Journal of Materials Processing Technology 212 (2012) 786–793

Contents lists available at SciVerse ScienceDirect

Journal of Materials Processing Technology

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

Control of wall thickness distribution by oblique shear spinning methods☆

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ARTICLE INFO

Article history:
Received 5 May 2011
Received in revised form 29 October 2011
Accepted 1 November 2011
Available online 6 November 2011

Keywords:
Shear spinning
Sine law
Incremental sheet forming
Thickness distribution control
Deformation behavior

ABSTRACT

A flexible method of forming circumferentially variant wall thickness distributions on the same shape is attempted using two oblique sheet spinning processes. The fundamental strategy entails the inclination of the flange plane of the workpiece during forming. In one type of synchronous dieless spinning, edge-hemmed aluminum blanks are formed for truncated cone shells, by synchronizing the motion of the spherical head roller in the axial and radial directions with the angle of the general purpose mandrel fixed on a bidirectionally rotating spindle. On the other hand, in the other type of force-controlled shear spinning, flat aluminum discs are formed by feeding perpendicularly to the flange plane of the workpiece and maintaining the thrust force along the plane via the roller tool, exerted onto the rotating truncated-cone-shaped die. The estimated wall-thickness distribution based on a simple shear deformation model nearly conformed to the measured thickness distributions of the products formed at several inclination angles of up to 15 degrees in the forming and both spinning methods. The low-cost value-added forming method seems to be practicable not only for metal spinning but also for other incremental sheet forming processes.

1. Introduction

Metal spinning is an age-old forming technique for making axisymmetric shell products from metal sheets or tubes. In recent years, the flexibility of spinning has been enhanced as a result of research and development (Music et al., 2010).

A dieless shear spinning method for a sheet metal was developed by Shima et al. (1997), and truncated cone shells were formed by substituting an inner roller for a mandrel. In another approach investigated by Kawai et al. (2001), cone shapes were formed without using a dedicated die by using workpieces with flange of sufficiently high stiffness to suppress shrink flanging at the forming point.

Some asymmetric spinning methods based on the positional control of a spindle and roller(s) have been proposed. Elliptical shaping in shear spinning was archived by Amano and Tamura (1984) by configuring a mechanical synchronous system between a rotating spindle and a roller moving in the radial direction with cams and links. It was also investigated by Gao et al. (1999) who considered another mechanical setup in which the spindle axis coincident with the revolution is offset. Similar elliptical spinning was presented by Sellin (1955) since a few decades. A flexible spinning machine using a mandrel and a three-dimensional cam was proposed by Xia et al. (2010). The non-axisymmetric spinning of tube blanks was investigated by Arai et al. (2005), who developed a synchronous spinning lathe using a numerical controller that included spindle angle control. Asymmetric shear spinning methods for metal sheets using computerized spinning machines were investigated by Amano et al. (1990). Similarly to the approach, Shimizu (2010) investigated asymmetric shear spinning while measuring axial and radial forces during the process. Härtel and Awiszus (2010) proposed an asymmetric spinning method based on the numerical model. On the other hand, several asymmetric spinning methods based on force control via roller(s) onto a mandrel have been proposed. A spinning method for forming convex and concave tripod shapes using a spinning lathe with spring-driven rollers was investigated by Awiszus and Meyer (2005). A conventional spinning method using fuzzy control based on measurement of forces was proposed by Finckenstein and Reil (1993). A shear spinning method using force control was proposed by Arai (2004), and asymmetric products have been formed by force-controlled spinning (Arai, 2005).

An oblique spinning method involving a tube blank was proposed by Shindo et al. (1999), who developed a novel spinning lathe in which roller tools are moved while rotating around a tube blank.

☆ This paper originally appeared in volume 51, number 597, (2010), page 984–989 of the Journal of the Japan Society for Technology of Plasticity, in Japanese. Under the terms of our special agreement with the JSTP, the paper having been translated into English, has been reviewed by international experts, and revised.

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doi:10.1016/j.jmatprotec.2011.11.002

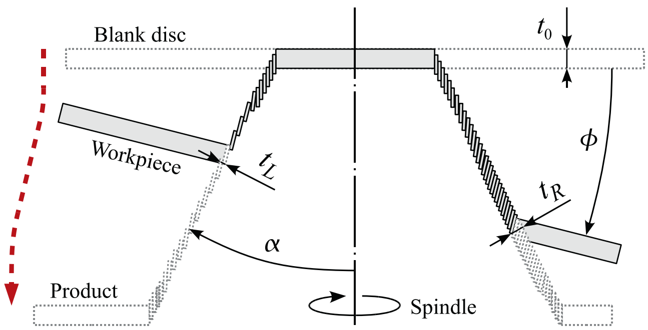

Fig. 1. Relationship among the half-angle, α, the inclination angle, ϕ, and the wall thicknesses in the oblique shear deformation model.

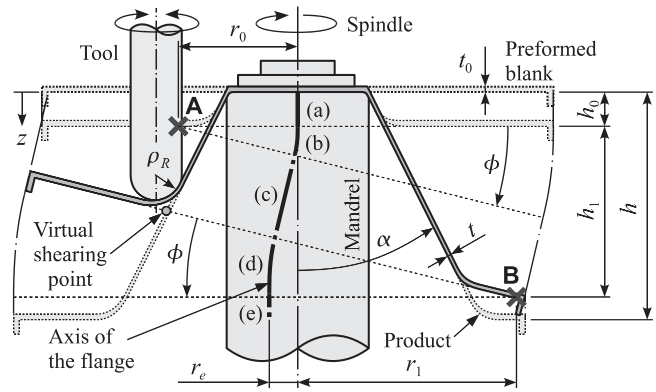

Fig. 2. Schematic of the experiment on controlling the wall thickness distribution in synchronous dieless spinning (half-angle, α; inclination angle, ϕ; original thickness, t_0; final wall thickness, t; axial position, z; height of product, h; initial forming height, h_0; oblique forming height, h_1; radial position of point A, r_0; radial position of point B, r_1; estimated radial displacement of flange, r_e; sphere radius of tool, ρ_R).

The forming force in a similar process was investigated Xia et al. (2006) by finite element simulations and trial forming. In incremental sheet forming (Matsubara, 1994), forming of curved products which differ from the intended shapes can be achieved through a method developed by Matsubara (1995).

In this study, a flexible method of forming products with variable wall thickness distributions on the same shape using the same blanks is investigated. Inclining the flange plane of the workpiece during the process is the fundamental strategy used in this method. Especially, circumferential wall thickness distribution of the product can be varied unlike traditional metal spinning processes.

The conventional spinning of metal sheets and the flow forming of metal tubes are spinning processes in which the axial distribution of the wall thickness of a product is adjustable (Wong et al., 2003). However, it is difficult to adjust the circumferential distribution in metal spinning without using a blank of nonuniform thickness or milling after forming. A spinning method, in which the circumferential distribution can be varied by simply changing the roller trajectory and in which normal low-cost blanks can be used, may be useful for optimizing the strength per unit weight of the product considering external force distribution, equalizing the thickness distribution in asymmetric forming, and keeping sufficient thickness when thread cutting on the wall of the product.

2. Methodology

In shear spinning, the final wall thickness t of a conical product is determined by the half-angle α and the original thickness t_0 of the blank in accordance with the sine law:

$$t = t_0 \sin \alpha. \tag{1}$$

This relation is also valid in previously proposed dieless shear spinning methods (Shima et al., 1997; Kawai et al., 2001), in which the flange plane of the workpiece is kept flat.

In the case of the dieless shear spinning of curved truncated cone shells, a predictive expression based on shear deformation perpendicular to a progressively inclined flange plane was proposed, and it was verified that the model closely coincides with measured thickness distributions along the outer and inner sides of curved cones (Sekiguchi and Arai, 2010a). By applying the model, it is predicted that the wall thickness distribution can be varied while retaining the same shape by altering the inclination angle of its flange plane during the process, as shown in Fig. 1. The wall thicknesses on the left and right sides of the product, t_L and t_R are geometrically calculated from the model using the inclination angle ϕ of the flange plane and the following simple equations:

$$\begin{cases} t_L = t_0 \sin(\alpha - \phi) \\ t_R = t_0 \sin(\alpha + \phi) \end{cases} \tag{2}$$

Similarly to the sine law in Eq. (1), according to this equation, a processed wall cannot be thicker than its original thickness, since the ratio of the wall thickness to the original thickness, t/t_0, is $\sin(\alpha \pm \phi) \le 1$.

In this paper, as indicated in Fig. 2, a product is formed in sequence from (a) to (e) by inclining the flange plane at points A and B in the dieless spinning method. Since the workpiece is rotated by a spindle axis, the position of the spherical head roller tool should be controlled synchronously in the radial and axial directions as illustrated in Fig. 3. The truncated cone was selected as the simplest product shape to investigate the variation of the wall thickness distribution in this study.

However, since the tip of the roller tool is spherical, the wall thickness estimated using Eq. (2) changes with the position of virtual shear deformation. In our preliminary experiments, the wall thickness was estimated along the line intersecting the flange plane and the surface of the intended shape to ensure consistency.

Note that, the oblique forming of a flange plane can also be performed by the force-controlled oblique shear spinning method (Sekiguchi and Arai, 2010b), although there are several differences, such as the machine structure, the necessity of a dedicated die, and the control method of the tool. In this study, the deformation behavior of the proposed method was investigated by considering the wall thickness distributions of truncated conical products formed at several inclination angles in comparison with those obtained by the force-controlled oblique shear spinning method. The basic forming conditions in this paper are shown in Table 1.

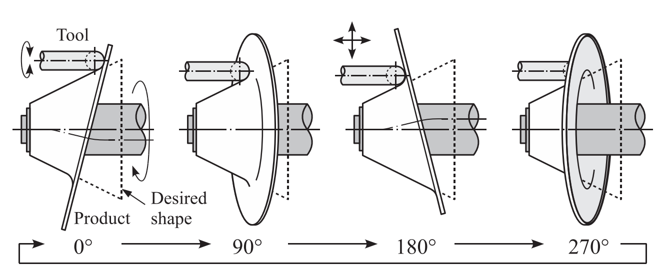

Fig. 3. Synchronous motion of the tool during one rotation of the spindle.