Journal of Materials and Environmental Science
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2020, Volume 11, Issue 9, Page 1445-1453

http://www.jmaterenvironsci.com

Effect of Titanium Alloying Element and Annealing Solution Treatment on Microstructure and Mechanical Properties of Manganese Steels

Najmeddin Arab

Department of Material Science Research Center, Saveh Branch, Islamic Azad University, Saveh, Iran,

Received 20 June 2020,
Revised 28 July 2020,
Accepted 30 July 2020

Keywords
- ✓ *Hadfield Steel*
- ✓ Microstructure,
- ✓ Carbide distribution,
- ✓ Solution Treatment,
- ✓ Grain boundary.

najmarab@iau-saveh.ac.ir ;
Phone: +988642433342;
Fax: +9886424330088

Abstract

Mechanical and microstructure of manganese steels are widely depended to chemical composition and heat treatment. In this paper, the effect of titanium content and solution treatment on improvement of microstructure and mechanical properties of manganese steels has been investigated. The microstructure of samples investigates by optical, SEM and FESEM microscopy. Also, mechanical tests such as tensile test, hardness and impact test were performed on the samples. Microscopic images and mechanical test results show that the presence of titanium and solution heat treatment, reduces the segregation of carbides in grain boundaries and improve morphology of carbides to spherical shape, and uniform distribution of alloying elements. Alloying of manganese steels by titanium and solution heat treatment, increase hardness, impact energy and tensile strength properties, so the hardness increase from 258 to 428 BHN in 0.3%Ti. The results show that the chemical composition and solution treatment of manganese steels are very important factors which can improve the working life and application of wear parts in industrial applications such as mining.

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, this steel is 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 which require impact resistance, wear, and 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 sections. These properties can be improved by using suitable alloying elements or 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 º C for suitable times according to thickness of components, and consequently water quenching, dissolve brittle phases and prevent the reformation of carbides during the cooling period and produce austenitic microstructure. The cares should be done to prevent 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 field, such as mechanical or microstructure improvements and role of alloying elements such as molybdenum and chromium [9]. These studies lead to higher mechanical properties and 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 affect the final properties of steel. [11-13]. Increasing the Al to composition caused increasing in solubility of carbon in austenite and improve the hardness but impact toughness has decreased [8]. Moreover, the effect of elements such as vanadium, niobium, molybdenum, nickel, chromium, hydrogen, sodium and cobalt are studied by many researches [14-20], but the effect of boron and titanium are less investigated because these are carbide former elements which are not regular in these steels [21]. The main purpose of this paper is evaluating the effect of titanium content and solution heat treatment on mechanical properties and microstructure of manganese steels.

2. Material and Methods

In this study, the effect of adding titanium alloying elements with 0.1%, 0.2%, 0.3% of weight percent to chemical composition of manganese steel and there effects on microstructure and mechanical properties of manganese steels have been studied. Table 1 illustrate the chemical composition of manganese steel in tests according to ASTM 128M specification. To study the Ti effects, the Fe-60%Ti was added to molten metal so the titanium content of molten metals was 0.1%, 0.2%, 0.3% weight percent respectively.

Table1: ASTM 128 M: Chemical Composition of Austenitic Manganese Steels

Grade	%C	%Mn	%Si(Max)	%P (Max)
B-3	1.12-1.28	11.5-14.5	1	0.07

2.1. Sand Molding

The molding procedure of samples was done by CO2/Silicate sand process. To prevent the chemical reaction between the sand and molten metal, the surface of molds was chromite sand and the silica sand was the support. Also, the surface of molds was coated by special coating. These samples had cylindrical shape with 30mm diameter and 300mm height. Figure 1 shows the pattern layout for molding.

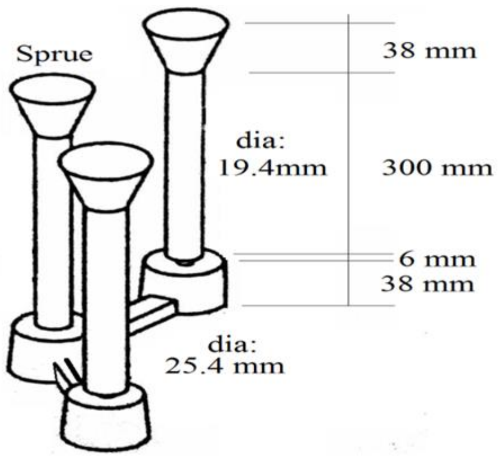


Figure 1 : Location of the Wilaya of Ghardaia and the area of Al Mansoura.

Melting and Casting 300 kg induction furnace was used for preparation of molten steel. High manganese and low alloy steel scrap added to furnace and after melting and calculations, the require graphite and Fe-60%Mn was added to molten steel to adjust the chemical composition according the table 1. Table 2 show chemical composition of molten before adding Ti.

Table 2: Chemical composition of molten steel before adding Ti.

%C	%Mn	%Si (Max)	%P (Max)
1.21	12.2	0.83	0.045

To adding 0.1%, 0.2% and 0.3% Ti to the molten and doing required calculations, the ferroalloy Fe-60% Ti was used. For degassing of molten steel the pure aluminum in .0.06% was added to molten steel in ladle. In each case, the tapping temperature was 1520^{o} C and the pouring temperature of molten steel to the molds was 1480 ^{o} C [16-18].
After the cooling of specimens to ambient temperature, the specimens discharged from the sand mold and shot blasting. Then solution heat treating was carried out in electric furnace. The gradient of temperature was 200 ^{o} C per hour.to reach the 1080 ^{o} C and stay 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, SEM and FESEM metallography and hardness, impact and tensile mechanical tests [19-24].

3. Results and discussion

3.1. Metallography and Microstructure

Figure 2 shows the microstructure of manganese steels with various content of titanium. The presence of titanium in casting, prevent the carbides formation at grain boundaries and breaks and distribute it inside the grains, and makes a uniform distribution of carbides in austenitic microstructure.

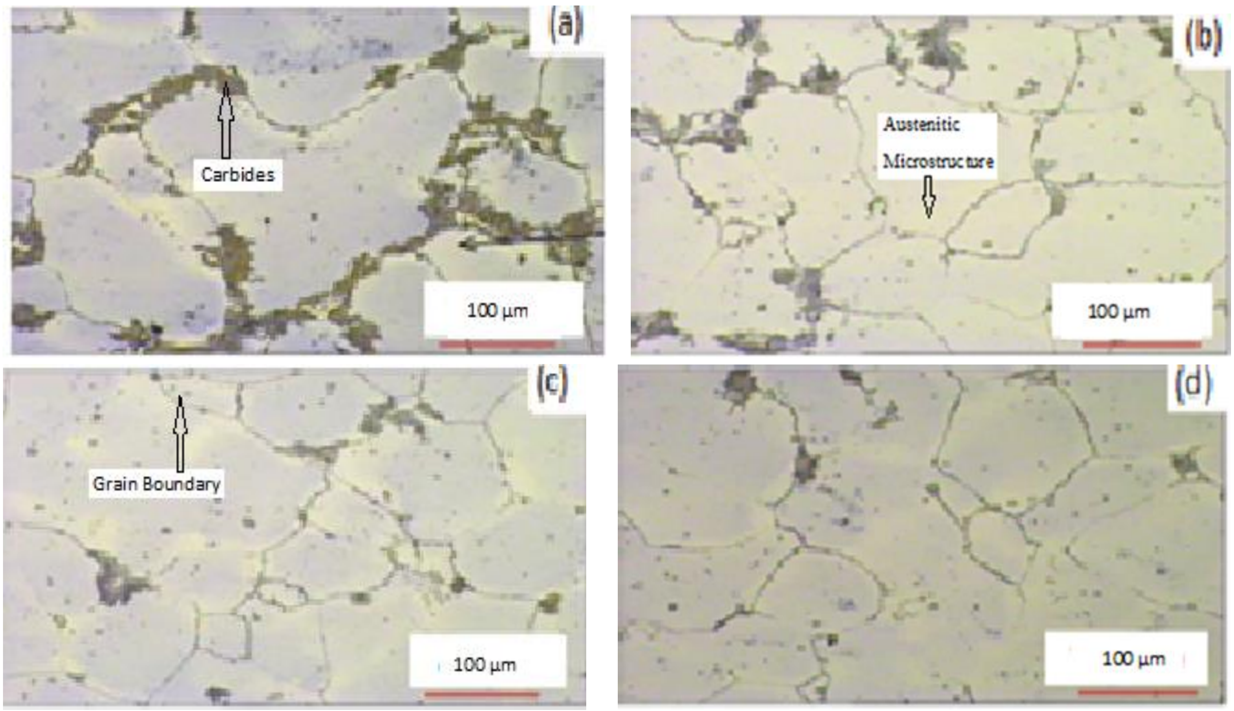
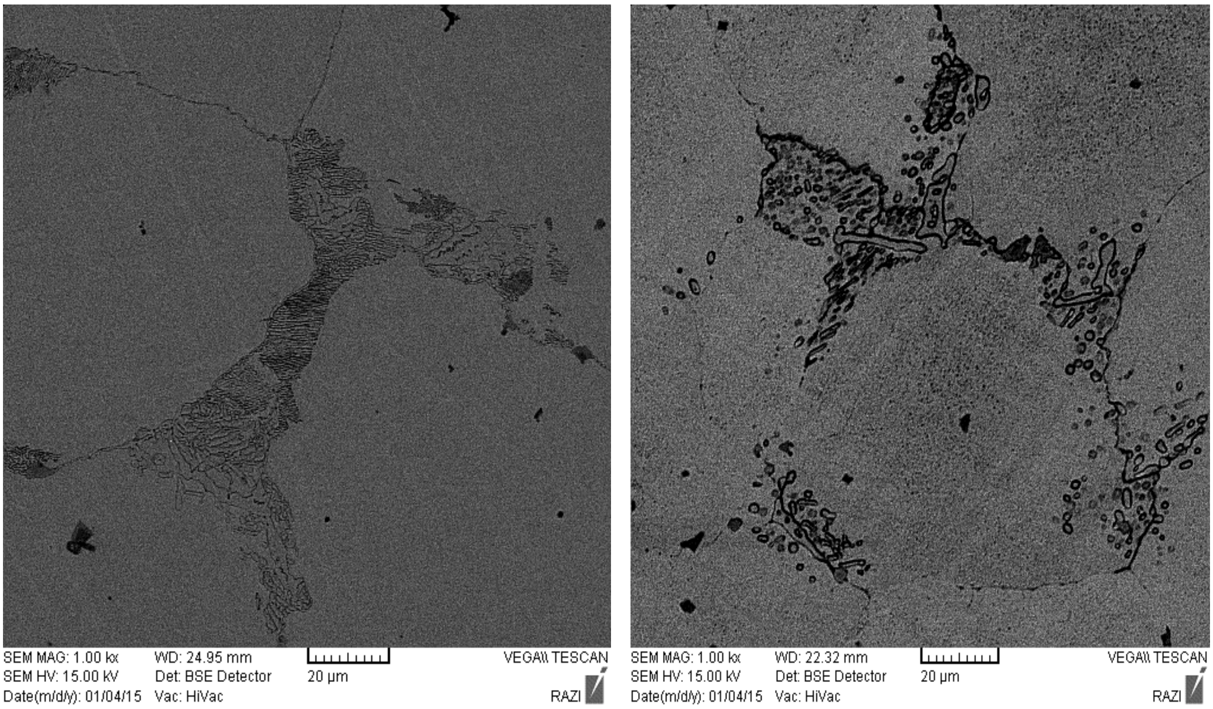


Figure 2: Optical microstructure of samples with various amounts of titanium in solution heat treated samples, a) 0%Ti b) 0.1%Ti c) 0.2%Ti d) 0.3%Ti

In solution treated manganese steel, increasing the titanium content, reduce the carbide precipitation in grain boundaries which reduces the brittle behavior of grain boundaries due to carbides segregation and improve the toughness. As seen from images, in 0.3% Ti, segregation of carbides in grain boundaries is less. In figure 2-a, the morphology of manganese carbides are layer type which segregated at grain boundaries, but most of the manganese carbides are dissolved in austenite in 0.3% Ti and remained parts have spherical morphology, figure 2-d. It means that the presence of titanium have minimum 2 effects: first improvement of dissolution of manganese carbides in microstructure and second: modification of remained carbide morphologies. Higher amounts of titanium can create titanium carbides which have opposite effect on toughness and impact resistance [24-25].
Figure 3 show the Scanning Electron Microscopy images of samples with 0.3% Ti content before and after heat treatment. As seen, the morphology of carbides before heat treatment is acicular which have more volume in grain boundaries. But after heat treatment, the volume percent of carbides reduced and the morphology of carbides are spherical.



a) Before Heat Treatment
b) After Heat Treatment

Figure 3: Scanning Electron Microscopy of Microstructure of casting sample with 0.3% titanium

Figures 4 and 5 show Field Emission Scanning Electron Microscopy (FESEM) images to determine the distribution of elements in the microstructure of 0.3 % titanium content alloy, before and after the annealing solution. Comparison of these images show, in heat treated casting with 0.3% content titanium, uniform distribution of alloying elements, and lower volume carbide formation in heat treated samples. Also the spherical shapes of carbides are visible in images. The mechanism of formation of spherical carbides is not well known, and some researchers studied this mechanism. Most of them reported that the reduction of carbide size increase tendency of carbides to stable morphology which is globular type and it has lower Gibbs free energy [26-28].

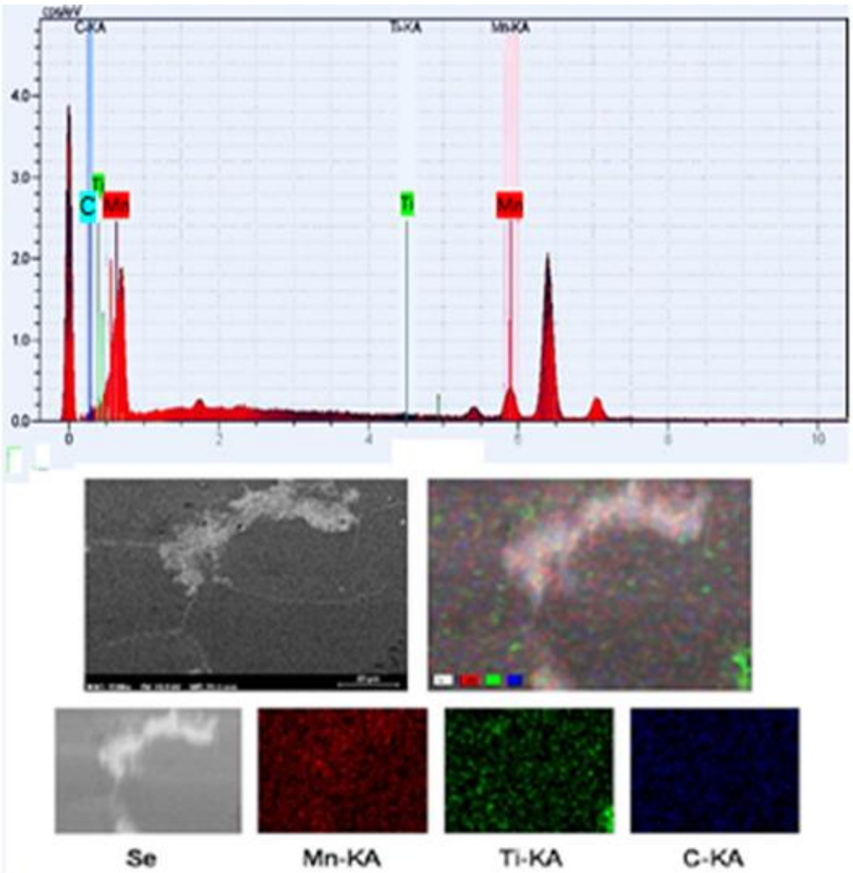


Figure 4: FESEM image of distribution of alloying elements in manganese steel with 0.3% % Ti content before heat treatment

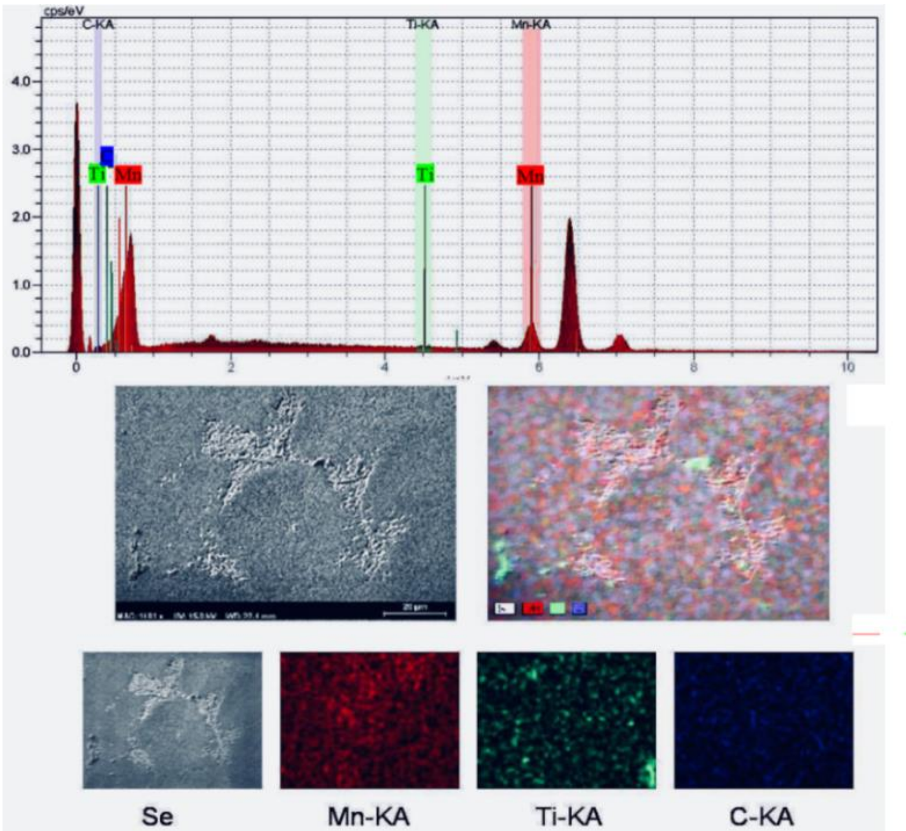
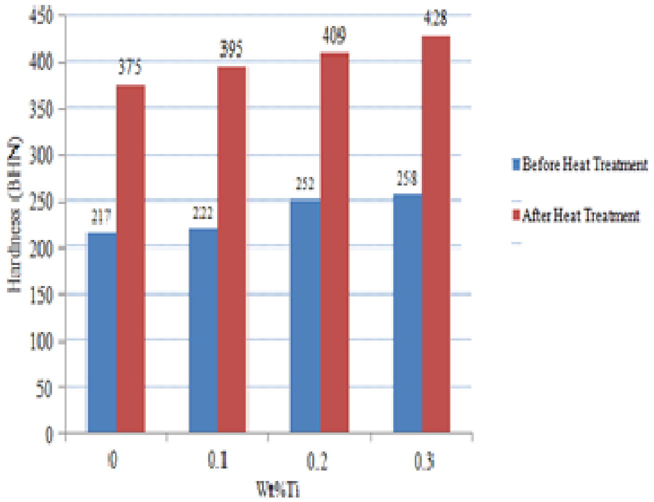


Figure 5: FESEM image of distribution of alloy elements in manganese steel with 0.3% % Ti content after heat treatment.

4. Mechanical Properties

4.1. Hardness

Figure 6 shows the effect of titanium content on Brinell hardness of samples before and after the solution heat treatment. In all samples, addition of titanium, increase the hardness. The maximum hardness achieve in 0.3% content titanium at solution heat treatment condition. Titanium content prevents segregation of carbides in grain boundaries and redistribution of carbides in whole of matrix by heat treatment improves hardness of samples.



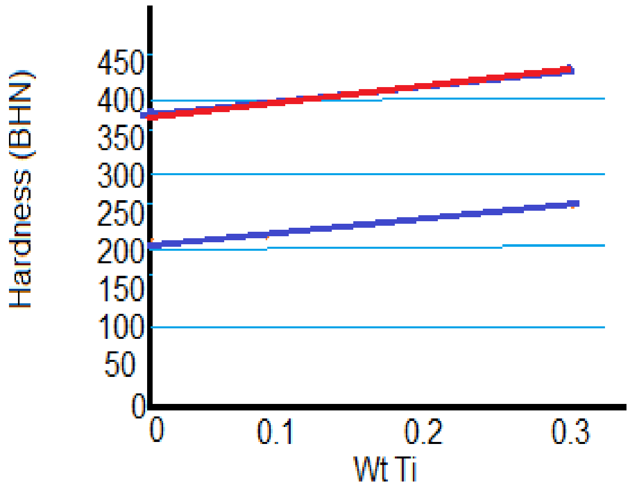


Figure 6: Effect of titanium content on hardness of samples.

4.2. Tensile Test

Manganese steels have high resistant to elastic deformation, and have high yield strength. But, because of its brittle nature, manganese steels have low tensile strength and low plastic deformation behavior in as cast condition. Titanium content in alloy steel, prevent of segregation of manganese carbide in grain boundaries and redistribution of carbides in austenitic microstructure by heat treatment, increase the plastic deformation capability and tensile strength. The details of these effects are shown in figure 7.

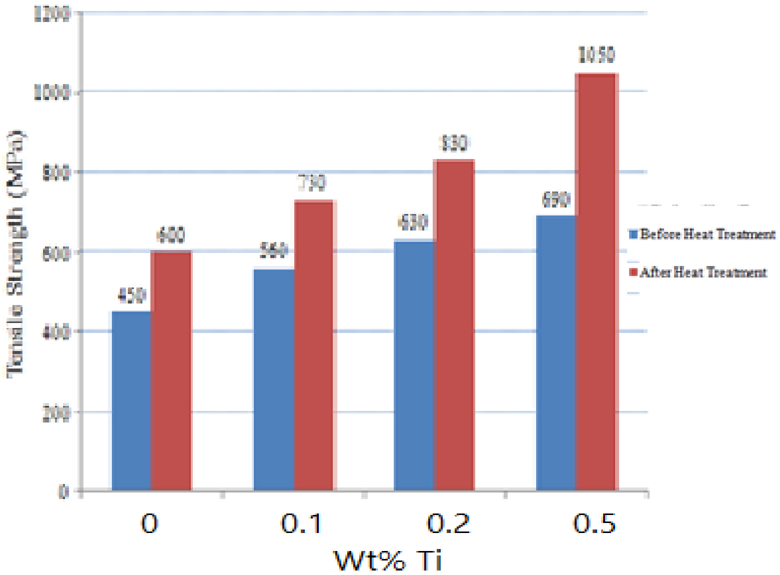


Figure 7: Effect of titanium content on Tensile Strength of samples.

Figure 8 shows stress-strain curve for heat treated 0.3% Ti content. Presence of Ti not only increase the tensile strength, but also improve strain hardening of steel.

4.3. Impact test

Figure 9 show impact test results for various amounts of titanium as an alloying element in austenitic-manganese steel samples before and after solution heat treatment. It is clear that the increase of titanium content to 0.3% increase the impact energy absorption.

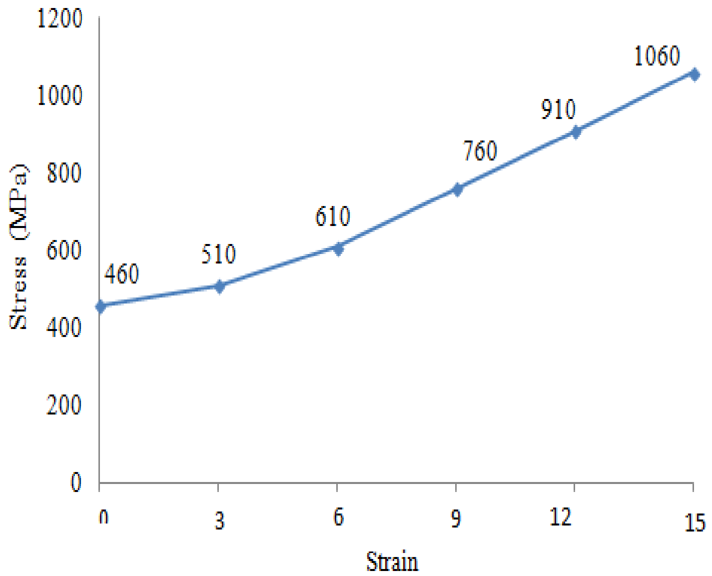


Figure 8: Stress-strain curve for heat treated 0.3% Ti manganese steel

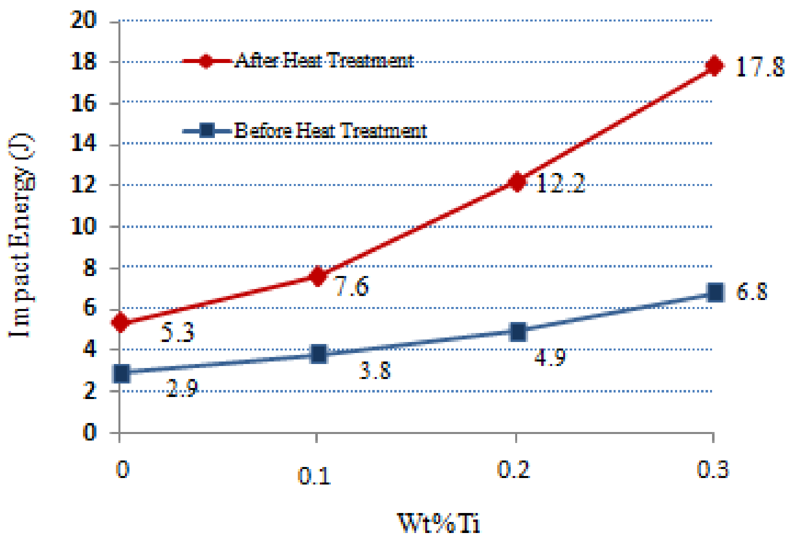


Figure 9: Effect of titanium content on impact energy of samples before and after solution heat treatment

Conclusion

The results showed that the presence of 0.3 titanium in cast structure prevents of creating layers of carbides at grain boundaries and breaks carbides, and creates spheroidal and uniform distribution of carbides in austenitic structure Also, by increasing the amount of titanium, the hardness of samples increases before and after heat treatment, but due to the formation of spheroidal carbides, the ductility does not reduce. The results of microscopic investigation and mechanical tests on manganese steels with titanium content, also show the following results:

- Annealing heat treatment dissolve carbides in austenitic microstructure of manganese steels and, the layer and acicular shapes of carbides changes to spherical shape.

- Presence of titanium in chemical composition of manganese steels prevent formation and precipitation of manganese carbide in grain boundaries and cause uniform distribution of remind carbide in austenitic microstructure. This action , prevent brittle behavior of steel and increase toughness of castings.
- By increasing the amount of titanium, the hardness will increase before and after solution heat treatment, without reduction of energy impact and ductility
- By adding 0.3% Titanium alloy element to manganese steels, the layer and acicular carbides shapes, changes to fine and spherical shapes in austenitic microstructure, which modify mechanical properties, carbides distribution and morphologies in both heat treated and non-heat treated steels.
- Combination of solution heat treatment and alloying by 0.3% titanium, give the optimum mechanical properties and microstructure modification in manganese steels.

References

1. A. D. Subhi and O. A. Abdulrazaq, "Phase Transformations of Hadfield Manganese Steels", *J. Eng. & Technology*, 25, No.6 (2007) 808-814.
2. A. K. Srivastava K. Das,"Microstructural characterization of Hadfield austenitic manganese steel", *J. Mater. Sci.*, 43 (2008) 5654–5658.
3. O. Bouaziz, S. Allain, C. Scott, P. Cugy, D. Barbier " High manganese austenitic twinning induced plasticity steels: A review of the microstructure properties relationships", *Current Opinion in Solid State and Materials Science* 15 (2011) 141–168.
4. F. Haakonsen, "Optimizing of Strømhard austenitic manganese steel" Thesis for the degree of Philosophe Doctor, Norwegian University of Science and Technology. May, (2009).
5. D. Hull 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, M Nganbe, "Wear of Hadfield Austenitic Manganese Steel Casting", *Scripta Mater.*, 42 (2000) 1107-12.
7. M. Abbasi, S. Kheirandish, Y. Kharrazi, J. Hejazi, "The fracture and plastic deformation of aluminum alloyed Hadfield steels" *Materials Science and Engineering A*, (2009) 72–76.
8. S. W. Bhero, B. Nyembe and K. Lentsoana," Common Causes of Premature Failure of Hadfield Steel Crushers and Hammers Used in the Mining Industry" *International Conference on Mining, Mineral Processing and Metallurgical Engineering* , ICMMME. April, (2013).
9. S. A. Balogun, D. E. Esezobor, J. O. Agunsoye, "Effect of Melting Temperature on the Wear Characteristics of Austenitic Manganese Steel", *Journal of Minerals & Materials Characterization & Engineering*, 7, No.3 (2008) 277-289,
10. W. Zhang, J. Wu, Y. Wen, J. Ye, N. Li, "Characterization of different work hardening behavior in AISI 321 stainless steel and Hadfield steel" *J Mater Sci*, 45 (2010) 3433–3437.
11. X. Jingpei, J. Qichuuan, H. Zhenming, L. Quanshun and K. Sommer, "Mechanism of work-hardening for Austenitic Manganese Steel under Non-severe Impact Loading Condition" *J. Mater. Sci. Technol.* 8 Issue 6 (1992) 406-410.
12. T.V, Ranjan, C.P, Sharma and A. Sharma, "Heat treatment principles and techniques", *New Delhi: Prentice-Hall of India Private Limited*; (1999).
13. R.H. Perry and D.W. Green, "Solid-solid operation and processing", *Chemical engineers handbook*. 8th ed. New York: Mc Graw-Hill Companies; (2008) 56-61.

14. W. Bleck and C. Haase, “Physical Metallurgy of High Manganese Steels”, *Metals*, 9, (2019), 1053 https://doi.org/10.3390/met9101053.
15. T. Jing and F. Zhang,“ The work hardening behavior of medium manganese steel under impact abrasive wears condition”, *Materials Letter*, 31(3-6) (1997) 275-279.
16. R.W. Smith, A. DeMonte and W.B.F. Mackay. ” Development of high-manganese steels for heavy duty cast-to-shape applications” *Journal of Materials Processing Technology* 153(1) (2004) 589-595
17. Li H, Zhihao J, Jinde L and Jun T. Modulated structure of Fe- 10Mn-2Cr-1.5C alloy. *Materials and Design*. 2002; 23(8):717- 720. http://dx.doi.org/10.1016/S0261-3069(02)00072-9
18. D. Canadinc, H. Sehitoglu, H.J. Maier and Y.I. Chumlyakor. Strain hardening behaviour of aluminium alloyed Hadfield steel single crystal. *Acta Materialia*, 53(6) (2005) 1831-1842.
19. C. Efstathion and H. Sehitoglu, “On the negative strain rate sensitivity of Hadfield steel. *Scripta Materialia*. 59(10), (2008) 1103-1106. http://dx.doi.org/10.1016/j. scriptamat.2008.07.027
20. C. Efstathion and H. Sehitoglu,“Strain hardening and heterogeneous deformation during twinning in Hadfield steel”, *Acta Materiala*. 58(5) (2009) 1479-1488.
21. V. N. Najafabadi, K. Amini, M. B. Alamdarlo, Investigating the effect of titanium addition on the wear resistance of Hadfield steel”, *Metallurgical Research and Technology* 111(6) (2014) 375-382
22. L.A. Dobrzanki, A. Grajcar and W. Borek, “Microstructure evolution and phase composition of high manganese austenitic steel” *Journal of Achievement in Materials and Manufacturing Engineering*. 31(2) (2008) 218-225.
23. A. García, A. Varela, L. García, M.C. Río, S. Naya, and M. Suárez, “Comparing the tribological behaviour of an austenitic steel subjected to diverse thermal treatments”. *Wear*, 258 (1–4) (2005), 203-207. http://dx.doi.org/10.1016/j.wear.2004.09.003
24. X.Yunhan, F. Liang, C. Qihong and Z. Jinhua, “Subsurface microstructure evolution of Hadfield steel under impact energy”, *Materials Science Forum*. 117 (2005) 475-480.
25. M. Abbasi, S. Kheirandish, Y. Kharrazi, J. Hejazi," On the comparison of the abrasive behaviour of aluminum alloyed and standard Hadfield steels”. *Wear*. 268(1-2) (2010) 202-207. http://dx.doi.org/10.1016/j.wear.2009.07.010
26. S. Kuyucak and R. Zavadil, “On the heat treatment of Hadfield’s austenitic manganese steels - Part II: Metallographic studies. *AFS Trans.* 108 (2000) 120-126.
27. W. Zhuang*, H. Zhi, H. Liu, D. Zhang and D. Shi, “Effect of Titanium Alloying on the Microstructure and Properties of High Manganese Steel”, *International Symposium on Architecture Research Frontiers and Ecological Environment*, E3S Web Conf., 79 (2019).
28. M. Azadi, A. M. Pazuki & M. J. Olya,” The Effect of New Double Solution Heat Treatment on the High Manganese Hadfield Steel Properties, *Metallography, Microstructure, and Analysis*, 7 (2018) 618–626.

(2020) ; http://www.jmaterenvironsci.com