

AUTOMATED EXTRUSION DIE DESIGN INTEGRATED WITH SIMULATION OF MATERIAL FLOW

Nikolay Biba^{1*}, Sergey Stebunov², Andrey Lishny², Alexey Duzhev²

¹Micas Simulation Ltd., 107 Oxford Road, Oxford, OX4 2ER, UK, micas@qform3d.co.uk

²QuantorForm Ltd. 115088 P.O. Box 74, Moscow, Russia, info@qform3d.com

*Corresponding Author

Keywords: extrusion, aluminium, simulation, dies, weld, design, profiles

Abstract. After years of intensive development the numerical modelling of extrusion has reached a certain maturity and practical applicability. An essential requirement for effective extrusion simulation is the availability of reasonably good quality 3D CAD models of dies however many die makers still produce their products using 2D drawings and do not have not full 3D models of them. To bridge the gap between requirements of simulation and limitations of industrial practice a new automated system of 3D die design has been developed. This system not only speeds up the creation of 3D models of the dies but also has an interface to simulation software QForm-Extrusion that provides rapid analyses of the material flow in newly developed dies and allows improving the design by virtual corrections before actual manufacturing. The paper presents basic principles of this approach and an industrial case study that illustrates all stages of such combined die design and simulation procedure.

Introduction

Our previous works on development and practical implementation of extrusion simulation have shown that obtaining of accurate results for complex shape thin profiles requires taking into consideration many parameters of the process. Our numerical model is based on Lagrange-Euler approach. The simulation starts in Euler domain that represents the space that is completely filled with the material prior to the start of the process. On the other hand the free end of the profile is represented by Lagrange model and this part of simulation domain increases its length beyond the die orifice. The simulation is capable of predicting this undesirable shape deterioration and finding ways to minimize it. Validation of the model has been performed for prediction of load, material flow pattern, profile temperature and die deformation using special model experiments and numerous industrial case studies [1]. Comprehensive analysis of the program accuracy has also been done within the International Extrusion Benchmark Tests in 2007, 2009, 2011 and 2013 by means of comparison of the simulation results with precisely measured experimental parameters.

The next step of development of our simulation model was introducing of mechanical coupling of material flow with die deformation. As it was shown in our works [2] the displacement and distortion of tool surfaces in some cases may have significant influence on the material flow. There are fine inclinations of bearing surface that may vary within just a few angular minutes and create local zones with choke or relief caused by die deformation. Though small, such bearing angle variation may have considerable influence on the material flow patterns. Moreover, due to elastic deformation of the tooling set, a mandrel may move in

a transverse direction that affects the accuracy of the actual profile shape and also significantly influences the material flow.

Meanwhile when we consider material flow coupled with die deformation we face some difficult problems. Relative linear displacement of the opposite sides of the bearing may reach half a millimeter or more that is actually comparable with a profile thickness. When the opposite bearing sides shift due to elastic die deformation, the tiny finite elements within the profile inevitably become critically distorted and further use of the initial finite element mesh in the material flow domain becomes impossible. In our model this problem is solved by automatic remeshing the simulation domain to provide best mesh quality during iterations in the coupled simulation when the die and mandrel are flexible [3].

After achieving very accurate predicting of material flow we expected high demand from the industry for our simulation software. Unfortunately we faced some practical obstacles preventing wide spread of simulation among die making and extrusion companies. Many die makers still develop their products using 2D drawings and do not have full 3D models of them. Moreover not every CAD model of a die can be successfully meshed. Only a sound solid body with exact fitting of surfaces can be used for mesh generation. The gaps between adjacent surfaces or overlapping surfaces in a model actually make mesh generation virtually impossible. In this case the model should be manually repaired using special programs for cleaning up the geometry that sometimes takes longer time than the simulation itself.

In this situation it is quite natural to make the next step and develop the software tool for creation and modification of die geometry and combine this software with simulation for virtual “error free” die design. With this in mind we have developed a system called QForm-Extrusion Die Designer (QExDD) that automates the die design routine and significantly speeds up the process of developing new dies. It also automates creation of 3D die models from existing 2D drawings. This system has been developed as OEM application powered by SpaceClaim. This QExDD system has a special interface to QForm-Extrusion software for data exchange in both directions that make joining their work seamless and easy. This system starts with 2D draft of the profile to which we add contours of pre-chamber, backer opening and a set of straight lines specifying location and direction of the webs (Fig. 1. a)

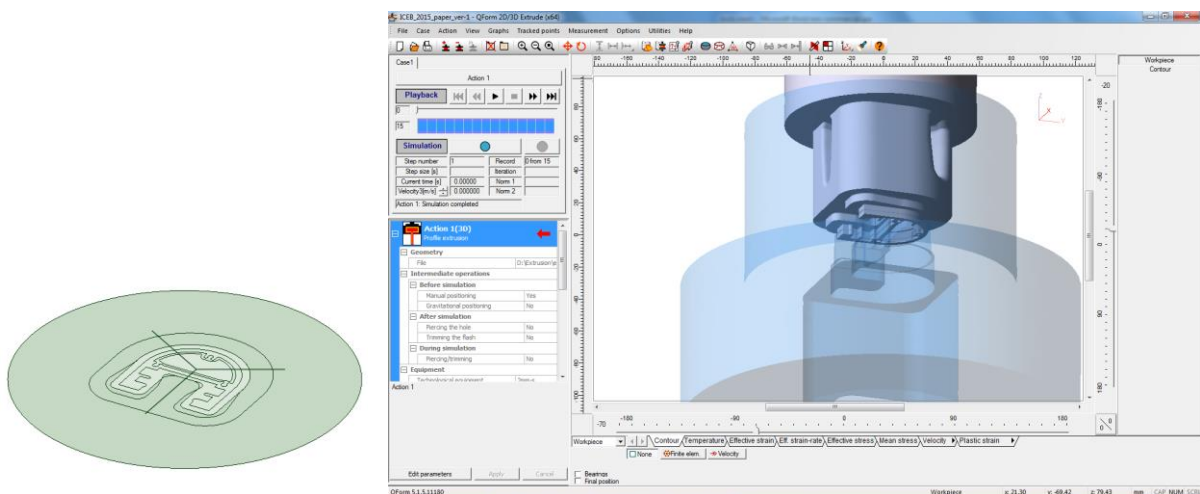


Fig. 1. 2D drawing of the profile with additional contours (a) and the model of the die set after creating it in 3D and transferred to simulation (b).

Case study: Die design development with QExDD system

QExDD is a system of parametric design of extrusion dies for solid and hollow profiles produced from aluminium alloys. QExDD was developed as OEM application in the environment of CAD system SpaceClaim belonging to ANSYS. This CAD implements an idea of direct modelling. This system enables creating, editing or repairing die set geometry. A 3D model of the die set created in QExDD can be transferred to simulation and virtual extrusion trials through special interface and finally it can be used by any CAM system for die set machining.

The die is the main element of any tool set so parametric design procedure starts from the die. To build the die we need an external contour of extruded profile, a pre-chamber contour and an outer contour of the die cap. Then using a special control panel (Fig. 2a) and the drafts of the contours (Fig. 2b) in few sequential steps we can specify all parameters and finally get a 3D model of a die (Fig 2c).

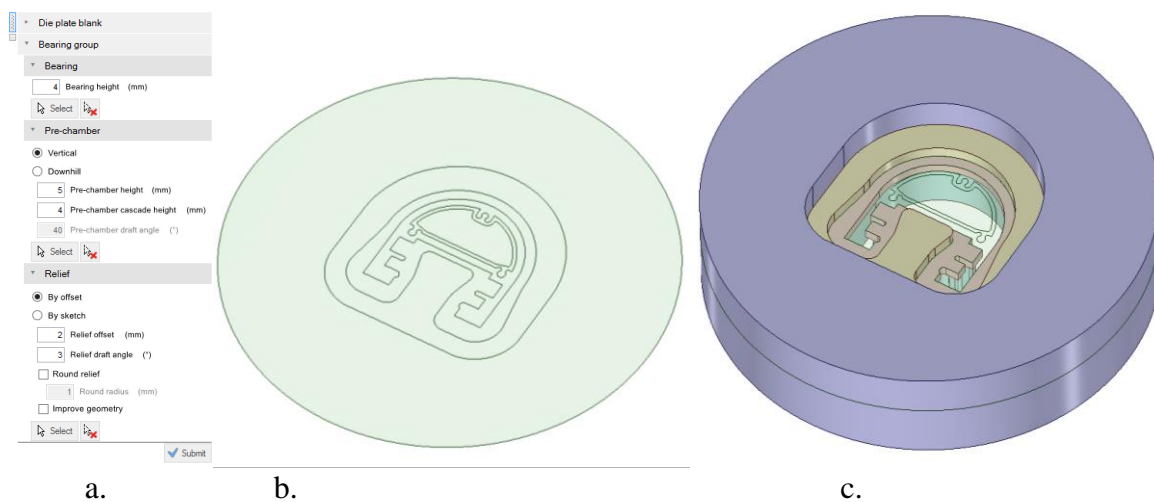


Fig 2. The control panel for creating a die block (a), 2D set of the contours specifying a die configuration (b) and a set of 3D solid bodies representing different parts of the die block (c)

The second stage is a mandrel parametric design. It requires an internal contour of an extruded profile, external contour of the mandrel, a die cap and the set of lines that define web locations. These lines coincide with middle lines of the webs (Fig. 3b). To speed up the work several webs may be created concurrently as a group if they have identical shapes and sizes. After selecting a central web line and typing the parameters of the web design in a control panel (Fig 3a) we can see a preview of our design (Fig 3c). Similarly we make the solid model of the backer using its inner and outer contours and proper values of parameters.

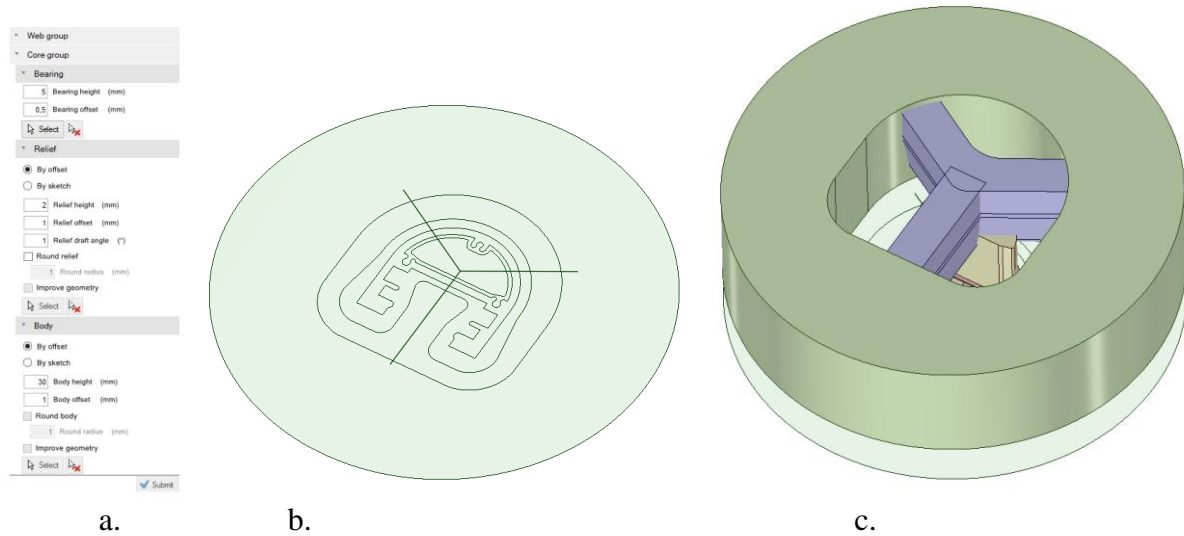


Fig. 3. The control panel for mandrel creation (a), web lines over 2D drawing (b) and the mandrel block with webs and core as 3D solid bodies (c).

During parametric design QExDD also provides automatic creation of the relief that is based on using the profile contour and some parameters like relief contour offset and its draft angle. The program has also a bearing editor for creating bearing length variation. Moreover the program can create the bearing design automatically. This method is based on some empiric rules. The bearing length varies according to the profile thickness, the distance to the geometric die center, size of adjacent porthole and pre-chamber in a specific point. Of course, bearing configuration created at the stage of design is a preliminary guess but it provides very good starting point for further bearing optimisation that is based on results of material flow simulation as shown later in this paper.

All created solid parts are to be merged together forming a die and a mandrel. In the mandrel all necessary fillets are to be added making smooth conjunctions in a web area. Finally we get a solid model of the die set as shown on Fig. 4b.

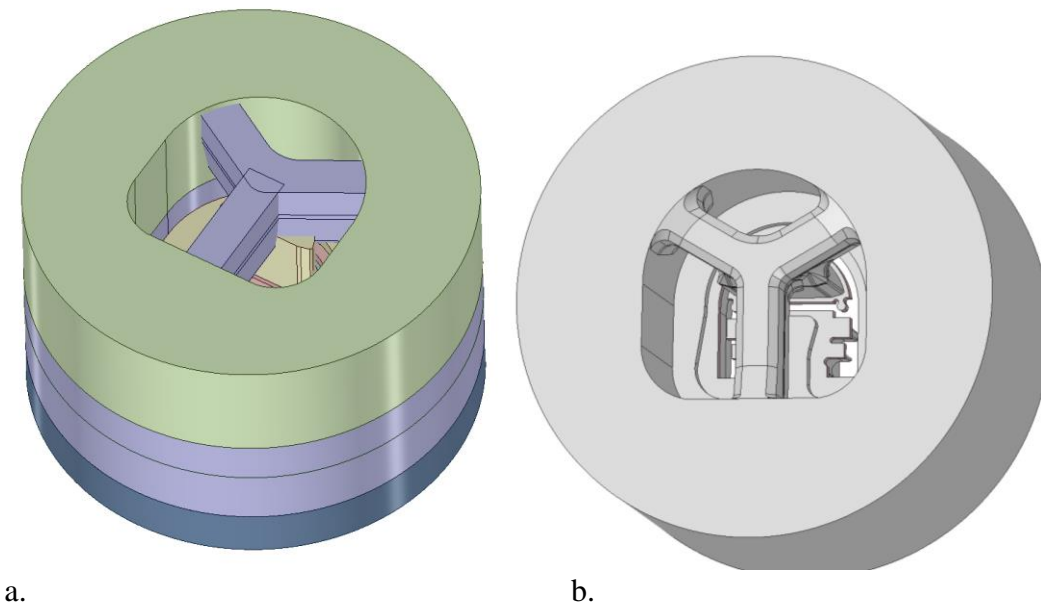


Fig. 4. The mandrel with webs and core and the die plate and backer as separate solid bodies (a); a complete tooling set as a single solid body ready to be for transferred for simulation (b).

Case study: die design improvement by means of simulation

The last step of the design work is saving the solid model of tooling set (Fig. 4b) in a special format and its automatic transfer to QForm-Extrusion for further mesh generation and simulation. The mesh generation is performed in QShape module where the model of material flow domain is also created. The material flow domain fills the inner space of the die and container including bearing area. The bearing configuration created in QExDD comes together with the die model and it is shown as a 3D curve placed on surface of an initially straight bearing (Fig. 5). On this picture in a special window of Bearing Editor we see the graph of bearing length drawn along the profile perimeter. Such presentation allows clear visualisation of the bearing and the bearing can be modified using built-in facilities without returning back to CAD system. The final modification of the bearing design can be saved as an IGES file to be used for the die manufacturing.

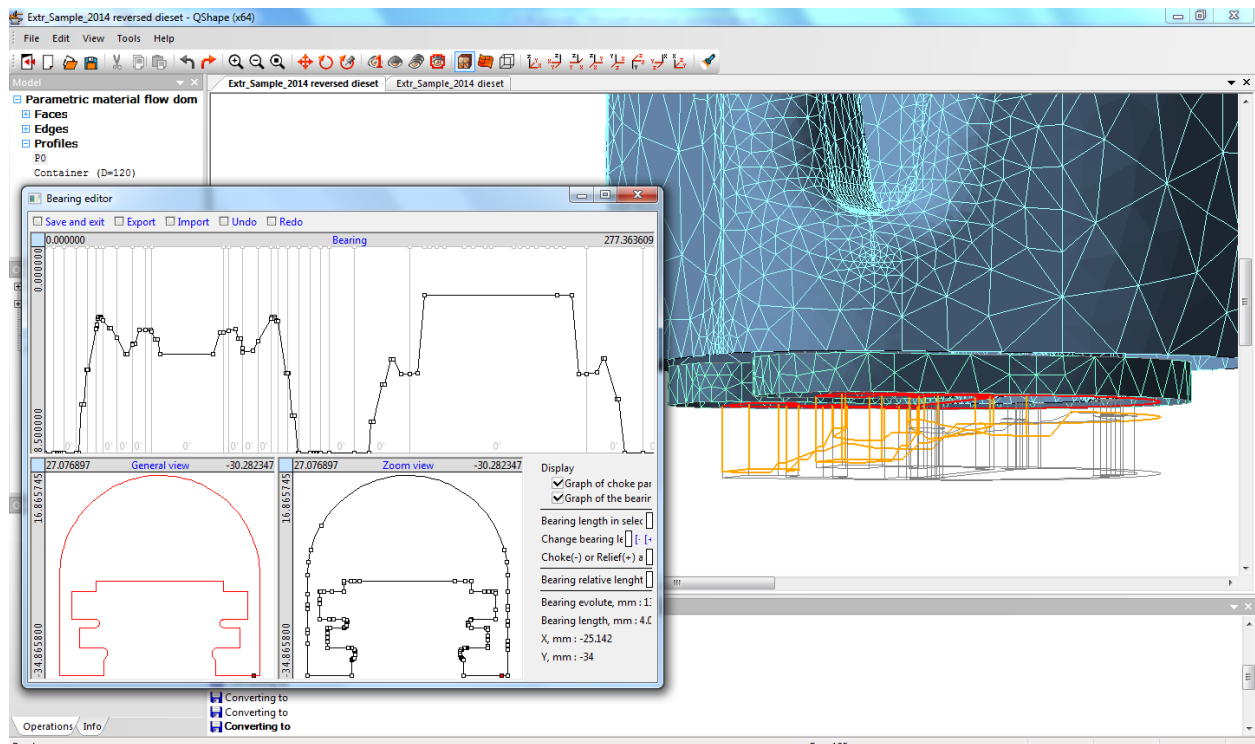


Fig. 5. Parametric representation of the material flow domain with the curve of bearing length placed on the bearing surface (on the right) and a drawing of the bearing as a graph along its perimeter (on the left).

The other process parameters have been specified as following: material AA6061, billet temperature 450 C, die temperature 400 C, ram velocity 5 mm/s. After the first simulation attempt we see that the material flow in the “legs” of the profile is much faster than in its rounded side (Fig. 6). Such large disproportion can be explained by too much material going from the portholes to the leg parts of the profile. It is clear that the initial design is unsuccessful.

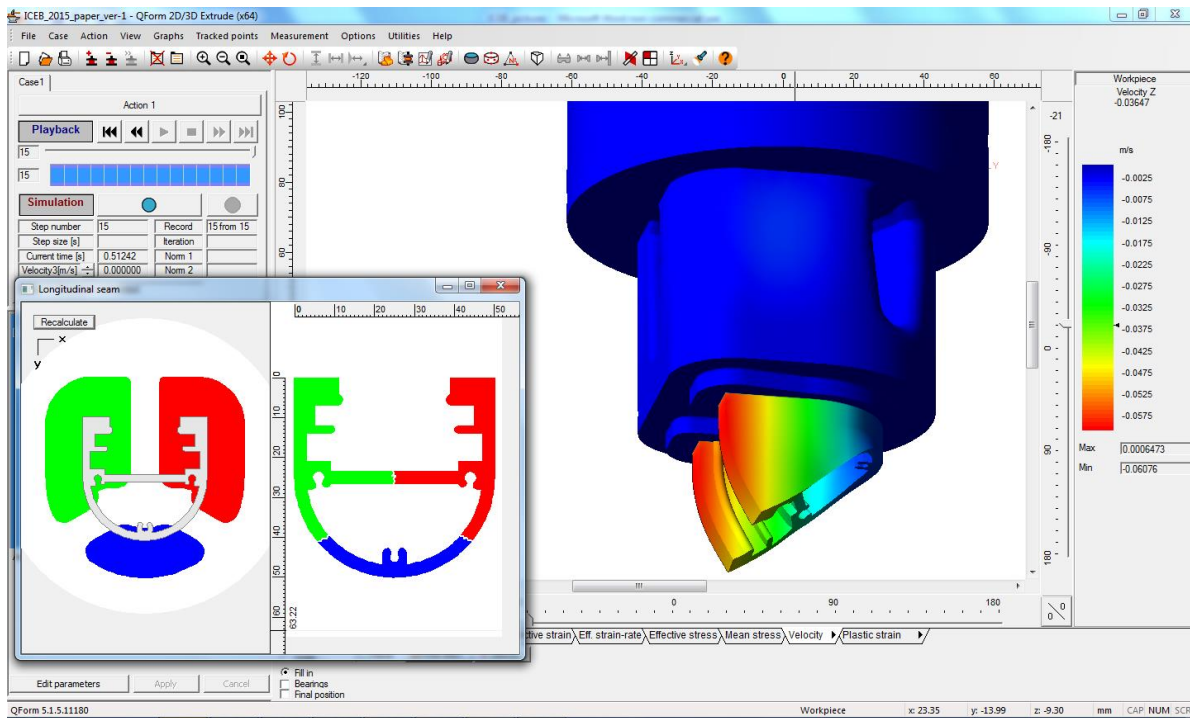


Fig. 6. The material flow obtained with the initial porthole design. The location of portholes over the profile and seam welds location are shown in boxes in lower left corner.

Let us change the location of the webs to reduce the amount of the material going to these legs areas. We just need to rotate the lines that specify the location of the webs as shown on Fig. 7a. Then by re-playing all subsequent steps of the design process we get solid model of the die set with opposite orientation of the webs (Fig. 7b) and respectively its finite element model of material flow domain (Fig. 7c).

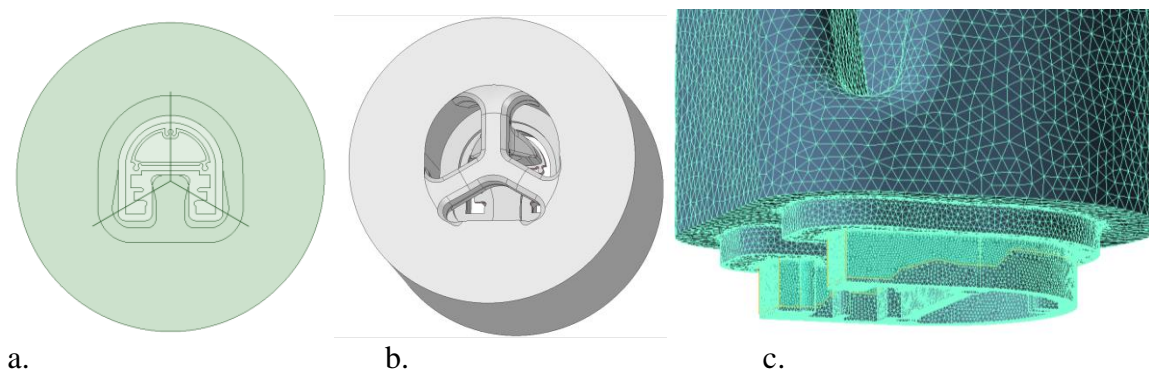


Fig. 7. Second variant of the web design presented as a drawing (a), as a complete 3D model (b) and as a material flow domain with the mesh ready for simulation (c).

After the simulation of this second design variant we have got more balanced material flow as shown on Fig. 8. Even though the legs of the profile still go faster than its rounded side now such velocity variation can be eliminated by proper modification of the bearing. As we see from the drawing of the bearing there is no way to increase the bearing length in the legs area because it is already long enough and its further elongation will not be effective. A more effective method is to apply a choke to these areas and this modification has been implemented on outer surfaces of the legs where it is easier to make (Fig. 9a).

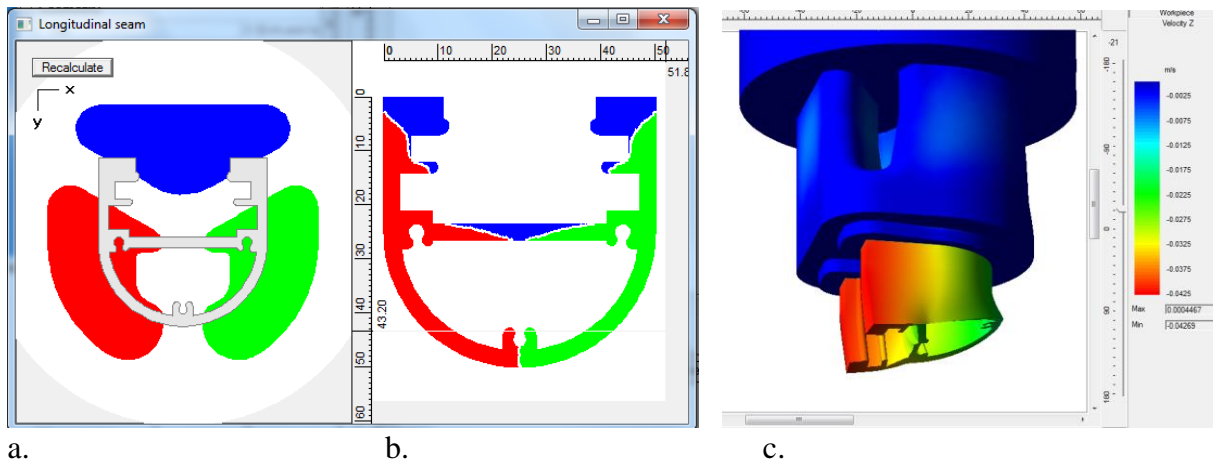


Fig. 8. Second variant of porthole design: the portholes placement over the profile (a), seam welds locations (b) and material flow pattern and velocity distribution (c).

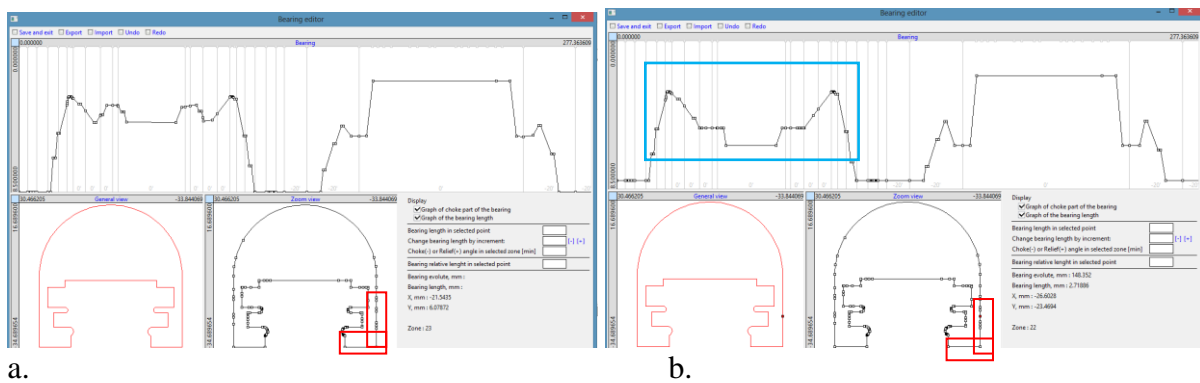


Fig. 9. Bearing design as it was generated by QExDD but with choke angle applied to the legs area within red boxes (a) and modified bearing design after the third simulation attempt (b)

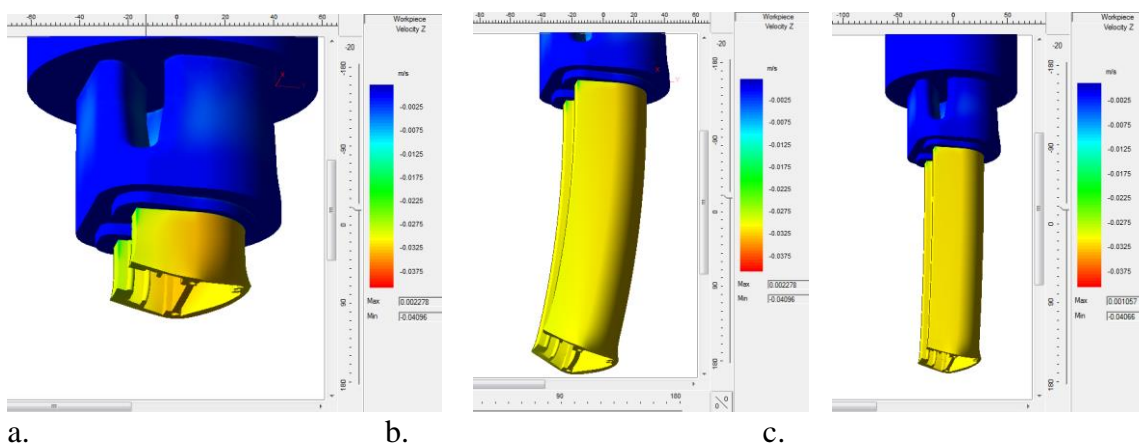


Fig. 10. The material flow after implementing of choke in the legs area as a third attempt of simulation: beginning of material flow (a) and extending of the profile (b); forth simulation variant with bearing design as on Fig. 9b (c).

Running the simulation with this modified bearing design we immediately see the effect. At the beginning of simulation the legs and the rounded part of the profile flow with the same speed while the inner profile web goes slightly faster (Fig. 10a). To be sure that the design is

really effective we proceeded with the simulation for a longer length and found that the profile has a slight bend towards the legs (Fig. 10b). That is why one more tuning of the bearing has been done as shown on Fig. 9b in the area highlighted by blue box. Then finally the material flow has become straight that is clearly seen even with extended profile length (Fig. 10c). It is important to notice that all simulation has been done in coupled mode that means that the material flow has been simulated concurrently with the deformation of the die and the die deflection. The axial displacement of the die is shown on Fig. 11a while Fig. 11b presents the bearing area with distribution of the angle due to its inclination. The distribution of the effective stress in the die crosscut is shown on Fig. 11c.

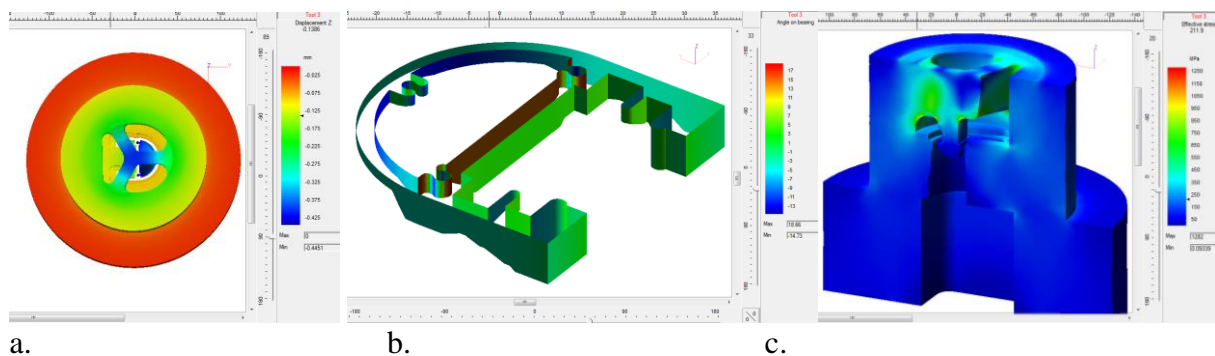


Fig. 11. The axial displacement distribution on the die (a), bearing inclination due to deformation (b) and effective stress distribution in the die (c)

Conclusions

1. Practical implementation of extrusion simulation has shown that it provides good accuracy of the results in terms of material flow, load, temperature and die stress.
2. The lack of good quality 3D die models prevents widespread implementation of simulation software for the needs of die making.
3. To speed up 3D die design and bridge the gap to simulation a special software system QExDD has been developed.
4. The effectiveness of the method of automated die design combined with simulation has been illustrated by an industrial case of hollow profile with massive legs.
5. In four iterations the die has been created and successfully modified to provide perfect straight material flow.

References

- [1] S. Stebunov, A. Lishnij, N. Biba, Development and industrial verification of QForm-Extrusion program for simulation profile extrusion in Proceeding of International Conference on Extrusion and Benchmark, Dortmund, Germany, 2009, pp. 41-42.
- [2] S. Stebunov, N. Biba, A. Vlasov, A. Maximov, Thermally and Mechanically Coupled Simulation of Metal Forming Processes in Proceedings of the 10th International Conference on Technology of Plasticity, Aachen, Germany, 2011, pp 171-175.
- [3] N. Biba, S. Stebunov, A. Lishnij, Simulation of material flow coupled with die analysis in complex shape extrusion, Key Engineering Materials, Vol. 585 (2014), pp. 85-92.