Study on the Spreading Characteristics of the Solder Sn-3.0Ag-0.5Cu on an Inverted V-shaped Substrate

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Abstract. The impact of the contact angle of a droplet, the included angle of a substrate and the droplet volume on the morphology and profile of the droplet is discussed, and the spreading characteristics of lead-free solder on an inverted V-shaped substrate are studied, which provides theoretical guidance and data support for a comprehensive study of the interface reaction and wetting mechanism between solder and substrate, and helps improve the brazing process to adapt to complex welding operations. Based on the method of finite element simulation, different contact angles, included angles of inverted V-shaped substrate, droplet volumes and other variables are entered in the model; the relevant physical parameters are defined according to the surface tension and density of solder Sn-3.0Ag-0.5Cu at temperature of 490K; the theoretical spreading results of the droplet are simulated and calculated by Surface Evolver by using the principle of energy minimization and the method of gradient descent; and the spreading distance, contact area and energy equivalence of the droplet are read out by program, which helps to investigate the spreading behavior and wetting characteristics of the droplet.

1 Introduction

It is of great value to study the morphology characteristics of the molten solder when it reaches a state of static equilibrium on a V-shaped substrate to accurately measure the geometric and physical parameters related to the wettability and to explore the spreading mechanism of the droplet and how the interface energy changes, which is also in line with the requirements of increasingly complex and diverse welding process. In the brazing process, it is often necessary to braze the solder into the V-shaped groove to achieve the chemical connection of the operating object. Due to the combined action of gravity component and surface tension, the wetting behavior and spreading characteristics of the molten solder are different from those of the solder on a horizontal substrate. However, few documents are found about the experimental and simulation study in this area [1,2].

The experimental study on the wettability and spreadability of a solder on a V-shaped substrate at different temperatures can provide theoretical guidance for the application of complex brazing process [3,4]. On this basis, some important parameters for the exploration of the three-phase interface characteristics can be obtained through the simulation study on the spreading behavior of the droplets of different volumes on the V-shaped substrates with different included angles and the changes of the droplet morphology, so as to help understand the interaction mechanism between the droplet and the substrate, and systematically analyze the mechanical relationship of the droplet on a special substrate and the change of contour structure characteristics resulting therefrom.

During the experiment, the complete melting of the solder requires a certain melting range, which results in that the solder always melts locally first in the process of heating, and the portion melted first will spread along the slopes of the substrates on both sides when the solder melts on the inverted V-shaped substrate, destroying the integrity of the droplet. Therefore, the experimental measurement of the spreading behavior of the solder on the inverted V-shaped substrate is always very different from the actual result. Hence, it is an effective method to establish a mathematical and physical model by using the method of finite element to simulate and analyze the theoretical spreading morphology of the molten solder Sn-3.0Ag-0.5Cu on the inverted V-shaped substrate under different conditions [5].

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2 Simulated Calculation

Corresponding mathematic models can be established in Surface Evolver according to the geometric and physical parameters of the spread droplet [4]. Fig. 1 is an original model based on the parameter characteristics of lead-free solder Sn-3.0Ag-0.5Cu, where the origin of coordinates is located at the midpoint of the bottom edge of the V-shaped substrate. In the process of building the model, the coordinates of each vertex of the model should be selected in accordance with the droplet volume, and the volume should be kept unchanged during calculation. At the same time, the physical parameters such as gas-liquid surface tension and density should be input to display the real-time iterations of the model via different windows.

On this basis, and based on the fact that the droplet reaches a state of stable equilibrium when the energy is minimized, triangular partition of the grid, averaging grid, linear approximation, quadratic approximation, and other calculation methods and the method of gradient descent were used to find the morphology when the energy function of the system was minimized. Fig. 1 shows the theoretical simulation results obtained by calculation.

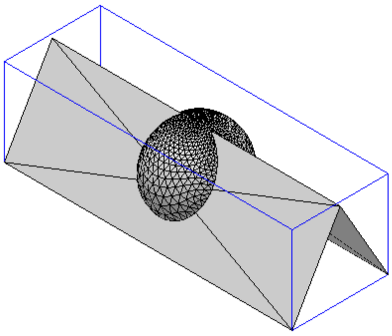

Fig. 1 Numerical Simulation Results of the Molten Solder on a V-shaped Substrate

By judging that the energy changes within 10-5, it could be determined that the function converged, i.e. the model reached the final state of stable equilibrium. Then, the coordinates of the points on the three-phase line and the side profile were read out to calculate the parameters such as the droplet's spreading distance and spreading height, which are used to characterize the wettability of the droplet, and to output important physical quantities such as interface area and energy size.

3 Result Analysis

The spreading morphology of the droplet on the inverted V-shaped substrates with different included angles was simulated and investigated when the droplet volume and the contact angle between the droplet and the substrate kept unchanged. The object of study was a tin-based lead-free solder Sn-3.0Ag-0.5Cu melted at 490K, the volume of the droplet was 1.0mL, and the contact angle with the substrate was 90°. Fig. 2 shows the simulation results of theoretical spreading morphology of Sn-3.0Ag-0.5Cu of the same volume on the inverted V-shaped substrates with different angles at 490K.

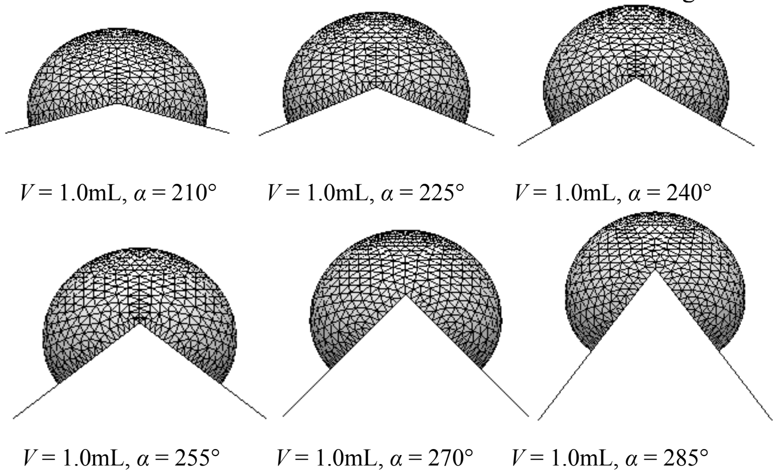

Fig. 2 Theoretical Spreading Results of 1.0mL Droplet on the Inverted V-shaped Substrates with Different Included Angles (Contact Angle θ = 90°)

Based on the simulation results, the coordinates of the points on the three-phase line and the gas-liquid interface were read out, so as to obtain the maximum spreading distance and height of the droplet on the substrate. Fig. 3 shows how the spreading distance changes with the included angle of the inverted V-shaped substrate when the contact angle and droplet volume keep unchanged. The spreading distance of the droplet along the y-axis decreases as the included angle increases. Similarly, the spreading distance along the substrate plane also decreases as the included angle increases. This shows that the gravity component has an obvious impact on the sliding behavior of the droplet.

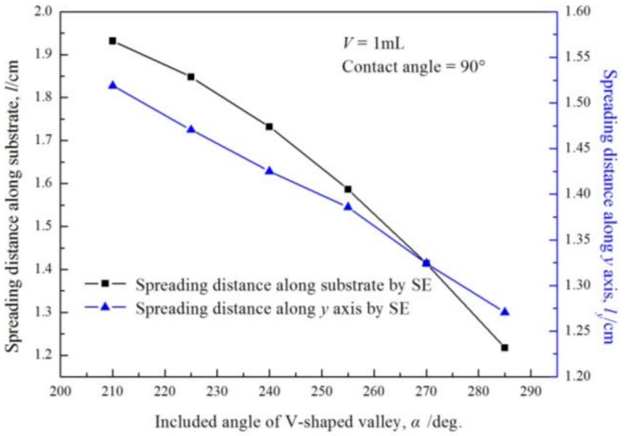

Fig. 3 Relationship between the Spreading Distance of the Droplet on an Inverted V-shaped Substrate and the Included Angle of the Substrate (Contact Angle θ = 90°)

Fig. 4 shows how the droplet height and the gas-liquid contact area change with the included angle of the substrate. It can be found that when the droplet spreads fully, its height decreases as the included angle increases, while its surface area increases linearly as the included angle of the substrate increases.

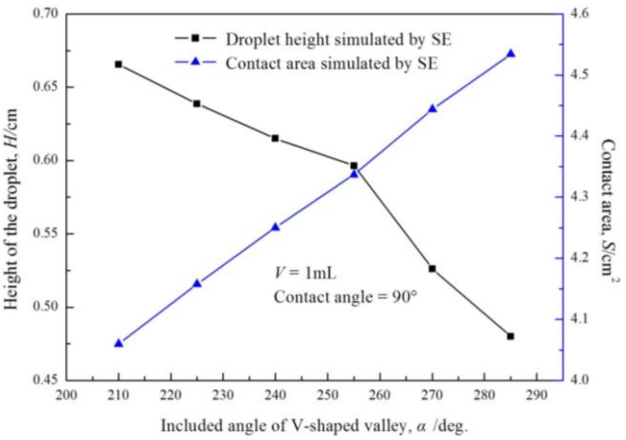

Fig. 4 Relationship between the Spreading Height and Contact Area of the Droplet on an Inverted V-shaped Substrate and the Included Angle of the Substrate (θ = 90°)

Fig. 5 shows how the sum of the interface energy and geopotential energy of the droplet changes with the included angle of the substrate. It can be found that the energy of a fully spread droplet increases as the included angle of the substrate increases.

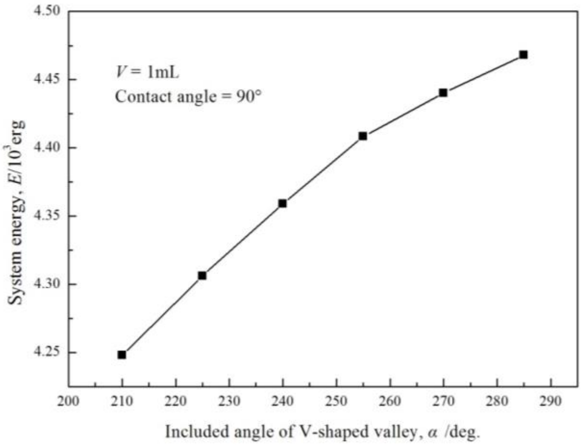

Fig. 5 Relationship between the System Energy and the Included Angle of the Substrate When the Droplet Spreads on an Inverted V-shaped Substrate (θ = 90°)

4 Conclusion

For the spread of a droplet on an inverted V-shaped substrate, when the droplet volume and the contact angle keep unchanged, the droplet height and the spreading distance along the substrate plane on both sides decrease as the included angle of the substrate increases, the system energy increases with the increase of the included angle, and the droplet spreads like a shell. It shows that the gravity component has a more obvious impact on the spread of the droplet on the inverted V-shaped substrate.

Acknowledgments

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