

Microstructure evolution of low alloy wear resistant steels during heat treatment procedure

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Abstract. Microstructure evolution of low alloy wear resistant steels during heat treatment procedure was studied in this paper. The results showed that During furnace cooling in homogenizing, Chromium/iron, Niobium, Vanadium and other hardly soluble carbides formed. But Chromium/iron carbides could resolve into austenite during quenching procedure, while the other carbides barely changed. Carbon addition grew the carbides into shuttle shapes and inflated the austenite grains. But Ni addition broadened the martensite lath width without dilating the austenite grains. And it hardly influenced the carbides formation. Vanadium addition seemed that the martensite lathes were cut into several discontinues sections. With the temperature rising, the boundaries got blurred, which might correlated with the decomposing of retained austenite.

1 Introduction

Recently, wear resistance of steel have become increasingly prominent in engineering. The loss of steel materials could be better controlled by modifying the material preparation procedure, such as smelting process, heat treatment process, rolling process, and coating. The alloy element content and heat treatment process, including temperature, isothermal holding time and cooling rate, played a significant role in improving the mechanical properties in wear resistance steels. Therefore, research in this area has attracted the attention of many researchers.

Carbon had a critical effects on the microstructure and properties of low alloy wear resistant steels^[1]. Carbon would accelerate austenite forming 30 times as large as Nickel^[2-4]. When Carbon content was higher than 1%, acicular plate martensite became the dominant morphology. Lath structure was refined with increasing Carbon content. When Carbon content is lower than 0.27 wt%, lath martensite and retained austenite or lath martensite, bainite and retained martensite can be acquired when quenched into water, resulting in nice plasticity and toughness^[5]. Nickel was an element that stablized austenite. Nickel, in mutual solution with iron, existed in both α and γ phase of steels, and strengthened them.

Vanadium participated as carbides and nitrides in steels. Vanadium increased solving time of carbides in austenite and homogenizing time of austenite composites. Solubility of vanadium in austenite is small and it formed dispersion particles to prevent the growth of austenite^[7]. Thus, it refines grains and improves steel toughness.

This work focused on effects of C, Ni and V on microstructure and properties of low alloy wear resistant steels. The hardness and impact toughness of low alloy wear resistance steels with different alloy composition were tested.

2 Experimental

Table 1 gives the actual chemical composition of tested steels. After casting, steel ingots were cut into slabs with a grinding wheel cutter. Then these slabs were partitioned into blocks with a Type DK77 numerical controlled wire-electrode cutting machine tool. These specimens were heat treated according to following procedures. First, they were heated at 1020°C for 0.5h, air cooling to room temperature, or heated at 1160°C for 24h, furnace cooling to room temperature. Second, they were austenized at 860-980°C for 0.5h, water quenching. Third, tempering was carried out at 150°C-600°C for 2h. Austenization is performed in Type SSJ-IIA high temperature chamber electric furnace and low temperature tempering is carried out in Type SX2-8-10 chamber electric furnace.

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Table 1 Chemical composition of investigated steels, mass %

Steels	C	Si	Mn	Cr	Mo	Al	Ni	others
LAWRS	0.29	1.82	0.94	1.96	0.30	0.03	-	-
LAWRS-Ni	0.30	1.85	1.00	1.94	0.35	0.33	0.31	-
LAWRS-V	0.30	1.79	0.97	1.96	0.32	0.05	-	V0.19
LAWRS-C	0.41	1.83	0.98	1.95	0.31	0.04	-	-

Type Olympus GX51 optical metallography acquisition system and Hitachi Type S-4300 scanning electron microscope (SEM) were used to observe the microstructure. The EPMA-1610 (Electronic Probe Microscope Analysis) was also employed to test the elements distribution, whose specimen preparation was the same to that of SEM analysis. The etching solution of the experimental steels was composed of 4% nitric acid and 96% alcohol.

3 Results and Discussion

3.1 Microstructure in homogenizing procedure

The OM (optical microstructure) and EPMA images of steels after homogenizing were gave in Figure 1. The homogenizing procedure was conducted at 1160°C and kept for 24h. As shown in Figure 1 (a), microstructure of

LAWRS samples was consisted with pearlite (the black region) and ferrite (the white and grey region). To be explicated, the white and grey region characterized two different orientations of ferrite. The average grain size of pearlite was about 100µm. Figure 1 (b) showed microstructure of LAWRS-C steel, which contained 0.4 wt% Carbon. Volume fraction of pearlite increased, and some of its grain size was up to 200µm. That was to say, increasing carbon content leads to coarse grains and more sharp angle pearlite blocks.

Through EPMA images, it could be shown that Carbon and Chromium elements segregated in ferrite-pearlite boundaries and pearlite block, while vanadium exhibited no obvious segregation in this dimension. This indicated that during furnace cooling in homogenizing, Chromium/iron carbides composed, while few Vanadium atoms existed as carbides. This might be due to the outward movements of carbon in early formed ferrite during its growing process.

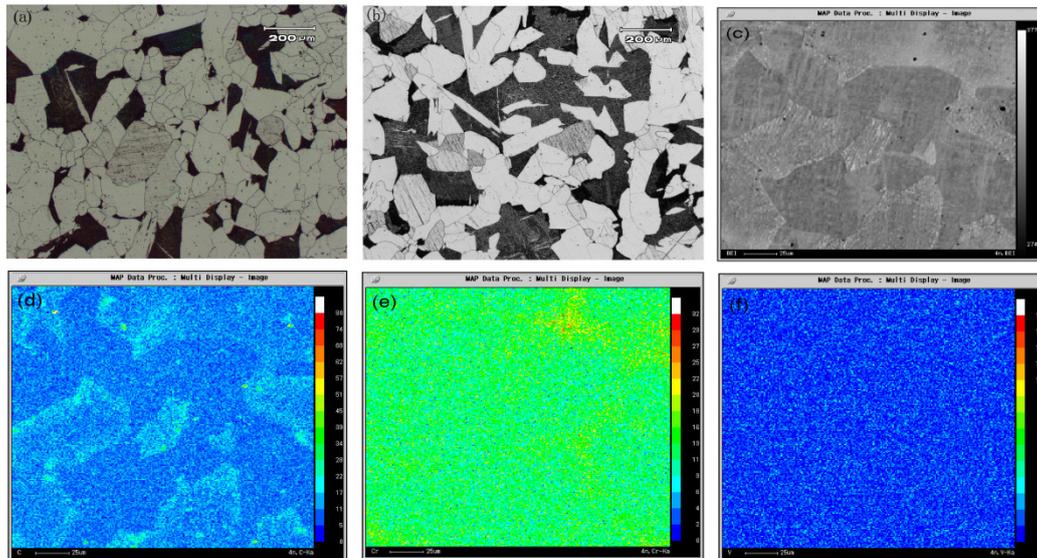


Figure 1. Images of OM and EPMA of steels after homogenizing at 1160°C×24h.(a) LAWRS, (b) LAWRS-C, (c)-(f) EPMA images of LAWRS-V, (d) Carbon distribution in EPMA, (e) Chromium distribution in EPMA, (f) Vanadium distribution in EPMA.

3.2 Microstructure in quenching procedure

It could be seen that, after homogenizing, particles contained iron/chromium carbides, whose precipitation nose temperature was around 650°C. Thus, these particles would mostly be resolved into austenite matrix during austenizing. To testify this, the experimental steels were austenized at 940°C for 0.5h, then quenched to room temperature. The results were shown in Figure . It can be seen that, lots of particles still existed in the martersite. And most of them distributed along the boundaries, such as grain boundaries, martensite block

boundaries, martensite lath boundaries. That could indicate that, the particles were mainly formed during furnace cooling in homogenizing procedure. And in the austenizing procedure, the temperature was not high enough for the particles to resolve. As mentioned above, the iron/Chromium carbides would resolve in austenizing. This would deduce that the particles might be Niobium and Mo carbides, which precipitate nose temperature were about 920 °C and 860 °C respectively. However to identify the composition of the particles, the EPMA and EDS should be conducted. Moreover, from the images, it also showed that the Carbon addition accelerated the growth of carbides. And the shape of carbides changed

from small rod shape to shuttle shape. It also seemed that the carbon addition would prompt the austenite growth, which lead to larger grain size, comparing with the LAWRS steel. On the other side, Ni addition only broadened the martensite lath width without dilating the austenite grains. And it hardly influenced the carbides formation. Vanadium addition seemed that the martensite lathes were cut into several discontinuous sections. Reason for this has not cleared yet. It might related to the retardation of austenite transformation during heating in the austenizing procedure. Since Boron distributed

mainly along the boundaries, the Boron addition increased the content of carbides.

From the results, it could be conducted that the carbides content was excessive for the carbides formation. And with the addition of Vanadium and Boron element, the quantity of carbides would distinctly raise, while with Ni and C addition, the solid solution strengthening would be significantly improved. But, the stability of martensite would correspondingly decrease, which might lead to poor impact toughness.

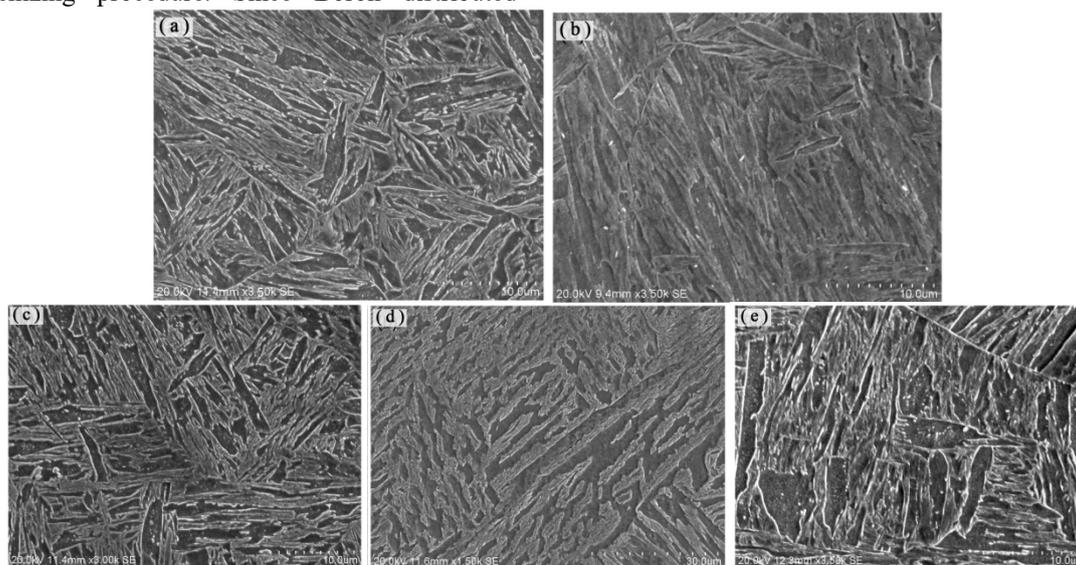


Figure 2. OM images of experimental steels after quenching procedure of 940°C for 0.5h. (a) LAWRS steel, (b) LAWRS-C steel, (c) LAWRS-Ni steel, (d) LAWRS-V steel, (e) LAWRS-B steel.

To verify the carbides, EPMA of LAWRS steel after 1160°C×1h homogenizing and 940°C×0.5h austenizing followed by water quenching to room was conducted. The results, shown in Figure 3, indicated that Chromium element was homogeneously dispersed. Since the Chromium atom could substitute the iron atom in the

same property in steels, the Chromium atom dispersion would reveal the Iron concentration gradient. That was to say, during austenizing, the Iron/Chromium carbides were resolved into the austenite. The carbides illustrated in Figure 2 were mainly Niobium and Mo carbides.

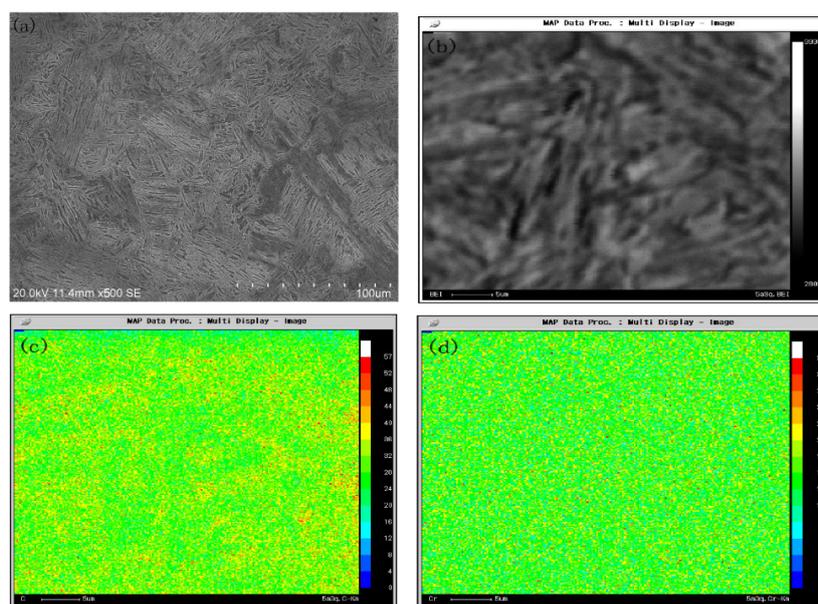


Figure 3. Images of EPMA of LAWRS steel after 1160°C×1h homogenizing and austenizing at 940°C for 0.5h and water quenching to room temperature. (a) microstructure by SEM; (b)-(d) images of EPMA, (c) Carbon distribution in EPMA; (d) Cr distribution in EPMA.

3.3 Microstructure in tempering procedure

SEM images of LAWRS steel after quenching at 920°C and tempering at different temperatures were shown in Figure 4. During tempering, carbides existed after quenching barely changed. But the retained austenite would decomposed into ferrite and Fe₃C, and with the tempering temperature raising, from room temperature to 520 °C, the Fe₃C character would change, including shape, size and content. Therefore, the microstructure evolution of steels with Carbon, Ni, Boron and Vanadium

addition would be similar. So the LAWRS steel tempering at different temperatures was studied as the representative sample. It can be seen that the temperature mainly effect the martensite lath boundaries. With the temperature raising, the boundaries varied obviously. This might be correlated with the location of retained austenite. As mentioned in previous works, the retained austenite mainly formed along the martensite lath boundaries. Therefore, with the retained austenite decomposing, the lath boundary blurred, as shown in Figure 4.

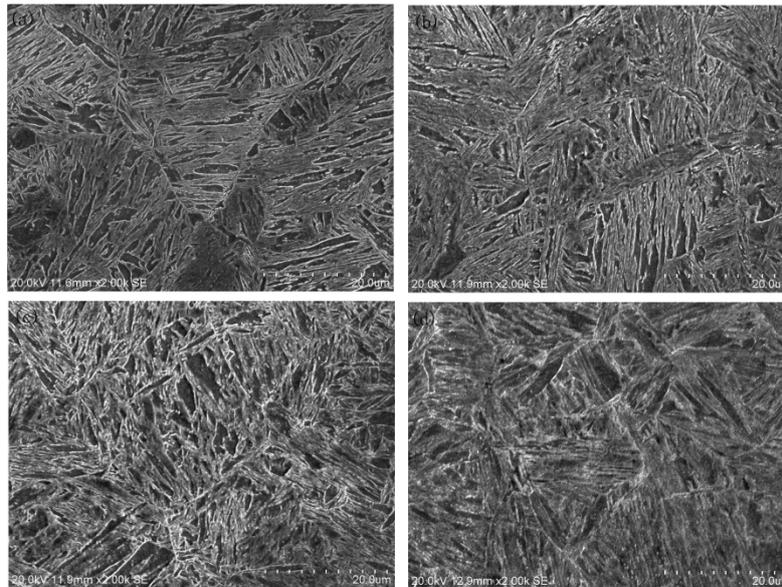


Figure 4. SEM images of LAWRS steel after quenching at 920°C and tempering at different temperatures. (a) tempering at room temperature, (b) tempering at 380°C, (c) tempering at 460°C, (d) tempering 520°C.

4 Conclusion

The conclusion were as following: From the experiment, several conclusions could be brought out as following.

- During furnace cooling in homogenizing, Chromium/iron, Niobium, Vanadium and other hardly soluble carbides formed. But Chromium/iron carbides could resolve into austenite during quenching procedure, while the other carbides barely changed.
- Carbon addition grew the carbides into shuttle shapes and inflated the austenite grains. But Ni addition broadened the martensite lath width without dilating the austenite grains. And it hardly influenced the carbides formation. Vanadium addition seemed that the martensite lathes were cut into several discontinues sections.
- With the temperature rising, the boundaries got blurred, which might correlated with the decomposing of retained austenite.

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