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Strength Prediction Model of Aluminum Alloy Friction Stir Spot Welding Using Machine Learning – Part I –

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Aluminum alloys are representative lightweight metallic materials applicable to automobile body structures and are indispensable for vehicle weight reduction. In this study, Friction Stir Spot Welding (FSSW), which enables lightweight and low-cost joining of wrought and die-cast aluminum alloys, is focused on as a joining technology for automotive body structures.

As shown in Fig.1, FSSW is a joining technique in which a high-speed rotating tool is inserted into overlapped sheets, and the materials are softened and stirred by shear and frictional heat to form a joint. In FSSW of aluminum alloys, it is known that the cross-sectional geometry, including a protrusion formed by material flow during the process (hereafter referred to as a “hook”), affects the joint strength. Although the hook geometry varies depending on the joining conditions, the relationships among joining conditions, hook geometry, and joint strength have not yet been sufficiently clarified or quantitatively evaluated. Consequently, evaluation of strength quality and optimization of joining conditions have required extensive experimental efforts.

Therefore, this study aims to model these relationships and to predict joint strength from joining conditions. To this end, a material flow analysis model was developed to predict the hook geometry through numerical simulation of material flow during FSSW process, and a strength prediction model was constructed using machine learning to predict joint strength from the hook geometry.

For the flow analysis model, a particle-based method, which is suitable for representing multiphase flow and large deformation phenomena such as those occurring in FSSW, was employed. The model was constructed by considering key factors influencing material flow, including changes in material viscosity, temperature rise due to shear heating, cooling due to heat transfer, and steep velocity gradients caused by velocity boundary layers. As a result, as shown in Fig.2, the predicted hook geometry and temperature history were in good agreement with the experimental results.

The strength prediction model was constructed as a regression model using experimentally measured hook geometries and joint strengths as training data. Since the hook geometry cannot be directly controlled during welding, joining conditions were diversified using an L36 orthogonal array to fabricate joints with a wide variety of hook geometries. A random forest algorithm, which has good generalization performance even with small datasets, was adopted as the regression model. As a result, as shown in Fig.3, a model that fits the experimental results well was successfully developed.

In conclusion, the series of models constructed in this study demonstrated that joint strength can be predicted from joining conditions.

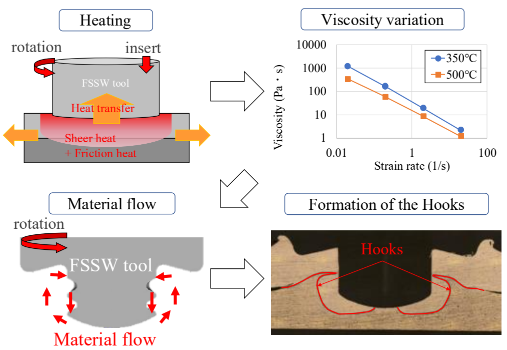

Fig.1 FSSW process

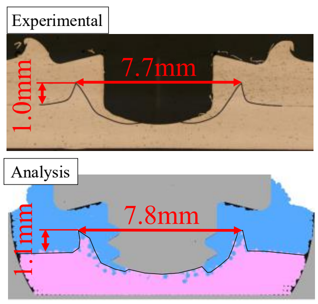

Fig.2 Hooks geometry of FSSW joint

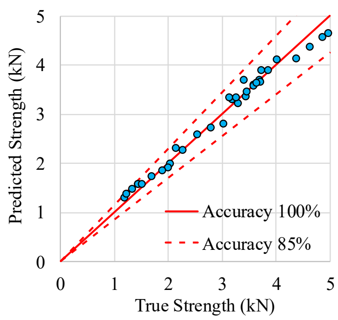

Fig.3 Parity plot of Strength prediction model