Crack growth rate in friction stir welded nugget under different R ratio fatigue load

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Abstract 2.0 mm thick 2198-T8 Al-Li alloy sheets with the parallel friction stir welds in the middle were used in this work. The center cracked tension (CC(T)) specimens with transverse welds were designed and welded by different welding parameters. Fatigue tests were performed and fatigue crack growths in the nuggets were measured and compared. Effects of rotation speed and welding speed on fatigue crack growth rates parallel to the friction stir welds were studied. It was shown crack growth rate in the nuggets can relate to the welding parameter. Residual K (K_{res}) approaches was used to predict fatigue crack growth rates in residual stress fields. Finite element models of the samples were built and the measured residual stress data put into the model. The virtual crack closure technique was used to calculate K_{res} and then K_{res} was used to calculate effective R values. Predicted crack growth rates were compared with experimental results.

Keywords Friction stir weld, Welded nugget, Fatigue crack growth rate, different R ratio.

1. Introduction

Friction stir welding (FSW), invented at The Welding Institute (TWI) in 1991, was widely used in modern aerospace industry. This new welding technique have successfully taken the pilot study stage and developed into a useful alternative in the manufacture of industrialized aluminum structures solid phase connection technology. Compared to traditional welding techniques, FSW strongly reduces the presence of distortions and residual stresses [1-4]. Also, the FSW performed well in the strength, fatigue and fracture resistant of aerospace aluminum welds, which has long inhibited the widely use of those alloys such as 2XXX and 7XXX series [5, 6]. These aluminum alloys are generally classified as non-weldable because of the poor solidification microstructure and porosity in the fusion zone [7]. Previous studies show that the grain size of the weld nugget has a strong effect on the mechanical properties [8]. In 2007, the air bus published a report which claimed that the FSW application in fuselage longitudinal seam connection of A340-500s and A340-600s has reduced 0.9 kg weight per meter relative to traditional riveting technology. A similar instance occurred in Boeing that the production efficiency in the manufacture of C-17 Global/MasterIII has improved tenfold with the FSW application.

2. Experimental procedure

2.1. Fatigue test procedure

2198-T8 Al-Li alloy plates were friction stir welded. The welding directions are perpendicular to the rolling direction. Cracks are the weld centre and grow in the weld. Center cracked tension (CC(T)) specimens ware chosen for the fatigue experiment. All samples have been cut into 220mmX70mm. The specimens have different rotation speed and welding speed: 800(rpm)/400(mm/min), 600(rpm)/200(mm/min) and 400(rpm)/100(mm/min). Fig.1 shows the sample geometries.

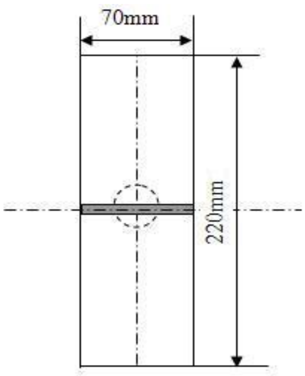
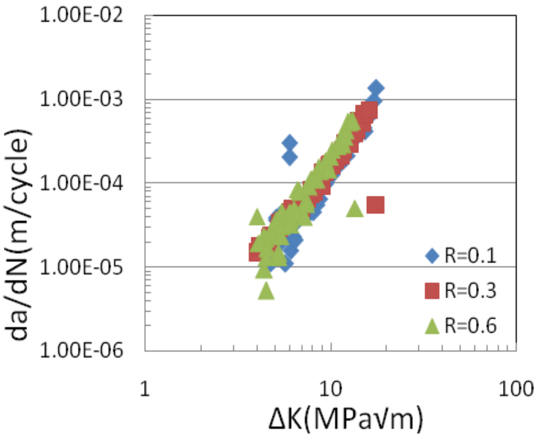


Fig.1 Sample size

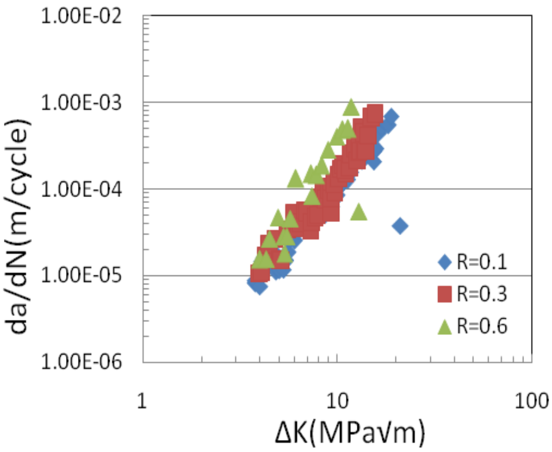
Instron8872 hydraulic servo fatigue testing machine was used. Samples with different rotation speed and welding speed were tested in three different R ratio: R=0.1, R=0.3 and R=0.6. Δ P was set a constant value 6.3 KN.

2.2 Results

In Fig.2, crack growth rates under three different R ratio fatigue loads were shown. For three different welding parameters, crack growth rates at R=0.1, 0.3 were shown in Fig. 3.
The experimental data from all specimens was compared in Fig.2 and Fig.3, for samples with crack, da/dN versus $\Delta K_{applied}$. Even though had different rotation speed, welding speed and R ratio, the crack growth rate of these samples tended to be the same tendency. Previous studies [9] indicated that the fatigue life was based on the R ratio, which shown the stress level played an important role in crack growing. However, the fatigue life of the three kinds of samples certificated that even in different rotation speed and welding speed, the microstructure was the primary factor controlling the crack propagation for cracks grow in the welded nugget.

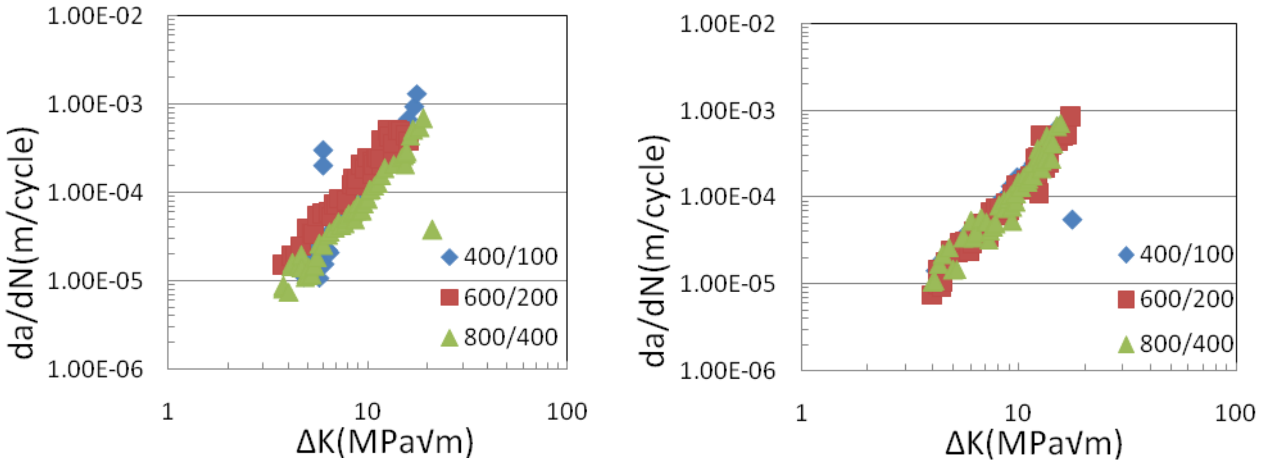


(a) 400/100



(b) 800/400

Fig.2 Crack growth rates at R=0.1, 0.3, 0.6



(a) R=0.1 (b) R=0.3

Fig. 3 Crack growth rate under different ratios for three different welding conditions

3. Numerical simulation

3.1 Numerical solution of K_{res}

The evaluation of residual K (K_{res}) was considered as a mature method of predicting fatigue crack growth rates in residual stress fields. Finite element analysis was used to calculate the stress intensity factor K_{res} from residual stress by using ABAQUS 6.10. The models were built using C3D8R (an 8-node linear brick, reduced integration, hourglass control.) entity elements around the notch tip and along the crack lines. The unit size gradual transition from 2.5mm to 0.5mm length. The virtual crack closure technique (VCCT) [10] was used for calculating strain energy release rate for unit sample thickness.

For plane stress, the relation between the strain energy release rate and stress intensity factor (SIF) was as follows:

$$K_{res} = \sqrt{GE} \tag{1}$$

$$\Delta K = \frac{\Delta P}{B}\sqrt{\frac{\pi\alpha}{2w}\sec\frac{\pi\alpha}{2}} \tag{2}$$

$$R_{eff} = \frac{K_{res}+K_{min}}{K_{res}+K_{max}} \tag{3}$$

If residual stresses were input to this model, K_{res} can be derived from Eqs. (1), R_{eff} can be derived from Eqs. (2) and (3). The crack growth rate can be calculated with the Paris formula.

3.2 Fatigue life in simulation

The fatigue life in weld nugget were compared to the experimental data, as shown in Fig.4 For Δ K less than 10MPa √ m, the experimental data was consistent with the parent material. When Δ K grew breakthrough 10MPa √ m, the experimental data was more in line with simulations.

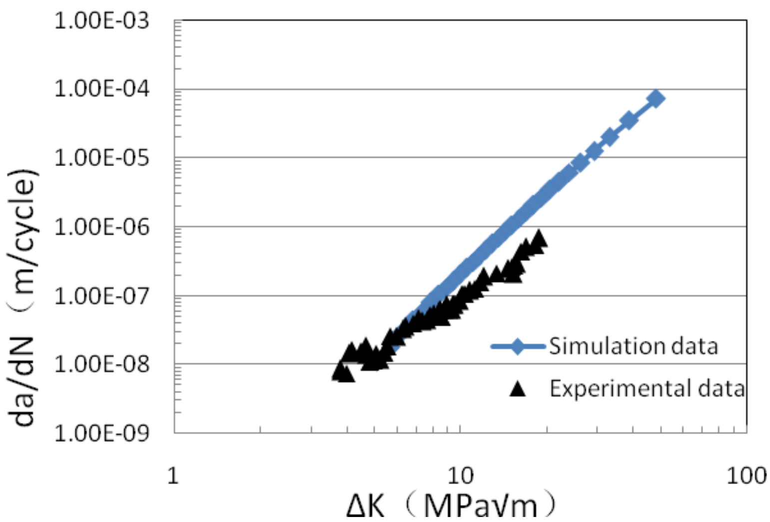


Fig.4 The crack growth rate in parent material and weld nugget

4. Conclusion

The crack growth rate in weld nugget of Al-Li alloy 2198-T8 friction stir welded was mainly decided by the microstructure, not the R ratio as common understanding.

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