Influence of Aging Process On Microstructures and Properties of High Manganese Steel Mn15Cr2V

Pham Mai Khanh, Le Thi Chieu

***Abstract*—The improvement of microstructures and properties of High Manganese Steel with 2%Cr and 1%V by heat treatment process with aging process was presented in this paper. Heat treatment for the Mn15Cr2V1 steel with the follow process: the sample is heated to 650^{0}C soaked in 02 hours at this temperature, cooling in air to room temperature; follow by austenizing at 1100^{0}C in 02 hours, cooling in water.**

The results showed: Uniform austenite, small size grain (level 6 according to ASTM). No any carbides grain boundary. The hardness value is 223HB (compare to 156HV of process without intermediate at 650^{0}C) and impact toughness average 115J/cm^2 (compare to 65J/cm^2 of process: heating sample up to 1100^{0}C, soaked in this temperature in 02h and quenching in water, then step 2: sample was reheated to 650^{0}C, soaked at this temperature in 02h then cooled in air to room temperature).

***Index Terms*—High Manganese Steel (HMnS), heat treatment, carbides, microstructures, mechanical properties, SEM**

I. INTRODUCTION

The High Manganese Steel (HMnS) appeared long time ago with the name “Hadfield steel”. It was patented by Sir Robert Hadfield in 1882. This steel is used in industrial applications such as impact hammers, crusher jaws, grinding mill liners, crawler treads for tractors, and railroad crossings [1]To meet requirement of work, the microstructure of HMnS is required to achieve uniform austenite and no carbides exist at grain boundary. Such microstructure received by austenizing casted parts made of HMnS at high temperature, followed by quenching in water.

But not always achieve that microstructure, especially in large parts or in the steel that contains some elements like chromium carbide, molybdenum, vanadium, and titanium [2]If after austenizing in microstructure, the residual carbides existing as the plaque carbides are distributed at the grain boundaries, they will cause brittle, destroying the details as big harm. On the contrary, if the small particles are distributed inside the austenite grain, they will increase the wear resistance of steel

[3, 4]Many different heat treatment is specified or recommended. One of them is worth reference. It is the treatment that consists of heating the castings to about 595°C (1100°F) and soaking them from 8 to 12 hours at that temperature, which cause substantial amounts of pearlite to form in the structure. The castings are then further heated up to about 980°C (1800°F) in order to reaustenitize the structure [1]By using a step-aging process after the austenization, an alloy that contains 0.8 %C-13 %Mn-1 %V, Atasoy, Ozbaysal and Inal [5] obtained carbides which homogeneously distributed through the austenitic matrix. The step-aging consisted of heating sample to 650°C for 1 hour followed by 950°C for 6 hours. The first step worked as a pre-aging forming precipitates above the critical size required for nucleation at the second stage. According to the article, the precipitated carbides were identified as V_4C_3 with a NaCl unit cell that exhibited a cube-cube orientation relationship with the austenite.

Imai and Namekata [5] showed age-hardening in a 0.44 %C-17%Mn-12%Cr-2%Ni-2.37%V austenitic steel. After a solution treatment at 1200°C for 1 hour, samples were aged at 500°C, 600°C, 700°C, 800°C and 900°C for times up to 150 hours. For increasing aging temperature, the hardness peak showed up at shorter aging times. The highest hardness of 450 HV was reached after 150 hours at 600°C and after 5 hours at 700°C. The precipitations were confirmed to be V4C3, that precipitate in the relationship with the matrix definite in the orientation parallel to {110} plane in the <111> orientation. The increase of hardness was related to coherency strains associated with these particles up to 160Å. When particles grew above this size, the coherency strain was relaxed and the hardness was decreased.

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II. EXPERIMENT PROCEDURE

Ele m-en t	C	Mn	Cr	V	Si	P	S
%	1.36	14.7	1.82	1.02	0.81	0.08	0.02

Table 1. Chemical composition of sample

After casting, the samples were removed from the mold at the temperature of 650°C, the samples were analyzed microstructure and hardness.

And the samples were heat-treated with 2 procedures:

Procedure 1 (PR1): Modified heat treatment includes 2 steps: Step 1: heating sample up to 650°C, soaked at this temperature in 2 hours then cooled in air to room temperature, then Step 2: sample was reheated to 1100°C, soaked at this temperature in 3 hours and quenching in water.

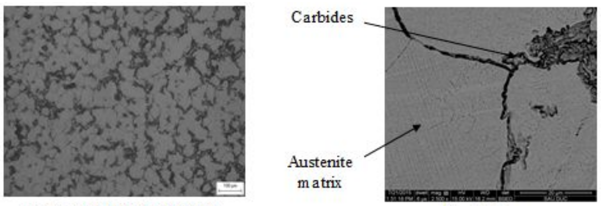
Procedure 2 (PR2): Modified heat treatment includes 2 steps: Step 1: heating sample up to 1100°C, soaked at this temperature in 3 hours and quenching in water, then Step 2: sample was reheated to 650°C, soaked at this temperature in 2 hours then cooled in air to room temperature.

After heat treatment, the samples were analyzed microstructure, determined the percentage of carbide on Axiovert 25A then had hardness and impact toughness test.
The impact of samples is in accordance with ASTM form Chapy E23.
The samples were also analyzed by SEM, BSED and EDX.

III. RESULTS AND DISCUSSION

3.1. Microstructure

- Microstructure of casting sample



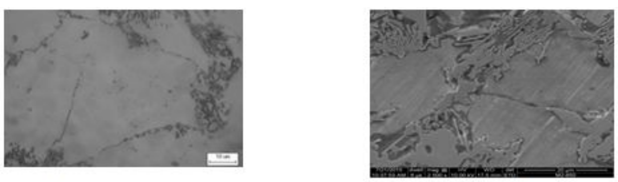
a) Microstructure of optical b) BSED

Fig 1. Sample after casting

The microstructure photograph of sample after casting shows the austenite matrix (casting austenite) and a lot of carbides located in grain boundaries (casting carbide) (fig 1). This is due to slow cooling during casting in the mold, carbides were precipitated at grain boundaries.

- Microstructure of sample by heat treatment process with intermediated heating (PR1)

The heat treatment 1 (PR1) is performed as follows: Heating sample up to 650°C, soaked at this temperature in 2 hours then cooled in air to room temperature. Sample then was reheated to 1100°C, soaked at this temperature in 3 hours and quenching in water.



a) Microstructure of optical b) SEM

Fig 2. Microstructure of sample at 650°C

After step 1: Heating at 650°C, the samples were studied microstructure in optical microscope, SEM and the distribution of elements by EDX line. The figure 4 shows the microstructure of sample after step 1. We can see that besides the carbides located in grain boundaries (casting carbide), the very fine particles of carbide within austenite grains appeared.

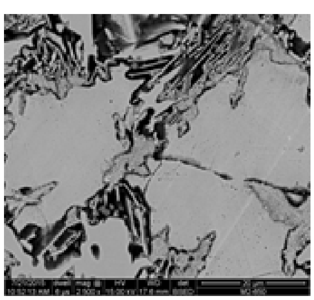


Fig 3.Results BSED of sample according to 650°C

The microstructure of sample holding at 650°C for 2 hours noticed the dispersion of little black uniform particles inside the grain .

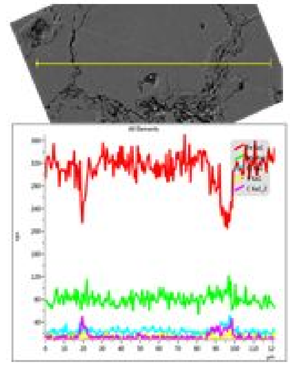


Fig 4.Results EDX lines of sample according to 650°C

On the EDX Line, the elemental distribution of the sample holding at 650°C for 2 hours, with 2mm (about 40 grains) (fig 4) showed some unusual positions, in which the iron content decreases, the concentration of the elements: carbon, chromium, vanadium increases. It allows to deducting that at this temperature, chromium carbides, vanadium carbides or carbides in complex types were precipitated.

Figures 5, 6 and 7 show the microstructure of sample which heat treatment by PR1:
After heating up to 650°C, the casting sample then was reheated to 1100°C, soaked at this temperature in 3 hours and then quenching in water.

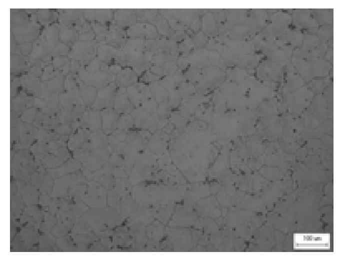
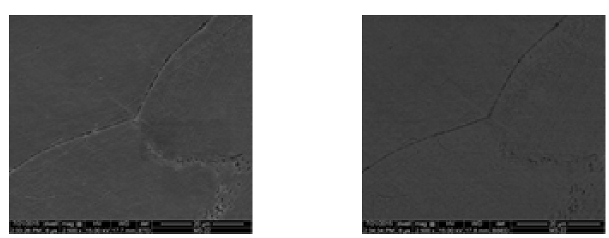


Fig 5. Microstructure of sample obtained by performing PR2

Although keeping in high temperature, austenite grain size is smaller than after casting. The average particle size is: 1,950 μm^2 (level 6 according to ASTM). It may explained that due to carbide precipitated inside austenite grain when soaking sample at 650°C not dissolve at 1100°C, they are less active than the carbides at grain boundaries and also inhibits the growth of austenitic grain material soaked at 1100°C. That effects enhance the mechanical properties of steel.



a) SEM b) BSED

Fig 6.Results of sample according to PR1

The SEM, BSED photograph show: no any carbides in grain boundaries of austenite.

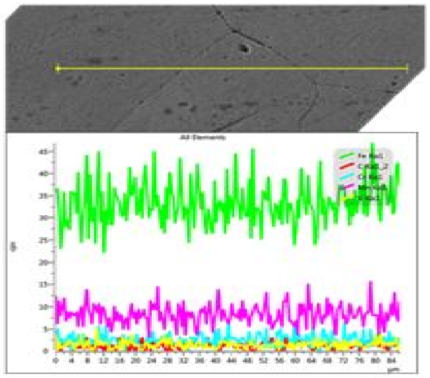
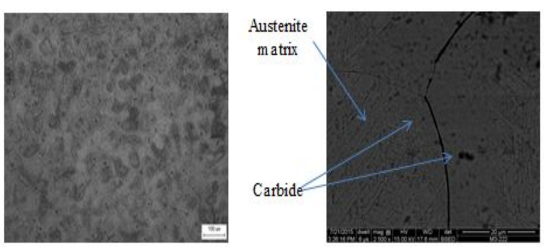


Fig 7.EDX lines of sample according to PR1

It can be seen that the carbide which precipitated in grain boundaries of austenite during heating at 650°C almost disappeared, it dissolved in austenite when the samples were reheated to 1100°C, soaked at this temperature in 3 hours subsequently (fig 7).

- *Microstructure of sample by heat treatment process PR2*



a) Microstructure of optical b) BSED

Fig 8.Microstructure of sample obtained by performing PR2

The microstructure obtained by heat treatment PR2 is almost not much different compared to the microstructure of sample after casting. In this microstructure, the grain size level of austenite matrix is level 5 according to ASTM (fig 8a).

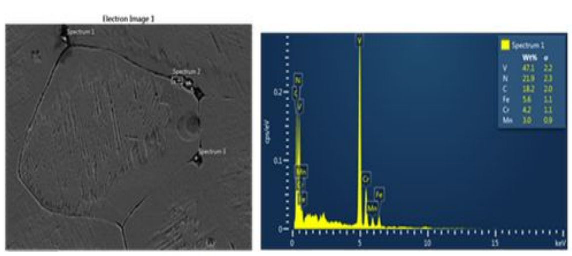


Fig 9.Results of sample according to PR2

The PR2 shows that the temperature of austenite is enough to dissolve completely carbides at the grain boundaries of austenite. Thus can be seen that the end of process (aging at 650°C) has not held uniform austenite microstructure. The carbides formed in the grain boundaries will cause stress concentration during deformation and cracks formed (fig 9). The mechanical properties as well as reduced may cause the destruction of steel.

3.2. Results of hardness testing

Table 2. Hardness of samples studies

Sample	HB
Sample 1 (As-cast)	175
Sample 2 (Sample according PR1)	223
Sample 3 (Sample according PR2)	154

The hardness results found: Sample 2 has the highest hardness value. The increase of hardness value is due to the appearance and dispersion of carbides in the matrix. It also coincided with the microstructure analyze. The small carbide particles dispersed in the matrix with very high hardness will increase resistance to abrasion for steels.

3.3. Results of impact toughness

Table 3. Impact toughness of samples studies

Samples	Impact toughness (J/cm^2)
Sample 1 (sample according PR1)	115
Sample 2 (sample according PR2)	65

The impact toughness results show: The valuable impact toughness of sample 1 is higher than the sample 2. This can be explained as follows: As heat treatment as PR1, the grain size of austenite matrix is smaller than PR2 because there is no carbides at grain boundary, the risk of destroying greatly reduced. Moreover, the small grain size of austenite has different orientations. Under the effect of force, the number of grain can participated deformation process so much more. Samples can withstand the greater force deformation before failure and therefore sample has higher toughness.

CONCLUSION

With the heat treatment for the Mn15Cr2V1 steel with the follow procedure 1 (Heating sample to 650°C, soaked in 2 hours at this temperature, cooling in air to room temperature; follow by austenizing at 1100°C in 2 hours, cooling in water), the results showed: Uniform austenite, small grain size (level 6 according to ASTM) and no any carbides at grain boundary. The hardness value is 223HB (compare to 156HV of process without intermediate at 650°C) and impact toughness average is 115J/cm^2 (compare to 65J/cm^2 of procedure 2: Heating sample up to 1100°C, soaked at this temperature in 2 hours and quenching in water, next sample was reheated to 650°C, soaked at this temperature in 2 hours then cooled in air to room temperature).

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