FEATURED IN FORGE

Predicting Material Fracture in Cold Forging

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Figure 1. Coils

Care should be taken in modeling the cold forging of fasteners through computer simulations. It has been shown that pre-forming operations have a significant effect on predicting cracking based on mathematical damage models. Pre-forming operations such as wire drawing and bar cropping should be included in the simulation model for highest accuracy and best predictive results.

Cold forging is a tough forming operation for mechanical component or fastener design that has limitations on the deformability of the workpiece material and tool life. In contrast to warm- and hot-forging processes, the deforming forces in cold forging are relatively high. Consequently, cold-forged material may have a tendency to crack due to the high deformation that exceeds the material's ductility limit.

Because it is hard to detect failed cold-forged products during production, fastener manufacturers can suffer from high rates of wasted raw material and press energy. To eliminate this problem, the accuracy of predictive modeling on fracture evolution during forging is crucial in order to decrease manufacturing and engineering costs. The effects of pre-forging operations like wire drawing and bar cropping on computer simulations of fracture evolution are discussed in this article.

Pre-forging Operations

Cold-forging materials (low- and medium-carbon steel alloys) were bought as coils from suppliers as shown in Figure 1. After the appropriate surface preparation (cleaning and phosphate coating), a wire-drawing operation was performed on each coil to eliminate any deviation from the desired circular cross-sectional shape. The diameter of the wire is reduced to 0.25-0.35 mm.

Figure 2 shows the inside of a forging press. As depicted, basic press components are moving relative to the stationary die blocks, forging-die stations on these blocks, grippers and the bar-cropping mechanism. The wire coil is attached to the press and fed automatically through the bar-cropping system by the rolls. Wire is then cropped to the predetermined workpiece length and passed off to the first gripper. The grippers are mechanical components that transfer the workpiece and pre-forms between forging stations.

During bar cropping, wire is constrained in a die while another die shears the material (Fig. 3). Here, shear and tensional stresses are dominant, and deformation is ductile. Engineers usually begin their forging simulations with the initial forging station. In most cases, this gives a sufficiently accurate prediction on material flow and forging forces. However, this modeling strategy may be deceptive for engineers who want to conduct failure analysis.

An example of a fractured bolt that was taken from serial production is shown in Figure 4. As seen in the picture, cracking initiated from the corners of the 12-lobe punch and propagated through the head of the bolt. The crack's shape shows that this was caused by the forging operation. One can simply analyze this phenomenon using a finite-element simulation and predict the location of the crack's origin (Fig. 5).

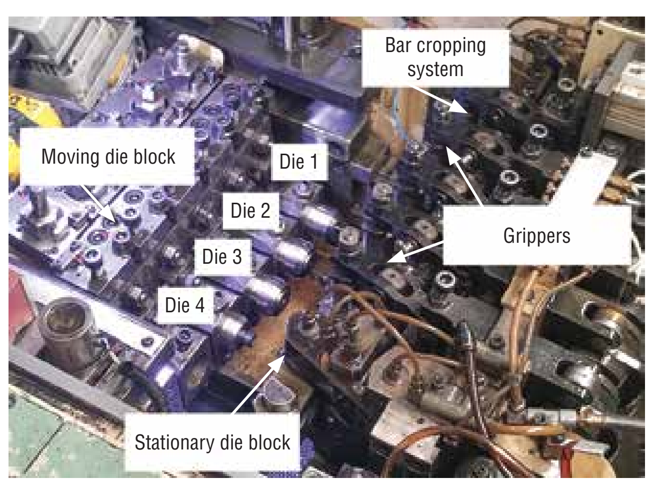

Figure 2. Forging-press components

In some analyses the crack and its path may not be as obvious as that in Figure 5, however. In such a case, the simulation and fracture model may not predict the fracture evolution or exact fracture locus. At this point, the modeling of pre-forging operations plays a critical role on prediction accuracy. The engineer should go back to the first step of the forming operation and analyze it step by step.

Modeling Pre-forging Operations

Finite-element simulation software packages, such as the Lematrie, Cockroft-Latham, Oyane and Johnson-Cook damage models, use different types of fracture and damage models. Most of the models use plastic effective strain for the damage calculation. At this point, calculation of exact values of generated plastic effective strain becomes important.

When an engineer starts with the first forging step in a numerical model, he or she simply ignores the residual strain that comes from the wire-drawing operation. As shown in Figure 6, wire drawing generates moderate plastic strains on the surface of the workpiece material. Taking this into account, we see that the calculated damage value will be significantly affected by these surface strains, thus leading to better predictive capability.

The next step that should be included in the simulation is bar cropping, which includes the drawn wire, the cropping die and the

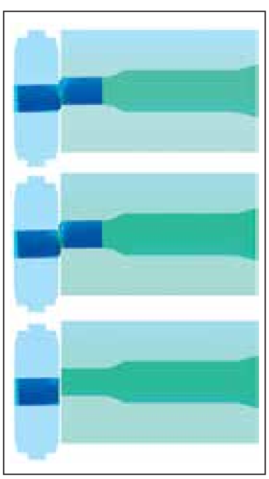

Figure 3. Bar-cropping operation

Figure 4. Fracture on cold-forged bolt

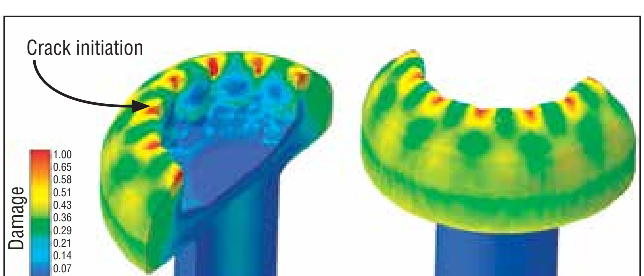

Figure 5. Damage distribution of cold-forged bolt

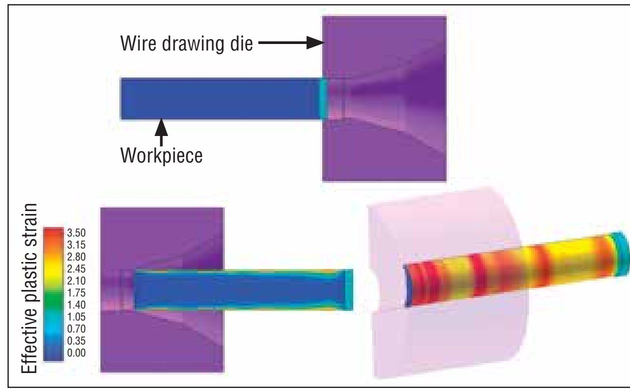

Figure 6. Effective plastic-strain distribution on workpiece after the wire-drawing process

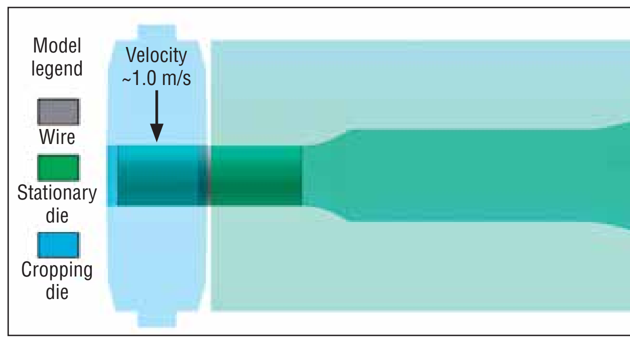

Figure 7. Bar-cropping model

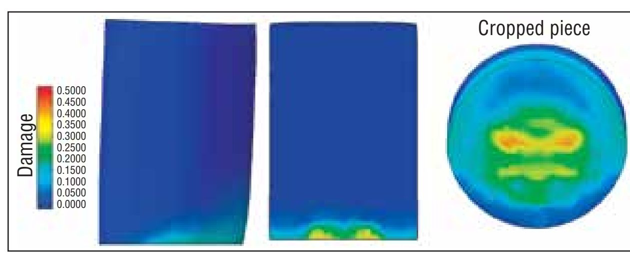

Figure 8. Damage distribution on cropped workpiece

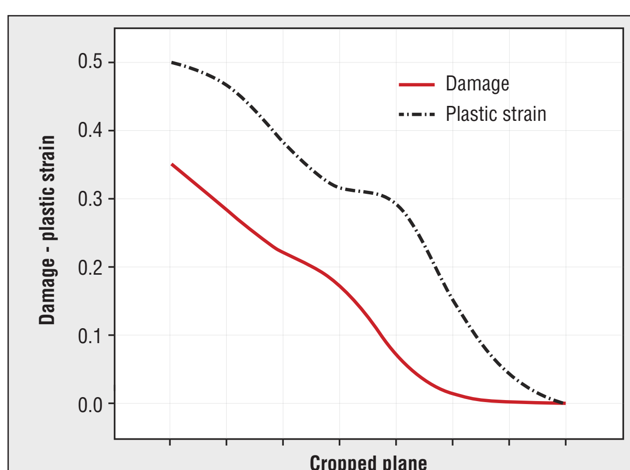

Figure 9. Variation of damage and effective plastic strain on cropping zone

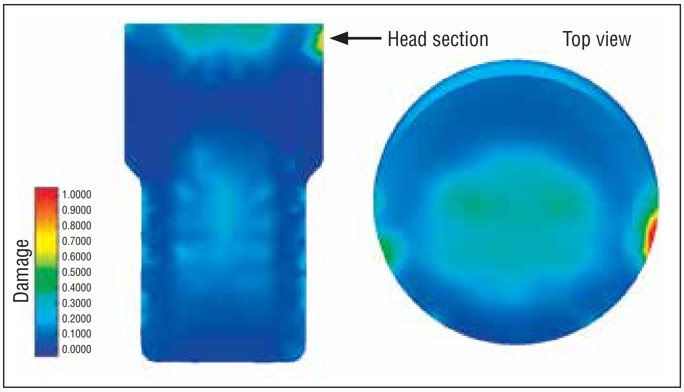

Figure 10. Damage distribution on extruded part (with pre-forging model)

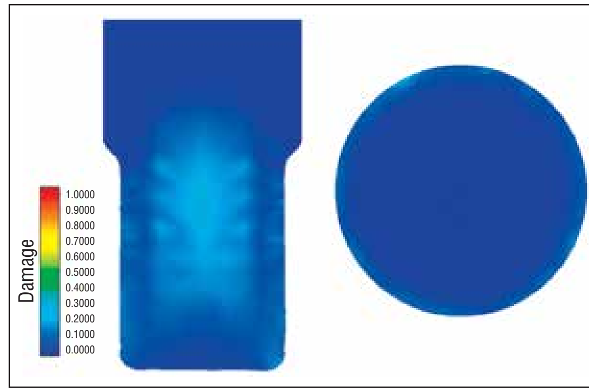

Figure 11. Damage distribution on extruded part (without pre-forging model)

stationary die (Fig. 7). This analysis was carried out in Simufact forming finite-element software.

Damage distribution after the cropping operation is shown in Figure 8. There are two important findings from this model. The first is that on the cropped surface the maximum damage value is about 0.35 at the center of the workpiece and decreases to zero through the surface (Figs. 8 and 9). Similarly, the maximum effective plastic strain was generated on the center of the workpiece, and it is about 0.5. The second finding is that the geometrical deviation of the workpiece from a perfect cylindrical shape was determined as shown in Figure 9. This occurs due to ductile deformation during cropping. Including this geometrical deviation to the first forging station is also important to determine surface planarity of the bolt during forging.

In most fracture cases in bolt cold forging, about 90% cracking is observed on the head of the bolt due to the forming of flanges or punch sockets. Here, crack evolution may be the result of a material defect or severe plastic deformation during forging. To investigate the damage on the head section of a pre-form bolt, an extrusion simulation was conducted using a workpiece taken from a bar-cropping model (along with the pre-forging model). The result of this simulation was then compared to the results of the extrusion model, in which the workpiece was simply drawn and taken to the model from CAD directly (without the pre-forging model).

Figures 10 and 11 show the damage distribution on the extruded workpiece for simulations carried out with cropped and CAD workpieces. As shown in Figure 10, the average damage value on the head section is about 0.3, although the damage value of the same location without the pre-forging model is about zero (Fig. 11).

The variations of damage value through the center to the surface on extruded parts are shown in Figure 12. Though the damage distribution tendency is similar for both models, the difference of generated damage on the head between these models is huge. This graph proves that an engineer who wants to conduct a failure analysis on a failed bolt and uses a simulation model without pre-forging models will underestimate the critical damage value on the fracture area and cannot gain reliable insight from simulation.

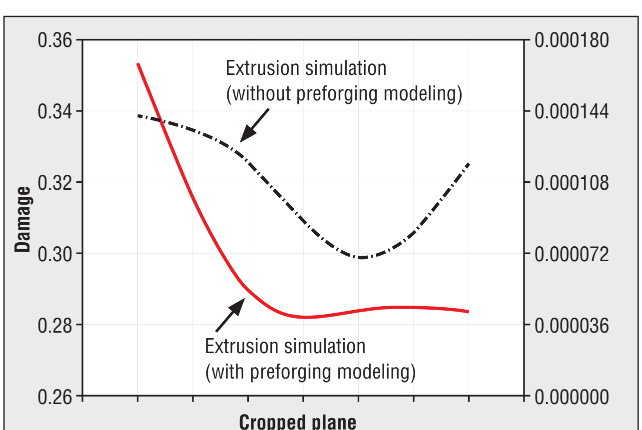

Figure 12. Comparison of damage on simulations with and without pre-forging model

Conclusion

The accuracy of finite-element simulations depends on many variables, including material properties, geometrical accuracy of CAD models, finite-element type and distribution. Even if all parameters in a metal-forming simulation were defined to the software properly, however, the model may not give any reliable data. An engineer could come across this type of problem during the failure analysis of fractured products. This article shows that pre-forming operations have a significant effect on predicting cracking based on mathematical damage models. Metal-forming operations like wire drawing and bar cropping should be included in the forging simulation model for high accuracy even though this requires more computational time.

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