Improvement of Microstructure and Mechanical Properties of Manganese Steels by Adding Boron Alloying Element

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Received: 19 May 2018 - Accepted: 27 July 2018

Abstract

Improvement of the mechanical properties and microstructures of industrial parts can improve working conditions, working life and reduce rejection rates and consequent, improve environmental effects of industrial developments. In this paper, the effect of Boron content in chemical composition ofManganese steel on improvement of microstructure and mechanical properties of manganese steels has been investigated. This improvement can reduce the consumption and rejection rate of castings and consequent environmental protection. The microstructure was investigated using optical, SEM and FESEM microscopy. In addition, mechanical tests such as tensile test, hardness and impact tests were performed on the samples. Microscopic investigations showed the presence of 0.007% Boron prevents of formation carbides in grain boundaries and also reduces the carbide sizes and cause uniform distribution. In the presence of Boron, annealing solution heat treatment, improve the morphology of carbides and modified it to spherical shape. The results of the research show that by increasing 0.007% Boron, fine and spherical carbides will form in austenitic microstructure of manganese steel which increase the hardness, toughness, tensile strength and modify carbide distribution and morphology in both heat treated and non-heat treated conditions. This results can improve casting operation time and rejection rates of castings in wear conditions as an environmental friendly material.

Keywords: Hadfield Steels, Boron Content Manganese Steels, Microstructure, Carbide Distribution, Mechanical Properties,

1. Introduction

Cast Austenitic-Manganese steel which are known as Hadfield steel, was discovered in 1882 by Robert Hadfield. Because of their special properties, Manganese steels developed very fast as a useful engineering material [1-2]. Today, these steels are widely used with slight change in the chemical composition and heat treatment in various industries. These industries include drilling, loader tooth, mines extraction, crushers, wear and abrasion resistant and cement industries and so [3-4]. Manganese steels (Hadfield) are very useful materials in industries that require the impact resistance, wear resistance high strength and ductility and also cost effective production [5]. Concerning the shape and size and various thickness of components, the properties are not uniform in all the sections. Those properties can be improved by using suitable alloying elements or the heat treatment. In as cast condition, manganese steels include manganese carbides and cementite and have a brittle structure [6]. Heat treatments at 1000 to 1100 ˚C for suitable times according to thickness of components, and consequently water quenching, can dissolve the brittle phases and prevent the reformation of carbides during the cooling period and produce austenitic microstructure.

The cares should be done to prevent the local melting due to carbon segregation [7-8].

However the solution treatment at high temperatures may lead to grain growth. Casting temperature and cooling rate of these steels in cast molds also affect the final size of austenite grains [4].

There are many researches in various fields, such as mechanical or microstructure improvements and role of alloying elements on mechanical and microstructures of Manganese steels [9].

These studies and researches improve mechanical properties such as wear and abrasion resistance [3,9-10]. Alloying elements also have other roles in the final properties of steels such as reduction of dissolved gases and reducing sustaining to impurities. Controlling each of these stages mainly effect the final properties of steel. [11-13]. Addition of Al to chemical composition of manganese steels increase solubility of carbon in austenite and improve the hardness but impact toughness may be decrease [8]. Moreover, the effect of elements such as vanadium, niobium, molybdenum, nickel, chromium, hydrogen, sodium and cobalt have been studied by researches [13-19], however, the effects of Boron are less investigated.

The main purpose of this paper is evaluating the effect of Boron content and solution heat treatment on mechanical properties and microstructure of manganese steels.

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2. Materials and Methods

In this study, the effect of addition of Boron as alloying elements with 0.0%, 0.003%, 0.005%, 0.007% of weight percent to chemical composition of manganese steel and its effects on microstructure and mechanical properties of manganese steels are considered. Table. 1. given the chemical composition of the manganese steel according to ASTM A 128M.Grade B-3 (wt. %).

Table. 1. ASTM A128 M: Chemical Composition (wt. %) of Austenitic Manganese Steels.

Grade	C	Mn	Si (Max)	P (Max)
B-3	1.12-1.28	11.50-14.00	1.00	0.07

2.1. Sand Molding

The molding of samples was done by CO_2/Silicate sand process. To prevent the chemical reaction between the sand and molten metal, the surface of molds was chromate sand and the silica sand was the support. In addition, the surface of molds was coated by special coating. These samples had cylindrical shape with 30mm diameter and 300mm height. Fig. 1. illustrate the pattern layout for molding.

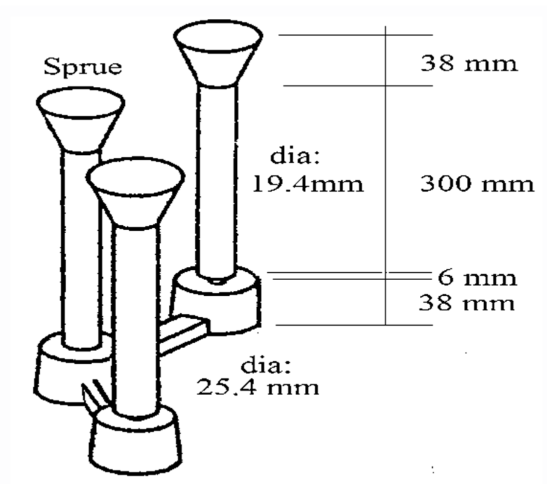


Fig. 1. The pattern system for molding.

2.2. Melting and Casting

The 300 kg induction furnace was used for preparation of molten steel. The high manganese and low alloy steel scrap were added in to the furnace and after melting, the require graphite and Fe-60%Mn were added to molten metal to adjust the carbon and manganese content. The Ferro-alloy Fe-10% B was used For adding of 0.003%, 0.005%, and 0.007% Boron to the melt and required calculations were done. For degassing of molten steel the pure aluminum in amount of 0.06% was added to the molten steel in ladle. In all the cases, the tapping temperature was 1520ºC and the pouring temperature of molten steel to the molds was 1480º C [15-17]. The chemical composition of molten steel after the adding of Boron is given in Table. 2.

Table. 2. Chemical composition (wt. %) of molten manganese steel with Boron content.

Heat	C	Si	Mn	Al	Cr	B
1	1.120	0.500	11.820	0.040	0.830	0.000
2	1.160	0.510	11.830	0.040	0.850	0.003
3	1.140	0.520	11.780	0.030	0.820	0.005
4	1.150	0.510	11.810	0.030	0.840	0.007

After the cooling of specimens to ambient temperature, the specimens were discharged from the sand mold and shot blasted. Then the solution heat treating was carried out in an electric furnace. The gradient of temperature was 200 ˚C per hour to reach the 1050 ºC and stay at it for one and half hours and then rapid quenched in hot water. After the cutting of runners and risers and shot blasting and machining, the specimens were prepared for optical and SEM metallography and hardness, impact and tensile mechanical tests [18-22].

3. Results and Discussion

3.1. Metallography and Microstructure

Fig. 2. shows the microstructure of manganese steels with different Boron content. The presence of Boron in casting, prevents the carbides formation at grain boundaries and distributes the carbides inside the grains, and makes a uniform distribution of carbides in austenitic microstructure. In solution heat treated manganese steels, increasing the Boron content, reduce the carbide precipitation in grain boundaries and reduces the brittle behavior of grain boundaries due to carbides segregation and improve the toughness. As seen from Figures, at 0.003% Boron, segregation of carbides in grain boundaries is less than for 0.0% Boron. In Fig. 2.-a, the morphology of manganese carbides are layered type which segregated at grain boundaries, but most of the manganese carbides are dissolved in austenite in 0.007 % Boron and remaining parts have spherical morphology, Fig. 2.-d. That means the presence of Boron has minimum 2 effects: The first is improvement of dissolution of manganese carbides in microstructure and the second modification of remaining carbide morphologies. The higher amounts of 0.007% Boron content can create Boron carbides which have opposite effect on toughness and impact resistance [23-24].

Fig. 3. shows the Scanning Electron Microscopy images of samples with 0.0 to 0.007% % Boron content after the heat treatment. As can be seen, the morphology of carbides before the heat treatment is acicular with high volume percent in grain boundaries. But after heat treatment, the volume percent of carbides reduced significantly and the morphology of segregated carbides are spherical.

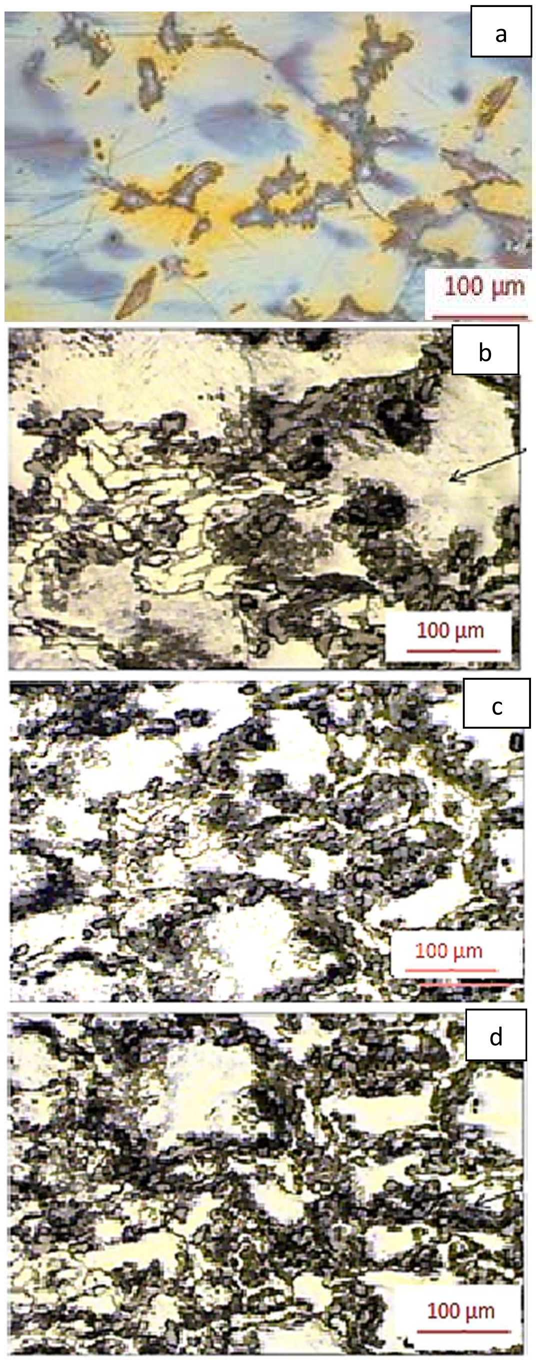
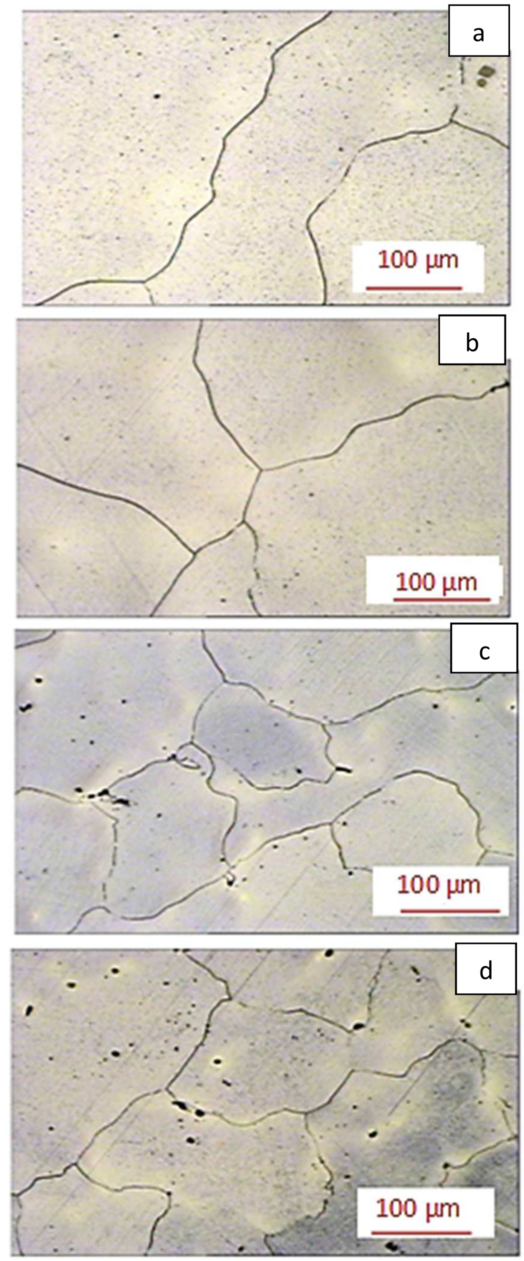


Fig. 2. Microstructure of samples with various amounts of Boron before the heat treatment a) 0.0% b) 0.003% c) 0.005% d) 0.007%



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3.2. Mechanical Properties

3.2.1. Hardness

Fig. 4. shows the effect of Boron content on Brinell hardness of samples before and after the solution heat treatment. In all the samples, addition of Boron increase the hardness. The maximum hardness was achieved for 0.007% content of Boron at solution heat treatment conditions. The Boron content prevents segregation of carbides at grain boundaries and redistributes of the carbides in Fig. 4.

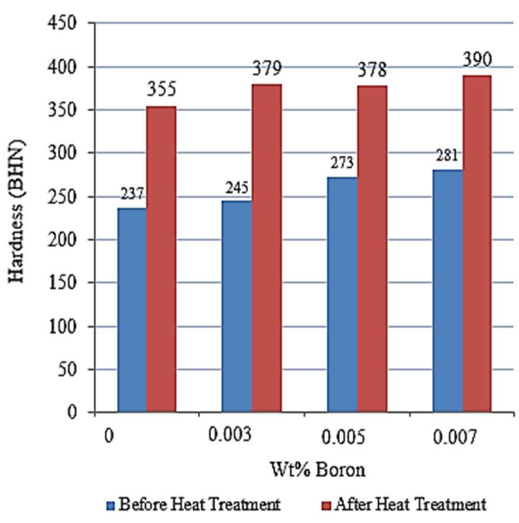

Fig. 4. Effect of Boron Content on hardness of Manganese Steel before and after solution heat treatment.

Whole of the matrix and the heat treatment improve hardness of samples by almost 38-55% for all ranges.

3.2.2. The Tensile Test

Manganese steels have high resistance to elastic deformation, and have high yield strength. However, due to their brittle nature, manganese steels have low tensile strength and low plastic deformation behavior in as cast condition [20-23]. The Boron content in alloy steel, prevent the segregation of manganese carbide in grain boundaries and redistributes of carbides in austenitic microstructure increase the plastic deformation capability and tensile strength. The details of those effects are shown in Fig. 5.

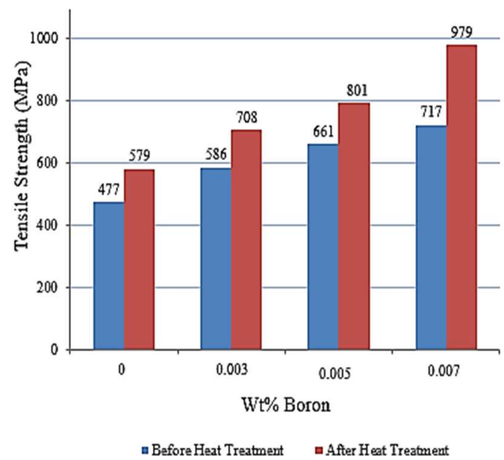

Fig. 5. Effect of the Boron Content on Tensile Strength of Manganese Steel before and after the solution heat treatment.

3.2.3. The Impact Test

Fig. 6. shows the impact test results for different content Boron content as an alloying element in austenitic-manganese steel samples before and after the solution heat treatment. It is clear that the higher Boron content improve impact energy toughness.

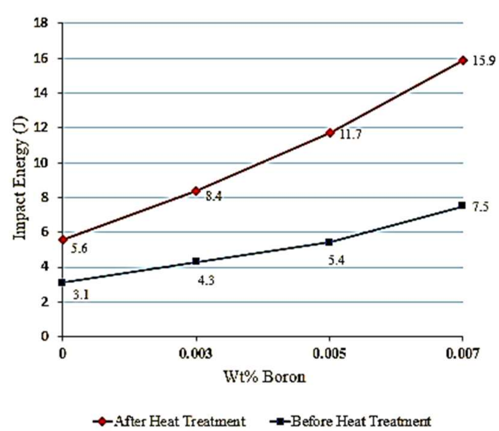

Fig. 6. Effect of the Boron content on impact energy of manganese steels before and after the solution heat treatment.

4. Conclusions

The results showed that the presence of 0.3 Boron in cast structure prevents creation of layers of carbides at grain boundaries and break down the carbides, and creates spherical and uniform distribution of carbides in austenitic structure I addition by increasing the amount of Boron, the hardness of samples increases before and after the heat treatment, but due to the formation of spherical carbides, the ductility is not reduced. The results of microscopic investigation and mechanical tests on manganese steels with Boron content, also show the following results:

1. By the annealing solution heat treatment, manganese carbides will dissolve in austenitic microstructure and their layered shape will convert into the spherical shape.
2. Presence of Boron in chemical composition of manganese steel prevents the formation and precipitation of manganese carbide in grain boundaries and cause uniform distribution of remaining carbide in austenitic microstructure. This phenomena prevents the brittle behavior of steel and increase toughness of castings.
3. By increasing the amount of Boron, the hardness will increase before and after the solution heat treatment, without reduction of impact energy and ductility.
4. At 0.007% Boron, fine and spherical carbides will be formed in austenitic microstructure of manganese steel which increase hardness, toughness, tensile strength and modifies the carbide distribution and morphology in both heat treated and non-heat treated states.
5. Combination of the solution heat treatment and alloying by 0.007% of Boron, give the optimum mechanical properties and microstructure modification in manganese steels.
6. Improvement of mechanical properties and microstructure of castings will increase the working life and operation of castings and reduce material consumption and consequently improve environmental friendly material for our world.

References

[1] Akeel D. Subhi and Omar A. Abdulrazaq, Eng. Technol., 25(6)2007.
[2] A. K. Srivastava and K. Das, J. Mater. Sci 43 (2008), 5654.
[3] Bouaziz, S. Allain, C. P. Scott, D. Cugy, Mater. Sci., 15(2011), 141.
[4] F. Haakonsen, “Optimizing of Strømhard austenitic manganese steel” Thesis for the degree of Philosophiae Doctor Trondheim, May 2009.
[5] Hull D. In: Deformation twinning, proceedings of a metallurgical society conference. Gainesville, Floride, Gordon and Breach Science, New-York; 1964.
[6] J. O. Agunsoye1, S. A. Balogun1, D. E. Esezobor1 and M. Nganbe, Scripta. Mater. 12(42)2000, 1107.
[7] M. Abbasia, S. Kheirandisha,b, Y. Kharrazi a, J. Hedjazi, Mater. Sci. Eng. 513(514)(2009), 72.
[8] S. W. Bhero, B. Nyembe, and K. Lentsoana, International Conference on Mining, Mineral Processing and Metallurgical Engineering (ICMMME’2013) April 15-16, 2013.
[9] S. A. Balogun, D. E. Esezobor, J. O. Agunsoye, J. Minerals Mater. Character. Eng., 7(3)2008, 277.
[10] W. Zhang, J. Wu, Y. Wen, J. Ye, N. Li, J. Mater. Sci., 45(2010), 3433.
[11] X. Jingpei, J. Qichuuan, H. Zhenming, L. Quanshun and K. Sommer, Chin. J. Met. Sci. Technol., (8)1992.
[12] Ranjan TV, Sharma CP and Sharma A. Heat treatment principles and techniques. New Delhi: Prentice-Hall of India Private Limited; 1999.
[13] Perry RH and Green DW. Solid-solid operation and processing. In: Chemical engineers handbook. 8th ed. New York: Mc Graw-Hill Companies; 2008, 56.
[14] T. Jing and F. Zhang, Mater. Letter., 31(3-6)1997, 275.
[15] R. W. Smith, A. DeMonte and W. B. F. Mackay, (153-154)2004, 589.
[16] H. Li, J. Zhihao, L. Jinde and T. Jun, Modulated. Mater. Des., 23(8)2002, 717.
[17] B. Emin, A. Frazal, Khalid and L. Chritopher, J. Mater. Process. Technol., 147(2), 2004, 145.
[18] C. Efstathion and H. Sehitoglu, Scripta. Mater. 59(10), 2008, 1103.
[19] C. Efstathion and H. Sehitoglu, Acta. Mater., 58(5)2009, 1479.
[20] Dobrzanki LA, Grajcar A and Borek W., J. of Mater. Manuf. Eng., 31(2), 2008, 218.
[21] A. García, A. Varela, L. García, M. C. S. Río, Naya and M. Suárez, Comparing. Wear., (258)2005, 203.
[22] X. Yunhan, F. Liang, C. Qihong and Z. Jinhua, Mater. Sci. Forum., (117)2005, 475.
[23] Majid A, Shahram K, Yousef K and Jalal H, Wear., 268(1-2)2010, 202.
[24] S. Kuyucak and R. Zavadil, AFS Trans., (108)2000, 120.