PLATE FORGING FOR CONTROLLING WALL THICKNESS DISTRIBUTION OF PRODUCTS

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Summary

Plate forging processes for controlling distributions of wall thickness of formed products are reviewed. In these processes, thinning and thickening of plates are performed to form complicated cross-sectional shapes of products. For cups having comparative large thickness and plates having complicated cross-sectional shapes, plate forging is more useful than billet forging due to due to comparatively small change in shape. Thickening and thinning processes of local potions in products, improvement of formability and forming processes of gears and plates are presented.

1. Introduction

In conventional stamping processes, sheets are mainly deformed by tensile force. The formed products have enough accuracy for outer shapes, whereas it is not easy to control the distributions of wall thickness. When the sheet is compressed in the length direction for thickening, buckling occurs, and the compression in the thickness direction for the thinning brings about a large increase in forming load. When the distributions of wall thickness are not optimal for requirement of local strength, the weight of the products becomes excessive. For automobile parts, the reduction in weight is significantly required to improve the fuel consumption. In particular, the excessiveness of weight is serious for parts having comparative large wall thickness. It is desirable to develop net-shape forming processes of products having an optimum distribution of wall thickness for required strength.

Although forging has the function of forming complicated cross-sectional shapes, conventional forging from bars is inappropriate to the production of cups having comparative large thickness and plates having complicated cross-sectional shapes due to large change in shape as shown in Fig. 1. For these products, forging processes from comparatively thicker sheets or plates are attractive. In these processes, forging operations are included in stamping operations to control metal flow. Thinning and thickening of plates are performed to form complicated cross-sectional shapes. The plate forging processes have the following advantages:

1) Forming of parts having optimum cross-sectional shapes by control of metal flow

2) Increase in formability due to compressive stress

3) Smaller number of stages than conventional stamping

4) Forming of step and gear shapes

5) Improvement of dimensional accuracy due to small scatter of volume of sheared plates.

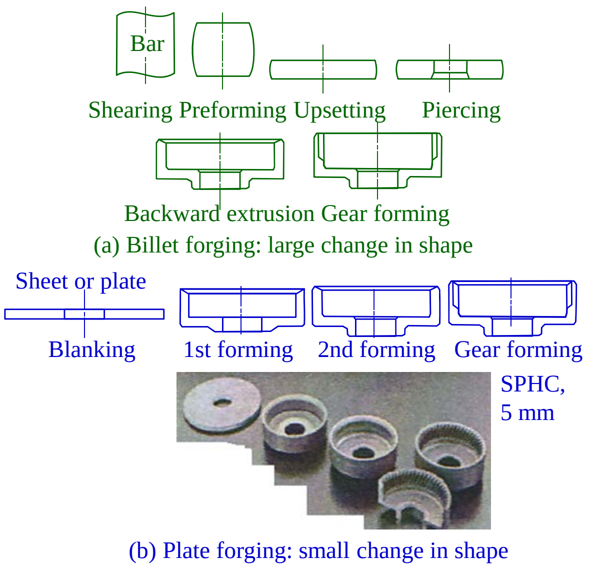


Fig. 1. Comparison between billet and plate forging processes [1].

The application of plate forging gradually increases mainly in the automobile industry as replacement of billet forging, powder metallurgy and casting. Functional parts used in transmissions, etc. are manufactured by plate forging.

On the other hand, the disadvantages of the plate forging processes are as follows:

1) Reduction in tool life due to high contact pressure
2) Increase in material cost due to expensive plates and large blanking scrap
3) Increase in press capacity due to large forming load and energy
4) Decrease in machinability and quenchability due to high formability of plates.

Nakano [2] classified the plate forging processes into some patterns of products as shown in Fig. 2, and exhibited the possibility of plate forging. Although sharp corners, different thicknesses and local shapes are generally finished by cutting, these portions are formed by controlling metal flow in the plate as net-shape forming. In the plate forging processes, upsetting, extrusion and ironing are added to typical stamping processes such as shearing, bending and drawing to form these portions.

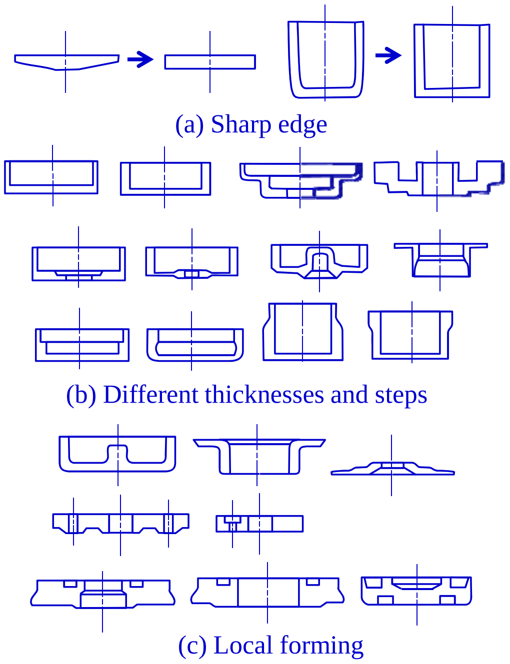


Fig. 2. Shapes of products obtained by plate forging processes [2].

2. Thickening

The flange of the step cup is thickened by the compression with the outer punch as shown in Fig. 3 [3]. In drawing of the bottom of the cup with the inner punch, the edge of the cup is pushed by the outer punch. Thickening of the flange is controlled by adjusting the stroke of the outer punch. A multi-motion press having three upper rams and two lower rams was designed to control these punches. The formed product approached an optimal shape, and the production cost was reduced by 30%. This part is used as a sheave piston of a continuously variable transmission [4].

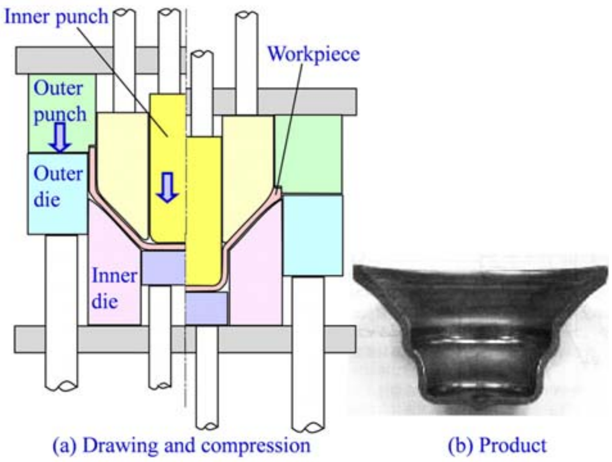


Fig. 3. Forming of step cup having thickened flange [3].

The wall thickness around an inner corner in the cup with a flange formed by three stages was increased by means of conical punches in the 1st and 2nd stages as shown in Fig. 4 [5]. Since the fatigue life of the formed cups used as disks of automobile steel wheels is greatly improved by the increase in wall thickness, the weight of the formed products is reduced by an optimum distribution obtained from the increase in wall thickness. The increase in thickness around the inner corner is obtained by compressing the side wall and conical bottom of the cup in the 3rd stage. A maximum 9% increase in wall thickness around the inner corner was successfully obtained for an angle of 25º for the conical punches used in the 1st and 2nd stages.

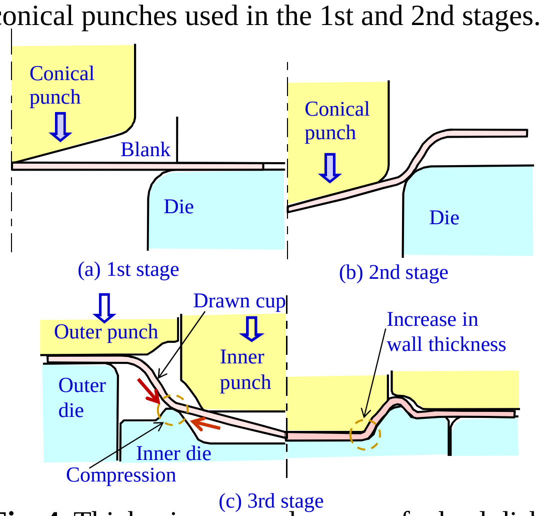
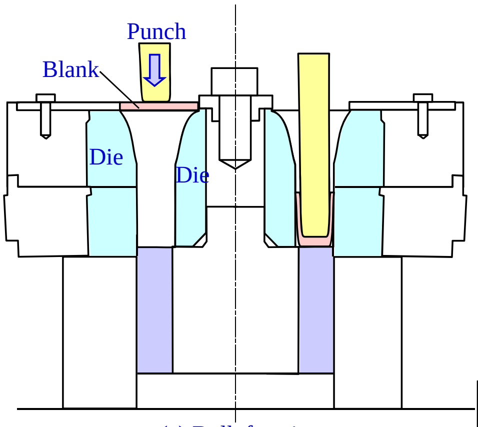


Fig. 4. Thickening around corner of wheel disk [5].

3. Thinning

Since deeply drawn cups have a non-uniform distribution of wall thickness, the distribution is controlled by plate forging. The side wall of the product is largely ironed to a thickness of 1.5 mm from a plate having a thickness of 5 mm as shown in Fig. 5 [2]. By employing deep drawing, ironing and sizing in turn, the thickness of the side wall is accurately finished. This part is used in an electromagnetic clutch.

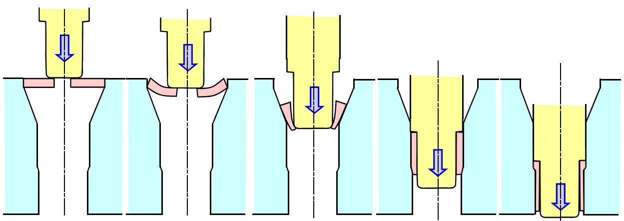


(a) Bulk forming

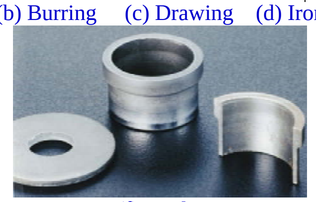
(b) Product

Fig. 5. Thinning of side wall by ironing [2].

An extrusion process is applied to perform partial thinning of products in the stamping. The plate is burred, and then is extruded into the thin flange as shown in Fig. 6 [6]. The thin flange is pulled by the friction of the punch simultaneously with pushing of the edge of the burred tube.



(a) Start (b) Burring (c) Drawing (d) Ironing (e) Extrusion

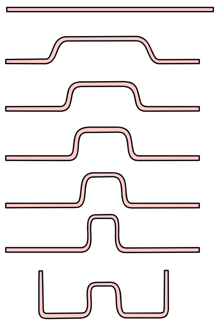


(f) Product

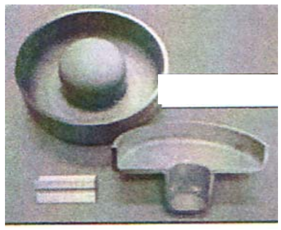
Fig. 6. Thinning of side wall by extrusion [6].

4. Improvement of Formability

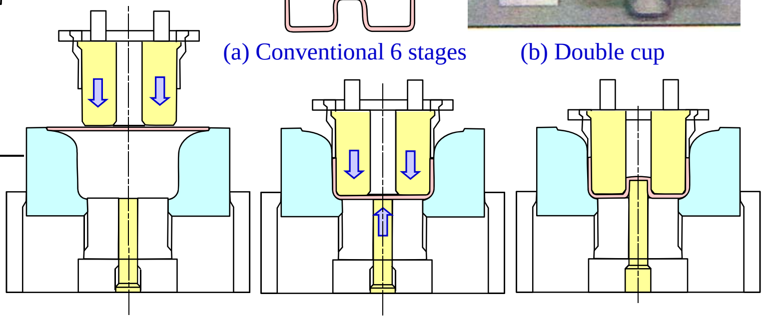
The forming process of double cups using a multiple ram is shown in Fig. 7 [1]. Although the double cups are conventionally formed by 6 stages, the process is reduced to only one stage by drawing the internal boss of the cup under compressing the bottom. The compressive force of the bottom is controlled with the stroke of the boss to prevent the rupture.



(a) Conventional 6 stages



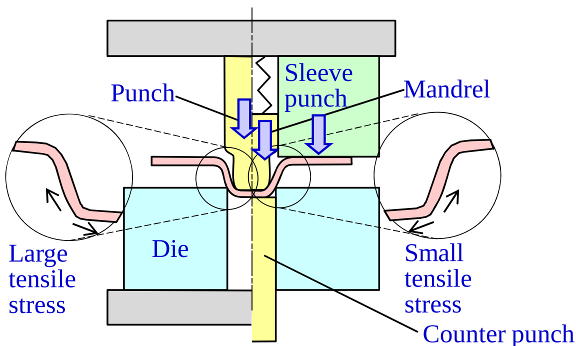
(b) Double cup



(b) One shot forming

Fig. 7. One shot forming of double cup with multiple rams [1].

The re-drawability of cups is increased by applying the compressive force to the flange portion with the sleeve punch as shown in Fig. 8 [7]. The tensile stress acting around the corner of the cup is decreased by the compression. This leads to the reduction in the number of redrawing stages. This part is used in a planetary gear unit for increasing or decreasing torque of an engine.



(a) Conventional drawing (b) Compressive drawing

Fig. 8. Improvement of re-drawability of cup by applying compressive force to flange portion [7].

Since magnesium alloy sheets have low ductility at room temperature, a cold two-stage stamping process for forming magnesium alloy cups having a small corner radius from commercial magnesium alloy sheets was developed (see Fig. 9) [8]. In the 1st stage, a cup having large corner radius is formed by deep drawing using a punch having large corner radius, and the corner radius of the cup is decreased by compressing the side wall with the outer punch in the 2nd stage. In the deep drawing of the 1st stage, fracture was prevented by relaxing the concentration of deformation with the punch having large corner radius. The magnesium alloy sheet was annealed at 500 ºC to increase the cold formability [9]. The square cup having a small corner radius was formed by the two-stage cold stamping.

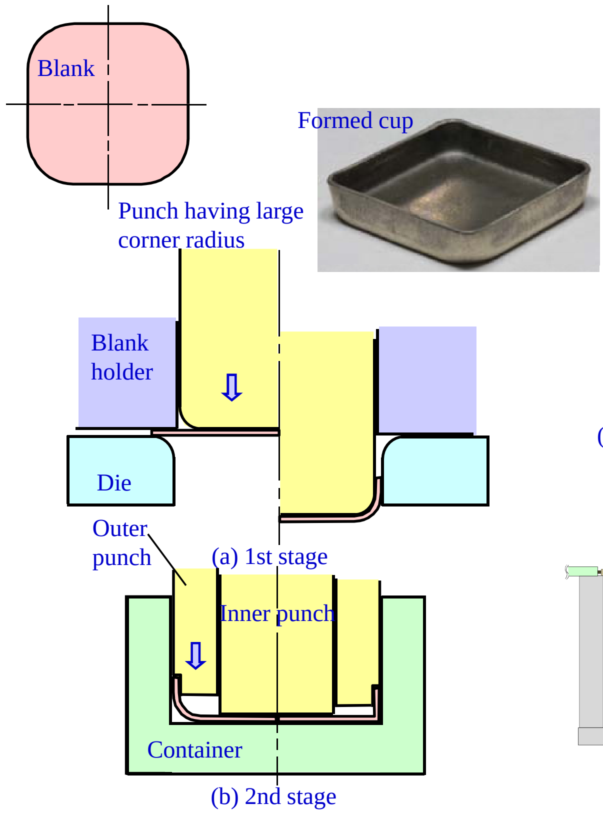


Fig. 9. Cold two-stage forming of magnesium alloy cups [8].

5. Forming of Gear

Gear drums used in automobile transmission are mainly produced by plate forging instead of the conventional billet forging. A plate is drawn into a cup, and the side wall of the cup is formed into a gear shape by ironing.

Although gear drums are conventionally made of mild steel plates having high formability, it is desirable to produce the gear drums from the high strength steel sheets owing to the reduction in the weight of automobiles. However, the spline forming of high strength steel cups having low formability is difficult due to severe deformation, in particular ultra-high strength steel cups. Mori et al. [10] developed a spline forming process of an ultra-high strength steel gear drum using resistance heating of a side wall of a cup formed by cold deep drawing and ironing (see Fig. 10). In Figure (a), the current is passed through the side wall of the cup between the upper and lower electrodes, and then the upper and lower electrodes are laterally and downward moved by the air cylinders, respectively as shown in Figure (b). Finally, the cup is formed with the punch and die (see Figure (c)). When the thickness of the side wall is kept uniform by applying ironing in the deep drawing of the cup, the side wall is uniformly heated by the electrification. In this process, the rapid resistance heating was used to prevent the oxidation and temperature drop [11].

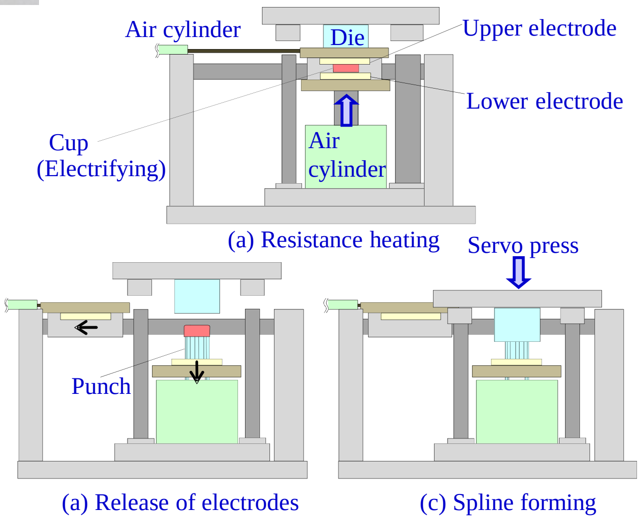


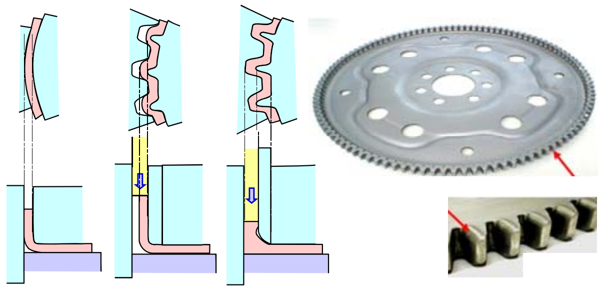
Fig. 10. Spline forming of steel gear drum using resistance heating of side wall of cup [10].

The ultra-high strength steel gear drum by the spline forming using resistance heating is shown in Fig. 11 [10]. Although the ultra-high strength steel cup ruptures for the cold forming, the ultra-high strength steel gear drum is successfully formed by means of resistance heating. The ductility of the ultra-high strength steel cup is improved by the heating. Since the resistance heating is very rapid, the cup is hardly oxidised.

(a) Cold forming (b) Warm forming

Fig. 11. Spline forming of ultra-high strength steel gear drum using resistance heating of side wall of cup [10].

The outer edge of the circular blank is formed into a gear as shown in Fig. 12 [12]. The edge is flanged and the flanged edge is shaped into a gear by the compression with the punch. The teeth are thickened by the flanging and compression.



(a) 1st stage (b) 2nd stage (c) 3rd stage (d) Formed gear

Fig. 12. Forming of disk gear having thick teeth [12].

To form a shape corner of the gear drum, the outer edge of the circular plate is bent by partial compression, and then the drawing and ironing are performed as shown in Fig. 13 [6].

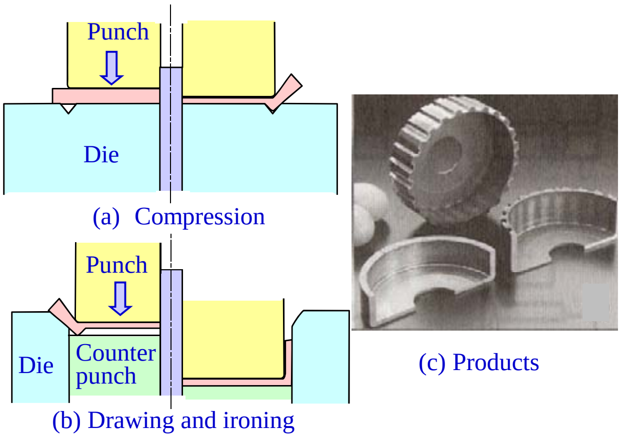


Fig. 13. Forming of gear drum having sharp bottom corner [6].

6. Forming of plates

When a plate having a complicated shape is formed by forging, the forming load largely increases. To decrease the load in plate forging, multiple stages are generally utilised, and not only transfer dies but also progressive dies are available in plate forging as shown in Fig. 14 [13]. This process is conventionally called fine blanking. In the fine blanking process, not only the shearing but also the change in thickness is included. The metal flow in the plate is controlled by repeating partial deformation in multi-stage forming, i.e. large increase in forming load is prevented by partial deformation. Therefore, the design of forming sequence is a key in the plate forging processes.

Fig. 14. Forming sequences in progressive dies for double gear [13].

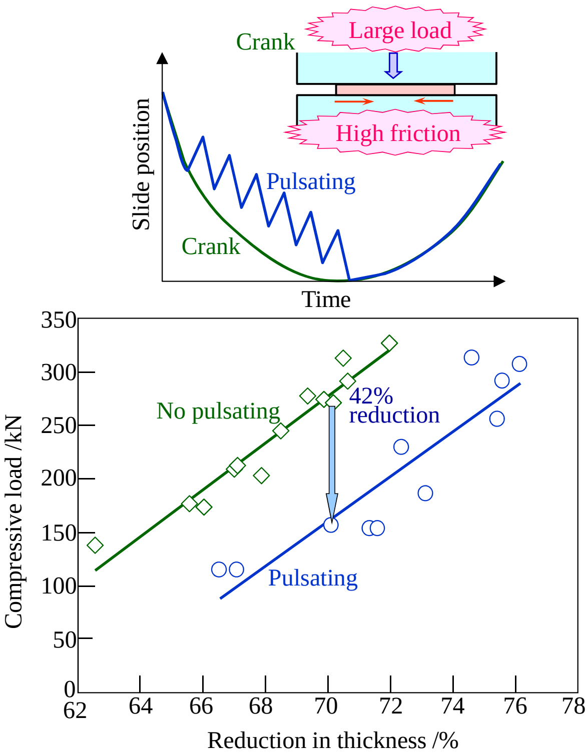


Fig. 15. Reduction in compressive load of plate by load pulsating [14].

Maeno et al. [14] proposed a plate forging process using load pulsating to decrease the forming load. In this process, the load is partially released at intervals of load to re-lubricate the surfaces of the plate. Gaps in the outer surfaces of the plate are caused in each release by the difference in elastic recovery between the die and plate, and the liquid lubricant is automatically fed into the gaps. The relationship between the compressive load and the reduction in thickness with and without the load pulsation in compression of a circular plate using a servo press is given in Fig. 15. The reduction in load by the pulsation is considerably large. Since most of mechanical servo presses have the pulsation function, the load pulsation is applicable to actual forming processes.

In plate forging, mild steel and aluminium alloy plates are generally employed. Although forging of stainless steel plates is desirable in industry, it is not easy to form the stainless steel plates having large flow stress. The load pulsating was applied to the forging of a stainless steel plate shown in Fig. 16. The load pulsation is effective not only for the decrease in forming load but also in the improvement of forming shapes. The cavity in the centre of the bottom is prevented by the decrease in friction for the load pulsation, and both upper and lower surfaces of the formed boss become flat. This is due to the change in metal flow caused by the decrease in friction.

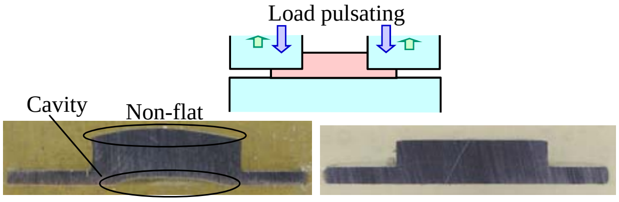


Fig. 16. Prevention of cavity in centre of bottom and flat upper and lower surfaces of formed boss by load pulsation in fogming of stainless steel plate.

7. Concluding Remarks

The plate forging processes are attractive for manufacturing products having a complicated shape. In these processes, forging operations are included in stamping operations. Since it is not easy to control distributions of wall thickness in plates by the forming due to large increase in forming load, it is desirable in industry to develop forming approaches and sequences for attaining appropriate metal flow in the plate. In addition, it is required to develop forming machines, tools, lubricants, etc. suitable for plate forging.

8. References

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