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Analysis of forging defects for selected industrial die forging processes

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ABSTRACT

The main goal of this paper is to identify defects in forgings in selected die forging processes. The major problem is the formation of underfills due to air pockets between the forging and the tool. In the literature there is no information about modeling of such defects using FEM software, therefore, attempts were made to build numerical simulations of analyzed processes. The high agreement of the numerical modeling results with the results of the macroscopic, microstructural and defectoscopic examinations confirmed the validity of the FEM modeling assumptions and justified the use of such IT tools for the analysis of industrial plastic working processes.

1. Introduction

Due to the high competition between forging producers, in recent years besides the price (the main consideration) the quality of the offered forged products is a factor increasingly often taken into account when choosing a supplier. This particularly applies to customers from automotive and aircraft industries where the requirements as to the forging accuracy and quality are the highest. Die forging processes belong to one of the most difficult manufacturing techniques. Even though this technology has been mastered quite well, the correct manufacture of forgings with complicated shapes (connecting rods, worm gears, constant-velocity universal joints, turbines, levers, etc.) which satisfy the customers' high quality expectations, requires much experience from the designers, technologists and machine operators [1,2]. The implementation of new forging designs, the continuous optimization of the existing technologies and the large number of factors having a bearing on the correctness of the whole process and their mutual interactions make forging processes very difficult to analyze. In each of the stages in the forging process there is a risk that an error will occur, resulting in a flaw — a forging defect. For this reason several CAD/CAM/CAE tools (usually based on FEM and physical modeling) and special measuring-control systems are used to design and optimize the whole forging process [1–9].

2. State of the art

The design of preforms and slugs for forging processes is an important element of improving product quality and lowering the production costs due to the material lost as flash or to the losses connected with incorrectly manufactured parts. Most researchers and experienced forging engineers are inclined to agree that the most common forging defects (underfills, folds) are the result of the improper geometry and/or incorrect position of the preform or the slug on the die insert. Such errors are often due to the unavailability of a particular bar section from the steel works or the lack of proper equipment resources for slug preparation. In die forging processes the proper spacing of cross-sectional areas along the length of the straight axis of the preform (slug)

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and the preparation of the latter through forming is highly important for the proper filling of the cavity die by the material [10–11]. Other causes of forging defects include: a too low temperature of the billet, the use of too strong drafts, the improperly made tools, incompletely removed scale, and crude technology. The forge is responsible for most of the causes of defects, but there are also factors for which the forge is not directly responsible, however it can control and supervise them in order not to allow the quality of its products to deteriorate [6–9,11–12].

There are plenty of studies and papers on the selection, design and optimization of billet geometry, but only a few works are devoted to the application of numerical FEM modeling to the analysis of the causes of forging defects. The possibilities of using numerical FEM simulations were presented in [11], where, among other things, numerical analysis of the shaping of a forging out of an ingot, with modeled casting pores, were performed. Subsequently an experiment was carried out for the same machining parameters as in the simulations. The ways in which defects propagated in the numerical model and in the physical model were compared. Numerical FEM modeling is used mainly to determine the optimal shape and dimensions of the preform and the slug. This is required when the forging has a complicated shape, as in the case of turbine blades, toothed gears, forked forgings, etc. [7,8].

Examples of alternative techniques of designing preforms/slugs, based on conventional engineering methods, are sequential analysis techniques using radiosity, the upper-bound approach, the slip-line field method and physical modeling using soft modeling materials. For instance, in [10] it is proposed to use the backward tracing method to design the proper shape of a turbine blade. In [13] a sequential technique based on the upper-bound method was used for the analysis of a preform geometry, whereby a preform shape was obtained through the selection of proper tribological conditions. The technique used by the author is approximate, making it possible to estimate the yield stress needed for plastic working processes. The total deformation power in this method is the upper limit of the power expended by the external forces. In order to determine the limit loads one must know or adopt assumptions concerning stress fields, strain velocity fields, the yield criterion and the plastic flow law. Assuming that plastic strain zone V_P consists of parts displacing relative to each other as stiff bodies inside of which there is uniform velocity field v^k and some of surface S_F is free of load, it follows from the principle of the power equilibrium of the internal and external forces that

$$\int_{S_V} F_i v_i dS \le \sum \int_{S_L} r^k \left(v^k\right) dS. \quad (1)$$

By determining the upper and lower limits one can define the interval within which the actual force is contained. The sequential methods are less accurate, but they are considerably faster than FEM, and the special program procedures can directly interpret analytical results.

Still another alternative method of designing the shape of a slug is the electric field method. In [14] various slug shapes were modeled using the theoretical electric field method and the results were optimized by means of artificial neural networks. An electric field is generated between two conductors with different voltages (Fig. 1).

In order to generate an electric field the initial dimensions of the billet are appropriately rescaled (usually enlarged 2–3 times) so that the final outline of the forging is within the initial outline (a cylindrical preform is assumed). Depending on the voltage applied, equipotential lines of different shape are generated. The authors used artificial neural networks to select the optimal electric field line.

In [15], using the finite volume method (FVM) and the parametric design method the authors developed a new procedure for designing an optimal slug for complicated forging shapes. The authors also used [16] a combination of artificial neural networks and genetic networks to optimize the initial injection parameters.

A survey of literature on optimal slug design indicates that despite the theoretical bases used, most of the methods encounter difficulties, especially at large plastic deformations.

Today forges most often use numerical software based on FVM and FEM to analyze the problem connected with the improper geometry and/or position of the preform. The producers of the current computing packages equip them with ever new functions enabling even better and more complete analyses of plastic working processes, making it possible, e.g., to detect defects in forgings and to analyze the durability of the tooling (Forge, QFORM, Simufact) [17–18]. Owing to such functions the user can

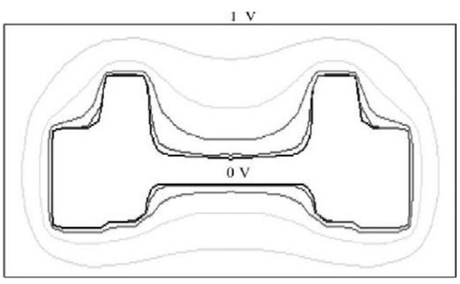

Fig. 1. Equipotential lines generated between two conductors [14].