

SIMULATION ANALYSIS OF MINIMUM BENDING RADIUS FOR LEAD FRAME COPPER ALLOYS

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Abstract:

Copper alloy has a lot of excellent properties, so it becomes an important alloy for lead frame materials for the integrated circuit. The minimum bending radius of three different copper alloys (Cu-Fe-P, Cu-Ni-Si, Cu-Cr-Sn-Zn) for lead frame materials was analyzed by using finite element. Tensile tests for the three kinds of materials were done to obtain yield stress, ultimate strength and other parameters. The strain-hardening exponent n and normal anisotropy index r of the materials were obtained according to the tensile tests. The minimum bending radius of corresponding materials was available with the simulation analysis, and consequently, the bending properties of the different materials were compared. The results show that the bending property of Cu-Cr-Sn-Zn alloy is the best, and Cu-Ni-Si alloy the worst.

1 Introduction

The integrated circuit IC is composed of a silicon chip, lead frame and plastic capsulation. The lead frame is a very key component of integrated circuit [1]. It can make the silicon chip fix well, connect the chip end and the external circuit, so that the chip information of IC can be well transferred and the heat can be easily distributed. High-performance copper alloys for lead frame materials have not only high electrical conductivity and high strength, but also have good bending performance.

The more researched copper alloys for lead frame materials are generally Cu-Fe-P alloy, Cu-Ni-Si alloy and Cu-Cr-Zr alloy. The Cu-Ni-Si alloy is a kind of typical precipitation strengthened alloy. It has high strength, but its drawback is poor heat resistance for brazing [2, 3]. Cu-Fe alloys are used

in most current production. The most widely used alloy for lead frame material is the Cu-Fe-P alloy [4, 5]. Cu-Cr-Zr alloy has high strength and high conductivity [6]. But the Zr element in the melting is easily oxidized. Cu-Cr-Sn-Zn alloy is a kind of new high-performance copper alloy for lead frame material, which has excellent high conductivity and high strength [7, 8]. Currently, more and more attentions to the material strength and electrical conductivity of high-performance lead frame materials have been paid. There is little research on minimum bending radius of lead frame copper alloy. The bending performance of lead frame materials is a very important factor for improving the quality of lead frame alloy and meeting the needs of high performance integrated circuit. In this paper, the finite element method is used to analyze the lead frame minimum bending radius of three

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different copper alloys (Cu-Fe-P, Cu-Ni-Si, Cu-Cr-Sn-Zn), and the bending performance of different materials are compared.

2 Bending Process Analysis for Lead Frame

IC lead frame is a very sophisticated part, which is pressed by a punching machine which has high degree of automation and high-speed velocity [9]. Figure 1 shows a schematic diagram of the lead frame, and the central location where the IC silicon chips are placed is obtained by the bending process. The bending process is an essential process for forming the lead frame, which makes a certain height difference between the lead frame and the central location where silicon chip is placed. In order to shorten the test period and cost, the finite element method is used to enhance the bending forming properties of three different copper alloys.

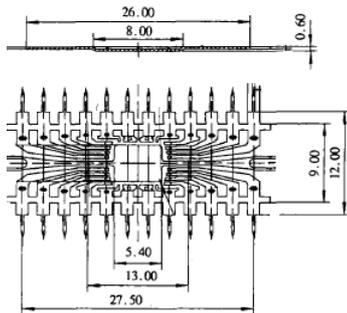


Figure 1. Schematic diagram of lead frame.

3 Simulation Model

The factors which affect the numerical simulation of the bending process of copper alloy for lead frame are materials, die clearance, rounded corners of die, sheet thickness, blank holder force, friction and lubrication, calculation methods and the speed of stamping. The main purpose of this paper is to compare the bending performance of three different copper alloys for lead frame materials. Therefore, the choice of different materials in the simulation process is a major factor. The parameters such as elastic modulus can be plotted/entered/input for simulation after tensile test and calculation. Parameter inputs such as elastic modulus can be used for simulation.

The copper alloys for frame materials chosen in this paper do not exist in the material library of

simulation software. Therefore, it is necessary to do tensile tests for the three kinds of materials. So yield stress, ultimate strength and other parameters can be obtained by the stress-strain curve. The tensile specimen made by ourselves is shown in Fig. 2. Figures 3, 4, 5 are the true stress-strain curves of Cu-Cr-Sn-Zn, Cu-Ni-Si and Cu-Fe-P alloys respectively.

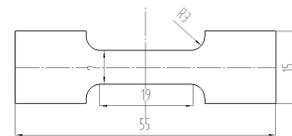


Figure 2. Tensile specimen.

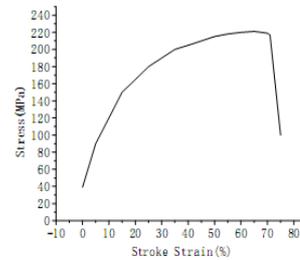


Figure 3. Cu-Cr-Sn-Zn stress-strain curve (specimen annealed).

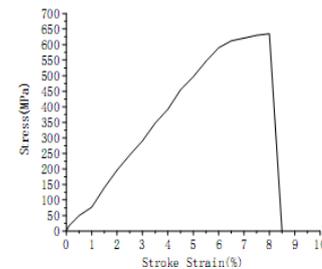


Figure 4. Cu-Ni-Si stress-strain curve (specimen deformed).

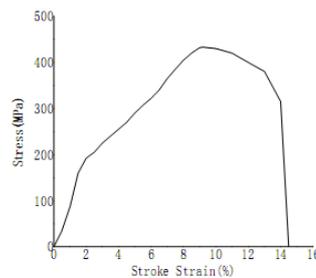


Figure 5. Cu-Fe-P stress-strain curve (specimen deformed).

The work-hardening exponent (n) and normal anisotropy index(r) of sheet metal have essential effect on sheet deformation, so the determination of n and r is important for the theory study and actual production. n is the work hardening exponent of the sheet metal during plastic deformation, and is closely related to the stamping property of the sheet metal. Usually, the following power function is adopted to describe the hardening property in stamping forming

$$\sigma = C\varepsilon^n \tag{1}$$

where, C is the strength coefficient, n is the hardening exponent.

Up to now, many methods have been put forward to measure n and r , such as one-point method, two-point method, three-stepped specimen method, curve-fitting method, etc. In this paper, the work-hardening exponents (n) of different materials are calculated by curve-fitting method according to the stress-strain curves. Then n value could be calculated as follows [10]

$$n = \frac{N \sum_{i=1}^N x_i y_i - \sum_{i=1}^N x_i \sum_{i=1}^N y_i}{N \sum_{i=1}^N (x_i)^2 - \left(\sum_{i=1}^N x_i \right)^2}, \tag{2}$$

where N is the number of data, x_i is $\ln \varepsilon_i$ and y_i is $\ln \sigma_i$.

r is a parameter to express the anisotropic property of the sheet metal which is the ratio of the strains in width to thickness directions expressed by the logarithmic strain, and can be calculated by the equation as follows

$$r = \varepsilon_b / \varepsilon_t = \ln(b / b_0) / \ln(t / t_0) \tag{3}$$

So the parameters of n and r used in numerical analysis are shown in Table 1.

Table1. Parameters of r and n

	Cu-Cr-Sn-Zn	Cu-Fe-P	Cu-Ni-Si
r	0.15	0.134	0.12
n	0.20	0.185	0.16

A lot of complex shapes of the actual work-piece increase the difficulty in creating a modeling in numerical simulation. The geometry details can generally be negligible. V-shaped bending is the most fundamental bending deformation, and every complex bending process can be simplified [11]. In this paper, a V-shaped bending model is used to carry out the numerical simulation. The scheme of a bending model is shown in Fig. 6.

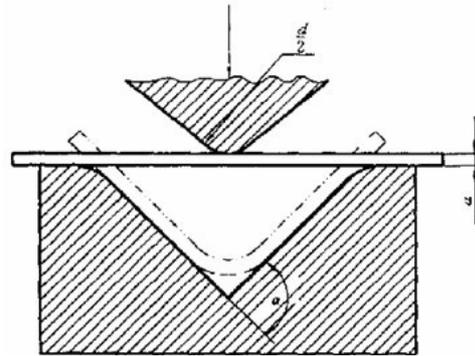


Figure 6. Scheme of bending model.

The length of the specimen is 120 mm, the width 20 mm, and the thickness 0.5 mm. The bending angle is 90 degrees. Copper alloy density is 8.92 g/cm³. The coefficient of friction between a copper alloy and a die made of steel is 0.18. Simulation velocity of the press machine is 1000 mm/s. The finite element model is shown in Figure 7.

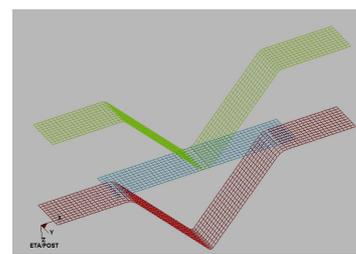


Figure 7. Simplified bending model.

A simplified model with different bending radii is created by CAD and input into simulation software Dynaform. The basic steps of pre-treatment for simulation are shown in Fig. 8.

4 Simulation Results

Under the condition that crack doesn't occur on the outer surface of the bending blank, the minimum bending-radius of the inner surface is called

minimum bending-radius r_{\min} . The ratio between the minimum bending-radius and the blank thickness is called minimum relative bending-radius. In practice, the forming limit of bending is expressed by R_{\min}/t .

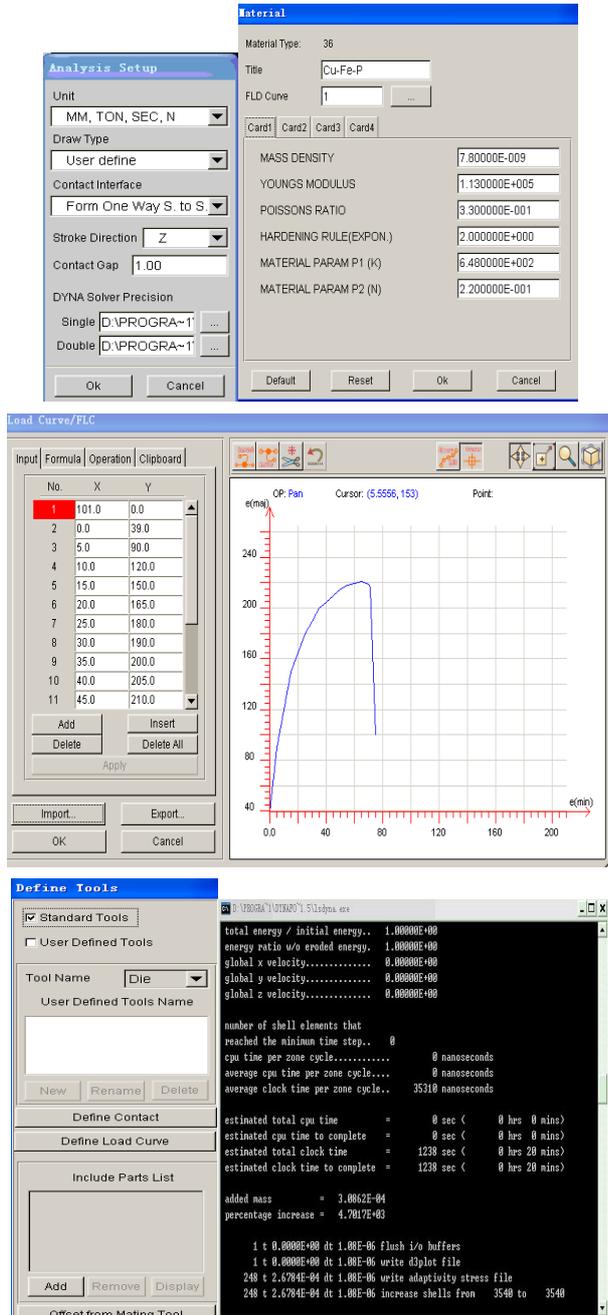


Figure 8. Main steps of pre-treatment for simulation

Relative bending radius (R/t) is the ratio of the inner radius to the thickness of sheet metal (0.5mm) for the lead frame copper alloys. The smaller the R/t

value is, the greater the deformation degree, and also the larger the tensile deformation of the outermost fiber. With R/t decreasing, when the tensile deformation of the outermost fibers overruns the critical deformation of materials, material rupture will occur. The minimum relative bending radius is a main characteristic of the bending performance of a workpiece, so simulation models with different bending radii of different materials are created. The critical states of rupture of each material are finally found, and the minimum bending radii of corresponding materials are obtained.

According to the numerical simulation analysis of different materials, the forming limit diagram (FLD) of each material can be obtained. FLD is an important method to evaluate the formability of sheet metal. When the bending radius of the model is less than the critical value, workpiece rupture occurs. When the bending radius is greater than this critical value, a workpiece is in a safe area.

Fig. 9 and Fig. 10 show the forming limit diagrams of the Cu-0.38Cr-0.17Sn-0.16Zn with their bending radius of 0.5mm and 0.4mm respectively. Bending radius of 0.5mm can be seen as a critical value. When the bending radius is equal to or greater than 0.5mm, the strains are in the security zone as shown in figure 9. When the bending radius of the model is less than 0.5mm, the deformation state becomes crack area. The strain is in the crack area as shown in figure 10. So 0.5mm radius can be used as the critical bending radius of Cu-0.38Cr-0.17Sn-0.16Zn alloy frame material.

Similarly, the critical bending radii of Cu-0.1Fe-0.03P alloy and Cu-3.2Ni-0.75Si alloy are respectively 0.7mm and 1.1mm as shown in Fig11 and Fig. 12. So we could get the corresponding minimum relative bending radius of the three different materials Cu-Cr-Sn-Zn alloy, Cu-0.1Fe-0.03P alloy, and Cu-3.2Ni-0.75Si alloy. Their minimum relative bending radii (R/t) are 1, 1.4, and 2.2 respectively.

5 Conclusion

(1) The tensile tests for the Cu-Cr-Sn-Zn, Cu-Ni-Si and Cu-Fe-P alloys have been carried out. So the yield stress, ultimate strength, the work-hardening exponent (n) and normal anisotropy index (r) can be obtained by the tensile test to numerically simulate the minimum relative bending-radius.

(2) The critical bending radii of Cu-0.38Cr-0.17Sn-0.16Zn alloy, Cu-0.1Fe-0.03P alloy and Cu-3.2Ni-0.75Si alloy are 0.5 mm, 0.7mm and 1.1mm respectively. The minimum relative bending radius of Cu-0.38Cr-0.17Sn-0.16Zn frame material is the smallest and the bending performance of Cu-0.38Cr-0.17Sn-0.16Zn is the best. The bending performance of Cu-0.1Fe-0.03P is then carried out. The minimum relative bending radius of Cu-3.2Ni-0.75Si is the worst.

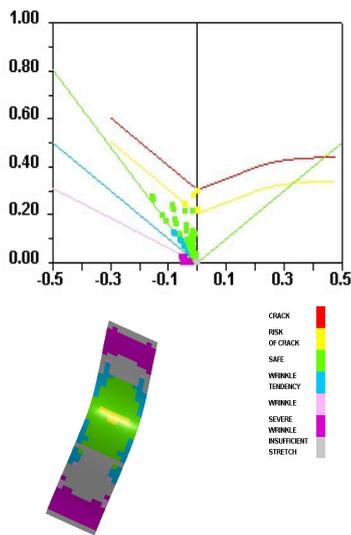


Figure 9. Cu-Cr-Sn-Zn forming limit diagram $R=0.5mm$.

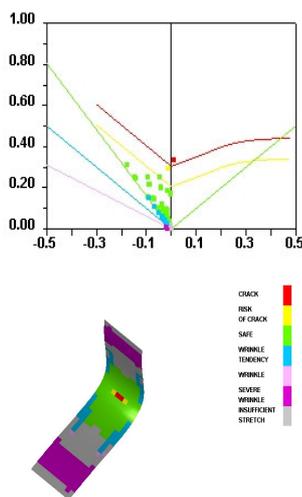


Figure 10. Cu-Cr-Sn-Zn forming limit diagram $R=0.4mm$.

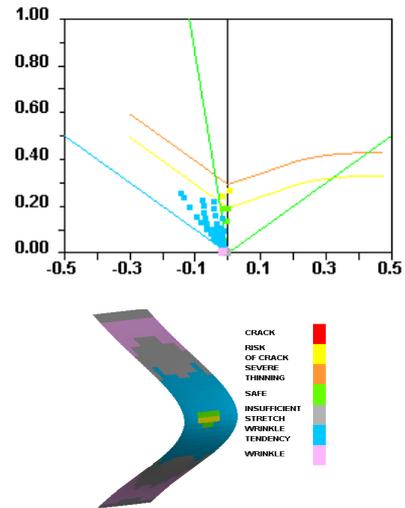


Figure 11. Cu-Fe-P forming limit diagram $R=0.7mm$.

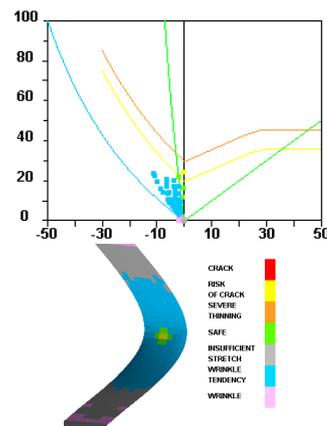


Figure 12. Cu-Ni-Si forming limit diagram $R=1.1mm$.

Acknowledgements

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