

# Influence of the Nb, V and Mo Elements on the Ecological Micro-alloyed Steel Properties

CARMEN OTILIA RUSANESCU<sup>1</sup>, COSMIN JINESCU<sup>2\*</sup>, GIGEL PARASCHIV<sup>1</sup>, SORIN STEFAN BIRIS<sup>1</sup>, MARIN RUSANESCU<sup>3</sup>, OLIMPIA GHERMEC<sup>4</sup>

<sup>1</sup> University Politehnica Faculty of Biotechnical Systems Engineering, 313 Splaiul Independentei, 060042, Bucharest, Romania

<sup>2</sup> University Politehnica Bucharest, Faculty of Mechanical Engineering, 313 Splaiul Independentei, 060042, Bucharest, Romania

<sup>3</sup> Valplast Industrie, 9 Preciziei Blv., 062202, Bucharest, Romania.

<sup>4</sup> University of Craiova, Faculty of Mechanics, Department of Engineering and Management of the Technological Systems, Drobeta Turnu Severin, 1 Calugareni Str., 220037, Turnu Severin, Romania

*This paper aims to present the remarkable toughness characteristics of the material obtained by use of fine grain steels namely three micro-alloyed steels with Nb, Nb and V, or Mo. We analyze the mechanical resistance behaviour of these steels, containing slightly higher than the limit of acceptability for trace chemicals elements, after forging, quenching and annealing (tempering).*

*Keywords: micro-alloyed steel, niobium, vanadium, molybdenum, hardening*

Micro-alloyed steels, called also 'high strength low alloy' (HSLA) steels represent an important category of steels which contain small concentrations (0.05 to 0.15 wt %) of alloying elements and are used in construction, transportation, oil industry, etc..

During hot deformation processes at which the micro-alloyed steels were subject, the dynamic re-crystallization phenomena affect the size of the austenitic grain at the end of deformation. These phenomena were found compared with the reference steel by torsional or tensile tests, these hot tests performed at different speeds showing a slow re-crystallization of austenite during deformation in the presence of micro-alloyed chemical elements [1, 2].

Micro-alloyed elements influence the material characteristics as existing in the form of a solution in austenite, as well as in the form of agglomerates [3-8]. During the deformation, a partial precipitation of micro-alloyed elements occurs, thus influencing re-crystallization of austenite. In the heat treatment performed within in the region of austenitic transformation, the steels behave differently depending on the chemical nature of micro-alloyed element. This demonstrates, for instance, the specific property of hardening by vanadium precipitation. Hardening by precipitation exceeding a certain strength

limit leads to a worse toughness together with increased material strength characteristics. A micro-alloyed steel with both niobium and vanadium is recommended for quenching and tempering, causing a control of austenite grain by precipitation of Nb during quenching, as well as a slight hardening by precipitation of vanadium during tempering treatment [5].

From an environmental perspective, the micro-alloyed steels are durable and 100% recyclable [9-11]. Previously, we reported some properties of micro-alloyed steels of the same kind [6-8].

## Experimental part

The investigated micro-alloyed steels have 0.21 % C (in average) and 1.4 % Mn (in average).

The chemical composition of the tested steel samples is given in table 1.

Steel samples were produced in our laboratory batches of 50 kg using selected raw residuals control of chemical elements. The ingots were forged into 20 mm diameter bar, from which samples were subject to heat treatments. The final forging temperature was 850°C. Samples were normalized, quenched and tempered as following: the steel 1 was normalized to 900 °C, the steel 2 was hardened by austenitizing at temperatures of 900, 1000, 1100°C, and the hardened steel 3 was back quenched and tempered at

No of steel sample	Elemental content, [%]											
	C	Mn	Si	P	S	Cr	Ni	Cu	Mo	Al	Nb	V
1	0.23	1.33	0.32	0.013	0.012	0.01	0.02	0.02	0.03	0.040	0.037	-
2	0.20	1.40	0.31	0.018	0.023	0.01	0.03	0.02	0.03	0.05	0.025	0.06
3	0.24	1.5	0.27	0.029	0.018	0.02	0.02	0.02	0.08	0.06	0.016	-

**Table 1**  
CHEMICAL COMPOSITION OF MICROALLOYED STEELS. IRON IS THE REMAINDER

\* email: cosmin.jinescu@yahoo.com

Steel	$R_{p\ 0.2}$ [Nmm <sup>-2</sup> ]	$R_m\ 0.2$ [Nmm <sup>-2</sup> ]	$A_5$ [%]	Z [%]	Hardening [ $R_m/R_p$ ]
1	591	724	21	53	1.225
2	565	671	16	52	1.188
3	521	782	11	30	1.500

**Table 2**  
MECHANICAL PROPERTIES  
AFTER FORGING

600°C or at 700°C. The optical microscope type BIM-105M was used for evidencing the microstructure of steels.

### Results and discussions

In spite of a Mo content for all steel samples, we denoted steel 1 as steel with Nb, steel 2 as steel with both Nb and V, and steel 3 as steel with Mo.

In order to characterize the material after the forging, the mechanical properties were determined and the results, are shown in table 2.

#### Properties of micro-alloyed steels after forging

The specified parameters in table 2 have the following significances:

$R_{p0.2}$  - Conventional strength is the stress corresponding to the initial section of the specimen, which specifies the residual plastic elongation that reaches the prescribed  $R_p$  - Tensile strength, being the ratio of maximum load supported by the specimen and the area  $A_0$  of initial cross-section of the specimen; value of 0.2 %, which is mentioned as an index unified effort:

$A_5$  - specific elongation at break standardized; Z - Stiction the plasticity characteristic to break standardized.

Note that steel with Nb and V in the forged state has relatively high mechanical properties and good plasticity. In the case of molybdenum containing steel, its plasticity characteristic (Z) after hot deformation is low (30%) due to an excess of hardening of the material ( $R_m / R_p$ ). The different structure of the steel containing Mo confirms its hardening compared with the other two steels, (fig. 1).

It is noted that, after forging the steels 1 and 2 show a structure of Fe-on very fine grain, but molybdenum steel (steel 3) has a composition of Fe + Be + Pe (ferrite +

bainite + pearlite). Note also the existence of fine carbides as intragranular precipitates. Some authors have studied the appearance of the steel microstructure with chemical element Nb [4, 5, 7]. Other authors have directed their works on investigation of various aspects of material surfaces by SEM microscopy [10].

#### Characterization of the hardening steels obtained by quenching

Owing to the relatively low carbon content of the steel, in comparison with other marks with similar applications (31VMn12, 35 Mn14, 33MoCr11), the material used for the experiments has been tested to demonstrate the influence of the hardening process.

To approximate the critical point  $A_{c3}$ , the corresponding temperature was calculated according to the mathematical relationship (eq. 1):

$$A_{c3} = 854 - 180 \% C - 14 \% Mn - 18 \% Ni + 45 \% Si + 1.7 \% Cr \quad (1)$$

which is valid for compositions: 3-6 % C,  $Mn \leq 3.5 \%$ ,  $Si \leq 1$ ,  $Cr \leq 1.5 \%$ ,  $Ni \leq 3.5 \%$  and  $Mo \leq 0.5 \%$ . Values for  $A_{c3}$  between 800-810°C were obtained.

Taking into account the low chemical element carbon content of steel associated with micro-alloyed element, the quenching treatment was performed at  $T_A = 930^\circ C$  in order to allow either total or partial dissolution of precipitated particles.

After hardening there were obtained the hardness values shown in table 3.

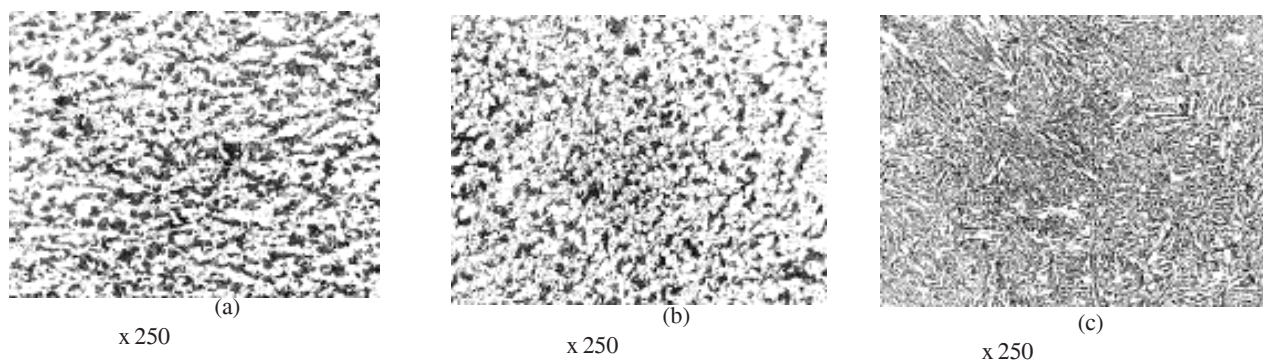


Fig. 1. Comparison of aspect of material structure after forging. Magnification: 250 (a) steel 1 micro-alloyed with Nb; (b) steel 2 micro-alloyed with both Nb and V; (c) steel 3 micro-alloyed with Mo

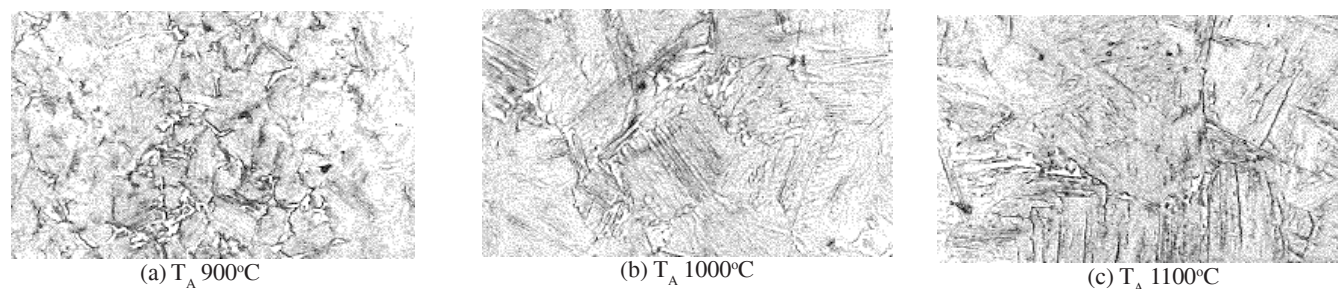


Fig. 2. Appearance of the structure of the material after hardening at different temperatures of austeniting for steel 1. Magnification x 1000.

As shown in table 3 all steels studied in this work have Rockwell hardness  $H_C$  between 41 and 47 HRC.

Steel sample	$H_C$ [HRC]
1	46
2	41
3	47

**Tbale 3**  
THE HARDNESS VALUES  
OBTAINED AFTER HARDENING  
TREATMENT FOR THE THREE  
GRADES OF STEEL

Analysis of the structure after tempering showed increased grain size of austenite with increasing heating temperature. The evolution of the austenitic grain size is observed by martensite orientation, figure 2.

The comparative appearance of the structure after tempering at  $930^\circ\text{C}$  for all three steels is shown in figure 3. The finest structure and a bainite composition were observed for the steel sample 1 which has also a residual austenite.

#### Annealing heat treatment

Annealing heat treatment was performed in two ways: one was at  $T_R = 600^\circ\text{C}$  minimum value of industrial control, and the other one was at  $T_R = 700^\circ\text{C}$  maximum temperature, both related to the critical point  $A_{c1}$ . The results of mechanical properties obtained after annealing are presented in table 4.

As the obtained result show, the characteristics of mechanical resistance have increased significantly after quenching and tempering compared to those at normalization. The mechanical resistance characteristics

decreased with increasing temperature of annealing, but the toughness increased.

It should be noted that for the steel with chemicals elements Nb and V as compared with the steel with chemical element Nb, the mechanical resistance increases although the tenacity values are lower - see the comparison between steel 2 versus steels 1 (and 3) due to precipitation of the hardening particles containing vanadium at annealing. This fact confirms the findings from the literature.

The structural analysis after recovery (figs. 4 and 5) showed the diminution of acicular aspect of quenching by increasing the temperature, but no significant differences among the three steels were observed.

Changes in the mechanical characteristics at high temperature recovery are due to the nature of structure obtained.

It is worth to notice a very fine steel structure for steel 2 micro-alloyed with both Nb and V, as well as the existence of many carbide precipitates in this steel.

It is evident that the double microalloying, with niobium and vanadium, of the C-Mn steels with low carbon content resulted in increased mechanical properties by annealing, due to vanadium precipitation; the toughness characteristics are also suitable. The characteristics obtained for steel 2 allowed assign the class of material strength of N 80, P 110 and C 95. Replacement of V with Mo in the low carbon steel (steel 3) led to similar results (the classes of grade L 110 and C 95) with the advantage of improving the corrosion characteristics.

The experimental results verify the theoretical data and give the sense of variation of mechanical characteristics.



Fig. 3. The appearance of structure after quenching with austenitising of material at  $930^\circ\text{C}$   
(a) steel 1 micro-alloyed with Nb; (b) steel 2 microalloyed with both Nb and V (c) steel 3 microalloyed with Mo

Steel	T [ $^\circ\text{C}$ ]	$R_{p0.2}$ [ $\text{Nmm}^{-2}$ ]	$R_m$ [ $\text{Nmm}^{-2}$ ]	$A_5$ [%]	Z [%]	KV [J]
1	600	600	725	19	59	112
	700	580	680	24	63	132
2	600	819	879	18	61	94
	700	736	806	18	63	105
3	600	829	908	17,5	62	100
	700	741	809	20	64	140

**Table 4**  
MECHANICAL CHARACTERISTICS AFTER HARDENING  
AND RETURNING at  $600^\circ\text{C}$  or  $700^\circ\text{C}$

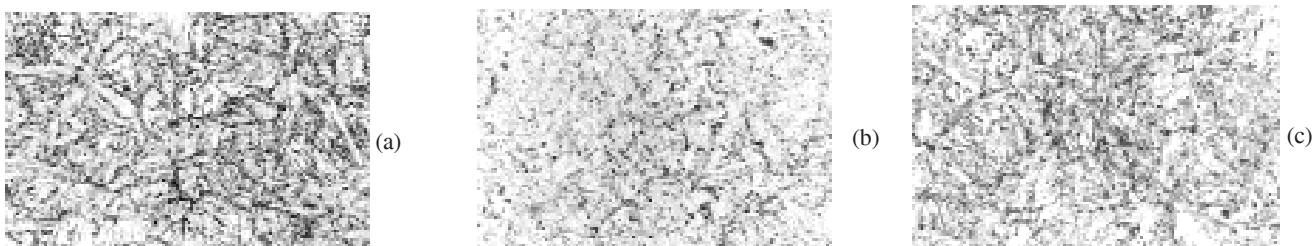


Fig. 4. Comparative structures of steels after tempering to at  $T_R = 600^\circ\text{C}$ . Magnification x 1000. The samples: (a) steel 1 microalloyed with Nb (b) steel 2 microalloyed with Nb and V (c) steel 3 microalloyed with Mo



Fig. 5. Comparative structures of steels after returning to  $T_R = 700^\circ\text{C}$ . Magnification  $\times 1000$ .

The samples: (a) steel 1 microalloyed with Nb; (b) steel 2 microalloyed with both Nb and V; (c) steel 3 microalloyed with Mo

## Conclusions

We demonstrated the obtaining of mechanical performances ( $R_c > 552 \text{ Nmm}^{-2}$ ) required for steel pipes used in oil processing and transportation by experiments carried out on three micro-alloyed C-Mn steels (0.31% C currently used) and with 1.4% Mn (higher than 1.1% Mn currently used) steels with 0.21 % C (lower than the current content).

The lower carbon content increased the toughness of the material by quenching and annealing. Thus, the micro-alloyed steel with niobium content yielded  $R_c$  value in the range of 552-758  $\text{Nmm}^{-2}$  and controlled tenacity. The double micro-alloying steel with Nb + V has increased strength characteristics by precipitation of vanadium at annealing and the corresponding value for  $R_c$  was (655-965  $\text{Nmm}^{-2}$ , with a controlled tenacity ( $KVM \approx 100$ ). The micro-alloyed steel with Mo had similar behaviour as Nb-V steel; in addition, this third steel has a trend to increase the corrosion resistance.

In the state of quenching and tempering, depending on the chemical nature of microalloyed element used and the tempering temperature, various levels of resistance to flow were obtained; thus, the material belongs to the N80 - P 110 classes, having in all cases the tenacity values of  $KV \geq 100 \text{ J}$ .

## References

1. RUSĂNESCU, C.O., RUSĂNESCU, M., J. Metall. Sect. B-Metall. **49** no. 3, 2013 p. 353
2. TÖRÖK, Z., OZUNU, A., POPESCU, E.C., Environ. Eng. Manag. J. **10**, no.1, 2011, p. 81.
3. BEGEA, M., STROIA, I., BOCA, E., VLADSCU, M., BEGEA, P., J. Environ. Protection Ecology, **8**, no. 2, 2007, p. 380
4. RUSĂNESCU, C.O., RUSĂNESCU, M., ANGHELINA, F.V., J. Optoelectron. Adv. Mater. **15**(7-8), 2013, p. 724
5. MIHALACHE M, MELEG T, PAVELESCU M., Rom. J. Mater. **40**, no. 4, 2010, p. 349.
6. POPESCU, S., MANOLE, C., PIRVU, C., Rev. Chim. (Bucharest), **64**,no. 8, 2013, p. 796
7. SANDU, A.V., BEJINARIU, C., NEMTOI, GHE., SANDU, I.G., VIZUREANU, P., IONITA, I. BACIU, C. Rev. Chim. (Bucharest) **64**, no. 8, 2013, p. 825
8. POPESCU, A.M.J., CONSTANTIN, V., OLTEANU, M. DEMIDENKO, O., YANUSHKEVICH, K., Rev. Chim. (Bucharest) **62**, no. 6, 2011, p. 626.
9. RUSĂNESCU, C. O., RUSĂNESCU, M., ANGHELINA FI. V. Optoelectron. Adv. Mater. Rapid Communications, **7**, (11-12), 2013, p. 947
10. VOICU, G., MOICEANU, G. BIRIS, S. 'T., RUSĂNESCU, C.O., Actual tasks on agricultural engineering – Zagreb, 2011, Opatija, Croatia, p. 153
11. GHERMEC, O., GHERMEC, C., DUBOVAN, S., RUSĂNESCU, C.O., Environ. Eng. Manag. J., **12**, no. 10, 2013, p.2019

Manuscript received: 19.12.2013

***Reînnoiți-vă abonamentele  
la REVISTA DE CHIMIE și  
revista MATERIALE PLASTICE  
pe anul 2015***

***Prețul unui abonament la  
REVISTA DE CHIMIE este de:  
200 lei pentru persoană fizică  
400 lei pentru universități  
500 lei pentru societăți comerciale***

***și la revista***

***MATERIALE PLASTICE este de:  
150 lei pentru persoană fizică  
200 lei pentru universități  
300 lei pentru societăți comerciale***

***Conturi:***

***S.C. BIBLIOTECA CHIMIEI SA***

***RO20 RNCB 0072049700600001 BCR sector 1  
RO51 TREZ 7065069XXX002561 Trez. sect. 6***

***C.U.I. RO 13751581***