

Phase Transformation and Its Effect on Mechanical Properties of C300 Weld Metal after Aging Treatment at Different Temperatures

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Abstract: The influence of aging temperature on phase transformation and mechanical properties of weld metal of maraging steel (grade C300) was studied. Microstructure was analyzed by means of optical microscopy, transmission electron microscopy, scanning electron microscopy and energy dispersive spectrum analysis. Gibbs free energy of Ni_3Ti and Fe_2Mo at different temperature was calculated by Thermal-calc software. The microstructure of weld metal in as-welded state is martensite. The yield strength of weld metal after 430 °C aging process may increase to 1561 MPa from 890 MPa in as-welded state, which is ascribed to the formation of spinodal constitute and GP zones. After 480 °C aging process, there are great deal of Ni_3Ti precipitates in the martensite matrix and 10% reverted austenite phase in the cellular grain boundary, and the yield strength increases to 1801 MPa. After aging process at 580 °C, there are many Fe_2Mo precipitates in the martensite matrix and 30% reverted austenite phase in the cellular grain boundary, and the yield strength is 1329 MPa, which is the lowest among the three cases. The phase transformation may also influence the toughness. It is found that precipitates make the toughness decrease and reverted austenite increases it. The mechanism of phase transformation on strength and toughness is discussed.

Key words: maraging steel; weld metal; aging temperature; precipitate; reverted austenite; mechanical property

Maraging steels, which are the aging strengthened martensite steels, can reach ultrahigh strength and remain good fracture toughness. The good comprehensive mechanical properties make them optimal candidate structural materials for aerospace and vehicle industry. Research work focusing on physical metallurgy, aging treatments, orientation relationship between precipitated phase and matrix, weldability and other characteristics of the steels have been reported^[1-11]. C300 steels, a member of maraging steel family, have the yield strength of about 2000 MPa. Their unique characteristics of good weldability and dimensional stability during aging treatments make these steels appeals to for fabrication of large structures.

Several welding techniques have been developed to weld maraging steels, where high joint coefficient can be obtained by electron beam welding with lower heating input^[3]. Tungsten inert gas (TIG) welding

is the most widely used welding method for joining large thin-walled pressure vessels and various parts and structures, especially for maraging steels, due to their high joint quality and relatively low cost^[5-9]. The properties of weld metal of maraging steels depend on welding filler metal, base metal and aging treatment process^[10].

For maraging steels, aging temperature influences the phase transformation and mechanical properties^[1-4]. Tewari et al.^[12] found that the strengthening of maraging C350 steel at aging temperature (<450 °C) is related to ordered and coherent phases such as m, S and X phases. Zhu et al.^[13] pointed out that at proper aging temperature conditions (480–530 °C), the main strengthening precipitation is ultrafine needle shaped Ni_3Ti intermetallic phase, which can effectively resist coarsening. The spherically shaped Fe_2Mo phase, which forms under over aging condition at higher temperature, has a lower contribution

to strengthening than Ni_3Ti . The formation of reverted austenite needs higher temperature. When the steel is aged at temperature higher than $530\text{ }^\circ\text{C}$, reverted austenite appears.

Up till now, most studies are for steels with uniform microstructure and composition distribution. Little study is presented for the case of weld metal. Formed by melting of filler metal and base metal and subsequent fast cooling, weld metal is composed of non-equilibrium structure, where composition segregation exists in columnar crystals. These characters may affect the microstructure and mechanical properties of aged weld metal. In this paper, the influence of aging temperature on phase transformation and mechanical properties of weld metal of maraging C300 steel was studied.

1 Experimental Materials and Procedures

Weld metal of C300 steel produced by pulsed TIG welding method was used for the experiment. Heat input of 16 kJ/cm was adopted and argon gas was used as the shield gas. Welding wire with the diameter of 1.2 mm was used as filler material. Interpass temperature was $100\text{ }^\circ\text{C}$. Chemical compositions of weld metal are shown in Table 1. The welds were treated at $840\text{ }^\circ\text{C}$ for 1 h for solid solution and air cooled to room temperature. Then they were treated at 430 , 480 and $580\text{ }^\circ\text{C}$ respectively for 4 h for aging and air cooled to room temperature. Aged samples were analyzed by means of optical microscopy,

transmission electron microscopy, scanning electron microscopy and energy dispersive spectrum analysis. The reagent for metallographic etching was $5\%\text{ CuCl}_2 + 35\%\text{ HCl} + 35\%\text{ H}_2\text{O} + 25\%\text{ C}_2\text{H}_5\text{OH}$. Foils for TEM analysis were ground to $40 - 50\text{ }\mu\text{m}$ in thickness and jet electropolished at $-25\text{ }^\circ\text{C}$ using 6% perchloric acid solution of methanol with 25 V voltage and 60 mA current. Mechanical properties of weld metal were evaluated with tensile and Charpy U-notch impact test. The size of impact specimens was $5\text{ mm} \times 10\text{ mm} \times 55\text{ mm}$.

Table 1 Chemical compositions of weld metal mass%

Ni	Co	Mo	Ti	Al	Fe
18.8	8.16	4.99	0.49	0.096	Balance

2 Results and Discussion

2.1 Microstructure of weld metal

The microstructure of weld metal in as-welded state is shown in Fig. 1. The weld metal presents cellular grain structure, which is martensite with high density dislocation tangles but no precipitate. Tensile test indicates that its yield strength is 890 MPa and tensile strength is 1020 MPa , much lower than that of C300 steel. To obtain ultra-high strength compared with parent metal, aging treatment, which may induce precipitation of small particles and greatly increase strength, is a necessary process for weld metal.

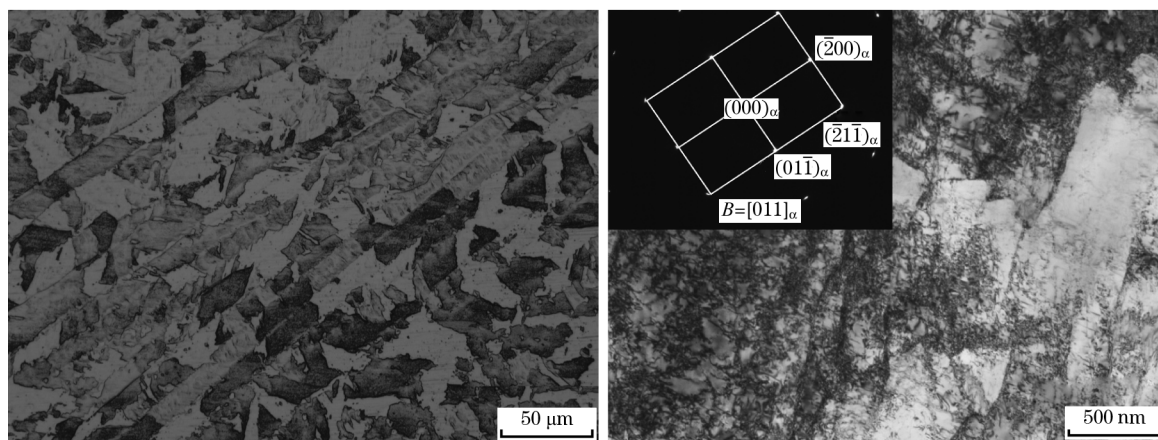


Fig. 1 Microstructure of weld metal in as-welded state

According to the precipitation strengthening mechanism, the strength increment caused by second phase in metal material is expressed by Orowan-Ashby equation^[14], as shown in Eq. (1)

$$\Delta\sigma_p = (0.538Gb \sqrt{f_v}/x) \cdot \ln(x/2b) \quad (1)$$

where, $\Delta\sigma_p$ is the yield strength increment; G is the shear modulus; b is Burgers vector; f_v is volume fraction of precipitates; and x is diameter of precipitates. It indicates that both increasing the volume fraction of precipitation phase and decreasing the

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