Dynamic Observation with Nomarski Microscope of Hydrogen-Induced Delayed Cracking in High Strength Steel Weldments†

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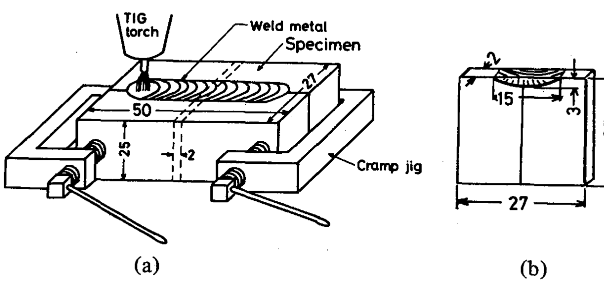
Weld cold cracking is one of the most serious problems in welding of high strength steel, and is well known to be hydrogen-induced delayed crack. However, its mechanism is not yet resolved, although many phenomena connected with it have been revealed. In recent years Savage et al[1,2] discussed an interesting mechanism of it utilizing a dynamic observation technique of weld cold cracking with an ordinary optical microscope, in which importance of plastic deformation prior to the cracking was urged. On the other hand, it is well known that Nomarski differential interference microscope has high detectable power against uneveness of surface due to plastic deformation. Therefore the authors have been trying dynamic observation of weld cold cracking utilizing a Nomarski microscope to study in detail the relation between the plastic deformation and the cracking.

Two base metals of HY-130 class high strength steel, whose dimensions were 50 mm in length, 13.5 mm in width and 25 mm in thickness, were fixed together with two cramp jigs as shown in **Fig. 1 (a)**, and then TIG-arc welding was done on the touching line of the base metals without filler metal in the conditions of 300A, 21V and 150 mm/min. Argon-hydrogen mixing gas was used as the shielding gas of TIG-arc welding, where the concentration of hydrogen was 2.5, 5 or 10% in 20 l/min of total amount of gas flow. The specimen was quenched in water immediately after the welding, and soon transfered into liquid nitrogen to minimize the loss of diffusible hydrogen. Then specimens for dynamic observation whose thickness was 2 mm were sliced mechanically as shown in **Fig. 1 (b)** and metallographically polished as soon as possible. It took about 7 to 8 min for the slicing and the polishing. Then, the specimen was set to a testing device described nextly. By the way, the touching surface in Fig. 1 (b) corresponds to what is called root face and thus the bottom of weld metal was affected by notch effect after the straining in the testing device in the same way as practical welding.



(a) (b)

Fig. 1 Illustration of (a) welding procedure and (b) test specimen for dynamic observation

Figure 2 (a) shows general view of testing device for dynamic observation and **Fig. 2 (b)** does its principle to bend the specimen. The dimensions of this device was very small, since it was designed for the observation with not only optical microscope but also scanning electron microscope. The device was composed of a monolithic frame, a screw bolt, a ball bering, a bending block and two rollers. The bending block was raised through the ball bearing by tightening the screw bolt, and consequently the specimen was bended. The bending strain was selected to 0.3, 0.5 and 1.0% perpendicular to the root face. Setting situation of the testing device on the stage of Nomarski microscope is shown in **Fig. 2 (c)**, where a trans-

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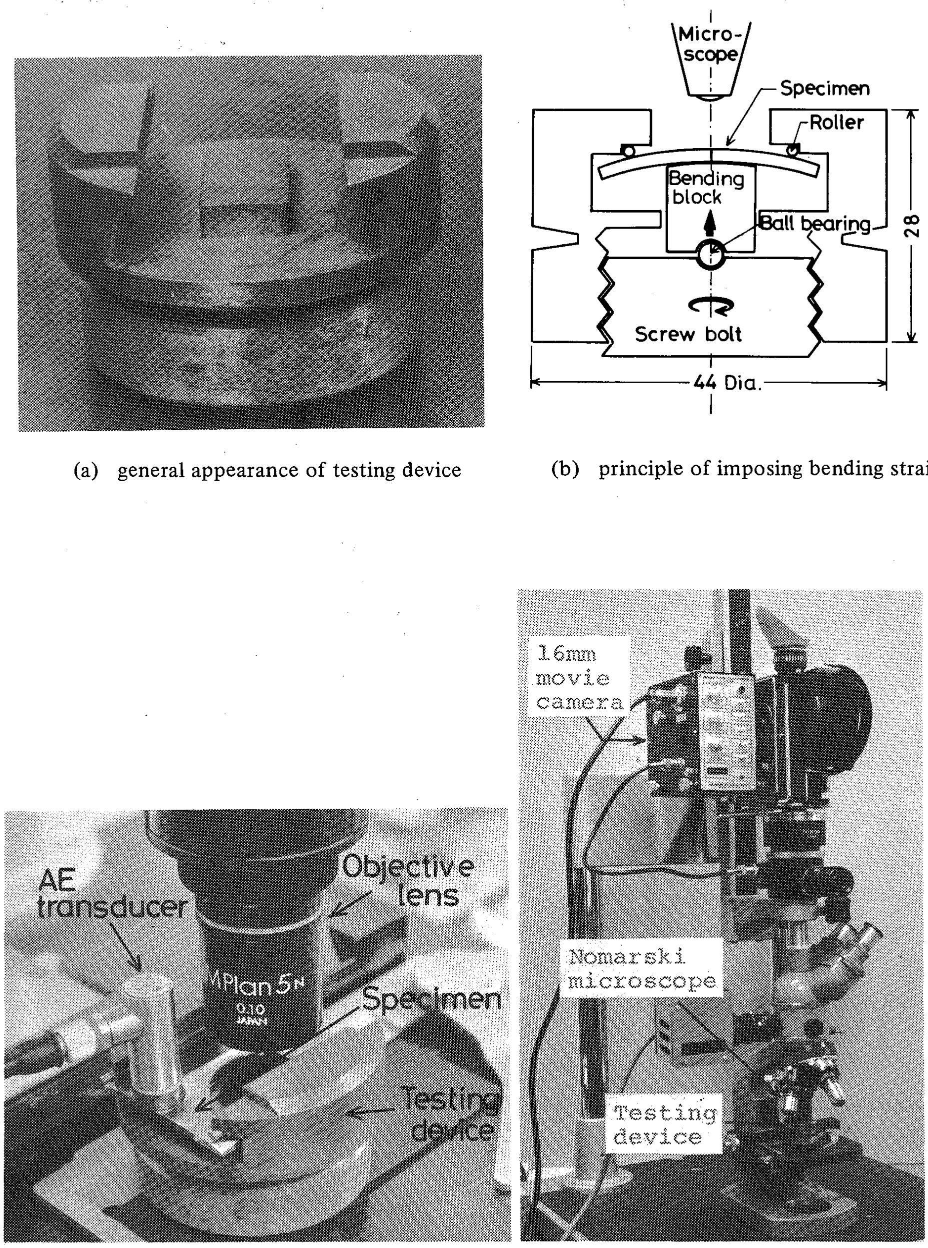


(a) general appearance of testing device

(b) principle of imposing bending strain

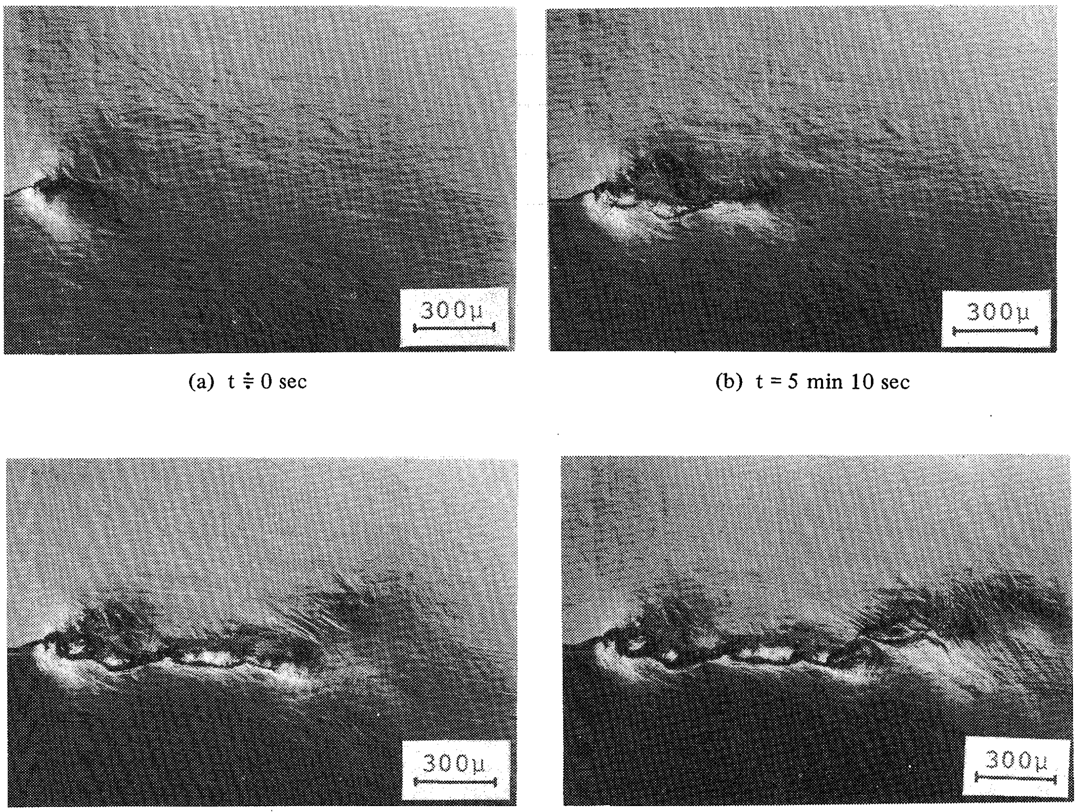
(c) setting of test specimen and testing device in Nomarski microscope

(d) Overall view of assembly for dynamic observation

Fig. 2 Apparatus for dynamic observation

ducer of acoustic emission was also fixed on the specimen. Then the change in plastic deformation and cracking was photographed with 16 mm movie camera shown in **Fig. 2 (d)** or 35 mm motor-driving camera.

An example of sequence of photographs during the testing is shown in **Fig. 3**, where the dark line seen at the left end of each photograph is the edge of root face. At $t \doteqdot 0$sec in Fig. 3 (a), small region deformed plastically is distinctively observed in the weld metal near the root. Moreover undulations in various directions were observed in almost whole weld metal and were due to very small plastic deformation. **Figure 4** shows an example of the undulations in a higher magnification. These undulations occurred along martensite laths and could not be detected with ordinary optical microscope. At t = 5 min 10sec in Fig. 3 (b), the region deformed plastically grew to about 800μ from the root. Then, at t = 5 min 20sec it was observed that crack grew from the root and AE were actively generated from this time. Furthermore, the crack grew following the growth of the region deformed plasti-



(a) $t \doteqdot 0$ sec (b) t = 5 min 10 sec

(c) t = 5 min 35 sec (d) t = 6 min 45 sec

Fig. 3 Change in plastic deformation and crack gowth vs. time.
Shielding gas: Ar + 10% H_2, Bending strain: 0.3%.

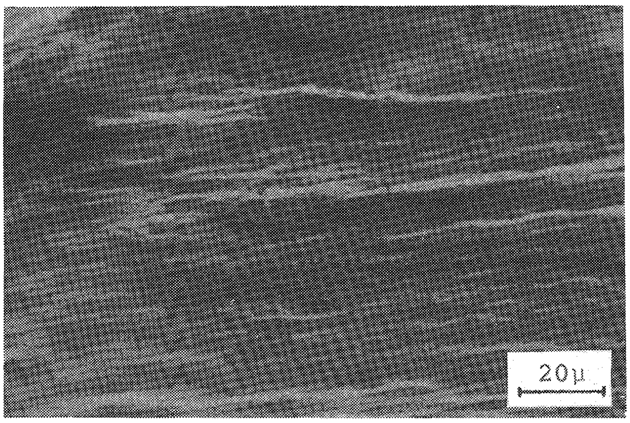


Fig. 4 Undulations along martensite laths due to plastic deformation

cally as seen in Fig. 3 (c) and (d).

As seen in Figs. 3 and 4 Nomarski microscope can reveal minute undulations occurred along martensite laths. On the other hand, it is reported[3] that quasi-cleavage fracture in hydrogen-induced delayed crack easily occurs parallel to martensite lath. Consequently it is considered that the correlation between diffusible hydrogen and plastic deformation is one of the key to solve the mechanism of hydrogen-induced delayed cracks and that dynamic observation with Nomarski microscope is very useful for this purpose. Therefore detailed studies are planned by the authors.

A disadvantage of Nomarski microscope is difficulty to distinguish the crack from the portions undergoing extremely large plastic deformation as seen in Fig. 3 (c) and (d). In this situation, dynamic observation with scanning electron microscope is desirable and a short note[4] utilizing this technique is reported in this Trans. JWRI.

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