Effect of thermal history on microstructures of spot welding in advanced high strength steel

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Improvement of the joint strength of spot welds is crucial for reliability of light-weight car body applying of advanced high strength steel (AHSS). The microstructures in nuggets are dominant factors for fracture pattern and joint strength, especially of cross tension strength (CTS), but the detailed microstructural phenomena and their effects on local fracture mechanisms have been unclear yet. This study is focused on the investigation of detailed microstructures in spot welds of AHSS with different thermal history. Different welds were prepared with different welding conditions to differentiate thermal history. Pulsed current pattern consisting of two short-time high-current post heating was applied after main welding to reheat nugget up to high temperature. In addition, joints were welded with various holding time before electrode release to differentiate cooling rate. Evaluation of their CTS was conducted based on JIS Z 3137. It is clarified that a pulsed current pattern with short holding time prevents fracture through nugget and resulted in high CTS. Main microstructures are martensite and small difference of micro Vickers hardness was observed between with and without pulsed current, though nuggets welded by long holding time were slightly hardened. Electron back scattered diffraction (EBSD) techniques revealed that all samples had elongated grain towards solidification direction and the (101) surface was observed along the longitudinal direction of prior austenite grains. This suggests that one of the most influencing factors on the selection of martensite block is prior austenite grain boundary. EBSD evaluation also shows that the fracture path in CTS test propagated across the prior austenite grain and the propagation is prevented in a joint with pulsed current pattern. These results suggest that slight difference of prior austenite grain formation were observed in these thermal history, but the crack sites, for example prosperous segregation, were changed through thermal history and the prevention of fracture initiation leads to high joint strength.

Keywords: *Quantitative characterization, Spot welding, Advanced high strength steel sheets*

1. Introduction

Tensile strength of steel sheets has been increasing in order to improve fuel efficiency and passenger safety of automobile bodies. Spot welding is mainly used in the assembly of car bodies, and the strength of the joint directly affects the reliability of the entire body. Cross tension strength (CTS) of advanced high strength steel (AHSS) sheet may decrease when the tensile strength exceeds 980 MPa. This has been pointed out to be due to a decrease in toughness of the nugget and stress concentration at the nugget edge due to low deformability in the heat-affected zone (HAZ) and base metal [1].

Various studies have been conducted to improve CTS. From the microstructural point of view, there have been reports on the reduction of carbides in martensite when holding time is increased and on the coarsening of austenite (γ) grains and the elimination of P segregation during post-insertion [2]. There are several reports that in-process post-heating pattern can reduces P segregation and suppresses brittle fracture [3]. It is thought that the properties of spot welds are determined by the superposition of these segregations and martensitic microstructures, but this has not yet been investigated extensively.

Therefore, the objective of this study is to clarify the relationship of martensite structure, segregation and joint strength through detailed microstructure characteristics.

2. Experimental and calculation procedures

A 1470 MPa class cold-rolled AHSS sheet of 1.6 mm thickness was used. Figure 1 and table 1 show a schematic diagram of the current pattern and welding conditions. Inverter DC welding machine was used. Electrode force and main welding conditions were determined to form nugget diameter of 5 mm. To differentiate microstretches of nugget, hold time between current stop and electrode release was varied from 0.1 s to 1.0 s. As in-process post-heating, the pulse current pattern consisted of two high-current and cool time was adapted. Cross sectional microstructures were evaluated by field emission scanning electron microscopy and element distribution was evaluated by field emission electron probe micro analyzer (EPMA). Micro-Vickers tests were conducted on the welds. CTS of these joints were evaluated as specified in JIS Z3137. Numerical calculations using the SORPAS finite element software were used to evaluate the temperature history.

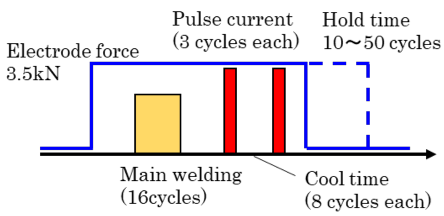

Fig.1 Schematic diagram of welding pattern

Table 1 Welding conditions

Frequency		50Hz
Electrode Force		4410 N
Main welding	Weld time	16cycles
	Weld current	5.9kA
Pulsed current pattern	Cool time	8 cycles
	Weld time	3 cycles
	Weld current	8.0kA
	Repetitions	2 times
Holding time		5, 50cycles

3. Results and discussion

3.1 Improvement of cross tension strength

Figure 2 shows CTS values and failure pattern of joints welded in each condition. Some of joints by only main welding show interface failure mode, which means brittle fracture in nugget, at hold time of 0.1 s. The CTS decreased as the hold time increased and all samples were fractured in interface failure mode at hold time of 1.0 s. In contrast, joints of the pulsed current pattern fractured in plug failure mode which means ductile fracture through HAZ, and the CTS was higher than that of the joints by only main welding at all hold times.

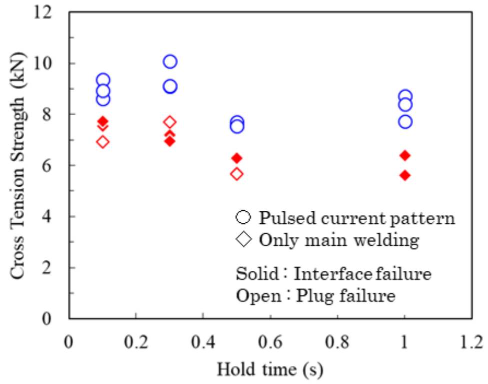

Fig.2 Joint strength and fracture pattern

3.2 Relationship of microstructures

Figure 3 shows the microstructures of martensite formed in a prior γ grain at the nugget edge. For comparison, the results for one prior γ grain in each field of view are shown. As is clear from the inter pole figure (IPF), a structure extending in the same direction within the elongated γ grains was observed in both cases. The area ratio of each packet group in the Close-packed planes (CP) map shows that the packet group, whose CP is along the longitudinal direction of prior austenite grains, is mainly formed. This suggests that the prior austenite grain interface has a large influence on the selection of the crystal orientation of the block. Figure 4 shows the results of EPMA analysis of the nugget edge. While there was slight difference in the distribution of Mn, P segregation decreased in the weld with pulse current pattern, as noticed in [1]. Micro-vickers test shows the hold time affects hardness of the nuggets, which were Hv 465 at hold time of 0.1s and Hv 480 at 1.0 s. Little difference was found between with and without the pulse current pattern.

Figure 5 shows the cross section when the load was stopped at 4kN during the cross tension test. When only main current is applied, cracks are observed to grow in a zigzag pattern perpendicular or diagonal to the direction of crystal growth. By applying pulse current, cracking was suppressed even under the same load. Based on these results, it is inferred that the pulsed current pattern reduces the number of fracture starting points such as the P segregation area, but the subsequent crack path is due to the prior γ grain. It was suggested that fracture is also affected by grain growth and martensite packet groups.

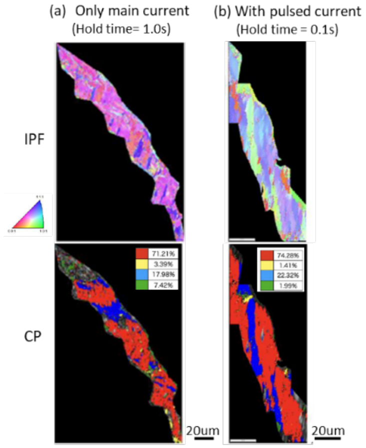

Fig.3 IPF and CP map of martensite structure at nugget edge.

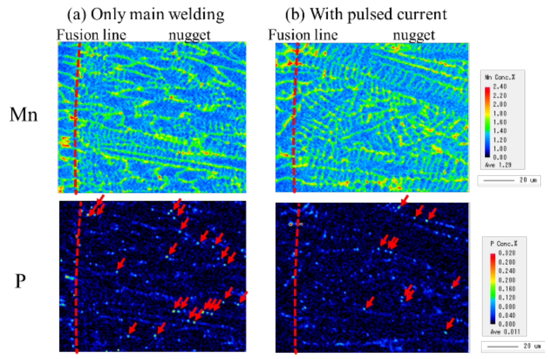

Fig.4 Element distribution of nugget edge evaluated by EPMA (Hold time 0.1s)

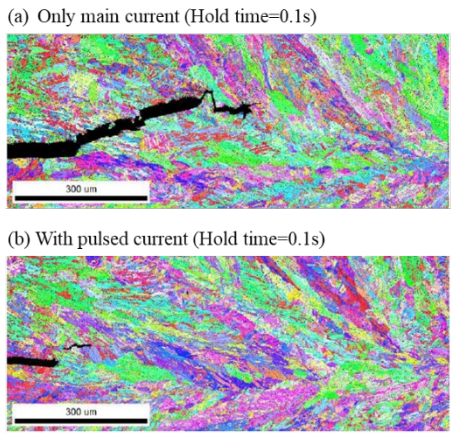

Fig.5 IPF map of fracture path after loading of 4kN.

4. Conclusions

Through the evaluation of fracture pattern and characterization of welds with various welding pattern, it was suggested that martensite packet group as well as element segregation affects fracture in cross tension tests and CTS. Diminishing phosphorous segregation by pulsed current pattern and preventing hardening nugget by short hold time can improve CTS although martensite martensite structures are slightly changed.

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