PRECISION FORGING ANALYSIS

Dushyant Singh Rathore
Department of Mechanical Engineering
Dronacharya College of Engineering, Gurgaon, Haryana

ABSTRACT
Contemporary forging industry is faced with different challenges and demands. It forced many forgers recently to make a review of traditional forging methods and to enter innovations in process and product design. Present day forging industry tends toward the replacement of conventional forging process (forging with flash) by precision forging. Precision forging enables manufacture of forgings with enhanced geometrical and dimensional accuracy, such as net-shape or near-net-shape components, in large quantities and with reasonable cost. Application of precision forging increases the competitive of this technology and offers many benefits to the product manufacturer - economical, technological and ecological. Crucial issues for successful application of precision forging are the process design, die design and die manufacturing. Compared to conventional forging process and tool design is more complex and more sensitive to potential errors. When design precision forging process, one have to take into account the great number of variables that have to fulfill some important aspects in order to realize the precision forging process on proper way. Therefore, a new approach in process planning as well as support of computers and engineering design tools are needed. In this paper, an outline of variables affecting the process of precision forging, requirements that they have to satisfy and critical aspects of the precision forging process are given. Basic tool concepts used in precision forging are also presented.

I. INTRODUCTION
In conventional precision forging the material is formed at ambient temperature or in semi-hot conditions. In the case of very complicated parts, a properly prepared charge is hot formed in isothermal conditions. Sometimes the super plasticity of the formed material is exploited. Initially, enclosed dies were used for forming [5, 12]. Thanks to the material savings and the lower costs of manufacturing products with enhanced properties at competitive prices, precision forging was increasingly applied to alloys of light materials such as aluminium, magnesium and titanium [10, 12]. The expression precision forging does not mean distinct forging process but rather approach to forging. The aim of this approach is to produce a net shape, or at least a near-net shape parts. Precision forging is sometimes described as close-tolerance forging to emphasize the aim of achieving required the dimensional and surface finish tolerances only after forging. Precision forging at ambient temperature, i.e. cold forging, is preceded by making a slug in a few hot forging operations. In conventional hot forging in half dies a substantial amount of the material is lost for the flash and allowances. For this reason closed-die forging (often employing complex formation, i.e. forward and backward extrusion) was adopted to make preforms for precision forging. Extrusion forging has this advantage that the stress is mostly triaxial compression whereby large deformations can be obtained without losing material cohesion. In addition, no die drafts are used in precision forming. The whole manufacturing process is generally divided into stages. As an example, the process of manufacturing a low-carbon steel product is shown in Figure 1.

Fig. 1. Flowchart of precision forging process

Metal bundles are delivered from a storeroom to a machine which cuts the rods into pieces with specified dimensions and weight. Then the pieces are heated up to a
temperature of about 900°C in an induction furnace. A constant process temperature must be maintained in order to ensure high quality of the forgings. Preforms heated up to a proper temperature are fed into a press where they are formed in 2–5 operations. The dies are preheated to a temperature close to the operating temperature to reduce the risk of die cracking as a result of thermal shock (Figure 2).

Fig. 2. Dies are preheated

The forging process lasts only a few seconds. The stability of the process and control conducted according to plan ensure high quality of the forgings. When they leave the press the forgings are subjected to controlled cooling (Figure 3). Then they go to a shot peening machine where they are cleaned from graphite. The clean forgings go to cold working where they are oiled and cold formed. In this way the precise shape of the finished forged product is obtained. After cold forming the forgings are washed and greased.

II. Tool and preform temperature
Proper temperature is critical for the reliable operation of the tools. It can affect the die’s narrow tolerance zones and the small spaces between the moving parts and the fixed parts of the tools. As a result of thermal expansion the clearance may decrease and the tool components may lock up. Also the thermal expansion of the die affects the quality of the forgings. Numerical simulations of the forging of CV joints showed large temperature differences in the die in the contact area, whereas already at a depth of about 5mm from the die’s inner surface the temperatures are much lower (Figure 4a). So large temperature gradients may adversely affect the state of stress inside the tools. This means that the temperature of the tools needs to be monitored, for example, by a thermovision camera (Figure 4b).

Fig. 4a. Die thermal field distribution determined by FEM

An equally important parameter is the temperature of the slug since it has an effect on the forged object’s microstructure and its material flow curve (its formability) and through thermal expansion it causes a change in the slug volume. The temperature distribution in slugs for different preform diameters was examined in [8]. The initial temperature of the preforms was 920°C. Then the specimens were cooled for 2 s at a temperature of 50°C in the press chamber as they were waiting to be forged. In spite of such a short cooling time the temperature difference in the outer layers amounted to about 50°C. This can have a significant effect on the forging process.

III. Slug geometry
In precision forging there is no flash gap and the charge material volume must be the same as that of the finished part. The allowable differences in mass can amount to 0.5–1%, the angle deviation in the cutting zone to 0.5–2° and the roundness deviation to 2 and 6°. This can be achieved by using special cutting. It is necessary to maintain so narrow tolerances for the preform in order to ensure high quality of the forged product. A too large slug volume may result in damage to the die or the press. During multioperation forging in closed dies proper distribution of slug material volume and slug preparation
through upsetting are critical for the proper filling of the die cavity. There exists a notion of an ideal metal body of revolution with appropriately distributed material masses. Therefore the design of preforms and slugs in forging processes is an important activity aimed at improving product quality and reducing production costs [1, 3, 11]. The preform’s shape and mechanical properties will affect the friction conditions at the die/slug interface while its geometry will have an effect on the die and the slug.

IV. Press settings

The settings of the forming machines are an important factor affecting the forging process. The main settings include:

Press workspace: The precision forging process and tools require that the tool workspace between the anvil and the press slide should be sufficiently large for the whole system of tools, including the auxiliary components. Moreover, the cooling and lubricating equipment should be integrated with the press.

Constant forging energy: Constant press energy is critical for reproducibility in precision forging in every stroke. Especially, when speed is increased during redesign a new forging process. Excessive energy causes an increase in the pressure inside the die, which may result in the elastic deformation of some tools (such as punches and counterpunches) and ultimately lead to an elastic rebound of the tool. Elastic deformations of tool components should be avoided since they can cause changes in geometry during forging.

Precision guidance of tool components: Precision guidance of the punch is required when the die is closed by the upper punch during forging. The gap between the punch and the die is usually smaller than 0.1 mm in order to avoid a material flash. Moreover, accurate positioning of tool components is necessary to obtain proper forged product geometry.

V. Lubrication and cooling

To a large extent the correctness of forming process depends on the lubricant used. The latter is used to both lubricate and cool. The lubricant should be characterized by a high flash point (so that it does not lose its tribological properties at high temperatures), low heat conduction (to prevent the object being forged from cooling down and the tool from overheating), proper viscosity at the operating temperature and a low coefficient of friction. Moreover, an optimum lubricant should not contain any components having an adverse effect on the process. Graphite, teflon, glass and other substances as well as intermediate metallic layers characterized by low flow stress are usually used in hot forging. In order to ensure healthier working conditions in the forging industry and minimize its environmental impact as well as to increase the life of the tools, the European Community has recently funded an industry research project called Brit-Euram aimed at developing environmentally friendly systems of tool lubrication (based on lubricants with optimum lubricating properties) for the warm forging of steel and to promote a wide use of forging with a smaller pollutant burden, better working conditions and higher productivity. It was found that in most hot forging processes no proper tribological conditions were ensured. This is mainly due to the high contact pressures and metal surface gains typical for hot forging, especially forward and backward extrusion forging. In all the cases it is necessary to provide additional lubrication in the form of lubricating film on slugs. Thanks to the project a comprehensive tool lubrication system has been developed. As regards the environmental impact and tool life, the best results have been achieved through the use of tool lubrication systems consisting of a graphite-based slug lubricating film and graphite-free oil greases for dies.

VI. Tools

The choice of a tool material is a very difficult task for designers and process engineers. The life of a tool and its suitability for production depend on many factors which often have opposing consequences. So far there are no clear-cut criteria for selecting tool materials and to a large extent one must rely on the experience of the manufacturers and tool users. Statistical data provided by different tool manufacturers indicate the most common causes of tool failures to be: tool fatigue cracking in cold working and excessive abrasive wear, material plastic flow and thermal fatigue in hot working [20]. The worst situation is in warm working since each of the phenomena can be equally critical. In such conditions the tools must withstand high pressures (as in cold working) and at the same time must be made of heat resistant materials (as in hot working). According to Lange et al, the life of a tool at high forging temperatures depends on wear in over 70% of cases. Therefore tool materials, their heat treatment and machining and tool design and fabrication accuracy must meet very high requirements. Tool materials should be characterized by hardness in a range of 50–55 HRC (considerably higher than that of the forged product), good hardenability, high tensile strength, high impact strength and low abrasibility.

Currently, warm- and hot-work tool steels: WCL, WWV, WNLV, which are characterized by very good mechanical properties (high tensile strength, high hardness, high abrasion resistance, high yield point – 2200 MPa) are quite popular tool materials. Also other alternative tool materials are considered. Moreover, special treatment, such as nitriding, surface coating and laser silicon carbide surface alloying etc., can significantly
reduce the abrasive wear and increase the hardness of the tool materials, particularly of their surface layer.

VII. Heat treatment
Heat treatment has a decisive effect on tool life. Figure 9 shows a heat treatment diagram for a hot-work tool steel. For instance, cracks which appear on the surface of a ground tool made of tool steel can be caused by improper tempering or by overheating during austenitizing. Such heat treatment faults can limit the possibilities of grinding the tool, even if proper precautions are taken.

Stress relief annealing: Tool steels are usually delivered annealed; further treatment is done by the user or in toolrooms. The treatment causes stresses to arise, which during heating up to the hardening temperature are released and cause, among others changes in the dimensions. Therefore tools which must meet high requirements for retaining their dimensions should be annealed after mechanical pretreatment (before the final treatment).

Hardening: It is impossible for steels subjected to hardening to ideally fully retain their dimensions. A change in the structure (from the annealed-state structure to the structure after hardening) means an increase in the volume, which as a result of tempering that follows is again reduced but not restored to the annealed-state volume. Because of buckling it is recommended to use the gentlest possible cooling medium and to perform intermediate cooling at 900°C for steels whose hardening temperature is above 900°C. Since there is a risk of strain cracking one should avoid cooling the tools to room temperature. The latter are usually cooled down to about 150°C. Then at a temperature of about 100–150°C equalization takes place aimed at eliminating the differences in temperature and structure between the surface and the core. Quenching in a hot bath and in vacuum (as a hot bath simulation) for hot-work tool steels has proved to be effective.

Austenitizing: The hardening temperatures specified by the manufacturers should be adhered strictly to. If the hardening temperature is too low, the increase in hardness is insufficient. If it is too high, it results in brittleness, increased grain size, a risk of cracks and so on. Also soaking times are important.

VIII. REFERENCES