IMPROVEMENT OF DEGRADATION OF TOOL STEELS DUE TO PLATING

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ABSTRACT

In order to evaluate the amount of degradation due to plating, SERT (slow extension rate test), delayed fracture test and fatigue test were conducted on JIS-SCM440 chromium molybdenum steel bars. Delayed fracture was observed on the plated specimen and the strength and the ductility were decreased by plating. After investigation of optimum condition for baking, baking at 473 K for 24 hrs was found to recover nearly from the degradation due to plating even at the low extension rate of $1.68x10^{-3}$ mm/min. Comparing the ductility and strength of fully plated specimen with those of partly plated specimen with two layers of nickel and without chromium, the degradation was found to be mainly took place at the final stage of plating. Although the diffusible hydrogen content of plated specimen was sufficient for hydrogen embrittlement, fracture was not originated at the inner subsurface but at around the outer surface. Microscopic observation by SEM indicated that the fracture was originated at around the final plating layer of chromium. These results suggested that the strength of plated material is affected by hydrogen embrittlement and the condition of the final plating process of chromium.

1 INTRODUCTION

Plating is used for tool steels to protect from corrosion and to improve the quality of fine surfaces. However, it is known that high strength steels are subjected to hydrogen embrittlement due to plating but the mechanism is not fully known(Plating[1]). Therefore in order to evaluate the quantity of the degradation, SERT(slow extension rate) test(Clark, et al.[2]), delayed fracture test and fatigue test were conducted on SCM440 tool steels. In order to improve the strength of the steel, the mechanism was studied by fractographic observation of the fracture surfaces and by measuring the absorbed hydrogen content in the steel and the effect of baking on recovering of the damage was discussed.

2 EXPERIMENTAL METHOD

The material used is JIS-SCM440 chromium molybdenum steel bars with diameters of 24 mm and 43 mm and is quenched at 1143 K and tempered at 653 K. The chemical compositions and the mechanical properties are summarized in Table 1 and Table 2, respectively.

Table1 Chemical compositions of test materials (wt%)

Material	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Pb	Sn	As	Sb
SCM440Φ24	0.40	0.22	0.66	0.02	0.026	0.12	1.04	0.16	0.14	0.20	0.007	0.010	0.001
SCM440Φ43	0.40	0.25	0.71	0.02	0.012	0.02	1.10	0.17	0.01	0.00	0.004	0.004	0.001

Table2 Mechanical properties of test material

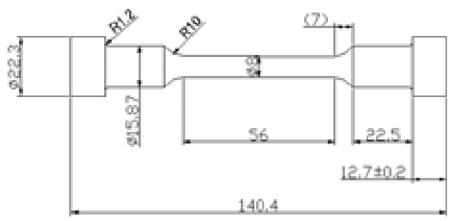
Material	Upper yield point	Tensile strength	Reduction of area (%)	Rockwell hardness
SCM440	1372	1503	54.7	45.5

The configuration of test specimens are smooth round bar tensile, notched round bar tensile with stress concentration factor of 3 and smooth round bar fatigue specimens and is shown in Figure 1. Some of the specimens were plated with two layers of nickel and one layer of chromium. SERT test and delayed fracture test was conducted by using Instron 5800 tensile test machine with 100 kN capacity on the smooth and notched tensile bar specimens. SERT test was conducted on slow extension rate of 1.17 mm/min, $1.67\text{x}10^{-2}$ mm/min, $1.68\text{x}10^{-3}$ mm/min or $1.68\text{x}10^{-4}$ mm/min. Delayed fracture test was held at an arbitrary constant load for relatively long duration. Fatigue test was conducted by using rotational bending test machine on fatigue specimens. Rotational rate of fatigue test was 3150 rpm.

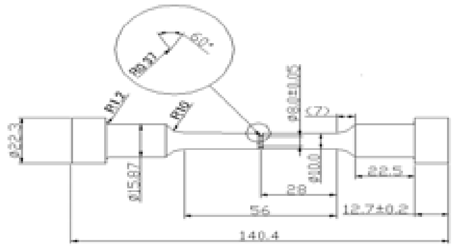
3 EXPERIMENTAL RESULTS

3.1 Result of SERT test

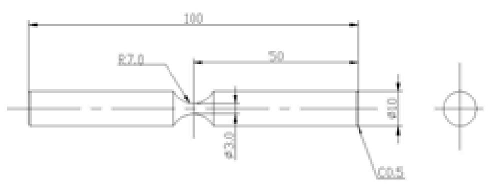
Figure 2 shows the relation between fracture strength of notched bar specimens and stroke rate by SERT test. The fracture strength indicates the maximum stress by multiplying the stress concentration factor of three to the normal stress at the root of notch. Decreasing the extension rate, the fracture strength of plated steel was decreased and the lowest fracture strength was about 30 % of the non-plated base steel.



(a) Smooth tensile bar specimen



(b) Notched tensile bar specimen



(c) Rotating bend specimen

Figure 1: Configuration of test specimens

3.2 Result of Delayed fracture tes

The relation of fracture strength and time to failure by delayed fracture test for notched specimens is shown in Figure 3. In the figure threshold strength for delayed fracture of plated steels is about 2500 MPa and the lower stress than the threshold does not lead to delayed fracture. Comparing the result with SERT test, fracture strength of SERT test is lower than the delayed fracture although a large portion of the time spent during the SERT tests is well below the final failure stress. One of the reason is considered to be the effect of slow extension rate on the easier concentration of hydrogen to the root of notch in SERT test.

3.3 Result of fatigue test

Figure 4 indicates the S-N curves by rotational bending fatigue test. As shown in the figure, fatigue limit of plated materials was less than the half of the non-plated base steels. This indicates that plating has a strong influence on fatigue strength, especially on fatigue limit.

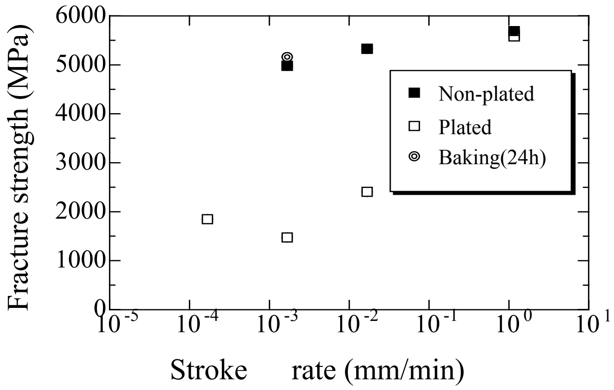


Figure 2: Result of SERT test (notched tensile specimen)

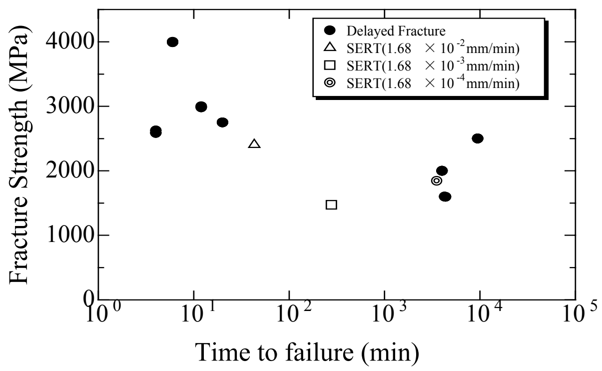


Figure 3: Result of delayed fracture test (notched tensile specimen)

4 DISCUSSIONS

4.1 Degradation in the process of plating

In order to investigate degradation during the process of plating, load-displacement curve of fully plated smooth specimen without baking was compared with that of partly plated smooth specimen with two layers of nickel and without chromium as shown in Figure 5. The difference in ductility is apparently seen in these figures. Comparing the differences in ductility, reduction of area for smooth tensile specimen was plotted as a function of extension rate in Figure 6. Plated specimens are remarkably degraded than the non-plated specimens especially at slow extension rate.

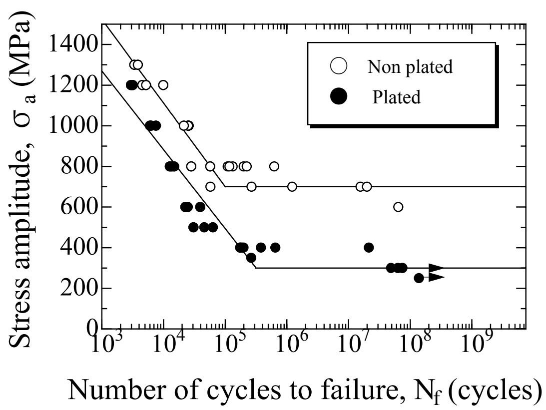


Figure 4: S-N curve of SCM440 steel

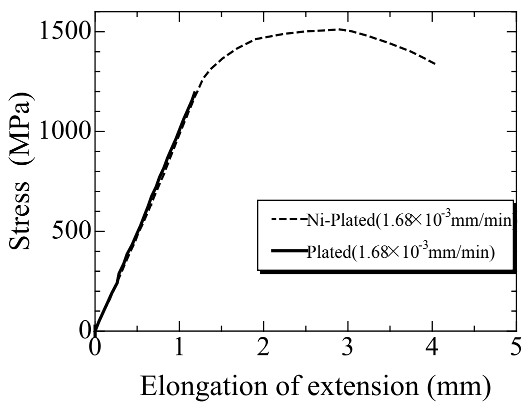


Figure 5: Comparison of load-displacement curves (smooth tensile specimen)

4.2 Effect of baking

Figure 7 shows the effect of baking time on the fracture strength in SERT test at the same strain rate. Fracture strength and time to failure increase with the increase of time for baking. Although the fracture strength nearly recovers at the time for baking of 24 hrs, 16hrs seems not to be insufficient (see Figures 2 and 6).

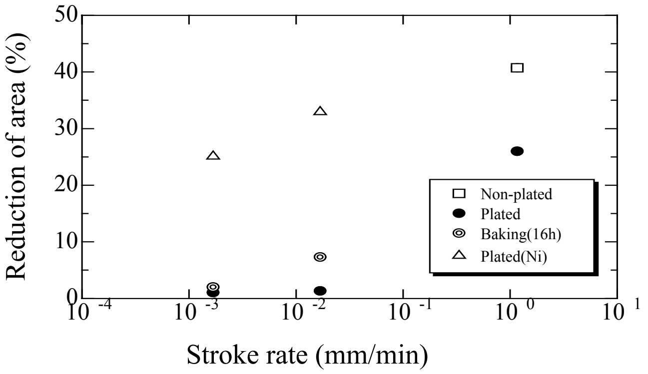


Figure 6: Dependence of stroke rate on reduction of area (smooth tensile specimen)

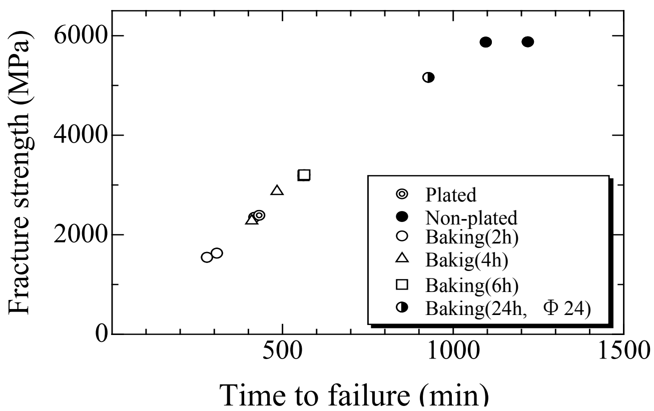


Figure 7: Effect of baking on fracture strength (notched tensile specimen at 1.68×10^{-3} mm/min)

4.3 Mechanism of degradation

Content of absorbed hydrogen due to plating was measured from a plated specimen as shown in Figure 8. In the figure the content of hydrogen was measured as a function of time using a fine measuring glass cylinder by accumulating the emerged hydrogen from the specimen left in glycerin at room temperature. Diffusible hydrogen content is estimated as approximately 0.9 ppm, which is assumed to be sufficient for causing hydrogen embrittlement. However, fractographic observation of fracture surface of plated specimens indicated that the origin of fracture in both of SERT test and fatigue test was not at the inner subsurface but around the outer surface. Figure 9 is an example of SEM photograph of fracture surface of plated smooth specimen by SERT test at 1.68×10^{-3} mm/min. Also small cracks were found on outside surface of plated smooth specimen before test as shown in Figure 10. These results suggest that the plated material is weakened by hydrogen embrittlement and the formation of surface cracks at the final stage of relatively hard chromium plating.

5 CONCLUSIONS

SERT test, delayed fracture test and fatigue test on SCM440 tool steels resulted in the decrease of the strength and ductility due to plating. Baking at 473 K for 24 hrs nearly recovered from the degradation. However although the diffusible hydrogen content in plated specimen was about 0.9 ppm which is sufficient to cause hydrogen embrittlement, fracture was not originated at the inner subsurface but at the outer surface. Comparing the ductility and strength of fully plated specimen with those of partly plated specimen, the degradation was found to be mainly took place at the final stage of plating. Small cracks were found on outside surface of plated smooth specimen. These suggest that the plated material is weakened by hydrogen embrittlement and formation of cracks by the final stage of relatively hard chromium plating.

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[1] Plating, Chapt.4, Design Data for Fatigue Strength(II), Japan Society of Mechanical Engineers (1965), 28. (in Japanese)

[2] W.G.Clark,Jr.,and J.D.Landes, ASTM STP 610, Stress Corrosion-New Approaches, (1975), 108.

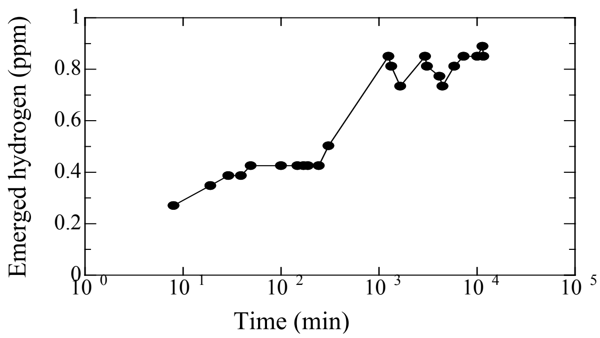

Figure 8: Emerged hydrogen from plated specimen

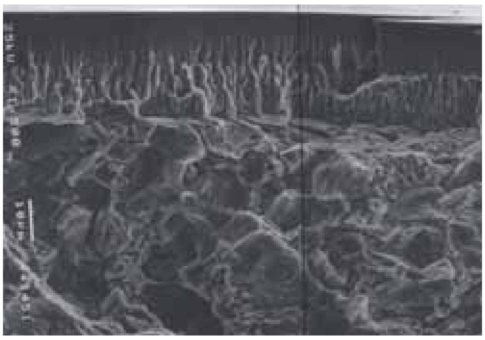

Figure 9: SEM photograph of fracture surface of plated smooth specimen.

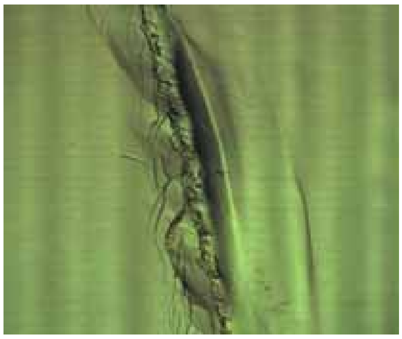

Figure 10: Enlarged photograph of surface of plated smooth specimen (X is the axial direction of the specimen)