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The Use of Finite Element Method to Predict the Hot Shear-Welding Process of Two Aluminum Plates

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Abstract

Hot shear-welding is a process of bonding two plates together by using shearing stress in a controlled manner. This study dealt with the hot shear-welding process of two aluminum plates. These two plates were piles up in the shear-welding mold. Due to the shearing stress, these two plates were cut off longitudinally, and meantime they were welded together. During this process the control of the surplus material flow is very important, and it can be realized by designing the overlapping length and the shape of the cavity. The commercial software Deform-3D was employed to predict the effect of these two factors. The overlapping length and the shape of the cavity that presents the optimum design was then developed to get a good shear-welding process.

Keywords: shear-welding, aluminum plate, welding die, surplus material

1. Introduction

In the last decades, the use of aluminum alloys in the automotive and aircraft industries appears to be the best technology solutions as well as a great challenge for the engineers. Furthermore many of the aluminum alloys used now in the automotive and aerospace industries are difficult to weld or unweldable with traditional welding processes. Hot shear-welding is a solid state welding process able to weld material traditionally considered difficult to weld or not-weldable. Besides that, by using this method, the filam and impurities can be discharged from the welding part with the surplus material, and here the surplus material is very easy to be wiped off. That means in the welding part the material distribution is uniform, which could results in the good welding conditions on the welding sections.

The hot shear-welding process is obtained by heating the two aluminum plates to be welded first and then adding shear stress to the plates. Distinguishing from directly adding normal stress on the plates at the welding part, the shear stress caused by the welding dies is the acting role in this process. Due to the shear stress the two plates will be cut off and at the same time they will be welded together. However, for different kinds of cavity shape and overlapping length, the surplus material shape and welding strength are different.

The purpose of the present research is to study the hot shear-welding process. Particularly the control of the surplus material flow is the main points that concerned about. For that, numerical simulation by DEFORM-3D was performed to predict the local values of this process i.e. strain, stress and the final shape of the welded plates. From these data, the effects of the cavity shape and overlapping length are investigated.

2. The hot shear-welding process design

As briefly described before, hot shear-welding process is obtained by first heating the two aluminum plates to be welded and then adding shear stress to the plates. In the case of the shear-welding mold, the position of the shear-welding dies should be adjusted to form a certain overlapping area, so that the shear-welding process could be ensured. The mold and the two plates will first be

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assembled and then heated together to a certain temperature. Then the force will be added. Due to the plasticity deformation, the overlapping area will be welded, and meantime plates can be cut off.

When the plasticity deformation and shear-welding process are undergoing at the overlapping area, the aluminum filam and impurities will be discharged out, so the contacting aluminum is relatively pure. The cavities in the welding dies play an important role in controlling the material flow. When adding force to the dies, plasticity deformation happens at the overlapping area, the two plates will be cut off and welded into one remained as the original thickness. Thus, the hot shear-welding process is completed.

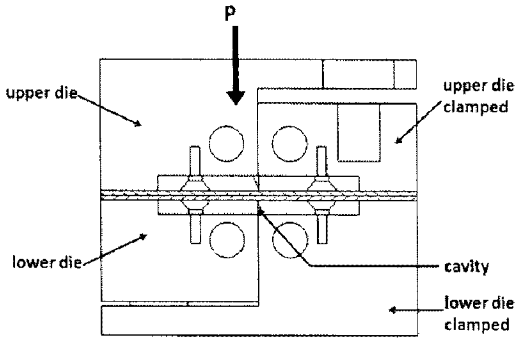

Fig.1(a) Assembly view

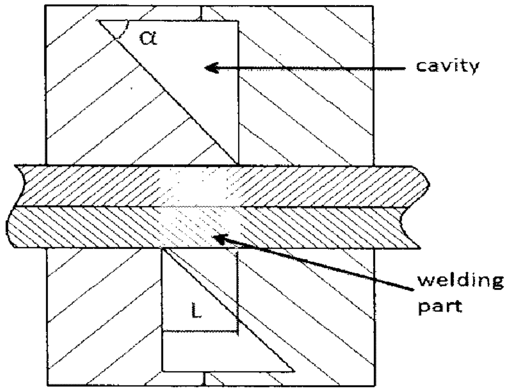

Fig. 1(b) Detailed view
Fig. 1 Die view for hot shear-welding process

Fig.1(a) illustrates the assembling view of the hot shear-welding process, as it shows the two aluminum plates are inserted into the gap between the upper dies and lower dies. Fig.1(b) shows the detailed view of the central part. It can be seen from the figure that the cavities are in the upper die and the lower die clamped, and can be characterized by angle α. The area marked yellow is the welding part, that is to say the dies above and below this area are overlapping (L is the overlapping length). By adding a vertical force to the upper die, the shear-welding process will happen. At the overlapping area the two plates are cut off and welded, as for the surplus material and impurities, they will flow into the cavity.

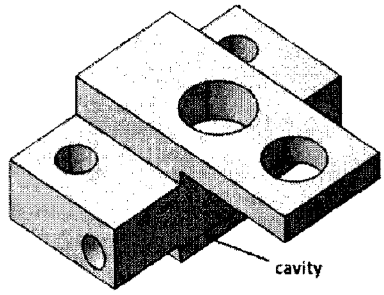

Fig. 2(a) Upper die

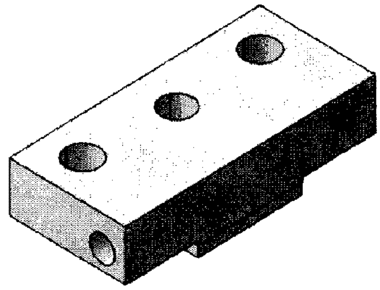

Fig. 2(b) Upper die clamped

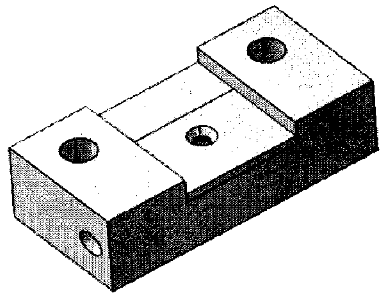

Fig. 2(c) Lower die

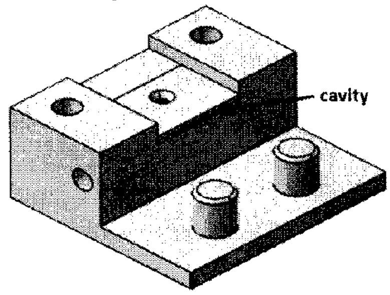

Fig. 2(d) Lower die clamped
Fig. 2 Dies shape for hot shear-welding process

Fig.2 illustrates the exploded view of the shear-welding dies. The pressing force is added on the upper die shown at Fig.2(a). As it can be seen, the cavities are on upper die and lower die clamped, where the surplus material flows into. During the shear-welding process, upper die and lower die clamped will be pressed down together as much as 1.6mm, which is also the thickness of the aluminum plate. However, upper die clamped and lower die clamped are fixed.

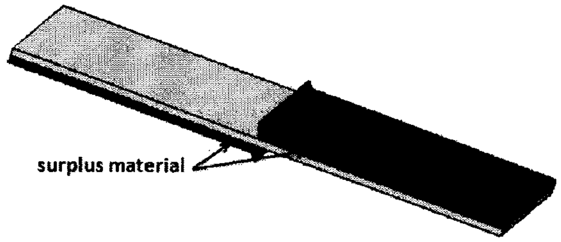

Fig.3 Welded shape with surplus material after hot shear-welding process

Fig.3 shows the final shape of the aluminum plates. The parts marked red are the surplus material, and at the deformed parts of them contain the filam and other impurities. The central part is the product that desired.

3. The simulation for hot shear-welding process.

3.1 The setting of simulation parameters.

In this study the software CATIA was used to build the geometries of the dies and plates, and the CAD model was then transformed to the finite element program DEFORM-3D to establish the finite element mesh. In the finite element simulations, the dies are treated as rigid body and only the plates are deformable.

In order to save the computation time and the data storage space, simplified model is employed. As the plate deformation of the central part is the major, in the simulation the plate was simplified to be 2.5mm in width and 5mm in length, while the thickness remained to be 1.6mm. That is enough to get a reasonable simulation result.

The material properties of AI5052 aluminum alloy given in the DEFORM database was used for simulation. The initial temperature for the plates is 440℃, and for dies it is 460℃.The speed of pressing down is 0.2mm/s.

In the numerical simulation of aluminum deformation the fri ction factor is an important parameter. In the present simulation, the shear friction model was used. In this model, the friction factor m is expressed as

$$m = \sqrt{3}\frac{\tau}{\sigma}$$

where τ is the friction shear stress and σ is the effective flow stress of the workpiece. Accordingly, a friction factor of 0.7 was assumed at the plate-die interface, while a friction factor of 0.4 was assumed at the plate-plate interface. The parameters used in the simulation as well as the friction factors are given in Table 1.

Table.1 The hot shear-welding simulation parameters

Material	AI5052
Initial plate temperature(℃)	440
Initial die temperature(℃)	460
Speed of pressing down(mm/s)	0.2
Friction factor between plate and die	0.7
Friction factor between plate and plate	0.4

3.2 Simulation process.

As mentioned before, in this study the cavity shape and overlapping length are the points that concerned. In the simulation process, 6 models are designed, of which the cavity shape or overlapping length is different from each other. The details are shown at Table 2.

Table 2 Detailed model type

model	overlapping length L (mm)	cavity face angle α (deg)
1	0.4	70
2	0.6	60
3	0.6	70
4	0.8	60
5	0.8	70
6	1.2	70

Here only one simulation process is illustrated to show how the two plates are welded. Fig.4 shows the substep view of the shear-welding process. It could be clearly seen that the surplus material is gradually extruded into the cavity. And Fig.5 is the iso view of the final product.

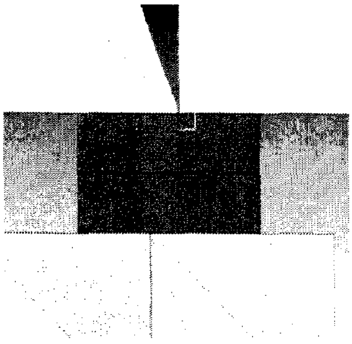

Fig.4(a) Preliminary step

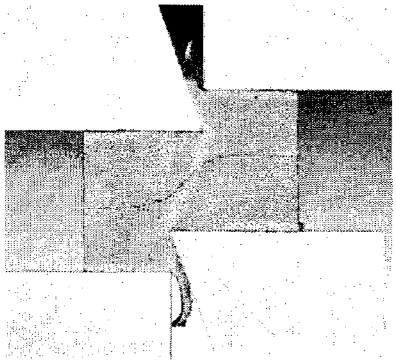

Fig.4(b) Middle step

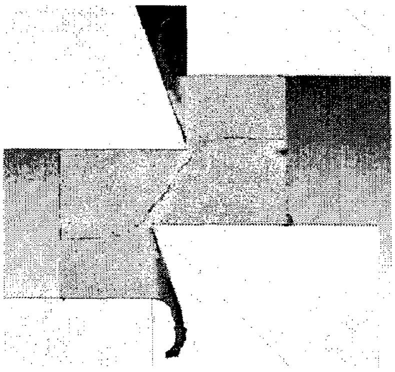

Fig.4(c) Last step

Fig. 4 Substep view of the hot shear-welding process

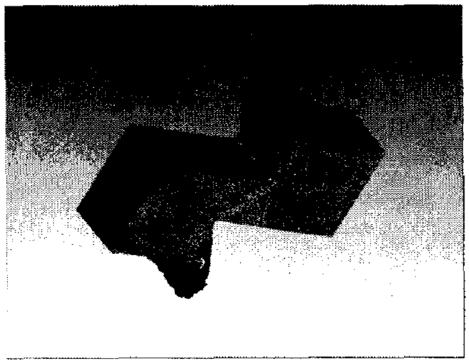

Fig.5 Iso view of the plates

4. Result and discussion.

In this study the sheet forming quality and effective stress are used to evaluate the welding quality. Here the sheet forming quality includes the forming qualities of surplus material and finished product, so it can be characterized by residual contacting line (w), seam angle (β) and overflow height (h), as shown in Fig.6 the red line is the residual contacting line, and the blue line is the welding line. It has been mentioned before 6 simulation processes are designed for investigation, the factor values for each simulation are listed in Table.3.

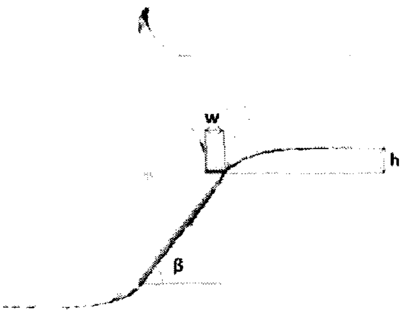

Fig. 6 Characteristic parameter on the plate

Table 3 Factor values

model	overlapping length L (mm)	cavity face angle α (deg)	w (mm)	β (deg)	H (mm)	effective stress (Mpa)
1	0.4	70	0.27	65	0.127	34.3
2	0.6	60	0.26	58	0.199	33.6
3	0.6	70	0.25	58	0.165	33.5
4	0.8	60	0.23	53	0.340	34.1
5	0.8	70	0.22	54	0.260	34.7
6	1.2	70	0.17	48	0.480	33.8

It can be seen from Table.3 that the overlapping length and cavity face angle have little influence on the effective stress. The values of effective stress vary little among different models, and there is no discipline to follow.

As Table.3 shows, the variation of residual contacting line is not very big among model 1to 5. However, the change suddenly becomes bigger in the case of model 6. It may be due to a fierce plasticity deformation over a large welding zone.

In the shear-welding process, the seam angle is very important. A seam angle of 60° is desired. It is seen form Table.3 the shorter overlapping length could causes a larger seam angle. The angle of 58° is the most close to 60°, so it is suitable.

As for the overflow height, if it is too big, the product thickness will be changed a lot, and it is not good for a welding process. Therefore a small overflow height is needed. The Table.3 shows that the overflow height changes with the changes of overlapping length and the cavity face angle, and at model 3 the smallest one can be observed.

5. Conclusion

In the present study, the hot shear-welding process was investigated. The finite element analysis confirms that the overlapping length and cavity face angle have much influence on residual contacting line, seam angle and overflow height, but less on effective stress.

In order to obtain a perfect shear-welding process, smaller residual contacting line, seam angle of 60° and smaller overflow height are needed. In this study, the simulation results reveal that the model 3 could supply the nearest product parameters to the needs. Thus the mold (overlapping length of 6mm and cavity face angle of 70°) can be considered as an optimum design.

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