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The Optimization of the Technological Parameters of Precision Die Forging of a Spur Gear Using a Computer Simulation

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Abstract

This paper deals with the optimization of the technological parameters of precision die forging in closed die in order to achieve a proper material flow in the die cavity for spur gears with a hub. This paper also studies the material flow in die cavity, effective plastic stress and strain, and temperature of drop forging using simulation software called SimufactForming. Forging cost is also compared between the closed and open die forging.

Keywords: precision die forging, closed die, spur gear, computer simulation, costs

1. Introduction

Manufacturing processes as a product in the area of the production of drop forgings must be still analyzed and improved to meet all customers' requirements, environmental legislation and international competition. The drop forging production using a precision die forging becomes the main field of research and development as an advanced method (Doege & Bohnsak, 2000).

Precision die forging can be divided into the drop forgings produced net-shape and near net-shape (with minimal or no final-cutting operations). Precision die forging can be used in a variety of dies with standard flash as well as flashless forging with open die cavity. However, application of precision die forging in forging with closed dies provides a better condition for high precision of drop forgings and utilization of forged material. Exact volume of billet (raw part) and suitable compensation method of forged material is needed to provide at the precision die forging in closed dies (Cermak, 2011; Dean, 2000).

2. Selected Parameters of Precision Die Forging

There are many technological parameters which influence the precision of drop forgings, as it is illustrated in Figure 1. One of them which is the focus of this research, is the design of suitable shape of billet inserted to the die. Another technological parameter of this paper interest is the design of forging tool. This parameter is closely related to the designed shape of the billet. Proper design of compensation method of forged material is also very important in the designing of a closed die (Vajo & Cinak, 1997; Douglas & Kuhlmann, 2000; Jolgan et al., 2008).

Suitable simulation software enables designers to study the influence of many effective variables by evaluating various combinations of them. Numerical simulation is convenient tool for the designers because the optimal conditions of forging process can be obtained quiet fast (Cermak & Jilek, 2010).

3. Preparation of the Research

Research on the optimization of the selected parameters which are dimensions of billet and tool design of precision die forging in closed dies has been conducted on a spur gear with straight teeth with a hub. Figure 2 shows the shape of the spur gear. This spur gear is frequently employed in machine industry – for example as a part of machine' mechanism and/ or a gear box (Davis, 2005).

The material for drop forging was case hardening steel DIN 17210 (16MnCr5). The best results within the frame of research of precision die forging of a spur gear in closed dies were achieved by using of this steel (Behrens & Odening, 2009). Chemical composition of steel DIN 17210 is shown in Table 1.

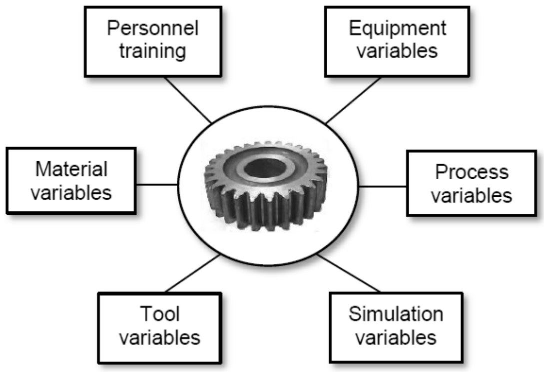

Figure 1. Effective variables on the precision of drop forgings

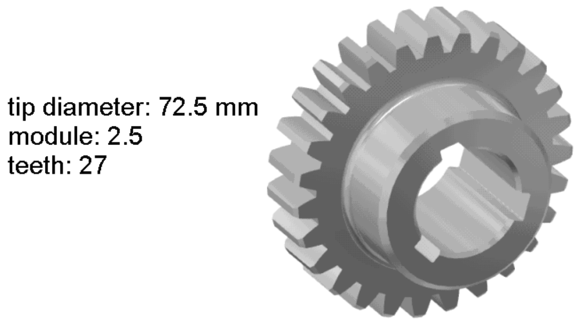

Figure 2. Spur gear with a hub

Table 1. Chemical composition of steel DIN 17210

	Chemical composition [percent by weight]					
	C	Mn	Si	Cr	P	S
min	0.14	1.1	0.17	0.8		
max	0.19	1.4	0.37	1.1	0.035	0.035

3.1 Conventional Forging Method

Nowadays, spur gears are manufactured by conventional hot die forging with flash. Manufacturing of this type of drop forging by forging in open dies usually consists of three forming operations: upsetting, rough forging and final forging. This usually results in an increase in production times, tooling costs and machine costs. Low efficiency of charging semi-products is another drawback of the conventional die forging. The final part has flash and web (Milutinovic et al., 2008).

3.2 Designed Forging Method

The above-mentioned limitation of the conventional die forging can be eliminated by the use of precision die forging in the closed dies. Manufacturing by drop forging of a spur gear will consist of one forming operation – precision hot die forging in closed die from a ring semi-product (billet). Two basic alternatives of the ring billet dimensions suitable for precision die forging are illustrated in Figure 3 (Cai et al., 2004).

The following compensation method has been designed for both variants of billet dimensions (shown in Figure 3):

- An axial compensator placed between lower and upper die, illustrated in detail 1 in Figure 4, is suitable for the alternative in Figure 3a),
- A container compensator placed bellow a hub of drop forging, illustrated in detail 2 in Figure 4, is suitable for the alternative in Figure 3b).

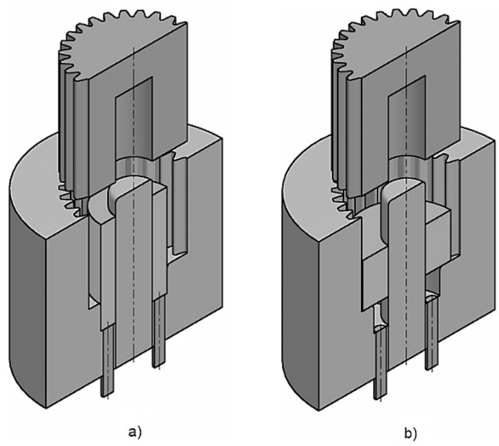

Figure 3. Design of the forging tool with possible alternatives of billet dimensions 4a), 4b)

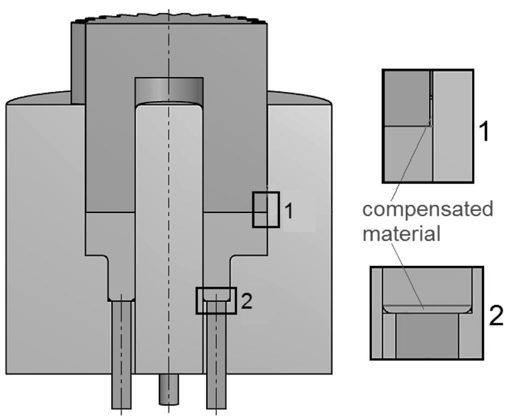

Figure 4. Method of material surplus compensation

4. Computer Simulation

Computer simulation is useful solution for prediction of the course of process and material behaviour in die cavity. In this way, it is possible to optimize the tool shape and design technological process and by that to considerably reduce financial costs of pre-production stages and production itself. Utilization of computer simulation at the forging processes allows also increase in quality of drop forgings and tool life (Kapustova, 2010).

Suitability of material flow in die cavity, effective plastic strain, effective stress and temperature of drop forging have been studied using the simulation software Simufact.forming (Simufact. forming, 2011). The program uses finite element method (FEM) and finite volume method (FVM). For starting the simulation it is necessary to properly define requires proper definition of the input data. For starting a simulation of a spur gear the following input data were defined:

- process - closed die forging in heat

- material of billet - DIN 17210 (1.7131)
- material of the tool - DIN 17350 (1.2344)
- temperature of billet - 1 100°C
- temperature of the tool - 250°C.

The picture illustrated in Figure 5 shows that the material flow in die cavity of closed die by the forging with ring billet placed in the bottom of a hub is wrong because of the relation of the lead. It is possibly to state that the designed dimensions of billet in Figure 3a) are incorrect and they do not guarantee faultless manufacturing of the given drop forging by hot forging.

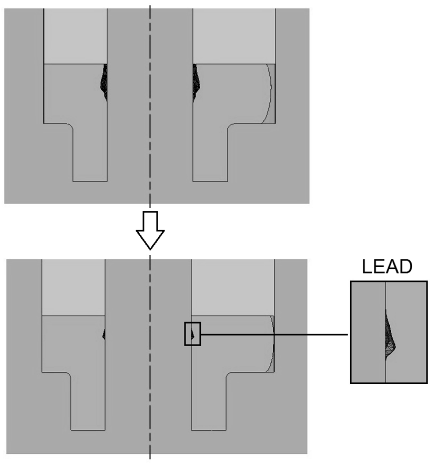

Figure 5. Incorrect material flow in die cavity

Computer simulation of material flow in die cavity where the ring billet is placed on the bottom surface of a ring with toothing is shown in Figure 6. Suitable material flow in die cavity in the temperature of hot forging for the dimensions of ring billet shown in Figure 3b) has been evaluated with the help of computer simulation. Both the progress of effective plastic strain and temperature areas of drop forging, where the ring billet fits on the bottom surface of a ring with toothing have been evaluated. The results of computer simulation are shown in Figure 7.

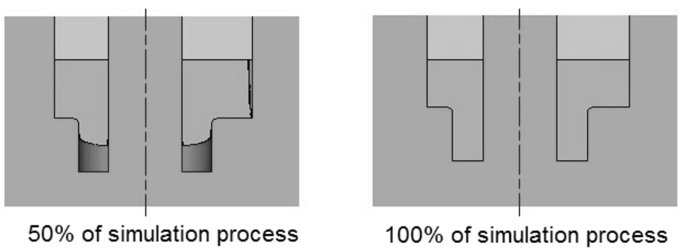

Figure 6. Suitable material flow in die cavity

5. Discussion

The choice of billet dimensions and design of the forging tool is very important for the design of the technological parameters of precision die forging. Two basic alternatives of ring billet dimensions and the shape of die cavity for the manufacturing of given drop forging of a spur gear have been considered. Improper material flow in die cavity where the ring billet fits on the bottom of the hub, has been detected during simulation. This improper material flow creates the increasing of forging load. The lead has been created near the forging spike in the area of ring with toothing. Optimal material flow in die cavity can reached in precision hot die forging in close dies with the use of ring billet placed on the ring and container compensator placed bellow a hub. The lower part of the teeth has been filled out firstly. The final filling in die cavity was ended when the fillets on the bottom of a hub were filled. Results show that the highest effective plastic strains were in the area of the fillets from toothed ring into the hub. The lowest effective plastic strain was in the area near the bore of the drop forging. Further results of effective stress show that the highest values happened to be in the area of the toothing and in the lower part of a hub.

Comparison of charging weight between the present and designed forging method of drop forging of a spur gear is shown in Table 2. Comparison of material costs for conventional and precision die forging of drop forging of a spur gear is illustrated in Figure 8.

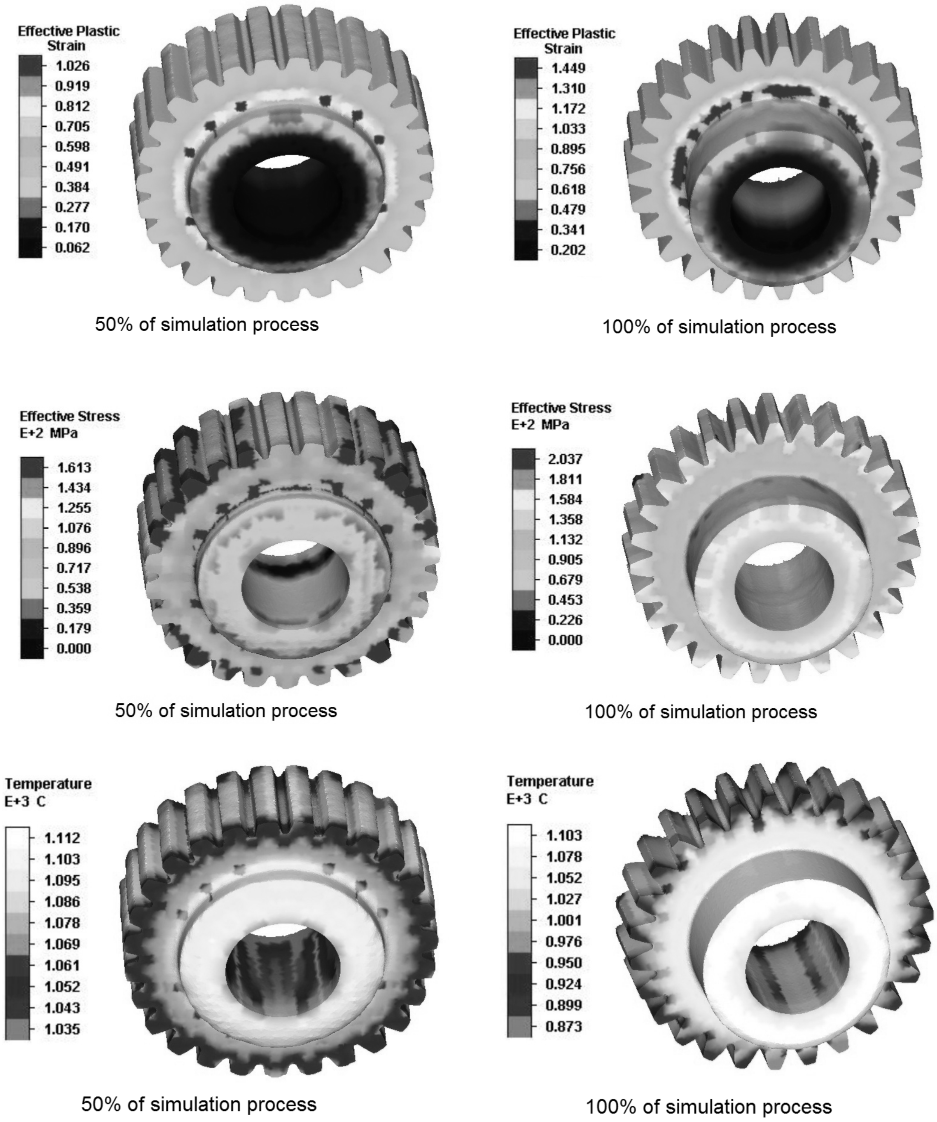

Figure 7. Results of computer simulation at the various stages of simulation process

Table 2. Comparison of charging weight of drop forging

Method	m_F [kg]	m_W [kg]	m_C [kg]
Conventional die forging	0.89	0.16	1.07
Precision die forging	0.55	0	0.57

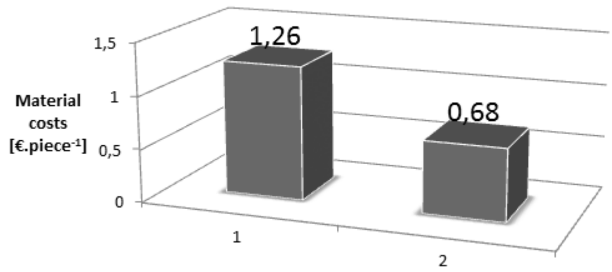

Figure 8. Comparison of material costs for drop forging

1 – conventional die forging, 2 – precision die forging

Regarding the calculation of material costs, the following cost formula is used:

$$S = m_C.c_{MAT} - m_W.c_W \text{ [€]}, \quad (1)$$

where: m_C – charging weight [kg], c_{MAT} – price of the steel DIN 17210 (approx. 1.20 €.kg^{-1}), m_W – waste weight (flash+web) [kg], c_W – waste price (approx. 0.16 €.kg^{-1}).

$$m_C = m_F + m_{FLASH} + m_{WEB} + m_S \text{ [kg]}, \quad (2)$$

where: m_F – weight of finish drop forging [kg], m_{FLASH} – weight of flash [kg], m_{WEB} – weight of web [kg], m_S – weight of scale [kg].

6. Summary

Precision die forging in closed dies has shown that is an efficient method of drop forging production compared to the conventional one. Optimal material flow in die cavity can reached in precision hot die forging in close dies with the use of ring billet placed on the ring and the container compensator placed bellow the hub. In comparison with conventional hot die forging of a spur gear with flash, it is possible to save material costs by more than 40 percent when using precision die forging in closed dies. This will help to compete internationally by offering a better quality at lower cost.

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