Journal of University of Science and Technology Beijing
Volume 11, Number 1, February 2004, Page 71

Materials

Effect of strong carbide forming elements in hardfacing weld metal

Yuanbin Zhang[1,2] *and Dengyi Ren*[2]

1) Department of Materials and Engineering, Shandong Institute of Architecture of Engineering, Jinan 250014, China
2) Department of Material Science and Engineering, Shandong University, Jinan 250061,China
(Received 2003-03-22)

Abstract: To achieve high carbon hard-facing weld metals with both high hardness and crack resistance, strong carbide forming elements Ti, Nb and V were alloyed into the weld metals, and their effect on the formation of carbides and the matrix microstructure were studied. Electron Probe Microanalysis (EPMA), Energy Dispersive Spectroscopy(EDS) and Transmission Electron Microscopy(TEM) were adopted to investigate the microstructure, then thermodynamics of the formation of carbides was calculated and their effect on the matrix was further discussed. It is revealed that Nb, Ti and V influence strongly the distribution and existing state of carbon, inducing precipitation of carbides accompanying with the depletion of carbon in matrix. But when only V are alloyed as carbide forming element, the carbides are scarce and distributed along grain boundaries, and the hard-facing alloy is too hard, while the using of only Nb or Ti could not reinforce the weld metals effectively. The hard-facing alloy reinforced with Nb, V and Ti can form dispersive fine carbides and low carbon martensite matrix.

Key words: hard-facing welding, carbides , niobium (Nb), vanadium (V), titanium (Ti)

[*This work was financially supported by Nature Science Foundation of Shandong Province (No.Y99F01).*]

1 Introduction

Hard-facing is widely used to improve surface properties of metals, in which welding metal having excellent resistance to wear is deposited onto a substrate. In the welding metal, hard carbides are requisite for improvement of hardness and wear resistance, meanwhile, a strong and tough matrix is also required to prevent the fall off of carbides and enhance the crack resistance.

Chromium (Cr) and tungsten (W) are two kinds of carbide forming elements universally alloyed into welding metal to form hard carbides. However carbides in welding metal are insufficient and the matrix solid solution is excessively strengthened due to higher solubility of Cr and W in steel. What is more, the carbides of Cr and W tend to precipitate along grain boundary, which results in the deterioration of the toughness of welding metal.

Titanium (Ti), niobium (Nb) and vanadium (V) are strong carbides forming elements and can combine with carbon (C) to form MC type carbides with high melting point and high hardness. Ti and Nb can also form primary carbides well distributed in liquid metal when their concentration is higher [1-3], then promote the nucleation of austensite and make the microstructure fine, which is favourable for improving the toughness of welds. In the present study, the effect of Ti, V and Nb were investigated.

2 Experimental

Alloying elements were transferred through electrode coating in which many alloy powder and RE modifier were mixed. H08A with diameter in 3.2 mm was used as welding wire.

The welds samples were surfacing welded on 9Cr2Mo substrate with welding current of 150 A and the interpass temperature under 40°C, and were cut off under water cooling condition.

The overall composition of welding metals were measured by X-ray fluorescence analyzer, micro-zone composition and elementary line distribution were investigated by JXA-8800R type Electron Probe Microanalysis (EPMA) and EDAX PV9100 Energy Dispersive Spectrometry (EDS) respectively. Microstructure was analyzed by H-800 type Transmission Electron Microscopy (TEM). HR-150D type hardness meter was used to measure the surface hardness.

Corresponding author: Yuanbin Zhang, **E-mail:** zhang-yuanbin@sohu.com

3 Results

3.1 Composition of welding metal

Composition and hardness of four kinds of welding metal are shown in **table 1**. Sample A with Nb and sample B with V contain almost the same amount of the other alloy elements, but the hardness of sample B is obviously high than that of sample A. Sample D contains all the three strong carbide forming elements, and the amount of carbon and alloy elements are somewhat higher than that of sample B, but the hardness is lower than sample B. As to the sample C, the content of Ti is lower than that of Nb in sample A and V in sample B due to the deoxidation effect and low transfer coefficient of Ti.

Table 1 Composition (mass fraction) and hardness (HRC) of welding metals

Welds	Composition / %						HRC
	C	Nb	V	Ti	Cr	Ni	
A	0.80	3.74	—	—	1.4	1.3	43
B	0.80	—	3.78	—	1.4	1.3	62
C	0.80	—	—	1.63	1.4	1.3	37
D	0.90	1.18	2.18	0.64	1.4	1.3	58

3.2 Distribution of carbides and alloy elements

Figures 1, 2, and **3** reveal the distribution of carbides and alloy elements in sample A to C respectively.

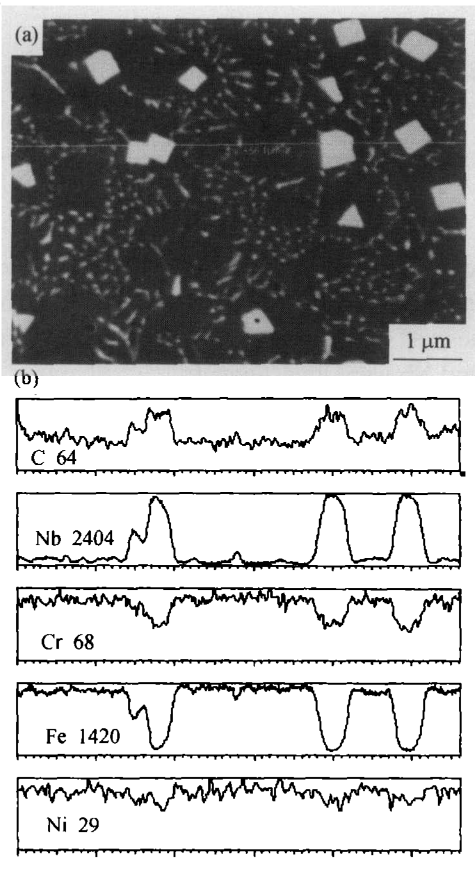

Figure 1 Element distribution in sample A, (a) second electron image; (b) EDS line scan map.

In sample A, plenty of carbide particles precipitate in two kinds of morphologies (see figure 1(a)): one is regular bulk particles with diameter of 2-4 μm adjacent to particle-free zone, the other is fine particles densely distributed at the zone far from bulk particles. Figure (1)b shows the elementary distribution along line A-A in figure (1)a. It is revealed that the peak values of C and Nb correspond to the particles sites, which proves that the particles are carbides of Nb. Distribution curves of Cr and Ni present valley value at the particle sites, then Cr and Ni dissolve in solid solution and little carbides of Cr and Ni have formed. The formation of carbides depleted the carbon in matrix sharply, then the soft matrix could not hold the carbides effectively, which resulted in the low hardness of sample A despite the existence of hard carbides particles.

Compared with A sample, carbides in B sample are scarce and precipitated along grain boundary (figure 2(a)). Since C, V and Cr all show peak value in their distribution curve at the particle site along B-B line in figure 2(a), the carbides in sample B must be complex carbides of V and Cr. Due to the smaller amount of carbides, most of C and V still dissolve in matrix, thus sample B is very hard (HRC63).

The distribution of carbides and alloy elements in C sample are similar to that in sample A, as shown in figure 3. But the hardness of C sample is even lower than that of sample A, this could be attributed to the lower alloy content.

Carbides in sample D are shown in **figure 4**. The carbides distribute uniformly throughout the welding metal and in most of them there is a grey core which had been proved to be oxides of RE and Ti [4]. It is just these oxides that provid heterogeneous sites for carbides and make them precipitated uniformly. EPMA results reveal that the carbides contain mainly Nb and Ti, while Cr dissolves in matrix mostly and V distributes equably between carbides and matrix. Therefore it is deduced that most of Nb and Ti combine with carbon to form carbides and inhibit the formation of carbides of V and Cr.

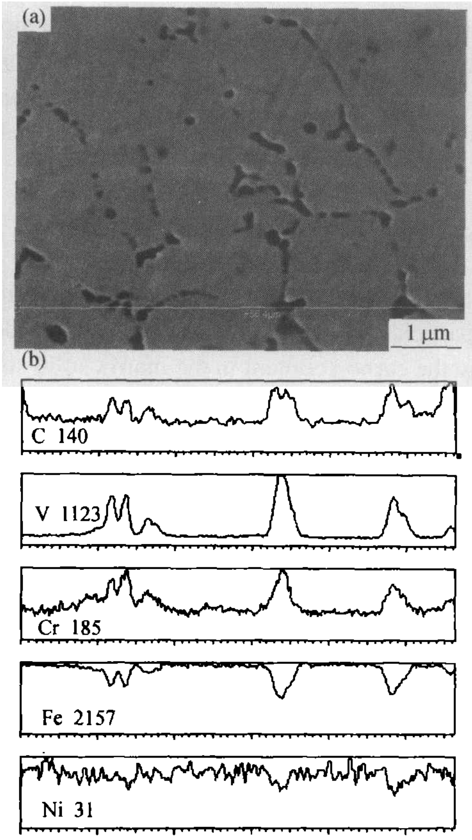

Figure 2 Element distribution in sample B, (a) second electron image; (b) EDS line scan map.

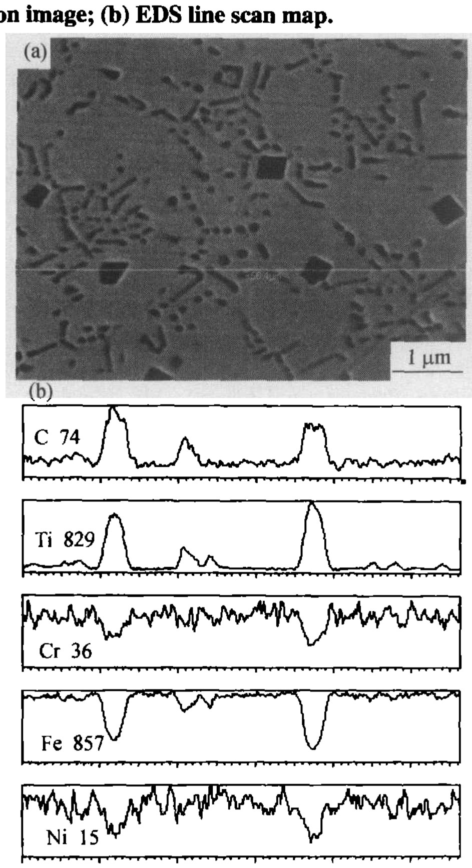

Figure 3 Element distribution in sample C, (a) second electron image; (b) EDS line scan map.

3.3 Microstructure of welding metal

TEM image of sample D is shown in **figure 5**. It is found that a bulk carbide with grey core distributes in the lath martensite (ML) matrix and between martensite lath is retained austenite film. ML contain low carbon content and have proper combine of strength and toughness, retained austenite film is favorable for preventing the propagation of crack. Obviously this kind of microstructure provids the welding metal with both high hardness and crack resistance. The formation of low carbon martensite in high carbon welding metal results from the carbides precipitating which depletes the carbon in the matrix.

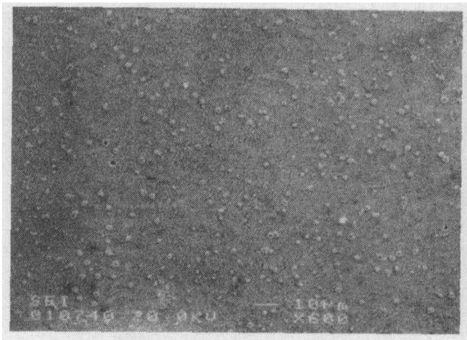

Figure 4 Carbides in sample D.

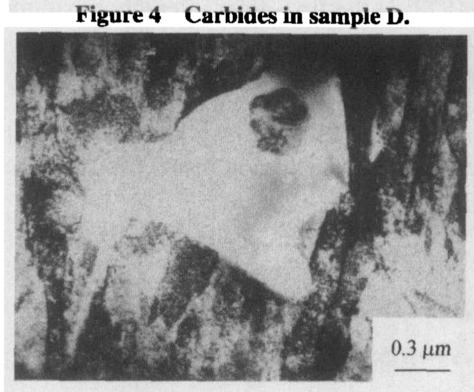

Figure 5 TEM morphology of sample D.

3.4 Thermodynamic analysis

Thermodynamic calculation for carbides formation is conducted assuming that stoichiometric carbides (MC) of Nb, Ti and V were formed and the welding metal met the regular solution model.

The forming reaction formula of MC in iron solution can be expressed as follows:

$$[M]+[C]=MC \quad (1)$$

where [M] and [C] represent M (Ti, Nb ,or V) and C that dissolved in iron solution.

The activity of M and C in equilibrium with MC in iron solution is given by:

$$\lg \alpha_M \alpha_C = \frac{\Delta G^\theta}{2.3026RT} \quad (2)$$

where α_M and α_C are the activity of M and C respectively, ΔG^θ is the standard free energy change, R the gas constant and R=8.314 $J \cdot K^{-1} \cdot mol^{-1}$, T the thermodynamic temperature.

The activity α_M and α_C can be calculated by following formula:

$$\alpha_M = f_M w_M \quad (3)$$

$$\alpha_C = f_C w_C \quad (4)$$

$$\lg f_M = \sum (e_M^{Mi} \cdot w_{Mi}) \quad (5)$$

$$\lg f_C = \sum (e_C^{Mi} \cdot w_{Mi}) \quad (6)$$

where f_M and f_C are activity coefficients of M and C in iron solution respectively, Mi stands for solute element in welding metal (Nb, Ti, V, Cr, C, Ni, *etc.*); w_M, w_C and w_{Mi} are concentration of M , C and Mi in weld metal respectively; e_M^{Mi} and e_C^{Mi} are the first-order interaction parameter of Mi on M and C respectively, and the relation between them and temperature are considered according to following formula [5]:

$$e_M^{Mi}(T) = \left(\frac{2557}{T} - 0.365 \right) \cdot e_M^{Mi}(1873) \quad (7)$$

$e_M^{Mi}(1873)$ is the first-order interaction parameter of Mi on M at 1873 K and is valued according to literatures [6,7].

The activity of Nb, Ti, and V in equilibrium with their carbide in iron solution meets following formula respectively:

$$\lg \alpha_{Ti}\alpha_C = -6160/T + 3.25 \text{ [8]} \quad (8)$$

$$\lg \alpha_{Nb}\alpha_C = -7167/T + 3.36 \text{ [9]} \quad (9)$$

$$\lg \alpha_V\alpha_C = (-105800+94.5/T)/19.1T \text{ [10]} \quad (10)$$

Computer procedure was programmed based on formula (3) to (10). By substituting the alloy content of sample A to D into the program respectively, equilibrium temperature (TMC) of carbides in these samples can be calculated and are listed in **table 2**.

Table 2 Equilibrium temperature of carbides in welding metal for samples K

Carbide	A	B	C	D
NbC	2081	—	—	1882
TiC	—	—	1932	1820
VC	—	1200	—	1159

The melting point of welding metal is about 1650-1750K. Then it is obvious that NbC and TiC could precipitate from liquid metal thermodynamically, while VC does not meet the thermodynamic condition for precipitation from liquid metal. For sample A and C, the precipitation temperature of NbC (or TiC) is higher than the melting point of welding metal, then precipitated NbC (or TiC) could grow to form coarse bulk carbides resulting in depletion of the carbon and Nb (or Ti) content around the carbide. For sample B, VC could only precipitate along grain boundary after the solidification of welding metal. As to sample D, both NbC and TiC could precipitate from liquid metal, but due to the lower precipitating temperature as well as the effect of oxides core, the carbides are well dispersed.

4 Conclusion

Nb and Ti can combine with carbon to form carbides particles in liquid welding metal and deplete strongly the carbon content in the matrix solid solution, while the forming tendency of VC is weaker than TiC and NbC, and VC readily precipitates along grain boundaries. When suitable amount of Nb and Ti are alloyed into welding metal together with V and Cr, the microstructure of the welding metal transforms to fine and dispersive carbides and low carbon martensite martrix and retained austenite film, which provides the welding metal with both good wear properties and crack resistance.

References

[1] Daqian Sun, Hui Gong, and Zhenfeng Zhou, *et al.*, Effects of alloying elements on the microstructures and mechanical properties of Ni-Fe weld metals [J], *China Welding* (in Chinese), 33(1999), No.2, p.33.

[2] Arnoldo Bedolla-Jacuinde, Microstructure of vanadium-, niobium- and titanium-alloyed high-chromium white cast irons [J], *Int. J. Cast Met. Res.*, 13(2001), p.343.

[3] Jian Chen, Baiyun Huang, and J.H. Lee, *et al.*, Carbide formation process in directionally solidified MAR-M247 LC superalloy [J], *J. Mater. Sci. Technol.*, 15(1999), No.1, p.48.

[4] Dengyi Ren, Modifying effect of rare earths on carbides in high carbon steel welds [J], *J. Chin. Rare Earth Soc.* (in Chinese), 16(1998), No.2, p.154.

[5] Ying Qu, *Physical Chemistry Calculation During Steel Smelting Process* (in Chinese) [M], Metallurgy Press, Beijing, 1993, p.29.

[6] Shoukun Wei, *Thermodynamics in Metallurgy Process* (in Chinese) [M], Shanghai Science and Technology Press, Shanghai, 1980, p.37.

[7] Xueyong Ding, Peng Fan, and Wenzhong Wang, Thermodynamic calculation for alloy systems [J], *Metall. Mater. Trans. B*, 30B(1999), No.4, p.271.

[8] Zhongting Ma, Evaluation of interaction parameters in metallic solutions by the isoactivity method [J], *Metall. Mater. Trans. A*, 30A (1999), p.3103.

[9] S.Zajac and B.Jansson, Thermodynamics of the Fe-Nb-C-N system and the solubility of niobium carbonitrides in austenite [J], *Metall. Mater. Trans. B*, 29B(1998), p.163.

[10] Aitao Tang and Fusheng Pan, Thermodynamic calculation of alloying elements affecting precipitation temperature of primary MC carbide in high speed steel [J], *J. Iron Steel Res.* (in Chinese), 1998, No.3, p.45.