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Development of a Non-isothermal Forging Process for Hollow Axle Shafts

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Abstract

This paper presents a novel non-isothermal forging process for a hollow axle shaft. The process consists of three operations: i) partially heat the initial tubular stock via induction heating, ii) deform the heated section into a solid, rod-like structure by upsetting the workpiece, and iii) shape the new 'solid' section into a flange by further upsetting the workpiece. The commercial finite element software Deform 2D is used to simulate the process and evaluate its feasibility. It is determined that the non-isothermal forming process does not require excessive forming loads and can be completed using the presses that are currently employed for axle shaft forging. Furthermore, the strains encountered in the process are reasonable for a hot forming process and the dimensional accuracy of the final product is acceptable. Future optimization of this process may lead to improved strain distributions and forming loads.

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Keywords: non-isothermal, forging process, hollow shaft

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1. Introduction

Due to increasing scrutiny into the fuel consumption and emissions of class 7 and 8 heavy duty vehicles (HDV), reducing vehicle weight is becoming increasingly important to HDV manufacturers. One of the most effective ways to do this is to create light weight power transmission components, because the powertrain accounts for 48% of weight of the HDV [1]. Major strides in this direction can be made by simply switching from the conventional, solid shafts employed in HDV powertrains to hollow components [2,3]. However, the switch to hollow shafts is expensive due mainly to the specialized equipment and operations that are required to fabricate complex hollow structures. The currently available manufacturing techniques for producing hollow power transmission shafts include rotary swaging, flow forming, spinning extrusion combined with cross rolling, tube hydroforming, extrusion combined with deep drilling, and extrusion followed by friction welding. Each of these techniques has its strengths and weaknesses, but they generally suffer from drawbacks, such as the low production rate, numerous operations, costly equipment. A brief review of the hollow forming techniques is given as a review of current capability with respect to the manufacture of hollow shafts.

Rotary swaging is an incremental cold forming process that can be used to produce hollow shafts by shaping the outside diameter of a workpiece using radially oscillating dies. Another form of rotary swaging, axial radial forming, can not only reduce the outer diameter of the workpiece, but also increases the wall thickness along target regions of the shaft. As a cold forming process, rotary swaging and axial radial forming take advantage of improved mechanical properties, tight tolerances, and good surface finishes. Although rotary swaging and axial radial forming have high flexibility in terms of shaping the exterior and manipulating the wall thickness of the part, high equipment cost and low production rate limit their application [4-6].

Flow forming deforms a rotating metal tube into a stepped axisymmetric part using mandrels and rollers. It locally shears the material between the roller and the mandrel and displaces it axially. Because the exterior shape of the workpiece is dictated by the kinematic motion of rollers, flow forming is able to form several steps at various axial positions with simple tool design and low tool cost [7, 8]. However, it is difficult to produce flanges with large aspect ratios utilizing flow forming.

Spinning extrusion is process that can be used to produce hollow and stepped axisymmetric parts from a sold billet with a spinning roller shaping the exterior and a punch forming the interior. However, products with a deep features and small diameters are beyond capabilities of spinning extrusion [9-11].

Stepped hollow shafts can also be produced by a combination of extrusion and deep drilling, where extrusion operation is used to shape outer geometries and deep drilling to create inner geometries [5]. However, material waste and tool wear are two main disadvantages of the process. Another technique that has been used to produce hollow shafts is based on a combination of extrusion and friction welding. In this process, backward extruded cups are joined by friction welding to produce a shaft. The major limitation of this process is the fact that it requires numerous operations on different equipment, making it unattractive for mass production [5, 12].

In order to realize cost effective hollow power transmission shafts, it is necessary to develop a forming process that utilizes equipment and techniques that are simple and i) either already used to make these components, or ii) inexpensive and easy to implement into current factory environments. This research focuses on achieving this goal by proposing a new non-isothermal forging technique that utilizes current automotive presses to create hollow structures from tubular stock. In this study, the heavy duty rear axle shaft is used as an example part to demonstrate how the non-isothermal forging process may be applied to create hollow shafts with flanged or upset features.

2. Forging Process Design

The axle shaft itself is a narrow, pole-like part with a flanged end that connects a wheel to the gears in the differential. It transmits torque from the differential to the wheel and, in some cases, bears the weight of the vehicle. Unlike the conventional solid axle shaft, the targeted hollow axle shaft geometry is composed of a solid flange and a tubular body, which is shown in **Fig. 1**. The conventional solid shaft is forged by first heating the portion of the shaft that is to be deformed with induction coils followed by one or more upsetting blows carried out with a specialized press. The non-isothermal forging process uses a tubular workpiece as the feed stock and is composed of the three operations: i) induction heating, ii) upsetting and iii) flanging. **Fig. 2** shows the steps of the