The enhanced method for estimating the risk of fracture appearances in closed-die forging has been developed in this paper for hard-to-form materials under process conditions, where a high vulnerability of fracture initiation during plastic deformation results from specific stress-strain state, non-uniformity of strain rate and temperature fields.

The methodology based on the forgeability compression test using a laboratory rig with the 5 MN hydraulic press and finite element simulation on QForm software while implementing the ductile fracture criteria at elaborated parameters has presented. The results have been verified at production conditions.

Thorough, cost-effective planning

New solutions in a forging technology (new component geometry or deformed material) often require predicting the formation of defects, which is best done during the process development stage, preferably with the most thorough and cost-effective approach. A development process supported with “failure prediction oriented” analysis will significantly reduce the number of tests and material losses for a trial batch.

However, efficient identification of the areas and conditions leading to defects formation (including cracks during forging) requires accurate studies to determine the final deformation and process parameters.

Among the conditions leading to failure during bulk metal forming, the most common are those that result from process conditions affecting viscous flow, e.g. temperature-compensated strain rate and/or intrinsic workability of the deformed material. Both of these cases are observed in this report.

The first example is the warm forging process on the hammer mill, which combines advantages of hot (e.g., reduction of compensated strain rate and/or intrinsic workability of the deformed material) and cold forming (e.g., no scale metal forming operations). On the other hand, the lower working temperature at increased strain rate results in lower forgeability and a higher probability of fracture.

Warm forging of AZ61 magnesium alloy is the example of another case, where Von Mises criterion of five independent thermo-mechanical parameters has established that domination of tensile stress is observed when the equation result is close to 1. The analysis is aimed to determine parameters of two selective stress criteria: Cockcroft & Latham (2) based on high tensile stress σ1, and Rice & Tracey (3) which considering the hydrostatic σm and effective stress σf at the moment of crack initiation.

The results allowed extrapolation of the analysis to industrial forging processes of complex-shaped parts while considering the ultimate deformation established during compression tests. The dependences of selected process parameters on the thermo-mechanical parameters in the point of fracture initiation and method for calculation of a critical deformation value is based on the Cockcroft & Latham fracture criterion is presented in Fig. 4.

Crack initiation risk analysis

Laboratory compression tests make it possible to determine both the failure criteria: Crack initiation point, while accounting for the most significant factors, such as the air cooling during transfer of specimens from the furnace to forging press, or cooling in die tools before deformation.
SIMULATION

Fracture criterion.

Principal stress, d) critical values of the
a) load, b) mean stress and effective strain

Fig. 4. Numerically estimated dependences of selected mechanical parameters at compression test of cylindrical specimens: a) load, b) mean stress and effective strain at the fracture initiation point, c) maximum principal stress, d) critical values of the decisive integral in the Cockcroft & Latham fracture criterion.1,2

It is essential to separate metal flow-related defects, like laps or flow-through defects, from those defects caused due to insufficient workability, as established from the forging process. FE simulation for estimating of conditions leading to fracture formation helps to identify the location and fracture conditions in forged pieces.

The results of compression test and numerical simulation ensured the development of material models and fracture models for analysis of forging technology. Examples of parameter distribution maps are presented in figures 7 and 8. The main result of the analysis is the point of maximum fracture initiation risk (point P) in the case of the surgical forces (see Fig. 7). The highest values of tensile and mean stresses were observed at this point. Consequently, maximum values of the Cockcroft & Latham fracture criterion may be found at this point, too.

Analysis of distributions of fracture criterion values (see Fig. 7c, 8d) indicated the fracture appearance area, which is highly vulnerable to the crack initiation in both analyzed cases. Crack initiation parameters have been identified by comprehensive analysis of simulation results. In the case of the surgical forces forging, a high tensile-stress concentration in the area of fractures resulted from specific geometry of the workpiece. Simu-

Toward new guidelines

The methodology for estimation of the fracture initiation risk based on the laboratory uniaxial compression test and numerical simulation has presented in this paper. The research results have validated by analysis of two industrial closed-die forging processes of materials with different crystallographic structure and forging conditions, commonly referred to as hard-to-deform while forging on a high-speed press. The distribution maps of fracture criteria parameters calculated using FEM and implemented models ensure accurate prediction of fracture location. The presented study provides a sufficient reliability and may become a basis for the development of guidelines on improvement the geometry of billets or workpieces, forging parameters, and making possible to prevent from crack initiation during the forging process.

References


Fig. 5. Comparison of simulated and experimental values of a) forging load, b) specimen temperature during compression of stainless steel specimen.1,2

Fig. 6. Analyzed parts: a), b) surgical forces of stainless steel; c), d) motorbike handle part of magnesium alloy with localization of cracks; b), d) forged parts’ a), c) are final products.

Fig. 7. QForm simulation results of surgical forces forging: a) the final shape with localization of point P; b) the tensile stress distribution; c) the estimation of fracture risk based on Cockcroft & Latham fracture criterion.

Fig. 8. Estimating of critical values of fracture criterion in the forged piece: a) real part; b) simulation result in the QForm; c) temperature distribution; d) Rice & Tracey fracture criterion distribution.12

Fig. 9. Distribution of fracture criterion in the forged piece: a) hard-to-deform while forging; b) the final shape with localization of point P; c) the tensile stress distribution; d) critical values of the decisive integral in the Cockcroft & Latham fracture criterion.1,2

Professors Łukasz Lisiecki and Piotr Skubisz are attached to the Faculty of Metals Engineering and Industrial Computer Science, AGH University of Science and Technology, Kraków, Poland. Contact Prof. Lisiecki at lisiecki@agh.edu.pl

Stanisław Kanselski and Paul Mordvinsev represent QFX Simulations Ltd. Contact them at market@qform3d.com. The authors acknowledge the financial assistance of AGH UST, agreement no. 11.11.110.292.