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Effect of inoculation by molybdenum and nickel on hardening phenomenon and wear behavior of high manganese steel

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Abstract

Manganese steel demonstrates a great rate of work hardening during service, together with good toughness, leads to its widespread use in the heart switching crossings of railways, excavators, mineral crushing equipment and other severe mechanical environments. The specification for the standard steel has 10–14% manganese and 1.0–1.4% carbon, although modern variants often include chromium as well. Its structure is fully austenitic in the normal quenched condition. In this study we focus on the influence of inoculation by molybdenum and nickel and molybdenum-nickel on the surface hardening or the hardened part and wear resistance of the manganese steel. The melting of this steel is carried out in an industrial electric furnace. The transformation of austenite during operation, thus determines the steel operating lifetime, the rate transformation of austenite to martensite can introduce a compromise between ductility and wear resistance of the steel to support large efforts without breaking. The purpose of this study is to improve the abrasion and friction resistance after heat treatment of this steel. The results showed that the inoculation by molybdenum and nickel and molybdenum-nickel has strongly influenced the structure crystallization character before hardening (Part hardened). Secondary carbides of variables form and finesse are observed in the microstructure, before heat treatment and disappeared completely by dissolution after heat treatment (quenching). Comparing to the base steel, a greater thickness of the hardened part, a hardness increase and a wear resistance improvement are observed.

Keywords: MANGANESE STEEL, INOCULATION, EFFECT OF MOLYBDENUM, EFFECT OF NICKEL, EFFECT OF MOLYBDENUM-NICKEL, HARDENED PART, WEAR RESISTANCE

1. Introduction

Austenitic manganese steel (1.0%–1.4%C, 11%–14%Mn, wt.%) combine high toughness and ductility with high work hardening capacity and good resistance to wear[1].The unique properties make them widely used in the engineering fields, such as metallurgy, mining and railway [2]. However, their work hardening capacity can only be obtained under heavy stress or high load impact. Under low load impact, their work hardening properties are poor [3]. The researches had revealed that the formation of deformation twins and its concomitant serious lattice distortion induced by interstitial carbon atoms result their work hardening in manganese steels [4]. However, deformation twinning can take place in manganese steels only roughly above 5% true tensile strain. At lower strain, they deform primarily by dislocation slip. Therefore, to improve the work hardening capacity under lower stress, the deformation mechanism must be changed in the manganese steels [5].

With the superior work-hardening characteristics, manganese steel is one of the excellent wear resistant materials, which has been widely used for more than a hundred years. The Manganese steel is a very special Fe-based alloy; it adopts an FCC structure from freezing point until room temperature, just like the pure iron which adopts a bcc structure from freezing point until room temperature [6].

In this study, we are particularly interested in steel characterized by the inoculation of two elements behavior (first are carbide forming elements and other are only strongly gammagenous) at concentrations ranging from 0.1% to 0.3% in steps of 0.05%. The main factor in hardening steel is, in practice, the precipitation of carbides. The need to condition the precipitation of carbides correctly, that is to say, to cause their precipitation within the grains of the steel is very important [7]. From a general point of view, this result is obtained, for many metals, by heat treatment, operations that cause structural transformations that can be presented as follows [8]:

- The dissolution of precipitates by heating to a temperature high enough (depending on the alloy composition and equilibrium conditions);
- Fast to prevent precipitation and thus keep cooling the alloy in the supersaturated state at room temperature.

The results highlighted steel compositions whose structural stability is higher than that of industrial steel standard quality.

It is now well established that it is useless to try to systematically connect the mechanical properties directly to the presence of alloying elements without considering the proportion of the latter, the carbon content and, especially heat treatments applied and the final structure [9].

Highlight key points from where most of the failures and contribute to help different actors to address an austenitic manganese steel wear problem with the best chance of success it is intended to.

2. Experimental procedures

2.1. Cast samples

Here Samples for metallography and the wear test are inoculated and cast in the form of cylindrical bars of 20 mm diameter and 100 mm in length (figure 1) in molds made from sand with sodium silicate [15].

Table 1. Chemical composition of the tested steel

C	Si	Mn	Mo	Ni
1.40	0.58	12.06	0.1-0.3	0.1-0.3

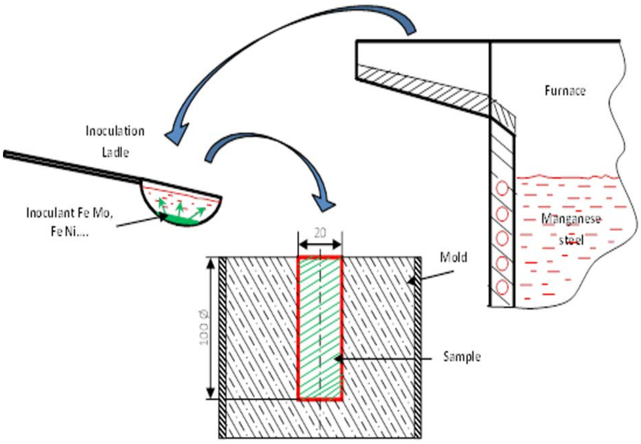


Figure 1. Inoculation and casting samples

The alloy is used in an electric arc furnace; the chemical composition is given in table 1. The additions of elements are added in the form of ferro-alloys (ferro Mo) and chemically pure metal (nickel).

2.2. Metallography

The preparation of samples for micrographic observation (optical, SEM) required by the conventional polishing method of preparation and finish with a fabric-covered diamond paste. All samples used for this study are attacked in nital 4%, except for samples of hardened parts are attacked by oxalic acid (electrolytic etching); the Table.1 shows the major components of the experimental steel.

Metallographic observation of different microstructures is performed on a scanning electron microscope and optical microscope such as “LEICA” with a camera [15].

2.3. Wear

To characterize the steel study, wear tests Friction, impact and hardening are performed under the same conditions of industrial farms. The results of the wear tests are given after annealing treatment because steel is used in this state [14].

The friction test is performed on a standard laboratory device used by the entire industrial world (figure 2).It consists in measuring the amount of material lost after passing 40 m sample on a quartz disk size 120 mm, with a rotational speed of 120 revolutions / minute and a load P of 0.5 Kgf. [15].

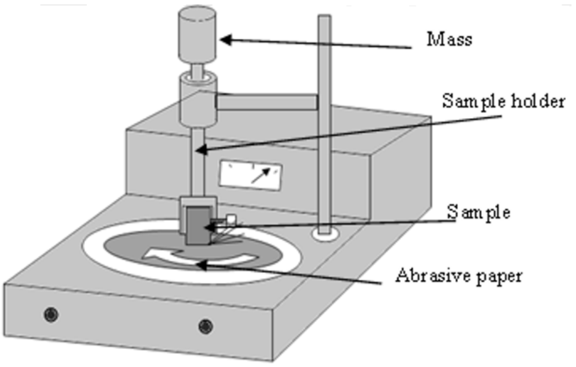


Figure 2. Abrasion test device

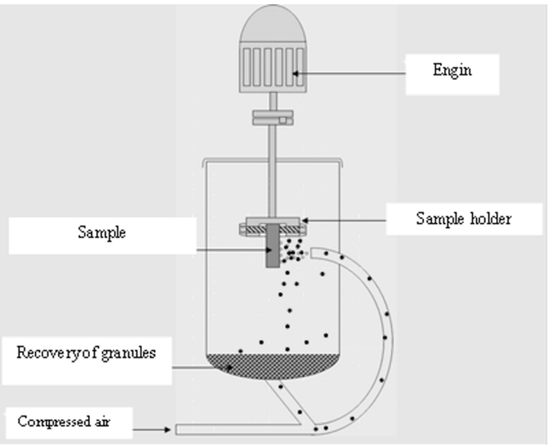


Figure 3. Impact test device

The impact test is another type of wear experienced by the material during operation and which determines its strength and durability. This test is to test samples under a jet of shots thrown in at a pressure of 5 bar (figure 3) white cast. The loss of material is measured after each minute interval for 10 minutes [15].

2.4. Tests hardening

Work hardening is a process of structural changes which take place without resorting to heat treatment during which the austenite is transformed into martensite under the effect of repeated impacts. The device used for this test is represented in (figure 4); this equipment ensures the same test conditions for all samples [13].

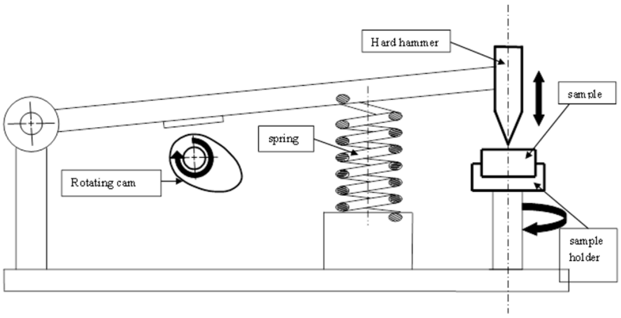


Figure 4. Hardening test device

2.5. X-rayTests

A Panalytical X Pert Highscore diffract meter with Cu-Kα radiation was utilized for the X-ray diffraction studies. The scalar dislocation density was determined by X-ray diffraction (XRD) using the method described in [12].

3. Results and discussion

3.1. Metallography

The studied base steel, whose chemical composition is given in Table 1, presented in the cast state a matrix of austenitic grains, manganese carbide and form of fineness variable (figure 5a). After heat treatment (annealing), the precipitated carbides are completely dissolved in the matrix. The microstructure in this state consists of two types of austenite [2], one enriched and the other depleted (figure 5b).

Concerning the influence of inoculation by nickel on studied steel cast state, we observe that the austenite grain is coarser compared to the base steel, but in general the grains of austenite have substantially the same size. As against the carbide precipitates increases and becomes almost globular shape (figure 6). This is probably explained by the fact that this element is dissolved in larger amounts in the austenite and manganese tends to bind with more carbon. After heat treatment the basic steel and the alloyed steel exhibit two types of austenite (an enriched and a depleted) in the microstructure. The enriched austenite occupies a large part of the matrix to 0.10 and 0.15% Ni, but it begins to decrease from 0.20% Ni (figure 6).

The inoculation by molybdenum in the studied steel is to improve harden ability and consequently its operating properties. By comparing the different microstructures observed on the basic steel, we note that molybdenum is the shape, the distribution and the amount of carbides (figure 6). 0.10 to 0.30% molybdenum acted on the formation of precipitates in the metallurgical structure of the steel in the as cast state. These are more or less large compared to those of the base steel and become in irregular shape by taking very elongated shapes. The molybdenum carbide effect associated with the manganese may be the cause of this transformation. This is only 0.30% Mo carbides precipitated that become more or less rounded, fine and well distributed (figure 6). On the heat treated condition, 0.10% Mo from the amount and form of the impoverished austenite are totally different than the base steel. There is an increase of austenite enriched at the expense of the impoverished. This trend continues up to 0.20% Mo in which the amount of austenite enriched occupies more than 90% of the matrix. This can be explained by the fact that molybdenum is stronger as carbide forming element than the manganese. The molybdenum quenching effect is very significant. The depleted austenite in this case takes a rounded shape and is distributed uniformly. Beyond 0.25% Mo, the amount of austenite impoverished begins to increase, changes shape and becomes almost dendritic.

In combined with 0.10% (Ni + Mo), in the as cast steel, carbide precipitates are very thin compared to other cases where the steel has been alloyed with only one element and are evenly distributed in the structure of the steel. These are globular shaped (figure 6). As against to 0.30% (Mo + Nb), they are virtually the same as those containing 0.1% (Ni + Mo) and are located at the grain boundaries of austenite As the austenite grains, they become to 0.30% form (Ni + Mo) (figure 6) is larger than most 0.10% (Ni + Mo). After heat treatment, we observe that the enriched austenite increases in the samples containing 0.10% (Ni + Mo), but decreased for those of 0.30% (Ni + Mo). The austenite depleted in this case dominates the enriched one (figure 6).

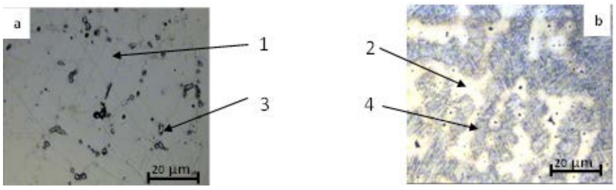


Figure 5. Master steel micrograph

a: before heat treatment, b: after heat treatment.
1. Austenite (γ) 2. Mn-enriched Austenite 3. Precipitate 4. Mn depleted austenite

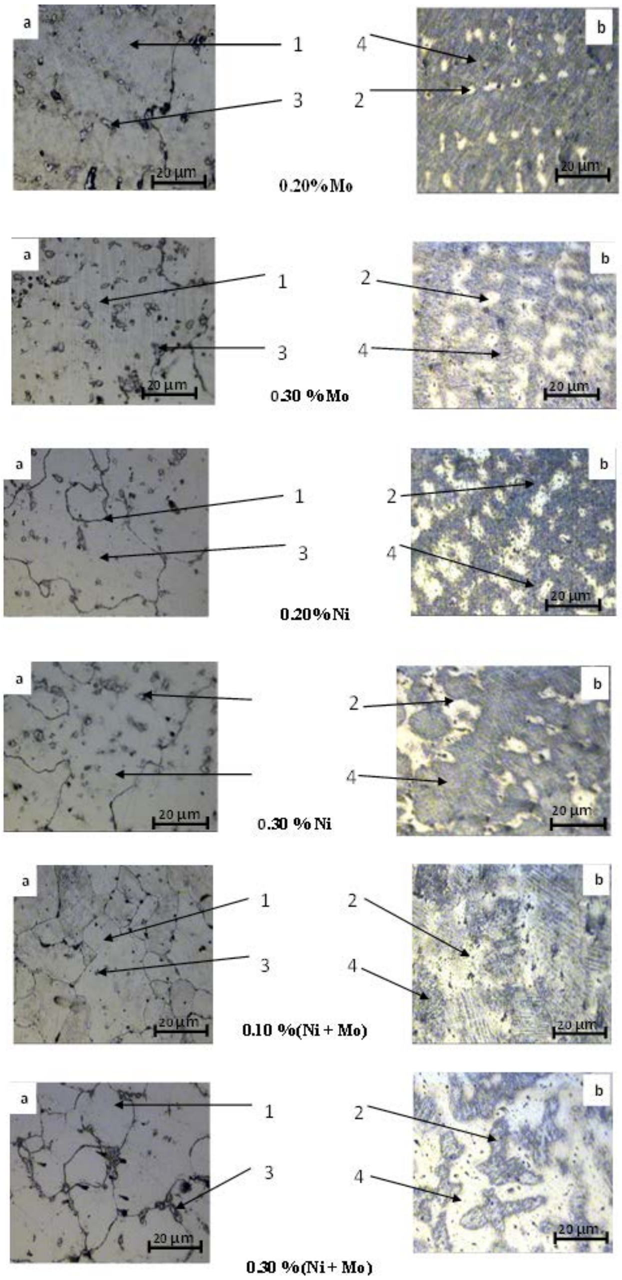


Figure 6. Manganese steel alloyed with Ni and Mo

a: before heat treatment, b: after heat treatment.
1. Austenite (γ) 2. Mn enriched austenite 3. Precipitate 4. Mn depleted austenite

3.2. Hardening test

The use of hardening test is necessary to determine the steel impact resistance used for the production of railway parts. These later are subjected to a heavy shock during their operation. Therefore, this test is very interesting to simulate the same conditions. Figure 8 shows micrographs of hardened zones with different thicknesses obtained in the samples. The test strain hardening has a significant improvement in hardness with a gap of 150 to 300 HV (Table 2) between the hardened surfaces of the base steel and alloy steel Mo and Ni, this reflects the structural transformation taking place and also the influence of these elements on this layer (figure. 7, 8, 9).

After hardening we see the emergence of two microstructural layers characterized by high hardness (table 2) of this layer compared to that of the structure of the heart is between 280 and 300 HV (figure 7)

Table 2. Micro hardness of the work-hardened layer

Master steel	0.3 Ni	0.3 Mo
460 - 503 HV	675 - 698 HV	700 - 760 HV

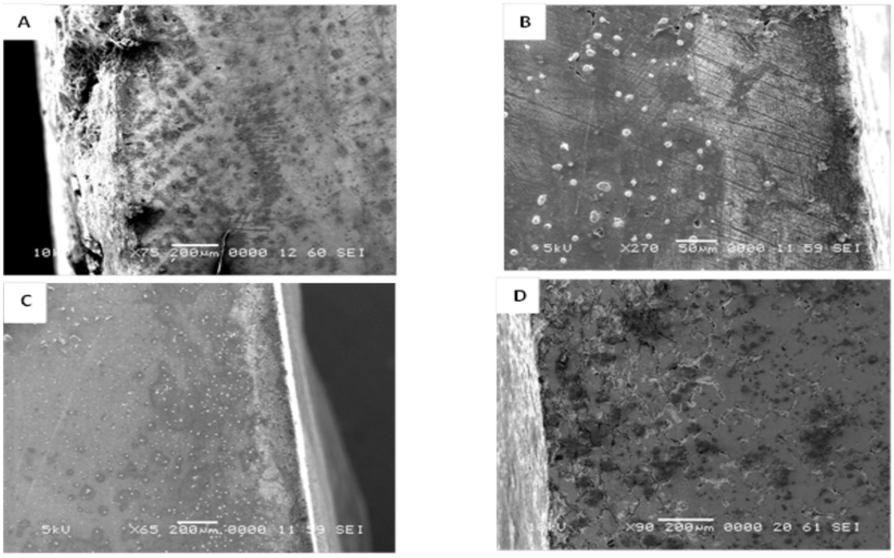
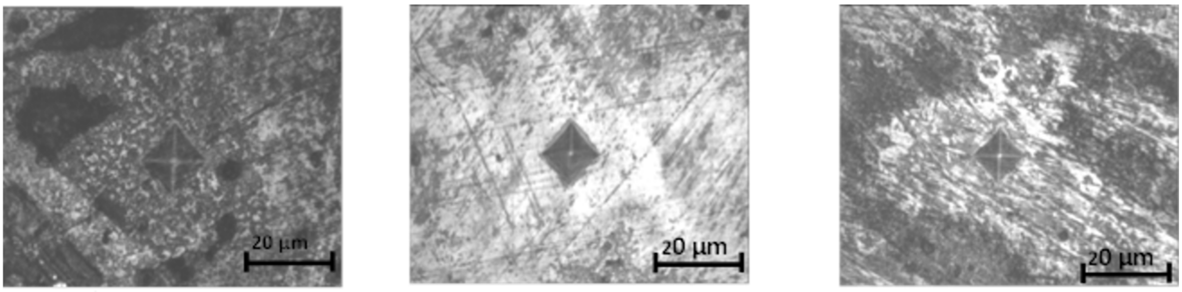


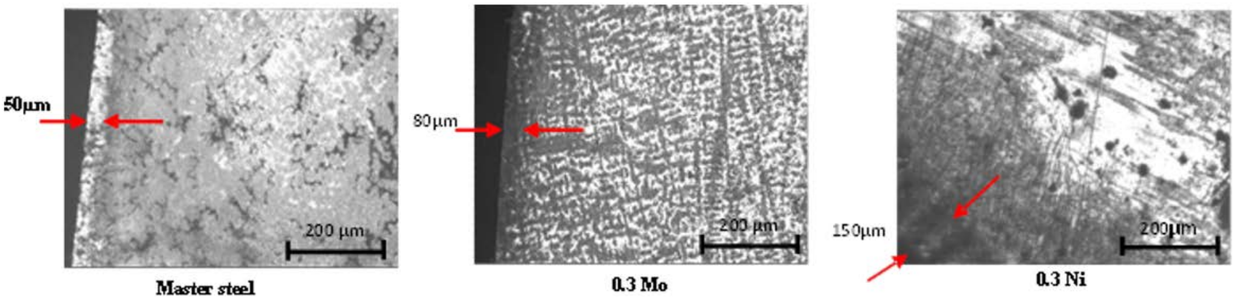
Figure 7. SEM microstructures of hammer-hardened part of the manganese steel

A = base steel B = 0.3% Ni C = 0.25% Ni D = 0.3% Mo



Master steel 0.3 Ni 0.3 Mo

Figure 8. Microstructures with imprint of the micro hardness of hardened part of examined steel
Attacked by oxalic acid (HV0.2)



Master steel 0.3 Mo 0.3 Ni

Figure 9. Microstructures of hardened part of examined steel.
Attacked by oxalic acid

3.2. X-ray studies

The X-ray diffraction of this steels under investigation, regardless of the number of revolutions, this method revealed a sharp phase texture (figure.10) .Measurement of the coherent scattering regions provides the values of structural parameters before and after inoculation of Mo and Ni (figure 10). In the Fe–Mn–C and 0.3 Ni steel, the coherent scattering regions vary slightly Slower with the strain, and the dislocation density is 0.3 Mo steel Lower compared to the other two steels (figure. 10).From the three studied steels, a maximal growth in the crystal lattice micro strain and dislocation density with increasing number of revolutions was observed in single crystals of Fe–13Mn–1.3C 0.3 Mo Ni (figure.9).

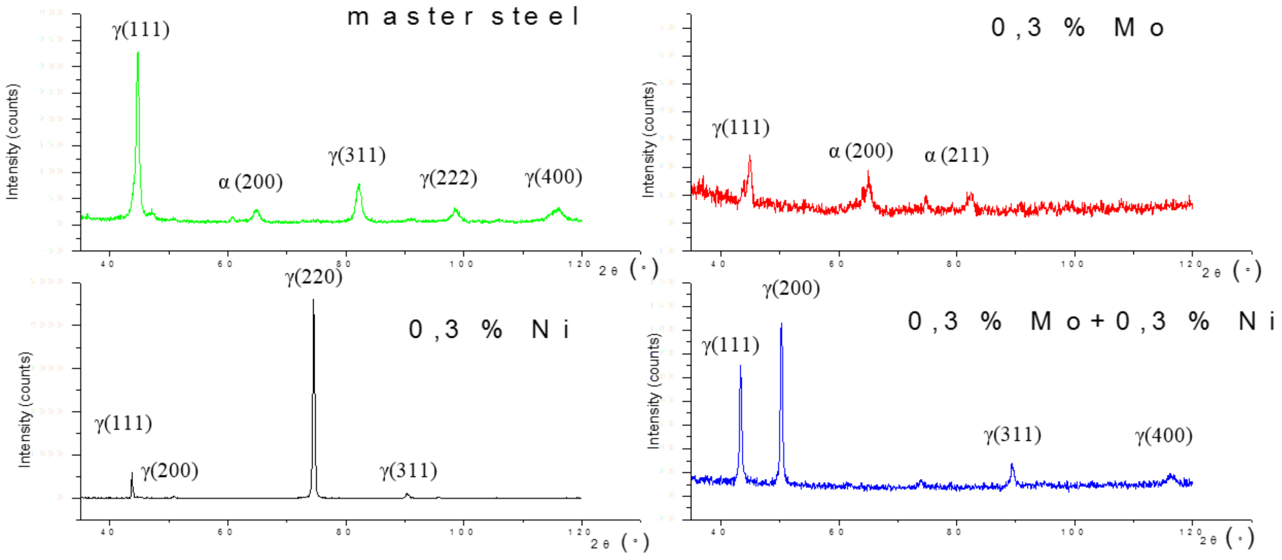


Figure 10. X-ray diffraction of examined steel

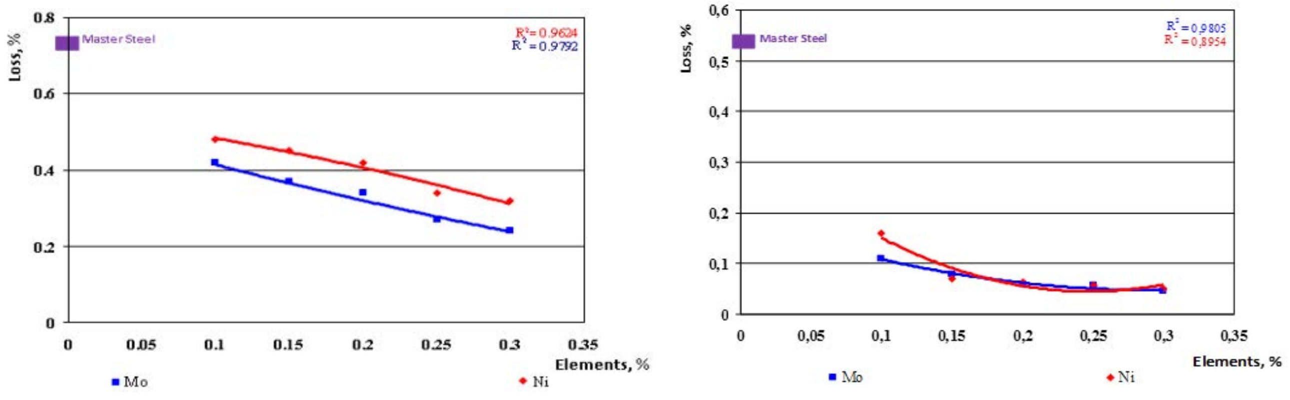
3.3. Wear

In order to characterize the studied steel, we used two wear modes. The first method is to measure the abrasion under the same conditions of factory farms and the second is to determine the impact wear as described in the experimental method. The results of wear tests are given after annealing treatment because steel is used in this state [10].

3.3.1. Friction wear

A State Treaty, molybdenum 0.1% is very more affecting this feature compared to nickel before and after heat treatment. This is explained by the effect of soaking it. From 0.15%, the influence of nickel and molybdenum join after heat treatment. We can always point out that these have greatly high resistance to abrasion. Based on tests performed on steel with one element addition, we note that the element molybdenum is best suited to withstand this type of wear (figure 11).

Upon addition of two elements (Mo-Ni), according to the experimental design adopted, we note that the mass loss expressed as a percentage decrease in a very significant manner (figure 12). The elevation of this property is mainly due to the increase in micro hardness, different austenite enriched and impoverished caused by the dissolution of these elements in the past.



Before heat treatment **After heat treatment**

Figure 11. Mass loss (%) by friction wear of steel alloyed with Mo and Ni. *Before and after heat treatment.*

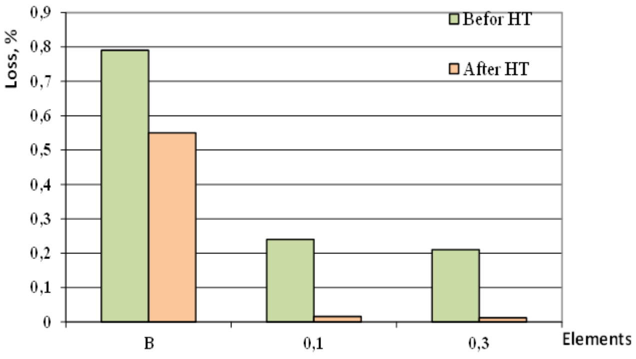


Figure 12. Mass loss (%) by friction wears of steel alloyed with Mo+Ni

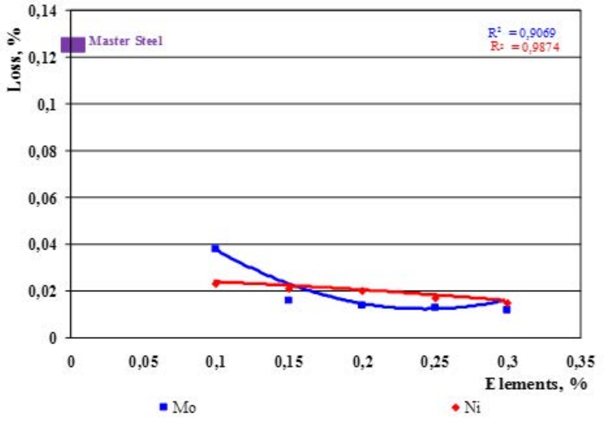
3.3.2. Impact wear

The use of impact wear test under the influence of shot is needed to determine the wear resistance of steel studied for the production of parts for crushing (beater crusher: part cement). These parts are undergoing significant impact on their operations. That is why this test is very interesting to simulate the same conditions.

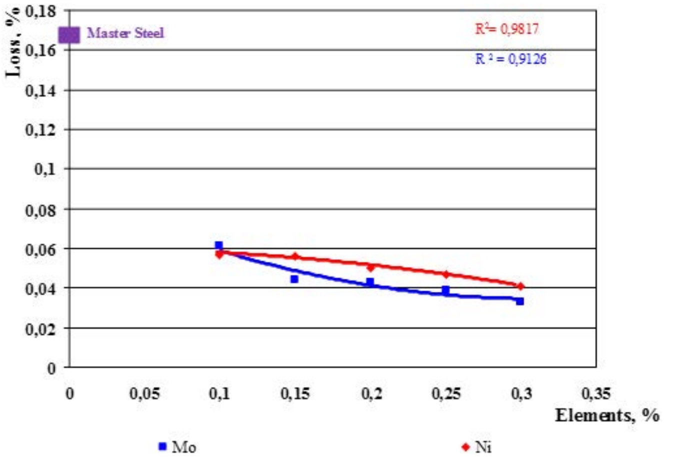
It is noted that the condition being treated, the influence of molybdenum and nickel all proportions gave the best results (figure 13). Upon addition of two elements (Mo-Ni), the impact mass loss at 0.1% (Mo-Ni) is the same as that of 0.3% Mo, by gradually decreasing it against 0.3% (Mo-Ni) (figure. 14).

The introduction of the two addition-cast elements made to increase the wear resistance by impact against the base steel.

The results of impact wear before and after heat treatment compared to the base steel are very remarkable compared to test abrasion. The loss of material after the wear test by impact compared to that measured after the wear test friction is estimated at four times less. This eventually leads us to conclude that there has been a change in the micrographic structure of the steel studied under the action of this test (impact) and that is highly hardened steel. (figure.14)



Before heat treatment



After heat treatment

Figure 13. Mass loss (%) by impact wear of steel alloyed with Mo and Ni. *Before and after heat treatment.*

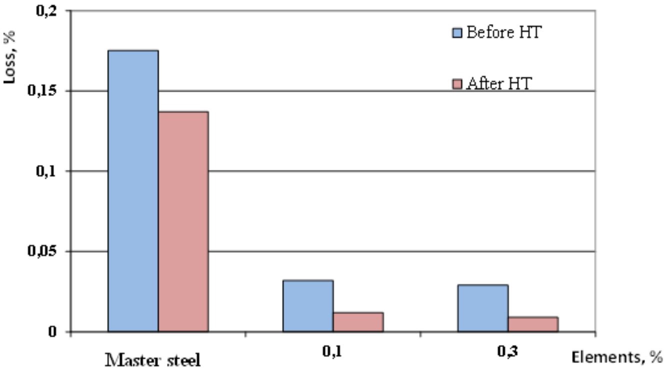


Figure 14. Mass loss (%) by impact wear of steel alloyed with Mo+Ni

Conclusion

The focus on improving operating manganese steel properties continues to grow because this alloy occupies an important place in the parts and pieces of railway, agricultural sectors mining, steel, mechanical etc. To achieve this, we have inoculated this steel with molybdenum (strong carbide-element) and nickel (gamma-element or strongly stabilizing austenite), the content of these elements is increased by inoculation from 0.1% to 0.3%.The inoculation by elements introduced in the studied steel gave a remarkable effect on the observed structures. The micrographs of different experienced steels observed before and after heat treatment showed:

- An appearance in various micrographic structures of variable fine carbides precipitated in large quantities relative to base steel;
- A formation of two types of austenite, and the other one enriched and depleted complete dissolution of precipitated carbides under the action of the heat treatment (annealing), the X ray confirmed this change in microstructure.

- A layer hardened harder and thicker than the base steel.

As for the wear resistance, it is especially strongly influenced by the addition of these elements to cast state and after heat treatment.

This study of the resistance to abrasion and impact of austenitic steel with 12% manganese annealing has led us to develop a new steel grade to meet the industrial requirements.

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