APPLICATION OF TECHNOLOGY TO COMPETE SUCCESSFULLY IN PRECISION FORGING

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Abstract

Global competition has intensified in the manufacturing world in general, and specifically in the forging industry. Forging firms from Asian countries, especially China and India, have established a significant presence in the global market by improving their technology and innovation, and delivering cost-effective solutions. They also have the added advantage of an inexpensive and highly motivated labor force. Some of these countries also receive support from their government in the form of tax breaks, free training, and an artificially maintained favorable foreign exchange rate. Thus, the forging industry of industrialized high labor rate countries can only survive in this global market by reducing labor costs (which often requires extensive capital investment for automation), increasing material utilization by reducing flash and scrap losses, by reducing lead times and above all by maintaining a technological advantage over their competition.

Keywords: Precision forging, FE simulations, Computer Aided Engineering.

1. Introduction

Global competition in the forging industry has brought to the forefront the issues of managing innovation and technological development while demanding continuous improvement of products and processes. Strategies for development and application of new technology are extremely important for maintaining a competitive position and protecting sales. This paper reviews some of the advances in forging technology with an emphasis on the application of virtual process simulation, press and tool design for complex forging operations and the need for continuous training.

As a result of inexpensive labor, it is expected that forging buyers will gradually shift to developing nations for acquisition of components with high labor content. In order to succeed in the global marketplace, forging suppliers from developed nations must focus on production of high value-added forgings, finished parts and sub-assemblies with the aid of new developments such as a) advances in the use of computer modeling in forging process development, b) advances in equipment design, c) use of innovative tool design for complex forging operations, d) appropriate training in advanced forging technologies, and e) information management and automation in forge shops.

2. Improvement of Profitability in Forging Processes

The profitability of a forging process depends upon various factors such as a) material utilization, b) defects and scrap rate, c) die wear and tool service life, d) utilization of forging equipment, e) selection of (optimum) process parameters by use of engineering tools such as FE simulation, f) automation and labor content, and g) information management to name a few. To survive and make reasonable profit in today's highly competitive environment, leading forging companies must:

a) increase material yield/utilization by 1) maintaining quality/reducing scrap rates and 2) reducing flash losses.

b) reduce die wear and increase die life.

c) introduce advanced die making methods to reduce lead time in die manufacturing and reduce die costs.

d) implement process modeling techniques using 3D Finite Element (FE) based simulation software instead of using trial and error methods that require long lead times.

e) work with their customer in developing "forging-friendly" assemblies and components for future applications.

The implementation of these action items, seemingly logical and straight forward, is not easy especially for medium to small size companies that represent the majority of the forging industry. In order to achieve their goal of being competitive in a global marketplace these companies need to make a conscious effort towards improving their technical expertise by making appropriate investments in hardware, software and human resources.

3. Significance of Computer Aided Engineering in Forging

Finite Element (FE) based process simulation is used by a large segment of the forging industry to analyze and optimize the metal flow and conduct die stress analysis before conducting forging trials. Thus, part development time and cost are reduced while quality and productivity are increased. Process simulation is commonly used to develop the die design and establish process parameters by a) predicting metal flow and final dimensions of the part, b) preventing flow induced defects such as laps and c) predicting temperatures (warm forging operations) so that part properties, friction conditions, and die life can be controlled. Furthermore, process simulation can be very beneficial in predicting and improving grain flow and microstructure, reducing scrap, optimizing product design and increasing die life.

4. Determination of Reliable Input Parameters for Process Modeling

The accuracy of FE process simulation depends on reliable input data such as tool/workpiece geometries, material properties, thermal data, equipment characteristics, interface friction conditions, etc. Material properties of the deforming material and the friction conditions need to be estimated through tests that emulate production conditions.

The cylinder compression test is widely used to estimate the material properties of the deforming material at room and at elevated temperatures in forging. Due to the friction at the billet-die interface, barreling is often observed at the center plane of the cylindrical test specimen. In the ERC/NSM, test results namely, a) upset load versus stroke and b) shape of the billet at the end of forming are used in an FE simulation based inverse analysis technique to estimate the flow stress by compensating for friction at the billet–die interface [1].

Prior to process modeling one needs to know what lubrication system will be used in production. The double cup extrusion test is used to quantify lubrication used in cold forging processes that involve high contact pressures and surface expansion, while the well known ring compression test is mainly used to test lubricants in hot forging or cold heading operations. The ERC/NSM has tested several environmentally friendly lubricants for replacement of zinc phosphate coating based lubricant using the double cup extrusion test. Another method of evaluating lubricants in cold forging is to use free extrusion in order to evaluate the coating/lubricants on the workpiece as well as the coating used on the tools [2].

The coefficient of friction and heat transfer coefficient are assumed to be constant at the entire die-workpiece interface during the forging stroke. In reality, however, these values vary with the interface pressure and surface sliding speed. Research activities are being carried out to estimate these values more accurately [3].

5. Improvement of Material Yield in Precision Forging

There is an opportunity of huge cost savings in hot forging with flash by a) identifying the optimum shape and size of the preform with the best possible material distribution to obtain complete cavity filling without defects, and b) modifying the flash design of the blocker & finisher die to minimize the loss of material into flash.

In an FE simulation-based study conducted at the ERC/NSM for a tier one aluminum forging supplier the material yield in a forging sequence similar to that seen in Figure 1 was improved by $\approx$ 19% by optimizing the preform and blocker die design (Figure 2). A yield improvement of 15 % was obtained with only preform optimization i.e. the incoming forging stock and reducer rolling operation were optimized to improve the material yield with the existing dies.

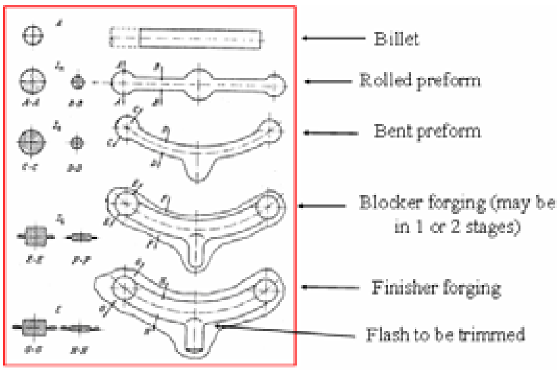
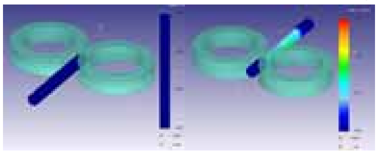


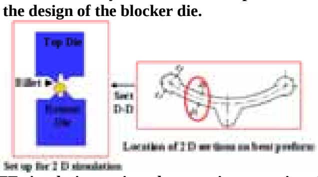
Figure 1: Forging sequence for a commercial automotive component [4].

Step 1: 3D simulation of current billet preforming (reducer rolling) and forging operations to validate the FE simulation model of the forging process.



Simulation of the reducer rolling process.

Step 2: 2D simulations at various sections/locations on the preform using the assumptions of plane strain/axisymmetric flow to optimize the shape & size of the preform and the design of the blocker die.



2D FE simulations using plane strain approximation.

Step 3: 3D simulation of sections which cannot be analyzed in 2D FEM using simplifying assumptions.

FE simulation of 3D sections.

Step 4: Final validation of the optimized preform shape and blocker design using 3 D simulation of the forging process.

Figure 2: Methodology for improvement of material yield in hot forging.

A similar study on front axle beams for heavy trucks was conducted at the Royal Institute of Technology - Sweden with funding from Imatra Kilsta AB [5]. The amount of flash obtained in production constituted 35% of the total workpiece weight of 115.4 kg. Using FE simulation, a yield improvement of up to 7.59% was obtained facilitating the design of a new shape for the reducer roller. Similarly, the material/point tracking function available in commercial codes such as DEFORM® or FORGE3® for tracking grain/metal flow can be used to identify material optimization areas without an extensive FE simulation study. Such a study was done by CDP-Bharat Forge Gmbh using FORGE3® [6].

The ERC/NSM has also conducted studies to increase profitability in microforming [7]. The surgical blade shown in Figure 3 initially required the removal of flash by grinding, which translated into high manufacturing costs. Using FE simulation with die stress analysis, the flash thickness was reduced so that it could be removed by electro-chemical machining (ECM).

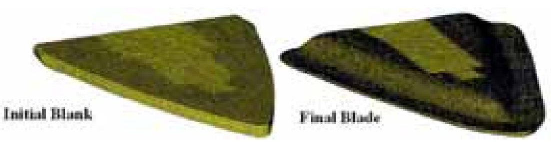


Figure 3: Microforming of surgical blades (Blank thickness = 0.1 mm; Final blade thickness = 0.01 mm) [7].

6. Process Design, Analysis and Optimization

6.1. Incremental Forming Methods

Simulation of incremental forging processes requires extensive computer time because a very small time step size must be used to analyze the localized deformation. Thread rolling, and orbital forming are examples of such processes (Figure 4 and Figure 5). At the ERC/NSM, orbital forging simulations using DEFORM-3D® were conducted to study and develop a robust assembly process of an automotive spindle and an outer ring.

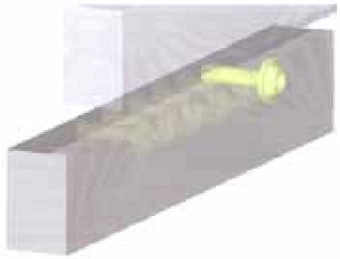


Figure 4: FE analysis of incremental forming processes using DEFORM® [8].

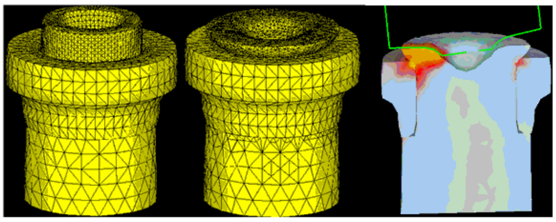


Figure 5: FE simulation of orbital forming (FE model and stress distribution) [9].

6.2. Die Service Life Improvement in Cold/Warm/Hot Forging

Estimation of die wear is extremely crucial for control of final part cost, quality and process efficiency. Figure 6 shows the FE simulation of a hot forging process done in QForm® to evaluate the progress of abrasive wear of the die cavity. The results of the simulation showed good agreement with experimental observations.

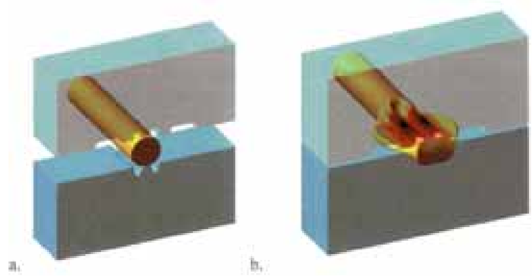


Figure 6: FE simulation of the forged part, a) at the beginning and b) end of simulation [10].

7. Warm Forging

When the product volume is large enough to amortize the tooling costs, cold forging is preferred to obtain precision tolerances. However, for cold forging large parts from difficult-to-forge steels warm forging (600-900°C) may be a better alternative. One of the world's largest forging companies, Hirschvogel with annual sales of 330 million Euros, uses warm forging technology to produce a variety of automotive products [11]. Optimized material flow within the forging plant allows Hirschvogel to optimize its internal (high equipment utilization rate, short time in-process, low inventory and work-in-process, robust planning and low costs) as well as external (on-time delivery, high accuracy, short lead times and competitive price) logistic objectives. These objectives must be achieved despite variation in the process parameters.

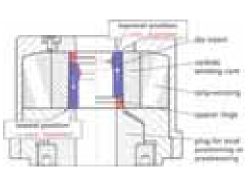
8. Tool Design

8.1. Adjustable Dies for Bulk Metal Forming

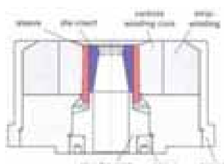
The introduction of cold forging dies with the possibility of varying the inner diameter of the die inserts provides extended possibilities of compensation for variations in process conditions. Figure 7 shows the STRECON ® VARI-FIT prestressed container for close tolerance cold forging applications such as spline profiles (Figure 7 b). Variation of the inner diameter is achieved by modification of the conical press fit between the die insert and the strip-wound container (Figure 7 d).

a) STRECON® VARI-FIT model.

b) Example spline component.



c) Principle of STRECON® VARI-FIT.



d) Principle of STRECON® VARI-FIT SL.

Figure 7: New developments in adjustable dies [12].

8.2. Alternative Die Design for Net-shape Forging of Gears

Precision forging of gears has been a widely researched topic due to the potential cost savings in forming gears to final dimensions without finish machining. Figure 8 shows two possible tooling concepts for forming precision gears. These designs were evaluated using FE simulation of gear tooth formation and the resulting forging loads. Forging trials were conducted on a 12000 KN mechanical press with the same process parameters as in the FE simulations [13]. Results showed that FE predictions were close to experimental values.

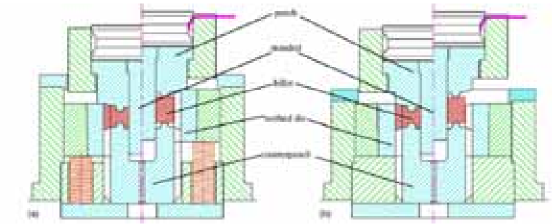


Figure 8: Schematics of gear forging tool designs with a chamfered punch and counter punch. (a) die is elastically attached to machine bed; (b) die is rigidly fixed to machine bed [13].

9. Advances in Forging Equipment

9.1. High Speed Forging

The DualDRIVE® design developed by Mueller Weingarten significantly increases die services lives while reducing cycle times at bottom dead center (BDC) in precision forging (Figure 9). The main purpose of this design is to reduce the die contact time (from approximately 35 ms to 60 ms) and hence to reduce the die wear during forging [14].

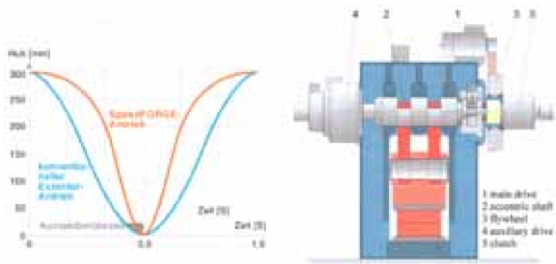
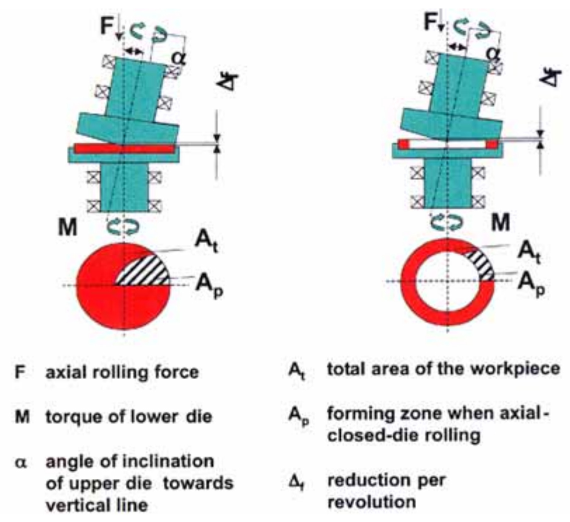


Figure 9: Schematic of a DualDRIVE® press with the kinematic cycle compared to that of a standard eccentric press [14].

9.2. Closed Die Rolling Machines

Figure 10 a and b show the diagrammatic view of the SMS Eumuco axial closed die rolling principle for disk shapes and ring shaped parts, respectively [15]. The upper and lower rotary units rotate about their vertical axes in the same direction, with the upper unit being inclined to its vertical axis by an angle ∝. The upper unit also has axial feed to deform the workpiece in a localized semi-parabolic contact zone. Thus, compared to a conventional forging press, a rotary forming machine generates lower loads. Figure 11 shows an example part formed with a closed die rolling machine [15].



a) Disk shaped parts. **b) Ring shaped parts.**

Figure 10: Operating principle of a closed die rolling machine [15].

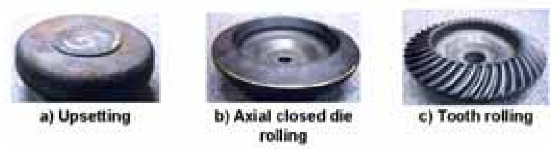


Figure 11: Axial closed die rolling sequence for a bevel gear [15].

10. Information Management in the Forge Shop

Management of complex engineering information in the forging environment plays a big role in ensuring that the desired production outputs are met. A forging company should have the ability to organize engineering knowledge and properly disseminate useful information to the respective departments for implementation. A number of forging companies have gone global with branches in various locations. Thus, information flow becomes complex and difficult to manage efficiently.

To date, companies such as Plexus Systems have developed computerized systems that can assist the management of information flow at various departmental levels e.g. Inventory tracking, shipping, receiving, engineering, purchasing etc [16]. At the engineering departmental level, information management systems can be helpful for storing and retrieving data pertaining to: a) tool designs, b) changing tool materials, c) product specification, d) process instructions, e) just-in-time jobs/rush jobs, f) process control plan, g) tool life tracking, h) machine specifications and drawings, i) press stress analysis, j) engineering drawing management, and k) dimensional control plans.

11. Training of Personnel

Due to global competition, the training of metal forming engineers, who are expected to plan and supervise the design and production of parts and dies, becomes increasingly important. Continuous improvements in forging technology and application of recently generated R&D results require that engineers be continuously updated in new methods, machines and process technology.

Universities may be required to restructure their design courses or develop new ones that address real design issues pertaining to forging. More importantly, for the course to be successful and cost effective there is a need to link universities to the forging industry in areas such as a) process sequence development, b) die/tool designs, c) press automation and design and d) computational tools such as CAE software, CAD and CAM systems.

12. Summary and Future Work

Competition to the forging industry comes from two primary areas: competing processes and materials and the highly competitive global industry. In order for the forging industry to remain viable and successful, there is a need for a comprehensive approach, through alliances, to support and address the research and development programs for reducing costs and lead times and increasing material utilization [17]. Global off-shore forging competitors are further strengthened by trade offset programs, direct and aggressive foreign government support, lower labor costs, and relatively cheap cost of capital.

There are several possible options available to the forging industry to realize some of the goals mentioned above in terms of improving their level of technological expertise in the design and manufacturing environment. Some examples are:

- Industrial Consortia with funding from the government or through cost-sharing,
- Industry-University Cooperative Research and Personnel Training Programs,
- Internship/Co-op programs for students and /or researchers.
- Internal training programs with or without external assistance.

Integration of the above tools and solutions, and consideration of other strategies to maintain technical and management excellence are needed for success in today's global forging environment.

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