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A new forming method of solid bosses on a cup made by deep drawing

Z.G. Wang [a,*], Y. Yoshikawa [a], K. Osakada (1)[b]

[a] Department of Mechanical and Systems Engineering, Gifu University, Yanagido, Gifu, Japan
[b] School of Engineering Science, Osaka University, Toyonaka, Osaka, Japan

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ABSTRACT

A new process for forming bosses on the bottom of a cup made by deep drawing is proposed: solid bosses are formed by compression of the cup bottom during deep drawing. By the combined effect of compression and deep drawing, bosses are formed with a lower load than simple compression or backward extrusion. It is found that high bosses can be formed with moderate punch pressure when only one side of the blank is lubricated.

1. Introduction

Recently, electronic instruments and mobile products are becoming smaller, lighter and less expensive. Since the instrument case accounts for a large proportion of the overall weight of an electronic device, reduction of the weight of the case has become an important issue [1]. Although the instrument cases are usually made of plate or sheet metal, they need bosses for positioning and fastening the member parts [2] and thus they cannot be formed only by deep drawing.

Backward extrusion is the most commonly used process for forming of bosses on a plate because of the high dimensional accuracy and low manufacturing cost [3]. However, backward extrusion of a thin plate requires a very large forming load and it is difficult to form bosses with large heights and small diameters.

The plate forging processes [4] were applied to forming of tooth-like parts [5], sieve piston [6] and hollow bosses [7]. In plate forging, a plate is compressed and a boss is formed as shown in Fig. 1. To obtain a high boss, frictional constraint is necessary to cause the flow to the boss, but it increases the compressing pressure extremely when the plate is thin.

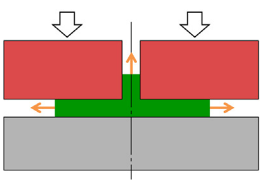

Fig. 1. Concept of boss forming in plate forging.

This paper describes a new plate forging process, compression-drawing for forming solid bosses on a plate product with a lower forming load. Fig. 2 shows the principle of compression-drawing.

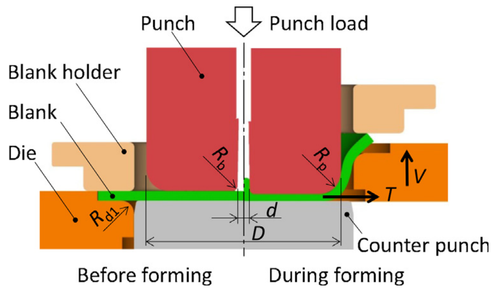

Fig. 2. Principle of boss forming by compression-drawing.

The die moves upward with a velocity V and the blank is drawn while a constant punch load is applied to the bottom of the cup. A boss is extruded from the plate when the plate is compressed plastically. In the case of Tresca yield condition, the compressing pressure p and the radial stress σ_r make a relation $p + \sigma_r = Y$, where Y is the flow stress. The tension force T generated by drawing causes radial tensile stress σ_r in the bottom part of the cup and is expected to decrease the pressure p.

Since almost the same products can be formed by backward extrusion and simple compression, these processes for boss forming are shown in Fig. 3. In backward extrusion, the blank is compressed between the punches and flows into the gap between the die and the punch. In simple compression, the blank is compressed without constraining by the die.

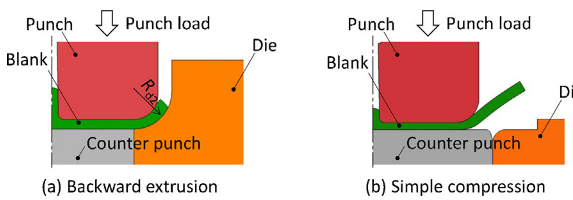

Fig. 3. Schematic diagrams of backward extrusion and simple compression.

* Corresponding author.

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2. Conditions for experiment and simulation

2.1. Experiment

The blank material is commercially pure aluminium A1050-O and the flow curve of this material is determined by tension test to be $Y = 168(\varepsilon + 0.02)^{0.12}$ MPa. A circular blank is cut off from a rolled sheet of 2.0 mm in thickness. The diameter of the blank is shown in Table 1.

The punch is 40 mm in diameter and has a hole of 2.5 mm in diameter to form a boss at the centre. The same punch is used for compression-drawing, backward extrusion and simple compression. The dimensions of the tools are also given in Table 1. The punch, counter punches and dies are made of die steel SKD11 (HRC = 61). The surface roughness of the punch and the counter punches is 0.07 μm R_a if not otherwise mentioned. The counter punches are polished with diamond paste after each forming test to maintain the friction conditions to be same.

As for lubrication, paraffinic mineral oil P460 (460 mm^2/s at 40 °C) is applied by brushing.

Experiments are carried out on an 1100 kN servo press KOMATSU H1F110 and the punch load is measured with a load cell installed in the press.

In compression-drawing, the blank set on the counter punch is compressed by the punch with a constant load and then is drawn with the die which is driven upwards at a velocity of 15 mm/s by an air cushion. The punch load is controlled to be constant during forming by moving the punch downwards.

Table 1
Dimensions of tools and blank.

Dimensions	Compression drawing	Backward extrusion	Simple compression
Blank diameter mm	60	40	56
Blank thickness, t_0 (mm)		2.0	
Punch diameter, D (mm)		40.0	
Punch profile radius, R_p (mm)		4.5	
Boss diameter, d (mm)		2.5	
Boss profile radius, R_b (mm)		1.0	
Die inner diameter (mm)		45.2	
Die profile radius, R_{d1} (mm)	2.5	–	2.5
Die profile radius, R_{d2} (mm)	–	7.0	–

2.2. Simulation

FEM simulation is carried out using a commercial code DEFORM 2D for axi-symmetric deformation and DEFORM 3D for 3D deformation. The blank material is assumed to be rigid-plastic and its flow curve is $Y = 168(\varepsilon + 0.02)^{0.12}$ MPa. The tools are rigid. The friction coefficient for the lubricated condition is 0.03, and that for non-lubrication is 0.3. These values of friction coefficient are determined by approximating the results of ring compression tests.

3. Examination of forming method by simulation

3.1. Effect of lubrication

In Fig. 4, the bottom thickness of the cup and the boss height are plotted against the average punch pressure in the cases of compression-drawing, backward extrusion and simple compression, for the lubricated condition. The average punch pressure at 50% reduction in thickness is about 100 MPa in compression-drawing and 200 MPa for backward extrusion and simple compression.

In all cases, the boss height is less than the boss diameter. Although the average punch pressure in compression-drawing is lower than those in backward extrusion and simple compression, the resulted boss height is lower. From this result, it is considered that a low friction condition cannot result in tall bosses although the punch pressure is low.

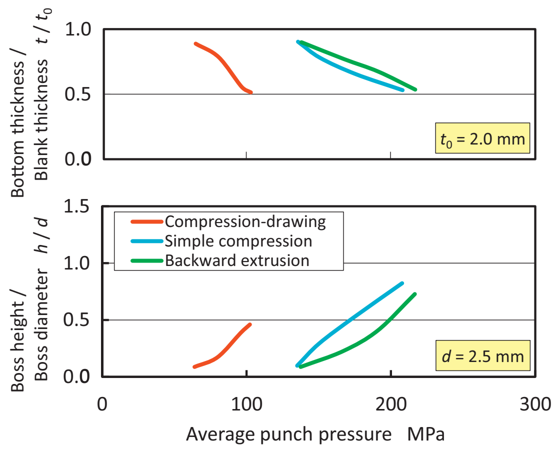

Fig. 4. Relationship between boss height ratio and average punch pressure in three forming methods under lubricated condition (FEM simulation).

The boss heights in the cases of lubricated and un-lubricated are shown in Fig. 5. Non-lubrication brings about higher bosses but it is apparent that the average punch pressure becomes extremely high, and lubrication cannot be avoided.

To attain an appropriate frictional condition to cause high bosses without increasing punch pressure too much, only one side of a blank is lubricated by leaving the other side un-lubricated. Let us call this lubricating method as one-side lubrication. The upper (boss) side is lubricated to reduce the friction because the friction at the corner radius hinders the flow to the boss. As shown by the broken line in Fig. 5, one-side lubrication brings about a high boss without increasing punch pressure too much.

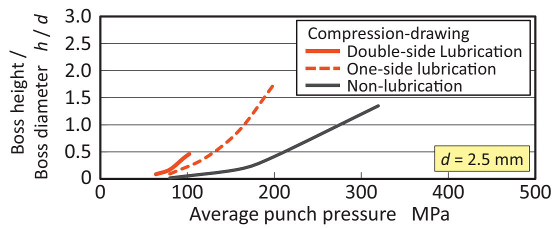

Fig. 5. Relationship between boss height ratio and average punch pressure for various lubrication conditions in compression-drawing (FEM simulation).

3.2. One-side lubrication

For the three forming methods in Figs. 2 and 3, the relationships between the boss height and the average punch pressure are given in Fig. 6. Compared to the cases of lubricating both sides, one-side lubrication leads to a boss of more than 3 times higher while the punch pressure is increased by about 2 times in all cases.

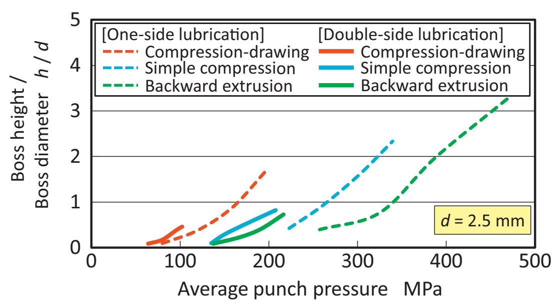

Fig. 6. Relationship between boss height ratio and average punch pressure in three forming methods with one-side lubrication and double-side lubrication (FEM simulation).

The forming process of a boss during compression-drawing with one-side lubrication is shown in Fig. 7(a) and the history of the load on the blank-holding die with the die stroke is given in Fig. 7(b). The points A, B, C and D in Fig. 7(a) correspond to the