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Fracture of reinforcing steels in concrete damaged by ASR

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HIGHLIGHTS

▶ Alkali-silica reaction is often accompanied by fracture of reinforcing steels.
▶ Fracture in reinforcing steels occurred at the rib base in the inside of the bend.
▶ Tensile residual stress of about 300 MPa occurred due to bending at the rib base.
▶ Risk of hydrogen embrittlement cracking was evaluated.

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ABSTRACT

Alkali-silica reaction in concrete structure is often accompanied by fracture of reinforcing steels. Possibility of hydrogen embrittlement cracking in reinforcing steels was investigated based on the results of Vickers hardness test, residual stress estimation and occluded hydrogen measurement.

1. Introduction

Japan currently counts some 40 alkali-silica reaction (ASR) damaged structures, including highway and railway bridges, confirmed to have fractured reinforcing steels. In places where fracture of reinforcing steels occurred, andesite type reactive aggregate which was prone to severe expansion had been used in the concrete. Additionally, reinforcing steel fracture was found frequently at the bent section of reinforcing steels in pier beams, and similar cases have been reported also for the footings. Data showed that ASR-caused deterioration was influenced by weather (rain water, sunlight, etc.) and tended to be particularly severe at locations where the amount of reinforcing steel was relatively small [1,2].

The results of the investigations focused on ASR-damaged structures in the Kansai area of Japan are presented below.

2. Properties of fracture surface [3,4]

Reinforcing steels taken from existing structures were examined, and their fracture surfaces were inspected to understand the properties of the fracture. Test specimens were also prepared to investigate the work hardening occurring at the bend where fracture was frequently found.

2.1. Fracture surface of actual reinforcing steels

All reinforcing steel samples were found to have corrosion in the bent section. In the Kansai area of Japan, sea sand contaminated with chloride had been used as fine aggregate for concrete. Fracture occurred at the bends, and cracks initiated at the bases of the ribs on the inside radius (Fig. 1). The cracked or fractured reinforcing steels had smaller radii of base curvature of the rib than those on the currently marketed products. The fracture surface was flat with very little plastic deformation as shown in Fig. 2, where cleavage and quasi-cleavage cracks which were evidence of brittle failure were predominant (Figs. 3–5). The only exception was the shear lip where ductile fracture surface was found (Fig. 6). Concrete materials such as Ca and Si were detected at the crack initiating point as shown in Fig. 3, suggesting that these cracks were already present at the time of concrete placing. Work hardening at the bend was confirmed by the hardness increases in the inside and outside of the bend. The inside and outside hardness values were about 50–80 (HV10) higher than those at the center of the bend or about 90 (HV10) higher than those in the straight part.

2.2. Fracture surface of bent reinforcing steel specimens

In the experiment using reinforcing steel specimens, cracks occurred in the cases of smaller bending radius of the bend or smaller radius of base curvature of the rib. Fig. 7 shows Vickers hardness

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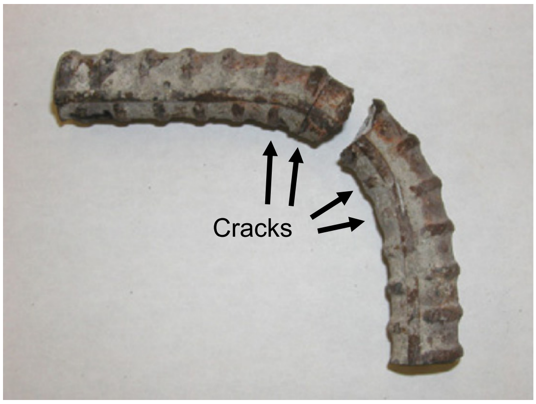

Fig. 1. A fractured reinforcing steel.

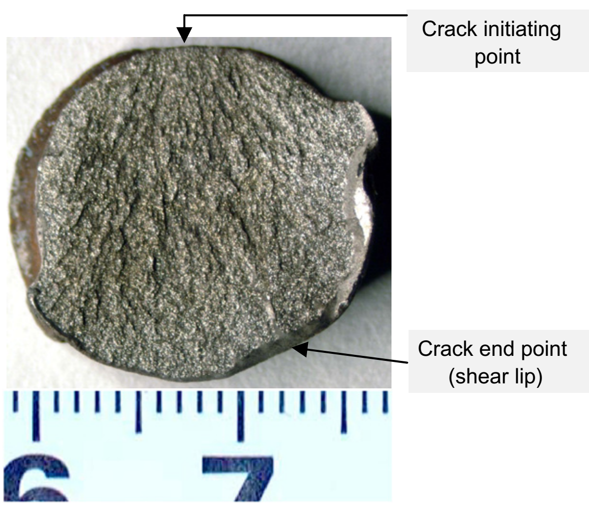

Fig. 2. Macro-view of the fracture surface.

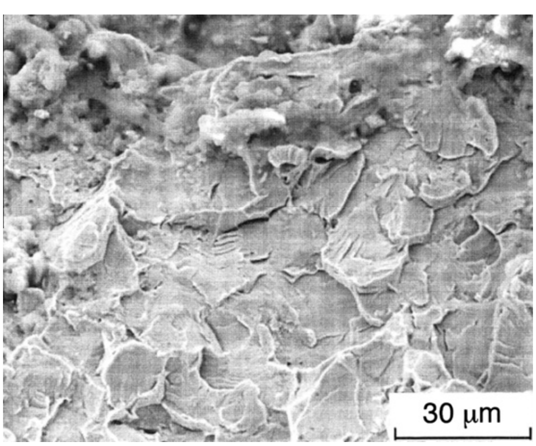

Fig. 3. Crack initiating point before pickling (cement hydrates are present).

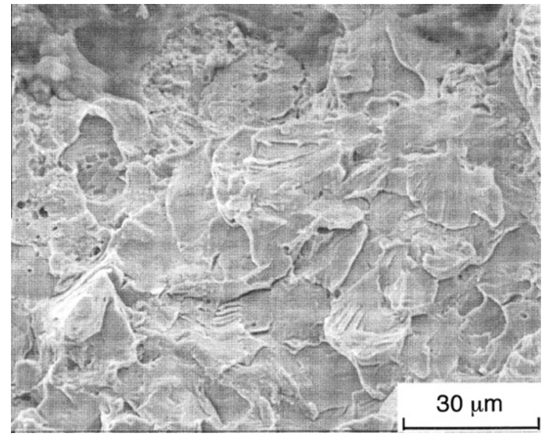

Fig. 4. Fracture surface near the crack initiating point after pickling.

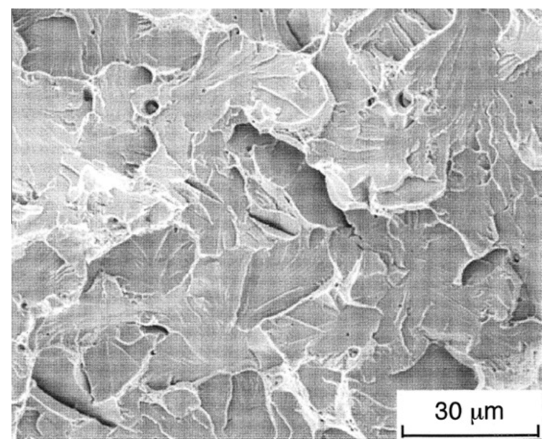

Fig. 5. Fracture surface about 12 mm inside from the crack initiating point.

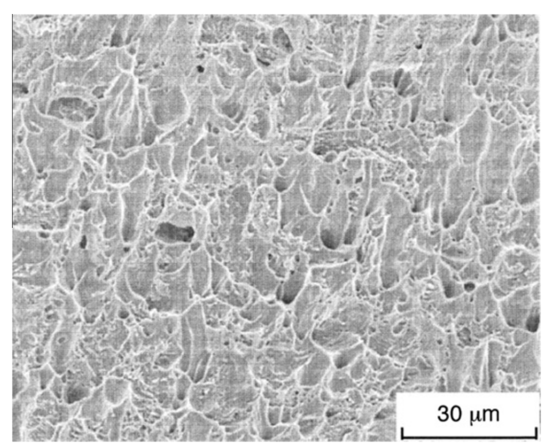

Fig. 6. Fracture surface of the shear lip.

measurement positions in the bent section and pictures of cracking regions. As shown in Fig. 8, there were hardness increases of about 70–80 (HV10) at the bend as compared to the straight part. The hardness values at the cracking region at the base of the rib further increased to reach 329 (HV10) for a bending radius of 1.0*d*, where *d* is the reinforcing steel diameter, or 291 (HV10) for 2.0*d*. According to the conversion of Vickers hardness values, tensile strength was estimated to be about 765–795 MPa at the bend or about 915–1035 MPa in the cracking region at the rib base. Moreover, work hardening or strain aging in the bent section may lead to toughness reduction in the reinforcing steel. Therefore, if cracks are present, it is highly likely that resistance against fracture is much affected.

3. Stress in bent reinforcing steel [4,5]

In order to estimate cracks and stress occurring in the site of fracture at the bend of reinforcing steels, residual strain and stress