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Measurement of Residual Stress in a Friction Welded Joint by Using Neutron Diffraction

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The mechanism that produces residual stress near the boundary of two metals connected by friction welding was investigated by neutron diffraction. This investigation showed that the residual stress near the boundary of friction welding was compressive (about 300 MPa) at the surface and tensile (about 200 MPa) at the center of the welded specimen. These results indicate that the residual stress was produced by the heat history during cooling after the upsetting process.

KEYWORDS: friction welding, residual stress, neutron diffraction method, work-hardening, heat conductivity

§1. Introduction

Friction welding is a bonding method that uses the heat generated by friction caused by the rotation of two contacting components under loading. It is used widely in automotive manufacturing, industrial machining, etc. since it can weld the different materials.[1)] However, the heat history in the welding process leads to high residual stress being generated at the welding boundary. In this study, the neutron diffraction method is applied to measure the residual stress, and the generation mechanism of residual stress at the bonding boundary is determined.

§2. Experimental Method

The shapes of specimen used for residual stress measurement by neutron diffraction and tensile testing are shown in Fig. 1. A SS400 carbon-steel bar and a type-304 stainless-steel bar were bonded by the friction welding. The diameter and length of each bar were 25 and 100 mm for residual stress measurement and 30 and 290 mm for tensile testing. The welding conditions were as follows: rotating velocity: 1200 rpm; friction pressure: 59 MPa; upset pressure: 118 MPa; and time: 118 MPa 10 sec. The burr caused by the friction welding was removed by mechanical machining. The Residual Stress Analyzer (RESA) at JRR-3M, which is operated by Japan Atomic Energy Research Institute (JAERI), was used for measuring the lattice strain of the welded specimens. The 110 diffraction of SS400 and the 111 diffraction of type-304 were measured. The wavelength l of the monochromatic neutron beam was 0.208872 nm. Diffraction patterns were taken at 1, 3, 5, 8, 15 and 30 mm from the welding boundary at the center and the surface of bar. The sampling area was 2 mm-width and 4 mm-height in parallel to the welding boundary. The strain measured by neutron diffraction was converted to the stress using E of 165 GPa and Poisson's ratio of 0.16 for SS400 (obtained from a calculation using a monocrystal model) and E of 231 GPa and Poisson's ratio of 0.19 for type 304 (obtained from the literature[2)]).

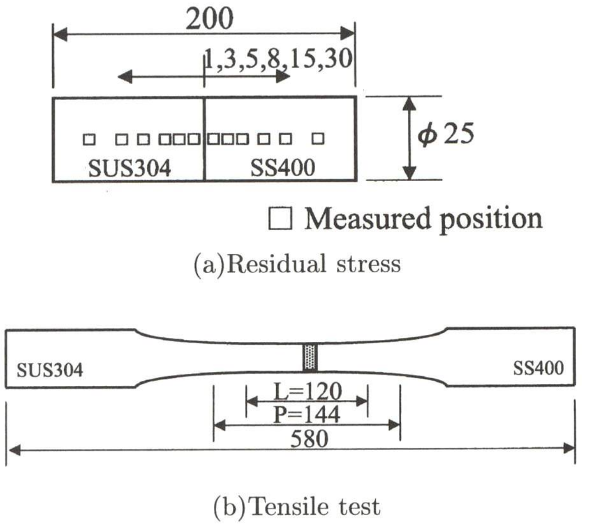

Fig. 1. Measurement point of the specimen(a) and dimensions of a specimen for tensile tests(b).

§3. Results and Discussion

3.1 Residual stress distribution near the boundary of friction welding

The diffraction patterns near the boundary of friction welding are shown in Fig. 2. The measurement range of neutron diffraction was between 30 and 120 degrees. Only the 111 and 200 diffraction peaks of SS400 and the 111, 200, and 220 peaks of type-304 appeared in this measurement range. These diffraction results indicate that intermetallic compounds were created by the friction welding. The residual stresses obtained near the boundary of friction welding are shown in Fig. 3. The residual stress at the surface of SS400 was compressive, about 300 MPa, and that at the center was tensile, about 200 MPa. These stresses disappeared at 5 mm from the welding boundary. In the case of type-304, the residual stress distribution was the same as that in the SS400, but it extended 10 mm from the welding boundary.

The mechanism that generates residual stress is dis-

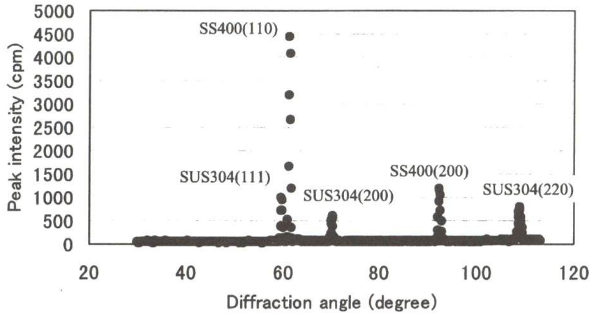

Fig. 2. Neutron diffraction pattern of friction welding boundary.

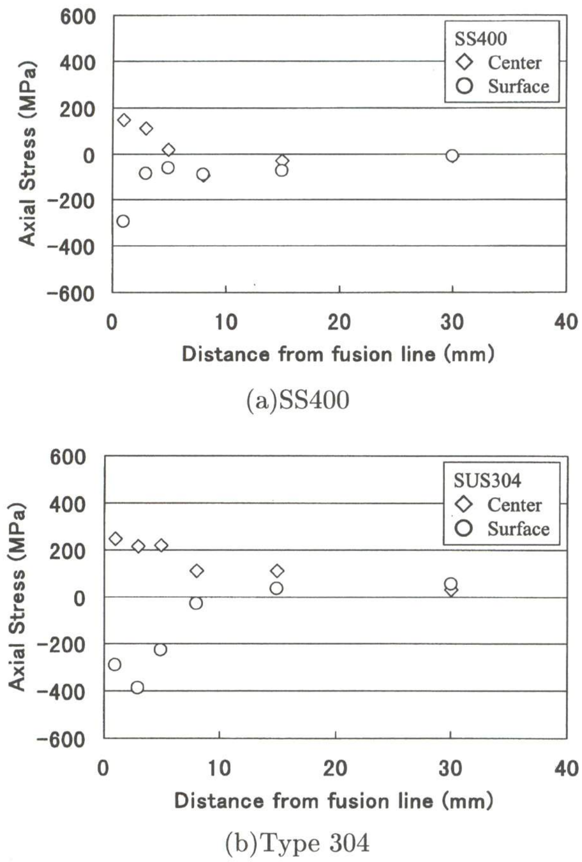

Fig. 3. Residual stress distribution of friction welding boundary.

cussed as follows. The surface temperature at the friction welding was 1073 K.[3] The difference of circumferential velocity makes the temperature at the surface higher than that at the center. However, heat radiation in the cooling process makes the temperature at the surface lower rather than that at the center. The neutron diffraction measurement showed that the residual stresses generate during the cooling process after the upsetting process. The residual stresses abruptly decrease in the 5 mm region from the boundary in SS400 and the 10 mm region in type-304. This difference in residual stress distributions is attributed to the effect of heat conductivity; that is, the heat conductivity of SS400 is 47.2 W/m/K and that of type-304 is 19.0 W/m/K.[4]

3.2 Mechanical properties of friction welded material

The results of tensile tests are listed in Table 1. All specimens fractured in the base metal of SS400. The yield and fracture strength of the friction welded specimens were the same as those of the SS400 base metal. The fracture also occurred in the base metal when it was friction welded to the SS400 specimens.

Work-hardening near the boundary of friction welding is one of the reasons that fracture occurred far from the boundary. The Vickers hardness near the boundary of friction welding is shown in Fig. 4. Vickers hardness in this area is 100 Hv more than that in the base metal. It is thus concluded that the friction welding increases the strength at the boundary by work-hardening. This result means that it is possible to evaluate the strength of component conservatively by evaluating the strength of base material.

Table I. Result of tensile test.

Material	Yield strength (MPa)	Fracture strength (MPa)	Fracture position
Type304	253	600	-
SS400	338	491	-
SS400-Type304(a)	398	529	SS400
SS400-Type304(b)	303	466	SS400

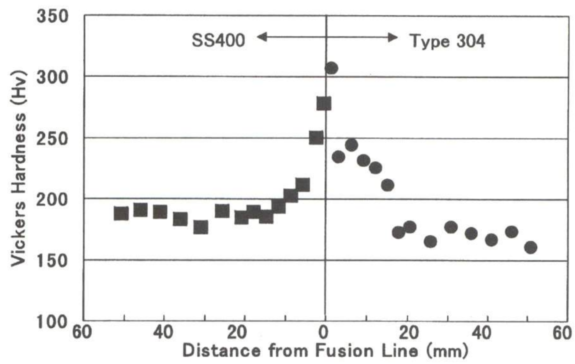

Fig. 4. Vickers hardness distribution after friction welding.

§4. Summary

1. Residual stress near the boundary of friction welding was compressive, 300 MPa, at the surface and tensile, 200 MPa, at the center of the specimens.
2. Residual stresses generate during the cooling process after the upsetting process, and the difference in the residual stress distribution in the two welded metals (SS400 and type-304) is attributed to the difference of heat conductivity.
3. Fracture during tensile testing occurred far from the boundary of friction welding because the yield strength at the boundary increases with work-hardening caused by the friction welding.

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