H4. INFLUENCE OF ALLOYING ELEMENTS ON NANOMETRIC CARBIDES PRECIPITATION IN 5% CHROMIUM MARTENSITIC STEELS

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Tempered martensitic steels containing 5% chromium, mainly used for forging and high-pressure die casting tools show a limited lifetime due to the severe thermo-mechanical working conditions. The resistance to stress at high temperature of these steels is directly related to the stability of alloyed carbides which are formed above 450°C during tempering. In order to improve high temperature mechanical properties, the more relevant route is to modify the secondary precipitation by introducing alloying elements. Consequently, carbide forming elements (W, Mo, V, Nb) as well as elements influencing the precipitation kinetics (Co, Ni) were added to a low-silicon AISI H11 steel previously studied, the well known Aubert & Duval steel : ADC3 (reference) [1]. The characterization of carbides formed during the heat treatment was carried out using techniques such as X-ray diffraction and Transmission Electron Microscopy (TEM). However, these techniques were not efficient enough to evaluate parameters of the population of small carbides with an average size lower than 5 nm. Thus, in order to evaluate the size distribution and the volume fraction of the secondary precipitates of nanometric size, small angle neutron scattering (SANS) experiments were performed. Also, the A ratio of the magnetic and nuclear contrasts between matrix and particles gives information on the chemical composition of the particles.

In this study [2], twelve grades of steel with different alloying additions were compared to the reference. Alloying additions corresponding to each grade is presented in table 1.

The neutron scattering experiments were performed at Léon Brillouin Laboratory on PAXE small angle instrument. Measurements were performed at room temperature, under a saturating magnetic field H=2 Teslas perpendicular to the incident neutron beam direction, in order to separate the magnetic and nuclear scattering cross-sections.

Reference	ADC3
Mo	Ref + 1.8%Mo
MoMo	Ref + 3%Mo
MoMoCo	Ref + 3%Mo + 3%Co
V V	Ref + 1%V
Ni	Ref + 1.5%Ni
NiNi	Ref + 3%Ni
Co	Ref + 3%Co
W	Ref + 1.6%W
Nb	Ref + 0.06%Nb
NiMo	Ref + 1.5%Ni + 1.8%Mo
NiV	Ref + 1.5%Ni + 0.7%V
NiW	Ref + 1.5%Ni + 1.2%W

Table 1: Alloying additions (in weight percent)

Volume fraction evaluated by SANS have shown that the number of small carbides (d < 5 nm) are about 100 times higher than the number of carbides with an average radius of 15 nm. Actually, this population of small carbides (d ~ 3 nm) will be more efficient in pinning dislocations and improving mechanical properties. The results have shown that a significant modification of the volume fraction and chemistry of nanometric precipitation are observed only for Mo, V and Ni additions (figure 1). The figure 1 shows green bars for the beneficial effect of Mo and V additions, whereas red bars represent detrimental effect of Ni addition on the volume fraction of small carbides.

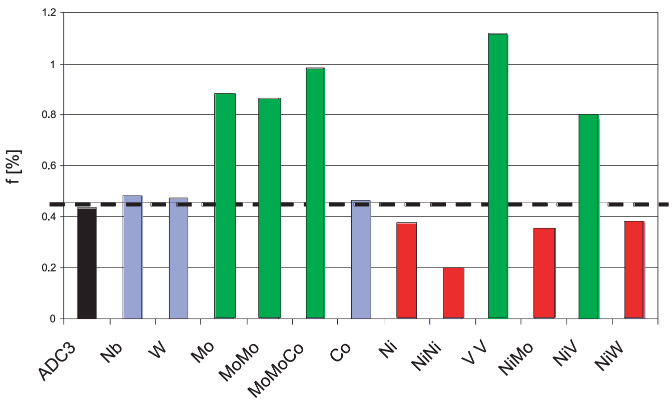


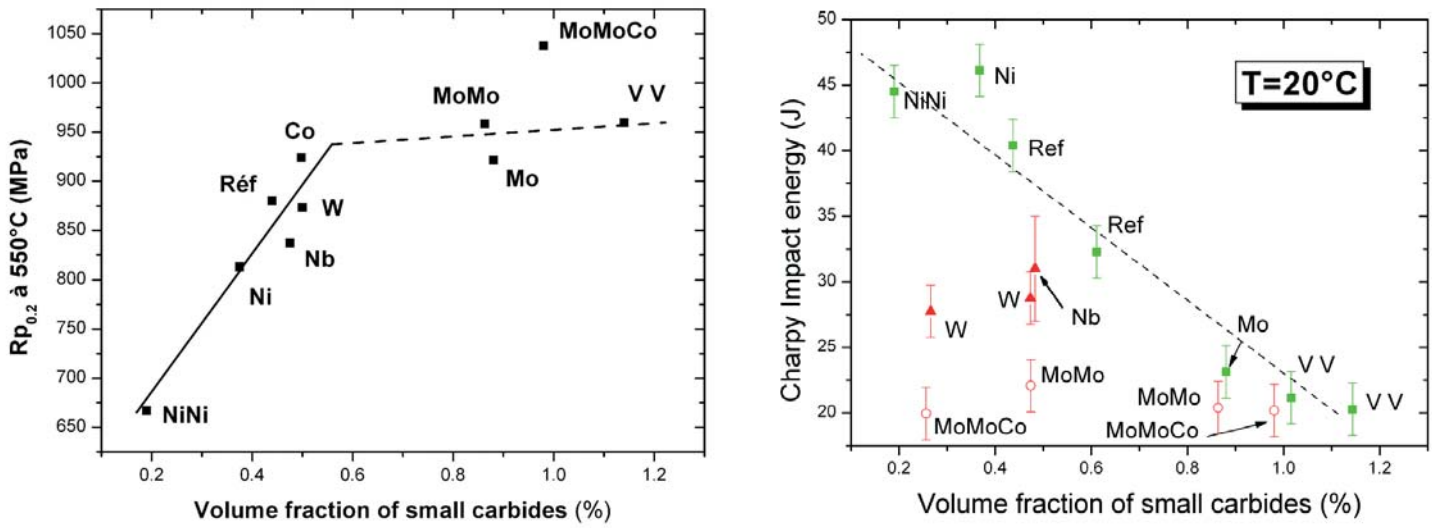
Figure 1: Influence of elements on the volume fraction of small carbides (d ~ 3 nm)

Moreover, results of mechanical properties showed that the volume fraction of small precipitates (VC in all grades and Fe_3Mo_3C in molybdenum grades) directly influences the mechanical resistance at high temperature (figure 2.a) but results in a detrimental effect on Charpy impact energy (figure 2.b). Red points on figure 2.b illustrate the influence of coarse carbides on Charpy impact energy.

In addition, above a volume fraction threshold (~ 0.6%), a saturation of the yield strength is observed. Two different mechanisms dealing with interaction modes between dislocations generated during the quench and precipitates are presented in [2] to explain the saturation.

The first hypothesis considers that increasing number of carbides in addition to the heterogeneity of precipitation can induce formation of Orowan Islands [3]. In that case, increasing the volume fraction of precipitates only increases the heterogeneity of the distribution, the “mean free path” of dislocations between Orowan Islands remaining constant [2].

The second hypothesis assumes a modification in main carbides crossing mechanism of precipitates by dislocations when volume fraction is above 0.6% (figure 2.a), changing from Orowan mechanism with formation of dislocation loops to shearing mechanism [2].



a) **b)**

Figure 2: relationship between volume fraction of small carbides and a) yield strength at 550°C. b) the Charpy impact energy.

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