High Strength Bolting Steel

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Synopsis

Recently, to enable power increase and weight reduction of engines, a demand has arisen for the development of higher strength bolts with tensile strength of 1 300N/mm² or greater.

However, such high strength bolts with tensile strength exceeding 1 200N/mm² are not immune to delayed fracture. An improvement of delayed fracture resistance is therefore needed.

Newly-developed steels (ADS2, 3,) introduced herein exhibit superior delayed fracture resistance to JIS-SCM440. This is due to optimization of microstructural factors such as impurity level, grain size, carbide morphology, etc.

1. Introduction

Recently, a demand for higher-than-ever strength steels has been increasing in machine structural applications. This is especially true for automobiles and heavy construction machinery, where development of higher strength steel, having tensile strength of 1 300N/mm² or above, has long been awaited. Unfortunately, however, the quenched-and-tempered low-alloy steels currently used for high strength bolts are not immune to in-service delayed fracture when their tensile strength exceeds 1 200N/mm² [1].

Delayed fracture has been found to be one type of hydrogen-induced material degradation, and its complete prevention is critical for wider-spread use of higher strength steels. Analysis of delayed-fractured bolts has indicated that prior-austenite grain boundary fracture is the dominant mode in the crack initiation site[2),3)]. This observation strongly suggests that one of the most promising remedies for the delayed fracture problem is to increase the grain boundary cohesive strength via mitigating impurity segregation to grain boundaries and controlling the grain boundary carbide morphologies[4)].

Based on these technical standpoints, the authors have developed new types of delayed-fracture-resistant high-strength steels (ADS2, 3 : ADS : Anti-Delayed Fracture Steel).

2. Concept for Developed Steels

The basic chemistry design concept of newly-developed steels is summarized in **Table 1**, and the compositions of the steels are given in **Table 2**.

1) ADS2: To suppress grain boundary embrittlement, the P, S, and Mn contents are reduced, and grain-refining element, Nb, is added. To allow a high tempering temperature, i.e. 450°C or above, 1.2%Cr and 0.4%Mo are added[5)].

2) ADS3: In addition to the above chemistry

Table 1 Alloy design for improving delayed fracture resistance

Item	Effect
Low P, low S, low Mn	Strengthening grain boundary
Nb, (V) addition	Fine prior-austenite grains
(V) addition	Fine and uniform carbides distribution
High Mo (V) addition	High temperature tempering

Table 2 Chemical compositions of developed steels

Steel	C	Si	Mn	P	S	Cr	Mo	Nb	V	Remarks
ADS2	0.34	0.28	0.37	0.008	0.005	1.26	0.40	0.026	Tr.	Developed
ADS3	0.49	0.28	0.31	0.009	0.004	1.02	0.68	0.034	0.32	
JIS SCM440	0.39	0.17	0.82	0.025	0.010	1.11	0.16	Tr.	Tr.	Conventional

design concept, ADS3 contains 0.6%Mo and 0.3%V so as to allow a higher tempering temperature, i.e. 550°C or above.

3. Features of Developed Steels

(1) Tempering characteristics

Figure 1 shows the tempering characteristics. It is apparent that newly-developed steels (ADS2, 3) show better resistance to temper softening than JIS-SCM440. Especially for ADS3, which contains 0.6% Mo and 0.3%V, the highest tempering temperature can be used to obtain a specific tensile strength.

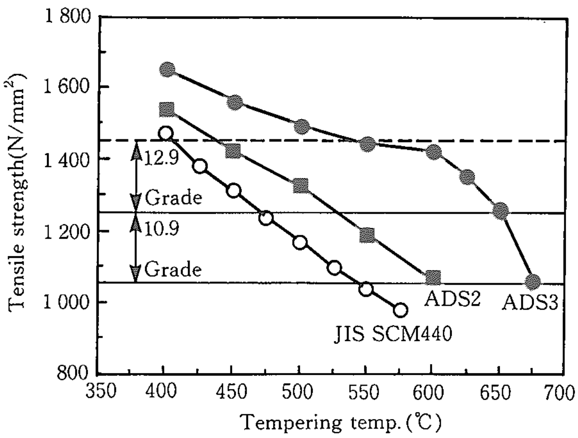

Fig.1 Effect of tempering temperature on tensile strength

(2) Delayed fracture resistance

To evaluate delayed fracture resistance, the sustained load tests under cathodic hydrogen charging condition[6], which simulate the severity of actual environment, are adopted. The sustained load tests (notched round bar specimen, stress concentration factor:α=5.0) have been carried out under cathodic hydrogen charging condition corresponding to 0.1 μA/cm. This hydrogen permeation coefficient, 0.1 μA/cm, has been adopted based on the fact that local pH in a crevice becomes as low as 3.5[7], and also on the experiment that maximum hydrogen permeation coefficient in pH=3.5 is around 0.1μA/cm for these steels (**Fig. 2**).

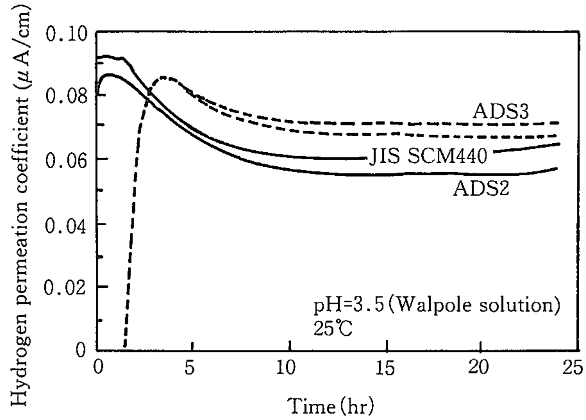

Fig.2 Electrochemical hydrogen permeation measurement in walpole solution of pH=3.5

The results of the sustained load tests are shown in **Fig. 3**. As compared with JIS-SCM440, newly-developed steels (ADS2, 3) exhibit higher delayed fracture threshold stress (σth) at the same tensile strength level. Especially, ADS3, which allows high tempering temperature, possesses the best resistance to delayed fracture among the three steels tested.

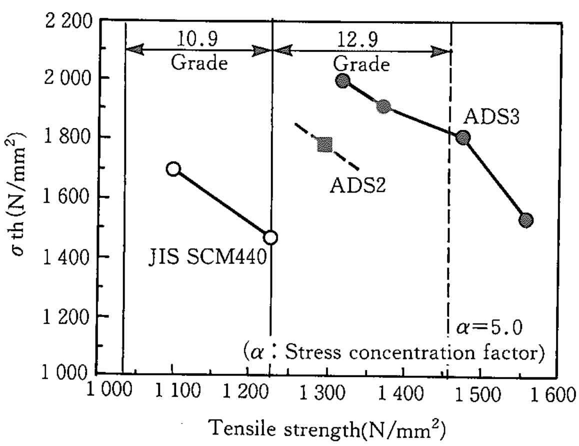

Fig.3 Effect of tensile strength on delayed fracture strength (σth)

Photo 1 shows SEM fractographs on the crack initiation site. For SCM440, an intergranular fracture mode is clearly revealed. For ADS3, in contrast, quasi-cleavage-like transgranular fracture mode is dominant. Apparently, in ADS3, grain

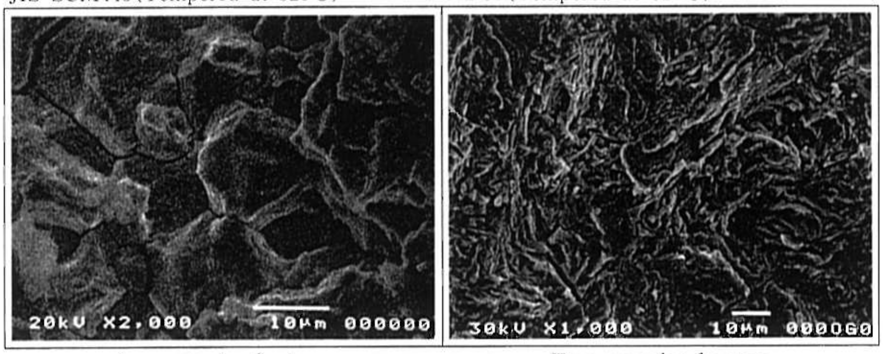

Photo 1 Fractographs of delayed fracture surface

boundary bonding force is increased due to impurity reduction, grain refinement and spheroidized carbide morphology. As a result, ADS3 exhibits exceptionally high resistance to delayed fracture.

4. Concluding Remarks

The above-mentioned newly-developed steel, ADS2, has already been applied to 12.9 grade high-strength bolts for automobile engines[8], and an extensive application test is now underway for ADS3.

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