Journal of Materials Processing Technology 214 (2014) 311–317

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

On a new concept of rotary draw bend-die adaptable for bending tubes with multiple outer diameters under non-mandrel condition

T. Wen*

College of Materials Science and Engineering, Chongqing University, Chongqing 400044, China

ARTICLE INFO

Article history:
Received 19 May 2013
Received in revised form
10 September 2013
Accepted 14 September 2013
Available online 23 September 2013

Keywords:
Tubular products
Tube forming
Rotary draw bending
Numerical simulation

ABSTRACT

A traditional rotary draw bending die on the numerically controlled (NC) tube benders or other benders can bend tubes with only one kind of outer diameter. It is difficult for such a situation to meet the requirement of modern manufacturing with characters of much varieties and small batch. The present study proposed a new concept of rotary draw bending die called MDB-Die (Multiple-diameter Bending Die), on which tubes with different outer diameters within a definite range can be bent using the same die by only adjusting the pads inside the die set. Numerical and experimental approaches were employed to investigate the forming process of tubes with different outer diameters when bent on the MDB-Die, especially on the characters of force and elastic-plastic deformation of tube wall, and the effects of groove shapes and bending parameters on the cross-section distortion and wall thinning in the process. Analytical expressions in simple tube bending based on plastic theories given by Tang (2000) for calculating the magnitude of stresses, together with the wall thickness change, deviation of the neutral axis, and section flattening, were also used for comparison. The result proved that tubes with different outer diameters (from 18 to 25 mm in the study) can be bent successfully on MDB-Die without degrading the bending quality, i.e., the aspect ratios of section distortion of less than 5% and wall thinning of less than 7.8%.

1. Introduction

As important lightweight structures and liquid conveying or heat exchanging components, metallic tubular parts are widely used in the fields of aeronautics and aerospace, automobile, oil and chemical industries, etc. It has great advantages of efficiency, cost, and quality when tubular productions are made by plastic forming technologies. Among them, bending is most commonly used, and till date, numerous tube bending approaches, such as rotary draw bending, press bending, drawing bending, and pushing bending have been developed in response to the diverse demands of tube specification, shapes, materials and forming tolerance. Due to the characters of high efficiency, stable quality, and ability to form tubular parts with complex shapes, rotary draw bending is the dominant approach and is used on most of the tube benders, especially the numerically controlled (NC) tube benders.

During the rotary draw bending process, complex uneven tension and compression stress distributions are induced in extrados and intrados of the bent tube, which may cause multiple defects or instabilities such as cross-section distortion, wall thinning (even cracking), wrinkling, and springback. Till date, as Yang et al. (2012) summarized, many studies have been conducted on tube bending, and most of them are concentrated on the analysis of multiple defects/failures, selection/optimization of the forming parameters, and tooling to promote the development of tube bending science and technology by using experimental, analytical, and numerical methods. Al-Qureshi (1999) employed plastic-deformation theory to calculate stress distribution and bending moment, which are needed for springback analysis. Orynyak and Radchenko (2007) proposed an analytical method for the investigation of the end effect in a pipe bend loaded by a bending moment with consideration for the action of internal pressure. Megharbel et al. (2008) introduced a theoretical analysis of the elastic–plastic bending of tube and section made of strain-hardening materials, while Li et al. (2007) discussed the role of mandrel in NC precision bending process of thin-walled tube.

Due to the complex physical and geometrical nonlinear characters of the plastic deformation in most tube bending processes, it is difficult to obtain comprehensive results by just using the analytic approaches; thus, numerical methods like FEM have been frequently used in the studies of tube bending in recent years, for example, Li et al. (2009) studied the deformation behaviors of thin-walled tube NC bending with large diameter and small bending radius via a series of 3D-FE models under ABAQUS platform. Meanwhile, attempts on the renovation of tube bending techniques have never ceased; e.g., the proposals of Free-Bending given by Gantner

* Tel.: +86 13018363383; fax: +86 23 65112879.
E-mail addresses: wentong@cqu.edu.cn, tonywen68@hotmail.com

0924-0136/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jmatprotec.2013.09.019

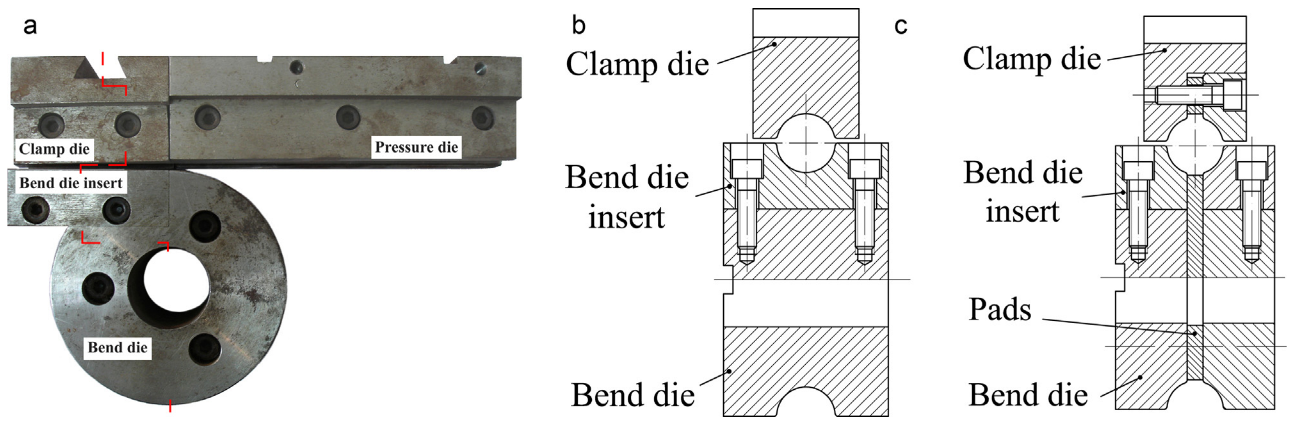

Fig. 1. Structure of the rotary draw bending die assemblage. (a) A set of rotary draw bending die (b) Section of traditional die (c) Section of MDB-Die.

et al. (2005) and Shear Bending given by Goodarzi et al. (2005), and the introduction of local induction heating in the bending of a large-scale pipe (Hu, 2000). Recently, with the increasing demand of light metal in some high-technological industries such as aeronautics and aerospace, bending of non-ferrous metal tubes have attracted more and more attention. For example, Wu et al. (2008) studied the bendability of the wrought magnesium alloy AM30 tubes using a rotary draw bender; Li et al. (2012) studied the springback characterization and behaviors of high-strength Ti—3Al—2.5V tube in cold rotary draw bending, while Lăzărescu (2013) investigated the effect of internal fluid pressure on quality of aluminum alloy tube in rotary draw bending.

However, in the existing techniques of tube rotary draw bending, a die set can bend tubes with only one kind of outer diameter. The whole die set must be replaced if the outer diameter of the tube is changed; thus, beyond all doubt, this would increase the cost and lower the efficiency. The current study put forward a novel concept of rotary draw bending die called Multiple-diameter Bending Die or MDB-Die based on one of the author's (Wen and Chen, 2009) former work, on which tubes with different outer diameters within a relative wide range can be bent on the same die by simply adjusting the shape of the die groove. Numerical and experimental methods were employed to study the elastic-plastic deformation of the tubes with different outer diameters when bent on MDB-Die without the use of a mandrel. The main purpose of the study was to obtain the fundamental understanding of the effect of groove shapes on the section deformation and wall thickness of the bent tube, and then prove the practical validation of such a concept.

2. Principle of the MDB-Die

Traditionally, a rotary draw bending die is an assemblage composed of a bend die and die insert, a clamp die and a pressure die, as shown in Fig. 1. Sometimes, a so-called wiper die and a mandrel are also used to improve the bending quality. During the operation, after each part of the die set is settled on the corresponding position of the bender, the tube is held tightly between the bend die insert and the clamp die; then, the bend die, die insert, and clamp die rotate together around the axis of the bend die, forming a bent shape. To clamp the tube and accomplish the processing successfully, the outer diameter of the tube should fit the die groove, which is usually a whole circle in section and comprises two semicircles of cavities of the clamp die and bend die insert.

Fig. 1(b) and (c) gives a comparison of the section of a traditional die and an MDB-Die. When compared with the traditional one, both the semicircles on the clamp die and the bend die insert of the MDB-Die are cut into two, between which pads with different thicknesses are inserted and the corresponding parts of the die are fixed together with bolts. As shown in Fig. 2, the groove shape of MDB-Die can be modified by adjusting the thickness of pads, and then tubes with different outer diameters can be held and bent on the same MDB-Die. Certainly, bending process with a MDB-Die is still the same as that with a traditional die.

Let us assume that the initial diameter of the die groove is D. As shown in Fig. 2(a), then D represents the maximum outer diameter of the tubes that can be bent on the die, and the initial thickness of pads is maximum of h_{max}. If the outer diameter d of the tube is less than D, namely, $d < D$, the pads thickness must be decreased to h, and there is

$$h = h_{max} - \Delta h = h_{max} - (D - d) \quad (1)$$

The pads consist of slices with thickness from 0.2 to 2 mm; thus, the whole pads thickness could be adjusted conveniently.

From Fig. 2, it is clear that the groove shape matches the tube outline completely only when the tube has maximum outer diameter, namely $d = D$. The smaller the d is, the larger the groove shape deviates from an ideal circle. Therefore, it is essential to know the deformation of the tubes with different diameters when bent on the MDB-Die.

3. Experimental and theoretical model

The experiment was conducted on an NC tube bender on which the processing parameters such as bending angle and bending velocity can be procedurally settled in advance. Welded tubes of AISI 1020 with a length longer than 300 mm were used; the outer diameter d was 18 mm with 2.5 and 2 mm of wall thickness t, $d = 20$ mm with $t = 2$ mm, and $d = 25$ mm with $t = 2$ mm, respectively. The diameter D of the die groove was 25 mm, bending radius r was 58 mm, and bending angles θ were 30°, 90°, 120°, and 150°, h_{max} was 7 mm, respectively. Under each condition, three tubes were

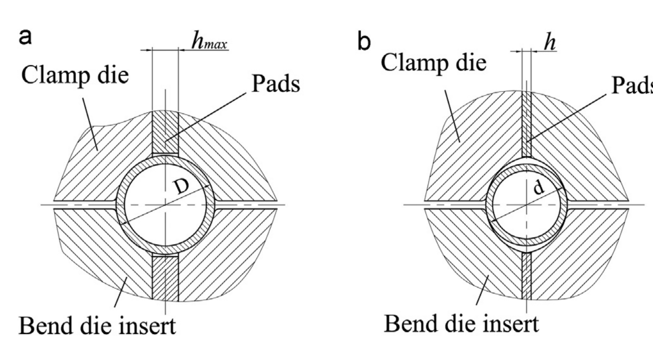

Fig. 2. Groove shape of MDB-Die when bending tubes with different outer diameters. (a) $d = D$, (b) $d < D$.