JMEPEG (1992) 1:751-754

# The Effect of Partial Substitution of Nb for V on Austenite Grain Size and Hardness of a Tool Steel

*C.N. Elias and C.S. Da Costa Viana*

**In the present work, the composition of H-13 tool steel was modified with respect to the vanadium content to include an addition of niobium to obtain improved austenite grain size control without altering the tempering response of the steel. Optical metallography and transmission electron microscopy (TEM) observation of extraction replicas showed that the new steel had a smaller austenite grain size and a finer carbide size distribution than the vanadium steel, which indicates a higher potential toughness.**

## 1. Introduction

THE amount of vanadium in a chromium-molybdenum steel must always be considered when choosing the temperature at which the steel is to be used. For instance, at 873 K, 0.5% V is sufficient to improve the mechanical properties,[1] but if the temperature is increased to 923 K, 1.0% V will be required to maintain the same level of mechanical properties.[2]

Normally, the specified amount of vanadium in H-13 tool steel takes into account the fact that part of the vanadium will go into solution in the austenite, before quenching, and will precipitate as fine carbides during the subsequent tempering treatment. The remainder stays as insoluble vanadium carbide particles, which are responsible for the austenite grain growth control.

Some researchers have studied the effects of partial or total substitution of niobium for vanadium on the mechanical properties of tool steels.[2-4] The basic assumption is that partial substitution makes it possible to keep austenite grain growth under control during heating and to induce vanadium carbide precipitation during tempering.

In this work, the effect of partial substitution of niobium for vanadium on the austenite grain growth and on hardness after tempering was studied in H-13 tool steel that was reheated in the 1273 to 1473 K temperature range and quenched at room temperature.

## 2. Materials and Methods

Two ultrahigh-strength steels—EH-13 and H-13 + Nb—designed for hot work were used. The materials were received as forged round bars with 35- and 30-mm diameters, respectively. The chemical compositions are shown in Table 1. The main difference between these steels was the vanadium content.

All of the specimens were solution treated at 1473 K for 30 min, followed by air cooling, reheating to different temperatures in the 1273 to 1473 K range, each for the same time period, oil quenched, and tempered in the 673 to 873 K range for 2 hr. The size and distribution of the various carbide precipitates were measured on carbon replica photographs of the quenched material obtained by TEM. Hardness was measured on the mid-plane of tempered specimens.

## 3. Results

Figure 1 shows the average austenite grain size as a function of reheating temperature. The grain size of the EH-13 tool steel is larger than that of the H-13 + Nb steel. However, as the temperature is increased above 1373 K, the difference between the two grain sizes is reduced due to carbide re-dissolution and coalescence in the niobium-containing steel.

Figure 2 shows the results of room-temperature hardness versus tempering temperature as a function of reheating temperature. The data indicate that hardness after tempering increases with reheating temperature and that hardness levels of both steels are nearly the same for each reheating temperature.

## 4. Analysis

The trends of the grain size versus reheating temperature distributions have been observed previously and are attributed to the effect of precipitates.[5] Based on this concept, it is possible to assume that the difference between the two curves comes from the distinct action of the vanadium and niobium carbide particles.

**Table 1 Chemical Composition of Steels**

| | Composition, wt% | | | | | | |
|---|---|---|---|---|---|---|---|
| | C | Mn | Si | Cr | Mo | Nb | V |
| H13 + Nb | 0.37 | 0.42 | 0.96 | 5.36 | 1.26 | 0.07 | 0.36 |
| EH13 | 0.43 | 0.32 | 1.03 | 5.30 | 1.32 | ... | 0.87 |

---

**C.N. Elias** and **C.S. Da Costa Viana**, Instituto Militar De Engenharia, Department of Mechanical and Materials Engineering, Pr. Gen.

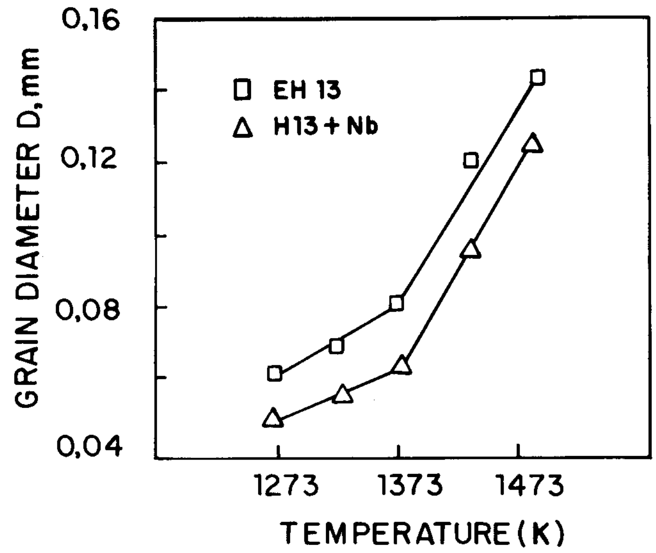

**Fig. 1** Average grain size as a function of reheat temperature for the H-13 and H-13 + Nb steels.

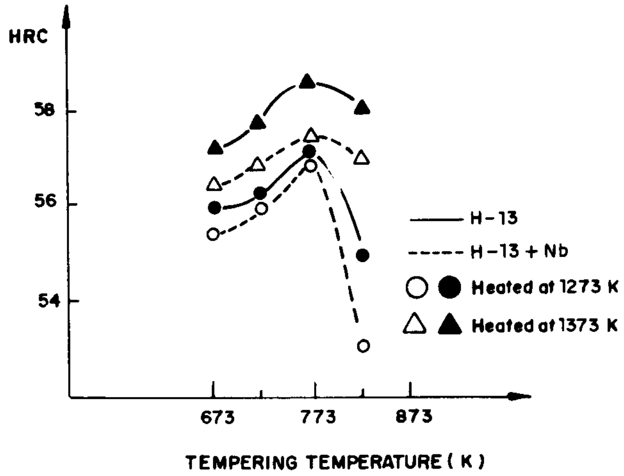

**Fig. 2** Effect of austenitizing and tempering temperature on room-temperature hardness.

**Table 2 Theoretical Weight Percent of V, Nb, and C in Solution in Austenite**

| Temperature |  | H-13 + Nb wt% |  |  | EH-13 wt% |  |
|---|---|---|---|---|---|---|
| K | °C | Nb | V | C | V | C |
| 1273 | 1000 | 0.0038 | 0.177 | 0.331 | 0.158 | 0.304 |
| 1323 | 1050 | 0.0060 | 0.308 | 0.354 | 0.375 | 0.310 |
| 1373 | 1100 | 0.0100 | 0.360 | 0.364 | 0.460 | 0.337 |
| 1423 | 1150 | 0.0159 | 0.360 | 0.364 | 0.670 | 0.395 |
| 1473 | 1200 | 0.0240 | 0.360 | 0.366 | 0.870 | 0.430 |

To analyze the effect of vanadium and niobium on grain growth, it is necessary to know the initial content of niobium and vanadium in the austenite of both steels in the solution treated condition. The carbide with the strongest effect on grain growth control should be the most stable, *i.e.*, the one with the highest dissolving temperature and the lowest precipitating temperature.[6]

In this work, it is assumed that the vanadium and niobium carbides that precipitate during air cooling from the solution treatment at 1473 K form a fine distribution that controls grain growth during subsequent reheating. Also, the precipitates that are not dissolved at 1473 K are considered to be too coarse to contribute.

### 4.1 *Amount of Alloying Elements in Solution*

Above 1273 K, the carbides of chromium and molybdenum go into solution in the austenite and no longer affect its grain growth.[7] As for vanadium and niobium, the amount in solution, as a function of temperature, can be obtained from:

$$\log [(\mathrm{Nb})\,(\mathrm{C})^{0.87}] = -7520/T + 3.11 \qquad \text{(Ref 7)}$$

$$\log [(\mathrm{V})\,(\mathrm{C})^{4/5}] = -10\,800/T + 7.05 \qquad \text{(Ref 8)}$$

where (Nb), (V), and (C) are the respective weight percentages of Nb, V, and C in solution in the austenite at the absolute temperature, $T$.

Table 2 gives these values for selected temperatures.

### 4.2 *Amount of Nb and V Available for Precipitation*

The weight percentage of vanadium and niobium available for precipitation as fine carbides responsible for grain growth control, at any particular temperature, is given by:

$$\%\mathrm{LP}\,(T) = \%\mathrm{LS}\,(1473\ \mathrm{K}) - \%\mathrm{LS}\,(T)$$

where: *%LP ($T$) is the weight percentage of vanadium or niobium available for fine carbide precipitation at temperature $T$; **%LS (1473 K) is the weight percentage of vanadium or niobium in solution at 1473 K; and %LS ($T$) is the weight percentage of vanadium or niobium in solution at temperature, $T$.

Table 3 shows the results of these calculations for both vanadium and niobium. Considering that the amount of carbide to be precipitated is proportional to that of its alloying element in supersaturation, one can see that the amount of fine vanadium

---

* LP: limit of precipation
** LS: limit of solubility

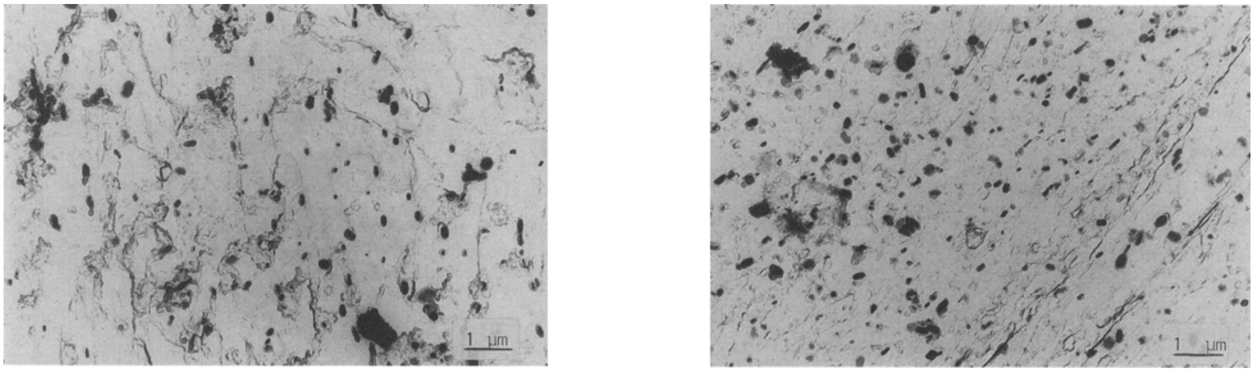

**Fig. 3** Precipitates present in **(a)** H-13 tool steel and **(b)** H-13 + Nb steel. TEM micrographs.

**Table 3 Theoretical Volume Percents of V and Nb in Precipitates Fine Form**

| Temperature | | H-13 + Nb, wt% | | EH-13 |
|---|---|---|---|---|
| K | °C | V | Nb | V,wt% |
| 1273 | 1000 | 0.183 | 0.020 | 0.71 |
| 1323 | 1050 | 0.050 | 0.018 | 0.69 |
| 1373 | 1100 | ... | 0.014 | 0.41 |
| 1423 | 1150 | ... | 0.008 | 0.20 |

carbides is higher than that of niobium carbides. The total amount of niobium and vanadium carbides present in the H-13 + Nb steel is smaller than the amount of vanadium carbide precipitates in the H-13 steel.

### 4.3 *Precipitate Volume Fraction*

Using the results given above, the volumetric contents of precipitates at different temperatures can be calculated by:

$$f_T = (D_{\mathrm{Steel}}/D_P)\,(W_P/W_{\mathrm{Steel}})$$

where $D_P$ and $D_{\mathrm{Steel}}$ are the density of the precipitate and of the steel, respectively; and $W_P$ and $W_{\mathrm{Steel}}$ are the weights of the precipitate and the steel at the temperature $T$.

It is assumed that

$$D_{\mathrm{NbC}} = D_{\mathrm{Steel}} D_{\mathrm{VC}} = 0.70\, D_{\mathrm{Steel}}$$

$W_P$ can be obtained from the balance of weight and the percentage of alloying elements dissolved at any particular temperature by:

$$W_{\mathrm{NbC}} = 1.11 \times 10^{-2}\ \%\mathrm{LP}\,(T)$$

$$W_{\mathrm{VC}} = 4.71 \times 10^{-2}\ \%\mathrm{LP}\,(T)$$

Assuming that there is no interaction between niobium and vanadium during the precipitation of VC and NbC, one obtains:

$$\text{Steel EH-13:}\ f_T = 0.70 \times 4.71 \times 10^{-2} \times \%\mathrm{V}\,(T)$$

$$\text{Steel H-13 + Nb:}\ f_T = 0.70 \times 4.71 \times 10^{-2} \times \%\mathrm{V}\,(T) + 1.11 \times 10^{-2} \times \%\mathrm{Nb}\,(T)$$

Using the expressions above and the data from Table 3, the volume fraction of particles in the EH-13 and H-13 + Nb steels at 1273 K can be calculated as $1.06 \times 10^{-2}$ and $1.20 \times 10^{-2}$, respectively. It is important to emphasize, however, that not only the amount of precipitates should be considered in analyzing the grain growth control. The size and distribution of the precipitates must be taken into account as well. This happens in the present case where the volume fractions calculated above do not differ appreciably, although carbon extraction replica measurements indicated an average particle size of 9000 nm for the vanadium steel and 3200 nm for the niobium modified steel after reheating at 1373 K.

In Fig. 3, note that there is a larger amount of finer carbides in the H-13 + Nb steel than in the H-13 tool steel. Consequently, the effectiveness of the carbides in the H-13 + Nb steel in controlling the grain growth is higher than that in the H-13 steel.

### 4.4 *Tempering Hardness*

The different levels of hardness in Fig. 3 can be assigned to the different austenitizing temperatures used. The smaller hardness values obtained with the modified steel can be attributed to the smaller contents of carbon and of carbides existing in this material.

## 5. Conclusion

The present results show that the partial substitution of niobium for vanadium in H-13 tool steel leads to a smaller austenite grain size and a finer carbide size distribution, without hardness loss after tempering. This also points to higher toughness values for the same level of mechanical properties.

## Acknowledgments

The authors are grateful to CBMM for financial support and to Dr. I. Hovell for reading this manuscript.

## References

1. C.A. Roberts, *Tool Steels,* American Society for Metals, 1980, p 517-519.
2. J.R.C. Guimarães, J.R.T. Branco, *Mater. Sci. Technol.,* Vol 10, 1986, p 1074-1076.
3. J.R.C. Guimarães, paper presented at the Int. Symp. Tantalum and Niobium, Tantalum-Niobium Study Center-TIC, Nov 1988.
4. F. Riedl *et al., Berg Hüttenmännische Monatsheft,* Vol 129, 1984, p 71-85.
5. T. Gladman and F.B. Pickering, *J. Iron Steel Inst.,* June, 1967, p 653-664.
6. R. Coladas *et al., Met. Sci.,* Nov, 1977, p 509-516.
7. H. Nordberg and B. Aronson, *J. Iron Steel Inst.,* Dec, 1968, p 1263-1266.
8. K.J. Irvine and F.B. Irvine, *J. Iron Steel Inst.,* Feb, 1967, p 161-182.