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Technical Paper

A forming technology of spur gear by warm extrusion and the defects control

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ABSTRACT

A forming process of spur gears by warm extrusion is proposed, the forming defects existing in this process such as the insufficient section of gear face and the underfilling of gear tooth which result in the geometrical dimensions of gear tooth are substandard or machining allowance is overlarge are discussed by using the numerical simulation method. The main reason causing the insufficient section of gear face is unbalanced velocity field distribution during the extrusion process; the lubricating condition and the die structure are two decisive factors. The die structure and extrusion speed are optimized by using the Response Surface Method with the goals of defects control and machining allowance optimization. The influence rules of PVR (Profile Variable Ratio of entrance section), PVR′ (Profile Variable Rate of entrance section) and the extrusion speed on forming quality are investigated, the prediction models of the machining allowance of gear face, tooth flank and tip are established. The accuracy of prediction models is verified by implementing numerical simulation and experiment. This work provides one of the feasible ways to manufacture spur gears with the whole gear teeth in the field of plastic forming.

1. Introduction

The traditional manufacturing method of spur gears is machining tooth from a forged round billet which has the disadvantages of low utilization of material and high cost. Especially, the comprehensive mechanical performance of gear parts is weakened as a result of metal fibers having been cut off. One method can effectively overcome the above shortcomings, preformed gear blank with whole tooth by using the forming technology, and then machining for the high-precision gears. This method is also beneficial to enhance the comprehensive mechanical performance and light weight of gear parts, because of retained metal fibers and increased power density [1].

Forging of gears is one of the forming technologies first suggested and extensively researched. Closed-die forging [2–4], divided flow method [5], floating die design [6] and a series of improved technologies have been developed. The main purpose of forging is to reduce the forming load and improve the forming precision. Although many breakthroughs have been made with the unremitting efforts of the academics and the engineers over the past decades, the contradictory relationship between forming load and forming precision is still not perfectly resolved. Therefore reduced the forming load and improved forming quality are still research focuses in recent years. Such as four alternatives of die designs, die is elastically attached or rigidly to machine bed with a flat or chamfered punch are discussed by Cai, Dean and Hu. The influences of different designs on the metal flow and load requirements through experiments and finite element simulation are investigated to reduce the forming force and improve the forming quality [7]. A new technological scheme for the cold forging of spur gears, in which the punch and bottom end faces are changed in order to lower the forming load, has been investigated by Hu et al. [8]. And they proposed a hypothesis of radial rigid-parallel-motive (RPM) flow mode, based on the RPM mode a novel specific gear forging technology is put forward by introduced upend forging process and constrained divided-flow technique. Compare with the conventional forging process, the forming force of the forging process put forward by them can be decreased about 35% [9]. The material analyses and forging tests presented by Behrens and Odening to prove an influence of material on the shrinking characteristics of hot forged parts, then the expectable shrinking of the formed teeth

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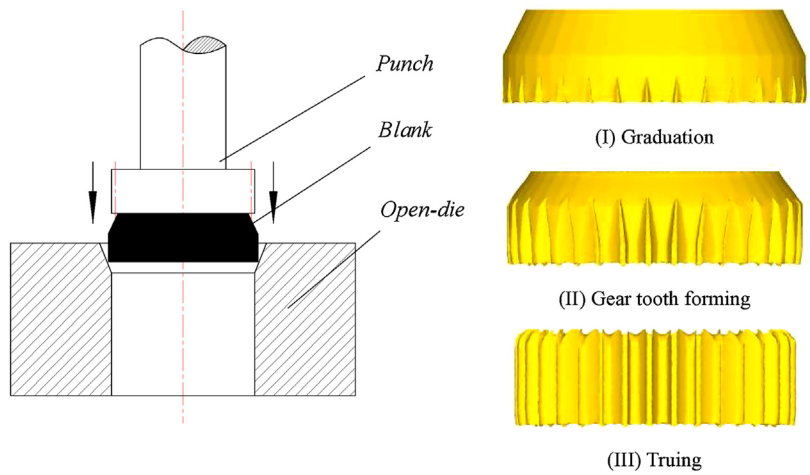

Fig. 1. Model of warm extrusion of spur gear with open-die and forming process.

contour is compensated by a geometric correction of the forging die to improve the accuracy of the forged gears [10].

Compared with the forging of gear, the open-die extrusion has the advantage of lower forming load, which has the great significance to prolong the die life [11,12]. Pinions and splined shafts that are with small modules have been manufactured by the extrusion [13,14]. Warm extrusion technology is a combination of the warm forming and the extrusion process, which has a series of obvious advantages. (1) Compared with the hot forming, this technology can effectively reduce the metal oxidation and decarburization; prevent overheating, overburning and grain growth. (2) Compared with the cold forming, this technology can manufacture large module gears, and avoid material cracking. (3) Compared with the gear forging process, this technology can overcome the problem of which the forging force is too large causing premature die failure [15–17].

Based on advantages of the warm extrusion, it is more applicable to manufacture the large module spur gears. However, because of the warm extrusion technology belongs to the open forming, the poor forming quality becomes a bottleneck of industrial application. The defects result in a large waste of gear face and the geometry size of gear tooth can not meet the requirements. In this paper, the reasons of causing the forming defects are analyzed, the die structure and extrusion speed are optimized by using the Response Surface Method (RSM) for defects control and improving the forming quality. The forming process of spur gear by the warm extrusion is developed. This technology provides one of the feasible ways to manufacture spur gears with the whole gear teeth in the field of plastic forming.

2. Warm extrusion process of spur gear and cause analysis of forming defects

2.1. Warm extrusion process of spur gear

The model of warm extrusion of spur gear with open-die and the forming process details are shown in Fig. 1. It consists of three stages. (I) Graduation stage, (II) Gear tooth forming stage, and (III) Truing stage. The structure of the punch adopts a gear-like design that is equivalent to a standard gear with its addendum being cut off. The structure of the open-die includes the entrance section and the forming section, as shown in Fig. 2. The entrance section has a correlative entrance angle (α) and height (H). The forming section has toothed contour by offsetting from the finished gear, the offset value is Δ for machining allowance. The deformation

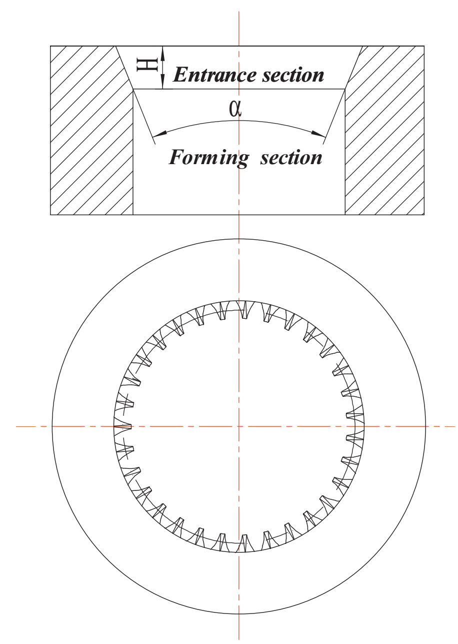

Fig. 2. Structure of the open-die.

zone is concentrated on the outer zone of blank and the inner zone only rigid translation during the extrusion of gear. The strains of outer zone include reverse axial strain caused by friction, besides radial strain. So the initial blank is chamfered on its head.

2.2. Cause analysis of forming defects

Fig. 3 shows an extruded gear with the typical defects such as the insufficient section of the gear face and the underfilling of the

Fig. 3. Extruded gear with the insufficient section of gear face and the underfilling of gear tooth.