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Selected methods of modelling of polymer during the injection moulding process

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Analysis and modelling

ABSTRACT

Purpose: The purpose of present paper was presenting chosen results of investigations on polymer flow during mould cavity filling phase of injection process. Advancement in the simulation software make possible to model more phenomena occurring during polymer flow in injection molding process.

Design/methodology/approach: The results of computer simulations of injection process have been compared with the results of video recording for the plastic flow during filling phase. For the simulating investigations a professional computer software Moldflow Plastics Insight ver. 6.1. has been employed. A specialized injection mould which enables observation and registration of the plastic flow during processing has been employed. The mould enables direct monitoring of the course of phenomena inside the mould cavity in two planes. To record the flow, a digital video camera has been employed. As an example the issue of stream flow (jeting) have been described.

Findings: The results of the investigations enabled documenting of specific phenomena which occur during plastics or their composites injection process. The registered video sequences have been compared with the results of numerical calculations and then it was estimated to what degree the computer simulation of injection process may be useful in practice.

Research limitations/implications: The camera enabled to register the flows with the rate of 25 fps. This reduced the scope of the investigations, since at higher plastic flow speeds the registered image became less clear. The investigations were performed on a wide scale, however, only chosen results have been presented.

Practical implications: Deep understanding of the phenomena which occur during filling the injection mould may lead to more effective design of the processing tools and shortening of the time for implementation and production time.

Originality/value: The transparent sight-glasses have been used, made of a material called Zerodur® which is characterized by the coefficient of thermal expansion close to zero.

Keywords: Computer assistance in the engineering tasks and scientific research; Monitoring of polymer flow during injection molding process; Mold flow analysis; Image analysis

1. Introduction

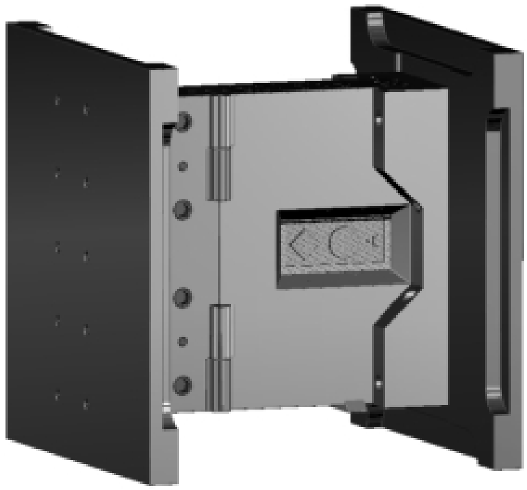
Processing of plastics and their composites by means of injection method is a widely used process in many branches of contemporary industry. The participation of the filled plastics (composites) in products designed for use, not only in everyday life, is still increasing. Due to this fact it is fully justifiable to perform the investigations in order to provide in-depth analysis of the phenomena which occur during widely understood plastics processing. The present paper is an attempt to present chosen part of results of investigations which consist in registration of plastic flow in the mould cavity during filling phase. Such investigations have been performed by several scientific research centres all around the world [1,2,3], however, the level of recognition of the phenomena occurring during filling the injection mould is still insufficient.

2. Methodology of investigations

2.1. Injection mould

For the investigations, a specialized injection mould with unique structure has been employed. The construction of such a mould was preceded by numerous attempts lead by means of several prototypes. The final design of the injection mould was prepared by means of professional software package with its commercial name I-DEAS NX ver.11. The final shape of the mould is shown in the Fig. 1. The mould enabled the authors to register the phenomena which occur during the flow of the plastic inside the mould cavity. The mould was equipped in two transparent sight-glasses (with the surface area equal at least the area of the mould). At the beginning the polycarbonate sight-glasses had been used. They ensured high level of transparency but the caused significant limitations in the value of processing temperature. At the injection temperature over 240 °C or at the high injection speed the sight-glasses deformation and degradation took place. Eventually, the sight-glasses have been prepared from the special ceramic material with the commercial name Zerodur® [4]. The material presents almost zero coefficient of thermal expansion, which makes it insensitive of high temperature gradient which prevails during filling the mould cavity (due to this fact glass sight-glasses were not possible). The sight-glasses were then placed in the mould so that the plastic flow recording would be possible in two planes perpendicular to the polymer flow direction. The recording was done by means of digital video camera. The camera enabled the recording with the maximal speed of 25 images per second. This speed was in many cases insufficient. Additionally, it became necessary to assembly special set of lightning based on the LED diodes. The sets were assembled in such a way that the additional lightning of the mould cavity where the recording took place would be possible. The recording was performed during full darkness in the lab (the tests were performed mainly at night). The mould cavity is in shape of rectangular prism with the dimensions 100x40x4 mm. Within this space, the modification of the final shape of the mould piece is possible on a large scale. This effect was achieved due to the modular structure of the mould cavity.

a)



b)

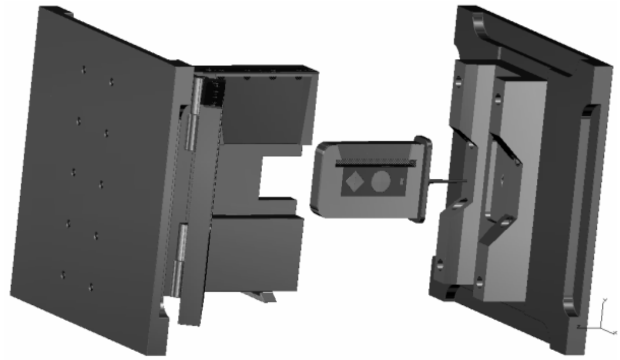


Fig. 1.Injection mould a) closed, b) open

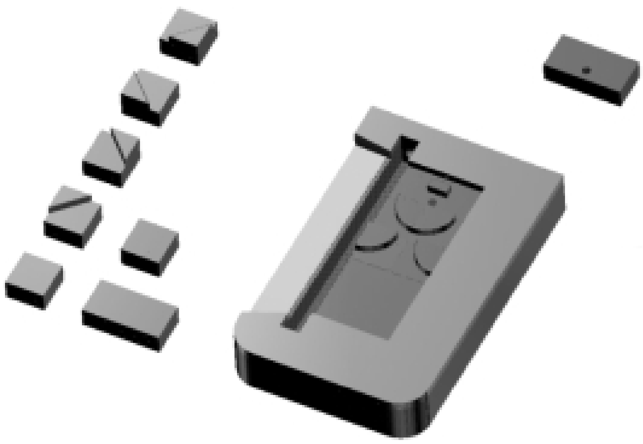


Fig. 2. Structure of the mould cavity

At one time, it is possible to use maximally ten modules with the dimensions of 10x10 mm. The details of the mould cavity structure are shown in the Fig. 2. The Fig 3 presents the test station.

2.2. Injection moulding process

The present paper presents the results achieved during investigations on PBT/PET. The composite PBT/PET + 15 % glass fibber of company Ticona Europe with the commercial name CELANEX 2302 was used. White colour of the injected plastic made it much easier to precisely record the flow. The machine used for the investigations was the Krauss-Maffei injection moulding machine with the symbol of KM 65/160. The machine was equipped in high-quality control system with symbol C4. Using very precise and modern machine enabled to solve the abovementioned problems. The investigations have been performed within wide range of variability of the injection conditions, however, in the present paper only results for chosen cases have been presented.

Fig. 3. Test station

2.3. Computer simulations

The computer simulation consisted in several numerical analyses in order to perform computer modelling of injection process for the chosen composite. The purpose of the investigation was to obtain the results which concern the predicted character of flow for the chosen plastic, and then to compare them with the experimental results. The comparison was to e.g. evaluate the degree of credibility of numerical calculations performed by means of professional computer software. For the investigations, the professional software by Moldflow with the name Moldflow Plastisc Insight ver. 4.1 and 6.1 has been used. In order to perform correct analysis the input of a number of input data became necessary. First of all the shape of the mould cavity and the injection gating system had to be designed. The design has been prepared by means of I-DEAS NX software package. On the model, the mesh of finite element was than plotted. Then, the data to the simulation software concerning material properties of the processed plastic have been input. In order to do it, in-built database with the plastics properties have been used. This helped to reduce the time needed to perform arduous lab tests concerning mechanical, thermal and rheologic properties of a composite. Final phase of the data input to the software the conditions for the injection process have been determined. It should be observed that the correct performance of abovementioned activities significantly influences the correctness and adequacy of the obtained results of calculation. Human factor at this stage is the most important. Inputting the data which differ, even in a minimal scale from the reality causes the occurrence of calculation errors which disqualify the results of investigations. In the Fig. 4 the viscosity plot for the composite used in the investigation is shown, and in the Fig. 5 the pvT chart. In order to model the rheologic properties of the plastic the seven-parameters model Cross-WLF [5-21] has been employed. Its mathematical form is defined by the equation (1). The chosen rheologic model is pretty complicated, but ensures very good imaging of the composite properties.

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

$$\eta_0 = D1\exp\left[\frac{-A1\left(T-T^*\right)}{A2+\left(T-T^*\right)}\right] \quad (1)$$

$$T^* = D2 + D3\cdot p$$

$$A2 = A2^{\sim} + D3\cdot p$$

with: η - viscosity, $\dot{\gamma}$ - shear rate, η_0 - zero viscosity, T - temperature, p - pressure, $n, \tau^*, D1, D2, D3, A1, A2^{\sim}$ - coefficients.

For the used plastic the following values of coefficient have been assumed: n = 0.2767, τ^* = 315000 Pa, $D1$ =4.6e+021 Pa·s, $D2$ = 340.15 K, $D3$ = 0 K/Pa, $A1$ = 55.644, $A2^{\sim}$ = 51.6 K.

The technical parameters of the injection moulding machine have also been input into the software. (e.g. clamp force, perpetual screw diameter, maximal injection pressure etc.).

Moldflow Plastics Insight enables the edition of solver parameters. It makes the manual definition of some values possible e.g. convergence tolerance, time steps or applied equation of state.

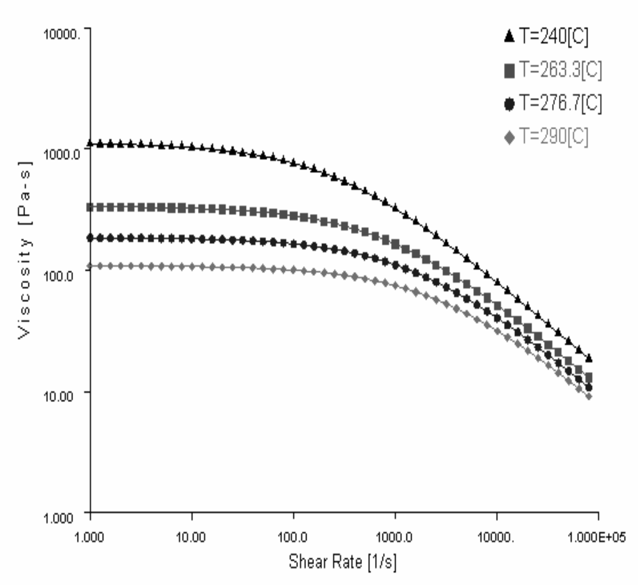


Fig. 4. Flow curves for used PBT/PET

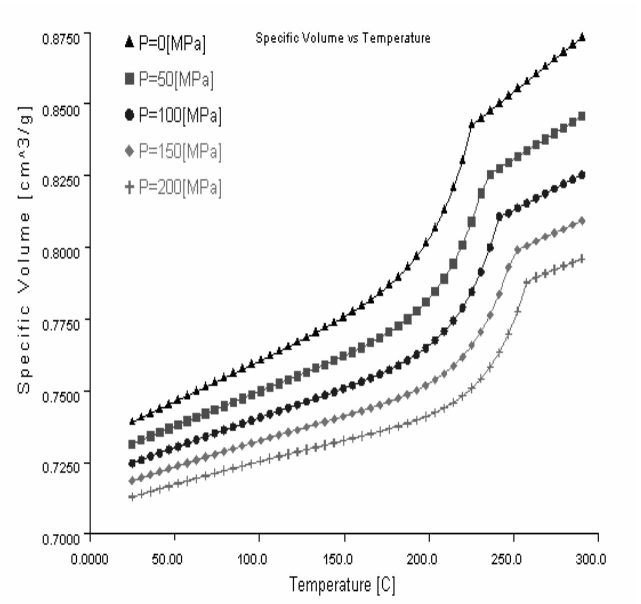


Fig. 5. pvT chart for used PBT/PET

In the Fig. 6 the model FEM of the part used for investigations has been presented. It was rectangular prism-shaped part. Additionally, the gating system for the mould was modelled. After input of material data and processing conditions, the numerical calculations have been performed. At the same time, the recording of the flow in injection mould have been done. The comparison of the experimental and simulation investigation results is shown in the Fig. 8. The comparison contains the frame-by-frame recordings obtained from the digital video camera with the corresponding computer simulation results.

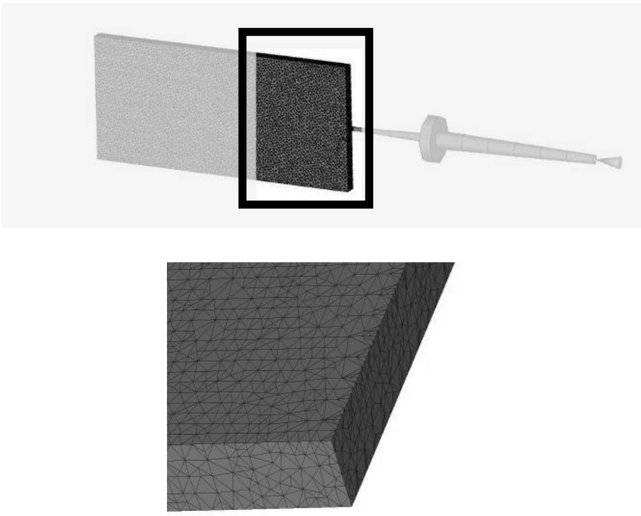


Fig. 6. FEM model of sample with marked region which was presented in results of investigations

The presented comparison concerns the process which was performed in the following conditions:

- volumetric flow rate 30 cm^3/s,
- maximum injection pressure 700 bar,
- injection time 1 s,
- cooling time 20 s,
- injection temperature 240 ºC,
- mould temperature ca. 25 ºC.

Process was performed so that not to lead to total fill-in of the mould cavity and not to skip the clamp phase. The reason for such a procedure was safety reasons and avoiding the damage to the sight-windows. Despite such an extensive limitation, it was possible to record the course of mould cavity filling in the area of interest.

Black frame box in the figure 6 was marked area witch was presented in results of investigations. In bottom part of figure 6 zoom of the selected region of the model was presented, for illustration of the mesh density. Performing of simulation of chosen phenomena required application of model that fulfilled special requirements number of finite elements that fall due to thickness of part wall shouldn't be lesser than six. Additionally it has been forced to take into consideration effects of inertia and gravitation in numerical calculations.

Simulation researches have been preformed with making use of three different methods of part modeling:

- 2D method (often named 2.5D method) basis of *midplane* type of model (midsurface),
- Intermediate method basis of *fusion* type of model,
- 3D method basis of *3D* model.

In the figure 7 FEM models used in simulation research with illustration kind of finite elements type used to build particular models, have been presented.

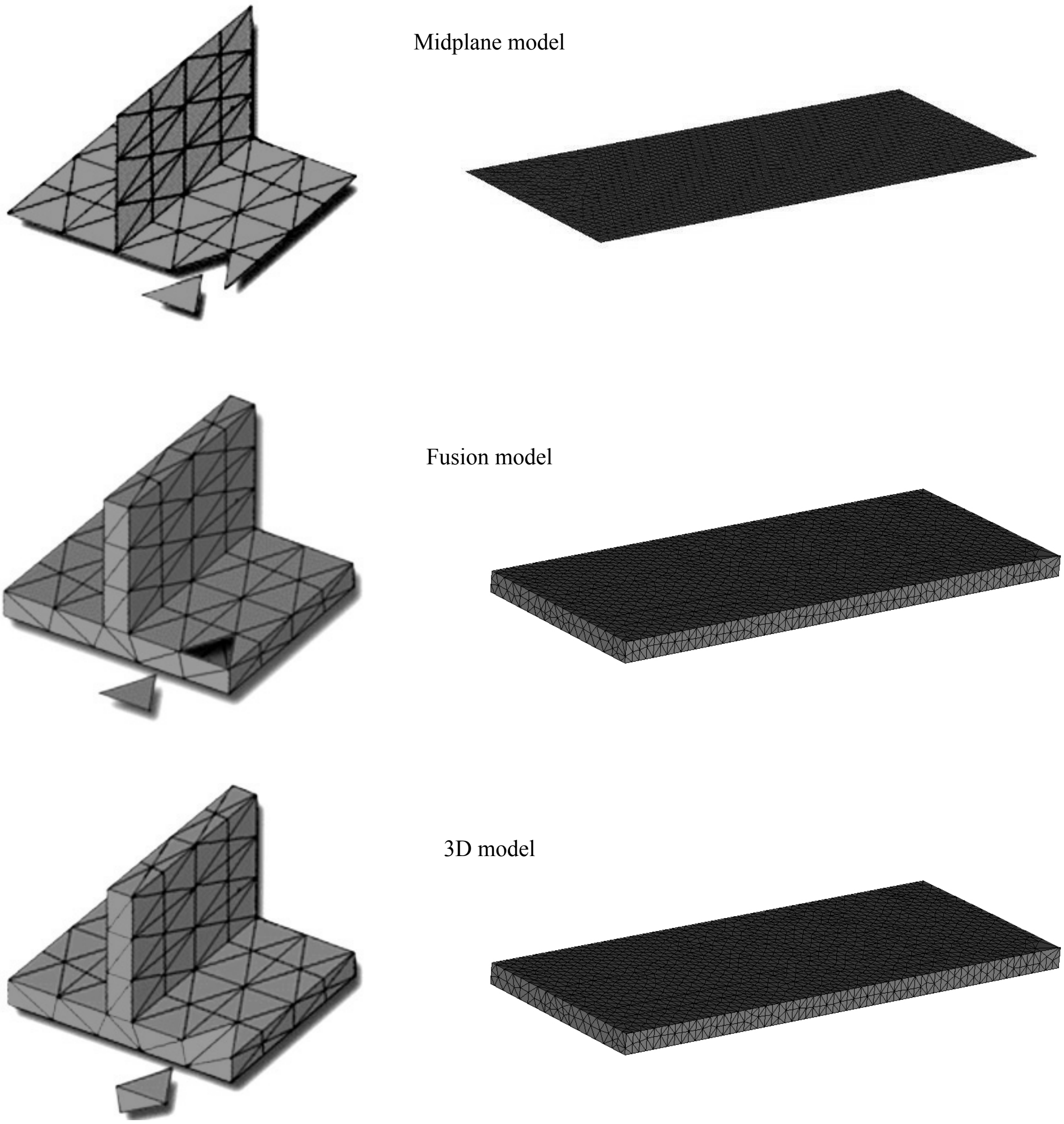


Fig. 7. FEM models used for investigations

3. Results of investigations

In the figure 8 comparisons of results of visualization and simulation investigations ware presented. Those illustrate difference in possibilities of the modeling between old (ver. 4.1 - midplane and fusion models) and newest (ver. 6.1 – 3D model) version of simulation software.

This comparison illustrates only expected behaviour of composite (its flow) in the first phase of filling the injection molding cavity. The authors didn't undertake the test of synchronization for example in the time of results of simulation and visual research. It is relatively hard to make because of many reasons (for example results of recording are determinate by technical parameters of camera that we are using, observation is possible only from the moment of appearance of polymer in cavity etc.). First tests of stream flow modelling were executed in about three weeks from the date of the preparation of this paper. Research described above will be in the future carrying on and results will be specified and more accurate described.

From the presented results we can see that only 3D model (with satisfactorily finite element mesh density) let us modelling as specific phenomena as stream flow. It should be notice that presented results of investigations has the preliminary character. Simulation programs, which enable modelling of this type of flows, are in the world scale something new (commercial market). We should expect that in not faraway future they will be far more improve.

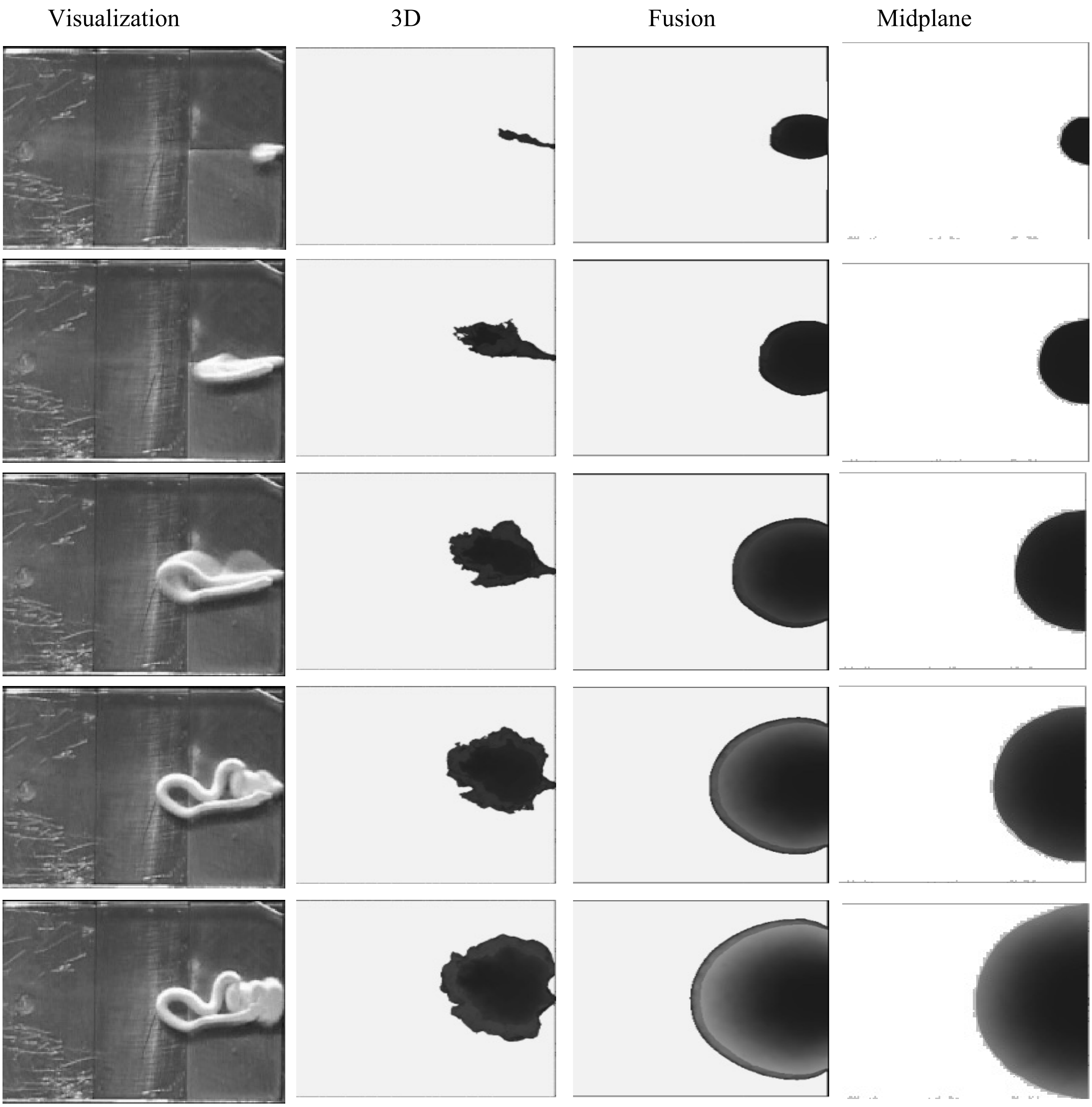


Fig. 8. Results of simulation and visualization investigations comparison

4. Conclusions

Based on caring on research the following conclusions have been drawn:

- Comparison of the results of composite flow during injection process with the results of simulation investigations enables to state that specialized computer software enable to predict the existence of specific phenomena for the given process. Modern simulation programs ensure satisfactory true representation of reality (beside the establishment of correctness of introduced initial and board conditions and reliability of data material of converted composite). This means that already in the product design phase, it is possible to predict and optimise the manufacturing process. Until recently not all of the phenomena characteristic for polymer flow could have been numerical modelized. Permanent dynamical extension within the range of simulation software caused, that nowadays it is possible to modelize practically all phenomena occurring during filling the injection mold cavity. Presented in the paper stream flow is the example of that phenomenon.

- Composite which has been chosen to research besides interesting rheologic properties characterized also proper colour in the fluid condition (because of conditions of conducting the video registration), which in considerable stages improved the quality of acquired results.

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