Simulation-Driven Design for Metal Forming Processes: Advancements, Case Studies, and Future Perspectives

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Abstract:

Metal forming simulation has taken the processes of the analysis and improvement of metal forming processes to the next level, providing accurate predictions of the finish product shape, possible defects, stress and strain distributions in workpieces and tools, temperature, load and other critical parameters. However, finding out an optimal preform design and the best forging parameters still relies on engineers' expertise. To make the development process faster, a simulation-driven design has emerged as a promising methodology, enabling the automated design of preforming tools starting from the 3D geometry of the finish forging dies. It is based on the use of the equipotential surfaces as an approximation of the preform shape and further creating of the preform dies. The paper presents special QForm Direct software and, through a practical case study, demonstrates how the industry can move from traditional trial-and-error methodologies to a more automated, precise, and cost-effective approach.

Keywords: hot forging; preform design; FEM; QForm; simulation, tools, preliminary dies

INTRODUCTION

Metal forming is a complex manufacturing process that involves the deformation of metal workpieces to achieve the desired shape. Traditionally, the development of forming technologies heavily relied on empirical methods, often leading to time-consuming and costly trial-and-error attempts. However, the advances in metal forming simulation have transformed how engineers approach process design and optimization.

Simulation tools provide invaluable insights into the behaviour of materials during forming, enabling engineers to predict and evaluate various process parameters. This allows for the virtual exploration of different design alternatives, minimizing the need for physical prototypes and reducing development time and costs.

Nowadays many forging companies use FEM simulation software to avoid defects in the developed technologies. Currently, it is a vital tool to be able to compete in this market. While simulation has been widely adopted in the metal forming industry, the challenge remains in determining the optimal technology at the stage of its design. Particularly difficult to develop the preform (blocker) tool designs to achieve defect-free in complex shape closed die forging technology.

This paper presents the principles and capabilities of QForm Direct, focusing on the concept of simulation-driven design in metal forming processes. The software solution was specifically developed for the purpose of automated preform die design. Together with the QForm UK simulation software it not only predicts material behavior and process outcomes but also guides the design of forging dies. Utilizing case studies from the industry, we illustrate the potential of this approach to enhance process efficiency, reduce material waste, and avoid surface defects.

THE FUNCTIONALITY AND APPLICATION OF QFORM DIRECT

QForm Direct is based on the method of equipotential surfaces for forging preform design. This methodology uses a potential flow approximation derived as solutions of the Laplace equation [1]. The method is based on the assumption that the preform shape in metal forming processes plays a vital role in determining the final quality of the product. The theoretical background and historical overview of the method implementation in metal forming can be found in [2]. QForm Direct utilizes the equipotential surface approach that is related to a hypothetical ideal flow of incompressible material with no rotational velocity vector component, which would otherwise lead to the formation of laps or folds [3]. This approach ensures more uniform metal flow, reducing defects and making it easier to fill a finished die completely. The method also helps to fill the dies with minimal flash and reduces forming load and avoids flow defects like laps and flow-through.

One of the key features of QForm Direct is the semi-automatic design of preliminary forging impressions. The software also allows automated geometry data transfer to QForm UK simulation software saving significant time and resources for the simulation preparation. In addition, it enables more automation in 3D die geometry design and its optimization, which promises further advancements in the field.

The application of QForm Direct is versatile and covers both cold and hot closed die forgings. Special algorithms of QForm Direct generate near-optimal preforming dies surfaces in an automated way based only on the geometry of the finish dies. An engineer is still responsible for the correct design of the finish dies and flash gutter geometry.

QForm Direct has been successfully implemented for the design of forging impressions for axisymmetric and complex shape parts and even in the optimization of the manufacturing process for gear sectors. In each of these applications, QForm Direct has consistently demonstrated its effectiveness in reducing material waste, lowering forging loads, and improving the overall quality of the finished product while the development of the optimal preforming tools design was automated and significantly speeded up compared to traditional manual design.

Traditionally, the design of preform shapes relies heavily on trial-and-error methods, which can be both time-consuming and resource-intensive. However, with QForm Direct, engineers can design the optimal preform shape through a simulated environment, reducing the need for in-metal tests and resulting in significant cost and time savings.

SIMULATION-DRIVEN DESIGN IN METAL FORMING:

THE USE OF EQUIPOTENTIAL SURFACES:

Hot closed-die forging leverages equipotential surfaces for optimized preform shape creation, a strategy central to QForm Direct's simulation methodology. These surfaces, derived from potential flow approximations, initiate a preform design process that prioritizes uniform die filling and minimizes flow defects.

The versatility of QForm Direct was put to the test in developing a hot forged arm preform shape. The software was used to create preforming dies, and the simulation showed no laps in the preform and complete filling of the die cavity. The resulting dies were manufactured and test, producing a high-quality finished part. [4]

OPTIMIZATION OF TECHNOLOGICAL PARAMETERS:

The simulation-driven design extends far beyond predicting material flow and reducing defects. It also allows for optimising various technological parameters, leading to a more efficient, productive, and cost-effective metal forming process. QForm UK, with its robust API, offers comprehensive solutions in this regard.

The optimization of technological parameters in metal forming is a complex process due to the interdependent nature of these parameters. QForm UK's API enables the programmable control of the simulation environment, allowing advanced optimization algorithms to adjust these parameters and seek optimal forging results iteratively.

This automated approach saves considerable time and resources while improving outcomes such as die fill, load capacity, and minimizing material waste. However, the journey of simulation-driven design optimization comes with the need for advanced optimization techniques and powerful computational capabilities. Despite these challenges, it remains a promising domain with immense potential. This paper, however, focuses on QForm Direct's implementation in preform design using equipotential surfaces, saving the complex topic of parameter optimization for future exploration.

INTEGRATION OF CAD AND SIMULATION SOFTWARE:

The integration of CAD and simulation software is a key aspect of simulation-driven design. By establishing a bi-directional data exchange between the two software platforms, engineers can seamlessly transfer geometry, material properties, and simulation results. This integration enables iterative design modifications based on simulation feedback, leading to improved product quality and process efficiency.

CASE STUDY: ALUMINIUM HOT CLOSED-DIE FORGED PREFORM DESIGN

Below is an industrial case of a hot closed die forging of an aluminium automotive part. Due to the high ductility of aluminium alloys in a hot state, it is a common practice to forge even complicated shapes in one or a maximum of two operations while the first operation is usually a simple preforming like upsetting or bending. This approach was tested for the given part using numerical simulation. A round bar with a diameter of 38 mm and a length of 220 mm made of AA 6082 aluminium alloy (3.2315 DIN) heated to 520 C is used as a billet. The equipment is a 1600-ton screw press. Fig.1 shows the simulation of the bending operation (Fig.1 a,b) and finish forging (Fig.1 c,d). Even though this technology variant provides complete filling of the die (Fig. 2a), severe laps appear in the finished part. The laps are highlighted by red spots in Fig. 2b, and the flow-through defects are indicated by red zones along the part ribs in Fig. 2c.

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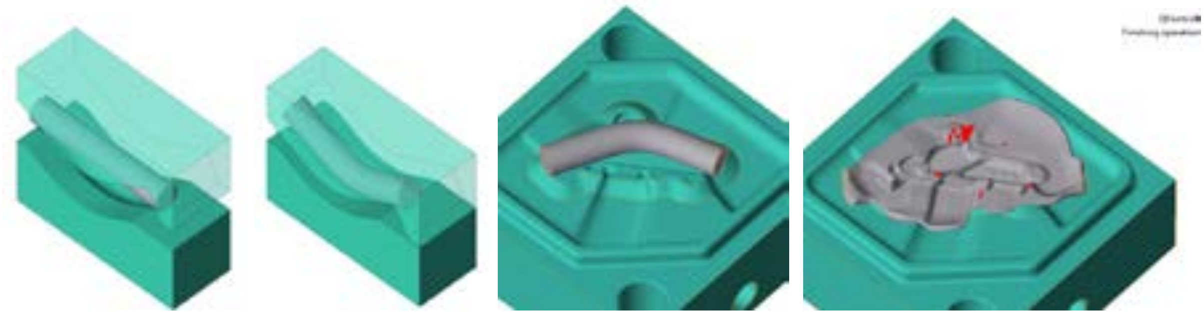
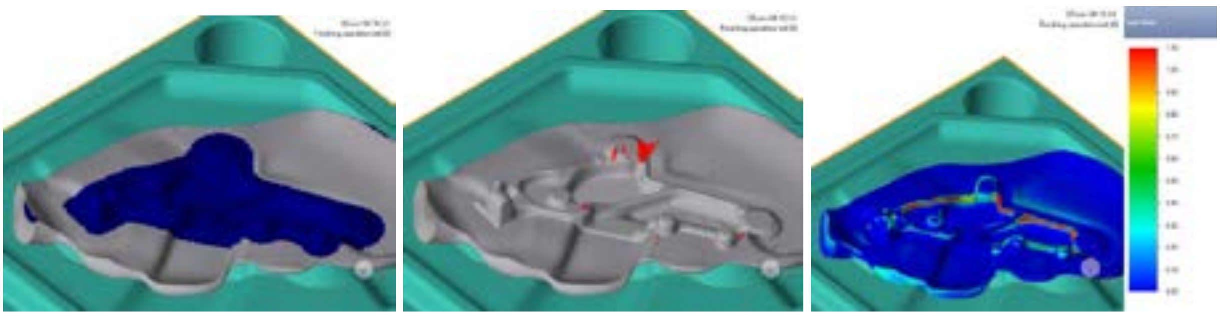


a b c d

Fig. 1. The bending (a,b) and finish forging operations (c,d) simulated in QForm



a b c

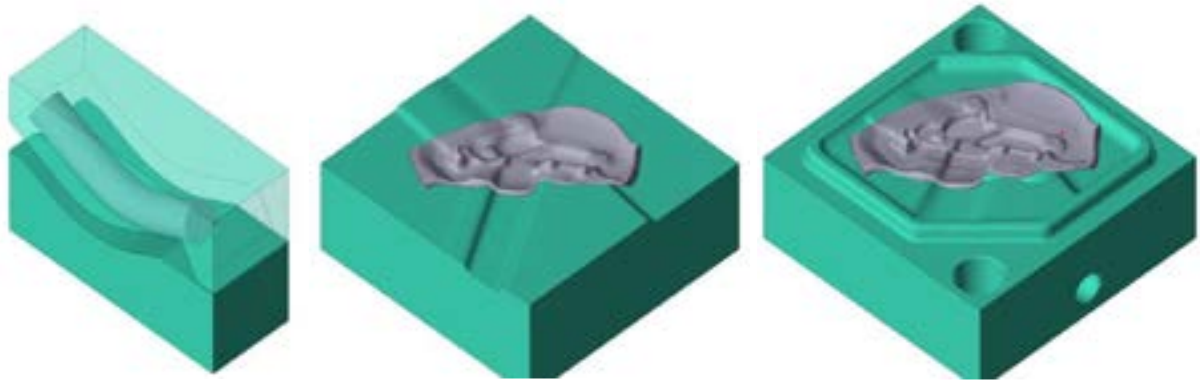
Fig. 2. The finish forging operation simulated in QForm: the die fills indication (a), laps (b) and flow-through defects (c).

Having these results, we decided to include one more intermediate operation and develop the preforming die shape using QForm Direct software. The equipotential surfaces generated by the program and used for creating preforming die cavities are shown in Fig. 3.

Thus, the modified technology consists of bending operation, preforming and final forging operations (Fig. 4). The forging sequence using this preform shape was simulated, and it did not show any defect in the finished part (Fig. 5).

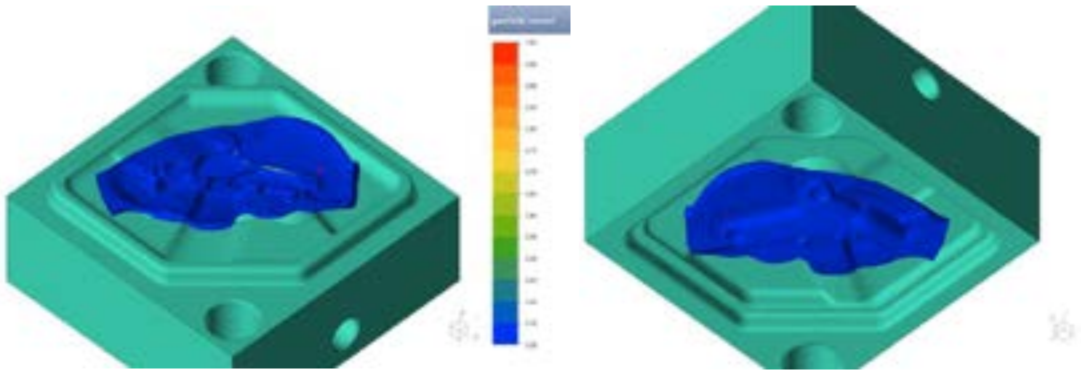
a b

Fig. 3. The equipotential surfaces generated by QForm Direct and used for the creation of the upper (a) and the bottom (b) preforming dies cavities.



a b c

Fig. 4. The bending (a), preforming (b) and finish (c) forging operations as the stages of newly developed technology simulated in QForm UK for numerical verification.



a b

Fig. 5. Flow-induced defects analysis in finished forged part. No defects on the upper (a) and lower (b) surfaces were predicted by the Gartfield indicator.

After successful verification of the modified technology by means of simulation, the preform dies were manufactured (Fig. 6a) while finish dies were left without any alteration as they have initially designed (Fig. 6b).

a b

Fig. 6. Photo of the actual upper and bottom forming dies made using the QForm Direct die geometry export: preforming (a), finishing (b).

The trial forgings have shown the perfect quality of the finished part without any defect, as shown in Fig. 7 and the technology has been used for regular production.

Fig. 7. Photo of the actual preform part top and bottom views (a, b) and finished part top and bottom views (c, d) forged using proposed technology (no material flow defects).

FUTURE PERSPECTIVES:

The simulation-driven design has already demonstrated its potential to improve metal forming processes. However, there are several areas for further development and exploration. These include:

- Advancements in multi-objective optimization algorithms to consider multiple conflicting objectives simultaneously, such as maximizing productivity while minimizing material waste or energy consumption.
- Integration of artificial intelligence and machine learning techniques to enhance the automation and intelligence of the simulation-driven design process. This includes using predictive models to suggest optimal process parameters and tool designs based on historical data and simulations.
- Incorporation of advanced material models and characterization techniques to capture the complex behaviour of modern alloys, composites, and advanced materials. This will enable engineers to simulate and optimize forming processes for cutting-edge materials accurately.
- Integration of real-time monitoring and feedback systems into the simulation-driven design process. By capturing real-time data during production, engineers can validate and refine simulation models, ensuring their accuracy and reliability.

CONCLUSION:

The transition to a simulation-driven design process for metal forming technologies, primarily through the utilization of QForm Direct, represents a paradigm shift in the forging technology development. The software presents a transformative approach to process optimization, reducing dependency on trial-and-error methods and improving product quality, cost-effectiveness, and efficiency.

The presented case studies demonstrate the effectiveness of simulation-driven design, optimizing complex shape parts preform design, and enhancing the hot closed die forging process. These successful implementations testify to QForm Direct's potential in revolutionizing metal forming processes, highlighting the need for increased adoption and further research into its advanced applications. By embracing this technology, forges can expect not only enhanced productivity and product quality but also a profound advancement in the science of metal forming technology.

Furthermore, the future perspectives outlined in this paper highlight exciting directions for further research and development, paving the way for the continuous improvement and innovation of metal forming processes. By embracing simulation-driven design, industries can enhance their competitiveness, reduce development time and costs, and achieve higher levels of process efficiency and product quality in the ever-evolving landscape of metal forming.