



Analysis of bulging process of aluminum alloy by overlapping sheet metal and its formability



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Abstract: The influences of strength coefficient K , work hardening exponent n and thickness t of the overlapping sheet on bulging process are analyzed based on hardening material model. Also, bulging experiments are carried out by taking the aluminum alloy LF21 as formed sheet metal, and selecting overlapping sheet with different thicknesses and material properties, by which accuracy of the above analysis result is verified in the aspects of geometric shape, thickness distribution and limit bulging height. The results show that higher strength coefficient K , larger work hardening exponent n and proper thickness of the overlapping sheet are helpful to improve the formability and forming uniformity of formed sheet metal.

Key words: overlapping sheet; aluminum alloy; bulging; power hardening material; formability

1 Introduction

In order to improve the plasticity of metal materials, on one hand, we can improve the inherent properties such as lattice type, chemical composition and microstructure of materials [1], and on the other hand, we can choose external conditions such as suitable deformation temperature and deformation rate [2–5]. Meanwhile, we can improve the formability of formed sheet metal by controlling or changing the force condition and stress state [6–9].

In overlapping forming process, we overlap the formed sheet metal with another sheet metal (called overlapping sheet) of different or the same kind of material. At the same time, the overlapping sheet takes the shape of the formed sheet metal, so that the formed sheet metal can be constrained and loaded with reverse pressure, so as to improve its formability [10–12]. SEMIATIN and PIEHLER [13] studied the forming limit of the aluminum overlapping sheet with stainless steel without lubrication by experiment, and the results showed that the unstable flow of the overlapping sheet material can lead to interface irregularities which have been associated with the local deformation, and local

deformation determines the forming limit of overlapping sheet. MASANORI et al [14] used the rigid die on overlapping sheets of the same material of pure aluminum in bulging test, and proved that the limit bulging height increased with increasing thickness of the overlapping sheet by changing the thickness, and that the stress state of the formed sheet metal and the overlapping sheet can lead to the changes of necking position by changing the contact conditions, and the two measures mutually inhibited the development of necking, and thereby improved the formability of formed sheet metal. TSENG et al [15] obtained the overlapping sheet bulging limit diagram through bulging tests on the Al/Cu overlapping sheet searching its the forming limit in different thicknesses. MASASHI and KAZUYOSHI [16] studied the formability of aluminum sheet metal cemented by the overlapping sheet of copper sheet, and results showed that the formability with overlapping sheet performed better than that of the two sheet metals formed separately. In this work, based on the model of power hardening material, the influences of properties and thickness of overlapping sheet on bulging uniformity and formability of formed sheet metal are analyzed. With the research object of aluminum alloy LF21 (formed sheet metal), overlapping sheets with different

thicknesses and properties are selected in bulging test to verify the accuracy of the analysis.

2 Analysis of overlapping bulging

The overlapping bulging and stress state in the process are shown in Fig. 1. The overlapping sheet is formed mainly under tangential tensile stress σ_ρ and circumferential tensile stress σ_θ . For the formed sheet metal, besides radial tensile stress σ'_ρ and circumferential tensile stress σ'_θ , it is also affected by the reverse compressive stress σ'_b from the overlapping sheet. So, there are two ways to improve the formability of the formed sheet metal by overlapping bulging. One is to take advantage of good property of the overlapping sheet to control the forming process of the formed sheet metal. While the deformation regularity between the formed sheet metal and the overlapping sheet is similar or identical, the deformation uniformity and the formability of the formed sheet metal can be improved correspondingly. The other way is to use the reverse pressure of the overlapping sheet to turn stress state of the formed sheet metal from plane stress state to three-dimensional stress state, which brings compressive stress on both sides of the formed sheet metal. As a result, all kinds of damage caused by plastic deformation can be prevented and, the thinning and fracture of metal can be restricted. Thus, the deformation uniformity and formability of the formed sheet metal can be improved.

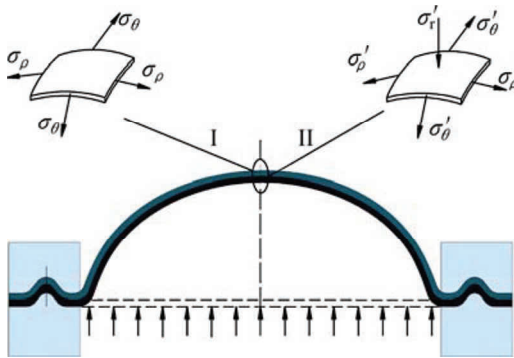


Fig. 1 Stress state of overlapping bulging (I—Overlapping sheet; II—Formed sheet metal)

By either way, the improvement of the formability of the formed sheet metal is associated with mechanical properties of overlapping sheet. Assume that the stress and strain of the overlapping sheet and formed sheet metal satisfy the power hardening material relations:

$$\sigma_1 = K_1 \varepsilon^{n_1} \quad (1)$$

$$\sigma_2 = K_2 \varepsilon^{n_2} \quad (2)$$

where K_1 is the overlapping sheet strength coefficient; n_1 is the overlapping sheet hardening exponent; K_2 is the formed sheet metal strength coefficient; n_2 is the formed sheet metal hardening exponent.

For the first way to improve the formability of formed sheet metal, deformation regularity of overlapping sheet determines the deformation uniformity of formed sheet metal. So, suppose that the overlapping sheet and the formed sheet metal have the same intensity coefficient $K_1=K_2$, when $n_1>n_2$, strain hardening effect and deformation uniformity of overlapping sheet are better than those of formed sheet metal. Under similar forming conditions, the deformation uniformity and the formability of the formed sheet metal can also be improved correspondingly. When $n_1<n_2$, strain hardening effect and deformation uniformity of overlapping sheet are poor. So it can do little help to the formability of the formed sheet metal.

For the second way to improve the formability of formed sheet metal, reverse compressive stress from the overlapping sheet can restrain the development of cracks inside the formed sheet metal and the greater the reverse compressive stress is, the better the sheet metal can be formed. The reverse compressive stress at any point on overlapping sheet is related to the deformation stage of formed sheet metal and overlapping sheet. It can be calculated from the derivation of Eqs. (1) and (2):

$$\sigma'_1 = K_1 n_1 \varepsilon^{n_1-1} \quad (3)$$

$$\sigma'_2 = K_2 n_2 \varepsilon^{n_2-1} \quad (4)$$

It is assumed that the work hardening exponents of overlapping sheet and formed sheet metal are equal ($n_1=n_2$), deformation regularities are similar ($\varepsilon_1=\varepsilon_2$), then with the constant thickness, the greater the overlapping sheet strength coefficient K is, the more helpful there will be to improve the formability of formed sheet metal. Also, the reverse compressive stress can be improved by increasing the thickness of overlapping sheet.

3 Experimental

In order to verify the accuracy of the analysis results, bulging experiment with different overlapping sheet materials was carried out. Diameter of the bulging die is 100 mm. The formed sheet metal is aluminum alloy LF21. The overlapping sheet includes aluminum alloy LF21, LF2, stainless steel SUS201 and copper alloy H62. Mechanical properties of the materials are shown in Table 1. Sheet blank size is 190 mm × 190 mm. The transmission force is viscous medium with the relative molecular mass of 600 k and the shear viscosity of 25260 Pa·s. The experiments were carried out on the

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