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Effects of Niobium and Molybdenum on Microstructures after Hardening and Wear Resistance of Austenitic Manganese Steel

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Abstract. Hadfield steel has been wildly used to manufacture railway crossings because of its excellent work hardening, high strength and toughness properties. The hardness of Hadfield steel is only about 20 HRC when subjected to water toughening. This low hardness is usually associated with poor wear resistance and severe plastic deformation, as well as abrasion of the working surface of the railway crossing during the initial service period, which remarkably reduces its service lifetime. In this study we focus on the influence of niobium and molybdenum on the phenomenon of surface hardening or work hardening and wear resistance. The transformation of austenite during operation, thus determines the steel operating lifetime, the rate of transformation of austenite to martensite can introduce a compromise between ductility and wear resistance of the steel to support large efforts without breaking. The objective of this study is to improve the wear resistance by abrasion and friction after heat treatment of manganese steel alloyed with niobium and molybdenum. The addition of niobium and molybdenum promotes secondary hardening and allows slower transformation of austenite during the heat treatment. The results showed that the introduction of niobium and molybdenum has strongly influenced the character of the structure crystallization before hardening (Part hardened) by precipitation carbides form and finesse variables is observed in the microstructure before heat treatment and complete dissolution is noted after heat treatment, for the hardened part (work hardening) we observed a greater thickness and hardness compared to the base steel and net improvement in wear resistance.

1 Introduction

The manganese steel or Hadfield steel is well known for its high capacity for hardening work and high wear resistance. The alloy of Fe-C-Mn with these properties of hardness and high work hardening rate is specifically used in castings parts crossing railways, jaw crusher, impact hammers etc..[1]. the main elements of a Hadfield steel include approximately 10 -14% Mn and 1 - 1.4% C. The high manganese content is used to lower the stacking fault energy and to increase the solubility of carbon and nitrogen in interstitial positions. The solubility of interstitial elements allows high concentration of carbon without precipitation of carbides. In addition, the carbon reduces the temperature of the martensitic transformation (Ms) during tempering and also during the deformation. [2]. The structural stability of manganese steels depends on the chemical composition and mechanical or thermal stresses to which it is subject.[3]

The main factor in hardening steel is, in practice, the precipitation of carbides. It needs to properly condition the precipitation of carbides, that is to say, to cause their formation within the matrix is very important [4]. In a general way, this result is obtained for many metals by heat treatment operations that cause structural transformations that can be summarized in a set of solution precipitated by heating to a sufficiently high temperature and rapid cooling [5].
The results show that the steel compositions whose structural stability is higher than that of industrial steel of 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 these latter and of the carbon content and especially the heat treatments applied and the final structure [6].

This work focuses on improving the wear behavior and the impact of manganese steel for the production of mechanical parts by the addition of alloying elements.
The objective of this study is to introduce the elements of alloy with carbide character. It is the added molybdenum and niobium in a range of content ranging between 0.1 and 0.3% with a step equals 0.05%

2 Experimental techniques:

2.1 Cast samples

The samples are prepared in an oven at industrial induction. They are cast in a mold made of sand with sodium silicate in the form of cylindrical bars of size equals 20X100mm and cut for various characterizations and heat treated (hyper quenching). Niobium and molybdenum are added as ferro-alloy (Fe-Nb and Fe-Mo). Chemical analysis of the base steel is presented in Table 1.

Table 1. Chemical compositions of experimental alloy (wt%)

C	Mn	Si	S	P	Cu	Al	V
1.40	12.06	0.58	0.032	0.058	0.23	0.17	0.038

2.2 Metallography

The preparation of samples for micrographic observation, needs polishing following the conventional method of preparation then finished with a fabric-covered diamond paste.

All samples used for this study are attacked by Nital at 4%, except for samples of hardened party are attacked by oxalic acid (electrolytic etching).

The metallographic observation of different microstructures is performed on an optical microscope such as "LEICA" camera.

2.3 Wear

For characterize the steel study, wear tests Friction, impact and hardening are made in the laboratory to simulate the same conditions of industrial operations. The results of the wear tests are given after treatment of hyper-quenching because steel is used in this state.

2.3.1Friction wear

This test is performed on a standard laboratory device used by the entire industrial world (Figure 1).

It consists in measuring the amount of lost material after passing of sample on a quartz disk size 120 mm, during 40 m, with a rotational speed of 120 rev / min and a load P of 0.5Kgf

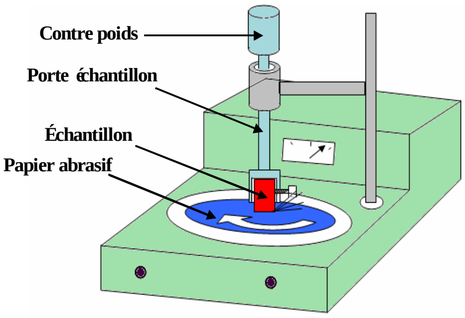

Fig. 1. Device used for testing abrasion wear.

2.3.2 Impact wear

The impact wear test is another type of wear experienced by the material during operation which determines its strength and life.

This test is to put the samples in a jet of shots thrown of a white cast at a pressure of 5 bar (Figure 2). The loss of material is measured after each minute interval for 5 minutes.

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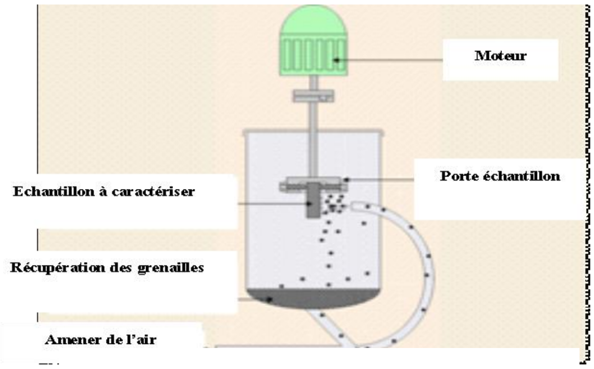


Fig. 2. Device used for testing impact wear.

2.3.3 Hardening Tests

The 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 presented by (Figure 3).

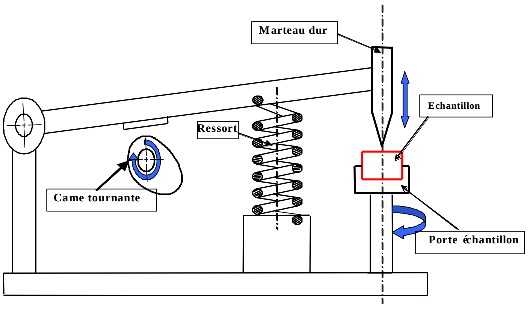


Fig. 3. Device used for testing work hardening.

3 RESULTS AND DISCUSSION

3.1. Metallography

Chemical analysis of the base steel is presented in Table 1. It is steel contain 12% of manganese solidifying according to diagram Fe-Mn-C gave the austenitic matrix in which are distributed carbides (Fe, Mn) $_3$C may vary in shape and fineness (4a). After heat treatment (annealing), the precipitated carbides are completely dissolved in the matrix. The microstructure in this state consists of two types of austenite, one enriched and the other depleted [10]. (figure4b).

A

B

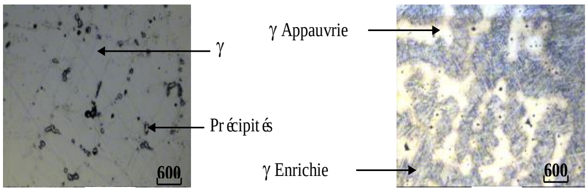


Fig. 4. Microstructures of the base steel.
a. Cast condition, b. After heat treatment.

The molybdenum introduction in steel studied is to improve hardenability and therefore its operating properties. By comparing the different structures observed with the steel base, we note that the molybdenum acts on the shape, the distribution and amount of carbides (Figure 5). 0.10 to 0.30%, the molybdenum acted on the formation of precipitates in the metallurgical structure of the steel in the rough casting. These are more or less large compared to the base steel and come in an 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 these become more or less rounded, fine and well distributed (Figure 5).

In the state treated, as of 0.10 % Mo quantity and the form of the austenite impoverished are totally different than the base steel (Figure 4 and 5). We notice an increase of austenite enriched [10]. with depends on impoverished.

This trend continues up to 0.20% Mo in which the amount of austenite enriched occupies more than 90% of the matrix. Perhaps this is explained by the carbide-forming effect of molybdenum more significant than that of manganese. The dipping action of molybdenum 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 (Figure 5).

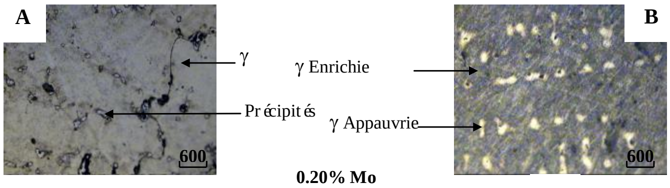
Concerning the influence of niobium, austenite grain is fine to 0.10% but higher contents, it becomes bigger. The precipitates are almost spherical in shape and are uniformly distributed in the matrix. Their quantity decreases to 0.10 % of niobium compared to basic steel and increases starting from 0.15 %. On the other hand, to 0.30 %, the latter arise at the joints austenite grains and are of irregular form (figure 5).

The heat treatment has always promoted two types of austenite as in other cases. The enriched austenite occupies a larger space, at 0.10% niobium but decreased from 0.15 to 0.20% Nb. Its quantity is comparable with that of basic steel. It starts to increase starting from 0.25 % of niobium compared to impoverished austenite (figure 5).

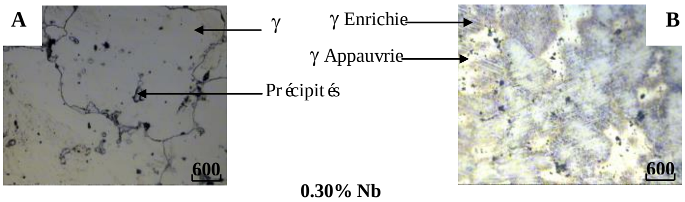
During the simultaneous introduction of the two elements (Mo + Nb) to 0.10 %, the enlargement of the austenitic grain compared to that of basic steel causes.

The precipitates have a spherical form in the austenite grain and are irregular with the joints of the grains. These precipitates are larger than those present in basic steel and the steel alloy separately at molybdenum and niobium, but distributed uniformly. To 0.30 % (Mo + Nb), the precipitated carbides are localised with the joints of the austenite grains (figure 5).

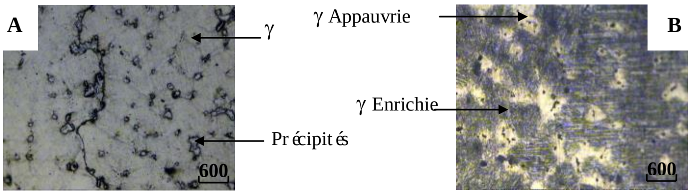
After heat treatment, we always notice a complete dissolution of the precipitated carbides. The rate of enriched austenite increases in alloy steel 0.1% to 0.30% (Mo + Nb), but from the 0.30% it rate decreases (Figure 5).



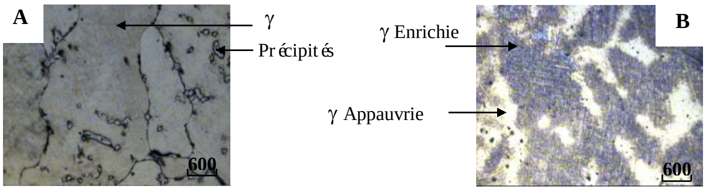
0.20% Mo



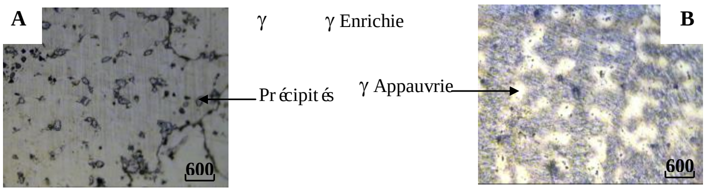
0.30% Nb



0.10 % (Mo + Nb)



0.10% Mo



0.30 % Mo

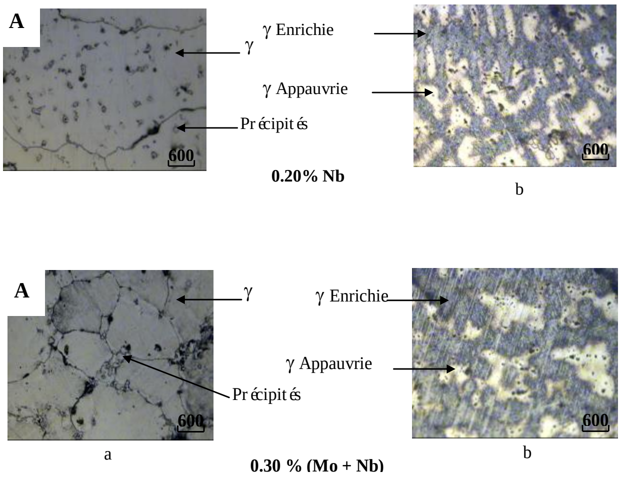


Fig. 5. Microstructures of manganese steel alloy with molybdenum niobium.
a. Cast condition, b. After heat treatment.

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In the treated state, molybdenum up to 0.15% is shown more influencing on this characteristic compared to niobium. This is explained by the soaking effect of this last. Between 0,25 and 0.30 %, the influence of niobium and molybdenum meets. We can always notice that these elements strongly raised the wear resistance by friction. According to the tests carried out on steel with only one element of addition, we notice that the molybdenum is the element adapted best to resist this type of wear (figure 6).

During the addition of two elements (Mo-Nb), according to the adopted experimental plan, we notice that the loss in mass expressed in percent decrease in a very significant way (figure 8).

The rise in this property is due primarily to the increase in the microhardness of various austenites enriched and impoverished caused by dissolution of these elements in these last.

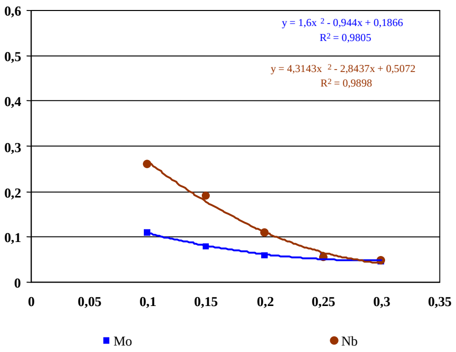


Fig. 6. Mass loss by friction of Nb Mo alloyed steel after heat treatment

3.3. Impact wear

The test of wear by impact under the effect of the shot is necessary to determine the wear resistance of the studied steel intended for the production of the parts of crushing (ex: beater: part of cement factory). Th se parts are undergoing significant impact on their rations. That is why this test is very interesting to simulate the same conditions.

It is noted that in the condition treated, 0.1% Nb the wear resistance is better, but beyond that level mass losses for both are almost similar elements (Figure 7).

Upon addition of two elements (Mo-Nb), the impact mass loss 0.1% (Mo-Nb) is close to 0.3% Mo and 0.3% Nb, on the other hand it decrease gradually to 0.3 % (Mo-Nb) ure 8).

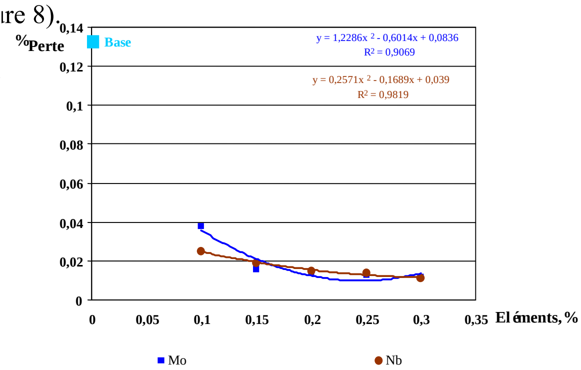


Fig. 7. Mass loss by impact of Nb Mo alloyed steel after heat treatment

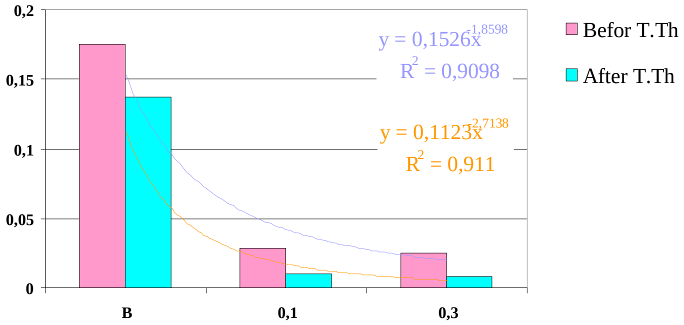


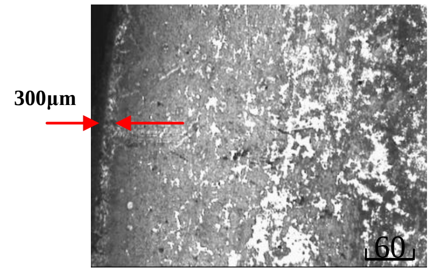
Fig 8. Mass loss (%) by the impact of treated steel and 0.1% 0.3% (Mo + Nb) before and after treatment.

3.4. Hardening Tests

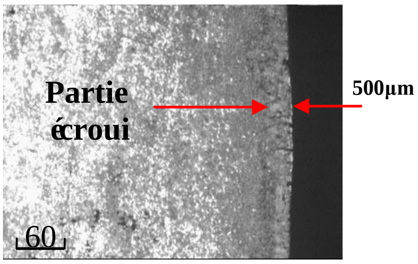
The use of hardenings test under the effect of a hammer is necessary to determine the impact resistance of the steel studied for the production of mechanical parts. Some of these pieces suffer a heavy blow when their operating.

Therefore, this test is very interesting to simulate the same conditions. The figure 9 shows micrographs of hardened zones with different thicknesses obtained in the studied samples.

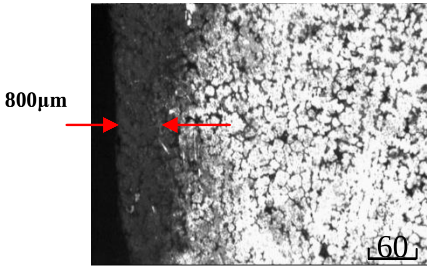
The test strain hardening has a significant improvement in hardness with a gap of 300 HV between the heart and the hardened surface of all samples experienced. This reflects the structural transformation occurred (Figure 9).



0.3 Mo+0.3 Nb



0.3 Nb



0.25 Mo

Fig. 8. mass loss by friction of Nb Mo alloyed steel after heat treatment.

4. Conclusion

The focus on improving operating manganese steel properties continues to grow because this alloy occupies a big place in railway, mining, iron and steel, mechanical, agricultural etc.

To carry out this objective, we combined this steel with molybdenum (strong carbide-element and auto dip) and with niobium (strongly carbide-forming element) whose content of these elements is carried of 0,1 % to 0,3 %.

The addition elements introduced in the steel studied influenced the formation of the structures examined. The micrographs of different steels experienced observed before and after heat treatment showed:
- Appearance in various micrographic structures, the precipitated carbides of variable fine in large quantities relative to the base steel;
- Formation of two types of austenite, one enriched and the other impoverished and a total dissolution of precipitated carbides under the heat treatment action applied (hyper-hardening).

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

This study led to the development of new steel grades to meet the industrial requirements.
However, the wear resistance of these steels is demonstrated, as it is precisely due to the emergence of hard constituents in the rough casting that after annealing, they dissolve in the austenite raising her strength characteristics. It therefore seems possible to obtain very stable and resilient austenitic structure with a small addition of molybdenum, niobium or the two elements.

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