

INFLUENCE OF RARE-EARTH ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF HIGH MANGANESE STEEL UNDER IMPACT LOAD

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Abstract

In this paper, the influence of rare earth (RE) on the microstructure and mechanical properties of austenitic high manganese steel (HMnS) Mn15Cr2V were investigated. The results showed that the microstructure, hardness and impact strength of RE modification sample is finer and better than non-modified sample. Under the effect of impact load, the hardness and the depth of the work-hardening layer of the modified steel was higher than that of the non-modified steel, thereby, the value of microhardness in the surface of the modified sample was 420 HV while it was only 395 HV in the non-modified sample. The value of the impact strength of the modified sample was up to 132J/cm² compared to the non-modified sample is only 115J/cm². Moreover, after impact load, the austenite nanoparticles had been found out on the surface of this steel, this is the cause of the increasing of mechanical properties in this steel.

Keywords: austenite nanoparticles, rare earth, grain size, subzero temperature

1 Introduction

The high manganese steel has particularly resistant to abrasion when working under impact conditions, under the influence of stress. Under the effect of continuous working (such as sandblasting), the steel is abrasive relatively quickly, as other steel. After casting and heat treatment, the microstructure of its has austenite, which contains carbon and manganese. This steel has a high manganese content (over 10% Mn) [1-5]. Manganese is an element of γ expansion, so the steel is austenitic (stable austenite at room temperature). This steel has full the austenitic phase so the steel has high toughness, low hardness, but when working under high pressure and impact, the austenite particle (type A1 lattice) becomes strong plastic deformation. As a result, the steel/the hardness property of the steel becomes strong, while the core retains the original microstructure maintain the toughness. This phenomenon of high manganese steel is called "deformation" [6-15].

Rare earth (RE) are rare elements in the earth, including 17 elements: Scandium, Yttrium, Lanthanum... These elements are difficult to fabricate. Researchers have shown that putting rare earth on steel will have a small effect on the structure and increase the impact strength of the

material. In addition, RE elements can also be used as deoxygenators and desulfurizers as they are readily oxidized to RE oxides of RE. During crystallization, the compound of RE decomposes in front of the austenite crystal. After passing through an instantaneous cooling process, they produce polycrystalline crystals instead of single crystals and under such conditions, several austenitic ions bind together and prevent crystallization of the crystals. Thus, they promote the same crystal growth and smooth the structure [16, 17].

The steel is alloyed by alloy elements as: Cr; V... M_7C_3 crystals size is larger than crystalline radii, reducing the length. However, the development of M_7C_3 is preferentially along the [0001] direction, so it is difficult to change the morphology. For this reason, the need for smoothing M_7C_3 bundles has been heavily researched. Rare earth elements are active surface elements, concentrated on a solid-liquid interface, which speeds up the cooling and inhibits the growth rate of austenite. When the first crystals of austenite appeared, they were bridged between carbide and austenite boundaries. The austenitic stalk branches connect together at the time the carbides become discrete and the shape of the carbide also changes from plate to plate or into rods [16, 18-20].

In this work, we present the results of the study on the effect of rare earth on the microstructure and mechanical properties of austenitic high manganese steel under impact load. The results proved that the HMnS steel with RE modification archive higher strengthen in comparison with other type of steel and the work-hardening mechanism was also changed as the old mechanism.

2 Experimental produre

In this research, the samples were melted in the induction furnace, the detail of chemical composition was shown in **Table 1**.

Table 1 Chemical composition of the samples

Sample	Fe	C	Si	Mn	P	S	Cr	V	RE
No.1	80.30	1.36	0.81	14.70	0.08	0.02	1.82	1.02	-
No.2	80.30	1.36	0.81	14.70	0.08	0.02	1.82	1.02	RE

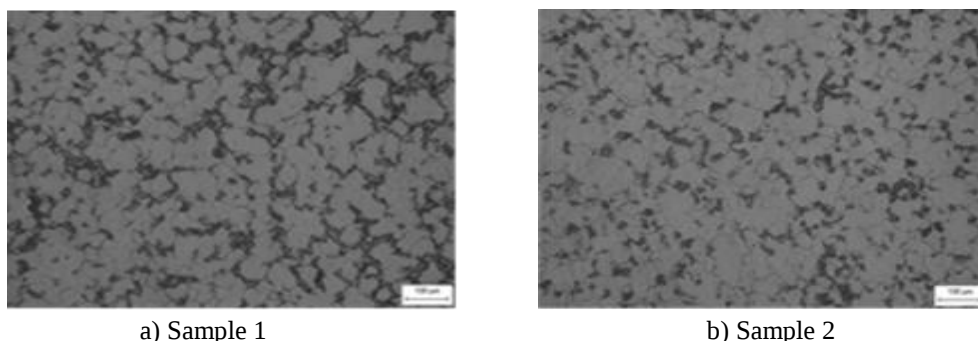
The samples then processing of heat treatment as following: heating up to 650°C, keep at this temperature for 02 hours, air cooling down to room temperature, then were heated up to 1100°C and holding at that temperature for 02 hours, finally were water quenching.

The experiment samples were carried out under the impact load. Samples were applied more than 3000 times by load of 100N/cm² from the high of 60cm for observation of microstructure and hardness of specimens after applied impact load. The value of needed force is bigger than 439.5 MPa. The hardness was determined by Hardness tester ARK600. The microstructures were observed by Axiovert 25A, SEM QUANTA 250, XRD and TEM.

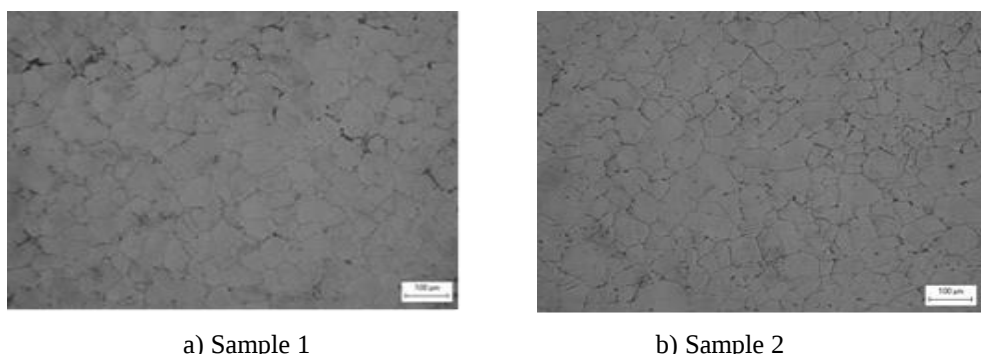
3 Results and discussion

3.1. Microstructure

Fig. 1 and **Fig. 2** shows the microstructure of the non-modified steels (**Fig. 1a**) and modified by rare earths (**Fig. 1b**). Samples have a V content of 1%, unmodified with an equivalent grade 5 equivalent grained ASTM. It can be seen that rare earth oxides with high melting temperatures cause heterogeneous crystallization of M_7C_3 carbide phase and austenite phase.

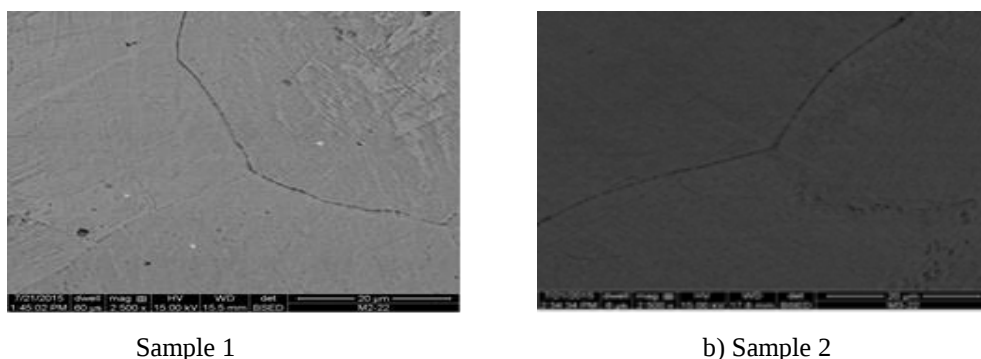


a) Sample 1
b) Sample 2
Fig. 1 Microstructure of non-modified sample (a) and modified sample (b) after casting



a) Sample 1
b) Sample 2
Fig. 2 Microstructure of non-modified sample (a) and modified sample (b) after heat treatment

On **Fig. 2**, It can be seen that both of the modified and non-modified samples, the carbide particles of both the modified and non-modified samples have completely dissolved into the austenite matrix and the austenitic particle size reaches grade 6 in accordance with ASTM. However, the modified sample is more uniform than the non-modified sample.



Sample 1
b) Sample 2
Fig. 3 BSE of non-modified sample (a) and modified sample (b) after heat treatment

The **Fig. 3a** shows the inverse scattering image of the non-modified sample after heat treatment. **Fig. 3b** is the modified sample's image after heat treatment. As in the microstructure,

backscattering electron images also showed that in the samples there was no concentration of carbide at the grain boundary (**Fig. 3b**), but in the austenitic granules there were appearance of a number of fine particles. The treatment of carbide dispersion within the austenitic matrix will contribute to the increasing of resistance to wear and impact toughness of the HMnS steel.

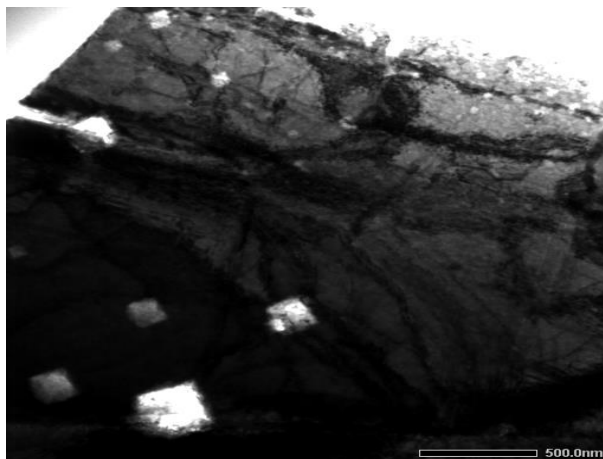


Fig. 4 Microstructure of TEM

From the observation of the optical image, in the microstructure of steel after heat treatment, almost all homogeneous austenite formed, only the use of TEM can show that there are carbide particles inside the austenitic particles. The size of these particles are very small. **Fig. 4** is the TEM image of the samples after heat treatment. From observations of the modified and non-modified samples by the TEM images, the small particles with approximate 60 nm in diameter length were observed with the non-modified and about 40 nm for the denominator (**Fig. 4**). These particles are playing the role of work hardening and abrasion resistance for the details. With the modified sample, the smaller finer particles appeared which increase the mechanical value compare than the non-modified sample.

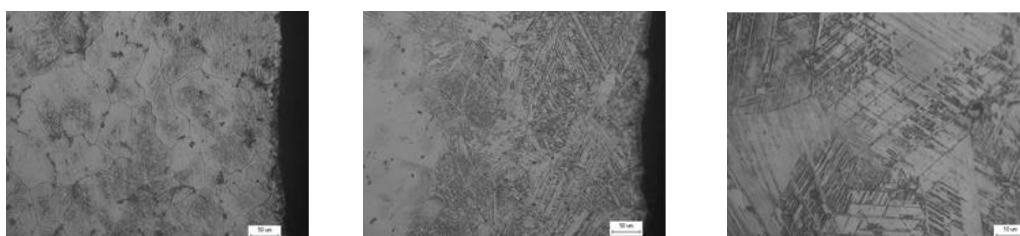


Fig. 5 Microstructure of non-modified sample 1 (a) and modified sample 2 (b;c)

The microstructure in **Fig. 5** shows that no martensitic structure can be observed (**Figs. 5a** and **5b**). At the magnification of 1000 times, the twinning deformation can be seen in the microstructure of modified sample (**Fig. 5c**).

On the **Fig. 6**, the hardness of sample 2 is higher than sample 1 (hardness reaches 420HV). The results of TEM analysis of the samples after impacted load did not show the martensitic

structure for both samples, but only the nano scale level. However, by TEM, unlike the non-modified sample 1 (**Fig. 6a**), the modified sample 2 (**Fig. 6b**) appear strange appearance microstructure with many white dots. According to the author [16], austenite nanoparticles were created by plastic deformation (white dots in **Fig. 6b**). Thus, the deformation creates the austenite nanoparticles. The formation of austenite nanoparticles on the surface will increase the durability by creating multiple boundaries that prevent slippage and create differently oriented twinning. In addition, the fine grain increase the impact strength of this steel.

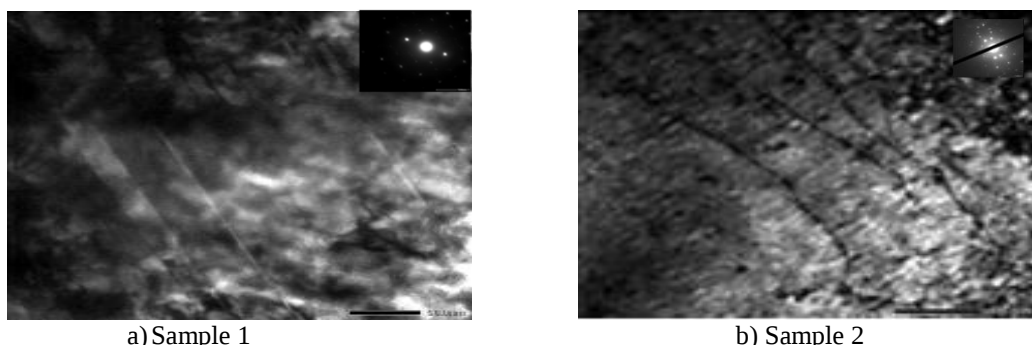


Fig. 6 Microstructure of non-modified sample 1 (a) and modified sample 2 (b)

Fig. 7 shows the inner surface of the sample 2 after the deformation process the sliding (**Fig. 7a**) are located at a distance of about 150 μm below the impact surface the impact surface where high hardness region is found (the maximum is 420HV). The deeper into the sample from the impact surface can be observed that the number of deviations decreases.

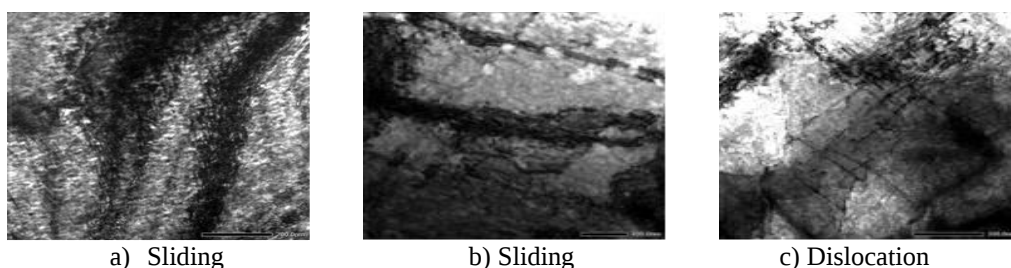


Fig. 7 Dislocation and sliding on the sample surface

3.2. Mechanical properties

The results of hardness samples (**Table 2**) showed that the modified samples exhibited higher hardness values than non-modified samples (240HB vs 223HB). This may explain the effect of the RE elements which increases the hardness value of the sample after heat treatment.

Table 2 Result of hardness

Sample	Hardness
Sample 1	223HB
Sample 2	240HB

Table 3 Result of impact toughness

Samples	Impact toughness (J/cm ²)
Sample 1	115
Sample 2	132

The results of the impact toughness showed that when the modified sample was performed with the heat treatment process as above, the impact toughness was higher than non-modified sample (132 J/cm² vs 115 J/cm²). The value of impact toughness is increased by the particle size of the modified sample decrease. It can be indicated that RE elements were playing the important role not only in the solidification process, but also during in the heat treatment, which contributes to the reduction of austenitic grain size, thus improving the impact toughness of the samples.

Table 4 Abrasion of sample

Sample	Sample 1 (1%V)			Sample 2 (1%V+RE)		
	Begin	End	Mass loss weight	Begin	End	Mass loss weight
Weight (g)	4.7150	4.3590	0.3560	4.5320	4.3960	0.1360

The results in **Table 4** show the same abrasion test parameter as described in the experimental section: the sample, when added by rare earths, decreased the amount of wear compare than the untreated sample. Microstructures as well as mechanical properties analysis results of the samples are explained by the fact that RE elements were created the dislocation in the lattice and then promote to increase the mechanical properties of the samples.

Micro-hardness

In **Fig. 8**, the result is the micro-hardness which measured from the sample surface to the core. From the result of the hardness, it can be seen that at the same treatment temperature, the modified (S2) has a higher hardness value than the non-modified (S1) sample. At the room temperatures, the surface hardness of S2 reaches 420HV while the S1 is 395HV. This micro-hardness results show the role of the modification agent in the work-hardening of HMnS steel. Modifiers, which play the role in the austenite grain size reduction process, can also affected on the formation of strengthen phase in this steel.

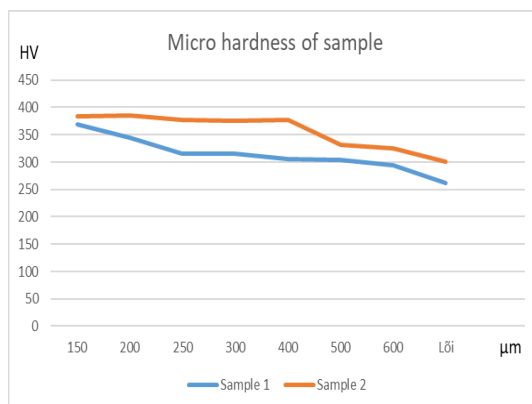
**Fig. 8** Microhardness of sample

Fig. 8 shows that for the region locating at the distance of 120 μm below the surface, the hardness value has a greater slope than the inside two samples. It can be commented that apart from durable elements such as particle size, carbide particles may also have the role of austenite nanoparticles produced by austenite particles. The modified sample S2 has stable hardness at great distances (about 400 μm). The depth and the value of hardening layers of sample 2 which will increase the wear resistance and impact toughness of this steel, is larger than the sample 1.

4 Conclusions

The results of the impact strength showed that when the samples were modified by RE and applied to the heat treatment process as above, the impact strength was 132 J/cm² higher than 115 J/cm² of the non-modified sample. This suggests that the role of the modifier in particle size reduction and the mechanical properties of this steel. The RE elements were greatly affected on the reduction of particle size, increasing the impact toughness of this steel.

The micro-hardness of the modified sample is higher than that of the non-modified sample (420HV is denatured compared to 395HV). Under the impact load, the microstructure of this steel have sliding, dislocation and nanoparticles. This structure were created by plastic deformation and austenite nanoparticles.

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