Multi-stage cold forging of thin-walled components
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Abstract
The bulk forming process of sheet metal has a high potential for the near-net–shape forming of metal components with thin wall thickness. However, the main critical challenges in this process are the high forming pressure and the difficulties in the control of metal flow in lateral or radial direction which are caused by the compression of thin workpiece in its thickness direction. In the present study, the multi-stage cold forging process was introduced to address the current challenges in the forming of thin-walled metal components with multiple wall thicknesses. The case studies were conducted through FE simulation and experiments and the results showed that this process is effective to reduce the forming load and improve the radial metal flow in the forming of two kinds of thin aluminium alloy components with multi thicknesses.

Keywords: Sheet; Metal; Cold forging; Multi-stage

1. Introduction
The forming process of sheets/plate workpieces by combining bulk forming process and stamping (sheet forming) process has a high potential for the near-net–shape forming of thin walled metal components with ribs and multiple wall thicknesses. The main critical challenges in the forming of such components are a high forming pressure and the difficulties in the control of metal flow in lateral or radial direction which is caused by the compressive deformation of thin workpiece in its thickness direction. Research and development has been focusing in the Sheet-Bulk Metal Forming (SBMF) processes as shown below but the process design rules or
solution have not been provided enough to address the current challenges mentioned above.

In the present study, an multi-stage cold forming concept was introduced into the bulk forming process of sheet metal to reduce the forming pressure and to facilitate the ease of metal flow in the lateral or radial direction during the forming of thin walled metal components. The feasibility of this forming concept was further elaborated through FE simulations and experiments on the two case of forming thin walled aluminum components with multiple thicknesses.

2. Previous research works and problem statement

Nakano (2001) and Nakano et al. (2006) had already started the development of combined forming of cold forging and thick sheet metal forming for automotive components and had named the process as “Flow Control Forming in Sheet Forming”, in which the plural forming modes such as fine blanking, deep drawing/redrawing, ironing and local upsetting/coining were combined. Merklein et al. (2011) provided an overview of the existing sheet bulk metal forming processes and highlighted the tooling aspects as well as the metal flow with the combination of upsetting /lateral extrusion and deep drawing/upsetting in multi-step upsetting process. However, there were limited reports on process design rules in these previous research works for reducing the forming pressure and controlling the lateral metal flow in forming the thin-walled metal components with multiple thicknesses and ribs.

Yang et al. (2011) had reported on the method of forming multi-ribs components in multi step forming operation in which the split punch was used to constrain lateral metal flow partially and to prevent the occurrence of defects such as folding and under-filling. Oyachi and Allwood (2011) examined a sheet thickening process by multi-step compression of workpiece with flat punch. Shiraishi and Nikawa (2010) reported the warm forming of flange and ribs on thin walled magnesium alloy component by partial compression of plate and partial constraint of material by back pressure through blank holder. These results were insightful but were insufficient to address the current challenges mentioned above in the forming of thin walled metal components with multiple thicknesses and ribs.

Danno (2013) has pointed out the lateral metal flow along tool surface needed to be adequately controlled in the forming of thin walled components with ribs to prevent forming defects such as wrinkling or bucking at flat portion and folding or shear of ribs as shown in Fig. 1.

![Defects caused by lateral metal flow in bulk forming of sheet metal.](image)

(a) Wrinkling or buckling (b) Folding or shear

2. Concept of multi-stage cold forging for thin-walled components

Two concepts of multi-stage cold forging process as shown in Fig. 2(a) and (b) were introduced for forming the thin-walled metal components with multiple wall thicknesses and ribs. The main objectives of the two process concepts are to reduce the forming pressure and to make the lateral metal flow easier. In this process, the workpiece (thick plate) is compressed in the thickness direction in multi step operation and the material is forced to flow outward from central area towards the free ends of the workpiece in a step by step manner. The inward metal flow and wrinkling at central area are prevented by the counter pressure through the use of die cushioning.
4. Case studies

Two case studies were performed to validate the concept A of multi-step cold forging process shown in Fig. 2-(a), namely, (1) forming of axisymmetrical thin component with vertical wall at periphery and (2) forming of C-shaped thin walled component with two thicknesses.

4.1 Forming of axisymmetrical thin component with rim at periphery

4.1.1 FE simulation and experimental conditions

FE simulation (2D) and experimental studies were performed on the forming process based on the concept A as shown in Fig. 2-(a) to form the target component as illustrated in Fig. 3. The workpiece material used was aluminium alloy AA6061-O (Annealed at 415°C ×2hr, FC & AC). Fig. 4 shows the flow stress –strain curve of the material which were used in the simulation. Fig. 5 shows the tooling setup for both simulation and experimental study. Two kinds of counter punch design (Tooling 1A and 1B) were used in forming step 1. The conditions of simulation and experiment were as follows.

- Initial workpiece size: Outer diameter \( D_0 = 21 \) mm, Thickness \( T_0 = 5.5, 5.9, 6.3 \) mm.
- Simulation: DEFORM-2D, Friction factor \( m = 0.12 \), Punch speed =0.1 mm/sec, Cushion load=17 KN.
- Press machine: 1100KN mechanical servo press (AIDA, NS1-1100D), 9s pm, Cushion load=17 KN.
- Lubrication in experiment: Multi application metalworking fluid Metalub® 315 (PANTEON CHEMICAL), 10% in water.
4.1.2 FE simulation and experimental results

Figs. 6 and 7 show the simulation results in forming step 1 (tooling 1A) and step 2. It was found that the material flows successfully from central region to outer region and the thick rim can be formed at the periphery. In this case of tooling 1A, the material was compressed vertically at its periphery in forming step 1 to reduce the tensile hoop stress in the periphery, as seen in Fig. 6. In the case of tooling 1B in forming step 1 shown in Fig. 8(a), the workpiece was not compressed vertically at its periphery and a higher value of damage factor (Cockroft-Latham, $DF_{\text{max}}$) was observed at the periphery as compared with the case of tooling 1A (Fig. 6). In the simulation of usual one step forging as shown in Fig. 9(b), a recess defect was formed at the inner fillet of rim because of an excess radial metal flow from the inner potion to the rim.
In the experiment, a sallow recess (Φ10 mm, depth 0.3 mm) at center on lower surface of the workpiece was fitted in the top of cushion at the center in the lower tool for the initial centering of the workpiece in forming step 1, as shown in Fig. 5(a). The thin walled sample with thick rim at its periphery was successfully formed experimentally without any internal defect as shown in Fig. 9(a), (b). However, as shown in Fig. 9(c) after forming step 1 by the use of tooling 1B, a severe cracking appeared at the periphery of workpiece where a large tensile hoop stress was induced and high value of damage factor was observed in the simulation as shown in Fig. 8(a). While the critical value of damage factor was not specified in this case, the tooling 1A was more feasible because the material was compressed vertically at its periphery to prevent the development of tensile hoop stress and to suppress the increase in damage factor as seen in Fig. 6.

4.2 Forming of C-shaped thin walled component with two thicknesses

The multi-step cold forging process shown in Fig. 10 (a) was employed to demonstrate the process feasibility in forming of a C-shape component of aluminum alloy with thin plate (P) and three thick pads (A,B,C). In this process, the radial inward metal flow was generated in the 1st and 2nd forming steps. The outward metal flow from inner area was prevented in 2nd forming step by the counter pressure through die cushion mechanism. A metalworking fluid Metalub® 315 (PANTEON CHEMICAL) was used as the lubricant instead of the conventional chemical conversion coating. As shown in Fig. 10(b), the component was successfully formed in this forming process. The forming load shown in Fig. 10(b) was very small as compared with the forming load of 6400KN which was predicted by FE simulation for the usual cold forging process in one forming step.
5. Summary

Two case studies were carried out for forming the thin aluminium components with multi wall thickness by the use of a multi-stage cold forging process. The FE simulation and experimental studies showed that this process is feasible to reduce the forming load and improve the metal flow in the lateral and radial direction during the forming of the thin aluminium alloy components.

References