The clamp force results revealed an (see fig. 4) important difference between the values of clamp force at substrate and overmold injection for the conssidered materials.

Analysing the results we can observ an decrease of the clamp force for HDPE/LDPE and PP/LDPE case study.
Values of the clamp force of 18% and 12% less for substrate injection o HDPE respectively for the overmold injection of LDPE were obtained and 20% and 30% less of the values for PP substrate injection rescpectively for the LDPE overmold injection.
Figure 5 presents the pressure at injection location results for substrate injection respectively at the overmolding stage and shows the evolution of the pressure during the fill-pack analysis. As in the case of the clamp force results important differences between the substrate and overmold stages can be observed in the case of pressure at injection location results.
The deflection result shows the deflection at each node of the part. Figure 6 presents the total deflections of the 3D part. The values of this result reflect also the influence of the re-melt zone on the deflections of the part. The maximum deflections were obtained at LDPE/PP case study.
Re-metl zone result (figure 7) shows places where the first component may not have completely frozen, or has re-melted, when the second component is injected. This result is generated at the end of an Overmolding Fill analysis using 3D analysis technology.
Remelting occurs when the first component has not cooled enough before the second component is injected, or when the melt temperature of the second component is high enough to cause melting in the first component. This result tells you where, on the boundary between the first and second components, re-melting is likely to occur. Re-melting of a thin skin increases structural strength between the components. However, it is generally undesirable because it causes unpredictable changes to the properties of the first component, such as its exact shape or optical properties.
Figure 7 reveals different results obtanined by simply changing the order of the material injection in the simulation. PP/LDPE and LDPE/HDPE case studies reveal a decrease of the re-melt zone.
In this study, taking account of the considered geometry in the overmolding injection analysis there were no weldlines results due to direction of the polymer melt flow.

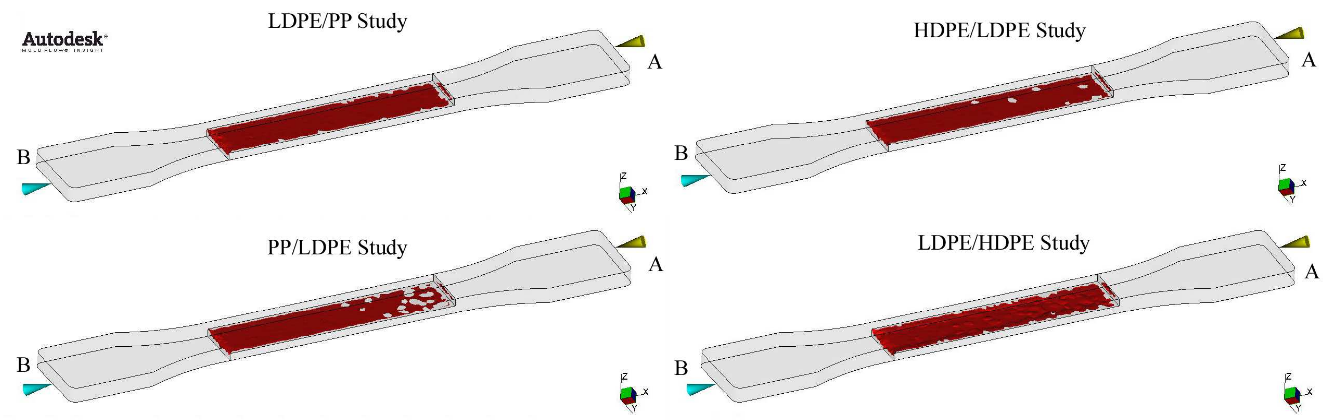


Fig. 7. Re-melt zone results for each case study [23]

Analizing all simulation results for the four considered case study there can be made a good selection of the order in wich the polymeric materials wil be used for injection molding of the two-component tensile test specimen.

4. CONCLUSIONS

The analysis with Autodesk Moldflow of the overmolding process offers the possibility of visualising the process evolution without being necessary to build the mold and to solve the eventual problems that can occur in the designing process of new parts. Furthermore, the obtained results can be utilised to do an accurate setup of the injection molding machine, therefore reducing the time from machine setup to production (no trial and error steps are needed).
The study revealed that the proper material combination in the case of overmolding a tensile test specimen is to utilise PP/LDPE and LDPE/HDPE, also for these combination there is a decrease of the necessary pressure and clamp force values for the overinjection stage on the injection process of the specimens.
Futher studies will be made using Moldflow interface with Ansys to study the mechanical properties of the finished part on a tensile test analysis. More, the obtained results on the injection molding will be used to injection molding of the tensile test specimen using the same materials considered in this study.
Using a universal testing machine a study on the mechanical behaviour of the two material tensile test specimens will be made. The adhesion between the

two materials will be analysed using a tensile test at different testing speed.

The aim of these further results will try to determine the influence of the interface layer between the two polymeric materials on the adhesions strength using different surface roughness. Also the remelted layer thickness at the interface between the two polymeric materials will be measured using optical microscopy.

Acknowledgements

The financial support of the National Authority for Scientific Research, through the grant PN II IDEAS 789, is gratefully acknowledged. The work of DOBREA DANIEL VALENTIN was supported by Project SOP HRD - EFICIENT 61445/2009.

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Received: 26 May 2010 / Accepted: November 20, 2010 / Abstract published online: December 5, 2010