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THE EXPERIENCE OF QFORM PROGRAM IMPLEMENTATION TO THE TASKS OF METAL FORMING SIMULATION IN INDUSTRY, EDUCATION AND RESEARCH

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Стаття підсумовує досвід розробки та реалізації програми Q–Form для моделювання задач обробки металів тиском. Підкреслено значення зв'язку моделювання течії матеріалу із вигином волоки(штампу), напруженнями та температурою інструмента. Дослідження даного випадку ілюструє використання моделювання для усунення дефектів матеріалу, економії матеріалу та збільшення строку використання інструмента. Вбудовані програмуючі пристрої дають можливість створювати моделі конкретного матеріалу для вивчення впливу мікроструктури на течію матеріалу та властивості виробу, що дуже важливо у сфері дослідницької діяльності. Програма User friendliness придатна для використання в навчальному процесі при підготовці студентів.
Ключові слова: *крайова задача, граничні умови, методи вирішення*.

The paper summarises experience of development and implementation of the program QForm for the tasks of metal forming simulation. The importance of coupled modeling of the material flow with die deflection, stress and temperature in the tools is emphasized. The case studies illustrate the use of simulation for elimination of material flow defects, material saving and extending tool life. Built in programming facilities provide possibility to create specific material models to study the influence of microstructure on the material flow and product properties that is very important in the field of research. The program user friendliness makes it suitable for students training that helps education.
Key words: *boundary value problem, boundary conditions, solution methods.*

Introduction. QForm metal simulation software project started more than 25 years ago is a lucky example of successful development both in technical and commercial aspects [1]. During its long history it has passed through several "reincarnations" when not only its functional has been extended but its the most fundamental features as data structure, architecture and numerical methods have been revised and drastically changed. Now it is more than just a program for simulation of bulk forging processes as it was started but it is more like an environment where any kind of technological metal forming problems can be simulated, analysed and even designed. Advanced users can enjoy possibility to build their own models of material behaviour by programming them in QForm because it possesses its own built-in compiler and debugger that make such work extremely fast and effective. Nowadays besides of traditional forging applications, QForm is widely used for many very special technologies as profile extrusion, shape and ring rolling, electric upsetting, incremental forming, heat treatment and others.

QForm is based on a novel concept of combination of Finite Element Method (mechanical problem) and Voronoi Cells (thermal problem) that provides fast and robust solution of coupled thermomechanical problems in the most complicated cases of large plastic deformation. The material model can be either rigid-visco-plastic or elastic-visco-plastic depending on the problem specifics. The advanced algorithms can provide coupling of the billet deformation with deformation and temperature in the dies and even with any press or other forming equipment. Coupling of the material flow also may include the dependence of the flow stress on microstructural parameters (for example, grain size) and vice versa. Clear and logically seamless interface makes QForm well accepted by practical industrial users and universities. The latter ones use it both for students training and research projects where its built-in programming facilities provide vital opportunities for creating novel numerical models of metals technology. Let us consider several typical examples of QForm implementation for industry and research.

Industrial implementations. When used in forging industry, QForm software allows detecting of defects in the body of forged pieces, such as flow-through defects, laps, underfill of die impression, flowing of excess metal on the die face, fracture caused by exhausting the resource of plasticity, positioning and buckling problems. The location of fibers and application of loading may be correlated at the design phase to avoid problem areas with undesirable macro- and microstructure, which is essential in the development of forging technologies for critical parts with the differences of heights and thicknesses through the body of detail.

Let us consider the forging example of piton-belay part Pivot for climbing from the DMM company, Llanberis, UK [2]. The flow-through defect, stroked with a marker (Fig. 1), has observed into the body of forged piece while using the initial forging technology.

Figure 1. At the top – is the photo of finished part, below – is the photo of the part forged by the initial technology. The defect location in the forged part is circled in black marker (courtesy of DMM)

The exact location of the defect found by simulation of the technology in the QForm software using a special field in the program and undersurface Lagrangian flow lines – tools for detecting of this type of defects. The simulation results are presented in Figure 2 and have shown clearly that undersurface flow lines are penetrating deeply from the surface into the body of forged piece, which is indicating the defect formation. The most likely areas of defect formation in forged pieces of complex 3D geometry are easily identifying visually using a special field (Figure 2, on the right) with the following checking out with undersurface Lagrangian flow lines that presented in Figure 2, on the left.

The cause of this defect has identified as the result of specific features for detailed technology analysis and metal flow visualization. The defect of initial technology has eliminated after several iterations of tool geometry refinement. It has verified by simulation of the optimized forging technology in the QForm software. Moreover, the volume of the workpiece has reduced by 20 % through downsizing of its diameter, which is an important aspect of cost reduction during the development of batch production technology.

The comparative analysis of the initial and optimized tool geometry presented in Figure 3. It has established that metal flow at the end of forging operation has changed due to modification of the tool central part of the instrument and metal did not flow in the opposite direction (see Fig. 4).

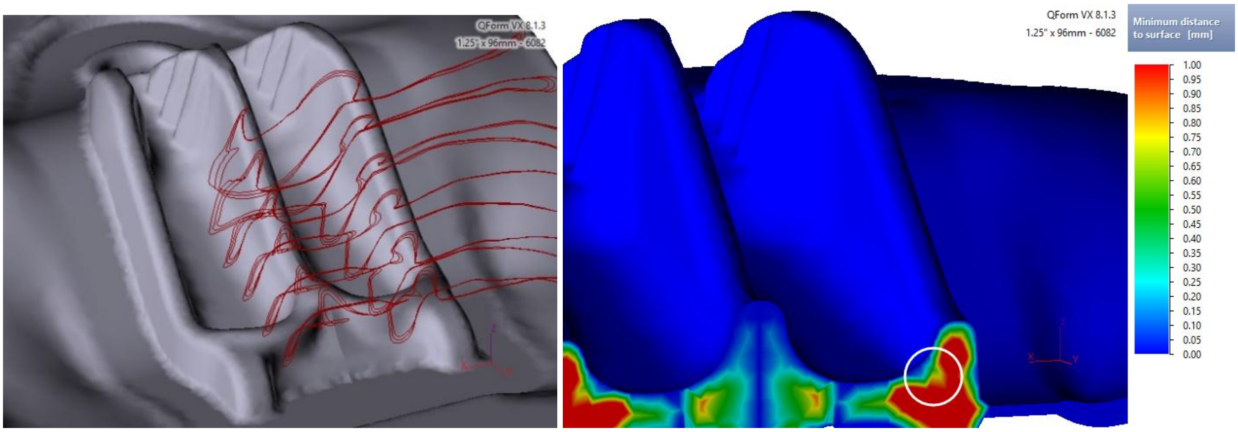

Figure 2. Simulation results: on the left – are near-surface lines, on the right – is a special field for crack detection in complex-shaped forged pieces

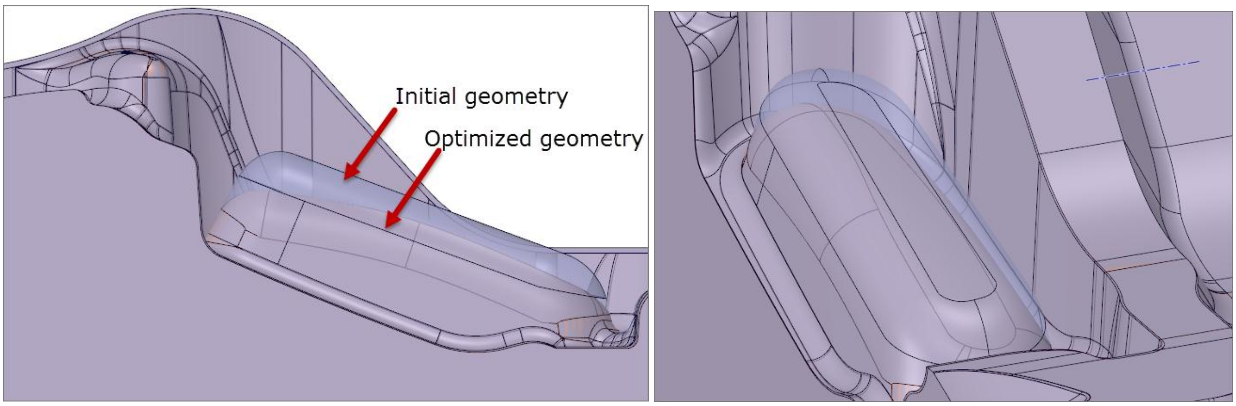

Figure 3. The comparative analysis of the original and optimized geometry of the below tool. The initial geometry is marked in blue transparent colour, optimized geometry – purple colour

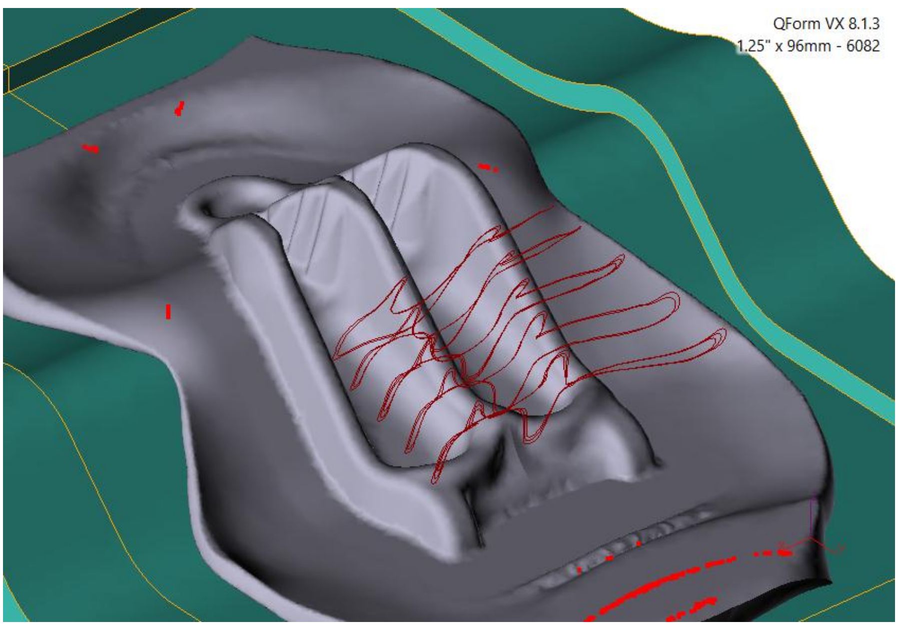

Figure 4. Simulation results for the optimized technology – there is no defect, the volume of the workpiece has reduced

The simulation results for optimized technology (Fig. 4) demonstrated the complete absence of the defect: undersurface flow lines are not penetrated deeply into the body of forged piece. Production by improved technology confirmed that parts have no defect appeared in the case of using initial technology.

Research implementations. Incremental forming processes can be performed in cold state and provide finish parts that do not require further surface machining. Meanwhile there are many questions regarding the process parameters that provide stable and repeatable technology. The implementation of numerical simulation may help in this task but firstly it is necessary to find the best method for adequate simulation of the incremental deformation. To find out what kind of the material model is to be implemented, the research has been accomplished. The scheme of the process is shown in Fig. 5a. The simulation has been performed using elastic-plastic model for a cold steel tubular billet having elastic module $E = 2 \cdot 10^5$ MPa and yield stress $\overline{\sigma} \approx 500$ MPa (Fig. 5b). For comparison, the same process has been simulated with the rigid-plastic model (Fig. 5c) and elastic-plastic model [3] but using material with significantly reduced yield stress $\overline{\sigma} \approx 50$ MPa that is similar to hot deformation (Fig. 5d). As we can see from the figures in case of rigid-plastic material model the billet deforms only locally while the elongation is practically absent. In case of reduced yield stress, even while using elastic-plastic model, the elongation exists but it is still very small.

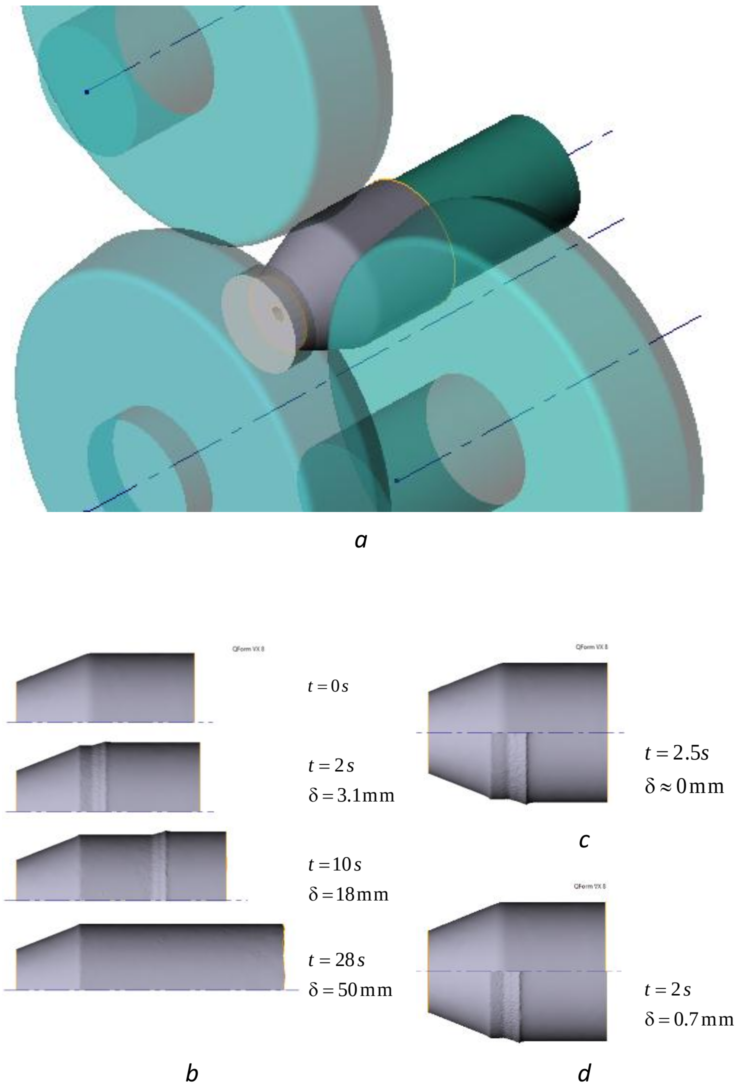

Figure 5. Scheme of flow forming (a) and the product shape at different stages of the process with the elastic-plastic material (b), rigid-plastic (c) and elastic-plastic model with reduced yield stress (d) (t is the process time, δ is the product elongation)

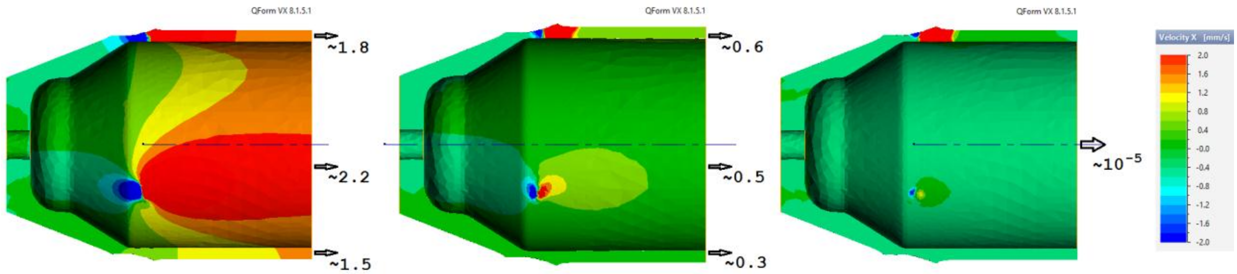

Figure 6. Distribution of axial velocity (mm/s) in the billet using the elastic-plastic material model with $\bar{\sigma} \approx 500$ MPa *(a) and* $\bar{\sigma} \approx 50$ MPa *(b) and the rigid-plastic material (c). Arrows show approximate velocity values in the points at end of the billet*

Presented example shows that the material reacts differently to local deformation depending on the material model. Fig. 6 shows the distribution of the axial velocity for three different material models. It is clear that well developed elastic strain causes displacement quite far from the local deformation zone that then is fixed by plastic deformation. On the other hand, in the rigid-plastic model, the deformation does not spread beyond the contact zones and the billet does not elongate at all (Fig. 6c). In the case of small yield stress, the elastic deformation is also small and may cause only very limited elongation (Fig. 6b).

Due to limited size of the paper here we cannot present more examples of QForm implementation in industry and research. More examples and related publications can be found at [1].

CONCLUSIONS

Two presented above case studies show that depending on the task QForm can be implemented as a practical tool for the technology development in conditions of mass production and for the research purposes when the applicability of the model itself is to be firstly proved. In both cases the results can be obtained fast and easily thanks to robust numerical model that works reliably for big variety of processes.

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