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Optimization of Heat Treatment to Obtain Desired Mechanical Properties of High Carbon Hadfield Steels

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Abstract: Manganese Steels have extensively application in industries due to good resistance to wear, high work hardening capability with high toughness and ductility. Carbon increasing in manganese Steels leads to produce grain boundaries carbides, that cannot be eliminate by long heat treatment. Thus the mechanical properties decrease. This paper purpose the optimum heat treatment cycle to minimize the grain boundaries carbides by changing in quenching solution.

Key world: Hadfield steel · Quenching rate · Mechanical properties · Carbide volume

INTRODUCTION

It is referring to 1883 the Invention and Producing of Manganese Steel (so called Hadfield Steels) which registered as no. 200 in the name of Sir. Robert hadfield (Sheffield, UK) [1,2]. Manganese steels have reputed in Steel industries due to their particular characters i.e. resistance to wearing associating with high impact strength, good ductility and also particular austenitic structure enhancing after heat treatment[3]. It mainly contains 1.2% carbon, 12-14 % Manganese. Austenitic microstructure of steels, is non magnetic and its toughness and ductility due to FCC matrix exhibit more advantageous comparing to Ferritic phase (with BCC matrix). Within these steels, Manganese is playing main role as ground austenitic phase stabilizer to room temperature [1-9].

There are two significance stages during producing desirable parts from Hadfield steel as: first melting and developing of appropriate composition, secondary proper heat treatment on casting parts. Microscopic structure of non heat treated cast part is included of Austenite in matrix, Carbide phase and a small set of Pearlite. Carbides generally develop on grain boundaries and between dendrites. To obtain desired toughness, microstructure of hadfield steels would be thoroughly austenitic [2].

These kinds of steels are strictly sensitive to section thickness. Austenitic mono phase obtain from heat treatment of austenitising and rapid quenching. Nevertheless at the thicker sections due to relatively low heat conductivity, the carbides precipitate as transgranular and grain boundaries and consequently may result to mechanical properties reduction [3].

Heat treatment probably results in developing toughness in alloy, therefore solution temperature would be too high so that carbide solve into austenite. In practice, the final structure will not be formed as austenite and some of carbides will be remained within grain boundaries, specially in thicker section [2,10]. Forming these carbides between austenite grain boundaries will minimize impact strength of said steel [11].

Traditional heat treatment includes austenitising and water quenching. Solution temperature range of heat treatment defined as 1010 to 1120?. Heating would be performed slowly to prevent inside cracking or cracking propagation. On the other hand quenching should be quick enough to minimize the carbides. To obtain a fully austenite microstructure after heat treatment there should not be allowed any transformation to austenite [1]. Since, carbon solubility at the high temperature (more than 1000?) in austenite (with Mn=11%) enhance to 1.4%, the austenitising process is carried out at high temperature [3].

One of the main ideas driving this work was to study the effect of cooling rate on carbide volume. The cooling rate should be high enough to minimize the carbide volume, so that the NaCl content in quenching solution was varied to changing the cooling rate.

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METHODS AND MATERIALS

According to fig. 2-1 Cylindrical models are created through Sodium Silicate / CO2 and silica sand procedure as closed feeding. To prevent burning on and obtain a qualified surface, proper coating material called Moldcoat 31 was used.

Arc furnace was used to melt the steel. Through steel melting continuously lime stone was charged in furnace to form slag, increasing efficiency and decrease heating lost. Table 1-1 illustrates chemical composition of final sample which analyzed by Spectrolab model quantometer

Slagging has been performed while melting temperature has been reached to 1500±10? and poured to preheated ladle which has aluminum layer at the bottom inside, then casting through transferring melted steel to mold has performed. Manganese samples heat treatment has been performed within electrical furnace (50 x 50 x 50 cm). Heat treatment cycle is showed in figure 2-2.

3 different quenching bath was utilized for quenching operation.1- Pure water, 2-solution with 1.5% NaCl and 3-solution with 3% NaCl. Metallographic examination has been done in according to with the ASTM E3-01 (metallographic samples preparation), ASTM E407-99 (metal micro etch) and ASTM 883-02(optical microscopic images). Specimens micro structures have been investigated by optical microscope (Olympus, PMG3 model) and austenite grain size determined in according to with the ASTM Code E112-06. Impact test has been also done according to the ASTM E112-06 by an impact machine of 300J capacity and charpy method. Fracture surface was investigated by scanning electron microscope. Micro and Macro hardness have been done on all heat treated specimens. Macro hardness test has been carried out by Brinel machine. Micro hardness test has been done by Germanischer Lloyd Micro hardness test machine (model LECO) according ASTM E384-05 through Vickers method.

Table: (1-1) weight percent of chemical composition

C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu	Nb	V	Sn
1.32	0.49	13.32	0.041	0.00004	1.91	0.009	0.039	0.014	0.016	0.041	0.005	0.02	0.005

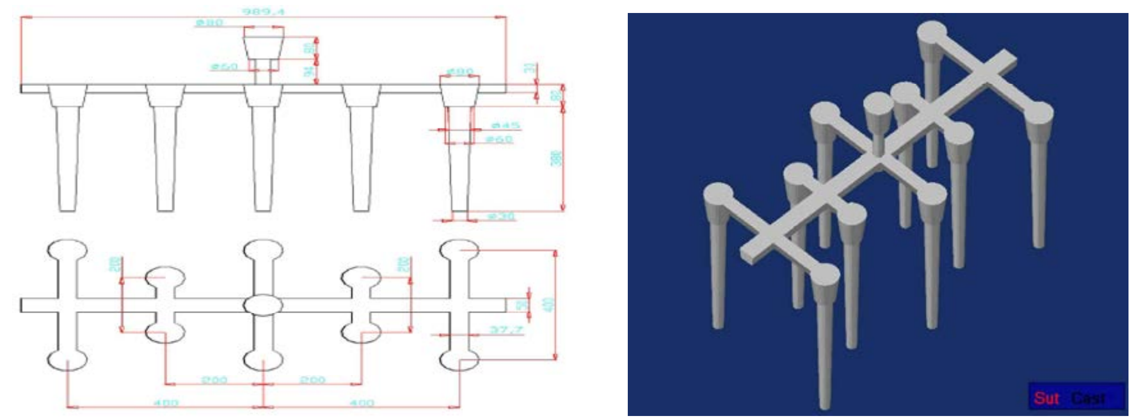

Fig. 2-1: Aluminum Mold schematic.

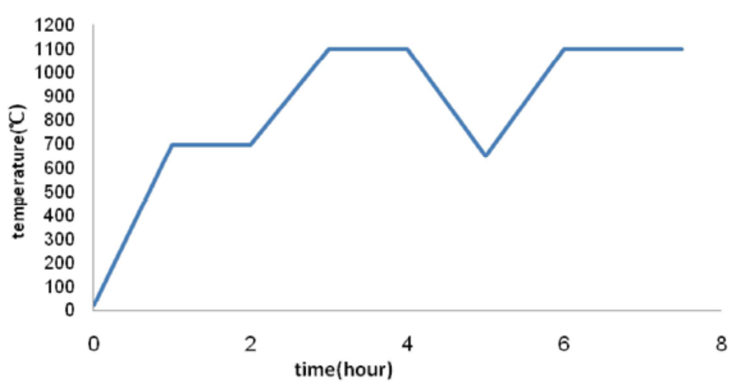

Fig. 2-2: Heat treatment cycle

RESULT AND DISCUSSION

Fig 3-1 shows the heat treated specimens micro structures. Carbide volume difference is obvious and well demonstrated. Salt weight increasing in quenching solution has significantly decreased carbide content in matrix structure and grain boundaries so that carbide content in different quenching solution determined as : Pure water : 6%, 1.5% NaCl solution: 4% and 3% NaCl solution : 2%.

The results proved cooling rate increases by increasing the salt content. Carbide volume was decreased because of cooling rate increasing. Considering undesirable carbides in final structure, it could be concluded that, with increasing NaCl content, may produce non carbide structure.

While verification of Hadfield steel's toughness related to quenching bath variation, results of Impact test assessed and final results showed that, through enhancing NaCl content in quench solution, mean required Impact Energy has been increased for 3 tested samples. As showed in Fig.3-2, mean impact energy for samples in different quenching bath is as follows: Pure water: 25 J, 1.5% NaCL: 42 J and 3% NaCl 59 J. This is due to increasing of NaCl content in quenching solution that leads to increase the cooling rate and restricted to forming of carbide in grain boundaries and finally increasing of impact energy and toughness.

To evaluate the toughness and ductility as the results of changing the quenching solution, the fracture surface of impact specimens was studied. Figure 3-3 shows that increasing of NaCl content in quenching

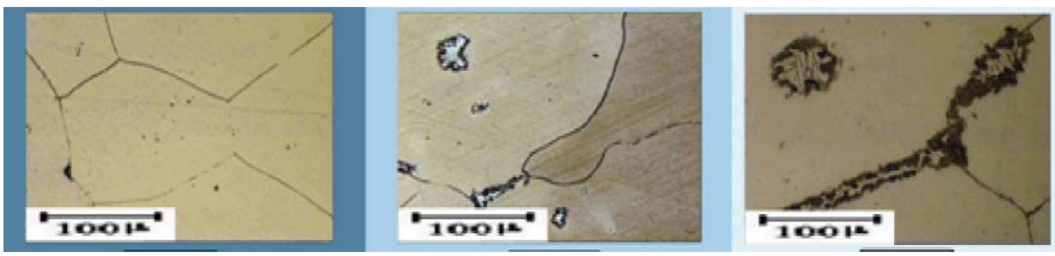

Fig. 3-1: Microstructure of heat treated specimens

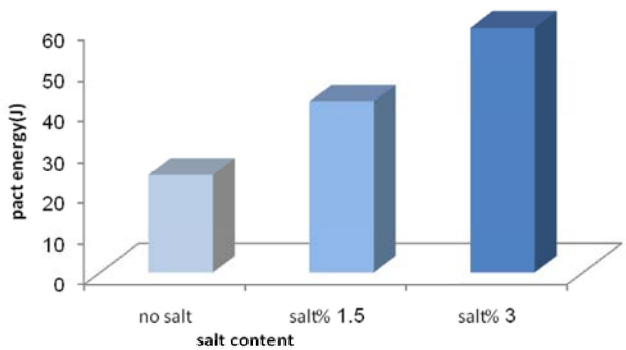

Fig. 3-2: Impact Energy vs. NaCl content in water of quenching bath

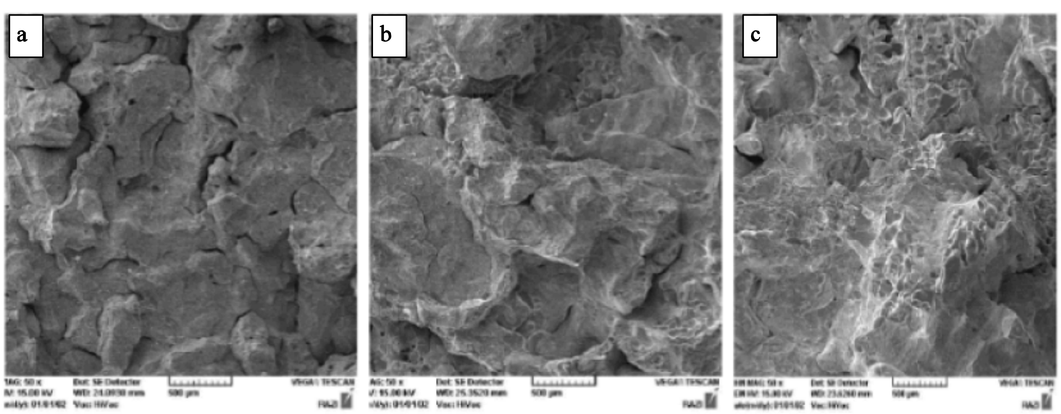

Fig. 3-3: SEM images of fracture surface a)Pure water, b)1.5% NaCl Solution, c)3% NaCl

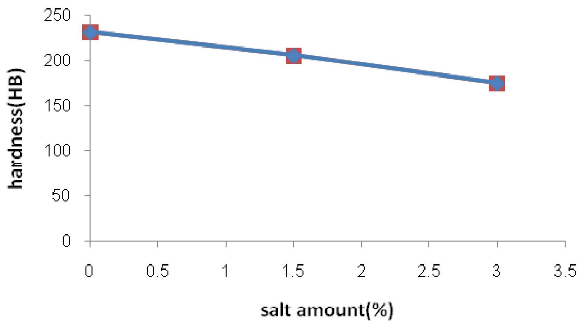

Fig. 3-4: Macro hardness vs. NaCl content

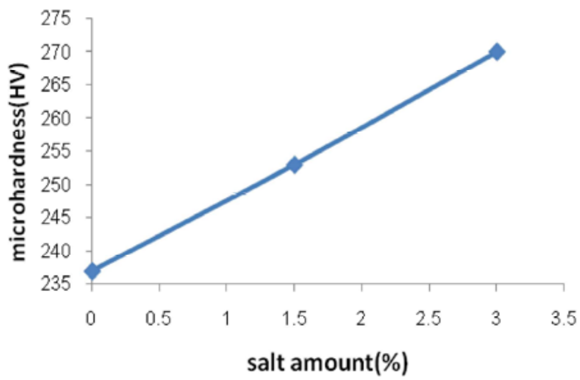

Fig. 3-5: Micro hardness vs. NaCl content

solution increasing the cooling rate, to avoid forming of carbides especially in grain boundaries, more ductile ruptures and finally limiting of non ductile and cleavage conditions. Thus it could be concluded that increasing of NaCl content in quenching solution causes absorbed energy improvement.

Fig.3-4 shows the macro hardness test results. As illustrated, macro hardness decreases as NaCl content increased which is related to cooling rates. Increasing quenching rate causes to decrease of carbides content. Considering that the carbides are hard phases in matrix and cause to enhance of general hardness by decreasing the carbide contents and general hardness decreases, consequently. Fig. 3-5 illustrates micro hardness test results. Based on what is observed at fig.3-5, increasing of NaCl content in quenching solution,results in hardness enhancing from 237 vickers to 270 vickers for samples quenched in pure water and 3% NaCl solution respectively, which is contrary to results of macro hardening. Since micro hardness results are related to the austenite grain in matrix, results seems to be logical, because enhancing of quenching solution cooling rate and consequently decreasing of carbide content, cause to matrix austenite retains more carbon as soluble carbon, that leads to micro hardness enhancing.

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