Journal of Materials Processing Technology 240 (2017) 1–11

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

A new method for manufacturing hollow valves via cross wedge rolling and forging: Numerical analysis and experiment validation

Hongchao Ji, Jinping Liu*, Baoyu Wang*, Xiaobin Fu, Wenchao Xiao, Zhenghuan Hu

School of Mechanical Engineering, University of Science and Technology Beijing, Beijing 100083, China

ARTICLE INFO

Article history:
Received 6 September 2015
Received in revised form 23 August 2016
Accepted 6 September 2016
Available online 8 September 2016

Keywords:
Hollow valve
Cross wedge rolling-forging
4Cr9Si2
Finite element analysis

ABSTRACT

Cross wedge rolling-forging (CWR-forging) is an innovative process for local plastic deformation that is suitable for forming hollow valves. This paper presents the numerical and experimental results of hollow valve production using this new method. The most popular production methods are described. Then, this study examines the formation of such valves through CWR-forging. A numerical model of CWR-forging using the finite element method (FEM) is developed to estimate the technological viability of this process. The distributions of effective strain, temperature, metal flow, force, and torque are analyzed as well. In this study, changing the stretching angle (β) can effectively avoid swollen holes. therefore, the forming quality of the workpiece can be greatly improved when the forming angle (α) is equal to 35° and the stretching angle (β) is equal to 5° and 4° in the knifing and stretching zones and the mandrel diameter is 4 mm, respectively. Numerical results are then verified under laboratory conditions. Experimental results are consistent with the FEM results, thus confirming that hollow valves can be produced through CWR-forging.

1. Introduction

In 2014, global vehicle production and sales reached 89 million vehicles (Qqjjsj, 2015). Each vehicle contains four cylinders, and each of the cylinders contains four valves. Thus, the demand for valves could reach 1.42 billion for new cars alone. Engine valves are traditionally solid, and the manufacturing process is mature. However, the solid valves developed for strengthening treatment still fail to satisfy current demands because of the constant development of new high-speed and high-load engines. Hollow valves can reduce weight significantly. Moreover, the hollow part of a closed cycle cools liquid sodium, lowers working temperature, saves energy effectively, and reduces emissions. Hollow valves are more efficient than solid ones; therefore, hollow valves must be produced for new-generation vehicles. Two methods are used to produce hollow valves: drilling into solid valves and reverse extrusion. However, these methods have many disadvantages, which include the following: 1) High manufacturing costs; 2) Low production efficiency; 3) Low material utilization ratio; 4) Complex manufacturing process.

Given the current mode of production, the requirements of modern manufacturing are difficult to meet. Therefore, an advanced manufacturing technology must be developed for hollow valve production.

A number of studies have been conducted on valve production. Tulsyan and Shivpuri (1995) analyzed a forging process for automotive engine valves. The important process parameters that affect die wear during the extrusion of exhaust valves were analyzed. Die wear is mainly influenced by velocities, temperatures, and pressures at the workpiece and die interface. Ji et al. (2015) used cross wedge rolling (CWR) and forging technology to produce solid engine valves. Using CWR and forging to form valves is feasible. The valves formed via this process do not cause unsatisfactory filling after forging. Biba et al. (1998) simulated the coupled problem of electrical upsetting in valves. Their method is based on a mixed formulation and provides a simulation of heat generation in conjunction with the coupled thermo-mechanical problem of non-steady-state viscoplastic material flow. Jeong et al. (2006) simulated the electrical upsetting and forging processes for the large exhaust valves of marine diesel engines. The manufacturing process was simulated through the finite element method (FEM) to predict the optimum process condition of an exhaust valve with a diameter of 73 mm. This optimum condition was derived from the simulation results. Jeong et al. (2005) also predicted the microstructure of Nimonic 80A for a large exhaust valve during hot closed die forg-

---

* Corresponding authors at: School of Mechanical Engineering, University of Science and Technology, No. 30 Xueyuan Road, Haidian District, Beijing 100083, China.
E-mail addresses: liujp@ustb.edu.cn, jhustb13@gmail.com (J. Liu), bywang@ustb.edu.cn (B. Wang).

http://dx.doi.org/10.1016/j.jmatprotec.2016.09.004
0924-0136/

ing. The grain size of forging part was consistent with the simulated results.

At present, countries worldwide have been establishing new technologies to develop hollow valve production to reduce costs and improve quality. In 2012, Mitsubishi Heavy Industries (2012) proposed a process in which a hollow valve rod and head are used to form hollow cylindrical blanks through cold forging. Morii and Yoshimura (2012) invented a method for manufacturing hollow valves. The stretching process involves the drilling of differently shaped holes in the hollow shaft. Thus, the shaft is molded into a specific shape. Kroos et al. (2014) presented another method for manufacturing hollow valves, in which a valve is divided into the hollow valve rod and the hollow valve head through rotating friction welding. Cooper et al. (2015) applied a layer manufacturing design to produce a hollow valve. They used the additive layer manufacture method (ALM) to design and manufacture a high-performance hollow valve, but the cost is very high. The production of ALM valves is suited only to high value motorsport applications.

CWR is a plastic forming process in which cylindrical workpieces are deformed into axisymmetric-stepped parts using two or more wedge tools that move along the tangent direction of the workpieces (Fu and Dean, 1993). The process is performed at an elevated temperature to generate low deformation forces. CWR possesses the following advantages: high production efficiency, low material cost, and high material utilization rate. Many scholars have conducted extensive research on CWR solid pieces. Li and Lovell (2003) predicted critical friction in a two-roll CWR process. The method uses Bowden and Oxley's friction models to obtain the critical rolling condition in CWR as a direct function of tool geometry and workpiece area reduction. Dong et al. (2000) analyzed the stress in CWR with application to failure. A number of studies have been conducted on the CWR process for hollow shaft production; for instance. Urankar et al. (2006a, 2006b) studied CWR theory and technology for hollow shaft parts. Experiments and finite element (FE) simulations were performed to determine the unstable conditions induced when the hollow shaft of a CWR plate piece is flattened. The failure conditions for the CWR of hollow shafts have also been established (Urankar et al., 2006a,b). Pater et al. (2015) presented numerical and experimental findings regarding the production of hollow parts using a new method of rotary compression. The researchers analyzed wall thickness on the basis of the rotary compression process for hollow parts. Similarly, Tomczak et al. (2015) analyzed wall thickness according to the rotary compression process for hollow parts. The distributions of effective strain and temperature were determined with the FEM. Winiarski et al. (2015) employed a new process for the formation of triangular flanges in hollow shafts from a Ti6Al4 V alloy. Numerical calculations were performed with the DEFORM-3D software. The conducted research for the alloy Ti6Al4 V confirms the effectiveness of the proposed method. Bartnicki and Pater (2004) studied the application of a three-roll CWR without a mandrel in the formation of hollow shafts. Bartnicki and Pater (2005) also analyzed the parameters of the CWR process through numerical simulation. Moreover, the plate wedge rolling processes of hollow shafts were examined comparatively. Composite processing technology is another important component of advanced manufacturing following the development of this technology. Kache et al. (2011) used the CWR operation for warm forging processes. Cross wedge rolled samples were tested at different temperatures. The microstructure and mechanical properties of rolled pieces were analyzed. Kache et al. (2012) combined the advantages of warm forging and CWR to develop a new process chain. The downsizing of CWR processes for experimental analyses to measure technological and monetary efforts is possible. Zhuang et al. (2015) applied roll-forging technology in the production of automotive front axle beams. The numerical and experimental results of their study showed a good agreement. Research results have important significance for comprehensively revealing the macro-deformation laws of the roll forging of automotive front axle beams. Meyer et al. (2015) generated crankshafts through CWR and the bidirectional forging of preforms. This process chain includes a CWR step, a lateral extrusion step, a bi-directional forging step, and a final forming step. At present, no research has explored the rolling preforms for hollow valves via the CWR-forging process.

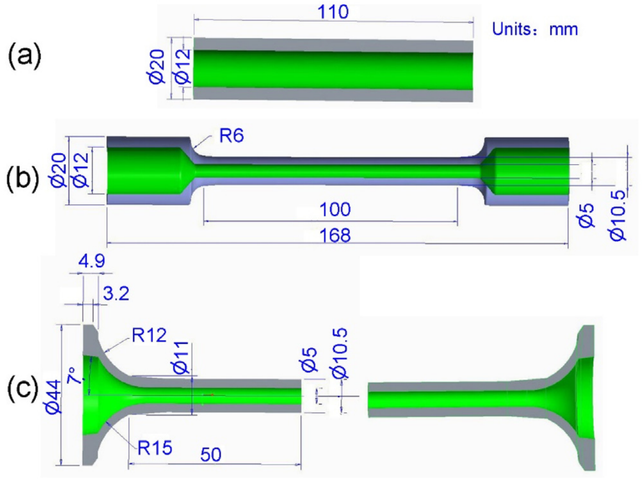

Fig 1. Diagram of CWR-forging for hollow valve blocking, (a) workpiece (b) CWR for rod formation (c) forging valve head.

The current paper presents a new process for forming hollow valve blanks through CWR-forging. At present, CWR is mainly applied to low alloy steel with large diameters (d > 25 mm). This steel is used to produce solid shaft parts. However, CWR is rarely used for heat-resistant hollow alloy shafts with small diameters (6–20 mm). CWR hollow valves are composed of materials with poor plasticity and hollow workpiece stability. Such valves are difficult to control given their small diameter. Nonetheless, these difficulties are easy to overcome.

Fig. 1 depicts the application of CWR to hollow valve blanks. The pipe material (Fig. 1(a)) is rolled out on the middle part of an elongated rod (Fig. 1(b)). Intermediate cutting can then be performed with a hollow valve blank. Finally, the forging process is initiated to generate a hollow valve blank (Fig. 1(c)) using the gas valve head and rod head for friction welding. This study focuses on the CWR-forging process.

CWR offers the following advantages over existing technology:

1) Production efficiency is high, with a billet of 6–12 per minute.
2) Precision is high, and consistency is good. These factors can improve the finished product rate by up to 99%.
3) Blanks can be obtained under the conditions of deformation, grain refinement, and uniformity. These blanks are conducive to improving the overall mechanical properties of valves.
4) The preform rod cavity is large. The valve head is hollow too.

The precise formation technology of the CWR-forging process for hollow valves is used to generate hollow valves with a near net shape and improve the organization performance and fatigue life of these valves. This technology is an innovation of the CWR technology. The method is advantageous given its high production efficiency, simplified production process, material and energy saving capability, enhanced mechanical properties, low cost, use of simple equipment, environmental friendliness, and easy-to-realize mechanization and automation, among other factors.