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Two-step forming for improvement of forming limit in rotary nosing with relieved die for fabrication of axisymmetric and eccentric nosed tubes

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ABSTRACT

This paper presents application of two-step forming for improving the forming limit in rotary nosing with a relieved die. Nosing is one method which is used for reducing the diameter of a tube tip. "Two-step nosing" is composed of two stages and different dies are applied for the two stages. The die shapes are determined based on the occurrence tendency of defects in "one-step nosing", where only one die is used through the whole process. In this research, a series of experiments and numerical analyses of one-step nosing was carried out for investigating the mechanism of the occurrence of defects. As a result, it is revealed that the occurrence of defects was highly relevant with the contact area between the die and tube. Based on the result of one-step nosing, the optimum die shapes were determined for the two stages, and then "two-step nosing" improved the forming limit 9% higher than one-step nosing under the optimum condition. Furthermore, "two-step nosing" was experimentally applied for forming eccentric nosed tubes, and its superiority was verified.

1. Introduction

Nosing is a reduction method of tube tips by applying circumferential compressive stress using rigid tools. Nosing is used for fabrication of various products, including structural tubes in buildings or machines, mufflers of motorcycles and vehicles, resealable cans with bottle shape and so on. Press forming and spinning are well known examples of nosing processes. In press forming, a tube is pressed into an axisymmetric cone die and the tube tip is deformed. Manabe and Nishimura (1984) summarized the mechanism of the nosing process based on experimental and theoretical investigation. Alves et al. (2006) investigated the expansion and reduction of a tube tip in order to clarify the effect of process parameters on the forming limit induced by some defects. Although the working process of press forming is simple and the productivity is high, the forming limit is low due to occurrence of some defects by the large working force. In spinning, on the other hand, a tool of a roller or bar contacts with a rotating tube and the tube is deformed by the tool, which moves back and forth on the worked surface. Kobayashi and Yoshimura (2011) proposed a method for generating an optimum tool path for the nosing process in spinning based on the Fuzzy Model, and Zoghi et al. (2012) investigated the effect of the contact area and spinning feed speed on the deformation behaviour of a tube in tube spinning. Becker et al. (2014) described a process, which combines the continuous bending process with an incremental tube spinning process, which allows suppression of springback in the continuous bending process. Although the forming limit of spinning is higher than press forming, the productivity is much lower as the deformation is small per one path of tool movement. Thus, press forming is superior in productivity and spinning is superior in formability. However, a method with both superior formability and productivity had not been established.

Rotary nosing with a relieved die was proposed by the authors, and their previous research works revealed that the proposed method realizes both high formability and productivity without heat generation so as to maintain the material strength. Kuboki et al. (2008a,b) reported the effect of forming condition on formability in rotary nosing with a relieved die. As a result, the previous work attained a high limit nosing ratio of 49%, against 10% in press forming, by optimizing the working condition for practically-used aluminum alloy A6063 with a thickness ratio of 1.7%. All the previous studies assumed that nosing should be conducted in a "one-step" manner. That is to say, nosing was conducted using only one relieved die through the whole process. However, usage of different relieved dies might be more effective, as multiple steps of forming are effective for attaining higher forming limits in other metal forming methods, such as deep drawing. For example, Katoh et al. (1995) worked on research for the increase of cup height by the redrawing process.

This paper presents "two-step nosing" for improvement of the

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forming limit in rotary nosing with a relieved die. Two-step nosing applies two dies with different contact areas between the die and tube for the first and second stages in the nosing process. The optimum die shapes for the two steps are determined based on the results in one-step nosing. Therefore, in this research, a series of experiments and numerical analyses of one-step nosing were carried out as a preliminary investigation, and two-step nosing was thereafter carried out to clarify its validity.

Furthermore, additional experiments were carried out for investigation of the applicability of two-step nosing to fabrication of eccentric tubes, which have different axes for the nose tip and the base part of the tube. The eccentric tubes are expected to be used for catalyst cases, pipe-connecting parts and so on. In the experiments, the effect of eccentricity on formability was clarified and improvement of the forming limit was attempted by the application of two-step nosing. In addition, "slant nosing" was proposed for examining the moving path of a tube for forming eccentric tubes. In slant nosing, a tube is coaxially arranged to the die at the beginning of nosing, and incremental displacement in a direction perpendicular to the central axis of the die is applied to a tube while the tube is pushed into the die. The forming limit should be improved by suppression of partial deformation which is caused by partial contact of the tube tip to the die.

2. Rotary nosing with relieved die for reduction of tube tip

A schematic of rotary nosing with a relieved die is shown in Fig. 1. In this method, a tube is relatively pressed into a relieved die while rotating one of them. The relieved die is composed of contact and relieved surfaces. The relieved surfaces are designed not to contact the tube. Kuboki et al. (2015) reported the availability of the relieved die for improvement of the forming limit in forming a nosed tube. As the relieved surfaces have a function that weakens the axial pushing force that causes buckling and compressive hoop stress on the tube tip producing wrinkle, the forming limit is improved. The defect mode in rotary nosing with a relieved die is shown in Fig. 2. Four types of defects were observed and they were (a) split, (b) polygonal wrinkle, (c) buckling and (d) wrinkle. The occurrence tendency of those defects varied depending on the contact area between the die and tube. Therefore, it would be significant to clarify the mechanism of defect occurrence and the effect of the contact area for improvement of the forming limit.

3. One-step nosing

3.1. Forming conditions

A series of experiments and numerical analyses of one-step nosing were carried out in order to clarify the effect of the contact angle of the relieved die on the forming limit and defect occurrence. A photograph of the experimental set-up is shown in Fig. 3. A lathe was used for nosing. A die was clamped and rotated by the chuck of the lathe, and a tube was set on the tool stand and pushed into the die at a constant velocity. An outline of a relieved die and tube is shown in Fig. 4. When the contact angle γ is zero, the die and the tube contact on three straight lines. The working conditions for the experiment and analysis are shown in Table 1. The lubricant for nosing was metal working oil G-3244, which was developed by Nihon Kohsakuyu Co., Ltd. for forming aluminum alloy.

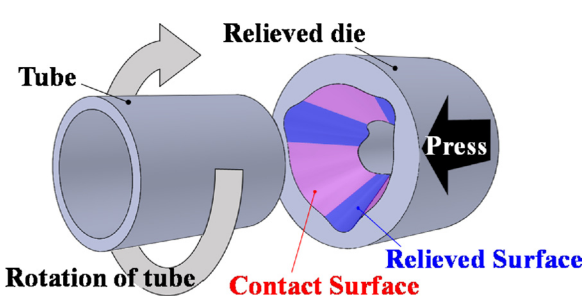

Fig. 1. Rotary nosing with relieved die for reduction of tube tip.

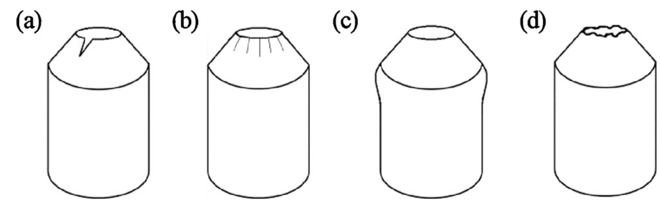

Fig. 2. Defect modes. (a) Split, (b) Polygonal wrinkle, (c) Buckling, (d) Wrinkle.

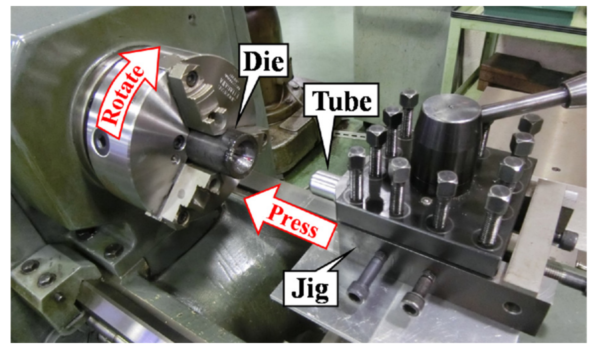

Fig. 3. Photograph of experimental set-up.

In the experiment, the tube was pushed until one of the defects occurred. Buckling was defined as increase of diameter of the tube by more than 2% from the original tube. Polygonal wrinkle, split and wrinkle were examined by visual reference. The diameter of the tube tip was measured at every 1 mm increase of pushing stroke, and the presence and mode of the defect were recorded. The forming limit was evaluated by limit nosing ratio κ_L which was defined by the following equation.

$$\kappa_L = \frac{D_0 - D_L}{D_0} \quad (1)$$

where, D_0 is initial diameter of the tube tip and D_L is limit diameter, which is the minimum diameter of a tube tip without any defects.

A model for numerical analysis is shown in Fig. 5 and the conditions for finite element analysis (FEA) are shown in Table 2. Elastic-plastic analysis was carried out for estimation of the deformation of the tube tip and pushing force during processing, which was not able to be measured in the experiment. In analysis, the commercial code ELFEN, which was developed by Rockfield Software Limited, Swansea, was used. A 3D dynamic explicit scheme was applied and a von Mises' yield criterion was adopted. The element type of the tube was a solid hexahedron and that of the die was a shell. The die was rotated and pressed over the tube tip while the other end of the tube was constrained. The heat generation by plastic deformation and friction would be smaller than heat dissipation, so the temperature change was neglected in analysis, as the tube temperature was low (about 20 °C) in the experiment. The friction coefficient was assumed to be 0.25 so that the forming limit might be equal to the experimental results in simple press forming. The usage of FEA does not focus on the quantitative prediction of defect occurrence, but on the qualitative examination of the deformation mechanism which leads to defects. The analysis was conducted based on a validity check on the defect occurrence in axisymmetric nosing, which was conducted by the authors, Kuboki et al. (2008a).