MICROSTRUCTURAL MAPPING OF THE AUSTENITIC MANGANESE STEEL-3401 IN RAPID COOLING PROCESS

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ABSTRACT

Hadfield's austenitic manganese steel which contained approximately 1.2% carbon and 12 to14% Mn is still commonly used for railroad components such as frogs and crossings and also for rock-handling materials. This paper presents the microstructural development of the austenitic manganese steel-3401 due to different heating regimes followed by rapid cooling process. The material is heated to 1050°C followed by a rapid cooling process which caused the solid solution of the carbides to be precipitated in the grain of the pure austenite phase. The tempering temperature is set between 400°C to 600°C at 50° C interval. The microstructural examination of the samples showed that the formation of austenite begins by precipitation of iron and manganese carbides at the grain boundaries, progressively followed by the appearance of a new constituent which later extended to the interior of the grains. The new phase formation increased with increasing temperature, showing temperature dependence of formation.

Keywords: Austenitic manganese steel 3401, Rapid cooling, Microstructural Mapping.

1. INTRODUCTION

The unique properties of Hadfield's manganese steel (1.2% carbon and 12-14% manganese) of high strength and high toughness, and resistance to wear and heavy impact loading make the steel very useful in a variety of applications, for example, railroads, grinding mill liners, crusher jaws and cones, impact hammer and even a bullet-proof helmets. It is usually used in the austenitic condition (1). A standard industrial practice to strengthen Hadfield steels is by solution annealing which is to heat-treat the material at 1000°-1090°C for up to 1 hour followed by a water quench [8-9]. This treatment results in the formation of solid carbides which causes brittleness and still pure austenite. To relieve this condition the steel is further tempered, resulting in the reprecipitation of carbides and manganese carbides in the grain boundaries followed by acicular precipitates extending into the grain as well as the appearance of troostite in the grain boundaries (19). This partial decomposition of austenite also depends on the time and temperature of the tempering condition.

Recently, many attempts have been made to improve the Hadfield base alloy properties by varying their composition as well as heat treatment [2].The work of Rao and Kutumbarao discussed alloys based on the Fe-Mn-C system for austenitic wear resistance steels and Fe-Mn-Cr used for austenitic corrosion-resistant steels. In the Fe-Mn-C steel, development has been directed towards increasing the relatively low yield strength in the annealed condition by precipitation hardening with fine carbides, often requiring complex multi-stage heat treatments [3]. The coarse inter-granular precipitation can take place during various stages of the heat treatments and lead to brittleness in cast-to-shape components [2-4]. The cast-to-shape components are highly used in the rail transportation applications [4]. Two important stages in the casting process have excited much interest since these will influence the final mechanical properties; the loss of some alloying elements (e.g. Mn, C) from the surface and the reverse process, which is transfer of materials (e.g. P, C, N, S, Si) from the casting. At times the loss of Mn in surface layers can be significant, e.g. 10-12%, markedly decreasing abrasion resistance and fatigue life of the cast component.

Morphological mapping of phenomena, particularly development of microstructure with heat treatment is a well known tool in metallurgical engineering. This entails the identification of expected microstructure features expected observed from previous work and relating them to observations in the current work. In this work, the heat-treatment behavior of Hadfield's austenitic manganese steel-3401 in rapid cooling process is investigated using microstructure mapping. In this study focus is given on the effect of iso-thermal process on the formation and decomposition of new steel phases investigated at various tempering temperatures and holding times.

2. MATERIALS AND METHODS

2.1 Experimental details

The Hadfield's manganese steel used was Krupp 3401 with the chemical composition as shown as in Table 1.

Table 1. Composition in Wt %

Composition	Standard a	Modified b
% C	1.0-1.2	1.059
% Mn	11-14	11.34
% Si	-	0.3694
% Ni	-	0.1345
% Cr	-	0.1362

a. Data supplied by the manufacturers.
b. Actual analysis composition

The chemical composition was obtained using atomic absorption spectrometry (Model: Leitz MPV2-L Spectrophotometer) Test specimens of 10 x 20 x 25 mm were prepared for metallographic inspection. They were cut from plates, by precision cutting machine in order to avoid phase transformation changes. Samples were heat-treated at 1050°C for 1 hour in a PID electric furnace (Vectar VHT-3), then quenched in water to homogenize the sample as an austenite phase.

First, all sampel were homogenized at temperature 1050°C for 1 hour before quenched in water. As a second treatment, sample was tempered at different temperatures for various holding times. The tempering temperatures were set between 400°C to 600°C at 50°C interval. These temperatures were selected based on the phase diagrams of pure Fe-Mn. Tabel 2. Shows the heating regimes for the samples.

Tabel 2. Heating regimes of the samples in water quenching

No	Temperature Homogenize	Holding time (minutes)	Temperature Tempering	Holding time (minutes)
1.	1050°C	60	-	-
2.	1050°C	60	400°C	120
3.	1050°C	60	450°C	30
4.	1050°C	60	450°C	60
5.	1050°C	60	500°C	30
6.	1050°C	60	500°C	45
7.	1050°C	60	550°C	15
8.	1050°C	60	550°C	30
9.	1050°C	60	550°C	45
10	1050°C	60	600°C	10
11	1050°C	60	600°C	25

After heating at varying times, the sample was quenched again in water. The sample was ground and polished using an automatic polishing unit. Grinding was performed using silicon carbide abrasive paper of grit P 100, P 350, P 600, P 800, P 1000, P 1500 and P 2000 respectively. Finally, the sample was polished using an alumina paste 1μ to obtain a mirror like surface, an etched using the etchant as shown in Table 3.

Table 3. Etchant composition for Mn-steel

Type solution	Composition	
Solution A	100 ml alcohol	3 ml HNO_3
Solution B	90 ml ethanol	10 ml HCl
Solution C	100 ml ethanol	2 ml NH_4OH

The samples were etched in the order of solution A, B, C followed by rising after each solution etching. The microstructure was characterized using an optical image analyzer microscope (Leica DMLM with RGB Video TV camera JVC model TK1270E) at a magnification of 200X

3. RESULTS AND DISCUSSION

3.1 Development of microstructure

3.1.1 Development of microstructure at heating regime of 1050°C followed by water quenching

The microstructure of Hadfield's austenitic manganese steel when heat treated to 1050°C then followed by rapid cooling process is shown in Fig. 1. Fig. 1 shows austenite grains of Hadfield's steel with twins as similarly found by previous researchers [9-10, 18]

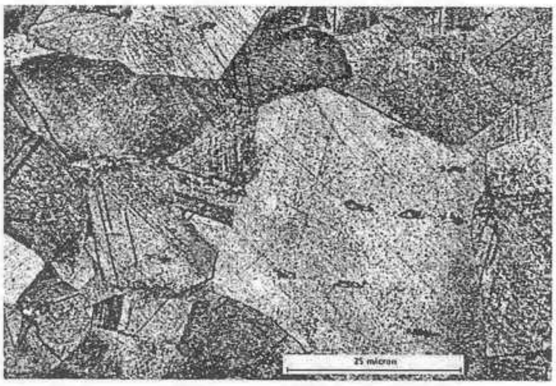

Fig.1 Sample No.1 - 1050°C for 1 hour - water quenching

3.1.2 Development of microstructure at tempering regimes of 400°C

Figure 2 show the microstructure of Hadfield's austenitic manganese steel after heating to 1050°C then subsequently reheated at in 400°C at various holding times followed by rapid quench in water. Fig.2 shows similar austenite grain structure with Fig.1 but with denser precipitation across the grains due to a longer holding time.

The observations follow the theory of diffusion by Ficks II Law, which describe that diffusion is also depend on time[16, 17].

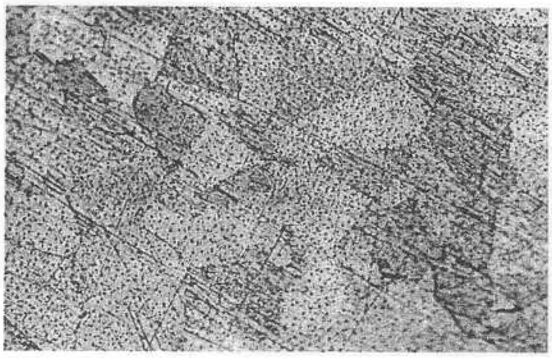

Fig.2 Sample reheat in 400°C for 120 minutes-water quenching

3.1.3 Development of microstructure at tempering regimes of 450°C

Figures 3 and figure 4 are showing the microstructure of Hadfield's austenitic manganese steel after the treatment of 1050°C subsequent reheating to 450°C at various holding followed by times quenching in water. These figures proved that the process of diffusion is also affected by the change of temperature as explained in Ficks 1 law [17].

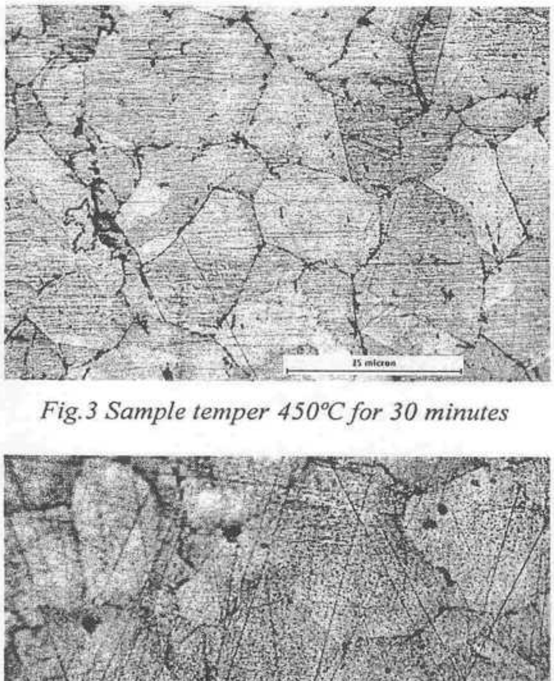

Fig.3 Sample temper 450°C for 30 minutes

Fig.4 Sample temper 450°C for 60 minutes

3.1.4 Development of microstructure at tempering regimes of 500°C

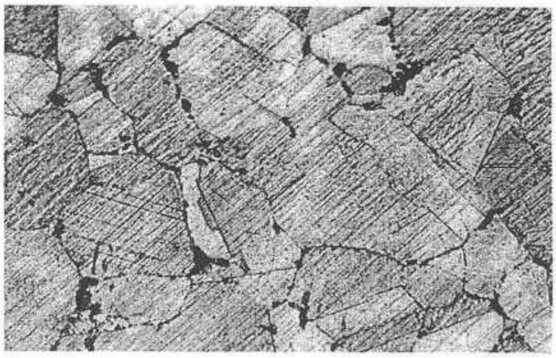

Fig.5 Sample temper 500°C for 30 minutes

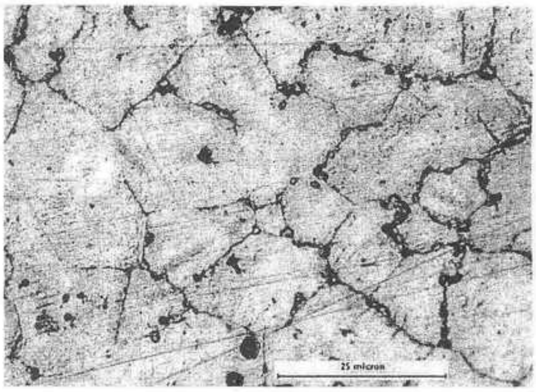

Fig.6 Sample temper 500°C for 45 minutes

Figure 5-6 show the microstructure of Hadfield's austenitic manganese steel after treatment 1050°C then subsequent reheating to 500°C at various holding times then quench in water.

Comparing reheated in temperature 450°C with temperature 500°C with the same interval time of 30 minutes, temperature increases, the possibility for diffusion in its grain boundaries is wisher. Comparing figure 2. to other figures, will giving interpretation of Ficks law became more obviously [16,17].

Rapid cooling make some of elements that precipitated in grain boundaries which could be carbide had dispersed back into the grain [9-11]. Diffusion of elements to grain boundaries may have caused a new phase formation as shown in Fig. 6.

3.1.5 Development of microstructure at tempering regimes of 550°C

Figure 7-8 show the microstructure of Hadfield's austenitic manganese steel after treatment 1050°C subsequent reheat in 550°C for a vary of time then quench in water. By increasing the tempering temperature, more precipitates were formed in the grain boundary the microstructure showing that more precipitate will form in grain boundary. In this case, it also follow both Ficks I and II laws although it is a rapid cooling process.

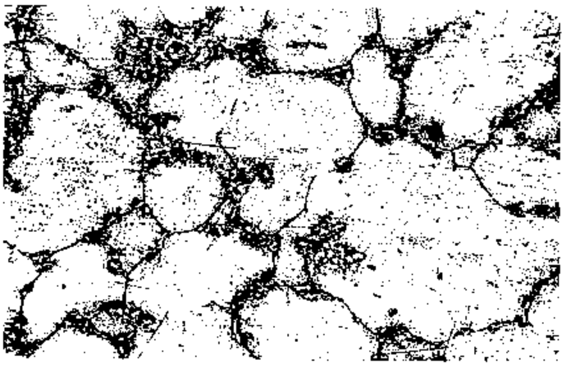

Fig.7 Sample temper 550°C for 15 minutes

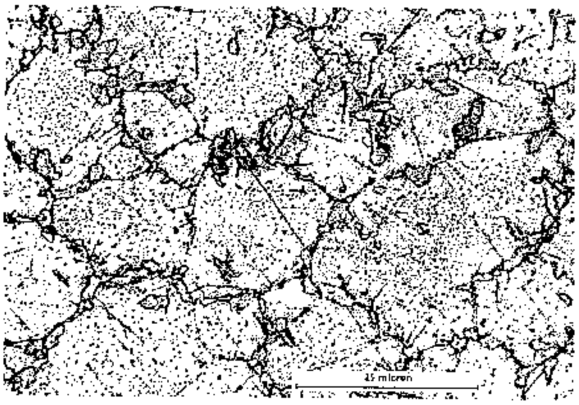

Fig.8 Sample temper 550°C for 30 minutes

On the other hand, at the same rate of cooling, the ability of dispersed precipitated in grain after cooling is subordinate depending to temperature treatment, and precipitation in grain boundary formed a new phase [16,17]. The tempering experiments demonstrate the kinetics of the decomposition of a new phase into a microstructure. This phenomenon predicted according the concept of diffusion and transformation [15-17]. A new phase is predicted as phase of ferrite in the phase diagrams of pure Fe-Mn phase diagrams.

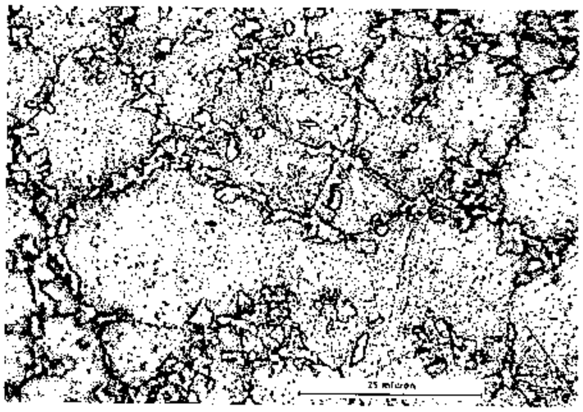

Fig.9 Sample temper 550°C for 45 minutes

Usually, a fully austenitic structure, essentially free of carbides and reasonably homogeneous with respect to carbon and manganese, is desired in the as-quenched condition, although this is not always attainable in heavy sections or in steels containing carbide-forming elements such as chromium, molybdenum, vanadium and titanium [11-13]. Microstructure in Figure 9 is more accurately showing these phenomena

3.1.6 Development of microstructure at tempering regimes of 600°C

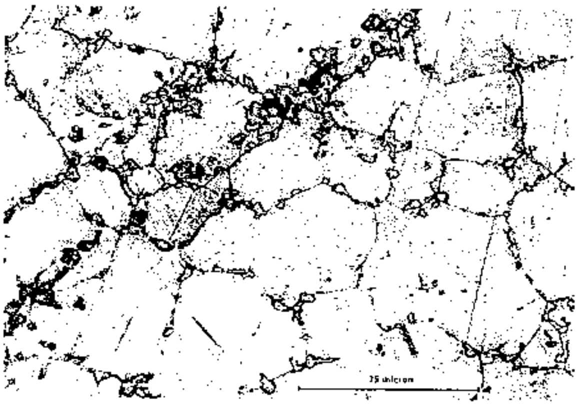

Fig.10 Sample temper 600°C for 10 minutes

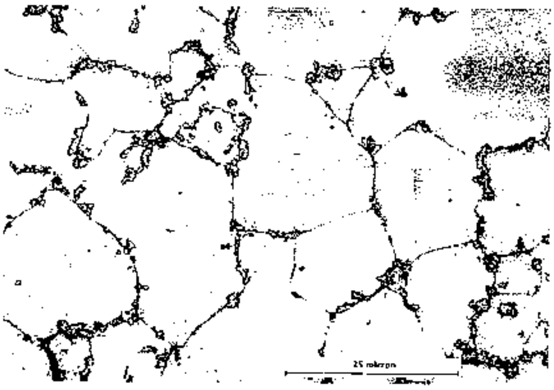

Fig.11 Sample temper 600°C for 20 minutes

Figure 10–11 show the microstructure of Hadfield's austenitic manganese steel after treatment 1050°C subsequent reheat in 600°C for a vary of time then quench in water. The microstructures in these figures described the phenomena of diffusion happening more obviously.

4. CONCLUSION

This paper presents the microstructural development of the austenitic manganese steel-3401 due to different heating regimes followed by rapid cooling process. The material is heated to 1050°C followed by a rapid cooling process which caused the solid solution of the carbides to be precipitated in the grain of the pure austenite phase. By tempering this austenite phase, a partial dispersion of austenite will occur. The time and temperature of tempering will affect the dispersion area in the austenite phase.

The tempering temperature is set between 400°C to 600°C with an interval of 50°C (figure 1 to 15) for various holding time. The microstructure examination of the samples show that the formation of austenite begins by precipitation of iron and manganese carbides at the grain boundaries, then progressively followed by the appearance of a new constituent which later extend into its grain. The kinetics process begins by diffusion process in its grain boundary.

Development in microstructure mapping resulting from such studies should also enriching phenomena in the subject of applied physical metallurgy.

The study helps to understand better about the kinetic aspects in phases and microstructure development for manganese steel alloys. Properties such as excellent toughness and good wear resistance are expected in produce in future. For the more the developed microstructure mapping presented will enrich the phenomena in applied physical metallurgy

Acknowledgements

One of the authors would like to express gratitude to Ir. Syarul Hadi from PT Growth Sumetera for kindly doing the chemical analysis of the Hadfield steel.

REFERENCES

[1] E.E. Frank, Evolution of the rail-bound manganese frog, Transport. Res. Rec. 1071 (1986) 43-44.

[2] P. Rama Rao, V.V. Kutumbarao, Developments in austenitic steels containing manganese, Int. Metall. Rev. 34 (2) (1989) 69.

[3] D.M. Rodionov, M.G. Lyubinov, Y.E. Mishutin, A. Stepanova, L.V. Smirnov, Segregation of impurities on the free surface of Hadfield Steel during heating, Phys. Met. Metall. 68 (5) (1989) 73-78.

[4] N.N. Stepanova, D.P. Rodionov, M.G. Lyubimov, S..V. Nesgovorov, V.K. Farafonov, L.B. Smirnov, Grain boundary embrittlement of Hadfield steel, Phys. Met. Metall. 68 (4) (1989) 179-183.

[5] R.W Smith, Development of high manganese steel for heavy duty cast-to-shape application, Journal of Materials Processing Technology 153-154 (2004) 589-595.

[6] Chojecki, I. Telejko, Effect of the chemical composition of Fe-Mn-C-P alloys on the brittle-ductile transition temperature in the solidification range, Steel Res. 63 (10) (1992) 447-452.

[7] E.H. Taylor, Internal Report Explosive Depth Hardening, C.P. Rail, 27 January 1987.

[8] E.H. Taylor Memorandum TRCHWORK (9-2-26(35-201-CIGGT)0M))496), 9, 1986.

[9] S.B. Sant, R.W. Smith, The mechanism of work hardening in austenitic Fe-Mn-C and Fe-Mn-C-V alloys, in: Proceedings of the Conference on Strength of Metals and Alloys, vol. 1, Pergamon Press, Montreal, Canada, 1985, pp. 219-224.

[10] S.B. Sant, R.W. Smith, A study of work-hardening behaviour of austenitic manganese steels, J. Mater. Sci. 22 (1987) 1808-1814.

[11] T.H. Middleham, some alloy additions to manganese steel, Alloys Met. Rev. 12 (112) (1964) 11.

[12] V.I. Grigorkin, G.V. Korotushenko, Effect of carbon, manganese plastic deformation and heat treatment on the structure and properties of austenitic manganese steel, Met. Sci. Heat Treatment Met. 2 (1968) 130-132.

[13] V.I. Grikorkin, I.V. Frantsenyuk, I.P. Galkin, A.A. Osetrov, A.T. Chemeris, M.F. Cheminilov, Increase in the wear resist of hammer mill hammers, Met. Sci. Heat Treatment Met. 16 (4) (1974) 52-354.

[14] G.I. Sil'man, N.I. Pristuplyuk, M.S. Frol'tsov, effect of vanadium on the structure and properties of high-manganese steel, Met. Sci. Heat Treatment Met. 22 (2) (1980) 124-127.

[15] Honeycomb, R.W.K, and Bhadeshia, H. K.D.H. 1982. Steels, Microstructure and Properties. Metal Park, Ohio : ASM International.

[16] Krauss, G. 1980. Steels: Principles of Heat Treating of Steels. Metals Park, Ohio: ASM International.

[17] Ashby, M.F., and Easterling, K.E. 1982. A first report on diagrams for grain growth in welds. Acta Metall.30:1969.

[18] J. Mendez, M.Ghoreshy, Weldability of austenitic manganese steel, Journal of Materials Processing Technology 153-154 (2004) 596-602.

[19] Micgalon D. Mazet.G and Burgio C. 1976. Manganese steel for abrasive environments. A conditioning steel process for Hadfield Manganese steel and a novel method of producing FAM bearings from the same material. Tribology International. Aug. 171-178.