A novel forming method for three-dimensional thin sheet metal

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Abstract: For conventional stamping, appropriate process can be applied on top and bottom die to enhance the performance and efficiency of the forming process. But it is difficult and expensive for the conventional stamping to form high strength large spring-back thin sheet components of complex shape in small batch. In an effort to improve forming precision and to minimize the cost, a novel spinning and pressing forming (SPF) method is presented in this paper. The forming performances, including forming forces and surface roughness, were evaluated with the processes of forming titanium alloy and Aluminum alloy sheets. Reduced forming forces, lower tool wear, improved surface roughness and lower cost were observed using SPF. The investigation illustrates a great potential of applying SPF for improving shape precision and reducing the cost.

Key words: Forming, Spinning, Pressing, Titanium Alloy, Aluminum Alloy

Introduction

To improve product esthetic appearance and surface functions, it is essential for any new product to be covered or supported by sheet metal with required three-dimensional (3D) surface. However it is generally recognized that much effort should be made in conventional forming and appropriate stamping or forging die should be used to improve the cost effectiveness, production efficiency, surface quality, and to shorten production lead time. For small batch and frequently shape-changing parts, the traditional forming method is still a big challenge. In order to meet with ever increased competitive requirement, various single-point increment forming techniques were investigated and the principle is shown in figure 1a. It is necessary for the single point increment forming to use a pin with a round head, that can move along a defined spiral line on metal sheet with the aid of a balance support post and a set of movable support posts, guide rod and press-pad. Most previous research papers [1-5] indicated that single forming technique is broadly applicable to any product whose outer surface is convex, and is examined for the forming of an aluminum sheet into cones and pyramids having arbitrary number of edges; moreover, the quality and surface roughness of the part depend on the cycle time of pin actions. Multipoint forming method is investigated for better flexibility and lower cost. The principle of multipoint forming method, shown in figure1b, includes top and bottom dies that are composed with a large number of adjustable pins for a defined curve surface. Researches [6-9] show that the applicability of multipoint forming method improved production efficiency and reduced die manufacturing lead time due to its flexibility to cope different shape.

Aiming at better flexibility and lower cost, this paper presents a novel spinning and pressing (SPF) method based on spinning and pressing theory for forming the sheet metal. In this method, the assembled balls are applied onto thin sheet forming process so as to achieve required 3D form shapes.

SPF Process Characterization

As shown in figure 2, the setup of SPF is composed with an inner tube with inner diameter of 165mm, an outer tube with inner diameter of 165 mm, a spindle blend part, a bottom die, a set of ball assembly and a die support seat. During the SPF process, the inner tube and outer tube clamp and hold the border of thin metal sheet; the outer tube are driven down vertically and the spindle blend part is spinning and pressing the assembled balls to rotate and press the sheet forming the shape that matches the surface of bottom die. In order to calculate each ball contact force F_s on the deformed sheet followiing assumptions are made: the volume of deformation is equal to the undeformed volume; the space between two balls is ignored and equals to the diameter of ball, and the moving trajectory of ball around central is circle. According to single point forming [10] and ball contact force F_s can be expressed as follows:

$$F_s = \sqrt{F_x^{\,2} + F_y^{\,2} + F_z^{\,2}} \qquad (1)$$

$$\mathbf{F_x} = \frac{\pi t_0 (h \tan\alpha + r\cos\alpha)\sigma_s \bar{\varepsilon}\, r^2 \cos^3\alpha}{\frac{90-\alpha}{360}\pi r^2 - \frac{1}{2} r^2 \sin\alpha \cos\alpha} \qquad (2)$$

$$\mathbf{F_y} = t_0 (h \tan\alpha + r\cos\alpha)\sigma_s \bar{\varepsilon} \qquad (3)$$

$$\mathbf{F_z} = \frac{\pi\, t_0 (h \tan\alpha + r\cos\alpha)\sigma_s \bar{\varepsilon}\, r^2 \cos^2\alpha \sin\alpha}{\frac{90-\alpha}{360}\pi r^2 - \frac{1}{2} r^2 \sin\alpha \cos\alpha} \qquad (4)$$

$$\mathbf{F} = \left[\sum_{i=2}^{n} F_{s_i} / \pi r^2\right] \pi R^2 \qquad (5)$$

Where $\mathbf{F_x}$ is radial force, $\mathbf{F_y}$ is the tangential force, $\mathbf{F_z}$ is axial force;t_0 is thickness of sheet, σ_s is yield strength of the sheet material, h is vertical distance of two balls, α is slant angle, r is the radio of ball, $\bar{\varepsilon}$ is effective strain, R is the inner radius of an outer tube and F is the total force required for the forming process.

During an SPF process, the action of sheet deformation not only comes from the press of spindle blend part, but also comes from the spinning of the balls. In other words, every deforming track is pressed and spun continuously by the acting balls, so the sheet harden will not occur during the process. Moreover, owning to ball spinning and pressing repeatedly, the spring-back of the deformed sheet will reduce significantly.

Figure1. Principle of single-point forming and Multipiont forming: (a) single point forming, (b) multipoint forming

SPF Experiments and result analysis

A number of experiments of SPF were carried out on an SPF facility developed in Jilin University. Different shapes of bottom dies were fabricated in order to produce metal sheets for cranioplasty. An example of such dies is shown in figure 2. The materials of sheets are titanium alloy and aluminium alloy, the thickness of the sheet is 0.5mm, and the diameter of sheet is 180 mm. An example of finished deformed sheets is also shown in figure 2. In the experiments, different ball sizes of diameter 7 mm and 3 mm were chosen for comparison. Moreover effects of ball spinning and pressing are observed against those of ball pressing without spinning. The spindle blend part rotational speed was 30 rev/min and feed rate was 0.5 mm/min down throughout the experiments.

Figure 2. SPM principle and setup

Forming forces

Forming forces are critical parameters to evaluate whether the method is good or not. Figure 3 illustrates the comparison of different forming forces required by ball pressing method on an SPF device with bottom die of irregular surface shape. The method of pressing balls without spinning balls presents a situation that is similar to multipoint pressing method. It has demonstrated that the forming forces being could be reduced by spinning balls during the balls pressing process when deformation is large. This may indicate that spinning balls has positive effects on plastic deformation. Such effects are more significant in titanium alloy sheet forming than in aluminum alloy forming. Figure 3a illustrates the force reduction due to ball spinning for titanium alloy could be around 14% in the plastic deformation stage. Figure 3b also illustrates such effects in aluminum deformation, and the force reduction in plastic deformation stage could be up to16.5%. It may be concluded that spinning ball is a critical action in SPF process.

Surface roughness and shape

Surface roughness at the beginning and in the middle of surface was random measured using KEYENCE VHX-900. Surface indentation under different materials and the same size of balls 7mm as a function of whole surface is shown as Figure 4. From figure 4a and 4b, it is obviously revealed that Ti alloy yields a better surface roughness than aluminum alloy does, and the reason is that aluminum alloy is softer than Ti alloy. The cross curves through the center of formed surface that is made from Titanium alloy are measured and compared to die skin and results are shown as figure 4c and 4d, in order to get a good comparison, the end of the curves are overlapped, it is also found that the gap between formed surface and die skin is changed with different positions, the gap in the middle is bigger than the edge’s, the tolerance is up to 0.9 mm, and the smallest value is 0.4mm on the edge. Moreover, the cross curves through the center of formed surface that is made from aluminum alloy are measured and compared to die skin with greater curvature radius and results are shown as figure 4e and 4f, it is indicated that the gap between curve of formed surface and die skin is much smaller, and the greatest tolerance reaches 0.52mm, yet the smallest tolerance is decreased to 0.23mm.

Figure3. Titanium and aluminum alloy forming force with different state of motion of balls under test conditions：Ball size is 7mm, rotational speed was 30 rev/min , and press speed is 0.5 mm/min: (a) sheet is Titanium alloy, (b) sheet is aluminum alloy

Figure 4. Different measure results of surface of aluminum alloy and Titanium alloy using the same

diameter ball 7mm: (a) Aluminum alloy (b) Titanium; (c) and (d) are titanium alloy surface and die skin alone different positions measured; (e) and (f) are aluminum alloy surface and die skin alone different positions measured

Conclusions

It has been demonstrated the feasibility and the advantages of SPF method for the application of forming high strength and large spring-back sheets with a small batch or individual needs. This paper illustrates the principle, test and analysis on the experimental results. Based on our experiments following conclusions are drawn:

1) By applying ball assembly instead of multi-pins or a single pin, SPF method not only saves the machining cost, but also improves productivity especially for small batch or individual need, such as medical cranioplasty.
2) SPF method can reduce much more forming force than pressing without spinning
3) For different diameter of balls, surface indentation has different effects; when the sheet material is softer, surface indentation is greater.
4) Allthough many experiments have proved that SPF could provide good results of thin sheet forming with better flexibility, the wrinkle on the bounder of sheet should be handled by properly selecting the pressure-pad-force.

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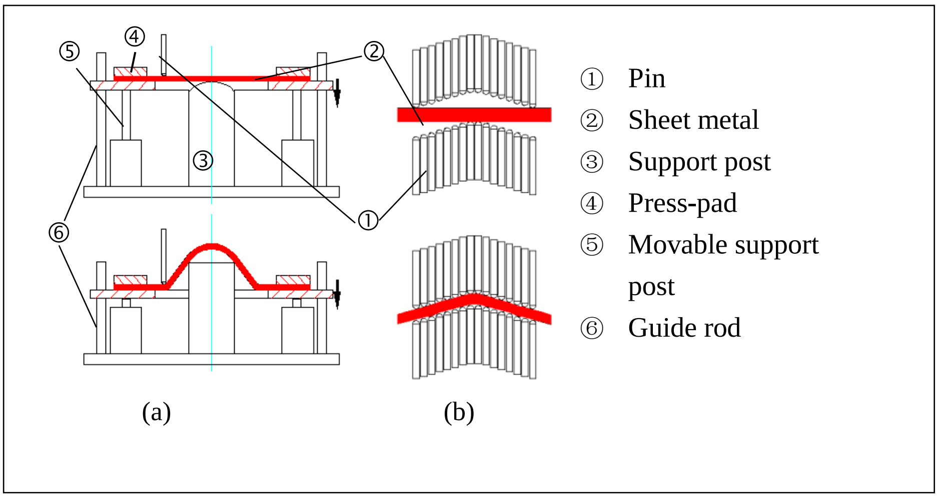

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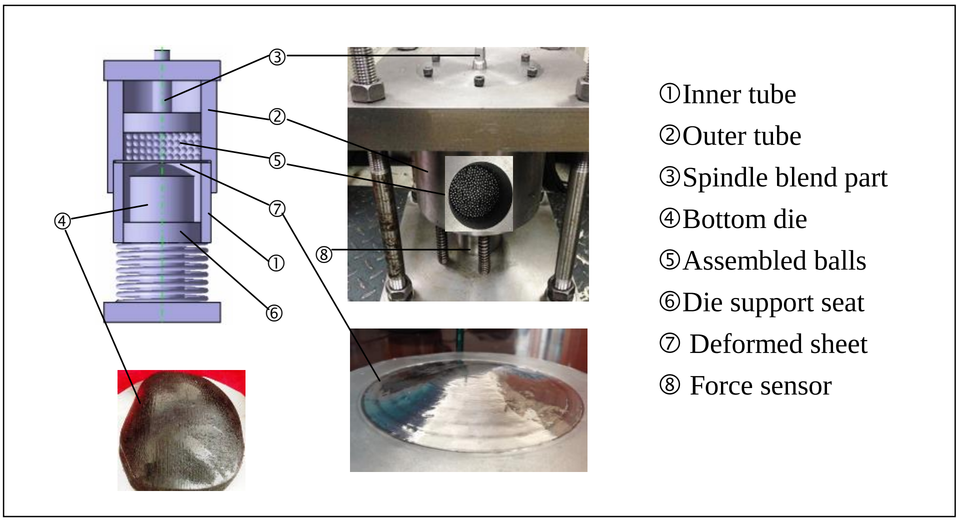
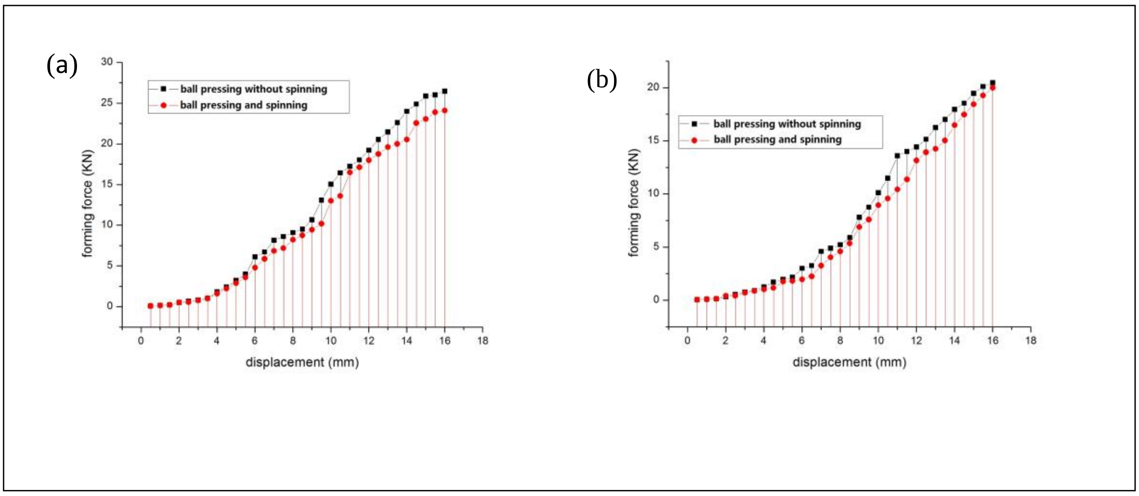


Figure 2 SPM principle and setup



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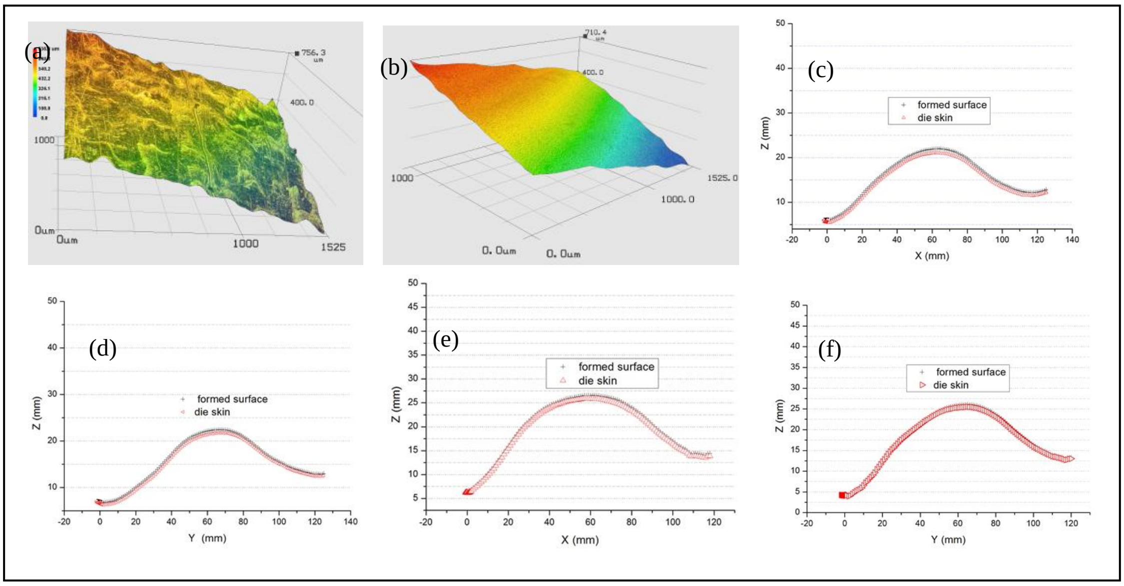

Figure 4 Different measure results of surface of aluminum alloy and Titanium alloy using the same diameter ball 7mm: (a) Aluminum alloy (b) Titanium; (c) and (d) are titanium alloy surface and die skin alone different positions measured; (e) and (f) are aluminum alloy surface and die skin alone different positions measured