Journal of Materials Processing Technology 229 (2016) 450–466

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Numerical simulation and experimental study on multi-pass stagger spinning of internally toothed gear using plate blank

Wenchen Xu[a,*], Xiaokai Zhao[a], Debin Shan[a,**], Jiumao Li[a], Qiang Deng[b], Xuchang Cui[b], Zhiyuan Li[b]

[a] School of Materials Science and Engineering, Harbin Institute of Technology, P.O. Box 435, Harbin 150001, PR China
[b] Changzheng Machinery Factory, Chendu 610100, PR China

ARTICLE INFO

Article history:
Received 26 December 2014
Received in revised form
29 September 2015
Accepted 2 October 2015
Available online 8 October 2015

Keywords:
Stagger spinning
Gear
Defect
Finite Element
Process optimization

ABSTRACT

Internally toothed gears have wide application as transmission components, for which spinning process is attracting increasing attention due to its high production efficiency and low cost. In this paper, a multi-pass stagger spinning process of internally toothed gear from plate blank was investigated through FEM simulation and process experiment. Two passes, i.e., drawing spinning and power spinning, were designed during stagger spinning. The deformation characteristics were analyzed, the mechanisms of spinning defects were revealed and the influences of process parameters were discussed. It is shown that the preform formed by drawing spinning in the first pass contributed to the filling of inner tooth cavity in the second pass. Underfilling and crack in the vicinity of the tooth were two typical defects, which could be effectively controlled through optimizing the spinning process. On this basis, the internally toothed gear was well formed with high productivity by stagger spinning on a CNC spinning machine, showing great potential for industrial application.

1. Introduction

Internally toothed gears are widely used as transmission components, such as clutch hub and planetary gear reducer, in modern automobile industry. Traditionally, those gears are mainly produced by cutting or cold forming process. Slotting and broaching are typical cutting operations. By slotting the teeth are machined incrementally into cup-shaped workpiece. However, the operation is only suitable for small-batch production due to long processing duration and complex tool kinematics. Broaching operation reduces the processing duration significantly, but it can only manufacture ring-shaped instead of cup-shaped inner gears. Compared with the cutting processes, cold extrusion and closed die forging greatly improve the production efficiency and save raw materials, but they demand for large dimensional forming equipment as well as high load which often lead to rapid abrasion of tooling.

Metal spinning has particular advantages for manufacturing rotationally symmetric components, widely used in automobile, aerospace and weapon industries. In recent years, novel metal spinning processes are successively developed to break through the limitation of traditional spinning technology, which are systematically summarized by Xia et al. (2014), wherein spinning forming of inner tooth or rib has attracted much attention because of the low load requirement and simple tooling. Xia et al. (2006) studied the spinning process of inner gear and analyzed the influence of process parameters on forming quality, indicating that the tooth height is non-uniformly distributed in axial direction in case of small wall-thickness reduction, insufficient spinning force, or poor deformability of materials. Moreover, stagger spinning was able to improve the forming quality of inner tooth at the open end of as-spun gear (Xia et al., 2009). Groche and Fritsche (2006) analyzed the bending loads acting on the mandrel responsible for the root breakage at the mandrel's teeth, and proposed a new tool concept of ring principle to prolong the tool life and simplify the mechanical implementation. Based on the relationship between the Berkovich indentation hardness and equivalent plastic true strain, Haghshenas et al. (2011) evaluated the strain distribution during splined-mandrel flow forming, indicated that the highest strain was located on the workpiece/mandrel interface in the thin wall region due to high local deformation in the recessed spline of the mandrel. This result was slightly different from the smooth-mandrel flow forming process (Roy et al., 2009), indicating the

* Corresponding author. Fax: +86 451 86418732.
** Corresponding author.
E-mail addresses: xuwc_76@hit.edu.cn (W. Xu), shandb@hit.edu.cn (D. Shan).

http://dx.doi.org/10.1016/j.jmatprotec.2015.10.001
0924-0136/

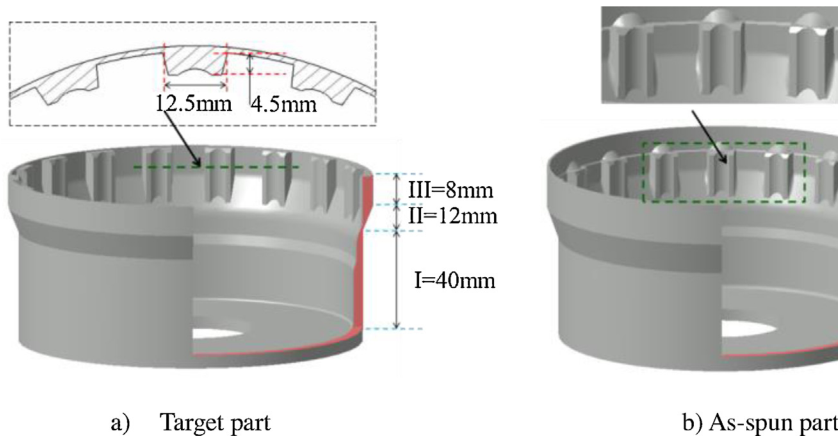

Fig. 1. 3D model of internally toothed gear.

complexity of metal flow and deformation in the vicinity of inner tooth.

To date, the spinning process of internally toothed gear is still not fully developed in spite of the commencement of limited commercial applications in automobile industry. To further simply the production process and increase the productivity, multi-pass stagger spinning of internally toothed gear starting from plate blank is of great potential. Usually, for multi-pass metal spinning, many process factors, such as pass design, roller trajectory, initial blank thickness and thickness reduction, exhibits important influence on the forming quality and productivity of as-spun workpieces, which needs deep understanding of the deformation characteristics and interaction of various passes. Zhan et al. (2007) established a reasonable 3D FEM model for multi-pass spinning including not only spinning process but also springback and annealing processes, providing an effective tool for determination and optimization of process parameters of multi-pass metal spinning. Wang and Long (2011) analyzed the evolution of wall thickness and the stress distribution of local forming zone during multi-pass conventional spinning, revealing the wrinkling failure mechanism at the flange area. Also, they proposed a novel roller path design method to improve the uniformity of wall thickness of spun part (Wang and Long, 2013). Xia et al. (2008) put forward a new multi-pass neck-spinning process to produce non-symmetric offset tube, indicating the feasibility for manufacturing non-symmetric workpiece by metal spinning. However, the multi-pass stagger spinning process of inner tooth starting from plate blank is rarely reported up to now. The filling mechanism of inner tooth and the influence of the preform spinning pass on successive spinning pass are not clear. In this study, FE simulation and experiment study were conducted on multi-pass stagger spinning of internally toothed gear using plate blank. The deformation characteristics in each pass were analyzed, the defect mechanisms and influences of process parameters on the forming quality were revealed. On this basis, the optimized stagger spinning process was obtained and the fully filled inner gear components were produced on a CNC spinning machine in high productivity.

2. Experimental and modeling procedures

2.1. Design of process scheme

Fig. 1a shows the 3D model of internally toothed gear with complex tooth profile, in which 18 teeth were uniformly distributed along circumferential direction. The gear consists of three regions along the axial direction. Region I is a cylindrical section with inner hoop step, Region II is a conical section with the first half of concave tooth and Region III is a cylindrical section with the second half of concave tooth. The outer diameter and height of Region I are 139.0 mm and 40.0 mm, respectively. The outer diameter and height of Region III are 148.0 mm and 8.0 mm, respectively. The total axial length of the gear is 60.0 mm and the maximum tooth height is 4.5 mm. To improve the filling of inner tooth tip, the projection blocks were added to the noses of the inner teeth in as-spun gear part to increase machining allowance (see Fig. 1b), which were then removed in the subsequent cutting process. To improve the production efficiency, the stagger spinning process starting from plate blank was adopted in the present work. Fig. 2 presents the spinning scheme for the gear consisting of two passes. In the first pass, the circular plate blank was flow formed into a conical preform under the action of drawing spinning. In the second pass, the internally toothed gear was progressively formed by power spinning.

2.2. Experimental details

Due to the complex contour of the gear, high impact load caused by severe plastic deformation occurred in the spinning process, thus a three-roller CNC spinning machine with good stiffness and anti-vibration was used in the experiment. Three rollers with different tip profiles were used to improve the forming quality of inner tooth. The spinning process was carried out automatically in two successive passes without inter-pass pause. Due to high processing velocity during stagger spinning, the as-spun workpiece was strongly cooled by liquid emulsion to avoid temperature rising and material softening in the spinning process. The as-spun gear component was sectioned axially through the tooth profile for microhardness test, conducted on a Vickers hardness tester under a load of 3 N and holding time of 15 s.

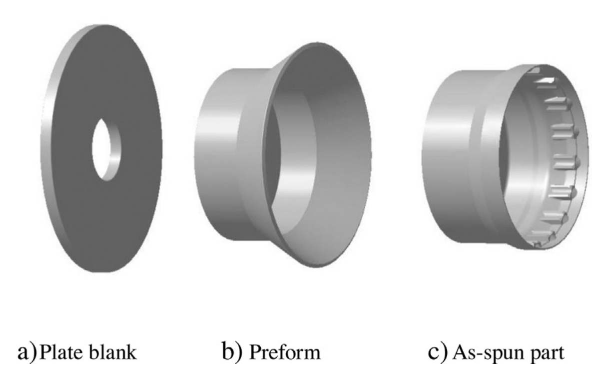

Fig. 2. Spinning process scheme of internally toothed gear.