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Effect of the Heat Treatment on Mechanical Properties of Fe– Mn–C High Manganese Steel

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Abstract- The influence of the heat treatment on mechanical properties and microstructures of the Fe-22Mn-0.6C high manganese steel were investigated at different temperatures. This composition was fabricated by melting and homogenized at 1200^{o}C. After heat treatment it was hot- rolled and cold rolled respectively to 3 mm thickness. The specimens were annealed at 700, 800 and 900 °C for 150 minute and then air-cooled. Field emission scanning electron microscope (FESEM), tensile tests were used to analyze the relationship between mechanical properties and microstructure after annealing process. The results show that, the excellent mechanical properties were obtained after heat treatment process. The tensile strength of material was decreased and the ductility of material was improved with increasing annealing temperature.

Keywords: High Manganese, Heat treatment, SEM, Cold rolling, Microstructure.

1. Introduction

The rise in the oil prices plays a major role in the automotive industry. In the next few years, fuel consumption and new anti-pollution standards will be most important subject for automotive industry. For this reason, the weight reduction is demanded for automotive industries. Structural components and body parts are subjected to demands for decreased weight. For this reason, high manganese steels have attracted much interest thanks to their extraordinary ductility and high strength properties for an application to automotive industry (Joeng et al., 2011). From this point, automotive industries focus on to reduce weight of vehicles by using advanced high strength steels (AHSS) such as high manganese. (Chung et al., 2011)

High manganese steels have a high manganese content that causes the steel to be fully austenitic structure. This austenitic structure is obtained by cold rolling and annealing. During plastic deformation by hot and cod rolled, high manganese steel contains mechanical twins. Twins are formed inside austenite grains by deformation and these twins play an important role in mechanical properties such as high strength and elongation. (Shen et al., 2013) The deformation mechanism of FCC materials is related on stacking fault energy (SFE). Mechanical twinning occurs at stacking fault energies roughly 18<SFE<24 mJ/m^2, the transformation of austenite to martensite happens in 12<SFE<18 mJ/m^2 . Chemical composition, temperature and grain size effect to the SFE. (Rezavi, Monajati, 2012) Apart from twins, carbide precipitations and grain size also affects the mechanical properties of high manganese steel. In high Mn steel carbide forms are such as M_3C ($(Fe,Mn)_3$ C) in the high temperature. Kang S. et al. include that in their study, the reversion of the tensile strength occurred between 700 and 800 ^{o}C because of the carbide precipitation hardening. However they also reported that, the coarsening rate of grains was increased over about 800 ^{o}C. That's why hardness value was greatly decreased after this annealing temperature. According to some reports, the high incidence of carbide precipitation was seen in the high Mn and medium C alloys such as Fe–22Mn–0.6C high manganese steel(Kang et al., 2010). Therefore, mechanical properties of high manganese steels not only depend on twins, but also depend on grain size and carbide precipitations.

In this direction, the aim of this work is to examine the effect of heat treatment on mechanical properties of high manganese steel. For this propose the effects of annealing temperature and annealing time on the mechanical properties and microstructural evolutions of Fe–24Mn–0,6C high manganese steel were investigated.

2. Experimental Study

High manganese steel was prepared by vacuum induction melting. The chemical composition of this steel is 22% Mn, 0.582% C, 0.03% P, <0.005% S and balance Fe (in wt%). It was melted by induction melting in a vacuum furnace and casted to bars. These bars were homogenized at 1200°C and cold rolled to 3 mm thickness. The heat treatment was carried out at 700, 800 and 900 ^{o}C for 150 minute and they were followed by air-cooling.

After annealing the specimens was grounded and polished for field emission scanning electron microscope (FESEM) Carl Zeiss Ultra Plus machine. The fracture zone of specimens also was observed using a field emission scanning electron microscope (FESEM) Carl Zeiss Ultra Plus machine with an energy-dispersive X-Ray spectroscopy (EDX) analysis system. In order to examine the mechanical properties of specimens, the tensile shear load tests were performed by MTS test machine.

3. Results and Discussion

3.1 SEM, EDX Analysis

Fig. 1 show the microstructure of specimens, which are annealed at 700, 800 and 900^{o}C for 150 minute. The microstructure of specimens annealed at 800◦C and 900^{o}C are fully austenite (Fig. 1a and 1b) and some grains are including annealing twins. The microstructure of specimen annealed at 700^{o}C is including carbide precipitations (Fig. 1c) EDX results of this specimen also show that the carbide precipitations have the higher carbon content than the matrix. Although the percentage of Al is %0,02 in the matrix, EDX result show that, the amount of Mn and Cr was increased from %22 to %38 and % 0,09 to %1,83 respectively in the precipitations (fig. 4). This is evidence of Mn_3C and Cr_3C precipitations.

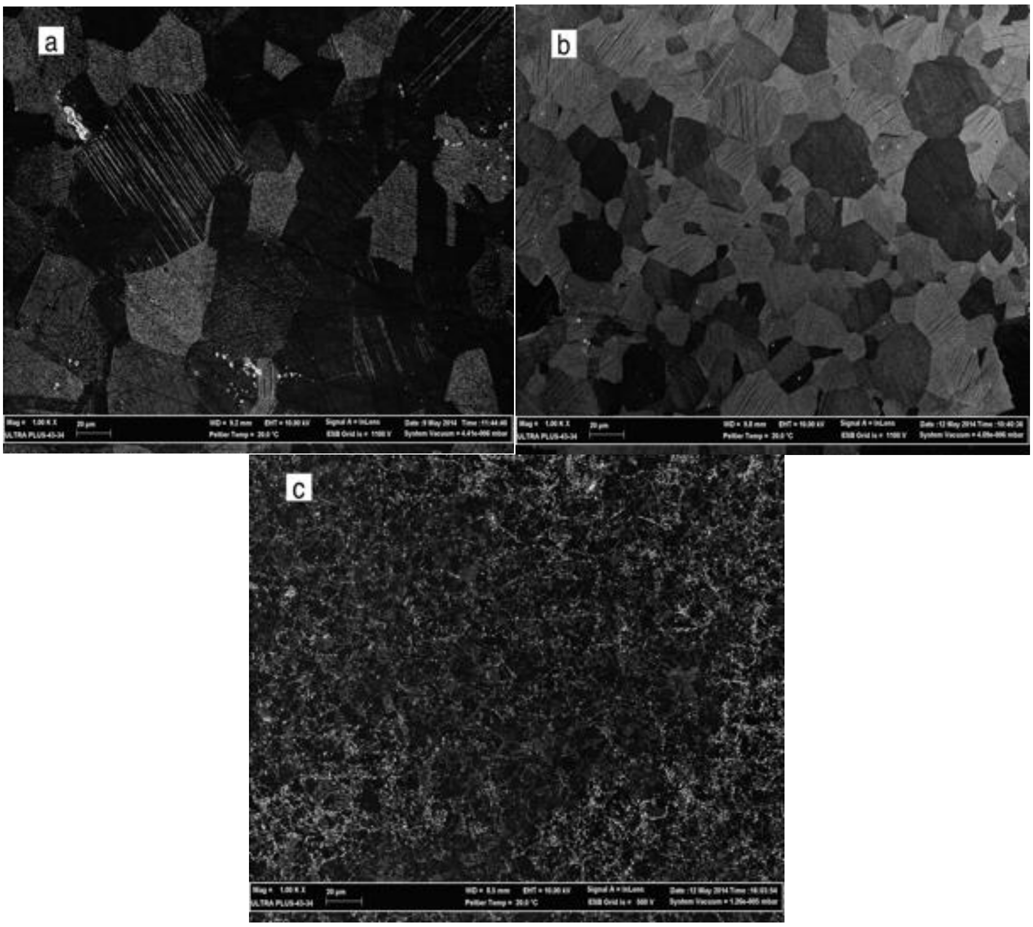
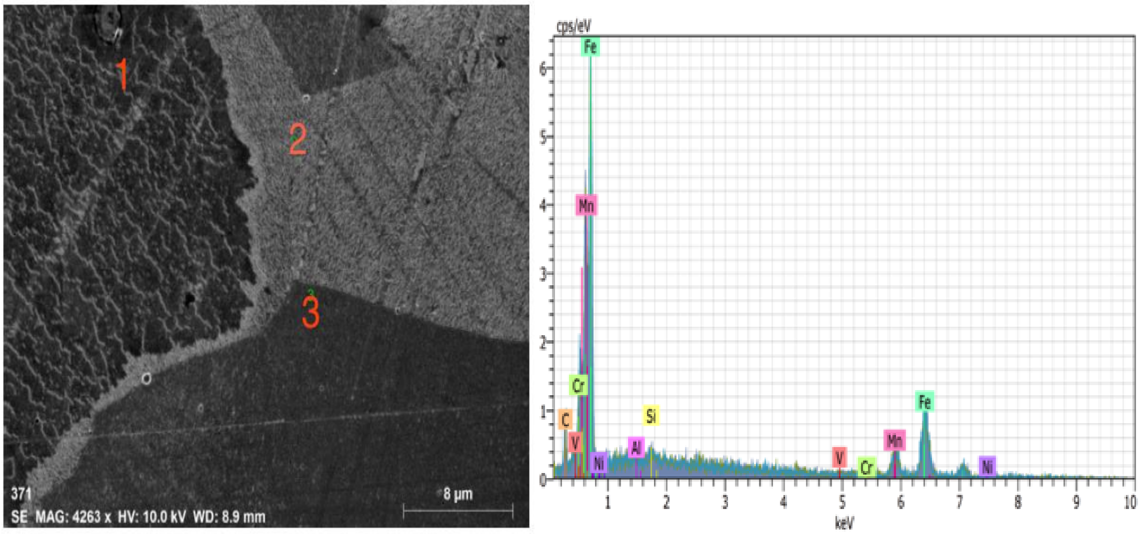


Fig. 1. SEM micrographs of the specimens annealed at (b) 900◦C, (c) 800◦C, (d) 700◦C for 150 minute in %50 cold-rolled Fe–24Mn–0.6C high manganese steel.

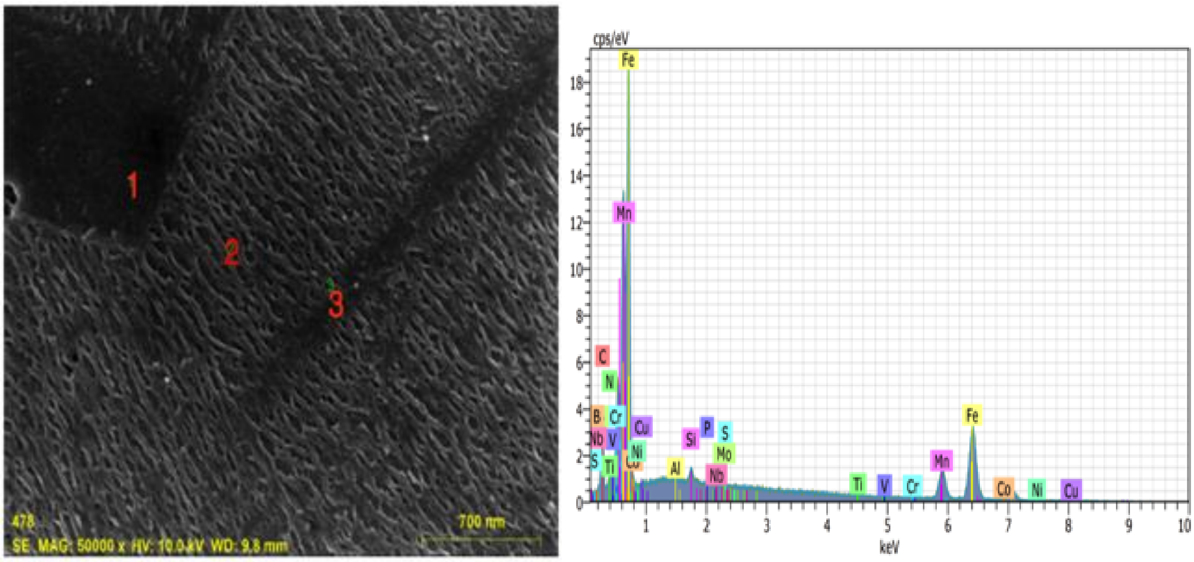
Fig. 2., Fig. 3. and Fig. 4. Show the EDX analysis of specimens. The multi point spectrum has taken on perlite region for fig. 2 and fig. 3. That’s why the carbon rate of these points higher than carbon

rate of matrix. The EDX analysis of carbide precipitation can be seen in Fig. 4. It can be seen in Fig. 4. The carbon rate is very high. It is result of carbide precipitations. There are few reports about the carbide precipitation. Especially in high Mn and medium C the carbide precipitations observed. Kang et. Al. concluded that, these precipitations affect the mechanical properties of material. Because, M_3C carbides lead to additional strain hardening in the tensile specimens. [15] It can be seen that from fig. 4. The Cr rate has increased dramatically. The amount of Mn and Cr was increased from %22 to %38 and % 0,09 to %1,83 respectively in the precipitations (Spectrum 1).



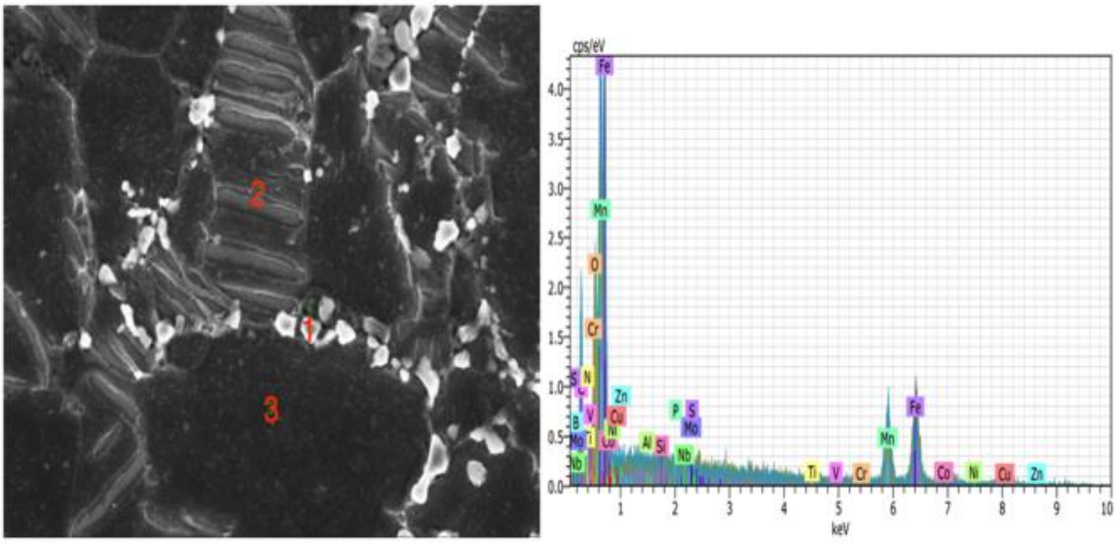
Spectrum	C	Al	Si	Cr	Mn	Fe
1	4.01	0.05	0.31	0.14	16.78	Balanced
2	2.99	0.02	0.30	0.15	18.31	Balanced
3	3.41	0.05	0.61	0.10	19.16	Balanced

Fig. 2. EDX result of specimen annealed at 900°C.



Spectrum	C	Al	Si	Cr	Mn	Fe
1	4.5	0.05	0.52	0.1	18.12	Balanced
2	4.6	0.07	0.09	0.08	17.92	Balanced
3	4.5	0.07	0.02	0.02	18.04	Balanced

Fig. 3. EDX result of specimen annealed at 800°C.



Spectrum	C	Al	Si	Cr	Mn	Fe
1	10.42	0.09	0.25	1.83	38.09	Balanced
2	1.90	0.00	0.36	0.18	23	Balanced
3	4.17	0.00	0.46	0.45	20	Balanced

Fig. 4. EDX result of specimen annealed at 700°C.

3.2 Tensile Behavior

Tensile specimens were tested at room temperature at a crosshead speed of 2 mm/min by a MTS (100kN Servohydraulic) test machine. The tensile strength of specimens are listed in Table 1. The tensile strength results are average of three samples for each annealed group. It can be seen that, the tensile strength of the annealed specimen at 700◦C is higher than that of the annealed specimen at 800◦C and 900°C. But the elongation of annealed specimen at 700◦C is lower than annealed specimens at 800◦C and 900◦C. The tensile strength of specimens reduced and the elongation increased with increasing annealing temperature. The SEM images of specimen annealed at 700°C are including carbide precipitations (Fig 1c.) The tensile strength of annealed specimen at 700°C is increased because of these precipitations.

Table 1. Tensile strength of test specimens annealed at 700°C, 800◦C and 900◦C.

Annealed Temperature (°C)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	%Elongation
0	1191	1597	2
700	534,6	946	25
800	395	838	58
900	255	695,8	61

The SEM image of fracture zone of specimens annealed at 800◦C and 900◦C exhibit ductile fracture but the ductile fractures were decreased at 700°C and brittle fracture areas can be seen at 700°C (Fig. 5)

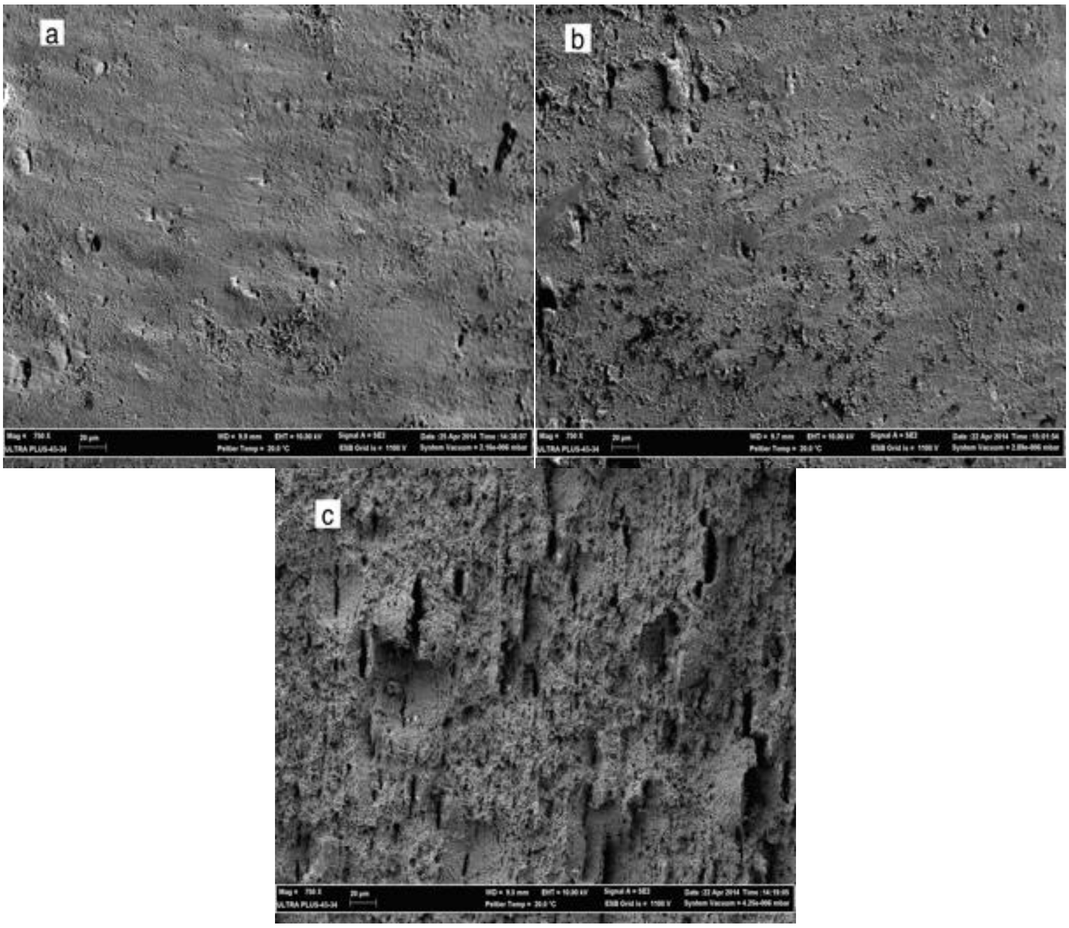


Fig. 5. SEM micrographs of fracture surface of specimens annealed at (a) 900◦C, (b) 800◦C, (c) 700◦C for 150 minute in %50 cold-rolled Fe–24Mn–0.6C high manganese steel.

4. Conclusion

The tensile and yield strength reduced and the elongation increased with increasing annealing temperature.

High density of the mechanical twins was observed at 800^{o}C and 900^{o}C. Instead of twins carbide precipitations was observed at 700^{o}C.

The hardness reduced with increasing annealing temperature. Carbide precipitations and annealing temperature affected to mechanical properties.

Grain size and twins destiny increased with increasing annealing temperature. The fracture zone of specimens annealed at 800^{o}C and 900^{o}C show very high ductile fracture.

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