Effect of Flux Coating Alloying Elements on Microstructure and Toughness of FV520(B) Steel Weld Metal (Postprint)

Authors: Li Jihong, Liu Juanjuan, Zhang Min, Liu Mingzhi, Tang Jiang

Date: 2023-03-18T00:00:00+00:00

Abstract

Medium-carbon ferromanganese and nickel powder were added to the welding electrode coating to transfer Mn and Ni elements into the FV520(B) steel weld. The effects of the coating alloy elements on the microstructure and toughness of the FV520(B) steel weld were investigated by means of metallographic analysis, impact testing, XRD analysis, and SEM observation. The results show that the microstructure of the FV520(B) steel weld consists mainly of tempered sorbite and lath martensite, with retained austenite and secondary precipitates present. As the alloy elements increase, the weld microstructure becomes finer and denser, the martensite laths become more uniform and fine, and the distribution becomes more dispersed. Compared with acidic coating, basic coating demonstrates a more significant effect in transferring alloy elements, thus resulting in superior impact toughness of the weld. Transferring Mn and Ni through the coating can increase the austenite content in the weld, thereby improving the impact toughness of the FV520(B) steel weld. Compared with Mn, the addition of Ni is more effective in enhancing weld toughness.

Full Text

Preamble

Vol. 29 No. 7
CHINESE JOURNAL OF MATERIALS RESEARCH
July 2015

Effect of Addition of Alloying Elements in Welding Flux on Microstructure and Toughness of Weld Seam of FV520(B) Steel

LI Jihong, LIU Juanjuan, ZHANG Min, LIU Mingzhi, TANG Jiang
(College of Materials Science and Engineering, Xi’ an University of Technology,

Xi’ an 710048, China)

Supported by National Natural Science Foundation of China No. 51274162, the Foundation of Shaanxi Educational Committee No. 14JK1539, and the Science and Technology Program of Xi’ an No. CX12163.

Manuscript received August 14, 2014; in revised form January 7, 2015
Corresponding author: LI Jihong, Tel: (029)82312205, E-mail: lijihong@xaut.edu.cn

Abstract

The influence of addition of alloying elements of medium-carbon ferromanganese and nickel powder in the welding flux on the microstructure and toughness of the weld seam of FV520(B) steel was investigated by means of impact testing, metallographic microscopy, SEM, and X-ray diffractometry. The results show that the microstructure of the weld seam of FV520(B) steel is mainly composed of tempered sorbite and lath martensite with some residual austenite and secondary phases. With increasing amounts of alloying elements Mn and Ni, the microstructure of the weld seam became finer, the martensite laths became thinner, and the distribution became more uniform. The addition of alloying elements into a basic flux rather than an acidic one showed much higher effectiveness in improving the toughness of the weld seam.

The induced Mn and Ni can enhance the austenite content in the weld seam, which in turn plays an important role in enhancing its toughness. Moreover, the induced Ni was more effective than Mn in enhancing the toughness of the weld seam.

Keywords: metallic materials, welding flux, alloying element, FV520(B) steel, microstructure, impact toughness

Introduction

FV520(B) stainless steel exhibits excellent corrosion resistance, impact toughness, and desirable transverse mechanical properties in large cross-sections. It also possesses good weldability similar to the 18-8 series stainless steels, making it widely applicable in fan manufacturing, particularly for producing medium-to-high speed fan blades that convey corrosive media [1, 2]. However, in practical applications, impellers made of FV520(B) steel frequently fail. The causes of failure are twofold: first, improper control of forging and heat treatment processes [3]; and second, insufficient toughness of the welded joint, which leads to crack initiation and fracture near the weld seam [4]. In view of this, the present study added medium-carbon ferromanganese and nickel powder to the welding electrode flux to introduce Mn and Ni elements into the weld metal, investigating their influence on and mechanism of improving the toughness of FV520(B) steel weld seams.

Experimental

Materials and Welding Parameters

The base material was FV520(B) stainless steel plates designated as A, B, C, D, E, and F, with welding test plate dimensions of 160 mm × 200 mm × 20 mm. The weldments were prepared with double-sided V-grooves. The welding currents used for root pass, filling, and capping were 120 A, 130 A, and 140 A, respectively. To reduce the tendency for cold cracking, the test plates were preheated to 200°C before welding, followed by a post-weld heat treatment: solution treatment at 1050°C for 1 h (water cooling) + adjustment treatment at 850°C for 2 h (water cooling) + aging treatment at 620°C for 1 h (air cooling).

Chemical Compositions

The chemical compositions of the experimental FV520(B) steel base material and the specialized stainless steel electrode core are listed in Table 1 .

Flux Coating Formulations

Six flux coating formulations were used, designated as #1, #2, #3, #4, #5, and #6 (corresponding to sample designations A-F). Among these, #1 and #2 were acidic fluxes, while #3, #4, #5, and #6 were basic fluxes. Formulations #1, #3, and #6 without added nickel powder served as reference samples. The electrode flux formulations are listed in Table 2 .

Testing Methods

Impact tests of welded joints were conducted according to GB/T 2650-2008 on a JB300 testing machine. Impact specimens were V-notched samples taken perpendicular to the weld seam and symmetric about the weld center, with the notch perpendicular to the weld surface and located at the weld center. Metallographic examination was performed using an OLYMPUS-GX71 metallurgical microscope. The relative contents of martensite and austenite in the specimens were analyzed using an XRD-7000 X-ray diffractometer (XRD) with Cu Kα radiation, employing continuous scanning at a rate of 6°/min over a range of 30–120°.

Results and Discussion

2.1.1 Weld Microstructure

Figure 1 shows the microstructures of the weld metals of samples A, B, C, D, E, and F after welding and post-weld heat treatment [Figure 1: see original paper]. As shown in the figure, the weld microstructures obtained from all six electrodes after post-weld heat treatment consist primarily of tempered sorbite and lath martensite, with residual austenite and secondary precipitates present. The lath martensite appears parallel, while the tempered sorbite and lath martensite are interwoven in a braided pattern. Figures 1a and 1b reveal that samples A and B exhibit two distinct regional microstructures with clear contrast, where some regions retain martensite morphology and numerous precipitates are visible on the matrix, showing obvious spherical aggregation. In contrast, after aging treatment, the weld microstructures of samples C, D, E, and F show clearly visible martensite lath packet orientations, essentially maintaining the original lath martensite orientation characteristics, with precipitates dispersedly distributed in the matrix and a small number of precipitate particles beginning to coalesce and spheroidize.

Comprehensive comparison of the six different weld microstructures shows that although the base material, welding process, and heat treatment process were identical, and the weld microstructures were all dominated by tempered sorbite + lath martensite + residual austenite + secondary precipitates, the weld microstructure became finer and more compact with increasing alloy element (Mn, Ni) content, while the martensite laths became more uniform, thinner, and more dispersedly distributed.

2.1.2 Austenite Content in Weld

XRD analysis was performed on the welds of samples C, D, E, and F to measure the austenite content. The XRD spectra of the welds are shown in Figure 2 [Figure 2: see original paper]. The results indicate that the weld microstructure is primarily martensite, with varying diffraction peak intensities among different welds. The martensite (110) diffraction peak is the strongest, while the austenite (111) diffraction peak is relatively prominent.

The austenite content was calculated using the formula [5]:

$$\phi_\gamma = \frac{I_\gamma}{I_\gamma + 1.4 I_\alpha}$$

where ϕ_γ is the volume fraction of austenite, and I_γ and I_α are the integrated intensities of the $(111)_\gamma$ and $(110)_\alpha$ diffraction peaks, respectively.

The peaks $(110)_\alpha$, $(200)_\alpha$, $(211)_\alpha$, $(111)_\gamma$, and $(200)_\gamma$ were selected to calculate the austenite content in the welds, with the results listed in Table 3 . The data show that the addition of Mn and Ni elements helps increase the austenite content in the weld, with Ni being more effective than Mn. Simultaneous addition of Mn and Ni results in a more significant increase in weld austenite content. The primary reason is that Mn and Ni are austenite-forming and stabilizing elements that can lower the As and Ms points of steel, increasing the chemical stability and content of reversed austenite in the weld [6]. The austenitizing effect of Ni is more pronounced than that of Mn because the increase in reversed austenite is related to the migration of Ni elements [7]. When the tempering temperature rises slightly above the As point, nuclei of reversed austenite phase form directly via shear transformation in high-Ni regions and grow longitudinally along lath boundaries into extremely fine needle-like reversed austenite.

Additionally, since the ferromanganese in the flux acts as a deoxidizer, Mn suffers significant oxidation loss, reducing its transfer efficiency, which results in a less pronounced effect on austenite content in the weld compared to Ni.

2.2 Impact Toughness of Welded Joints

Figure 3 presents the impact test results for the welded joints of samples A, B, C, D, E, and F [Figure 3: see original paper]. Sample E exhibits the highest weld toughness, with its impact absorption energy increasing by approximately 50% compared to sample C, which also used a basic flux. Comparison of the impact toughness between samples E and F demonstrates that adding nickel powder to the flux can effectively improve the impact toughness of the weld. The main reason is that Ni increases nucleation sites during crystallization in the molten pool, refines the grain structure, and expands the austenite phase region, reducing the amount of residual austenite and thereby enhancing weld toughness [8].

Figure 3 also shows that the impact toughness of samples welded with acidic electrodes is significantly lower than that of samples welded with basic electrodes. Acidic electrode flux contains more acidic oxides such as titanium oxide and silicon oxide, exhibiting stronger oxidizing properties that cause greater burn-off of alloying elements during welding and higher diffusible hydrogen content, resulting in poorer crack resistance. Basic electrode flux contains more marble and fluorite, along with higher amounts of ferroalloys as deoxidizers, which reduces the oxygen and hydrogen content in the weld and decreases non-metallic inclusions, thus providing higher ductility and toughness.

Compared with the base metal, the impact toughness of the welds is significantly lower. This is attributed to two factors: first, the post-weld heat treatment process was insufficient to fully improve the impact toughness of the weld; and second, inevitable impurity elements such as S and P in the electrode segregate to grain boundaries, reducing grain boundary surface energy and promoting intergranular brittle fracture, thereby decreasing weld toughness.

Figure 4 compares the austenite content and impact energy for samples C, D, E, and F [Figure 4: see original paper]. The results show that impact absorption energy follows the same trend as austenite content, indicating that austenite content in the weld directly affects the magnitude of impact absorption energy. The reason is that austenite in the weld is distributed as thin sheets between lath martensite packets. When cracks encounter residual austenite, they branch, increasing the energy consumed during propagation [9–11]. Therefore, transferring austenite-forming alloying elements to the weld increases the austenite content and improves weld impact toughness. The austenite content in sample E increased by 6% compared to sample C, with impact absorption energy increasing by 30 J. Comparison between samples E and F shows that the Ni-containing sample E generated more austenite and provided a more significant improvement in weld toughness, demonstrating that Ni is more effective than

Mn for enhancing weld toughness.

2.3 SEM Analysis of Weld Impact Fractures

Figure 5 shows the micro-morphologies of the fibrous zones in the impact fractures of welds for samples C, D, E, and F [Figure 5: see original paper]. The fracture morphologies all exhibit equiaxed dimples, which are relatively shallow. Fine micropores formed by detachment of second-phase particles from the matrix can be observed at the bottom of some dimples and on cleavage platforms.

Comparing the micro-morphologies of the fibrous zones in fractures of samples D and E with sample C, the fractures of Ni-added samples D and E show denser, more uniformly sized dimples, with more numerous fine micropores formed by detachment of secondary precipitates at the bottom of small dimples. The addition of Ni increases the austenite content between martensite laths in the weld, which is continuously distributed within the tempered sorbite matrix and is extremely fine, creating a high degree of dispersion with tempered sorbite. This microstructural morphology results in more uniform dimple distribution and greater dimple density on the fracture surface, thereby improving weld toughness.

Conclusions

1. The microstructure of FV520(B) steel weld seams consists primarily of tempered sorbite and lath martensite, with residual austenite and secondary precipitates present. With increasing Mn and Ni alloy element content, the weld microstructure becomes finer and more compact, the martensite laths become more uniform and thinner, and the distribution becomes more dispersed. Transferring Mn and Ni alloying elements through the flux increases the austenite content in the weld, thereby improving the impact toughness of FV520(B) steel weld seams.
2. Compared with acidic flux electrodes, using basic flux electrodes is beneficial for improving the impact toughness of FV520(B) steel welded joint weld metal.
3. The impact fracture morphology of FV520(B) steel welds shows equiaxed dimples. The fracture surfaces of samples with Ni addition exhibit denser and more uniformly sized dimples, demonstrating that Ni is more effective than Mn for improving the impact toughness of weld metal.

References

[1] J. L. Fan, X. L. Guo, C. W. Wu, Y. G. Zhao, Research on fatigue behavior evaluation and fatigue fracture mechanisms of cruciform welded joints, *Materials Science and Engineering A*, 528(29/30), 8417 (2011).

[2] FAN Junling, GUO Xinglin, ZHAO Yanguang, WU Chengwei, Predictions of S-N curve and residual life of welded joints by quantitative thermographic method, *Journal of Materials Engineering*, (12), 29 (2011).

[3] ZHANG Yiliang, ZHU Yunqing, ZHANG Zhenhai, Blower impeller fast fracture detection and failure analysis, *Journal of Safety and Environment*, 7(1), 132 (2007).

[4] ZHANG Min, CHAO Lining, LI Jihong, ZHANG Meili, Failure analysis on fracture of gas blower turbine wheel, *Hot Working Technology*, 40(12), 190 (2011).

[5] ZHOU Qianqing, ZHAI Yuchun, Aging process optimization for a high strength and toughness of FV520B martensitic steel, *Acta Metallurgica Sinica*, 45(10), 1249 (2009).

[6] XU Zuyao, Effect of alloying elements in special steel heat treatment, *Ordnance Material Science and Engineering*, 3(1), 1 (1982).

[7] ZHANG Futian, JIANG Jian, SONG Jianxian, HAN Ci, Study of Mossbauer spectroscopy of Ni9 steel rotary austenitic phase transformation, *Acta Metallurgica Sinica*, 22(4), 169 (1986).

[8] Zhu Dong, Wang Fuxing, Cai Qigong, Zheng MingXin, Cheng Yinquian, Effect of retained austenite on rolling element fatigue and its mechanism, *Wear*, 105(3), 223 (1985).

[9] XU Zuyao, Low-carbon martensite and interlath austenite in steels, *Iron & Steel*, 22(3), 33 (1987).

[10] H. Nakagawa, T. Miyazaki, Effect of retained austenite on the microstructure and mechanical properties of martensitic precipitation hardening stainless steel, *Journal of Materials Science*, 34, 3901 (1999).

[11] S. D. Antolovich, B. Singh, Study on the toughness increment associated with the austenite to martensite phase transformation in TRIP steels, *Metal Trans*, (8), 2135 (1971).

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.