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VANADIUM MICRO-ALLOYED HIGH STRENGTH STEELS FOR FORGINGS

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To fulfill the industrial demand of forged steels with high tensile properties and microstructural requirements coupled with reduced cost, the possibility to increase the properties of C-Mn steels by means of precipitation strengthening as achieved by micro-alloying (and without the addition of expensive elements such as Mo and Cr) has been evaluated. In order to do that, the effect of V addition has been exploited by means of metallurgical modelling followed by a laboratory ingot manufacturing. Heat treatment has been designed aimed to achieve the desired target tensile properties. Results show that ASTM A694 F70 grade requirements can bel fulfilled by 0,15% V addition and a proper heat treatment in a ferrite-pearlite microstructure, representative of a forged component.

Key words: micro-alloying steel, vanadium, chemical composition, heat treatment, mechanical properties

INTRODUCTION

Today, there are essentially three methods for manufacturing high strength steels, i.e., steels with yield strength in excess of about 410 MPa and UTS levels above about 515 MPa, according to ASTM A694 specification as reported in Table 1 [1].

These methods are;

- Innovative heat treatments on low allowed steels.
- Micro-alloying medium carbon steels.
- Adopting micro-alloyed multi-phase steels.

This paper will focus on the second group [2-3]. Increased yield strength can be achieved by precipitation mechanisms or by improving hardenability. Concerning the hardenability increase, Mo or Cr are usually added, with increasing materials costs. Boron is sometimes added to steels in small concentrations to increase hardenability [4], especially in the case of high thickness components.

As far as concerns precipitation strengthening the use of V is normally preferred over Nb because of he solubility behavior which permits the dissolution of VCN particles at lower temperatures [5] further favoring grain size refinement.

Even higher strengths can be achieved by adding higher N levels in the range of 150 - 200 ppm [2].

Moreover, since V is easily dissolved into the austenite during re-heating, lower billet re-heating temperatures are required with the consequence of lower production costs on the shop floor, more uniform properties and lower straightening costs. Even if the use of V as micro-alloying element is quite common in the case of flat product (plate or coils), it is not so common in the case of forgings, especially in the case of high thickness forged components.

Table 1. **ASTM A694 requirements [1]**

Grade	$R_{p0,2}$ / MPa	R_m / MPa	A_5 / min %
F42	290	415	20
F46	315	415	20
F48	330	425	20
F50	345	440	20
F52	360	455	20
F56	385	470	20
F60	415	515	20
F65	450	530	20
F70	485	565	18

Main novelty of this paper is to show the evidence of the possibility to fulfill the tensile properties and microstructural requirement of F70 grade in high thickness forgings, by the addition of V to a CMn steel without Cr and Mo addition.

EXPERIMENTAL

Materials

A 0,20 % C, 1,00 % Mn 80 kg ingots with V addition and without any other elements addition has been cast by means of Vacuum Induction Melting (VIM) plant.

The ingot was hot rolled down to 20 mm thick plate, with finish deformation temperature above 1 000 °C, reproducing an industrial forging process.

From the rolled material, specimens have been cut and quenching and tempering (Q&T) treatments have

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been performed with two different austenitisation temperatures (980 °C and 1 050 °C) followed by tempering at different temperatures.

Microstructure analysis and hardness measurement of the heat treated specimens has been carried out by means of light microscopy (LM) after 4 % Nital etching. Tensile tests have been performed on the most promising cases.

RESULTS AND DISCUSSION

Steel chemical composition design

Based on [6] the effect of V addition starting from a 0,20 % C, 1,00 % Mn steels on the hardness for different microstructures after quenching has been evaluated and is reported in Figure 1. Results show the beneficial effect of V addition on the hardness of ferrite/pearlite containing microstructures (from microstructure n4 to microstructure n7). In particular, if 0,15 % V is added more then 100 Vickers hardness points are gained by the material for a ferritic microstructure, typical of high thickness forgings. The effect of tempering temperature on martensite (red curve), bainite (green curve) and ferrite (blue curve) is reported in Figure 2. Results show how the tempering process does not "temper" the ferrite. It has to reminded that the adopted model does not take into account secondary precipitation hardening phenomena which may anyway occur, and which need to be proven by experimental tests. Following to this observation results in Figure 2 can be considered as conservative.

Heat treatments

Based on the above results a 0,2 % C, 1,0 %Mn with 0,15 % V addition and without any other elements addition as been cast by means of Vacuum Induction Melting (VIM) plant. After hot rolling specimens were austenitised at 1 050 °C and 980 °C, cooled in air so to avoid any bainite formation and to obtain a fully ferritic-pearlitic microstructure; specimens were the tempered in the range 540 °C - 660 °C for 30 minutes holding. Microstructures obtained after cooling are reported in Figure 3.

Both microstructures are fully ferritic: larger ferritic grain size is found in the case of 1 050 °C austenitisation temperature (Figure 3a), as expected. Results of hardness measurements on quenched and tempered ma-

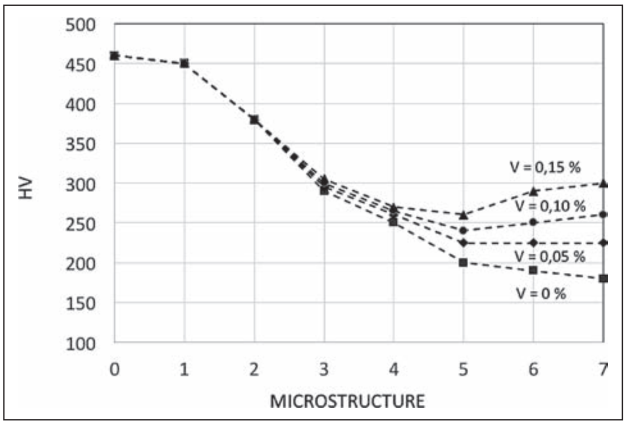

Figure 1 Effect of V addition on hardness in microstructures 0 – 7 where: 0 = 100 % martensite, 1 = 90 % martensite -10 % bainite, 2 = 50 % martensite – 50 % bainite, 3 = 5 % martensite – 95 % bainite, 4 = 10 % bainite-90% ferrite, 5 = 50 % bainite – 50 % ferrite, 6 = 10 % bainite – 90 % ferrite, 7 = 100 % ferrite.

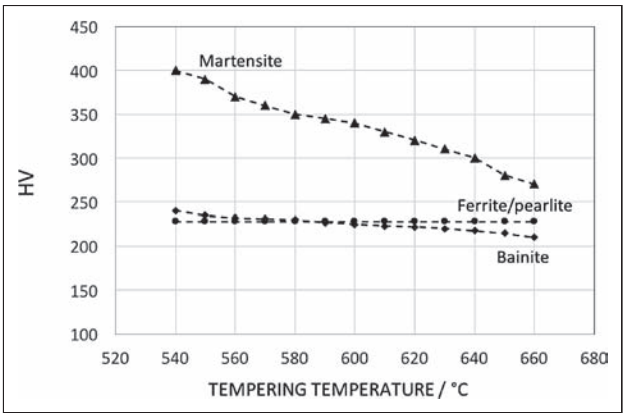

Figure 2 Tempering effect on martensite, bainite and ferrite. Tempering time: 30 minutes.

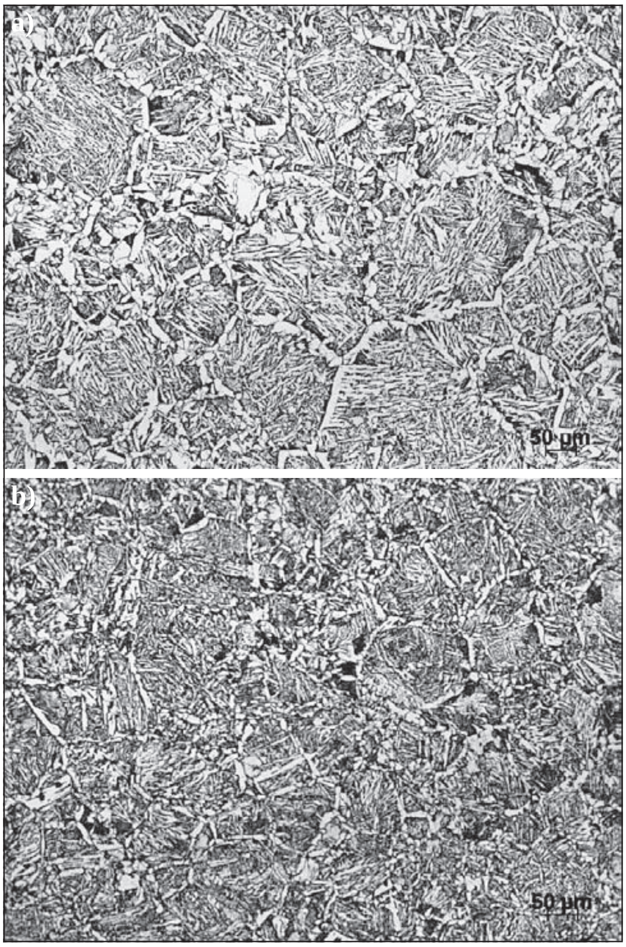

Figure 3 Microstructure after austenitisation and cooling. a) austenitisation temperature = 1 050 °C; b) austenitisation temperature = 980 °C

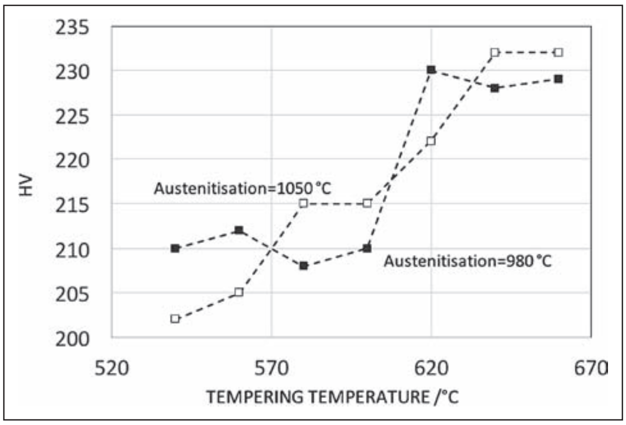

Figure 4 Effect of tempering on hardness (white symbols: austenitisation at 1 050 °C; black symbols: austenitisation at 980 °C)

terials are reported in Figure 4. Results show that secondary precipitation hardening occurs during tempering, with the consequence of an increase of ferrite hardness of more than 20 HV. The secondary precipitation is completed in the temperature range 640 °C - 660 °C. Slightly higher hardness values are obtained in the specimens after austenitisation at 1 050 °C with respect to 980 °C: this is due to the possibility that not all the V present in the matrix is fully solubilized at 980 °C. Anyway also at this lower temperature (quite near to those usually adopted in the industrial practice) the strengthening mechanism by VC appears quite strong and almost fulfilled.

Tensile properties of Q&T materials after tempering at 640°C are reported in Table 2. Results show that tensile properties of F70 grade according to ASTM A694 are fully achieved with the ferrite-pearlite microstructures reported above.

Table 2 **Tensile properties of materials after tempering at T = 640 °C**

Austenitisation temperature / °C	$R_{p0,2}$ / MPa	R_m / MPa
980	490	682
1 050	520	714

CONCLUSIONS

Results show that ASTM A694 F70 grade can be achieved by 0,15 % V addition to a standard medium C steel, on microstructures which are representative of those typically found in high thickness forgings. In particular results show that yield strength values higher than 500 MPa can be achieved in e ferritic/pearlitic microstructure hardened by vanadium precipitation. These values are quite higher than those normally achieved in this clacc of products when micro-alloying mechanisms are not activated. Moreover, no Cr or Mo addition are required without significant cost increase. Also the heat treatments conditions to submit the material to fulfill such properties are not far from those which are commonly used for standard C - Mn steels, appearing therefore quite promising for further developments.

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Note: The responsible for English language is: Elisabetta Petricci, Italy