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The effect of precipitation hardening on the properties Hadfield steel

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ABSTRACT

The precipitation hardening in chromium containing Hadfield steel is considered as the most traditional mechanism for promoting the technological and mechanical properties of such high alloy steel. Two methodologies of precipitation hardening were suggested to attain the strengthening mechanical and technical properties of this steel. Different precipitates of chromium carbides were stimulated through either pre and post solution hardening treatment. Thereby, the results of the two mechanism were compared in terms of precipitation morophology, compositions, and mechanical properties. It was found that the deteriorative of toughness was significantly observed at the post solution treatment. Fine chromium carbides Cr_7C_3, and $Cr_{23}C_6$ were observed throughout the austenite matrix at 650^{o}C, and 700^{o}C as the temperature of pre-solution treatment technique. It was found that the morophology of chromium carbides has the most significant effect on promoting the strain hardening property of Hadfield steel studied. When conducting the age hardening regime followed the solution treatment observed the best toughness of Hadfield steel.

1- INTRODUCTION

Hadfield steel is considered as the most high alloy steel that is applied in different categories of applications, owing to its high impact toughness. In addition, it has the capability of multiplying its initial hardness through strain hardening mechanism [1,2]. Certainly, its mechanical and technical properties is premised on its odd microstructure that is consisting of austenite as the dominant phase. The austenite structure has the ability in generating hard bcc or BCT martensite structure through strain hardening mechanism, exploiting the strain energy gained from the duty [1,3-5]. Although, fcc-austenite structure has the ability in generation bcc-structure through accommodating much strain at the working conditions, but the rate of strain hardening is incessantly a subject of search [6]. Many workers proved that precipitation hardening mechanism of austenite structure with fine precipitates should has the significant effect on strain hardening mechanism of austenite structure [7]. proved that chromium carbides precipitates have a strong effect on promoting the strain hardening of austenite structure of Hadfield steel, promoting its wear abrasion resistance [8,9]. On the other hand, there were many trials for attaining further development in such property by adding vanadium, titanium, and molybdenum [10,11]. Chromium is considered as the most economic alloying element that can be used in alloying of Hadfield steel, owing to its affinity in forming different categories of carbides M3C7, M23C6, MC6 [11,12]. Certainly, each category of these carbide can be precipitated at significant temperature with distinguished size [1,13-15]. Thereby, it is crucial to identify the temperature at which the free energy of each category is much negative, allowing its formation. So, this research was designed to identify the most proper temperature for precipitation chromium carbides with fine size and distribution by using two methodologies.

2- Experimental Study:

One heat was conducted by melting high carbon scrap and ferroalloys on magnesite crucible induction furnace 30 Kg capacity at 1600^{o}C, and poured in sodium silicate – sand mold of standard sample cavity, cored with Co2 according to ASTM A781. to avoid the effect of segregation. The ingots were cut into specimens with definite dimensions for investigation and characterization. The chemical composition of the studied steel is shown in Table.1 Two regimes of heat treatments were carried out, based on the precipitation hardening temperature either before or after solution treatment process. Where, samples were preheated at 600^{o}C, and then solution treated at 1100 followed by rapid quenching in water, these samples were signed as pre 600^{o}C, as shown in Fig.1. On the other hand, in the second regime the samples were allowed for precipitation hardening at different temperatures 600,650,700 and 750^{o}C after applying the solution treatment process, they were signed as post 600,650.700 and 750^{o}C. Optical and scanning electron microscope were employed to track the morphology and the distribution of carbides throughout the austenite matrix. Macro, and micro hardness tests were performed after each regime of heat treatment to evaluate the change of hardness regarding to the precipitation after different methodologies of heat treatment. Compression test was applied for the samples after different heat treatment processes where samples prepared in dimensions 15*15*20mm. The impact toughness was determined to evaluate the effect of precipitations on the toughness of the austenitic structure. where, the samples prepared according to charpy standard. Eventually, wear resistant was studied by using pin on disk wear tester at different loads and constant velocity at 200 rpm to find out the behavior of steels at the wear abrasion condition. X-Ray diffracttometer equipped with Cu tube was used for identification the discrepancy in phases among the investigated steel after different heat treatment conditions.

Table.1 The chemical composition of utilized Hadfield steel specimen

C	Mn	Cr	Si	P	S	Mo	Fe
1.075	18.78	1.42	0.441	0.048	0.007	<.001	Ba

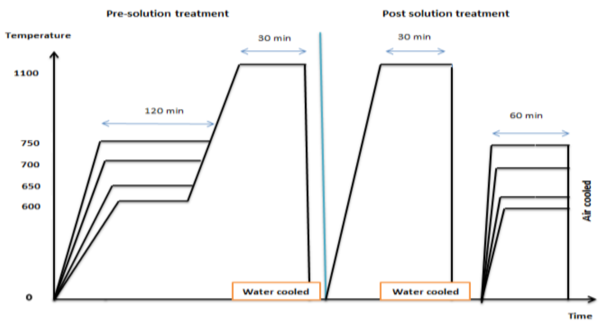

Fig. 1 The schematic showing heat treatment processes for different specimens.

3- Results and Discussions:

3.1 Thermodynamic calculations

It is clear from Fig.2. that M_7C_3 as Cr_7C_3 can be precipitated at certain temperature 580-650^{o}C. However, wide range for cementite precipitation was observed from 580-950^{o}C. Then, it is expected that at the studying range of temperatures Cr_7C_3 and cementite can be formed. It is well known that Cr_7C_3 has the significant effect on promoting the characteristic properties of Manganese steel while cementite has a deteriorative effect, in particular when precipitating on the austenite grain boundaries [16,17].

3.2 Microstructure observations

3.2.1 Optical microstructure observations

show in Fig.3. Microstructure observations show that the carbide precipitates are strongly distributed with fine size at the pre solution treatment at 600-750^{o}C. On contrary, cementite networks at the austenite boundaries are clearly observed at the post-solution treatment conditions, shown in Fig.4. in particular at 650, 700, and 750^{o}C. It was well proved that cementite networks have the catastrophic effect on high manganese steel. At the meantime, round morophology of carbide is obvious at the pre solution treatment condition at 700, and 750^{o}C. Then, it can be said that cementite precipitation is strongly stimulated at the post solution treatment conditions, while the carbides precipitation is regularly stimulated at the pre-solution treatment conditions. Low area fraction as shown in Fig.5. with coarse structure was observed at 750^{o}C. Surely, it is expected that the coarsening of carbides will impose negatively on the characteristic properties of high manganese steel.

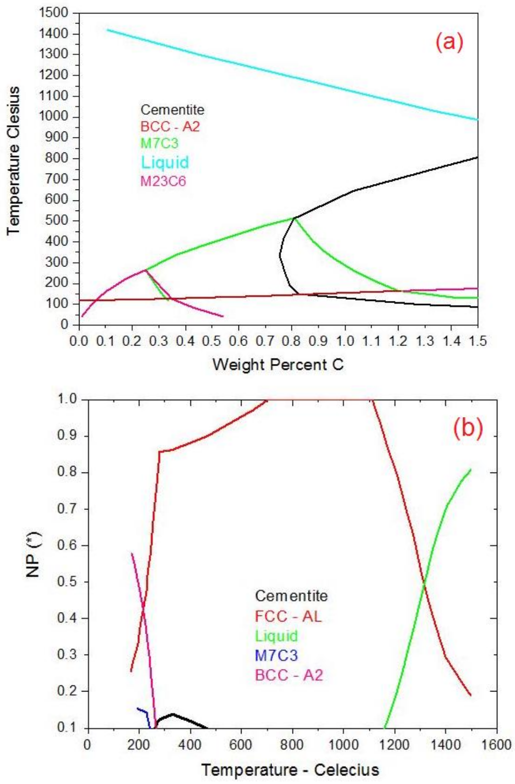

Fig. 2 Thermo-calc of a)weight percent ,b) temperature Celsius

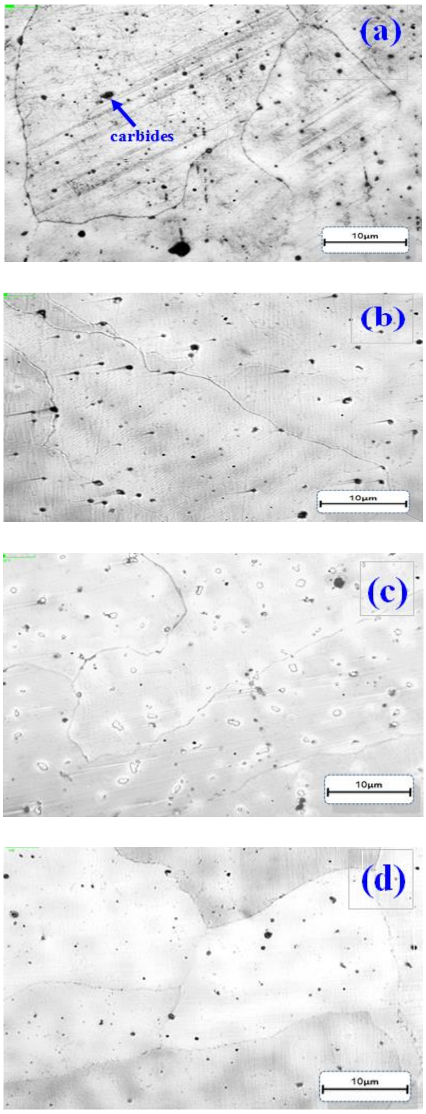

Fig.3 Pre-solution treatment at a=600^{o}C ,b=650^{o}C ,c=700^{o}C and d=750^{o}C.

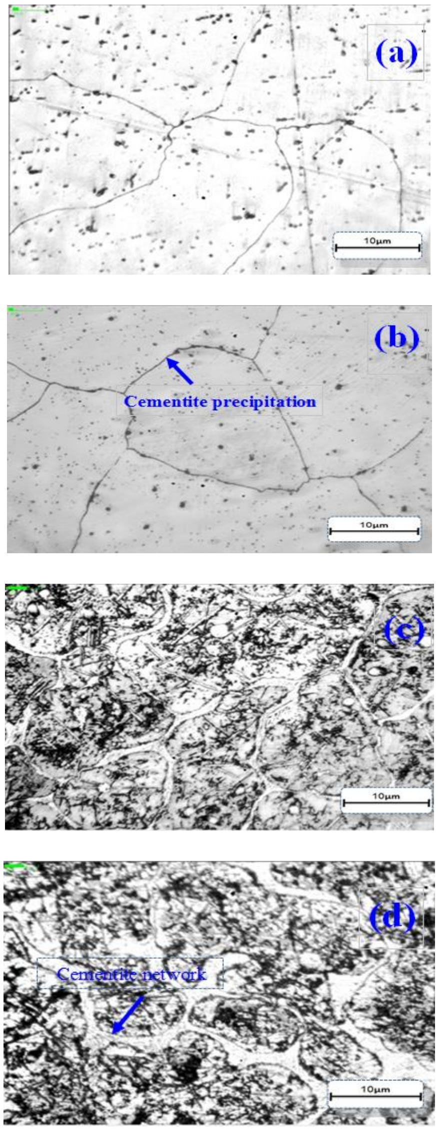

Fig.4 Post solution treatment at a=600^{o}C ,b=650^{o}C ,c=700^{o}C and d=750^{o}C.

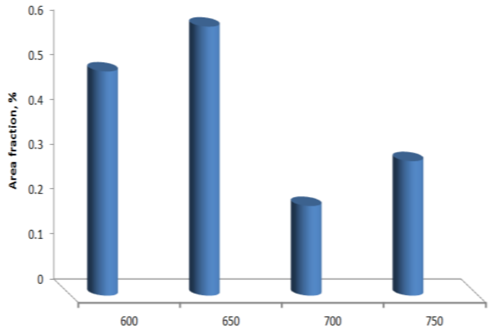

Fig.5 Area fraction of samples

3.2.2 SEM observations

It is clear from Fig.6. SEM observations prove that cementite network, and carbides based on chromium are the dominant phase at the austenite boundaries at the post solution treatment conditions. On contrary, by using EDS and mapping technique, it is clear that chromium carbide precipitates existed throughout the austenite matrix for the pre-solution treated steel.

3.1 Mechanical properties

3.1.1 Compression test

Although, yield strength of the post solution treated conditions is quite higher than that was observed at the pre-solution treated steel, but high ultimate strength was observed at the pre-solution treatment conditions as shown in Fig.7. In addition, strain hardening property of the pre-solution treated steel is significant in comparing with the strain hardening property of the post solution treated steel. No doubt, fine distribution of carbides can be considered as the main reason in multiplying the strain hardening character of steel, regarding to their interaction with dislocations [18]

By using strain hardening exponent equation, it was possible to monitor the strain hardening property of the investigated steel. Fine carbide precipitates are the powerful parameter in promoting the strain hardening of the investigated steel. Thereby, it was found that the pre-solution treated steel perform with high strain hardening character in comparing to that was observed in post solution treated steel, as shown in Fig.8. In addition, pre-solution treated steel at 750^{o}C has the highest capability for strain hardening in comparing with the other pre-solution treated Hadfield steel. Certainly, this is attributed to the growth of the carbide structure at the expense of carbon content in the austenite matrix, which allows for direct strain hardening generation into ά-martensite with no further generation into ε-martensite during the plastic deformation zone [19].

$$\log\sigma = \log k + n\log\varepsilon \qquad \text{(Equation 1)}$$

3.1.1 Impact toughness

As aforementioned the precipitation of cementite on the austenite boundary has a catastrophic Effect on the characteristic toughness of high manganese steel, as being clearly observed in Table. 2. However, round precipitates with fine size has the great impact on promoting the toughness of austenite matrix. Then pre- solution treatment at 700^{o}C has the high toughness value among the steel tested. In fact, the morophology of carbides play the main role in the discrepancy of the toughness of Hadfield steel after different heat treatment condition. Pre-solution treatment at 700^{o}C shows the best toughness among the different heat treatment conditions. In regarding to the roundness character of carbides, it is believed the high roundness character of carbides has the key parameter in promoting the toughness of Hadfield steel.

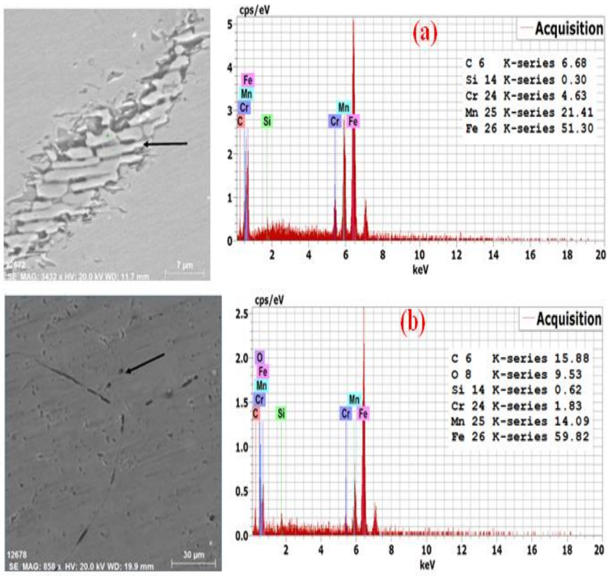

Fig.6 SEM observations Pre-solution treatment and Post solution treatment

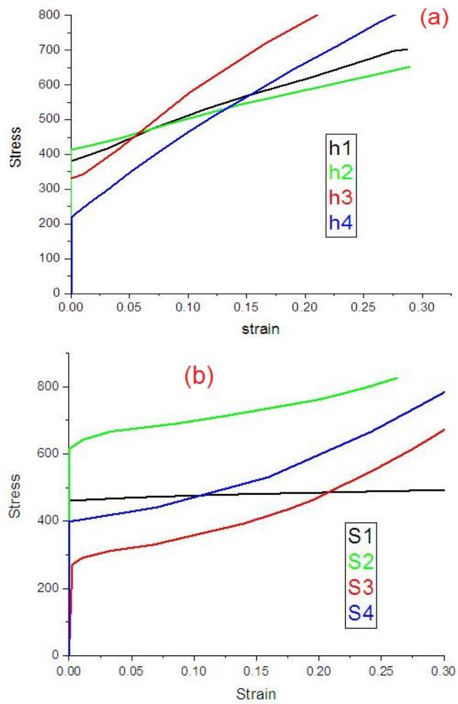

Fig.7 Comprasion Test of samples a) Pre-solution treatment b) Post solution treatment

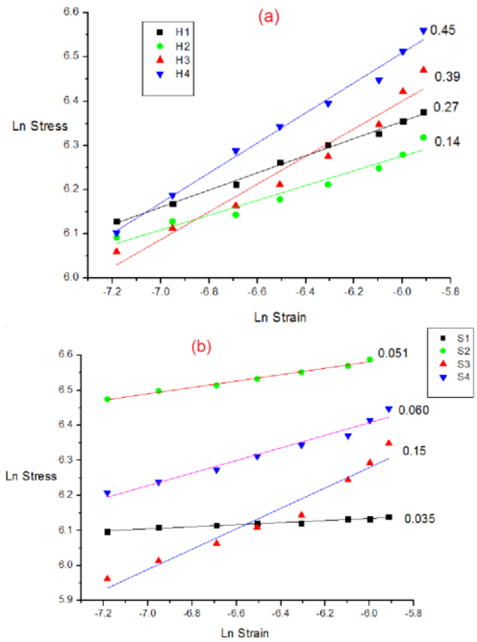

Fig.8 Strain hardening Property of samples after applying Comprasion test a) Pre-solution treatment b) Post solution treatment

Table 2. The Impact toughness Hadfield steel specimens

samples	Heat treatments	Energy (Jol.)
1	S1100+600	8
2	S1100+650	6
3	S1100+700	8
4	S1100+750	6
5	H600+1100	12
6	H650+1100	18
7	H700+1100	60
8	H750+1100	16

3.1.2 Wear abrasion resistance

Although, cementite network has a great effect on the localized hardness of austenite matrix, but it performed as the worst phase against abrasion wear certainly, this can be attributed to its effect on promoting the micro-catting wear mechanism with les strain hardening capability. On contrary, fine carbide precipitation formed at pre-solution treatment conditions effectively promotes the wear abrasion resistance as shown in Fig.9. Surely, it is expected that this enhancement is owing to the fact of high strain hardening capability of Hadfield steel, which is multiplied by the fact of carbide precipitation [20-22].

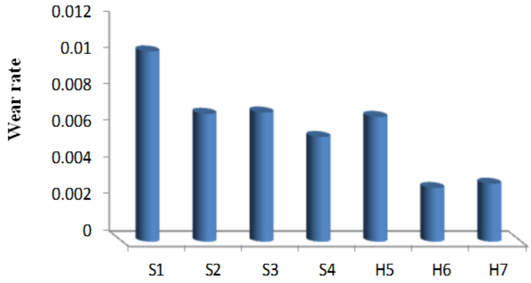

Fig.9 Wear abrasion resistance

3.1.3 Worn surface observations

As given in Fig.10. SEM, in conjugation with EDS Prove that chromium carbides act as obstacle for promoting the wear mechanism through the worn surface of pre-solution treated steel. Micro-cutting mechanism is rarely observed in the worn surface, while the dominant wear mechanism in the worn surface is micro ploughing mechanism.

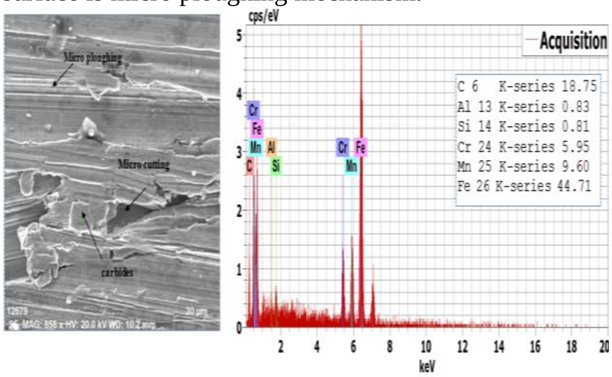

Fig.10 SEM observations after applying Wear test

3.2 Hardness test

Hardness values refer that the cementite network at the austenite boundaries of the post solution treated steel act positively in increment of hardness value. While, the pre-solution treated steel show reasonable hardness values as shown in Fig.11. Surely, the low hardness value refers that austenite is the dominant phase.

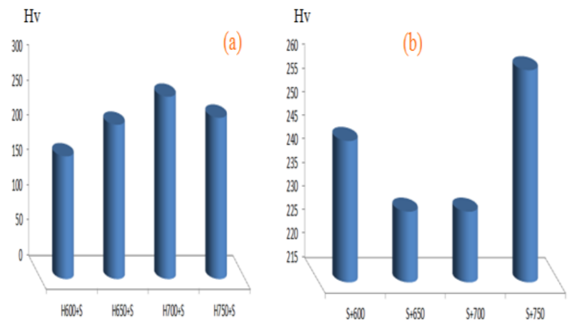

Fig.11 The hardness for samples investigated a) Pre-solution treatment b) Post solution treatment

3.3 XRD Observations

XRD shows that the austenite is the dominant structure among the investigated steel. However, it is clear that carbide precipitations is observed significantly in the steel that was subjected for age hardening after solution treatment, as given in Fig. 12. XRD assures the results that were collected from different investigations as being discussed previously.

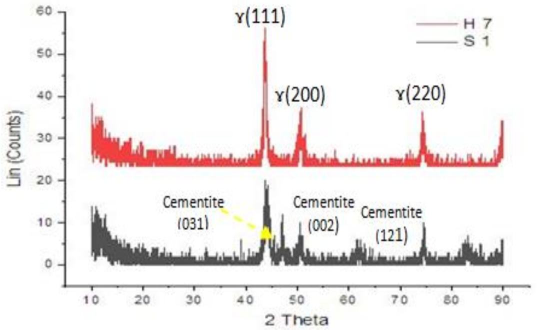

Fig. 12 X-Ray Diffraction results for samples investigated H7) Pre-solution treatment S1) Post solution treatment

4. Conclusions:

A- Age hardening regime has the powerful effect on carbide precipitation in Hadfield steel.

B- Network cementite and carbides are observed at the austenite boundaries, with great deteriorative effect on the toughness of Hadfield steel, when age hardening regime followed the solution treatment observed the best toughness of Hadfield steel.

C- Fine carbides throughout the austenite matrix are commonly observed in Hadfield steel at the condition of age hardening followed by solution treatment.

D- Fine carbides precipitation formed at pre-solution treatment conditions effectively promotes the wear abrasion resistance.

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