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CCT diagram of HN5MVNb steel after intercritical annealing

J. Lis, B. Gajda, A. Lis

Institute of Materials Engineering, Czestochowa University of Technology,
42-200 Częstochowa, Armii Krajowej 19, Poland

Continuous Cooling Transformation (CCT) diagram has been obtained for partly austenitized HN5MVNb low-carbon bainitic steel. The steel was austenitized at 973 K during one hour, followed by cooling at rates within 0.045÷13 K/s. Metallographic observations with SEM, revealed existence of a dual-phase structure for all investigated cooling rates. Vickers hardness measurements allowed for approximate YS evaluation. Kinetics of bainite – martensite structure formation was evaluated from dilatometric data. A material constant *k* for mathematical calculation of martensite transformation kinetic was established.

1. INTRODUCTION

The technological significance to determine CCT diagrams of steels cooled from intercritical austenitizing is the ability of microstructure analysis in heat affected zone (HAZ) of welds formed from ($\alpha+\gamma$) temperature region. Knowledge of these CCT diagrams will also help to plan heat-treatment procedure, which leads to formation of the dual - phase ferrite - martensite structures in thin products of rolling mills.

2. EXPERIMENTAL PROCEDURE

The HN5MVNb steel used for the study was made in an induction furnace under argon gas protective atmosphere. The steel composition given for element mass contents in pct was: 0.044% C; 5.21% Ni; 0.06%Mn; 0.59% Cr; 0.4% Mo; 0.24% Si and microadditions of Nb, V and Al. Sulphur content was lowered below 0.005% S and phosphorus below 0.01% to improve HAZ mechanical properties of welds. Ingots were control rolled into plates 12 and 16 mm in thickness. From them the cylindrical samples 3 mm in diameter and 30 mm length were cut off and heat-treated in Bähr Quenching Dilatometer Type 805A/D.The six thermal cycles were applied. Samples were heated separately in a dilatometric furnace to 973 K, maintained at the temperature for one hour, and cooled with various cooling rates established between temperatures 973 K to 773 K: 13 K/s, 3.85 K/s, 1.78 K/s, 0.55 K/s, 0.2 K/s 0.045 K/s. Temperature was measured with Ni Cr-Ni thermocouple welded to the sample. Dilatation during cooling was registered by galvanometer unit electrically connected to X-Y plotter. The dilatation was also measured simultaneously optically on flat film. The dilatation curves were digitalized and analysed using PC computer system and compared to the negatives. The volume fractions of different phases formed were established with computer program from electronic data.

After nital etching microstructures were observed with light optical microscopy (Neophot II) and scanning electron microscopy (SEM) (JOEL 5400).

3. EVALUATION OF THE RESULTS

Dilatation curves were used to create diagrams of kinetics of phase transformations during continuous cooling as a function of time and / or temperature. As an example, volume fraction of phase transformations as a function of temperature for the sample cooled at the rate of 3.85 K/s is shown in Fig.1. Recrystallized ferrite α_R in amount 47.5% and new formed austenite 62.75% which occurred at 973 K / 1 hour annealing were the initial structure constituencies for cooling experiments. After cooling the microstructure consisted of 47.5% recrystallized ferrite α_R and 25.9% of lower bainite, 21.35% of martensite and 5.25% residual austenite. Residual austenite was not observed with dilatometric studies in sample cooled with higher cooling rate – 13 K/s. Only lower bainite and martensite have been formed.

The diagram of kinetics of phase transformation as a function of time for the sample cooled at the same rate 3.85 K/s is shown in Fig.2. It is obvious that recrystallized ferrite will not transform during cooling. Thus, phase transformations, which were studied as a function of time, refer to newly formed austenite in (α+γ) temperature range. That austenite transformed into α'_B – bainite, α'_M- martensite, and some amount of untransformed austenite retained in the structure – marked as $\gamma_{retained}$ in Fig.1 and Fig.2. The beginning of lower bainite start transformation was observed after 156 seconds in temperature 542 K. It was assumed that bainite transformation was completed after 197 seconds and then martensite transformation started at temperature Ms. The end of martensite transformation at M_f temperature was measured after 294 seconds. The dashed area represents retained austenite.

The same procedure of analyses of dilatometric curves and microstructure observation with an optical microscopy was applied for other samples. Additionally the Vickers hardness measurements were done for each specimen at load 5 kg = 49.05 J.

The results of dilatometric investigations allowed for creation of CCT diagram for HN5MVNb steel austenitizied 973 K/1h. This diagram is shown in Fig. 3.

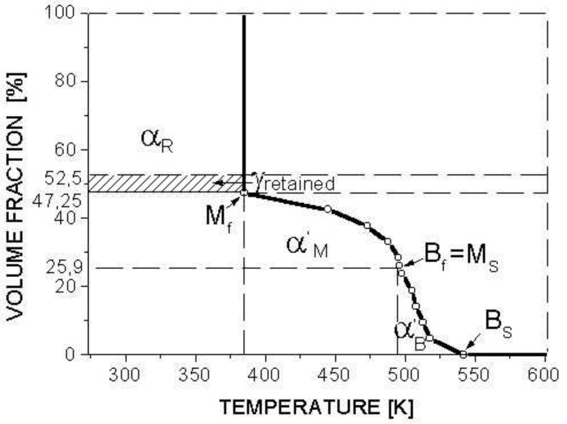

Fig.1. Phase transformations of austenite as temperature function for HN5MVNb steel after austenitizing 973K/1h and cooling at rate 3.85 K/s

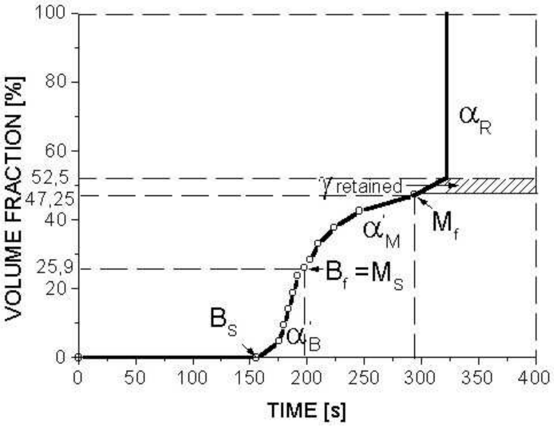

Fig.2. Kinetics of phase transformations of austenite for HN5MVNb steel after austenitizing 973K/1h and cooling at rate 3.85 K/s.

Details of microstructures were investigated using SEM at magnification 2000 x and higher due to small resolution of the optical microscopy. The characteristic microstructure of martensite and bainite and retained austenite formed after cooling at 3.85 K/s is shown in Fig. 4. Cementite carbides within bainitic ferrite are seen. The largest carbides (small dots) are smaller than 250 nm in width. Similar carbides are shown in recrystallized ferrite regions and bainitic ones. The regions of lower bainite and self-tempered martensite, which are marked on CCT diagram based on morphology of observed carbides, were established using both dilatometry and SEM. The presence of self tempered martensite M for the decreasing cooling rate from 0.55 via 0.2 to 0.045 K/s was confirmed by the decrease in hardness from 328 HV5 to 308 HV5 and then increase to 322 HV5 due to intense carbide precipitation.

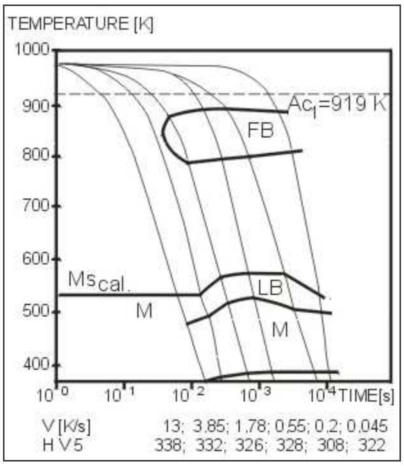

Fig.3. CCT diagram of HN5MVNb steel after austenitizing at temperature 973 K/1 h

where:

FB – bainitic ferrite,

LB – lower bainite (α'_B),

M – martensite (α'_M).

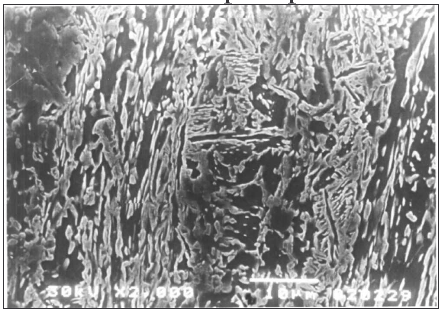

Fig.4. Microstructure of HN5MVNb steel cooled from 973 K/1h at rate 3.85 K/s.

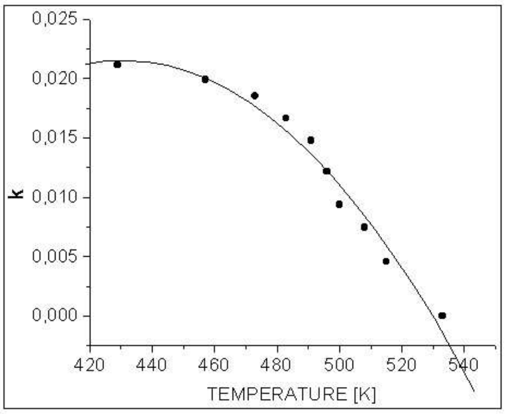

Fig.5. Function k=f(T) for the sample cooled at rate 13 K/s.

4. DISCUSSION OF RESULTS

For description of dual – phase microstructures the kinetics of martensite transformation was needed. The exponential equation (1) [1] was used:

$$f_m = 1 - \exp(-k(M_S - T)) \tag{1}$$

where: f_m is the fraction of martensite formed.

The k=f (T) coefficients were calculated as a function of temperature for sample cooled at the rate 13 K/s from experimental data using equation (1).

Experimental values of *k* coefficient with the transformation temperature change are marked with dots while continuous line in Fig.5 represents the mathematical polynomial regression fit which was estimated by means of mathematical polynomial regression equation:

$$k = (-0.475) + 0.002T - 2.614T^2 \tag{2}$$

At cooling rate 13 K/s the Ms temperature was 538 K. The yield strength (YS) of HN5MVNb steel was calculated from the hardness measurements data HV5 (in VHN). The following relationship (3) exists between $R_{p\,0.2}$ and HV, which was given by Dieter [2]:

$$R_{p0.2}(\mathrm{MPa}) \approx 3.33(\mathrm{HV})[0.1]^m \tag{3}$$

where: m is the strain hardening exponent in Ludwik equation. m ≈ 0.15 is a reasonable compromise for HSLA steels.

Thus based on hardness measurements the YS of ferrite - martensite dual - phase microstructure was established in the range 885÷975 MPa which was in good agreement with experimental data. The equation (3) applies to HN5MVNb steel annealed in $(\alpha+\gamma)$ temperature range at 973 K during 0.2 to 1 h, which has ferrite - martensite dual - phase microstructure after continuous cooling. In previous investigation it has been shown that the yield strength of HN5MVNb steel plates [3] was almost as predicted as from equation (3).

5. CONCLUSIONS

During austenitizing of HN5MVNb steel at 973 K/1h dual - phase structure of about 45% ferrite and 55% new austenite is formed.

CCT diagram of HN5MVNb steel cooled from 973 K /1h was determined for cooling rates in between 13 K/s ÷0.045 K/s.

After cooling, the ferrite – martensite dual phase microstructure was formed which had an average HV5 hardness in the range 308 to 338 VHN.

Values of coefficient “k” from mathematical model given by equation (1) were determined, which also fit well to martensite transformation kinetics description in the function of temperature given by equation (2).

The existence of residual austenite in martensite – bainite and recrystallized, polygonal ferrite “dual – phase” structures were observed as a consequence of the austenite enrichment in carbon and alloying elements during intercritical austenitizing or annealing which may happen in HAZ of welds.

REFERENCES

1. H.K.D.H. Bhadeshia, Bainite in Steels, The Institute of Materials, London, 1992.
2. G.E. Dieter, Mechanical Metallurgy 3rd edn, Mc Graw-Hill Book Company, New York, 1986.
3. A.K. Lis, J. Lis, C. Kolan and L. Jeziorski, Inżynieria Materiałowa, No. 6 (1998) 1325.