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AUSTENITE FORMATION OF STEEL-3401 SUBJECTED TO RAPID COOLING PROCESS

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ABSTRACT

Hadfield's austenitic manganese steel is still commonly used for railroad components such as frogs and crossings and also for rock-handling materials. This material contains approximately 1.2% carbon and 12 to14% Mn. 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 1050ºC 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 400ºC to 550ºC at 50º 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

INTRODUCTION

The unique properties of Hadfield's manganese steel (1.2% carbon and 12-14% manganese) are high strength and high toughness, resistance to wear and heavy impact loading that make the steel very useful in variuos applications, such as railroads, grinding mill liners, crusher jaws and cones, impact hammer and even a bullet-proof helmets. It is usually used in the austenitic condition (Frank, 1986). Recently, many attempts have been made to improve the Hadfield base alloys properties by varying their compositions and heat treatments. Some of these were discussed by Rao and Kutumbarao (1989), particularly for alloy based on the Fe-Mn-C system and used for austenitic wear resistance steels, and those based on Fe-Mn-Cr used for austenitic corrosion-resistant steels (Smith et. al, 2004). A standard industrial practice to strengthen Hadfield steels is by solution annealing which is to heat-treat the material at 1000-1090ºC for up to 1 hour followed by a water quench (Taylor, 1986; Sant and Smith, 1985). This partial decomposition of austenite also depends on the time and temperature of the tempering condition. The coarse inter-granular precipitation can take place during various stages of the heat treatment and lead to brittleness in cast-to-shape components (Rao and Kutumbarao, 1989; Rodionov et al, 1989; Stepanova et al, 1989). The cast-to-shape components are mainly used in the rail transportation applications (Stepanova et al, 1989). Morphological mapping of phenomena, particularly development of microstructure with heat-treatment is a well-known tool in metallurgical engineering (Karaman et. al, 2001).In this study, the heat-treatment behavior of Hadfield's austenitic manganese steel-3401 in rapid cooling process is investigated using microstructural mapping. The study focuses on the effect of iso-thermal process on the formation and decomposition of new steel phases investigated at various tempering temperatures and holding times. The study on the effect of the selected temperatures to the austenite phase transformation on steel-3401 has never been carried out by previous researchers.

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. Samples were heat-treated at 1050ºC for 1 hour in a PID electric furnace (Vectar VHT-3), then quenched in water to homogenise the sample as at austenite phase. At beginning, all samples were homogenized at temperature of 1050ºC for 1 hour before quenched in water. As a second treatment, samples were tempered at different temperatures. The tempering temperatures were set between 400ºC to 550ºC at 50ºC interval. These temperatures were selected based on the phase diagrams of pure Fe-Mn. Table 2 shows the heating regimes for the samples.

Table 2: Heating regimes of the samples in water quenching

No.	Homogenising Temperature	Holding time (minutes)	Tempering Temperature	Holding time (minutes)
1.	1050ºC	60	-	-
2.	1050ºC	60	450ºC	30, 60
3.	1050ºC	60	500ºC	45
4.	1050ºC	60	550ºC	30, 45

After heating at various holding times, the sample was quenched again in water. Later it 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 of 1μm to obtain a mirror like surface, then 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, and C. The microstructure was characterized using an optical image analyser microscope (Leica DMLM with RGB Video TV camera JVC model TK1270E) at magnification of 200 times.

MICROSTRUCTURAL DEVELOPMENT

The microstructure of Hadfield's austenitic manganese steel when heat-treated to 1050ºC then followed by rapid cooling process is shown in Figure 1. It shows austenite grains of Hadfield's steel with twins as similarly found by previous researchers (Sant and Smith, 1985 and 1987; Inoue et. al, 1998; Mendez et. al, 2004). The microstructure of Hadfield's austenitic manganese steel after heat-treated to 1050ºC followed by reheating to 450ºC and quenching in water for 30 and 60 minutes are shown in Figures 2 and 3 respectively. These figures show that the process of diffusion is also affected by temperature changes as explained in Ficks 1 law, that is the diffusion process is strongly influenced by temperature. Diffusion takes place due to a difference in concentration of elements which produces the driving force that required for the diffusion process (Ashby and Easterling, 1982).

Figure 4 shows the microstructure of Hadfield's austenitic manganese steel after heat-treated to 1050ºC and subsequently reheated to 500ºC then followed by quenching in water. By comparing Figure 4 with Figures 2 and 3, the Fick's law was obviously observed, i.e. the carbides precipitation at grain boundaries is more pronounced at 500ºC.

The microstructure of Hadfield's austenitic manganese steel after heat-treated to 1050ºC and subsequent reheat in 550ºC followed by quenching in water are shown in Figures 5 and 6. It shows that by increasing the tempering temperature, more precipitates were formed at the grain boundaries especially in Figure 6. However, fine precipitates are also seen in Figure 6. Here, it is believed that large carbides precipitation at grain boundaries had reached the saturation limit, hence rapid cooling had caused some of the elements to be re-precipitated into the grains. Various authors had also observed that rapid cooling may caused some elements that precipitated in grain boundaries, which could be carbide, to be dispersed back into the grains (Middleham, 1964; Sant and Smith, 1985 and 1987; Bhadeshia, 1985).

Figure 1: Austenite grains of Hadfield's steel with twins

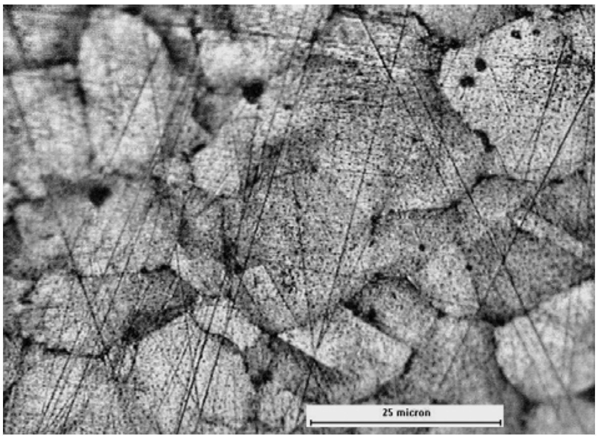

Figure 2: Tempering the sample at 450ºC for 30 minutes

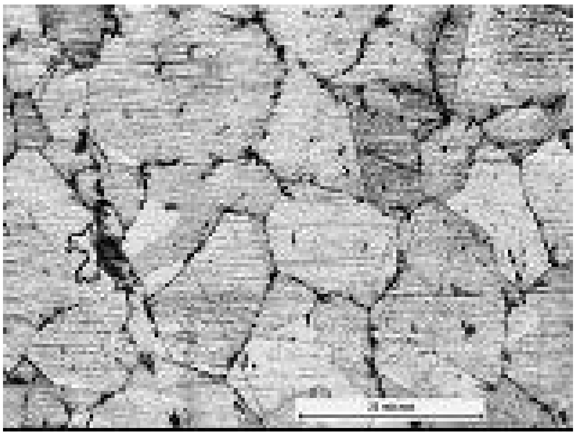

Figure 3: Tempering the sample at 450ºC for 60 minutes

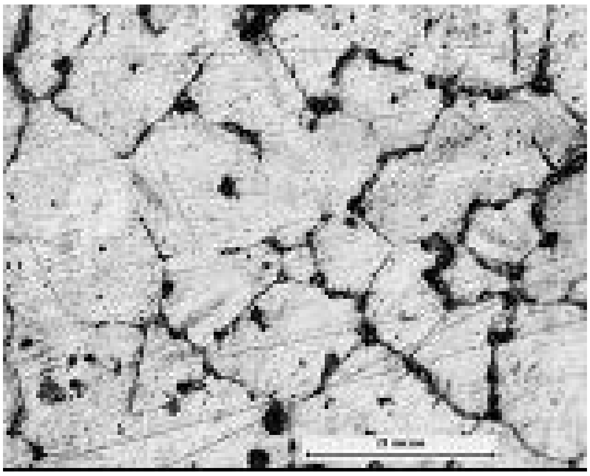

Figure 4: Sample tempered at 500ºC for 45 minutes

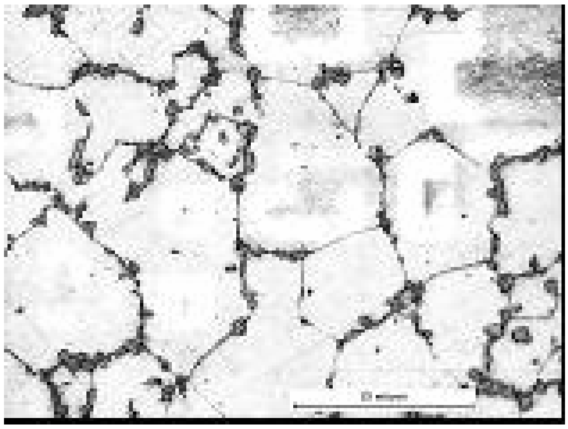

Figure 5: Sample tempered at 550ºC for 30 minutes

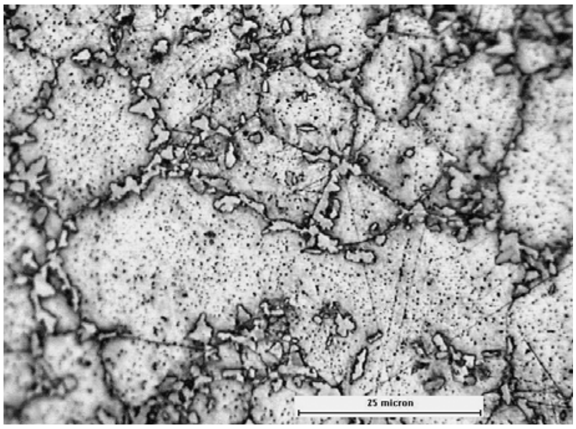

Figure 6: Sample tempered at 550ºC for 45 minutes

Generally, the ability of these precipitates to be dispersed into the grains after rapid cooling is weak but this depends on the treatment temperature. It was also stated that precipitation at grain boundaries caused new phase formation (Krauss, 1980; Ashby and Easterling, 1982). The tempering experiments demonstrated the kinetics of the decomposition of a new phase in the microstructure (Miyamoto et. al, 2003; Smith et. al, 2004). This phenomenon was expected and it follows the concept of diffusion and transformation (Honeycombe and Bhadeshia, 1982; Krauss, 1980; Ashby and Easterling, 1982). 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 (Middleham, 1964; Grigorkin and Korotushenko, 1968; Grigorkin et al, 1974).

CONCLUSIONS

This paper presents the microstructural development of the austenitic manganese steel-3401 due to different heating regimes followed by rapid cooling process. The heat-treated material of 1050ºC followed by rapid cooling process 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 occurs. The tempering time and temperature affect the dispersion area in the austenite phase. The microstructure examination of the samples showed 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 of this process begins by diffusion at the grain boundaries. The result from this microstructural mapping study provides some useful data in the subject of applied physical metallurgy and to better understand the kinetics of these microstructural changes for manganese steel alloys. Properties such as excellent toughness and good wear resistance are expected from this steel grade.

REFERENCES

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

Bhadeshia H. K. D. H.., Diffusional formation of ferrite in iron and its alloys, Materials Science Vol. 29, pp. 321 to 386, 1985

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

Grigorkin V.I., Korotushenko G.V., 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.

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

Honeycombe, R.W.K, and Bhadeshia, H. K.D.H. 1982. Steels, Microstructure and Properties. Metal Park, Ohio : ASM International.

Inoue K., Mukherjee K., Otsuka K., Chen H., Displacive Phase transformations and their Applications in Materials Engineering,The Minerals, Metals and Materials Society, Warrendale, Pennsylvania, U.S.A., (1998), pp. 69–78

Karaman I., Sehitoglu H., Chumlyakov Y.I., Maier H.J. and Kireeva I.V., Extrinsitic stacking faults and twinning in Hadfield manganese steel single crystal , Scripta mater. 44 (2001) 337–343

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

Mendez J., Ghoreshy M., Mackay W.B.F., Smith T.J.N., Smith R.W., Weldability of austenitic manganese steel, Journal of Materials Processing Technology 153–154 (2004) 596–602

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

Miyamoto G.., Shinyoshi T.., Yamaguchi J.., Furuhara T.., Maki T.., Uemori R., Crystallography of intragranular ferrite formed on (MnS + V(C,N)) complex precipitate in austenite., Scripta Materialia 48 (2003) 371–377

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

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

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

Sant S.B., Smith R.W., 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.

Smith R.W.., DeMonte A.., Mackay W.B.F., Development of high-manganese steels for heavy duty cast-to-shape applications, Journal of Materials Processing Technology 153–154 (2004) 589–595

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

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