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Cold-forged fasteners

Impact of Simulations on Cold-Forging Designs

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The predictive value of process and product modeling by finite-element simulations has helped in the cold forging of fasteners. In this case, the punch used in a wheel-bolt forging was reconsidered and redesigned to eliminate the punch "sticking" in the hollow section of the forging.

The power of finite-element simulations in our industry has increased during the last decade because of their high predictive ability in all applied disciplines, especially in metal-forming operations. Metal-forming simulations are used to develop unique processing techniques by eliminating the high number of laboratory tests required in such research, but they are also used extensively for the predictive detection of possible material failures, forging force detection, proper die design and topology optimization in the industry.

While simulations have impact on costs, they also ease the work of people in production. For instance, increasing the service life of dies with numerical simulation results in the office leads to a decrease in the number of die-changing operations that are done by laborers.

Compared to hot forging, material flow in cold-forging operations is less fluid. Consequently, die designing requires a lot of experience and ability to predict possible problems with the help of finite-element simulations during the design stage. This article shows that, despite the best efforts, unpredictable process failures may occur even though complete process design was coupled with finite-element simulations. Stunningly, however, the reasons for these failures again were solved with simulations that show the impact of engineering software on the forging industry.

An Unexpected Problem in Wheel-Bolt Forging

The cold-forging process is essential in bolt manufacturing because of the severe plastic deformation delivered to the workpiece by presses, which significantly strengthens the material without wasting any material as chips. The workpiece material is at room temperature, however, and forged material may be on the critical line of its fracture strength during deformation. Although all textbooks mention these kinds of material forging problems, failures can also be seen as a part of the whole die system. An example of this is the topic of this article.

During the production of M12x1.5x12 wheel bolts, punch failure was seen on the fourth forging stage, which caused us to increase the number of punches required to complete the specified fastener. The hexagonal shape of the bolt head is prepared on the third stage, and the final dimension of the hexagon and hollow section of the head are formed simultaneously on the fourth forging stage (Figure 1). Here, the punch was seen to stick in the formed hollow section, probably during the pull-out of the punch in the forging sequence, and it fractured (Figure 2).

The forging die system includes stationary and moving dies. The moving-die system includes a die spring that enables the deformation of the hexagonal bolt head and the moving of the punch through the semi-bolt. At the end of the deformation, the

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hexagonal die and punch move concurrently in opposite directions to pull out. Here, it is crucial to understand the material flow during the process. Many metal-forming simulation software packages include forging die springs in their libraries, but the exact modeling of the spring movement is not possible. However, complex die movements can be simulated more easily by defining specific die movements as a function of time.

Finite-Element Simulation: A Quick Discovery

A finite-element simulation of this four-stage forging process was prepared. At first, the forming and pull-out operations on the fourth forging stage were modeled without a punch to determine the value of the decrease in hole diameter (Figure 3).

The hexagonal die consists of a deforming part and a relaxation part. While the deforming part forges the material, the die wall was angled to decrease the friction between the flowing material and the die in the relaxation part. This allowed the material to flow more easily. It was seen that the deforming part was pushing material during pull-out, however, which led to a decrease in the diameter of the hole in the bolt on the wheel-bolt forging. As a result, the hole diameter specified to be between 11.01 and 11.05 mm was decreased to around 10.62 mm. This led to a significant increase in the contact pressure between the punch and material.

After a critical point, the punch becomes unable to move in the cavity due to increased pressure, and it fractures as a result of high tensional stress. To eliminate that, the punch geometry was revised due to predetermined decrease on the hole diameter as depicted in Figure 4. Therefore, it was predicted that the contact pressure between material and punch was decreased.

Prove the Solution

Finite-element simulations give forging designers a chance to prove their solutions without conducting any trial-and-error tests on the shop floor. To prove a proposed solution, a new punch can be designed in CAD software and easily adapted to the simulation. As mentioned previously, the punch geometry was revised because of the forging simulations we carried out.

The best way to draw a proper conclusion is to repeat the simulations with revised

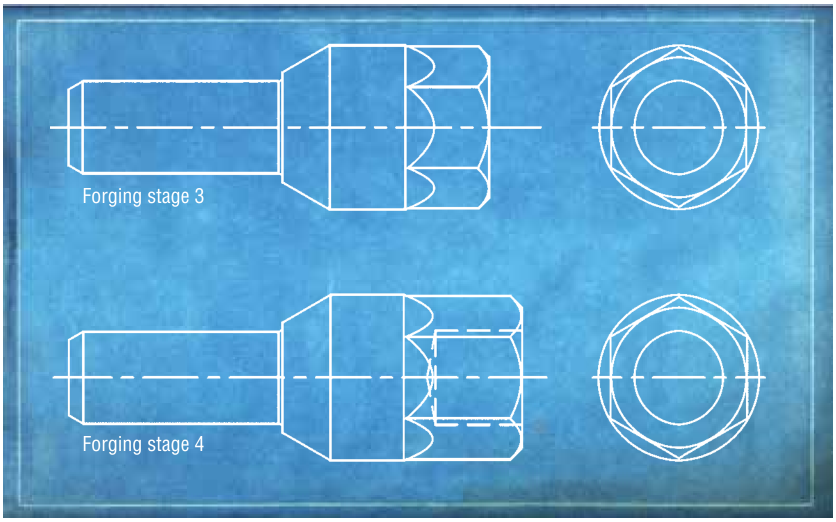


Figure 1. Third and fourth forging stages of M12 wheel bolt

Figure 2. Photo of failed punch

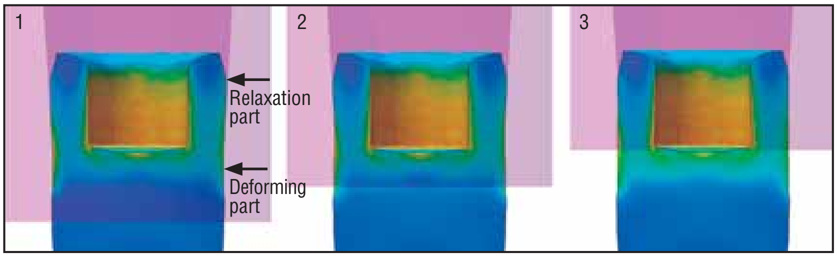


Figure 3. Material forming during pull-out

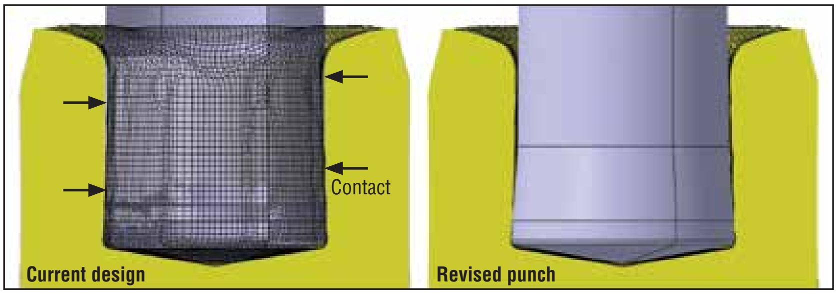
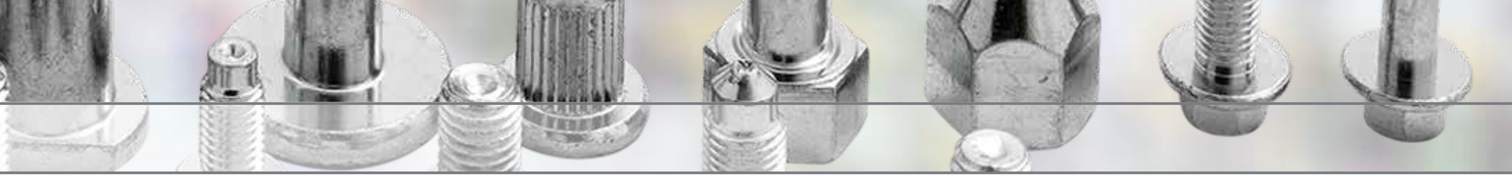


Figure 4. Current and revised punch designs



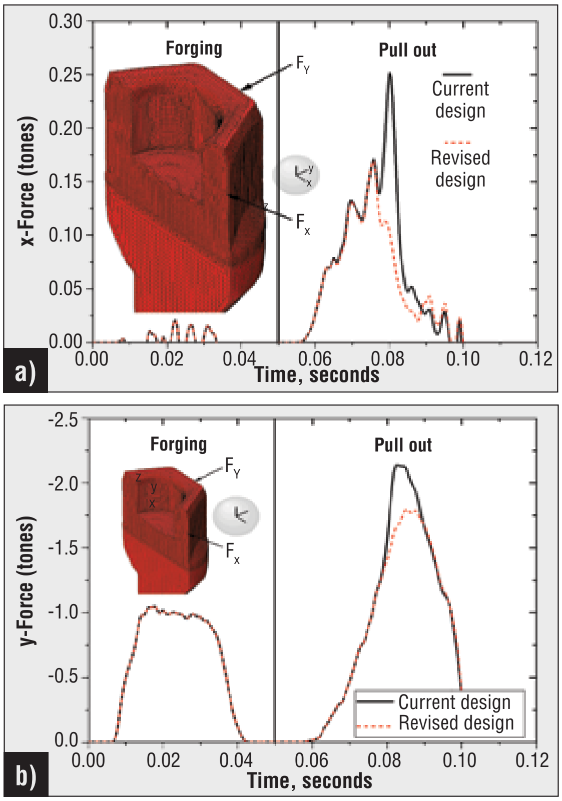


Figure 5. Force-time curves during forging and pull-out: (a) x force, (b) y force

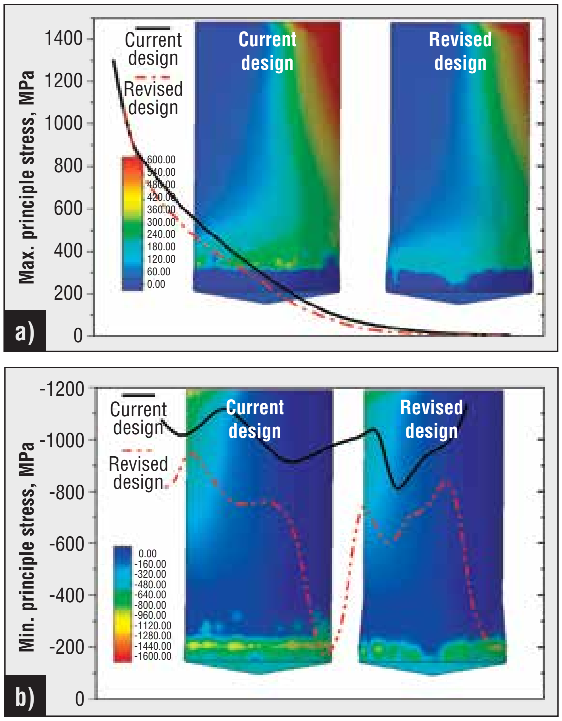


Figure 6. Principle stress distributions on punch: (a) maximum and (b) minimum principle stresses

designs and compare significant mechanical variables (such as forging forces and generated stresses) to previous results. This methodology was performed, and the forging forces of current and revised designs were compared as shown in Figures 5a and 5b. It can be assumed that forging forces in the direction of x and y axes are responsible for the jamming of the punch in the hole of the semi-bolt. As seen Figures 5a and 5b, while revision did not alter the force history during the forming of the bolt, exerted forces on the punch were decreased during pull-out. This shows that the revised punch will not experience high pull-out loads, which leads to plastic deformation and fracture.

Thanks to advanced simulation software, it is easy to conduct stress analyses on a specified component of the die system. As we know, conducting forming simulations with elastic dies requires a lot of computational power and long CPU times. In industry, however, time is a critical variable and cannot be wasted.

In simulation software, users do not need to run 3-D simulations with elastic dies to determine stress distribution on dies and punches. Special die-load modules allow users to apply forging forces calculated from previous simulations conducted with rigid dies and apply these loads to elastic dies. In this way, CPU time is significantly decreased.

Using this module, maximum and minimum principle stress distributions on the revised punch were determined and compared to the current design as shown in Figures 6a and 6b. Stress values were collected through a path on the circumference of the punch surface. These distributions are very important to determine the fatigue life of the punch. It can be seen that both stresses were significantly decreased with the design of a new punch.

Conclusion

The importance and efficiency of finite-element simulations used on cold-forging applications were illustrated in this article by presenting a unique problem that occurred during wheel-bolt forging. A little time invested to prepare and run simulations eliminated a great deal of effort in labor and design, the loss of time on inactive forging presses, consumed energy and the cost of trials. Based on obtained numerical results, new punches were manufactured, and forging trials were conducted that showed the modeling results were consistent with the actual application. The wheel bolt was successfully cold forged with a single day of numerical work. Additionally, punch life was increased by a factor of four times in contrast to the previous design.

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