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Welding Residual Stress Relaxation at the Weld Bead Toe of a Non-load Carrying Fillet Joint under Cyclic Loading Condition[†]

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Abstract

Experimental evidences proved that the crack initiation is mainly caused by the damage accumulation, which can be described by means of macroscopic or microscopic cyclic plasticity, such as hysteresis loops, ratcheting and cyclic creep. Another important aspect is the one represented by the residual stress field generated during a welding process, since it can deeply influence the mechanical response under cyclic loading. In the present work an FE analyses is conducted to examine the welding residual stress relaxation at the weld bead toe of a non-load carrying fillet joint under cyclic loading condition.

KEY WORDS: (residual stress), (unconventional plasticity), (cyclic plasticity), (relaxation), (fatigue).

1. Introduction

Crack initiation is one of the most challenging issues among the fatigue failure processes of materials and structures. Experimental evidences proved that the crack initiation is mainly caused by the damage accumulation, which can be described by means of macroscopic or microscopic cyclic plasticity as a consequence of the irreversible contributions such as hysteresis loops, ratcheting and cyclic creep. Another important aspect is the one represented by the residual stress field generated during a welding process, since it can deeply influence the mechanical response under cyclic loading.

In the present work the model categorized by an unconventional plasticity model [1-5] has been adopted for the FE simulations, aiming to describe the metals behavior under cyclic loading conditions and focusing the attention on the welding residual stress relaxation, not only under macroscopic yielding but also under macroscopically elastic condition. The FE analyses for a non-load carrying fillet joint is conducted to discuss the effects of two different weld toe shapes on the relaxation of residual stress. Moreover, in order to introduce the welding residual stress fields, a thermo-elasto-plastic analysis for welding process have been conducted for two different weld toe shapes and discussed in relation to the relaxation behavior of welded residual stress fields.

2. Constitutive equations and numerical procedure

2.1 Material and FE models

Fig. 1 shows FE geometry for the non-load carrying fillet joint used in this paper, where the welded toe shape has been differentiated in two types: a straight and a rounded ones. For sake of simplicity 1/4 of the whole bar has been modeled due to the double symmetry of the sample. In addition, a mesh refinement (i.e. 0.05 mm minimum element dimension) has been realized in the proximity of the welding toe, where the largest stress concentration tends to appear.

The extended Subloading Surface Model [5-7] is able to describe the generation of plastic strains within the yield surface by means of a loading-surface (i.e. subloading surface), which can be obtained through a similarity transformation from the conventional yield surface. Classical theories define a neat distinction between elastic and plastic regions, allowing an irreversible stretch only within the latter. On the contrary, the subloading surface model abolishes the separation into domains, stating that a plastic response can be realized for every change in the stress state with the satisfaction of loading criterions. Furthermore, the insertion of a mobile similarity center, function of the plastic strain, makes this theory particularly suitable for investigating the cyclic mobility of materials.

Fig. 2 describes the stress-strain evolution calculated in the numerical analysis for monotonic loading and two cyclic tensile loading/unloading cases.

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Table 1 Cases investigated in the analyses.

				Pre-load (C) and Cyclic stress (F) (unit: MPa)			
				C=0		C = -300 (R=-∞)	
				F=180 (R=0)	F=300 (R=0)	F=180 (R=0)	F=300 (R=0)
Bead shape	Straight (S)	Welding residual stress	no	S-180	S-300	S-C180	S-C300
			yes	SW-180	SW-300	SW-C180	SW-C300
	Ball (B)	Welding residual stress	no	B-180	B-300	B-C180	B-C300
			yes	BW-180	BW-300	BW-C180	BW-C300

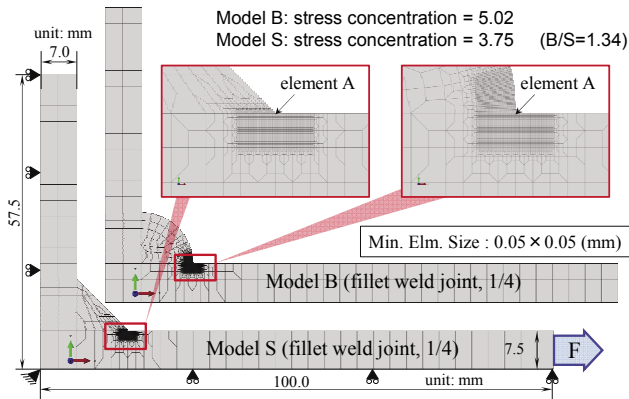


Fig. 1 Meshes adopted for the FE simulation.

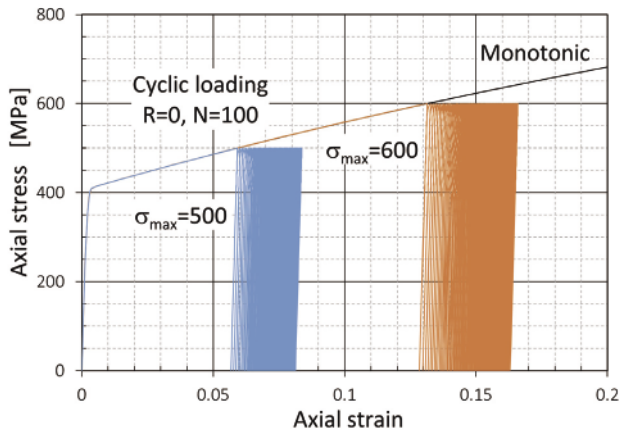


Fig. 2 Model response of stress-strain curve.

2.2 Calculation of welding residual stress field

A residual stress distribution for the aforementioned FE models has been obtained by means of two different approaches. One uses a 300 MPa compressive load before applying a cyclic sequence, and another consists in running a preliminary thermo-elasto-plastic analysis for the simulation of a welding process. The latter has been realized considering temperature dependent material parameters and assigning a temperature history for the weld toe.

Fig.3 shows the distribution of residual stress fields around the welding toe obtained by the FE analyses. Then, it is found that the maximum value of stress in Model B is larger than the one in Model S. In addition, the residual

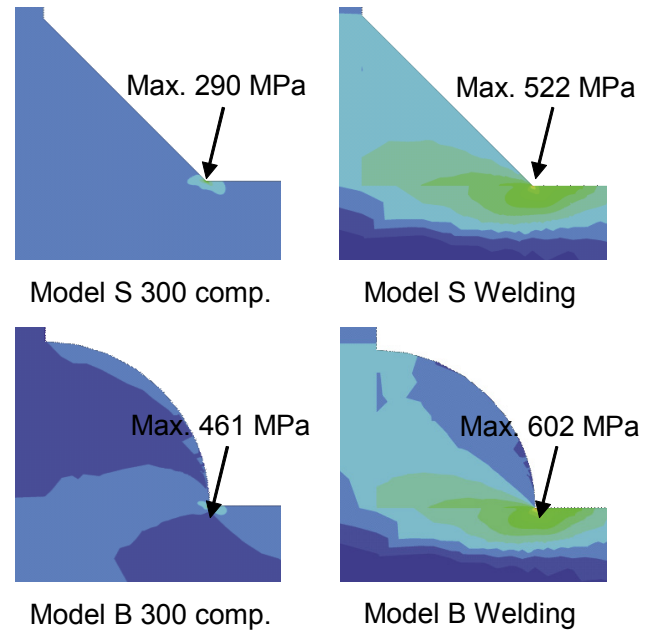


Fig. 3 Distribution of welding residual stress

stress field, resulting from the welding process simulation, shows higher values and a wider distribution.

3. Result and Consideration

In order to discuss the effect of weld toe shapes on the residual stress relaxation, a FE analysis has been carried out applying two different maximum amplitudes for the cyclic loads: 180 and a 300 MPa. Table 1 reports the 16 cases investigated in this work, considering for each of them a total number of 100 loading/unloading cycles.

Figs. 4 to 6 display the axial stress-strain curves and the residual stress for the element located in the bottom-right part of the weld toe (where the mesh has been refined). Fig.4 points out that the values of stress and the plastic strain accumulation in Model B are bigger than those in Model S. On the other hand the FE analyses, which consider a residual stress field from the thermo-mechanical simulation (Fig.5), indicate the formation of a smaller irreversible accumulation in Model B. This can be explained considering that a larger material hardening is induced for the Model B with higher constraint, and then local mechanical response becomes stiffer than the other.

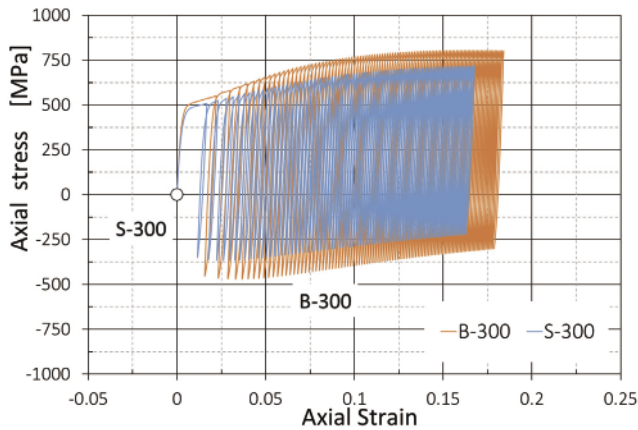


Fig. 4 Stress-strain curves (S-300, B-300 cases).

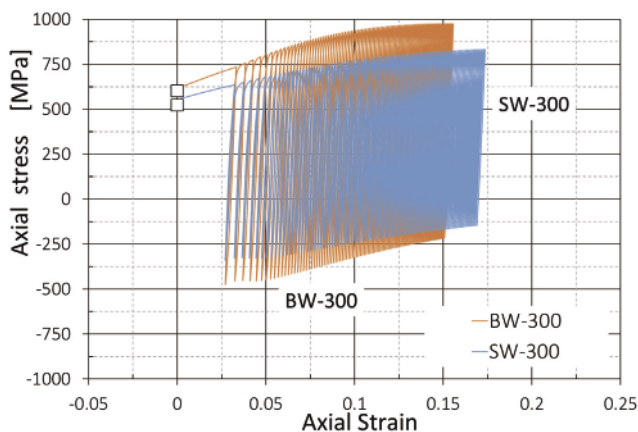


Fig. 5 Stress-strain curves (SW-300, BW-300 cases).

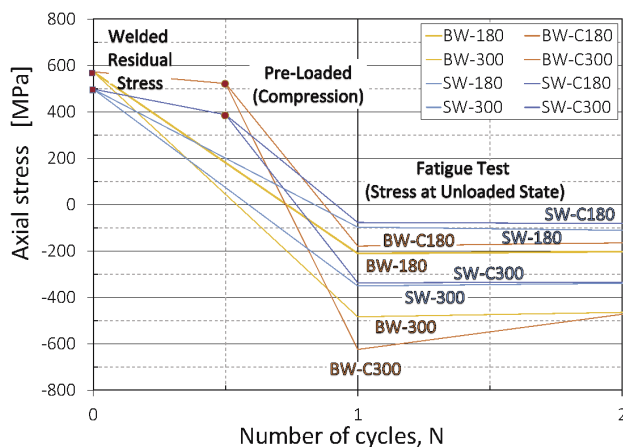


Fig. 6 Residual stresses vs. number of cycles

Moreover, the initial residual tensile stress in tensional direction transforms into compressive stress just after applying a tensile cyclic load, $N=1$. Hysteresis loops move upward along the loading axial direction with increase of number of cycles.

4. Concluding remark

The study presented the FE study of a non-load carrying fillet joint under cyclic loading condition, by considering the welding toe shapes effect on the residual stress relaxation. The results proved a substantial difference induced by the geometry:

1) During the cyclic loading onto the Model without welding residual stress fields, the plastic strain accumulation of the round shape weld toe is larger than in the straight type. On the other hand, considering the welding residual stress, the plastic strain accumulation in the round shape weld toe became smaller due to the material hardening effect.

2) The initial residual tensile stress transforms itself into a compressive one just after applying a tensile load. The residual stress is gradually relaxed during the cyclic loading. Here we should note that all the resultant conclusions can be affected by the geometries and the magnitude of applied stresses.

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