Numerical Simulation of Resistance Spot Welding Process for Automotive High Strength Steel

Du-Youl Choi¹,², Masahito Mochizuki² and Masao Toyoda²
¹Technical Research Laboratories, POSCO, Korea
²Graduate School of Engineering, Osaka University, Japan

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Introduction

For the design of car bodies, durability and crashworthiness of spot welded body structures are of critical concerns. Traditionally, most of car makers have used rigid link elements to represent spot welds in the body structure in their crash analysis. The role of this rigid link is simply to transfer the load across welded components. Details of the metallurgical and mechanical changes in the spot welds have not totally been considered. Since spot welds on traditional low carbon steels generally experience ductile failure during impact, this modeling approach works well. However, it is anticipated that vehicles using higher strength steels will experience less ductile failure modes during impact. To increase the quality of crash simulations, further improvements of the spot weld modeling are needed. Thus, it has increasingly become important that the engineering performance of the spot welds should be evaluated based on the different residual stress and microstructure distribution generated by the welding processes.

In this study, the nugget formation behavior of high strength steel with welding parameters was investigated using the finite element analysis and the weld properties such as the distribution of microstructure, residual stresses and mechanical properties were predicted.

Model Description

A coupled finite element analysis procedure is used to account the electrical, thermal, metallurgical and mechanical interaction during resistance spot welding processes. The modeling procedure is implemented with the commercial finite element code SYSWELD. Typically axisymmetric models as shown in Fig. 1 are used for the process simulation to acquire detailed information during welding processes.

The electrical contact resistance has dominant effects on the formation of weld nugget. It's important to appropriately treat the electrical contact resistance in the computational simulation. In this study, the dependence of contact resistance on the contact pressure, temperature and material yield strength is incorporated according to the model.

The results of the process simulation include weld attributes such as nugget size, penetration and indentation. The thermal histories obtained were used as the input for the prediction of the microstructure, hardness and residual stresses.

High strength steel with the composition of 0.1C-1.5Mn-1.0Si is selected for this study. The steel sheets are uncoated and 1.4 mm thick. The yield strength of substrate steel is 431 MPa and tensile strength is 658 MPa.

The electrode caps are made of a RWMA Class II copper alloy and with dome radius type of 6 mm tip diameter. The representative welding conditions applied in this study is shown Table 1.

<table>
<thead>
<tr>
<th>Table 1 Welding conditions</th>
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<tr>
<td>Current type</td>
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<tr>
<td>Electrode force</td>
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<tr>
<td>Welding time</td>
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<tr>
<td>Holding time</td>
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<td>Welding current</td>
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Results and Discussion

Generally high strength steel (HSS) has higher electrical contact resistance than mild steel (MS) due to its high yield strength and bulk resistivity. Thus, the resultant nugget growth behaviors in HSS and MS are also different as shown in Fig. 2. The final nugget diameter of HSS is larger than that of MS and the start of nugget formation is occurred in early weld time. The predicted temperature distribution is presented in Fig. 3 with the real metallographic examination showing good agreement in nugget size and deformation of sheets.

Metallurgically, resistance spot welding is a hardening process in the weld nugget as well as the heat affected zone due to the extremely high cooling rate, typically in the range of 1,000 to 10,000 °C/sec. As a result of the rapid cooling in the weld, nearly 100% martensite in melted zone and high temperature heat affected zone and ferrite and martensite dual phases in lower temperature heat affected zone are predicted as shown in Fig. 4.

From phase proportions and cooling rates at various position of weld metal and heat affected zone, the hardness can be calculated. Fig. 5 shows the hardness distribution from weld center to base metal. The calculation shows a large gradient in hardness and generally in agreement with experimentally measured values.

Residual stress analysis was also conducted. The above nugget size, microstructure and residual stresses of the spot weld are can be mapped onto a single weld coupon to determine its static performance.

Fig. 2 Nugget growth behaviors with materials

Fig. 3 Comparison of nugget geometry

Fig. 4 Predicted phase proportion

Fig. 5 Predicted hardness distribution

Conclusions

Coupled finite element modeling procedures were used to simulate the electrical, thermal, metallurgical and mechanical changes for resistance spot welding process of automotive high strength steel. Through the application of modified electrical contact resistance model, the difference of nugget formation behavior comparing with mild steel was well represented. Weld properties such as microstructure, hardness and residual stresses could be predicted by coupling with metallurgical model.

References

(1) S. S. Babu et al, ‘Empirical Model of Effects of Pressure and Temperature on Electrical Contact Resistance of Metals’ Science and Technology of Welding and Joining 2001 Vol. 6 No. 3, p126