Prediction of Shear Fracture Loads of Resistance Projection-Welded Steels by FEM

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1. Introduction

Resistance projection welding (RPW) is a welding method, which induces local resistance heating at a small projection made on the base material. One of the methods for evaluating projection welded part is the lap-shear test. In the lap-shear test, the fracture mode can be divided into pullout fracture (PF) and interfacial fracture (IF) modes. Patil et al. (2018) numerically predicted the shear fracture mode using the damage model, but it is not easy to utilize as it is hard to obtain the damage model parameter of welded part through the test [1]. Therefore, this study predicts the shear fracture load and mode of the projection welded part using finite element method (FEM) and ductile failure model.

2. Experiment

To perform lap-shear test with welded specimens (Fig. 1), RPW experiments were conducted first with DP780 and 980 steels with thickness of 1.0 – 1.8 mm. The welding conditions were set in the range of current $I = 5 \sim 10$ kA, pressing force $F = 3 \sim 5$ kN, welding cycle $t = 5 \sim 10$ cycles. After welding experiment, the lap-shear test was conducted to get the shear fracture load and mode with respect to various nugget diameters. The specimens with expulsion were not used. The strain rate was set to be 10 mm/min and gauge length $L = 50$ mm. The load-displacement (P-δ) curves from experiments were presented in Fig. 2 with FEA results.

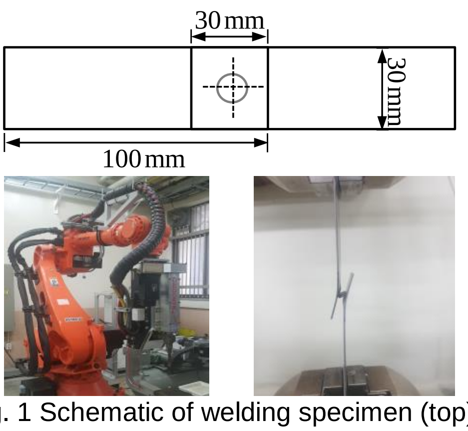

Fig. 1 Schematic of welding specimen (top), welding and lap-shear tests (bottom)

Table 1 GTN model parameters used in FE model

Material	DP980		DP780	
region	HAZ2	FZ	HAZ2	FZ
f_0	0.0015	0.0015	0.0013	0.0013
q_1	1.2	1.3	1.2	1.4
q_2	1.0	1.0	1.0	1.0
q_3	1.44	1.69	1.44	1.96
f_c	0.01	0.02	0.1	0.05
f_F	0.09	0.2	0.2	0.1
ε_N	0.1	0.1	0.12	0.1
σ_N	0.2	0.2	0.22	0.18
f_N	0.04	0.068	0.11	0.05

3. GTN model

To predict the shear fracture load and mode by numerical method, Gurson-Tvergaard-Needleman (GTN) fracture model was used for finite element analysis (FEA) [2]. In Abaqus, GTN yield condition is expressed as follows

$$\Phi = \left(\frac{\sigma_e}{\sigma_y}\right)^2 + 2q_1 f^* \cosh\left(\frac{3q_2\sigma_m}{2\sigma_y}\right) - (1 + q_3 f^{*2}) = 0 \quad (1)$$

σ_e, σ_y are effective von-mises stress and yield stress, respectively. q_1, q_2 and q_3 are constants and f^* is a function of critical void volume fraction, f_c and fracture void volume fraction, f_F. The void growth rate in the GTN model is as follows

$$\dot{f} = (1 - f)\dot{\varepsilon}^p_{kk} + A\dot{\varepsilon}^p_{eq} \quad (2)$$

$\dot{\varepsilon}^p_{kk}$ and $\dot{\varepsilon}^p_{eq}$ are the plastic strain rate and the effective plastic strain rate, respectively. The strain distribution A in Eq. (2) meaning void generation is expressed as a function of the effective plastic strain, and mean (ε_N) and standard deviation (σ_N) of the normal distribution and the void volume ratio f_N. Table 1 shows the selected GTN model variables by best fit of P-δ curves of IF and PF modes in lap -shear test. The initial void volume fraction f_0 is determined by equation suggested by Frankiln [3].

4. FE modeling

FE model of lap-shear test specimen of Fig. 1 was created by Abaqus / explicit. Plane symmetric model was constructed for reducing computational time. The nugget area of FE model was divided into several sections and material properties of heat affected zone (HAZ) were assigned to each section. GTN yield model was considered only FZ and HAZ2 section since the crack only propagates to the one of those directions when fracture occurs. Fig. 3 shows the boundary condition and shape of nugget region of FE model.

5. Results and discussion

Since GTN fracture model was used in FE model, the shear fracture load and mode can be predicted. Fig. 2 compares the *P*–*δ* curves from FEA and experimental results for specimen constituted with same material and thickness (*t*). When the fracture occurs, initial crack from HAZ propagates to HAZ2 direction in PF mode. In contrast, crack propagates to FZ direction in IF mode. Fig. 4 shows the nugget region of real lap-shear test specimen and FE result for dissimilar material set (DP780 1.4mm - DP980 1.0mm). In FEA result, crack propagation direction and position are the same with the experimental result. The shear fracture load and modes of the FEA results were compared with 33 experimental results, and the material sets showing maximum errors in each fracture mode are shown on the table 2 with nugget diameter (d_n). The fracture mode of FEA results was same with experimental results for all material sets.

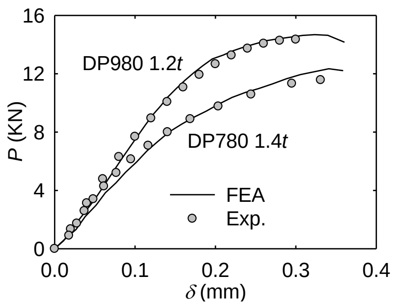

Fig. 2 Comparison of *P*–*δ* curves from FEA and experiment

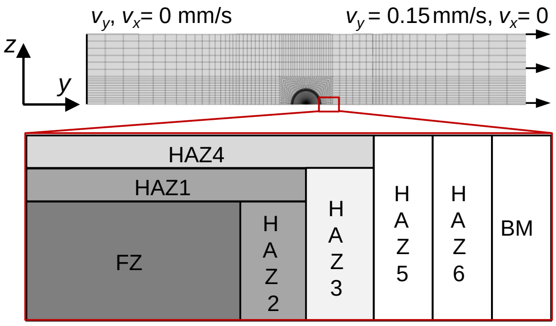

Fig. 3 Boundary condition and section of nugget area of FE model

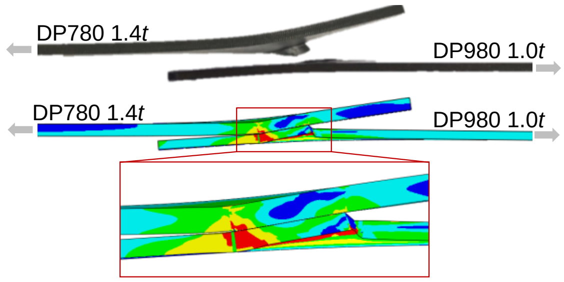

Fig 4 Comparison of test specimen and FEA result for dissimilar material set

Table 2 Comparison of shear fracture loads of experimental and FEA results

material set (σ_{t1}, t_1, σ_{t2}, t_2)	d_n (mm)	P_{exp} (kN)	P_{FEA} (kN)	error (%)	mode
DP780 1.4*t*– DP780 1.0*t*	5.89	13.6	12.4	8.8	PF
DP780 1.0t – DP980 1.4t	5.45	11.8	10.4	11.9	IF

6. Conclusions

To predict fracture load and mode of projection welded part in lap-shear test, FEA model was constructed by using GTN fracture model. Welding and lap-shear tests were conducted for DP 780 and 980 steels to get GTN model parameters of welding part. A comparison of fracture load and mode from the FEA and experimental results was performed, and the conclusions are as follows.

1. The *P*–*δ* curves and fracture mode from FEA and experimental results are the same for all material sets.

2. In PF and IF modes, the shear fracture loads from FEA results exhibit maximum errors of 12 % and 9 %, respectively.

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