

Standard Harmonization in Hydrogen Embrittlement Evaluation Using Equivalent Metrics

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High-strength steel sheets exceeding 1 GPa are increasingly employed in automotive body structures to satisfy both vehicle weight reduction and crashworthiness requirements. Recent developments in steel manufacturing technology have enabled the practical use of ultra-high-strength grades exceeding 1.5 GPa, making hydrogen embrittlement one of the most important reliability concerns for automotive applications. Consequently, the establishment of reliable and globally harmonized evaluation methods has become essential for material qualification and procurement.

Hydrogen embrittlement susceptibility is evaluated using several testing methods. Among them, U-bending tests are widely adopted by Japanese automotive manufacturers because they can incorporate the influence of forming strain introduced during press forming processes. In contrast, four-point bending tests specified by ISO standards are commonly used overseas as stress corrosion cracking evaluation methods. As global procurement of automotive steel sheets expands it is increasingly important to correlate the results obtained from these different test methodologies. However, direct comparisons between U-bending and four-point bending tests under identical testing conditions have been limited.

In this study, hydrogen embrittlement susceptibility obtained by the two bending methods was compared using a 1470 MPa grade cold-rolled martensitic steel sheet. Hydrogen charging was conducted through immersion in an NH_4SCN aqueous solution. The crack threshold concentration was determined by gradually decreasing the solution concentration until no cracking occurred. Experimental results showed that the crack threshold concentration was 0.01 g/L for the U-bending test and 0.1 g/L for the four-point bending test. These results indicate that the U-bending test provides a significantly more severe assessment of hydrogen embrittlement susceptibility than the four-point bending test under otherwise identical conditions.

Fractographic observations using scanning electron microscopy revealed clear differences in fracture mechanisms between the two test methods. Near the fracture origin, the U-bending specimens exhibited predominantly trans granular fracture with quasi-cleavage features, whereas the four-point bending specimens showed mainly intergranular fracture. The difference in fracture morphology suggests that strain and dislocation structures introduced during U-bend specimen preparation promoted hydrogen accumulation at deformation-induced defects, resulting in a different fracture process from that observed in the four-point bending specimens.

To identify a common parameter capable of explaining the difference in crack susceptibility, finite element analyses were performed for both bending configurations. The stress state around the specimen edge surface, which corresponded to the fractured initiation site, was investigated. Three stress parameters were evaluated: uniaxial tensile stress, von Mises stress, and hydrostatic stress. The analyses revealed little difference between the two test methods in terms of tensile stress and von Mises stress. In contrast, hydrostatic stress showed a significant difference and corresponded well with the experimentally observed crack susceptibility.

Based on these findings, hydrostatic stress at the edge surface near the fracture origin was proposed as an equivalent evaluation metric. Verification tests demonstrated that equivalent hydrostatic stress produced equivalent fracture times regardless of the bending test method employed. Furthermore, fracture time varies systematically with hydrostatic stress, indicating that hydrostatic stress is a suitable parameter for correlating hydrogen embrittlement susceptibility between U-bending and four-point bending tests (Fig.1).

The results demonstrate that hydrostatic stress can provide a unified basis for correlating hydrogen embrittlement susceptibility among different bending test methods. This approach offers a practical means of harmonizing domestic and international evaluation standards and contributes to more efficient qualification of advanced high-strength steels in the global automotive supply chain. The applicability of the proposed metric has also been confirmed for steel sheets with different microstructures, indicating its potential as a universal evaluation parameter for future standardization activities.

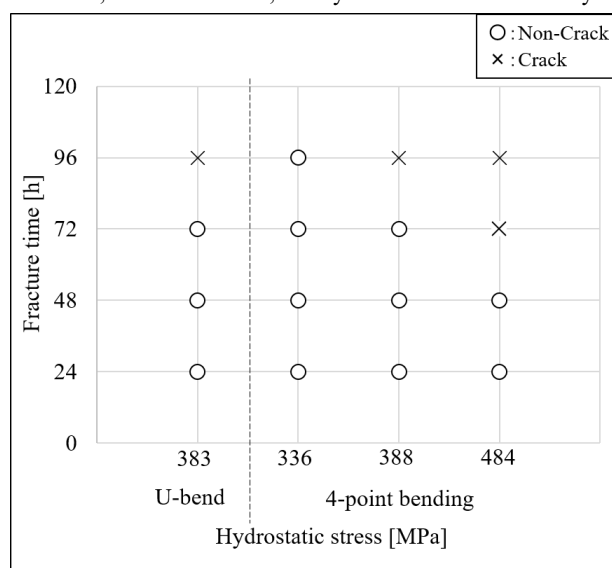


Fig.1 Relationship between hydrostatic stress and fracture time