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Age-hardening of surface aged hardening alloy ①

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[Abstract] Steel T8 treated by plasma surface decarburizing was alloyed by the Xu-Tec process with Co, W and Mo. An alloyed layer of Fe-Co-W-Mo with low carbon content was formed on the surface of the high carbon steel, thus an advanced gradient composite was produced. The specimens then were treated by the solution and aging treatments. The characteristics of age-hardening of the alloying layer were studied. The hardness of the surface layer increases from HV200 to HV1200 after the solution treatment at 1190 ℃ and aging at 400 ℃ for 30 min. The results show that the surface aged high speed steel possesses not only high surface hardness, but also enough bulk strength.

[Key words] high carbon steel; plasma decarburizing; age-hardening; surface aged hardening alloy
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1 INTRODUCTION

The double glow plasma surface alloying technique (Xu-Tec process) was invented by XU[1,2]. The surface aging alloy of Fe-Co-W-Mo was formed on surface of the ingot iron by this technique[3], which possesses very strong abilities of age-hardening and temper softening resistance[4]. Because of the low strength of the substrate, its application in industry however is restricted. The strength of the substrate must be improved for making the surface alloy of Fe-Co-W-Mo possible for the industrial application. A cheap method of improving the strength of the substrate is using steel with a high carbon content as substrate material. The aging alloy of Fe-Co-W-Mo contained very low carbon, hardened by way of precipitation of intermetallic compounds[5,6]. Thus, there is a contradiction: on one hand the carbon content in the substrate being high, on the other hand, the carbon content in the surface of the substrate being low as far as possible. For solving the contradiction, a steel T8 treated by plasma surface decarburizing is used as substrate. The steel T8 treated by plasma decarburizing is alloyed by Xu-Tec process with Co, W and Mo (simply expressed as DA). An alloying layer of Fe-Co-W-Mo with low carbon content formed on the surface of the high carbon steel is an advanced gradient composite. In this paper the age-hardening characteristics of the surface aged alloy are investigated.

2 EXPERIMENTAL

Cutting the DA plate into small specimens, with dimension of 4 mm × 4 mm, for the solution and aging treatments. The experiments were carried out in a high temperature tube heater with protective gas. The specimens of DA were heated at 1160, 1190, 1210, 1230 ℃ respectively for 5 min, then quenched in water. Metallographic cross sections were prepared for structure analysis and measurement of the microhardness and the distribution of alloy content after solution heat treatment. The specimens were then heated at 400, 450, 500 and 540 ℃ respectively for the isothermal aging treatment and the equal time (30 min) aging treatment. The observation of the structure and the measurement of the microhardness were also carried out after the aging treatment. The characteristic of the age-hardening for DA was studied through the above experiments, and the optimum processing of the solution and aging were determined at last. The specimens treated by the optimum processing were heated at 600, 650 and 700 ℃ respectively for 2 h to study temper resistance. The optical microscope, Neuphot, is used for observing the structure, the SEM with energy spectrum for investigating the distribution of alloy content, the microhardness tester of M-400-H1 for measuring hardness. The composition of the DA is listed in Table 1.

3 RESULTS AND DISCUSSION

The microstructures of the samples with the impression after soluting at 1190 ℃ and soluting at 1190 ℃ + aging at 400 ℃ are shown in Fig.1. From the isothermal section of the ternary phase diagram of Fe-Mo-Co at 1200 ℃ and equavalent proportions of W and Mo[7,8], like the structure of the sample center, the structure of the surface with low carbon high cobalt contents of DA is an austenite as that at high temperature. Thus, the structure in the surface alloying layer is alloy martensite with low carbon, and that in the center is acicular martensite with high carbon after solution treatment; and the structure in surface alloy layer is tempered martensite and that in the

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Table 1 Composition distribution of surface alloyed layer of DA on steel T8 (%)

Distance from surface/ μm	6	12	18	24	48	60	66	72	78
w(Co)	12.42	9.01	8.32	7.85	7.04	6.67	6.58	5.84	3.51
w(W)	1.19	1.84	2.38	2.86	2.09	2.34	2.21	2.21	1.05
w(Mo)	0.62	2.43	2.88	3.37	3.29	3.15	2.92	3.41	1.24

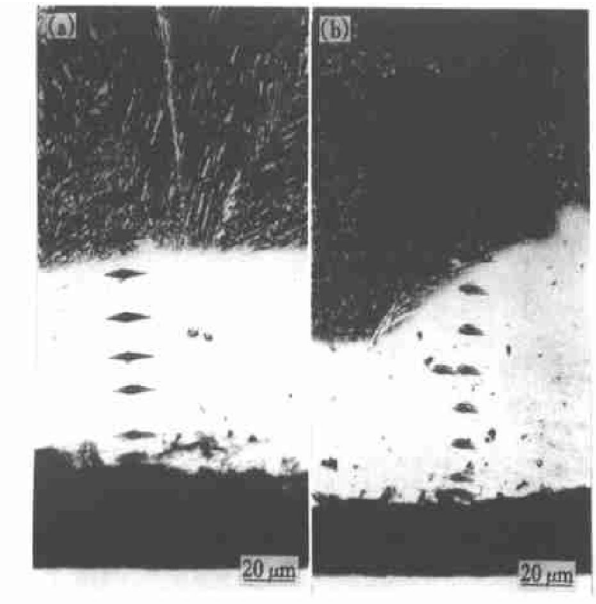

Fig.1 Structure of solution treatment (a) and solution treatment + aging treatment(b)

center is the tempered troostite after soluting and tempering at 400 ℃(Fig.1) . The hardness increases gradually from the surface to the center after solution treatment, and the hardness in the surface alloying layer increases but that in the center decreases after aging (Fig.1) . The distributions of the hardness are shown in Fig.2 . As well as the surface alloy of Fe-Co-W-Mo formed on the surface of the ingot iron[4], the surface aging alloy of Fe-Co-W-Mo formed on the surface of the high carbon steel by DA possesses a very strong ability of age-hardening, the hardness in the alloying layer drastically increases, from HV200 of the solution state to HV1100 after soluting at 1190 ℃and aging at 400 ℃ for 30 min. The hardness of the substrate under the surface alloy layer is still over HV350 after aging (Fig.2) . It showed that the surface age alloy of DA possesses high surface hardness, also possesses higher strength of the bulk material compared with surface aged alloy formed on ingot iron[4]. The changes of the hardness have similar tendency for 1160, 1210 and 1230 ℃, the difference among them is only the aging temperature at which the maximum hardness is obtained, the maximum hardness is obtained at 400, 450 and 540 ℃ for soluting at 1160, 1210 and 1230 ℃ respectively, as shown in Fig.3 . With different solution temperature, the age temperature obtained the max hardness is different. This may be related with types of compounds dissolved in matrix during solution treatment process. The hardness of high speed steel strengthened by carbide is only increased by HRC 2 ~ 4[9], but that of DA is increased by HV800 or so after tempering. It shows that the strengthening of DA is mainly caused by intermetallics strengthening. When the temperature of the solution treatment is lower, the major part of the compounds dissolved in the matrix may be carbide and the precipitate may be fine carbide, but along with increasing temperature of solution, more intermetallics are dissolved in the matrix and the precipitate may be fine intermetallics. The majority of intermetallics are the compounds of $(FeCo)_3(WMo)_2$ type and $(FeCo)_7$-$(WMo)_6$ type[10,11]. Because the intermetallics have a stronger ability of the anti-accumulating than the carbide, the maximum

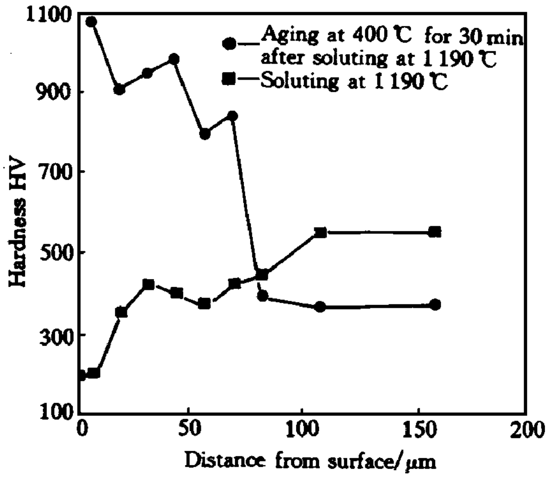

Fig.2 Distribution of hardness after solution treatment and solution treatment + aging treatment for DA

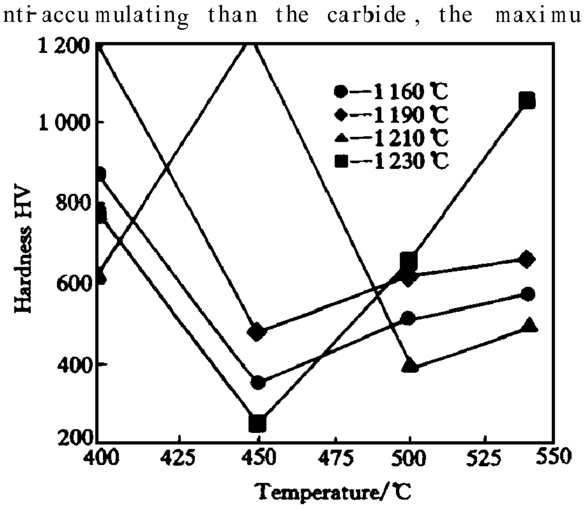

Fig.3 Aging hardness —aging temperature curves for DA

hardness of the specimens treated at the lower solution temperature is obtained at lower temperature, but that of the specimens treated at the higher solution temperature is obtained at the higher temperature. The isothermal age-hardening curve of the DA is shown in Fig.4 for aging at 540 ℃ after soluting at 1 230 ℃. As the surface age alloy formed on the surfaces of the metallurgical aged high speed steel[11] and the ingot iron[4], the surface aged high speed steel of DA also possesses a very strong ability of hardening, after soluting at 1 230 ℃, the hardness is increased from HV230 to HV480 when aging at 540 ℃ for 10 min, to HV900 for 20 min and to HV1 100 for 30 min. The specimens aged at 540 ℃ after soluting at 1 230 ℃ were reheated for 2 h at 600, 650 and 700 ℃, respectively, the anti-temper softening test for the DA was finished, the result is shown in Fig. 5. Compared the surface age alloy formed on the surfaces of the metallurgical age high speed steel and ingot iron, the anti-temper softening ability of the DA is lower[11,4]. It shows that the mixed strengthening of carbide and intermetallic compound is preferred for DA.

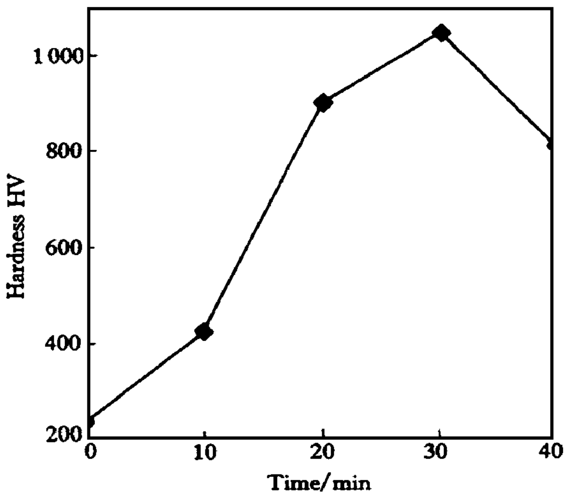

Fig.4 Isothermal aging curve of DA

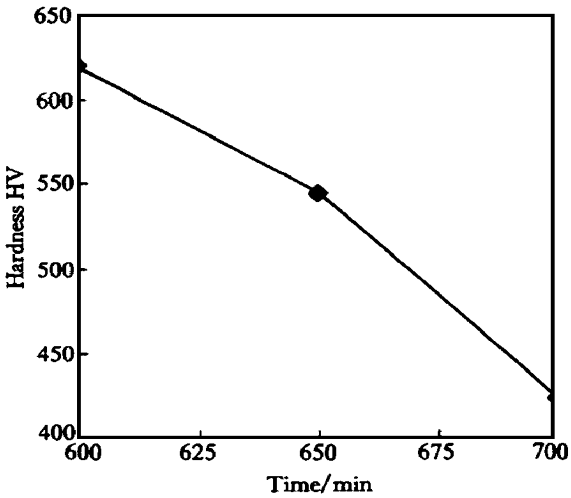

Fig.5 Anti-temper softening curve for DA

4 CONCLUSIONS

1) The surface aged high speed steel with cobalt may be formed on the surface of high carbon steel by the DA.

2) The surface aged high speed steel also possesses a very strong ability of age-hardening as metallurgical age high speed steel, and the surface aged alloy forms on the surface of ingot iron.

3) The ability of the anti-temper softening of the DA is lower than that of the metallurgical age high speed steel, and the surface aged alloy forms on the surface of ingot iron.

4) The surface age high speed steel of DA possesses not only high surface hardness, but also high strength of the bulk material.

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