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Effect of Element Addition and Heat Treatment Process on the Properties of High Manganese Steel

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***Abstract*—The changing of properties of HMnS by alloy elements addition and heat treatment was presented. Studying about the hardness of HMnS were increased when the Mn contents increased. On the other hand, the Cr content has effective on the hardness and microstructure of this steel also, but with the Cr content was increased from 2% to 2,5%, the hardness of high Manganese steel was not much changed. With the research about HMnS, it was added the Cr and applied the advanced heat treatment process, the microstructure of this steel was formed the chrome carbide particles with grain fine which dispersed in the matrix with the formation of these dispersed carbide particles will contribute to increasing the alloy's abrasion resistance. With the difference in heat treatment processes, the microstructure and hardness were also changed. When the sample was heat-treated according to the model heat treating; the particle size of the sample is also significantly reduced. This explains why the hardness value of the sample increases significantly. Also, under the impact load, on the surface layer of this steel, the microstructure does not appear the martensite structure form but only see the twinning on the surface. These are new findings on the mechanism transformation of high manganese austenite steel when working under the impact of the impact force. The mechanism of transformation is quite different from the previous view of phase transformation under the impact force of high manganese austenitic steel.**

***Keywords*—austenitic manganese steel; alloy elements addition; heat treatment; microstructure.**

I. INTRODUCTION

In the trend of strong growth of science and technology, material engineering in general and metallurgical engineering, in particular, has made great strides. Besides the creation of new materials, the consolidation and optimization of the production and use of marking material have become more complete. The original Austenitic Manganese Steel was found by Sir Robert Hadfield in 1882. It is the high ductility and toughness; working under high impact conditions and good abrasion resistance. Today, the development and use of austenitic manganese steels increase powerfully by studying the composition changes and adding alloying elements, given the new heat treatment to improve the quality and performance of steel [1]. In high manganese steel, it is added the other elements. The carbon content is changed from 0.7 to 1.45%; in addition the Manganese content also is changed from 11 to 14%. Chromium increases the initial hardness and the hardness after deformation. Chromium reduces ductility by increasing the number of embrittling carbides in the austenite. Chromium is added to manganese steels usually contain 2-4% chromium [1]-[4].

Hadfield steels can change their mechanical properties by acting normal force, the impact which usually appears in the impact working environment. Under the environment, the steel has converged necessary properties as high wear resistance, high hardness, sufficient strength and ductile. This is very important for heavy industries in which high Manganese steel use widely. The pictures show three outstanding applications that are clinker, chain of tank and bucket teeth …. Each of them must work on very harsh conditions as high impact, high wear resistance. Therefore, our materials need especially mechanical properties that are better than other steels. In particular, the material must have high hardness, high abrasion, and sufficient ductile. For example, with a chain of the tank, the component runs on topographies as on the soft ground, under the river, on rock…. If the material of the chain does not meet these requests conducting to failure in operation. At room temperature, the steel is so ductile and has a microstructure of Austenite and become stiffer under acting impacts, force. This is particular strengthening mechanism of the steel [1], [5]-[8].

Fig. 1. Typical applications of High Manganese steel (bucket teeth, rock crushing equipment, chain of the tank)

Now, there are many the publishing works about the influence of elements alloys and add force on the properties of HMnS. According to those researches, the mechanical properties of HMnS were best when the Mn contents around 13%. But in recently years, with HMnS, the research about the mechanism of increasing strength under the impact load is changed so much [9]-[14]. Following the new standpoints, high manganese steel can get excellent wear resistance, better strengthened as well as hardened by adjusting more than 13%Mn with some alloy elements such as Cr, Mo,… Therefore, the heat treatment processes are also changed [10], [15]-[18].

In this research, the authors tried to improve the mechanical properties of this steel by added some alloying elements such as Mn, Cr, and heat treatment processes combined.

II. Materials and Methods

On the other hand, for investigation of the effects of Cr composition on microstructure and mechanical properties of steel were prepared. 2 types of 6 samples were poured, and the compositions were presented in Table 1.

TABLE I
THE CHEMICAL COMPOSITION OF STEEL

Type	Samples	C	Si	Mn	Cr	V
I	**I-1**	1.14	0.775	12.80	1.95	0.02
	I-2	1.23	0.762	16.10	2.20	0.03
	I-3	1.2	0.585	18.40	2.10	0.04
II	**II-1**	0.80	1.1	13.7	0.03	0.02
	II-2	1.13	0.78	12.8	1.91	0.016
	II-3	0.85	1.13	12.9	2.53	0.03

After heat treatment processing, the samples were impacted load then dissected the microstructure and hardness. In this article, we have used 2 types of heat treatment processes. A muffle furnace was used for these heat treatments. The first heat treatment process was called by Normal heat-treatment process. The specimens were austenitized at 1050°C for 3 hours to dissolve the more stable carbides and quickly cooled in water (Fig. 2).

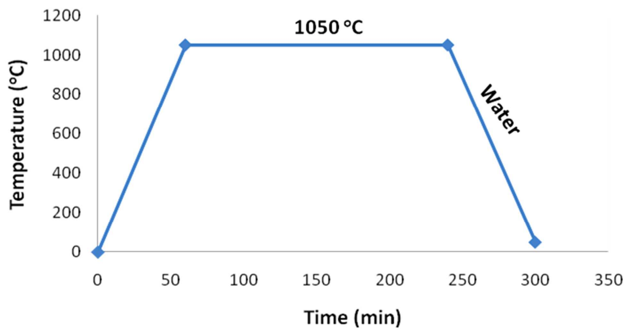


Fig 2. Normal of the heat treatment process

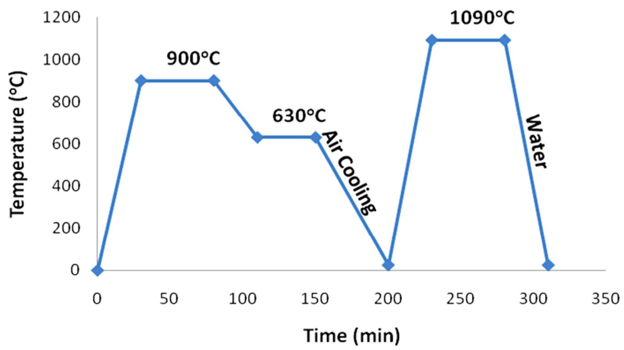


Fig 3. Model of the heat treatment process

The second way to heat treat samples is quite complicated and called by a new heat treatment process [19], [20]. The specimens were annealed before water quenched. Processing of this heat treatment, the sample was heated up to 900^{o}C, keep the temperature for 50 min and cool down 630^{o}C ad keeping in 40 min, then cooling in the air to normal temperature, and finally water quench at 1090^{o}C for one hour (Fig. 3).

If high manganese steel with austenite structure suffers impact load, plastic deformation occurs on the surface of steel, which results in great increasing of the hardness of surface. The experiments were carried out at the load. Samples were applied more than 1000 times by load of 12N/cm2 for observation of microstructure and hardness of specimens after applied impact load.

III. RESULTS AND DISCUSSION

A. *Effects of Mn content*

1) *Results about hardness*

The results are presented in Figs 4 and 5.

Fig. 4. The hardness of samples type A with Normal heat treatment process.

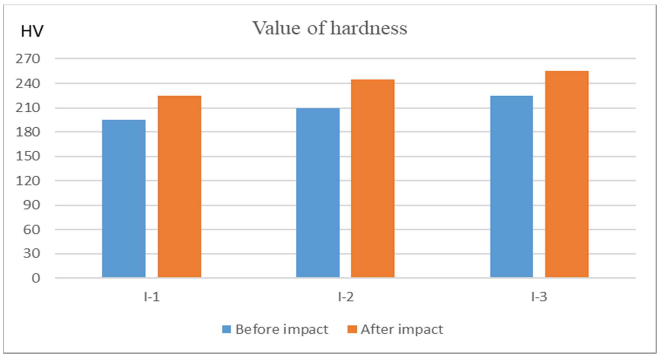


Fig 5. The hardness of samples type A with new heat treatment process

The hardness of high manganese steels totally increases after applied impact load for more than 1000 times. All hardness of samples is higher than 200 HV after application of impact loading. The difference of hardness of one alloy between before and after applied is about 30 HV. The hardness of alloys with the same composition, but varied heat treatments are different. The value of hardness of new heat treated samples is higher than Normal heat treating samples. All alloys heat treated with new heat treatment process has exceeding hardness values. Alternatively, with the Normal heat treatment, sample 3 is only one that has hardness reached the standard values, due to manganese content of 18%.

2) *Microstructure*

Figs 6 and 7 are showing the microstructure of samples A-1 and A-3 with the technology of Normal heat treatment. The bulk phase is austenite, and there are carbides within the grains and along boundaries. The measured grain size in sample I-1 is approximately 171µm, larger than that in sample I-3, which is 120µm. There are increasing amounts of carbides both at grain boundaries and within the grains. The carbide size was around 20µm. Sample I-3 with higher Mn content addition has a smaller grain size than sample I-1.

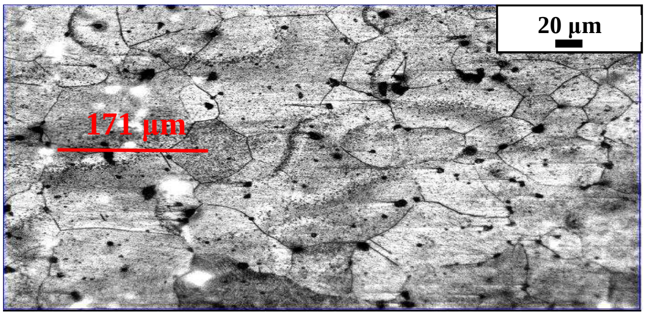


Fig 6. The microstructure of sample A-1 with Normal heat treatment process

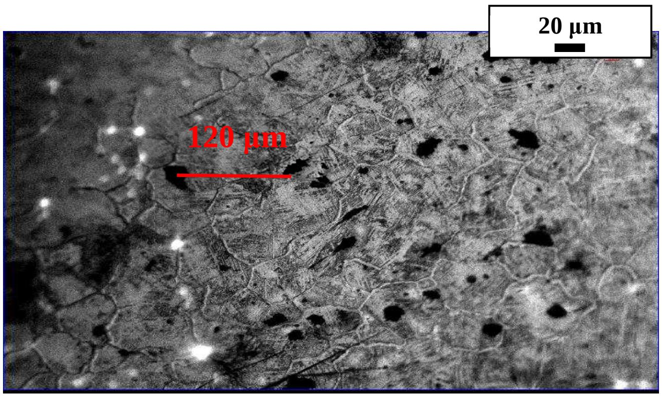


Fig 7. Microstructure of sample A-3 with Normal heat treatment process

The sample are impacted the load, the microstructure have twinning. Thereby, hardness measurements increased. Fig 8 showed the microstructure of sample I-1 after to applied impact load. After applying of impact load, twins are observed in the microstructure of the steel. Twins can be clearly observed. The effects of impact load are also changed with a different grain size of steel. With a small grain, the deformation of twins occurs very easily. Twins formation rate is also larger follows increasing of hardness. With the difference in heat treatment processes, the microstructure and hardness of samples were also changed. In the heat treated microstructure images of sample I-1 and I-3, showing in Figs 6 and 7, the undissolved carbides can be found that in the samples almost on the grain boundaries and a little within the grains. At the Fig 8, the higher fraction of undissolved carbides is on grain boundaries, about 20µm. The amount of undissolved carbides in these alloys is expected to increase the wear, but also to reduce the toughness of the alloys.

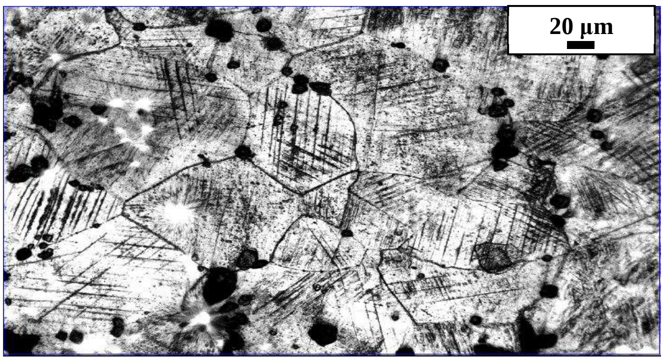


Fig 8. The microstructure of sample A-1 after impact load

The microstructure of sample I-3 with new heat treatment process is showed in Fig 9. In this case, the undissolved carbides can be found that in the samples almost within the grains and a little on the grain boundaries. The small particles present within the grain of this sample are expected to have a positive effect on the abrasive wear resistance, without giving too much loss in toughness. The heat treatment is a very important factor. When the samples were heated at 900^{o}C, carbides on grain boundaries are dissolved almost. In the grain, the little of carbides have in the microstructure. That explains the difference hardness of samples with difference technology of heat treatments.

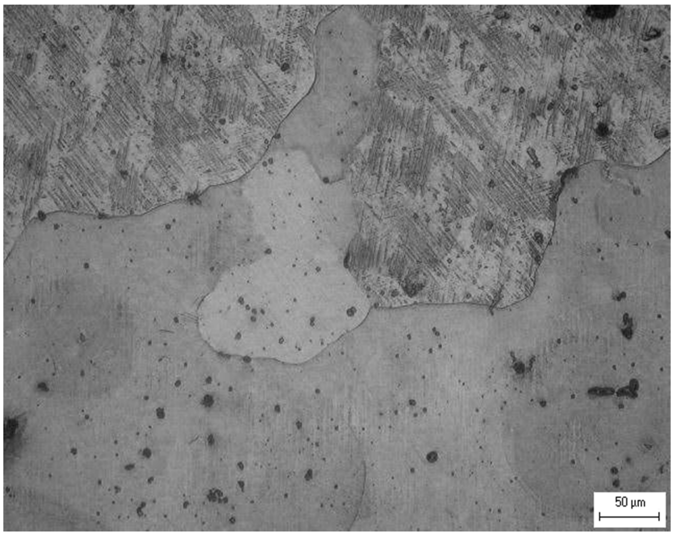


Fig 9. The microstructure of sample A-3 with new heat treatment process

B. Effects of Cr content

1) Hardness: The samples of type II with difference in Chromium contents are heat treated with only new heat-treatment

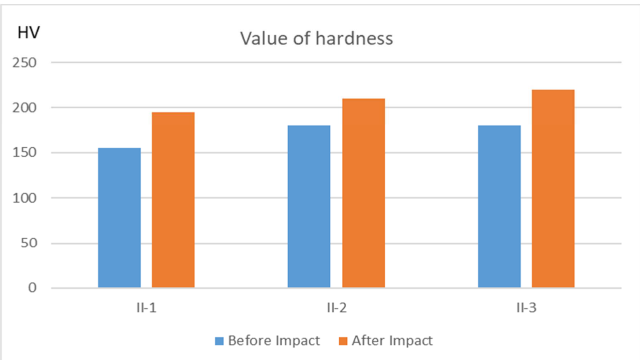


Fig 10. The hardness of samples type B with New heat treatment process

After applying impact load, the hardness of austenitic manganese steels were increased. When the Chromium contents were increased, the hardness of this steel were increased, but the hardness was not much increasing when the Chromium composition increased from 2% to 2,5%. The final hardness in Hadfield steel with Chromium addition is a little higher than that of standard Hadfield steel.

2) Microstructure: The microstructure of samples B-1, B-2, B-3 with 0%, 2% and 2.5% Cr in composition before and after impact load were shown in Figs 11, 12, 13.

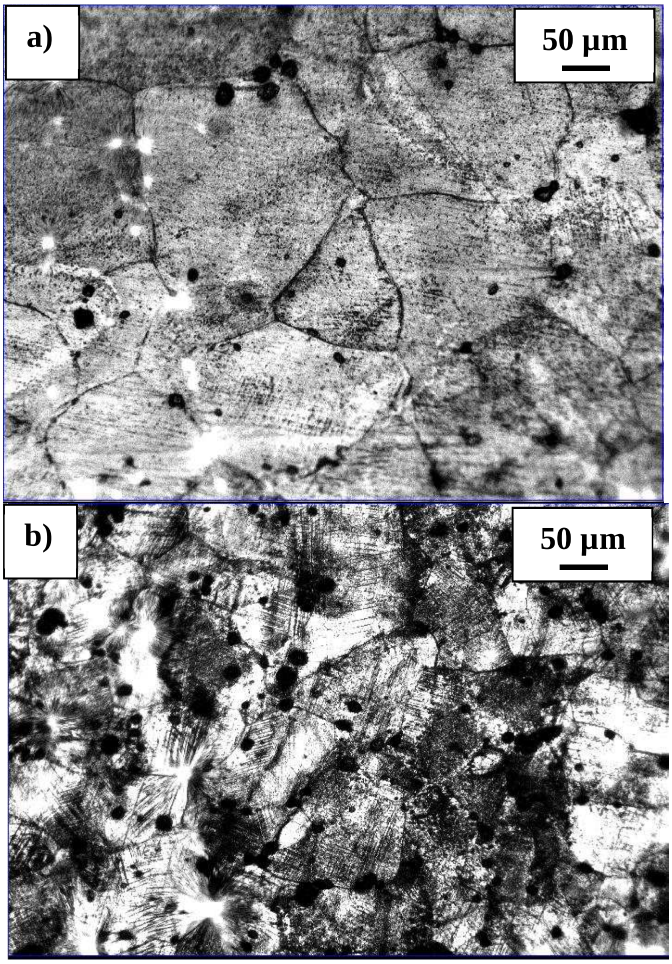
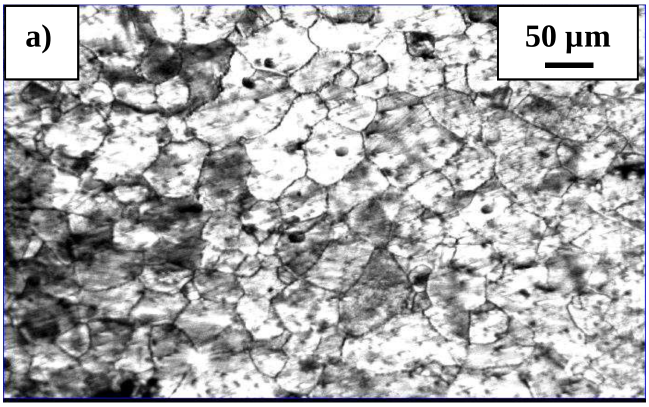


Fig 11. The microstructure of sample B-1. a) Before impact load b) After impact load

Following the microstructure pictures, is has almost austenite, and there are some carbides in the grains and grain boundaries. The measured grain size in High Manganese steel was decreased when the contents of Chromium addition are increasing. Twinning is stronger if applying of higher load. Thereby, hardness measurements increase a large number followed the bigger load. Microstructure development in Austenitic High Manganese steels are showed in Figs11b, 12b and 13b during the twinning and work hardening in steels. After applying of impact load for 1000 times, twins are observed in the microstructure of the steel. And the carbides are partly dissolved into the microstructure. In a comparison of impact load applied on samples, the deformation of twins is stronger in samples applied heavier load. That agrees with previous research of High Manganese steel. Alloy B-2 and B-3 with Chromium addition have smaller grain size then alloy B-1, but its final hardness is a larger one. With a small grain size, the deformation of twins occurs very easily. Twin formation rate is also larger follows increasing of hardness.

In a high magnification, the carbides are found in Fig 11a, 12a, and 13a. A higher fraction of undissolved carbides is on grain boundaries, and the grain size of carbides is about

20μm. A few of twins are also observed even though in the heat treated microstructure. The amount of undissolved carbides in these alloys is expected to increase the wear resistance, but also to reduce the toughness of the alloys. The heat treatment is also an important factor. That explains the different hardness of alloys heat treated with the technology of new heat treatment process.



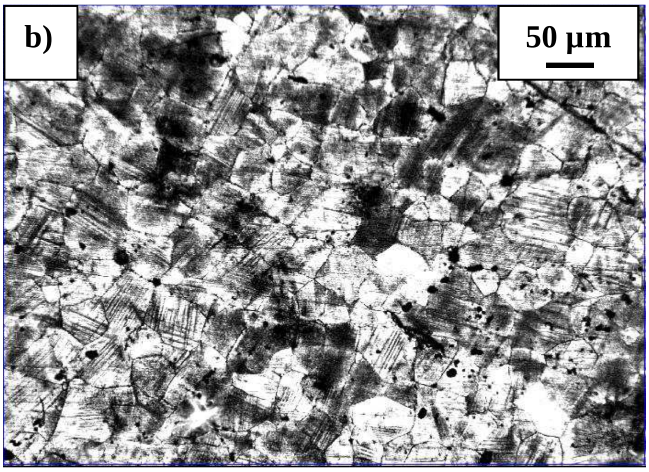
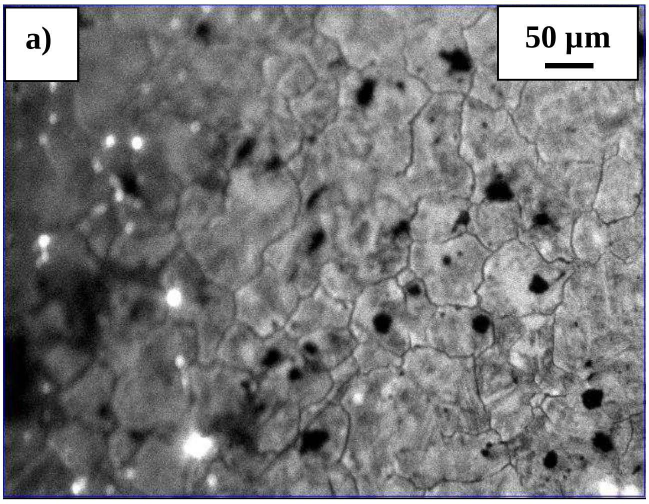


Fig 12. The microstructure of sample B-2. a) Before impact load b) After impact load



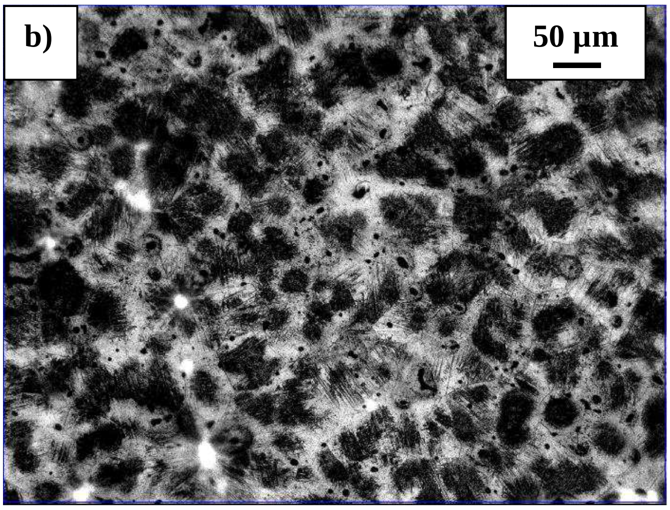
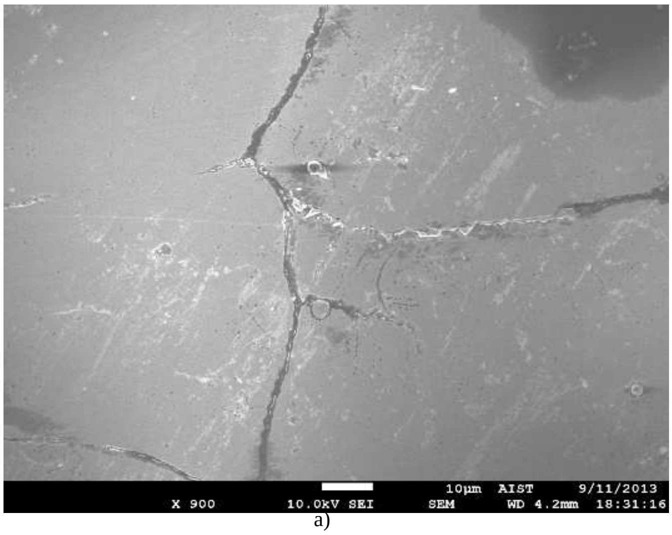


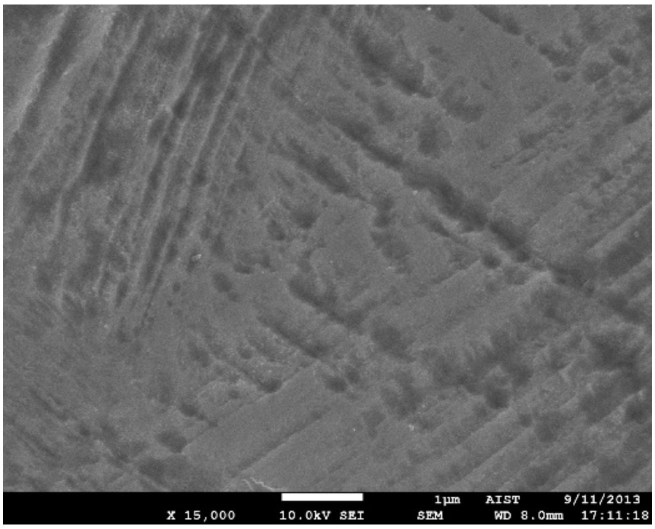
Fig 13. The microstructure of sample B-3. a) Before impact load b) After impact load

Deformation of twins is expected to make different hardness after impact loading. The transformation occurs even though at room temperature.

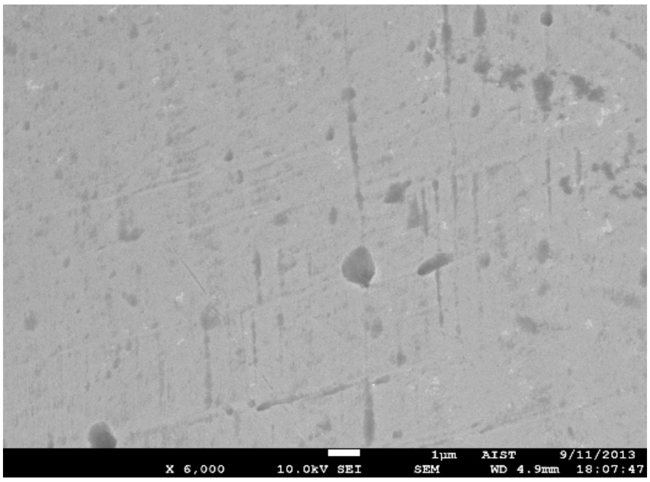


a)

b)



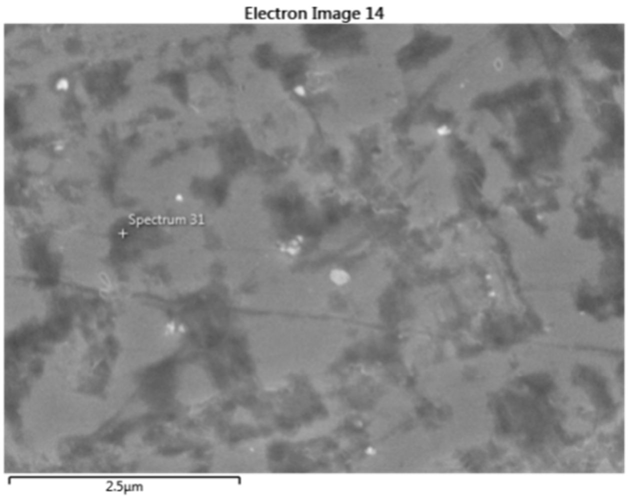
c)



d)

Fig 14. SEM of sample B-1 (a;c); B-2 (b;d) – after heat treatment (a;b) and impact load (c;d)

Fig 14 shows sample SEM images B-1 and B-2 after heat treatment (a, b) and after impact load(c, d) the same impact mode. See that the non-alloyed samples have passed the heat treatment after abrasion to create a very deep scratch, while the 2% metal alloy after abrasion scratches create very faint. In order to be able to define further the organization as well as the type of carbide particles that exist in steel, after microstructure analysis using optical microscopes, impregnated samples and scanning electron microscopy methods (SEM and atomic analysis according to points (EDS points)). SEM analysis and point-based elemental analysis (EDS point), the samples that have passed the heat treatment after impacting, have not found the martensite structure but only saw the appearance of twins on the austenite background, once again show that the hardening effect after impact is due to twinning deformation. Also, for highly efficient alloyed samples, it is achieved by dispersing carbide particles inside the austenite substrate. This is clearly demonstrated by EDS analysis.



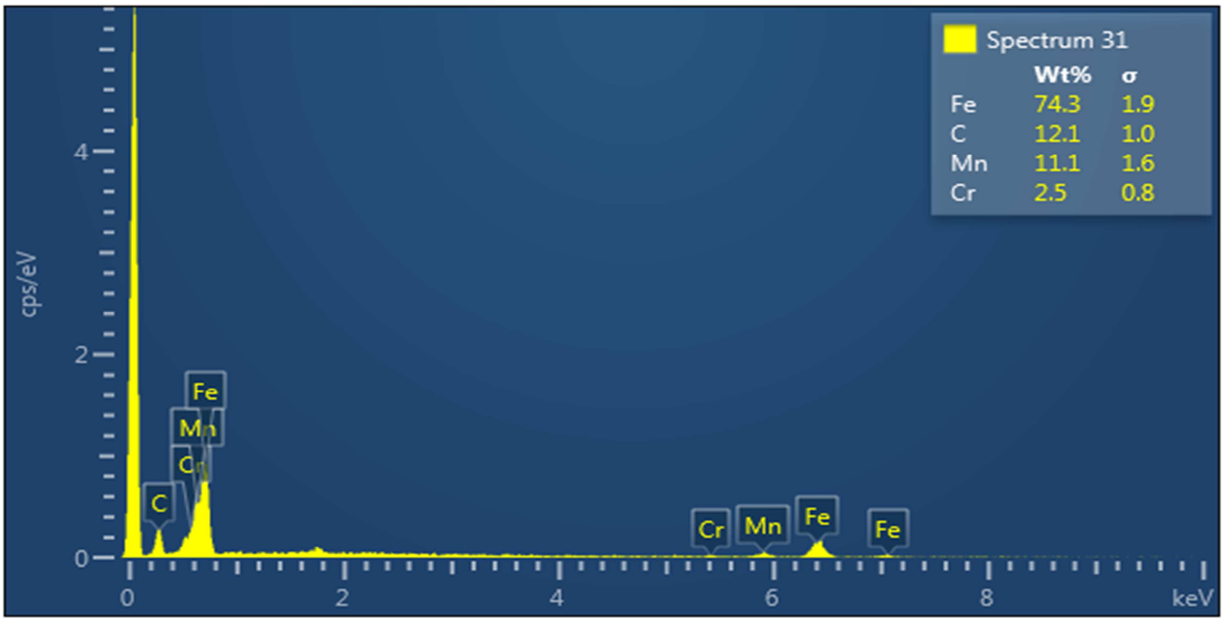


Fig 15. EDS of sample B-2 – after heat treatment

Fig 15 shows the results of EDS's sample B-2 analysis after heat treatment. In Fig 15 it is possible to see scattered carbide particles in austenite. These carbide particles act as hardening and sliding barriers, increasing the wear resistance of steel. This means increasing the amount of Cr, the more amount of sliding phase, the more created the twin, the more stiffness. In addition, as analyzed above, with increased Cr content, more carbide, smaller austenite particle size, under the impact, duplex tends to be multidimensional, increase in slip resistance, and ability to stabilize objects whether increase.

IV. Conclusions

When the HMnS were added the Manganese and Chromium which created the carbides that increase the hardness of its. When increasing Manganese composition, the hardness of High Manganese steels is increased. When increasing Chromium composition, the hardness of High Manganese steels is also increased but the Chromium content not need to more than 2.5%. Under applying with high impact load, the hardness of High Manganese steels increased, that is based on the work hardening. Twins are observed in microstructure and deformation of twins is the main role to work hardening occurred in high manganese steel. A New heat treatment process is necessary to research and develop. Following the New heat treatment process, the carbides are distributed in the austenitic matrix as reinforcement cause increasing the hardness of steels, during annealing.

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