IOP Conf. Series: Materials Science and Engineering **328** (2018) 012006 doi:10.1088/1757-899X/328/1/012006

Investigation on Simultaneous Effects of Shot Peen and Austenitizing Time and Temperature on Grain Size and Microstructure of Austenitic Manganese Steel (Hadfield)

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Abstract. Optimal conditions to increase life time of casting parts have been investigated by applying various cycles of heat treatment and shot peening on Hadfield steel surface. Metallographic and SEM microstructure examinations were used to determine the effects of shot peen, austenitizing time and temperature simultaneously. The results showed that with increasing austenitizing time and temperature of casting sample, carbides resolved in austenite phase and by further increase of austenitizing temperature and time, the austenite grain size becomes larger. Metallographic images illustrated that shot peening on Hadfield steel surface; Austenite - Martensite transformation has not occurred, but its matrix hardened through twining formation process.

Keywords: Hadfield Steel, heat treatment, shot peen, austenitizing, grain size, twining

1. Introduction

Austenitic manganese steel (Hadfield steel) is widely used in cement industry, mining, railways and other heavy industry due to its relatively good toughness and wear properties. Hadfield steels contains about 2.1% C and 12% Mn first produced in 1882 by Robert Hadfield [1, 2]. It exhibits high toughness, high ductility, high work hardening ability and excellent wear resistance. Because of the excellent combination of these properties, this steel has been accepted as a very useful engineering material. It is widely used in the earthmoving, mining, quarrying, oil well drilling, steelmaking, railroading, dredging, naval, lumbering excavators, and mineral crushing equipment [2-4].
Despite the desirable properties of the Hadfield steels, the main limitation of their applications is due to non-dissolved carbides in the austenite matrix from improper heat treatment. The wear resistance of these steels can be improved by increasing hardness through addition of limited content of carbon. Their wear resistance could also be increased by adding elements such as titanium and vanadium as inoculations [5 - 7]. There are two significant steps in Hadfield steel production, namely melting and developing of appropriate composition and secondary, proper heat treatment on casting parts [6]. Strength, ductility and wear resistance properties of Hadfield steels increase with controlled heat

treatment at the suitable temperature. If heat treatment temperature was adjusted improperly, tensile strength and ductility would be reduced [8].
The toughness and the high wear resistance are important properties of the Hadfield steel. The hardness of the Manganese austenitic steel is not high and similar to that of medium carbon steels. The impact resistance of heat-treated Hadfield steel is high and generally are bent on the impact rather than the failure of the device. This hardness of the surface layer increases during the operation which caused them to be the more wear resistant [9]. In practice, due to low surface hardness, Hadfield steel is commonly exposed to work hardening process such as shot blasting in order to increase the wear resistance [10,11]. The deformation mechanisms responsible for the high strain hardening rate include interactions between interstitial carbon atoms and dislocations interactions between dislocations and twins and interactions between twinning systems [12-14].
The casting Hadfield steels are not efficient because the grain boundary carbides formed during solidification and will greatly reduce the flexibility. Deposition of carbides in austenite grain boundary that result to reduce strength of the steel to a minimum. In addition to, the perlite Regions in steel microstructure must be transformed into austenite during heat treatment [15]. Austenitizing makes dissolution of the carbides and form of the single-phase austenitic structure. With an increase in the austenitizing temperature, the carbide solubility and grain size are increased, but excessive austenitizing temperature will cause decarburization of the surface. The austenitizing temperature of the Hadfield steel is in 1050 to 1200 °C and it is kept at this temperature for 1 to 2 hours to dissolve of the carbide phase [16]. Due to the opposite influence of heat treatment on austenite grain size and presence of carbide, this paper investigates to determine the optimal heat treatment temperature and time on the austenite grain size.

2. Experimental Method

In order to examine the simultaneous effects of the austenitizing temperature and shot peening time on the Hadfield steel structure, 19 different samples were casted as detailed in Figure. 1. A sample without heat treatment and shot peen operations as controlled sample was kept aside and 18 samples were heat-treated at different quench and shot peen cycles.
The chemical composition of melt for casting and preparation of samples were performed according to ASTM A-128 standard of the manganese austenitic steels. The chemical composition of melt is shown in Table 1.
Samples heat treatment were performed at different temperatures 970 °C, 1060 °C and 1150 °C and maintenance times were 30 or 60 minutes. Finally, they were cooled by choppy water. Then, samples were shot peened for 30 or 60 minutes. Heat treatment cycle of the samples was performed at 25 °C to 650 °C with rate of 100 °C/h. Then, samples were kept at this temperature for 30 minutes for homogenization and stress relieving.
Finally, in order to reach a final heat treatment, the austenitizing temperature (970, 1060 and 1150 ºC), they were rapidly heated to the desired temperature with rate 100 °C/h. Heat treatment furnace, for the resistive ceramic samples, with a capacity of 250 liter is used. Samples for reduction grain size and increasing the hardness and wear resistance, have undergone 30 and 60 minutes shot peening. Then, grinding for samples with P100, P600 and P2500 was done and samples surfaces were etched using a solution of 2% Nital. The metallographic structures of the sample with the optical microscope and photographic were used. The metallographic images were compared with the standard images (DIN50601) and the grain sizes of the samples were calculated and compared. To study samples microscopic structure, the cross-sections of shot peening were taken, and the results of SEM analysis were compared.

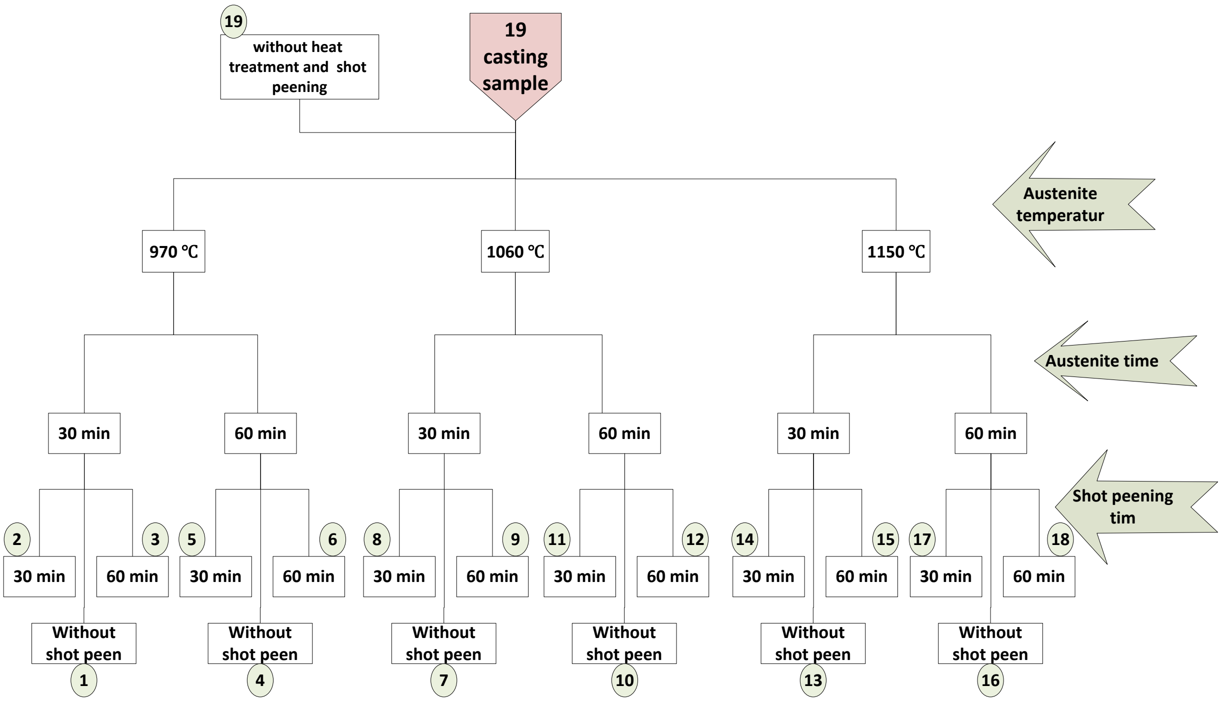


Figure 1 Different heat treatments and shot peening cycles of samples

Table 1 Chemical composition of melt

Element	C	Si	Mn	P	S	Cr
%	1.24	0.64	14	0.044	0.003	2
Element	Fe	Mo	Ni	V	Al	
%	Balance	0.19	0.074	0.031	-	

3. Results and Discussions

Figure 2 shows as-cast steel structure which includes austenitic matrix in bright areas with a high percentage of iron, manganese and chromium carbides which formed a continuous network at grain boundaries. These carbides caused brittleness of austenitic manganese steels.

Figure 3 shows the effect of heat treatment temperature (970 – 1150 ºC) at 30 minutes constant maintenance time (before the shot peening operation). The metallographic images show that the samples microstructures include the austenite matrix and non-dissolved carbides. With increasing heat treatment temperature, percentage of non-dissolved carbide decreases, and their formation was removed in grain boundaries. During further increase in temperature (1150 ºC), grain boundaries carbides completely disappeared and just a little percentage of carbides remain in the austenite grains.

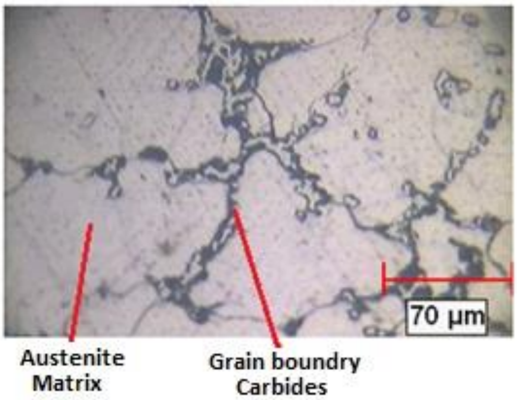


Figure 2 As-cast Hadfield steel microstructure without heat treatment and shot peening.

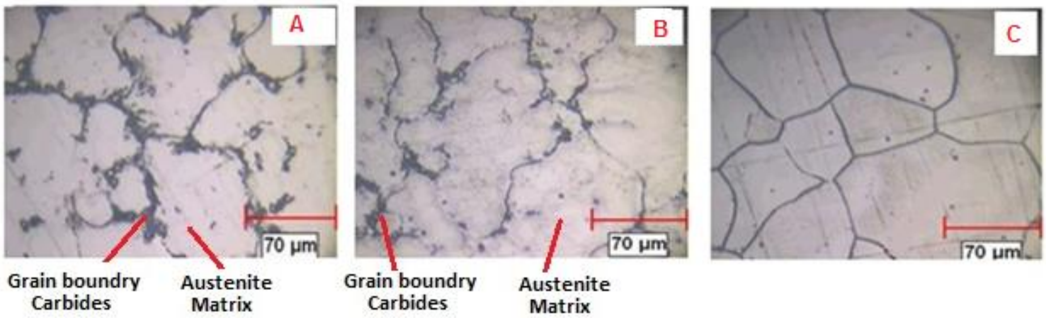


Figure 3 Effect of heat treatment temperature at 30 minutes constant maintenance time without shot peen A: 970, B: 1060 and C: 1150 ° C

Figure 4 shows the effect of heat treatment temperature (970 – 1150 ºC) at 30 minutes constant maintenance time (before the shot peen operation). Figures 3 and 4 shows that with increasing temperature, non-dissolved carbide percentage in grain boundary reduced and finally will reach to a very small percentage. To compare Figures 3 and 4, it shows that increasing the maintenance time (30 to 60 minutes) effect on reducing and discontinuity of grain boundary carbide poorly, and austenite grain size was larger. The austenite grain size in various samples as shown in Table 2, where it was obtained by DIN 50 601 standard method. It is clearly evidence that with increasing austenitizing temperature and holding time, the austenite grain size becomes larger and grain size number becomes smaller.

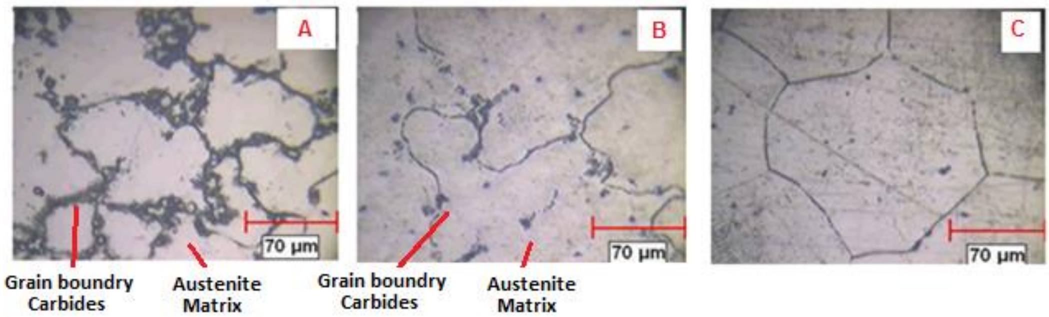


Figure 4 Effect of heat treatment temperature at 60 minutes constant maintenance time without shot peen A: 970,

B: 1060 and C: 1150 ° C

Table 2 Samples Austenite grain size

Grain size number	Austenitic time(min)	Austenitic temperature (˚C)	Sample Number
7	30	970	1
7	60	970	4
6	30	1060	7
5	60	1060	10
5	30	1150	13
4	60	1150	16
7	Without Heat Treatment	Without Heat Treatment	19

In totality, the microscopic images of samples with different heat treatment cycles show most of the restructuring and solubility of carbides, and their morphologies are related to the austenitizing temperature. Then, by increasing the austenitizing temperature, the amounts of dissolved carbides in the structure are decreased, and therefore, austenite grain size is increased. It was found that with increasing time of holding of samples at high austenitizing temperature, the austenite grain size would become larger. For the simultaneous effect of austenitizing temperature and the shot peening treatment on the microstructure, the metallographic images of heat treated specimens in 1150 ºC for 60 minutes and 60 minutes shot peen are shown in Figure 5.

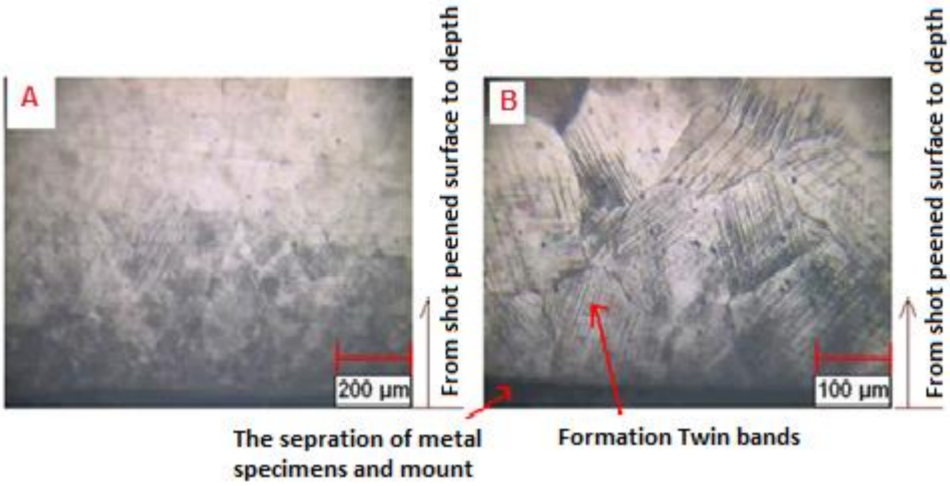


Figure 5 Effects of simultaneous shot peen on metallographic structure of the sample under heat for 60 minutes in 1150ºC magnification of (A) 100X, (B) 200X.

As shown in Figure 5, the sample surface has hardened by shot peening operation, but in the centre, the austenite grains remained unchanged. Parallel lines and changes of twin directions can be seen in various grains. Work hardening of austenitic grains in the surface layer, with a thickness about 0.3-0.5mm, are specified in Figure 5 (a). According to Figure 5, it suggests that the surface's shot peening is appropriate, and also, the austenitic to martensitic transformation has not taken place, whereas, the work hardening by the twin mechanisms is only done, and also, slip into the surface layer is caused by the shot peening operation. Figure 6 shows the metallographic image of the austenitic grains where both work hardening, and non-work hardening have occurred.

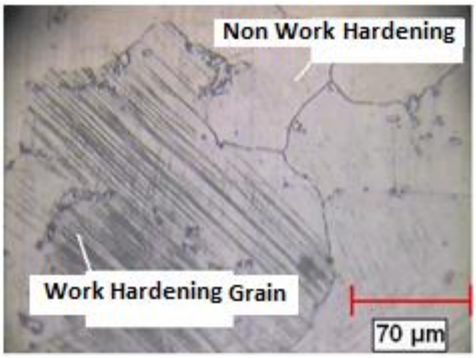
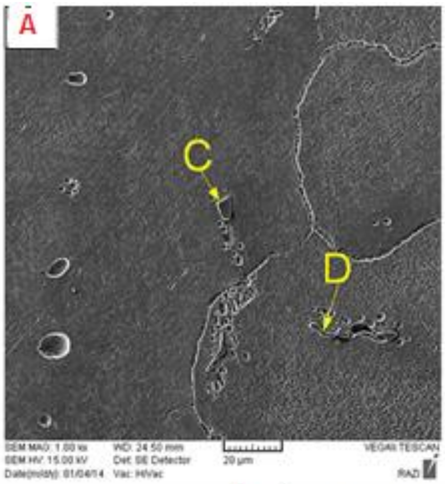


Figure 6 Illustration of the austenite grains after heat treatment in1060 ºC for 60 minutes and shot peened for 60 minutes.

To inspect different phases in the electron microscopy images and phase elemental analysis of the EDS, the two heat treatment samples at 1060 ºC for 60 min and 1150 ◦C for 30 minutes have been prepared, where both samples were shot peen for 60 min period.



B — Spectra: 12-ZONE C

Element	Series	unn. C [wt.-%]	norm. C [wt.-%]	Atom. C [at.-%]
Carbon	K series	3.62	3.72	15.17
Silicon	K series	0.00	0.00	0.00
Chromium	K series	9.19	9.45	8.91
Manganese	K series	21.63	22.23	19.84
Iron	K series	61.18	62.88	55.20
Molybdenum	L series	1.68	1.73	0.88

C — Spectra: 12-ZONE D

Element	Series	unn. C [wt.-%]	norm. C [wt.-%]	Atom. C [at.-%]
Carbon	K series	3.47	3.37	13.86
Silicon	K series	0.00	0.00	0.01
Chromium	K series	8.83	8.56	8.14
Manganese	K series	23.34	22.62	20.35
Iron	K series	66.70	64.64	57.22
Molybdenum	L series	0.84	0.82	0.42

Figure 7 A) SEM image B, C) EDS analysis of sample heat treatment in 1060 ° C for 60 min and 60 min shot peening at points C and D (500X magnification)

Figure7 shows SEM image and EDS analysis for heat treatment sample at 1060 ºC for 60 minutes and shot peen for 60 minutes. C and D points indicate a presence of carbide elements of iron, manganese, molybdenum, and chromium. Figure 8 shows twinning treatment in Hadfield steel structure, where the shot peen operation has occurred. The parallel lines of the microstructure was observed. These parallel lines are due to crystalline directions in the austenite grains. Twin lines have formed in different directions. It also shows the effect of the shot peening treatment whereby the twinning treatments have formed, but martensitic transformations do not take place.

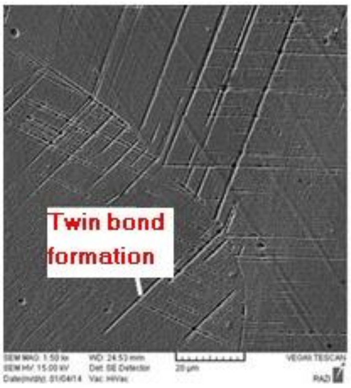


Figure 8: SEM image of the sample heat treatment at a temperature of 1050° C for 30-minute shot peening for 60 min at 1500X magnification

4. Conclusions

A fully austenitic manganese steel with a grain size suitable can be created using a proper heat treatment, such as heat treatment at 1150 ° C for 60 minutes per inch thickness pieces and then quenching in water bubbling on the structure of the Hadfield ASTM128A grade C.
By various cycles of the heat / quench treatment for the manganese steel, according to the absence of the new grain boundaries, the grain size of the Hadfield manganese steel cannot be smaller. The austenite grain size can be increased with the increasing of the temperature and time of the austenite treatment. At the lower temperature of the austenite heat / quench treatment (970°C), the continuous carbides is maintained even with an increase in the heat treatment time.
With the shot peening mechanical operations on the surface, the transformation of austenite to martensitic steel (Hadfield) does not take place. The work hardening signs have been affected by the phenomenon of the twins that is indicated in the visible parts by the metallographic images. To investigate of the metallographic structure of the shot peened surface layer, the twin bands difference direction in the orientation of the crystalline arrangement of the grains have observed.

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