

Parameter estimation for spot weld fracture prediction models using data assimilation

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Improving the accuracy of spot weld fracture prediction is a critical issue in vehicle crash analysis, because it directly affects the evaluation of vehicle body deformation and occupant protection performance. Conventional fracture prediction methods enhance accuracy by modeling the nugget and the heat-affected zone (HAZ). However, identifying material properties for each region requires micro-scale tests or welding simulations, which increases testing cost and development lead time. In this study, data assimilation is utilized to estimate spot weld joint properties using only existing standard experimental data from CTS, TSS, and LTS tests.

The spot weld is subdivided into the nugget, the HAZ, and the base metal. The nugget is modeled as an elastic body using a combination of solid and shell elements, and fracture is assumed to initiate in the HAZ. The HAZ and the base metal are modeled with shell elements, and are characterized by the Krupkowski hardening law together with the Modified Mohr–Coulomb (mMC) fracture model. The estimation targets are the material and fracture properties of the HAZ. Using a particle filter, which is one of the data assimilation methods, the hardening coefficient K , hardening exponent n , and initial strain ε_0 in the Krupkowski hardening law, as well as the fracture parameter c_2 in the mMC model, were estimated. The parameter estimation algorithm based on the particle filter is outlined as follows:

- I. Candidate parameter sets (particles) are generated from a noninformative prior distribution by Latin hypercube sampling, and an analysis is performed for each particle.
- II. The maximum load and displacement are computed from each analysis result, and the likelihood of each particle with respect to the experimental results is evaluated.
- III. Weights are assigned to the particles according to their likelihood, and the resulting parameter distribution is approximated as a posterior distribution using a Gaussian mixture model.
- IV. The mean value of each Gaussian component is selected as a new candidate value and re-analyzed, and the parameter set that best reproduces the experimental results is finally adopted as the estimated value.

Using the HAZ properties obtained by the particle filter, accuracy validation was carried out for sheet combinations in which the sheet thickness or material combination differs. The sheet combinations are summarized in Table 1, and the validation results are shown in Fig. 1. As a result, the prediction error of the simulated fracture loads relative to the experiments was generally within $\pm 10\%$, confirming that the fracture loads are predictable.

These findings demonstrate that, by employing a data assimilation approach, the material and fracture properties of the HAZ can be inferred solely from standard CTS/TSS/LTS test results, enabling prediction of spot weld fracture loads for sheet combinations with different thicknesses and materials with an accuracy of approximately $\pm 10\%$. On the other hand, the present study uses the mMC model, and the range of stress triaxiality covered by CTS/TSS/LTS tests is limited. To further improve prediction accuracy, it is necessary to introduce test methods that can provide different levels of stress triaxiality. In addition, fracture initiating in the nugget has been reported for ultra-high-strength steel sheets, and extending the spot weld model so that nugget fracture can also be taken into account is an important subject for future work.

Table 1 Type of sheet combination

Purpose	Specimen Type	Upper Plate		Lower Plate		Plot Color
		Tensile Strength [MPa]	Thickness [mm]	Tensile Strength [MPa]	Thickness [mm]	
① Parameter Estimation	CTS	270	1.6	270	1.6	Orange
	TSS	780	1.6	780	1.6	Magenta
	LTS	980	1.6	980	1.6	Green
	LTS	1180	1.0	1180	1.0	Blue
② Accuracy Validation	CTS	270	2.0	270	2.0	Orange
			2.0	980	2.0	Brown
			2.0	1180	2.0	Brown
		780	1.0	780	1.0	Magenta
			1.5	980	1.5	Green
			2.0	270	0.8	Yellow
		980	2.0	980	1.5	Yellow
			2.0	980	2.0	Blue
			2.0	270	0.8	Blue
		1180	2.0	980	2.0	Blue
			2.0	1180	2.0	Blue
			2.3	980	2.0	Blue
	LTS	980	2.3	1180	2.0	Blue
			2.3	1180	2.3	Blue
			1.0	980	1.0	Green
			1.4	980	1.4	Green
			2.0	980	2.0	Green

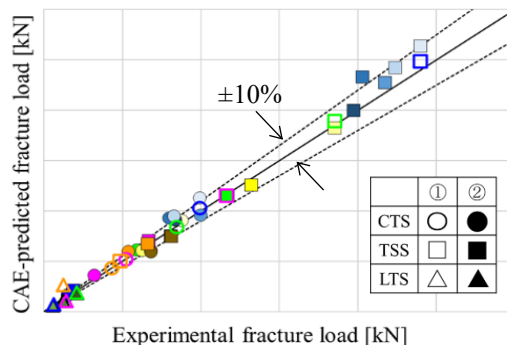


Fig.1 Validation results