Jerzy Pacyna, Robert Dąbrowski, Teresa Skrzypek
University of Mining and Metallurgy, Cracow, Poland

THE EFFECT OF VANADIUM ON THE KINETICS OF PHASE TRANSFORMATIONS OF UNDERCOOLED AUSTENITE IN THE STEELS OF LOW CONTENT OF OTHER ELEMENTS

ABSTRACT

The investigations were performed by means of the dilatometric method on two model alloys of almost similar chemical compositions but of differentiated concentration of vanadium (0.14 and 0.77%). The samples of each alloy were austenitized at the temperatures, when almost all vanadium carbides of MC type remained undissolved, and at the temperatures of dissolving of MC carbides when entire vanadium passed into austenite. It was observed that vanadium bound into MC carbides affects weakly the kinetics of transformations of the undercooled austenite and its influence is much stronger when it is completely dissolved in the solution (austenite).

INTRODUCTION

In the course of years the views on the effect of alloy elements on the structure and properties of steel have been gradually changed. The need of application of steels of strictly determined properties contributes to the necessity of designing of new steel compositions, based on precise investigations of the role of respective alloy elements (including also vanadium) in the steel composition.

There are numerous literature data on the effect of vanadium on the kinetics of phase transformations of the undercooled austenite and also on steel hardenability, resulting, among others, from the works by Wever and Rose [1], Popov [2], Kunitake and Ohtani [3], Grossmann [4] and Pickering [5]. These data are very generalised because they were obtained during testing the real alloys, seldom the model ones, which significantly hinders the recognition of mechanisms of the effect of vanadium as such.

This work attempts to evaluate the effect of vanadium (both when it is dissolved completely in austenite and when it is almost completely bound in MC carbides) on the kinetics of phase transformations of the undercooled austenite in steels of low contents of other elements. This evaluation should be enabled by the execution of CCT diagrams (Continuous-Cooling-
-Transformation at constant cooling) for model alloys of the specially selected chemical composition.

INVESTIGATION MATERIAL

Two model alloys were chosen for the assumed target, i.e. of near-similar carbon content (0.33 and 0.42%) and of differentiated vanadium concentration (0.14 and 0.77%). The background (concentrations) of the alloy elements in the tested alloys were nearly the same and maximally

low, i.e. in such a rate which was allowed by the conditions of the induction furnace in which the alloys were prepared.

The chemical compositions of the two alloys are given in Table 1.

Table 1. *Chemical compositions of tested model alloys (% by mass)*

Alloy no	C	Mn	Si	P	S	Cr	Ni	Mo	V	Al
2	0,33	0,26	0,07	0,01	0,015	0,01	0,01	0,01	0,14	0,087
4	0,42	0,25	0,13	0,01	0,013	0,03	0,02	0,03	0,77	0,06

These alloys in the form of ingots of about 50 kg mass were forged into rods 20×35 mm cross-sectioned and annealed for normalizing.

INVESTIGATION METHODS AND HEAT TREATMENT

The investigations of kinetics of phase transformations of the undercooled austenite were performed for each alloy cooled from two temperatures. Ac_3 was the first temperature at which not only pearlite but also entire ferrite was transformed into austenite and almost all vanadium carbides of MC type remained undissolved. The Ac_3 temperatures of both alloys were fixed by the dilatometric method. They were, respectively, 810ºC for alloy no 2 and 825ºC for alloy no 4.

The temperature at which all the MC carbides were dissolved in austenite represented the second (higher) temperature. For alloy no 2 it was 1020ºC while for alloy no 4-1200ºC. These temperatures were determined by Bungardt's diagrams [6], Adrian's formulas [7] and, additionally, were verified by the metallographic method by means of observations of microstructures of samples of the tested alloys, quenched from higher and higher temperatures.

The four CCT diagrams (for two alloys, austenitized at two different temperatures) were made by means of the DT1000 dilatometer, manufactured by the French company, Adamel. The changes of Δl lengthenings of the ø 2×12mm samples were digitally recorded, depending on the temperature T. The possibility of differentiation of the obtained dilatograms enabled a precise determination of the beginnings and ends of respective transformations. The Ni-NiCr thermocouples, connected by electrosparks with the sample, were used for temperature measurements.

The samples were heated with the velocity of 3ºC/s to the temperatures given above, held for 1200s and next cooled with different velocities, applying a regulated blow of argon.

The hardness measurements for all cooling courses were made with the Vickers apparatus of the HPO 250 type, at the penetrator load of 5 kG. Each sample was subject to 3 hardness measurements out of which the arithmetic mean was calculated. The results were placed in circles" on respective cooling curves on the CCT diagrams.

INVESTIGATION RESULTS AND DISCUSSION

Figures 1a and 1b present the CCT diagrams for alloy no 2, executed for the austenitizing temperatures of 810 and 1020ºC. The comparison of these diagrams shows the effect of dissolved vanadium (up to 0.14%) on the kinetics of phase transformations of the undercooled austenite.

As it can be seen:

− with the increase of austenitizing temperature from 810 to 1020°C the time to the beginning of the pearlite transformation was lengthened and the temperature of the beginning of ferrite precipitation, especially in the range of the highest cooling velocity, was relatively strongly decreased;

− the increase of the austenitizing temperature is accompanied by the decrease of the temperature of beginning of the bainite transformation Bs;

− in spite of introducing 0.14% vanadium and respective carbon concentration into the solution, the authors did not succeed in exceeding the critical velocity and determine the temperature of the beginning of the martensite transformation Ms experimentally (using the highest cooling velocity of the DT 1000 dilatometer); therefore the Ms temperatures, calculated according to Andrews' formula [8], are marked on both diagrams;

− the dissolving of vanadium carbides in this solution results in the clear growth of hardenability and hardness both, especially in the range of the highest cooling velocity.
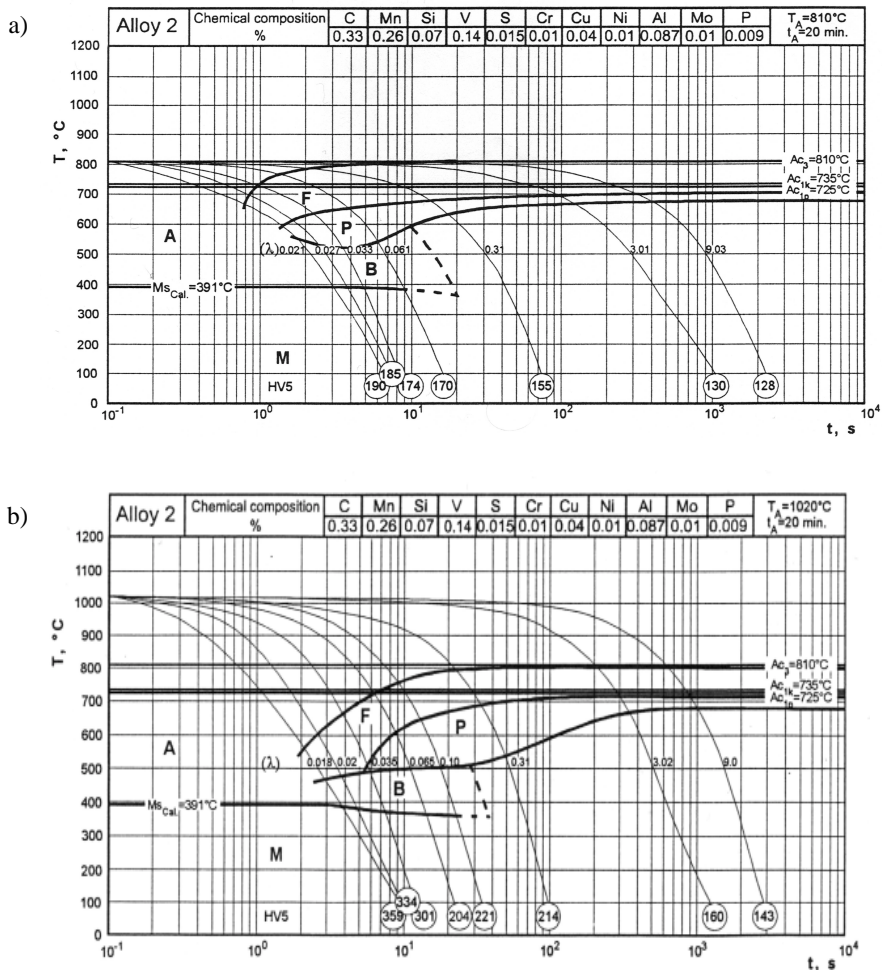

Fig. 1. CCT diagrams for model alloy no 2 (0.14% V), made by means of the dilatometric method; a) for T_A = 810°C, b) for T_A = 1020°C

The CCT diagrams (Fig. 2a and b) for alloy no 4 (0.77% vanadium), executed for the austenitizing temperatures of 825 and 1200°C, respectively, indicate that:

– the application of the lower austenitizing temperature (825°C) results in the diagram which is almost identical as for alloy no 2 (Fig. 1a) which was also austenitized at the temperature equal to Ac_3;

– with the growth of the austenitizing temperature from 825 to 1200°C the temperature of the beginning of ferrite precipitation decreases, also in the range of the highest cooling velocities;

– the increase of the austenitizing temperature is accompanied by a very clear shift to the right (towards longer times) of the temperature of the beginning of pearlite precipitation as well as the lengthening in time of the range of bainite formation, which resulted in keeping the high hardness of samples of this alloy up to the slowest cooling velocities,

– despite introducing 0.77% vanadium into the solution, the critical cooling velocity was not exceeded, therefore the Ms temperature calculated according to Andrews' formula [8], is marked on the diagram in Fig. 2b for alloy no 4.
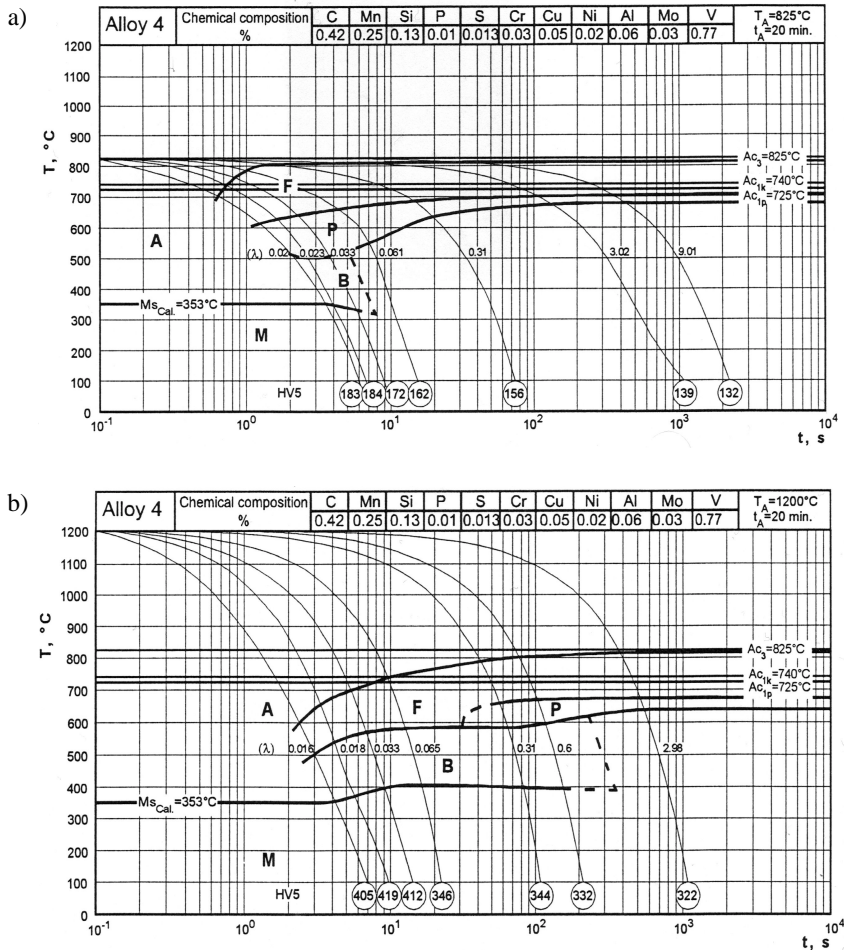

Fig. 2. CCT diagrams for model alloy no 4 (0.77%V), made by means of the dilatometric method; a) for T_A = 825ºC, b) for T_A = 1200ºC

The evaluation of the effect of fully dissolved vanadium (0.14% for alloy no 2 and 0.77% for alloy no 4) on the kinetics of phase transformations of the undercooled austenite is possible owing to the comparison of CCT diagrams in Figs 1b and 2b. It results from the above diagrams that:

− the range of pearlite precipitation was strongly shifted towards longer times in alloy no 4;

− the higher concentration of vanadium in austenite caused a clear increase of the temperatures of the end of ferrite precipitation and the end of pearlite formation. Because of this, since the area of diffusion transformations had not been separated from the area of intermediate transformation, also the temperature of the beginning of bainite formation Bs was increased.

CONCLUSIONS

The investigations performed in this work on the effect of vanadium on the kinetics of phase transformations of undercooled austenite in the steels of low content of other elements showed that:

− in the range of concentrations up to 0.14% vanadium increases slightly both hardenability and hardness of the alloy (for the highest cooling velocities) which is the result of a clear decrease of the temperature of the beginning of ferrite precipitation and a slight lengthening of the time to the beginning of pearlite transformation;

− dissolving of 0.77% of vanadium in austenite does not affect the temperature of the beginning of ferrite precipitation but it increases the temperature of the end of precipitation of this phase, lengthens the time to the beginning of pearlite transformation and increases the temperature of the beginning of bainite transformation Bs. However, such amounts of vanadium dissolved in austenite can be found first of all in hot-working and high-speed tool steels where besides vanadium there are many other alloy elements dissolved in austenite;

− vanadium bound in MC carbides affects weakly the kinetics of phase transformations of undercooled austenite. Only when it is dissolved in austenite (0.14% - 0.77%), its influence is much stronger.

REFERENCES

1. Wever F., Rose A.: *Atlas zur Wärmabehandlung der Stähle.* Verlag, Stahleisen M.B.H., Düsseldorf, 1961.

2. Popow A. A., Popowa L. E.: *Izotermiczeskije i termokineticzeskije diagrammy raspada piereochłażdiennogo austenita.* Metallurgia, 1965.

3. Kunitake T., Ohtani H.: *The transformation in vanadium containing steels on the continuous cooling.* Sumitomo Search 10 (1973) p. 78–86.

4. Grossmann M. A.: *Elements of hardenability.* American Society for Metals, Cleveland, 1952.

5. Pickering F. B.: *Vanadium as hardenability and temperability additive in quenched and tempered steels.* Metallurgy and Applications. J. M. Gray [ed.], 1986, p. 305-324.

6. Bungardt V. K.: *Die Löslichkeit des Vanadinkarbids im Austenit.* Archiv für das Eisenhüttenwesen 27 (1956) p. 61-66.

7. Adrian H.: *Model termodynamiczny wydzielania węglikoazotków w stalach niskostopowych o pod-wyższonej wytrzymałości z zastosowaniem do badań hartowności.* Rozprawy, monografie, AGH, Kraków, 1995.

8. Andrews K. W.: Journal Iron Steel Inst. 203 (1965) 7, p. 721-727.