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# Visualization of nugget formation in resistance spot welding of multi-stackup sheets†

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**KEY WORDS**: (Resistance spot welding) (Nugget formation) (Numerical modeling) (Sheet thickness)

## 1. Introduction

With the demand of lightweight vehicle structures, resistance spot welding of multi-stackup steel sheets is increasingly applied in some complex structures such as front longitudinal rails, A, B, and C pillars, and the bulkhead to inner wing. However, due to the difference in mechanical and physical properties for different sheet grade, the contacts of the workpieces and resultant weld current flow are complex in welding process. As a result of this, the weld nugget sizes at the faying interfaces become an issue. Therefore, it is essential to obtain an understanding of the welding process [1].

In this study, a combined thermal-mechanical/thermal-electrical incremental model has been developed to reasonably predict the nugget formation in resistance spot welding process. These calculations would provide guidance in the selection of welding variables for resistance spot welding of multi-stackup assemblies.

## 2. Numerical Modeling

**Figure 1** shows an example of multi-stackup steel sheets with various sheet gages and material properties. Galvanized coated low carbon steel (SAE1004) and high strength steel (DP600) was used in this study. A weld nugget will develop first at the sheet-to-sheet interface, and then in an increasing volume of material about the sheet-to-sheet interface. At the completion of weld cycle, the current is shut off and the hold cycle begins. The water-cooled copper electrodes extract a significant quantity of heat from the weld area. Because the electrodes are in contact with sheets, the weld region is effectively quenched. Finally, the electrodes are retracted and a completed weld is developed.

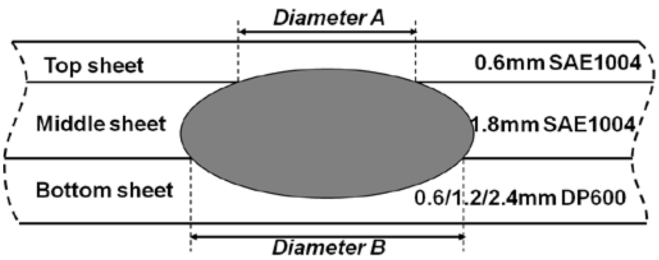


**Fig. 1** Weld nugget configuration and dimensions for resistance spot welding of multi-stackup steel sheets.

Resistance spot welding of multi-stackup steel sheets was prepared using a DC current. The welding schedules employed are given in **Table 1**. The welding time contains three current pulses with 140ms and two cooling pulses with 20ms.

The detailed governing equations, boundary conditions and numerical method are given in our previous paper [2].

**Table 1** Welding parameters for stack-up steel sheets

| Welding parameters | Value |
|---|---|
| Electrode force (kN) | 5.5 |
| Welding current (kA) | 9.5 |
| Squeezing time (ms) | 200 |
| Welding time (ms) | 460 |
| Hold time (ms) | 100 |

## 3. Results and Discussion

Before applying the electrical current, an electrode force is applied to bring the workpieces into intimate contact. The electrode-to-sheet and sheet-to-sheet deformation influences the weld current density. After applying the welding current, the temperature of the sheets would rise by the generation of the joule heat. **Figures 2**(a), 2(b) and 2(c) show the temperature distributions for the welding times of 240ms, 360ms and 460ms under an electrode force of 5.5kN and a welding current of 9.5 kA, respectively. Firstly, high temperature has built up at two faying interfaces between the multi-sheets. As the welding time is increased to240ms, shown in Fig. 2(a), the maximum temperature switched from top-to-middle sheet interface to middle-to-bottom sheet interface due to the switch of the high current density and diameter **B** begins. At the welding time of 360ms shown in Fig. 2(b), a weld nugget initiated at the faying interface **A**. As the welding time is increased to 460ms, the weld nugget at the two interfaces grows bigger.

Since the sheet thickness has a significant effect on the sheet-to-sheet pressure, it would be useful to know how the sheet thickness affects the nugget size for a fixed electrod force. To study the effect of sheet thickness combination on the weld size of multiple stacks of steel sheets, the thickness of the bottom sheet (DP600) was varied from 0.6 mm to 2.4 mm, while the gages of the top and middle sheets (SAE1004) are fixed at 0.6 and 1.8 mm, respectively. Weld

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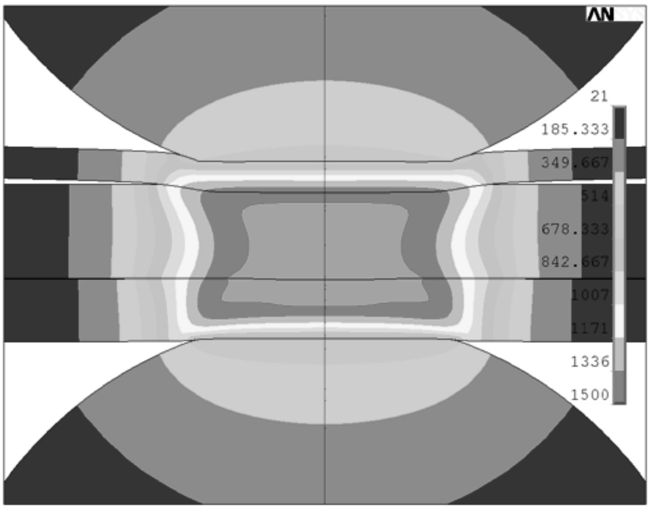
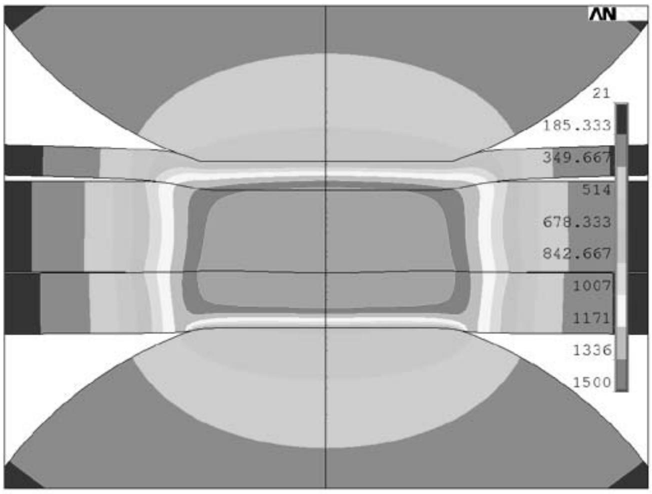
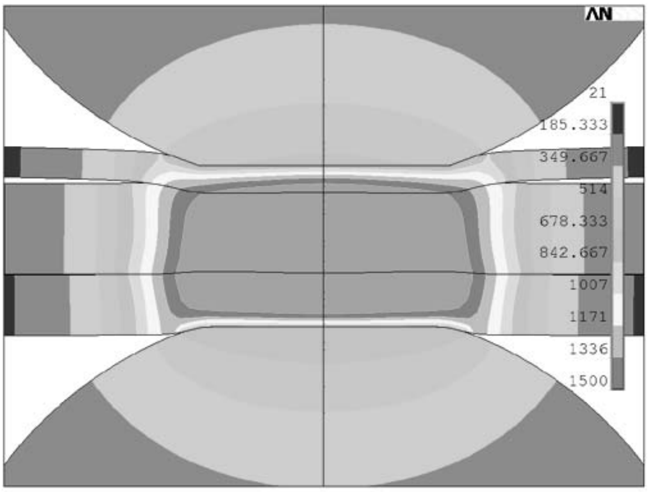



**(a) 240ms**



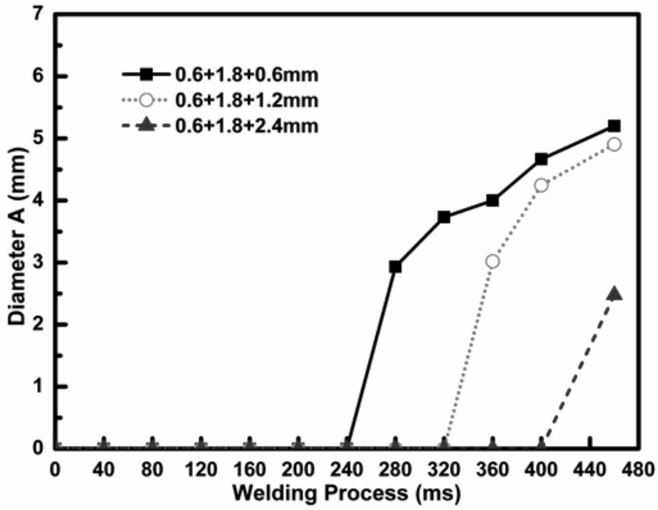

**(b) 360ms**



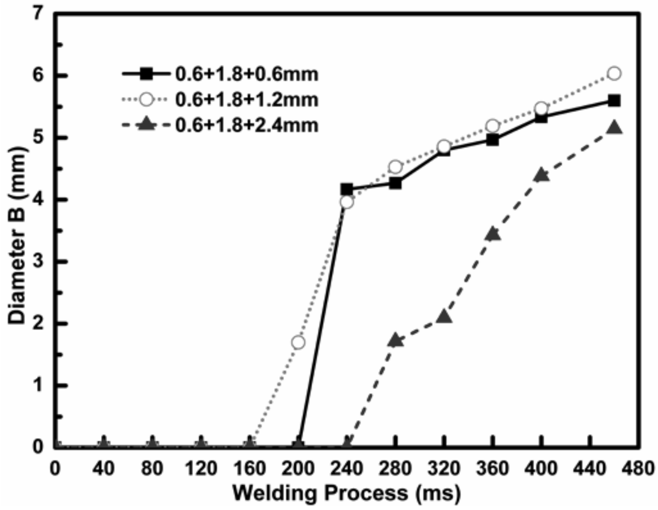

**(c) 460ms**

**Fig. 2** Temperature field during the welding process for 0.6mm SAE1004 +1.8mm SAE1004 +1.2mm DP600 under a welding current of 9.5kA.

nugget sizes were modeled and the results are shown in **Fig. 3**. The diameter **B** at the faying interface between top and middle sheet is always greater than the minimum acceptable weld size, 5 mm. However, there is a significant decrease in the diameter **A** at the faying interface between middle and bottom sheet. It is shown that, when the thickness of the bottom sheet is 2.4 mm, the weld size at the faying interface **A** is less than the minimum required weld size (i.e.4 mm) [3].




**(a) Diameter A**




**(b) Diameter B**

**Fig. 3** Effect of the bottom sheet gage on nugget diameter (a) Diameter A, and (b) Diameter B.

## 4. Conclusions

The conclusions of this study are summarized as follows:

(1) A finite element model has been developed to predict the weld nugget size for RSW of multiple stacks of steel sheets.

(2) The weld nugget on the faying interface of DP600 forms earlier than that on the other interface of SAE1004 in RSW. It is due to the fact that the greater bulk and contact resistivity of DP600 would lead to a quicker heat development in the weld cycle than SAE1004.

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