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Deformation behavior in boss forming with small punch/die diameter ratio☆

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ABSTRACT

Sheet metal parts with bosses or small pins can be manufactured by half blanking. This paper focuses on deformation in small boss forming on a sheet metal by half blanking at small punch/die diameter ratios of 1–1.8. In the case that the boss diameter is less than the sheet thickness, the boss height became lower than the depth of punch penetration at a punch/die diameter ratio of 1. The mechanism of decrease in the boss height and countermeasures to the problem were investigated through the FE analysis. The results showed that the boss height was improved up to the same level as the depth of punch penetration by both increasing punch/die diameter ratio and applying an appropriate blank holding force. The boss height was also affected by the material ductility and a higher boss was formed for the not-annealed sheet under the same forming conditions. The punch/die diameter ratio did not make a big difference in the mean punch pressure although a larger force was needed by using a larger diameter punch.

1. Introduction

Small pin or small shaft components are generally produced by multi stage forging, in which the small billet cut from a wire is transferred from stage to stage by means of a gripper. However, when scaling down this process, billets or semi-finished parts tend to stick to the transferring gripper due to small weight, which makes correct positioning difficult. The sheet metal extrusion process has a possibility to overcome the problem. A small pin or boss is extruded on a sheet metal in the first stage, formed into a desired shape in the following stages and blanked out in the final stage. In this method, handling of the pins or semi-finished parts is easy even in a small size since the pin components are connected to the sheet throughout the stages. Hirota (2007) conducted small pin forming on a disk specimen and showed that the height of pin was considerably affected by the constraint of the specimen. Lim et al. (2010) demonstrated the progressive forming of micro-pins and revealed the effect of varying punch diameter to pin diameter on the pin height. Ghassemali et al. (2011) investigated the microstructure inside the pin based on the hardness and strain distributions. The same technique has been applied to more complex shapes. Hirota et al. (2010) tried to form a stepped shaft on a disc specimen and reported the advantage of two-step forming for a longer stepped part with a smaller load. Chan and Fu (2013) formed a cylindrical and flanged part in three stages and showed that the dimensions and properties of the extruded parts were affected by the grain size as well as forming conditions. Fu and Chan (2013) revealed the effect of grain size on the quality of the parts in detail for the same forming process. These researches have been aimed at producing small pin components from a sheet metal in a progressive die system, where a large punch/die diameter ratio and a deep punch penetration were adopted to make a long pin. In addition, the pin component was designed to be blanked out from the sheet at the final stage.

On the other hand, a short pin or short boss formed with a small punch/die ratio, which is not blanked out and used as a part of sheet metal components, is also demanded for positioning or assembling another parts. Zheng et al. (2005) conducted the experiments and numerical simulations for the boss forming with a punch/die diameter ratio of 1.5 and reported the specific features of the process concerning the material flow, strain distributions, shrinkage cavity and fracture. A short boss can be formed on a sheet by backward extrusion of the sheet. Merklein et al. (2012) introduced the process as a kind of coining or press forging with some

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Table 1
Mechanical properties of the materials tested.

Material (JIS)	Thickness (mm)	Tensile strength (MPa)	Uniform elongation (%)	Total elongation (%)	Remark
A1050-h24	2	122	1.6	6.7	Semi-hard
A1050-O	2	106	35.4	45.5	Annealed

practical applications. Murakami et al. (2005) investigated the dimple defects found in press forging and provided some countermeasures. In press forging, high forming load often becomes a problem. Zhang et al. (2008) studied boss forming of magnesium alloy on the bottom face of rectangular box at elevated temperatures. Wang et al. (2013) carried out boss forming on the bottom face of drawn cup and reduced the forming load by using the compression drawing method.

This study deals with the boss forming by half-blanking with the punch/die diameter ratios of 1–1.8 and the deformation at the transition range between extrusion and blanking was discussed. The experiments using pure aluminum sheets and numerical simulations were carried out and the effects of the punch/die diameter ratio, blank holding conditions and material ductility on the boss height were investigated.

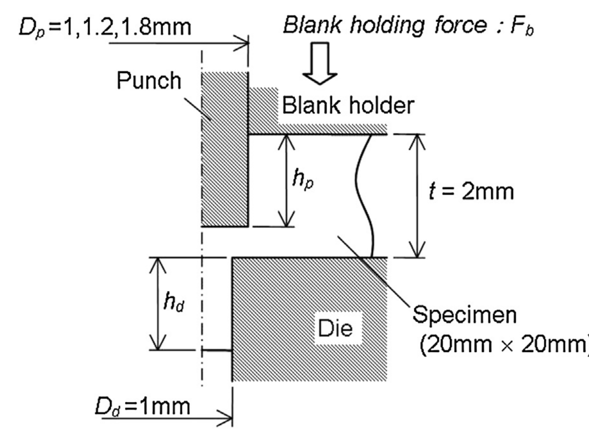

Fig. 1. Dimensions of the tools and specimen for boss forming.

2. Experimental procedure

Two kinds of pure aluminum sheets of 2 mm in thickness were used for the experiments, of which mechanical properties are shown in Table 1. The experimental setup is illustrated in Fig. 1, in which the tools are made of alloy tool steel. A boss was formed on the center of a square specimen (20 mm on a side) by using a hydraulic press, where the punch/die diameter ratio D_p/D_d was varied as 1, 1.2 and 1.8 by changing the punch diameter. Both the target boss height and the maximum punch penetration were set to 1.5 mm (75% of the sheet thickness) and achievement of the target boss height with a smaller punch penetration was aimed. Punch penetration was stopped when the target boss height was obtained. In the case using the blank holder, the force was given by the coil springs. Before forming, a mineral base oil with a low viscosity was pasted on both sides of the specimen as a lubricant. After forming, a counter punch was used to eject the boss from the die hole. The combinations of parameters are summarized in Table 2. The boss diameter was varied only in the case I (blanking mode). The boss height was evaluated with a mechanical surface profiling device. Load-stroke curves were also measured by using a strain gauge load cell (capacity: 5 kN) and a contact type displacement sensor (ranges: 0–10 mm).

Two dimensional finite element analysis was carried out by using the commercial software MSC. Marc. The problem was modeled as axisymmetric and the sheet and the tools were supposed to be an elasto-plastic body and rigid bodies, respectively. Shear friction factor was set to 0.1 and adaptive remeshing techniques were applied to simulate the large deformation around the tool edges correctly.

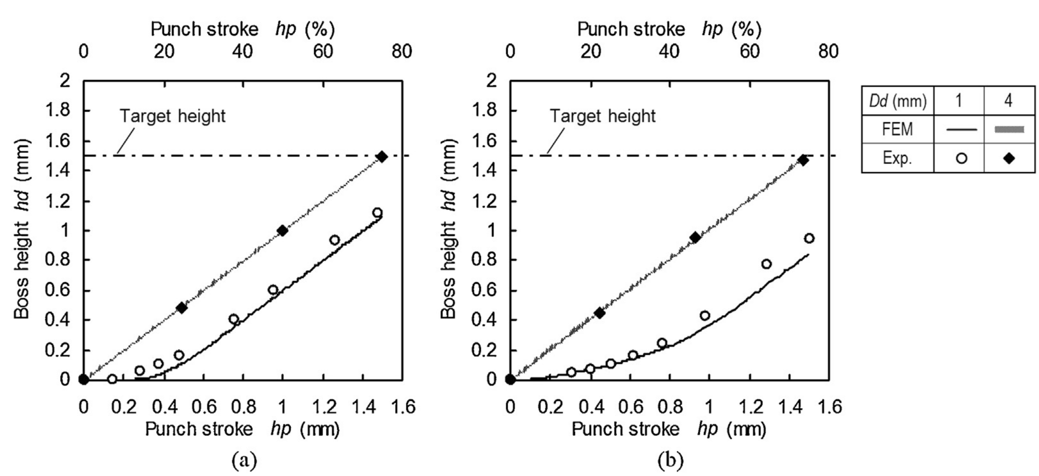

Fig. 2. Difference in boss formation in half blanking depending on the boss diameter for (a) A1050-h24 and (b) A1050-O.

Table 2
Test conditions.

Case	Boss diameter D_d (mm)	Punch/die diameter ratio D_p/D_d	Depth of punch penetration h_p (mm)	Blank holding force F_b (N)
I	1, 4	1	≤1.5	0
II	1	1, 1.2, 1.8	≤1.5	0
III	1	1, 1.2, 1.8	≤1.5	≤3000