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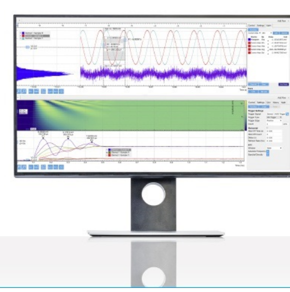

A Novel Method for the Prediction of Adhesive Strength for Two-Component Injection Molding of Thermoplastics with Thermoset Rubbers

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Abstract. Two component injection molding is a widespread technique to produce polymer products that consist of two materials. This technique is commonly used to combine various material properties, or functionalities in one product. The ‘hard-soft’ combination where a stiff material is over-molded by a soft layer, is one example, often seen in valve like products where the soft part is used as a seal. Thermoplastic elastomers (TPE’s) are commonly used is this case. However, TPE’s have only limited properties for chemical and temperature resistance. For such applications it would be beneficial to use a thermoset rubber as EPDM, NBR, NR, etc. Although injection molding of thermoset rubbers is not that uncommon, using it in an over molding process is rather rare and not much is known about the final properties of the over molded product. One of the most important parameters is the adhesion between the two materials. Recommendations for good adhesion can be found in literature for specific material combinations, but data on predicting the strength of adhesion in thermoset rubber over molding in function of material and process settings does not exist. This paper presents a novel, empirical method to predict the strength of adhesion in function of material and process settings.

INTRODUCTION

Numerical simulations for injection molding are commonly used for predicting process specific parameters and properties of the final molded product. This is done for single as well as for multicomponent injection molding. They predict flow patterns, clamping force, pressure during processing, fiber orientation, warp shapes, etc. Most often, numerical simulations are performed for the injection molding of thermoplastic materials. Using numerical simulations for two component injection molding of thermoplastic materials and thermoset rubbers is, as far as we know, uncommon. Moreover, commercial simulation software packages as Autodesk Moldflow have no straight-forward way of simulating this process [7]. Next to this, predicting the strength of adhesion between over molded materials is rather new. Nowadays, research is conducted in determining the strength of adhesion of overmolded organo sheets [1] and the healing capabilities of materials in weldlines [2]. Predicting strength of adhesion between a thermoset rubber and a thermoplastic material is new. This paper shows a possible workflow to determine the strength of adhesion between a thermoplastic material and an over-molded thermoset rubber via simulations. A combination of existing simulation software as Autodesk Moldflow, measurements and scripting was used to create novel results.

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WORKFLOW

Previous to this research, measurements have been conducted to determine the strength of adhesion on tensile strips produced, produced in a 2K plate mold. This has been done for the HDPE M80064S and EPDM 005K material combination which is described by G-J Bex et al. [8]. The measurements describe the strength of adhesion for these tensile strips, as function of interface temperature between the rubber and thermoplastic material (1), curing of the thermoset material at the interface (2) and packing pressure during injection molding of the thermoset material (3) [3,4,8]. In the presented script, all the measured adhesion strengths are scaled from 0 to 1 (normalize data) and implemented as function of its specified parameters. To predict the adhesive strength for new designed over-molded products, numerical simulations are needed. In this case Autodesk Moldflow 2017 was used for the injection molding simulations. The first step is to implement the product and mold geometry in the simulation software. Next there is also a need for the material characteristics and the process settings. The test product for which the strength of adhesion will be predicted is shown in Figure 1. The product is a tube-like geometry over molded with a rubber ring for sealing purposes. The figure also shows the cooling set-up, consisting here of three cooling channels and a central bubbler.

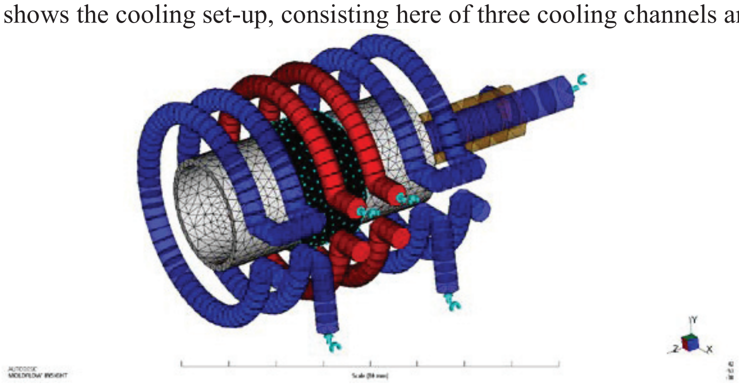

FIGURE 1. simulation case: tube with rubber ring

The product is manufactured using HDPE M80064S and EPDM 005K, of which the rheological and curing properties were measured [5]. To predict the final strength of adhesion, three important simulation results are needed as input for the presented script: the temperature of the thermoplastic part insert during rubber injection (i), the degree of cure as function of time (ii) and the internal pressure during the injection and packing phase (iii). Those three results are exported from Autodesk Moldflow as an XML format. As this file contains all nodal result data, which are used to produce new plots with combined results. Also the UDM-mesh file which contains all node locations is needed to reproduce the product for further calculations. Using this data, the developed script automatically finds the surface between the first component and the over molded rubber part. At this step, the script creates a new 2D mesh to plot and calculate the new results. For all nodes on the new created mesh, the right temperature, the cure and pressure data is found within the results data present in the XML files. Combining this data with the normalized input data, the script can produce novel plots which show the influence of a specific parameter on the strength of adhesion. The complete workflow is shown in Figure 2.

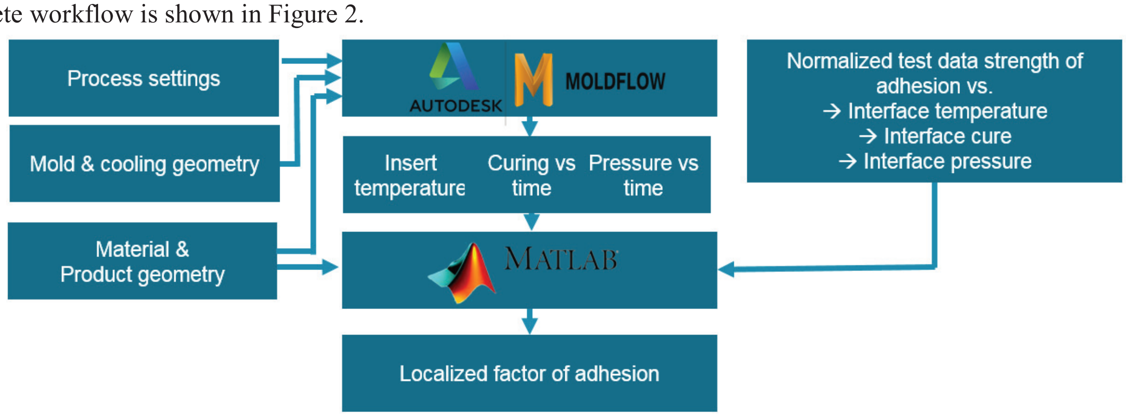

FIGURE 2. workflow to determine the localized strength of adhesion

NOVEL SIMULATION RESULTS

The presented script produces results which show the influence of individual parameters on the strength of adhesion, assuming the two other parameters have an optimal value at each point of the interface. It shows normalized values, between 0 (no adhesion) and 1 (optimal adhesion) for three individual parameters. The factor ‘$f_{temperature}$’ shows the hypothetical influence of temperature on the strength of adhesion, ‘f_{cure}’ the influence of the degree of cure and ‘$f_{pressure}$’ the influence of the local interface pressure. Although not shown in this paper, the script provides plots in function of time, so the development of adhesive strength can be monitored during the injection phase, packing phase and curing phase. These visualized time-steps are the same steps as available in the Autodesk Moldflow simulation result window.

Figure 3 on the left, shows the temperature at the surface of the interface. According to the simulations, the regions closest to the outer edges of the rubber ring, are the warmest. The surface temperatures lay between 128°C and 133°C. With these simulated surface temperatures, the script finds the corresponding adhesive strength, measured on the tensile strips. This measured tensile strength is normalized towards a value between 0 and 1 and plotted on the created mesh between the thermoplastic material and the thermoset rubber. Fig. 3 on the right, shows the $f_{temperature}$. As the interface temperatures are very near to the optimum, the simulated result shows an expected normalized strength between 0.8 and 0.99.

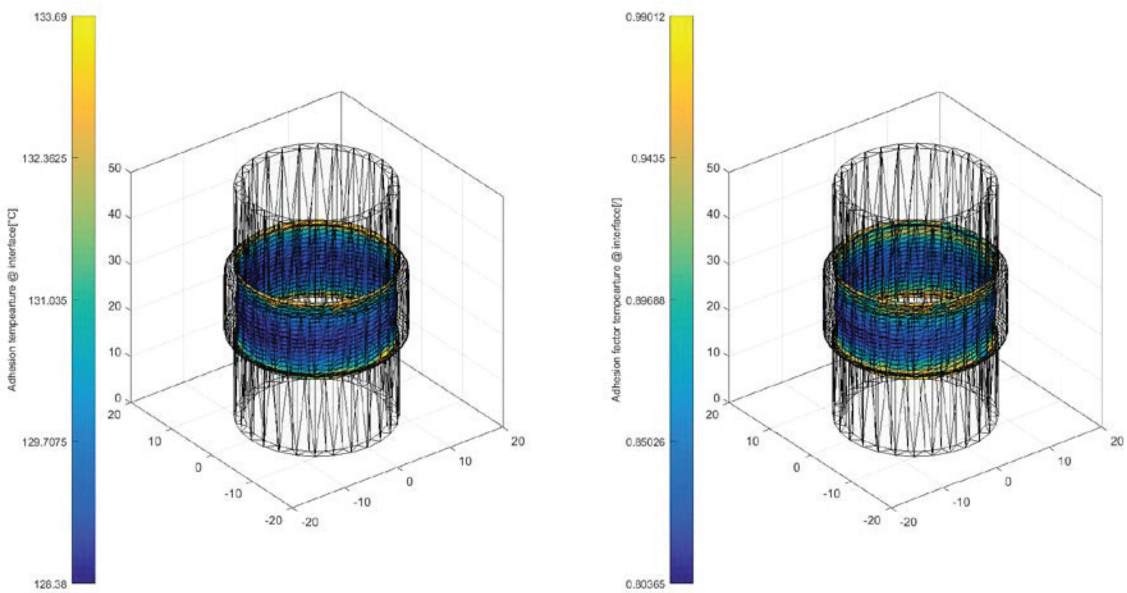

FIGURE 3. (left) Temperature at insert surface, (right) Simulated factor of adhesion vs. temperature: $f_{temperature}$

The second result is the factor of adhesion in function of the curing at the interface. The cure results in Figure 4 on the left, show the curing degrees at the end of the curing phase (1100s) at the surface of the rubber part, ranging from 0 to 0.86, where 1 is complete curing. Curing of the rubber ring is at its highest (0.7-0.86) at the middle section of the surface between the two product parts, whereas the edges show a lower degree of cure (less than 0.25) and even points where the rubbers is not cured at all. This has an effect on the adhesion as shown in Fig. 4 on the right. The factor of adhesion (between 0 and 1) varies between 0.11 and 0.96 (f_{cure}). At the edges of the product, a lower factor of adhesion is noticed compared to the calculated factor in the center, this due to a lower degree of cure at the edges in the rubber ring.

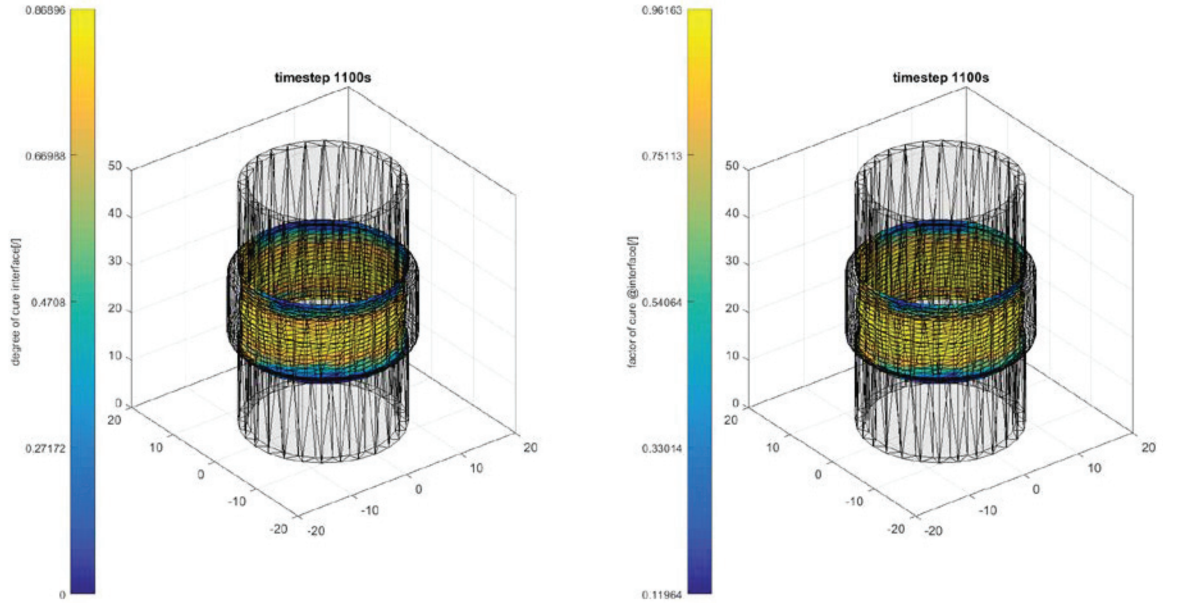

FIGURE 4. (left) Degree of cure at product surface, (right) Simulated factor of adhesion vs. degree of cure: f_{cure}

As last influencing parameter, pressure is displayed. Figure 5 on the left shows the pressure at the interface at the end of the packing phase (200.5s). Although pressure is equal on all locations during the packing phase, this does not mean that it results in an equal adhesive strength over the complete interface. Due to temperature differences, pressure has a localized effect. Fig. 5 on the right shows the $f_{pressure}$. This plot is very similar to the $f_{temperature}$ plot as the effect of pressure is temperature dependent. The $f_{pressure}$ shows an influence in a relative strength of adhesion between 0.69 and 0.98, where 1 is the maximum value.

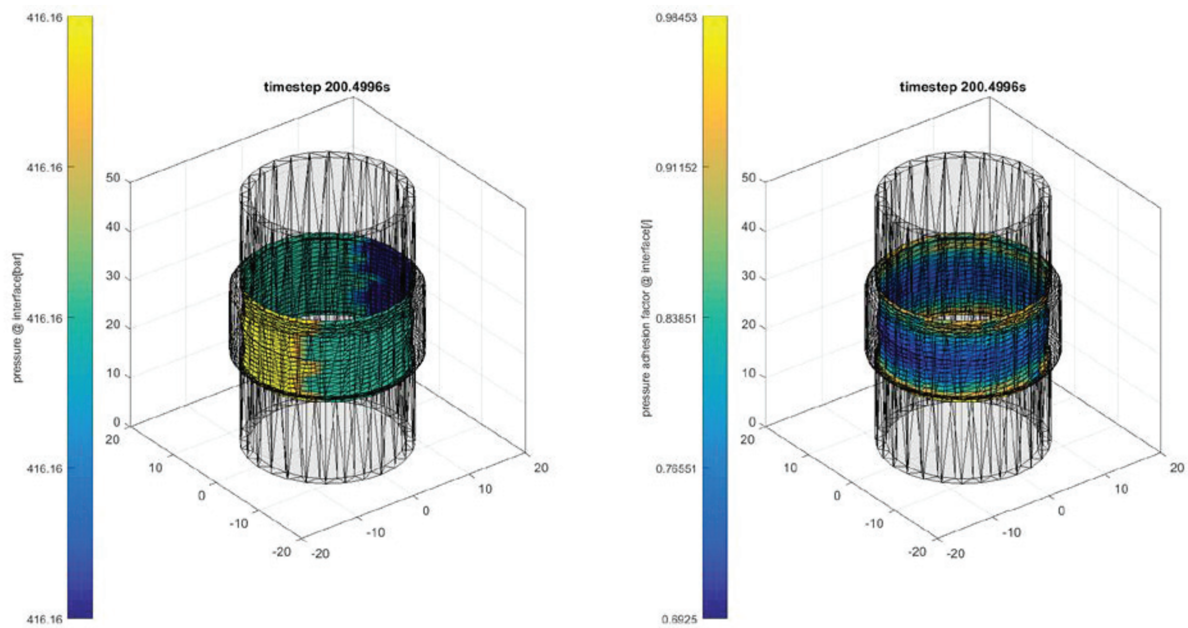

FIGURE 5. (left) Pressure at product surface, (right) Simulated factor of adhesion vs. pressure: $f_{pressure}$

CONCLUSION

The developed script uses measured adhesion strength data obtained by tensile testing of 2K molded test-strips obtained with well-defined processing parameters. With this data, the script is able to predict the individual influence of local values of temperature, cure and interface pressure on the expected local adhesion strength (assuming optimal values for the two other parameters). This approach can be used as initial assessment of the influence of injection molding process parameters, such as mold temperatures, injection speed, injection temperature and even mold design as they all affect the curing degree, insert temperature and packing pressure. In that way, it also can be used to optimize the product and mold geometry and even more important, to refine process settings. A more in depth design of experiments will be carried out to obtain a more realistic model that describes the adhesion strength as combined effect of local temperature, curing degree and packing pressure, in order to obtain more insight in the cross effects between these three parameters. A disadvantage of the proposed approach is that the adhesive behavior must be characterized in advance for each new material combination.

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