injection molding, warpage, anchor plane

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INTERPRETATION OF WARPAGE SIMULATION RESULTS IN ASMI

Abstract

The article describes the problematic of interpretation of warpage simulation results in Autodesk Simulation Moldflow Insight. Warpage results are relatively easy to obtain from injection molding analysis, but the result interpretation demands higher skilled user. For detailed warpage evaluation based on specific dimensions is application of anchor plane necessary. Theory of anchor plane creation is described and anchor planes were applied for inspection of critical dimension on molding "terminal box".

1. INTRODUCTION

It would be difficult to imagine the modern world without injection molded plastics products. Today, plastics are an integral part of everyone's life. Properties of the plastic materials such as high strength to weight ratio, the volume to price ratio, corrosion resistance, ease and speed of production have resulted in an ever-increasing use of them. Nowadays, in new part designs, plastics are used not only as a material for producing parts but also as alternative to metal materials [1].

The design of molded plastic parts as well as design of molds for plastic injection processes is comparatively complicated process. It is needs takes into the account costs, production time, part design, ergonomic and aesthetic requirements. The part development process includes conceptual design – CAD model, engineering analysis, process simulation, manufacturing of prototype and testing [1, 2].

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The utilization of CAE methods allows through simulation to speed up the mold design process and the injection molding process optimization. Research in plastic injection molding area has brought a many scientific papers with the aim to improving optimization algorithms of mold design [3].

Injection molding with its excellent dimensional tolerance is one of the most common methods in mass production of plastic parts. Generally, injection molded products do not need any finishing or secondary operations [1]. This process consists of four stages that include melting, injection, holding and cooling [2]. Process parameters, plastic material properties and product design criteria are the critical factors in determining the final product quality.

1.1. Utilization of CAE technologies in process of molded part development

Nowadays technical drawing of injection molded part is not sufficient to describe complex shapes in 2D drawing. Reason for using 3D CAD model are wide opportunities to exact describe shape of part, easy making of cut views and detail views. More important reason to use 3D CAD model is direct import into CAE process simulation of injection molding and mold manufacturing with CAM software. Using 3D CAD model for CAM software has become integral part of mold manufacturing. CAE process simulation of injection molding is becoming stepwise integral part of mold manufacturing process.

With help of CAE simulation mold designer can test various construction solution of injection mold without need cost a time consuming mold corrections [6, 7]. Whole process of integration CAE simulation in this process can be described as shows on Fig. 1.

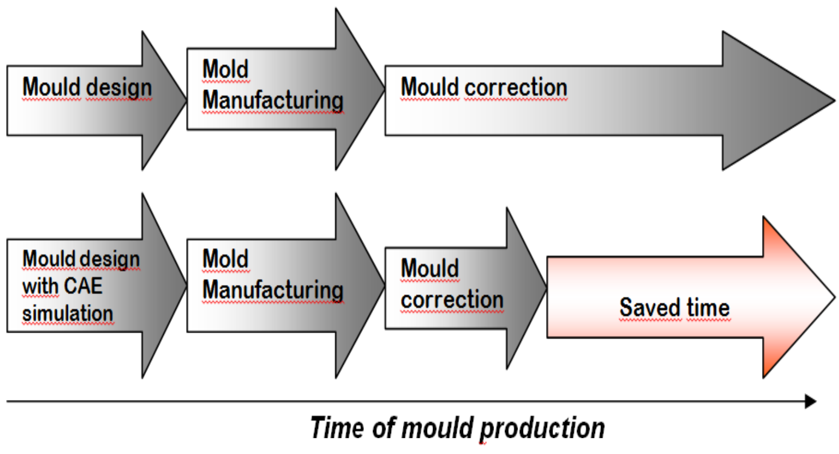

Fig. 1. Time dependence of CAE simulation integration in mould production process [source: own study]

2. WARPAGE OF INJECTION MOLDED PARTS

Warpage of the molded plastic parts is one of the most important problems occurring on final injection molded part. Warped parts may not be functional, visually acceptable or fit into assembly. Different shear rate profiles, cooling profiles and packing pressure history along the cross-section of part cause differences in orientation, density and these phenomena affect the shrinkage. Therefore, there will be variation in shrinkage in the part. Imbalance of shrinkage in any section of a part will produce a net force that could warp it. The stiffness of the part and the shrinkage imbalance level determine the warpage amount. If the part is too stiff to allow deflection, residual stresses will be created in the part that may cause problems later in its life [1]. If the shrinkage of a material is completely isotropic with respect to thickness, flow direction and distance, and packing pressure plastic parts will not warp. Asymmetric shrinkage and unequal contraction in the different directions cause warpage. When considering the contributors to warpage, it is convenient to identify shrinkage due to:

- variation in shrinkage from region to region (differential shrinkage), as shown Fig. 2,
- temperature differences from one side of the mold to the other (differential cooling) – Fig. 3,
- variations in the magnitude of shrinkage in directions parallel and perpendicular to the material orientation direction (orientation effects), as shown Fig. 4.

The Fig. 2 (left) shows a thin rib attached to a thick top. In general, the cooling rate of the top will be lower than that of the thin section. The top will have increased crystalline content and therefore, will shrink more and cause the warpage shown.

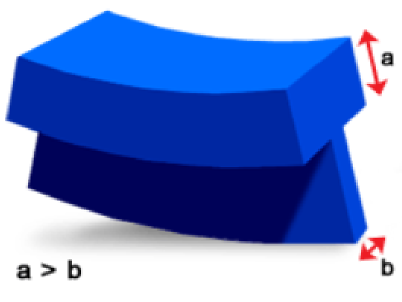

Fig. 2. Warping of molding due differential shrinkage [4]

Figure 2 (right) (a) shows saddle warping of a centrally gated disk with high shrinkage at the center. Conversely, if the shrinkage is higher around the outer part of the disk, the resulting warpage may cause the disk to dome, shown in (b).

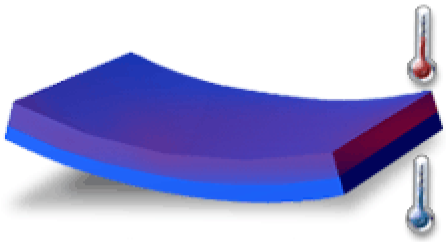

Fig. 3. Warping of molding due differential cooling [4]

Shrinkage due to differential temperature typically results in bowing of the component, as shown in the figure below. Usually this type of shrinkage is due to poor cooling system design. While the part is in the mold, temperature differences from one side of the mold to the other cause variations in shrinkage through the thickness of the component. In addition to this, any temperature differences at ejection will cause further warpage as both sides of the part cool to room temperature.

Orientation causes variation in the magnitude of shrinkage in directions parallel and perpendicular to the material orientation direction [5]. This type of shrinkage can produce warpage similar to that of differential shrinkage. Figure (a) below shows the warpage when parallel shrinkage is greater than perpendicular shrinkage. On the other hand doming can be produced if the perpendicular shrinkage is higher than parallel shrinkage, see (b).

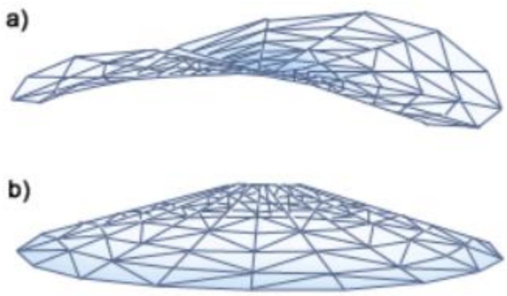

Fig. 4. Warping of molding due orientation effect [4]

Each of these types of shrinkage will contribute to the total warpage of the product. Moreover, process parameters such as melt temperature and holding pressure have an effect on the rate of shrinkage in the different directions [5, 6].

Thus, different melt temperature and holding pressure will affect the warpage amount of the part. Non-uniform shrinkage in different directions could be determined using the material pressure-volume-temperature (pVT) relation diagrams [4].

2.1. Warpage simulation in CAE

Warpage analysis of injection molded part is available in all major CAE simulation software for injection molding process. Autodesk Simulation Moldflow Insight (ASMI) is capable to perform warpage with all three types of FEM mesh (midplane, Dual Domain, 3D) used in this product to simulate injection molding process. Default displaying of molding warpage is visualized with “best fit” technique, where the mutual position of original model and deformed part is aligned in the sense of minimal difference between original and warped positon of all (or selected) nodes as presented in Fig. 5.

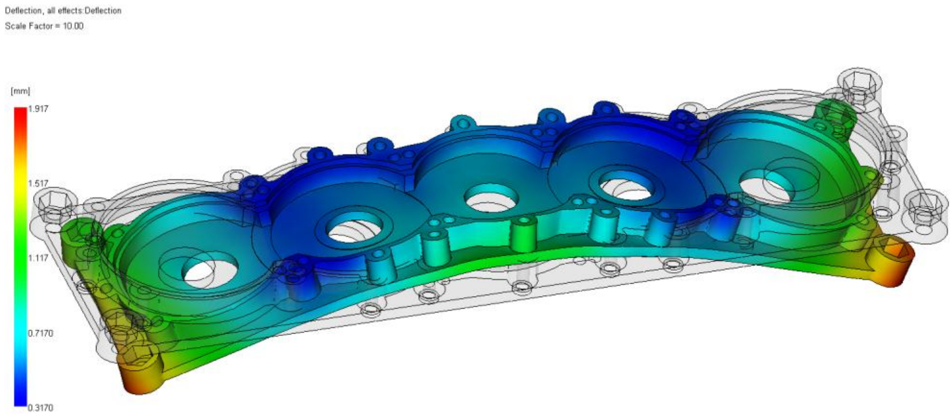

Fig. 5. Visualization of molding warpage (10x magnified) [source: own study]

Using of “best fit” technique for warpage visualization is preferable in early stages of product development, where is important to obtain visual behavior of molding warpage to identify problem areas. The designer can fast identify the changes in warpage when a change in design or molding condition is made [7].

When evaluating if the molding meets the dimension requirements specified in production drawing is using of “best fit” technique very problematic if not even impossible. In case when evaluating of specific dimension is necessary application of anchor planes.

2.2. Anchor planes

After a Warp analysis has been run, a reference plane against which warpage will be measured must be defined. This is the anchor plane, which is defined by three points called anchor points being selected on an undistorted part. Position of the anchor plane has to be performed carefully and each evaluating each dimension necessitates an individual anchor plane. Critical is the location of anchor plane, mostly across a flat part section where is easy to visualize the deflections, where the implications of the deflections can be most clearly interpreted and where the specific dimension values readout. The possible locations for an anchor plane include the: base of a part that is required to lie flat on a surface, the joining plane to a mating component.

The anchor plane is defined by selecting three locations (nodes) on the part. This plane is used to measure the deflections, and the sequence in which the anchor points are defined is important as this affects the warpage results. The anchor points do not have to be on the corners of the part. Typically they are placed at fixing points of the finished assembly, or along edges where two parts meet.

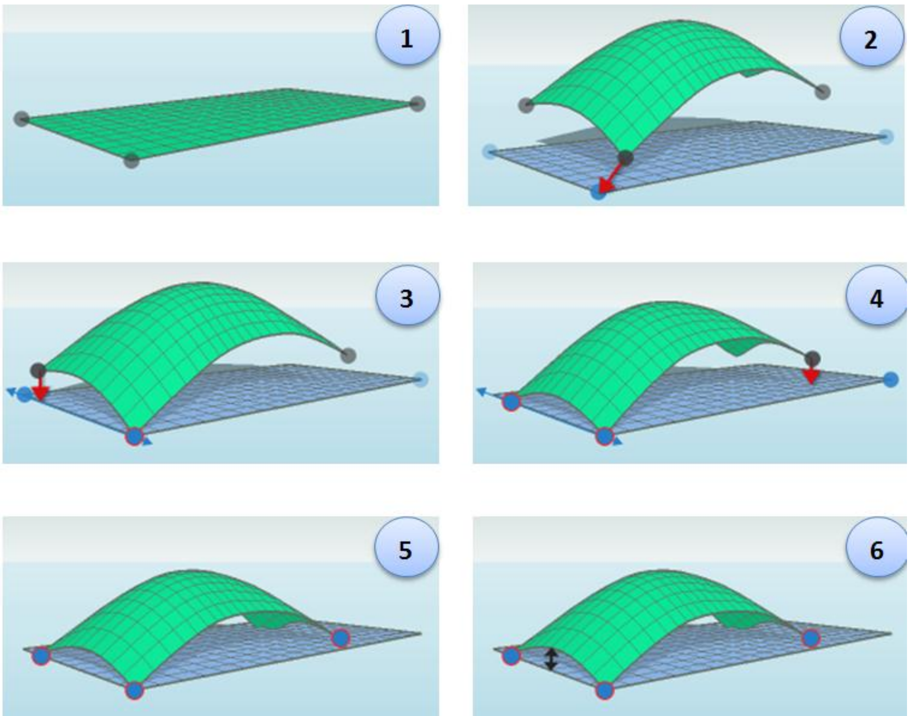

Fig. 6. Defining of anchor plane (1–5) and measurement of displacement from undistorted geometry [4]

Setting up an anchor plane is presented on Figure 6 (steps 2–4). Three anchor points set on an undistorted part (Fig. 6–1). The distorted part must be oriented in relation to this plane for measurement. The first anchor point defined is the front center point (Fig. 6–2). The corresponding point on the part to be measured must always align with this anchor point. The second anchor point defines a line from the first anchor point (Fig. 6–3). The corresponding second point on the part to be measured must be placed along this line while still maintaining the positioning of the first anchor point. The third anchor point defines the anchor plane.

The third point on the part to be measured is now placed on this plane while maintaining the position of the first two anchor points (Fig. 6–4). The part is now oriented correctly in relation to the anchor plane. The distance from the anchor plane to the part is now a repeatable measurement of the warpage (Fig. 6–6).

3. EVALUATION OF PART WARPAGE

Evaluation of part warpage using an anchor plane is presented on simulation result for molding "terminal box" (Fig. 8), made of Latamid 66 H2 G/25-V0CT1. On the drawing are specified critically dimensions that must be maintained if the molding has to meet the quality criteria.

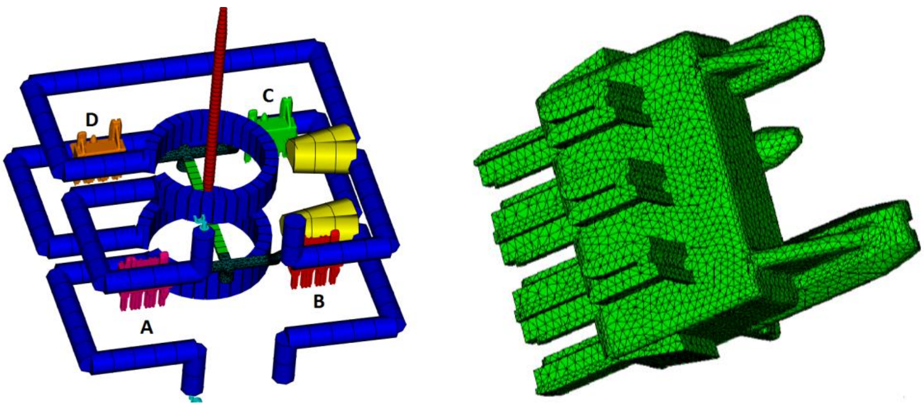

Fig. 7. FEM mesh for injection molding simulation of "terminal box" in 4-cavity mold [source: own study]

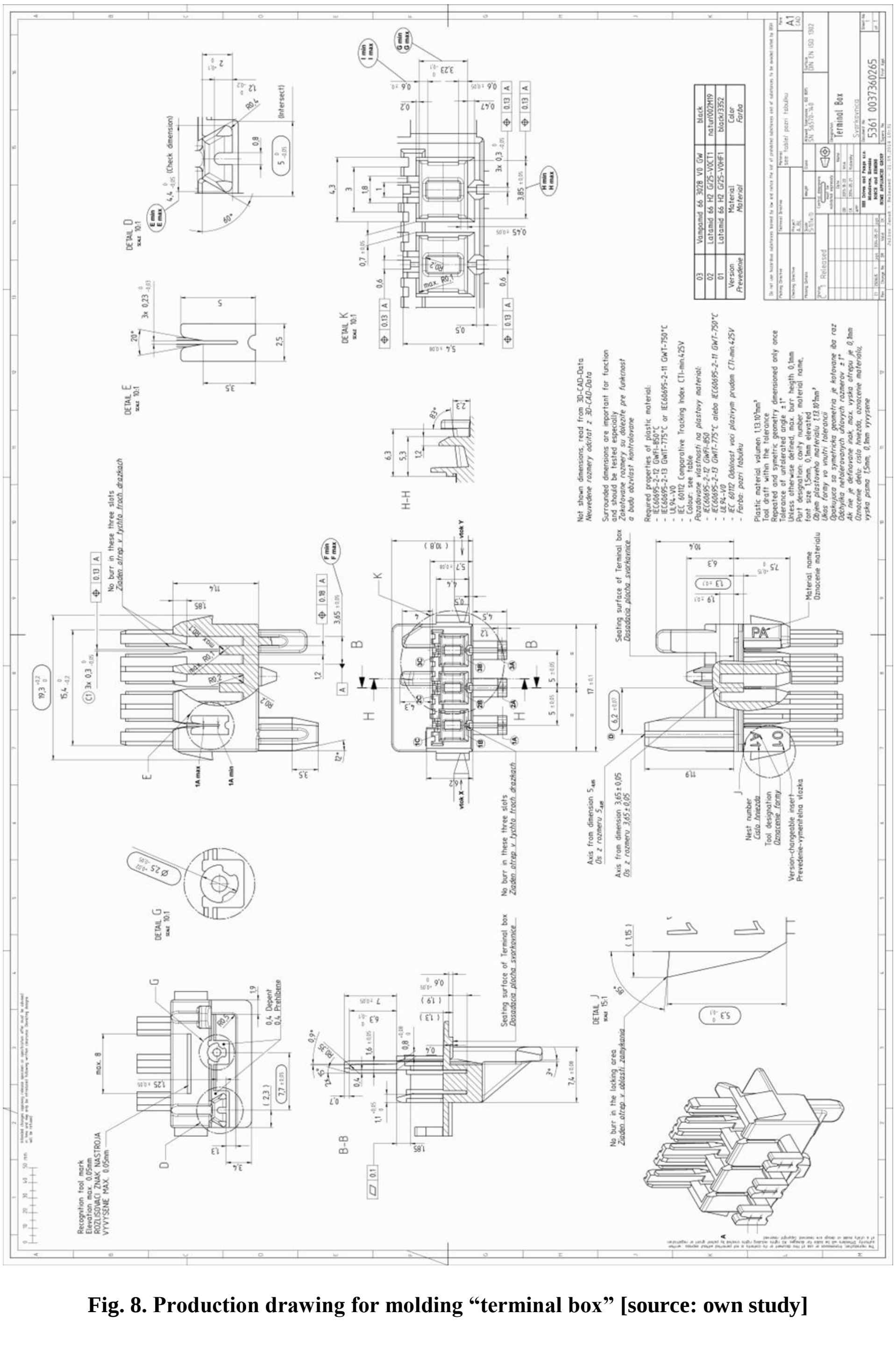

Fig. 8. Production drawing for molding "terminal box" [source: own study]

Molding is injection molded in four cavity mold. For this mold was a 3D mesh prepared, with 1552000 elements (including runner system, cooling lines and mold block (Fig. 7). Each cavity was marked with letter according to figure 8, to easily identify differences in warpage between molding from different cavities. Issue when defining the anchor planes in multi-cavity mold, is to pick-up always the same three corresponding nodes on each cavity when evaluating the same dimension. It has to be noticed that the gating location was not the same for all four cavities. Cavity A and C have the same gating location, that differs from gating location for cavities B and D (B and D same gating location). Injection molding conditions were chosen as default for this material. Injection time and packing profile was set as "automatic".

3.1. Warpage of specific dimension

To present application of anchor plane when evaluating molding warpage a dimension on the part was selected from "Detail D" 4,4 $_{-0,05}$ mm, Fig. 9 (left). Using anchor planes in ASMI has some limitations. Anchor plane is not suitable for evaluating dimensions from cylindrical sections (Fig. 9 – "Detail G") and the anchor plane must be placed on molding nodes, so is not possible to place anchor plane on virtual construction axis (Fig. 9 – right).

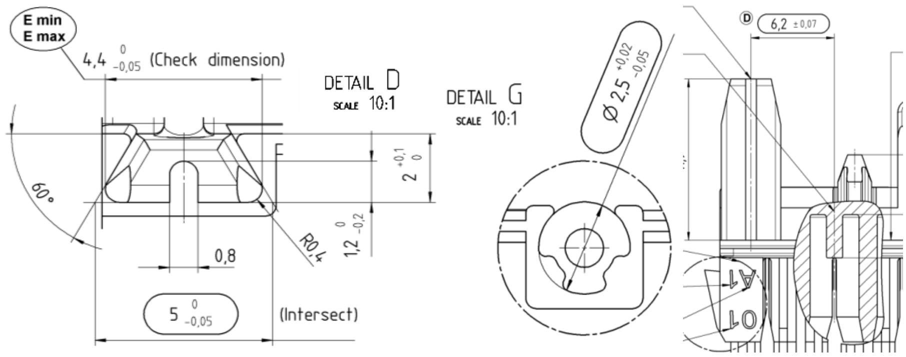

Fig. 9. Inspected dimension on "terminal box" molding (left) and dimensions where the anchor plane is not applicable [source: own study]

For the specified dimension were created anchor planes on the side of the slider. The distortion of the nodes on the opposite side was calculated. Results are presented in Fig. 10. Best result for this evaluated dimension was obtained in cavity D. Three nodes representing the anchor plane are shown as grey spheres.

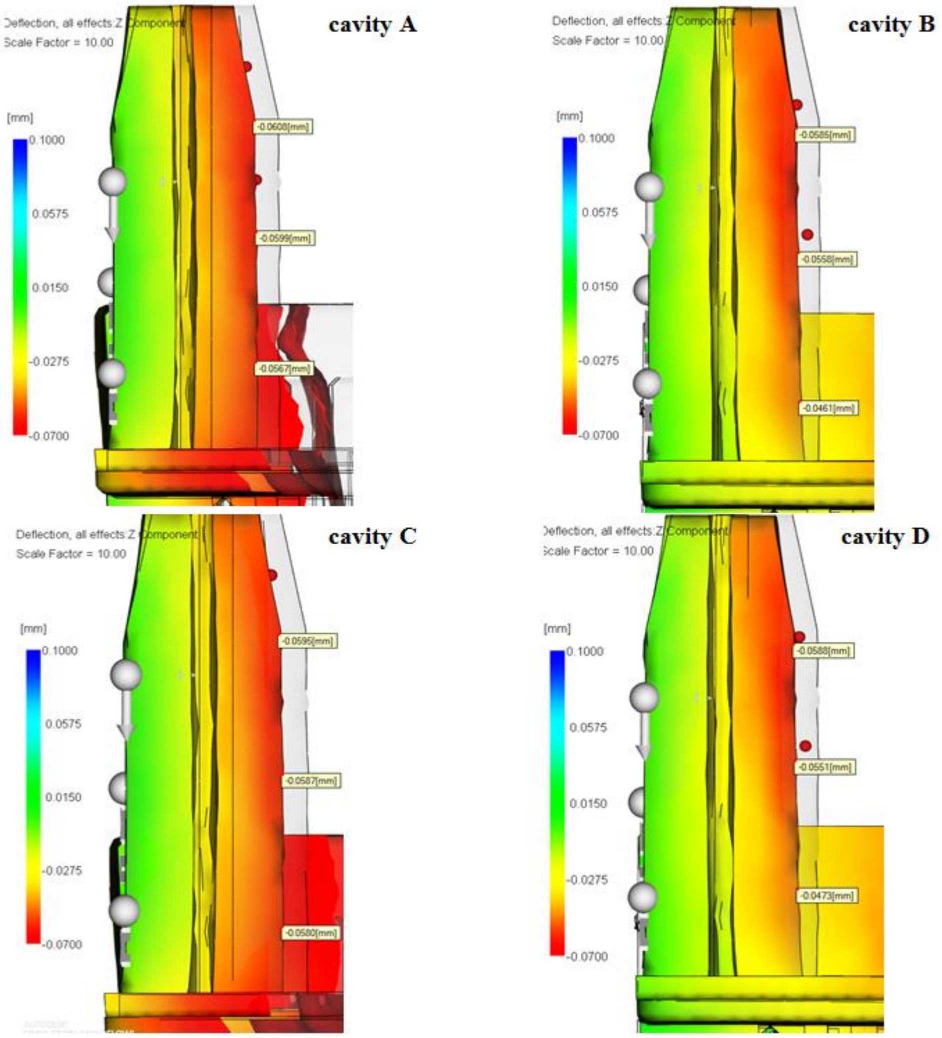

Fig. 10. Distortion of slider side regarding to anchor plane (visualization 10x magnified) [source: own study]

It is obvious from the figure 10, that the gating position (same for cavity B-D and vice-versa) has influence on the distortion value and final warpage.

4. CONCLUSIONS

The injection process is one of the most important methods of polymer processing, so he became the subject of a comprehensive analysis using specialized engineering software CAD/CAM/CAE. The simulation of the temperature distribution and polymer flow in the channels and the cavity mold and cooling conditions affecting the change in the size, shape and deformation of an injection molding part is essential both to modify the same compact structure and proper design of the mold, which is one of the most expensive processing tools. The ability to analyze the injection molding process in the form of the computer simulation allows to optimize the process parameters, the geometric features of an injection molding part with injection mold and the best selection of materials and processing equipment having suitable properties (e.g. volume and weight of the injected polymer, injection pressure, clamping force closing of the mold). The results of the simulation of the injection molding process is influenced by many factors, including detailed description of material properties, accuracy of models, molds and runner system, and the type and characteristics of the mathematical model describing the phenomenon subjected to simulation.

In this paper a problematic of warpage evaluation was described. Evaluation of molding warpage with “best fit” technique is relatively easy and does not place great demands on the skills of Autodesk Simulation Moldflow Insight (ASMI) users. However if there is a need to check the warpage results for exact inspected dimensions the anchor plane must be used. Defining an anchor plane expect Autodesk Simulation Moldflow Insight (ASMI) user with higher skill level. On the sample of “terminal box” molding was a warpage of inspected dimension evaluated.

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