

Evaluation Technique of LME Cracking Susceptibility in Resistance Spot Welding of Zinc-Coated Steel Sheet

1. Introduction

Application of high-strength zinc-coated steel sheets to automobiles for auto body weight reduction, improvement of crashworthiness and corrosion resistance is increasing, and weldability in resistance spot welding, which is the main welding method used in vehicle assembly lines, is important. In resistance spot welding of high-strength zinc-coated steel sheets, melted zinc from the Zn coating may cause liquid metal embrittlement (LME) cracking in welds. Therefore, a study aimed at elucidating the mechanism of LME cracking and developing a welding process for suppressing this phenomenon is currently in progress¹⁾. In addition, the development of high-strength steel sheets that consider LME cracking susceptibility is also required.

To conduct the above-mentioned developments more reliably, JFE Steel and JFE Techno-Research Corporation developed the “LM-CAST testTM” (LME-Cracking by Applied Strain Test), which enables quantitative evaluation of the LME cracking susceptibility of resistance spot welds of steel sheets^{2,3)}. This paper presents an overview of the test technique and an example of the evaluation results.

2. Overview of LM-CAST testTM

LME cracking in resistance spot welding is a type of cracking in which the zinc coating on the steel sheet surface melts due to the heat of welding, and the molten zinc penetrates the coarse austenite grain boundaries in the heat affected zone (HAZ), causing them to open and form cracks under tensile loading. Accordingly, the temperature in the welding process and tensile strain (bending strain) are large influencing factors. The LM-CAST test is a technique for quantitatively evaluating the temperature and nominal strain range where LME cracking of materials occurs, by using a testing device that makes it possible to apply an arbitrary bending strain at an arbitrary timing during resistance spot welding.

Figure 1 shows a schematic image of the developed LM-CAST test testing machine. The testing machine consists of a resistance spot welding machine, a bending block installed on the lower electrode side and a yoke for press-bending the test specimen. The bending blocks are interchangeable, making it possible to apply an arbitrary bending strain depending on the radius of the bending block. This device also monitors the movement of the resistance spot welding machine, and the yoke can be rapidly lowered at any desired timing after the termination of the welding current, thereby applying bending strain, corresponding to the curvature radius of the bending block, to the top side of the lower sheet in the weld. **Photo 1** shows (top) a photograph of the external appearance and (bottom) the cross-sectional microstructure of the test specimen after peeling off the upper sheet of a resistance spot weld, in which LME cracking is observed. LME cracking with a concentric circular shape has occurred in the region where the zinc coating layer on the outer side of the nugget was melted. (Nugget: the weld fusion zone formed by resistance spot welding.) Here, whether LME cracking occurs at the temperature in the welding process and the preset bending strain can be clearly judged from the timing of strain application by the yoke and the thermal history at the site of the LME cracking. It should be noted that the thermal history was calculated by a heat conduction analysis, since it is

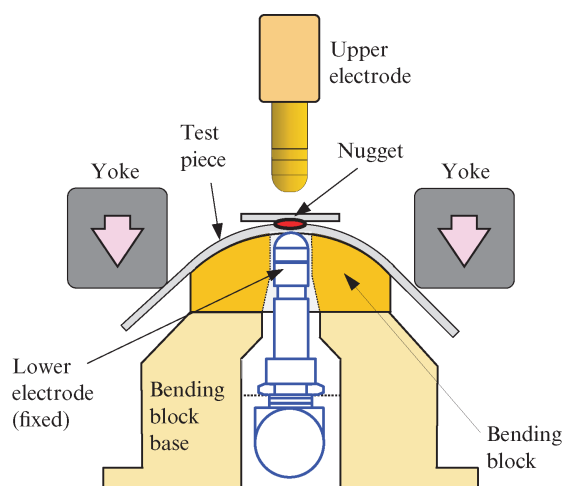


Fig. 1 Schematic image of testing machine²⁾

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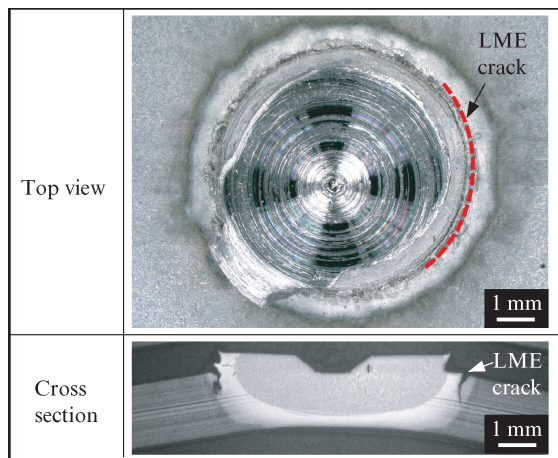


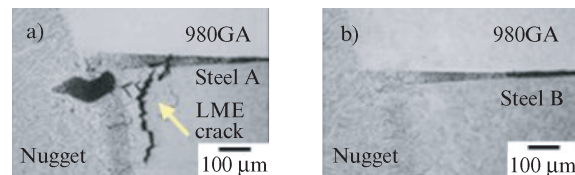
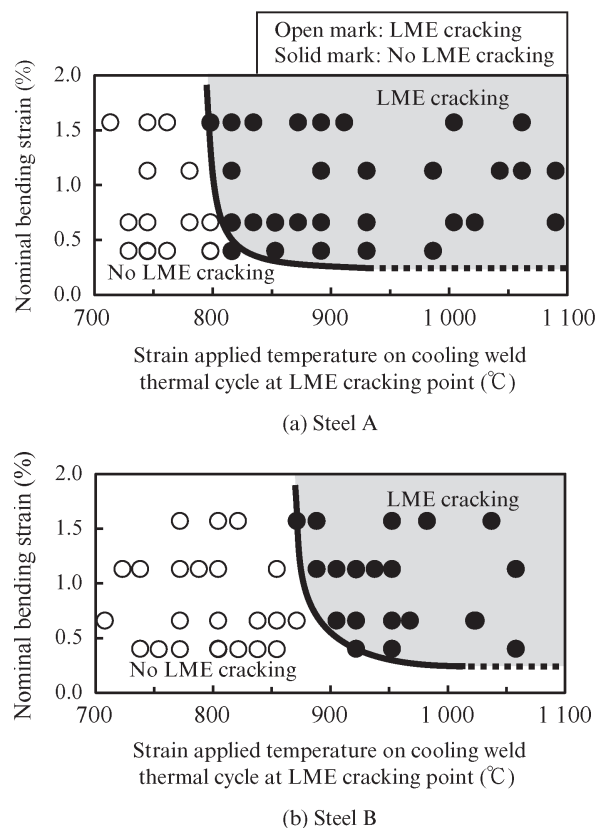
Photo 1 LME crack appearance of LM-CAST test specimen

difficult to measure the thermal history at the site of LME cracking due to the steep temperature gradient in the vicinity of a resistance spot weld. It is possible to clarify the temperature and nominal strain range for LME cracking by carrying out tests as described above while varying the timing of bending strain application and the strain level.

3. Example of Evaluation Results by LM-CAST testTM

Two types of steel sheets (Steel A: 980 MPa grade, Steel B: 1 180 MPa grade, thickness: 1.6 mm) with different chemical compositions were prepared in the laboratory, and an evaluation of LME cracking susceptibility was carried out by the LM-CAST test. Prior to this test, LME cracking in these steel sheets was evaluated using two-sheet lap resistance spot welding with disturbances, in which a 980 MPa grade galvanized (GA) steel sheet was used as the mating sheet. As the disturbances, the electrode tilt angle and the clearance between the lower electrode and the lower sheet were set at 5° and 2 mm, respectively, and welding was performed under conditions of a hold time of 120 msec and nugget diameter of 4.0 to 4.5 $\sqrt{t}$ (t: sheet thickness). **Photo 2** shows the cross-sectional microstructure of the obtained nugget edges. In Steel A, LME cracking occurred in the HAZ, but LME cracking did not occur in Steel B.

Next, the results of the evaluation of these steel sheets by the LM-CAST test are shown in **Fig. 2**. At all nominal strain levels, the temperature range for occurrence of LME cracking was narrower (i.e., the lower-limit temperature was higher) in Steel B in comparison with Steel A, indicating that Steel B has lower LME cracking susceptibility. This result is consistent with the evaluation of LME cracking resistance by resistance spot welding with disturbances, and shows

Photo 2 Cross-section of the nugget edge in resistance spot welding with disturbances³⁾ ((a) Steel A, (b) Steel B)Fig. 2 Evaluation results of LME cracking susceptibility by LM-CAST test³⁾

that a comparative evaluation of the LME cracking susceptibility of different steel sheets is possible, and the temperature and strain range for LME cracking can be analyzed by using the LM-CAST test.

4. Conclusion

This paper introduced the LM-CAST test, which makes it possible to quantitatively evaluate LME cracking susceptibility, which addresses the issue of LME cracking resistance in resistance spot welding of high-strength automotive steel sheets. In the future, we intend to actively utilize this evaluation technique to make further contributions to the development of high-strength automotive steels with high safety and reliability. This technique is supplied through JFE Techno-Research Corporation as part of the line-up of the solution business brand “JFE ResolusTM” for man-

ufacturing industries developed by JFE Steel.

References

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