STRUCTURAL CHANGES OF C-Mn-Nb-V STEEL DURING THE REHEATING

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ŠTRUKTÚRNE ZMENY OCELE C-Mn-Nb-V POČAS OHREVU

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Abstrakt

Na zistenie zmeny štruktúry priemernej veľkosti austenitického zrna (AGS) a precipitačného správania bol ohriatí materiál C-Mn-Nb-V. Teploty ohrevu boli od 950 do 1250ºC a časy ohrevu boli od 10 do 60min. Po ohreve boli pozorované nejaké zmeny priemerných AGS. Teplota 1100ºC zobrazuje, že AGS začína narastať od 78 do 162μm. Je to zapríčinené prekročením teploty rozpustnosti precipitátov. Táto teplota je hraničnou teplotou pre abnormálne AGS a je zapríčinená kotviacim účinkom karbidov a karbonitridov Nb k hraniciam zŕn, ktoré sú rozpustené počas ohrevu. Priemerné AGS boli stanovené metódou počítania zŕn po kružnici. Namerané údaje boli porovnané s vypočítanými. Hodnoty boli vypočítané dvoma rovnicami na základe regresnej analýzy, pričom jedna rovnica je podľa Dutta-Sellar-ovho modelu. Rovnica (1) pomocou programu MATLAB zobrazuje dobrú zhodu s nameranými údajmi, ale je aplikovateľnou pre rýchle výpočty. Koeficienty závislé na vstupnej AGS, chemickom zložení ocele, procesných podmienkach a aktivačnej energie rastu zrna boli použité pre výpočet rovnice (2a). Obe rovnice sú vhodné pre porovnanie s nameranými údajmi. Vplyv času výdrže na rast AGS aplikovaním rovnice (2a) preukazuje dobrý popis zmeny AGS, ak sa vstupné AGS menili od 40 do 100μm. Bolo navrhnuté stanovenie ±5% a ±15% odchýliek nameraných a vypočítaných údajov pre jednotlivé rovnice $d_\gamma = a_1.T_{reheat}^{a_2}.t_{reheat}^{a_3}$ a $d_\gamma^n - d_{\gamma,0}^n = A.\exp(-Q/R.T).t$.

Abstract

The material C-Mn-Nb-V steel was reheated in order to find out structural changes and precipitation behaviour of austenite grains size (AGS). Reheating temperatures were from 950 to 1250 ºC and reheating times were from 10 to 60min. After the reheating some AGS changes were observed. Temperature 1100ºC showed that AGS began to rise from 78 to 162µm. It was caused by exceeded precipitation dissolution temperature. This temperature is threshold temperature for abnormal AGS and it is caused by drag effect of Nb carbides or carbonitrides to grain boundary which are soluted during the reheating. After the reheating of material the average AGS by calculating method of grains at the circular line was determinated. Measured data were compared with calculation data. Calculation data were created by two equations on the basic of the regression analysis and one of them Eq.2 is according to Dutta-Sellar model. Eq.1 by MATLAB program showed a good coincidence with measured data, but it is applicable for the fast calculation. Coefficients dependence on input AGS, chemical composition of steel, processing conditions and activation energy of grain growth were used for derived equation (2a). Both equations are suitable for comparison with measured data. Influence of holding time on growing of AGS application by equation (2a) showed the good description of change of AGS, where the input AGS was changing from 40 - 100µm. Determination of ±5% and ±15% deviations of measured and calculated data from equations $d_{\gamma} = a_1.T_{reheat}^{a_2}.t_{reheat}^{a_3}$ and $d_{\gamma}^{n} - d_{\gamma,0}^{n} = A.\exp(-Q/R.T).t$ were designed, respectively.

Keywords: HSLA steels, heating temperature, holding time, average austenite grain size (average AGS), precipitation behavior, MATLAB

1. Introduction

Needs of automotive industry and other types of product-line still require the improvement of weight-strength proportion. Research works are oriented to sophisticated application ways of physical metallurgy principle to technology process. It is focused on achieving of high strength, plasticity and toughness properties of high strength steel materials.

The aim of the present work is to research influence of reheating temperature and time on average AGS changes and precipitation behaviour of material. The C-Mn-Nb-V steel (according to the ULSAB classification) is HSLA steel with the R_e=210-550 MPa. This steel is characterized by [1-4] as steel with high strength, good toughness and weldability. Perfect mechanical properties are obtained by balanced chemical composition with the controlled thermomechanical processing. HSLA is alloying separately with Nb, Ti and V or in their combination [1,5]. These microalloying elements are segregated on the grain boundary and thereby they improve the strength properties.

One of the important parameters for ensuring of uniformity and uncoarsening austenite microstructure is the reheating temperature. This temperature influences on a grain size, precipitation dissolution degree and austenite stabilization. Hence we need to know the reheating temperature for the required dissolution for the following microalloying elements: carbides, nitrides and carbonitrides. Guarantee of uniformity and uncoarsening can be achieved by delaying of austenite grains growing during the reheating process in the furnace. Delay effects are made by non-soluble particles of carbides, nitrides or carbonitrides which show a strong drag effect to grain boundary. These particles lose their function of delaying whereby they enter to solid solution after exceeding the specific temperature (precipitation dissolution temperature) and AGS begin to grow [6, 7]. The strong influence of temperature on the grain size can be interpreted as a measure for dissolution of Nb and V carbonitrides [8]. Next parameter to ensure the uniformity and uncoarsening austenite microstructure is the time, which has a weak effect [6, 7]. The difference in precipitates population develops on solidification but reheating to a high (1200ºC) temperature causes complete dissolution of the precipitates regardless of position removing all particle pinning. [9,11]. Commercial reheating is usually carried out at lower temperatures, between 1150 ºC and 1250ºC for HSLA steels [10, 11].

2. Experimental procedure

The chemical composition of the researched C-Mn-Nb-V steel is shown in **Tab. 1**. The samples were reheated from 950 to 1250ºC with a holding time on temperature from 10 to 60 min and the process was finished by their quenching. The experimental material microstructure was investigated by optical microscope Olympus Vanox-T. For optical microscopy of original AGS the etching in picric acid was used. Determination of average AGS by calculating method of grains at the circular line was realized.

Table 1 Chemical composition of steel

Element	C	Mn	Si	P	S	V	Nb	Ti	Al	B	N	O	H
[wt.%]	0,12	1,54	0,12	0,004	0,001	0,18	0,048	0,010	0,015	0,0005	0,0042	0,0015	1,30 [ppm]

3. Results and discussion

3.1 Influence of reheating temperature on the average AGS

The reheating process is designed to take microalloying elements, particularly V and Nb back into solution for subsequent preciptiation during or immediately after rolling to achieve

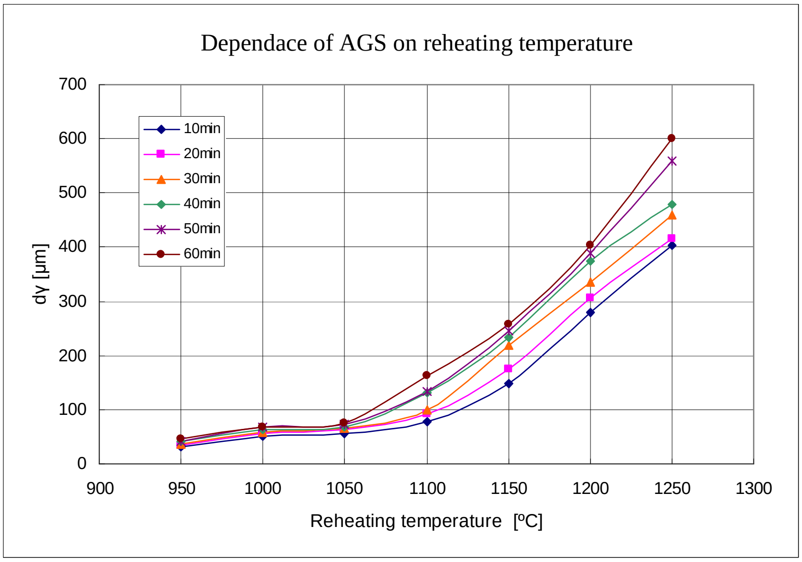

Fig.1 Average AGS at reheating temperatures

desired strength levels via grain size control and dispersion strengthening. Reheating above ≈1200ºC would case complete dissolution of all pinning precipitates and a coarse grain structure would, there, be expected. Reduced driving force for grain growth for reheating below 1050ºC in conjunction with little dissolution of pinning precipitates should lead to a greater grain size. Reheating to temperature range of approximately 1100-1250ºC would result in dissolution of the (Nb,Ti,V)(C,N) precipitates [11].

The effect of reheating temperature on average AGS of steel is shown in **Fig.1**. It can be seen that average AGS increased with the increasing temperature. Average AGS are between 35 μm (at the lowest temperature and holding time) to 600 μm (at the highest temperature and holding time). Temperature above 1100ºC represented the strong influence of NbC, Nb(CN) to an abnormal growth of the AGS. According to [12] grain coarsening during reheating occurs at a temperature significantly (100-150ºC) below the solubility temperature calculated for coarse particles.

Numerical processing of measured data enabled by non-linear statistical method to derive regression equation, which describes dependence of AGS on reheating parameters in form:

$$d_{\gamma} = 6{,}589\,.10^{-28}.\,T_{heat}{}^{9{,}51}.\,t_{hold}{}^{0{,}2437} \qquad [\mu m] \tag{1}$$

Comparison of experimental and calculated data is shown in the **Fig. 2**.

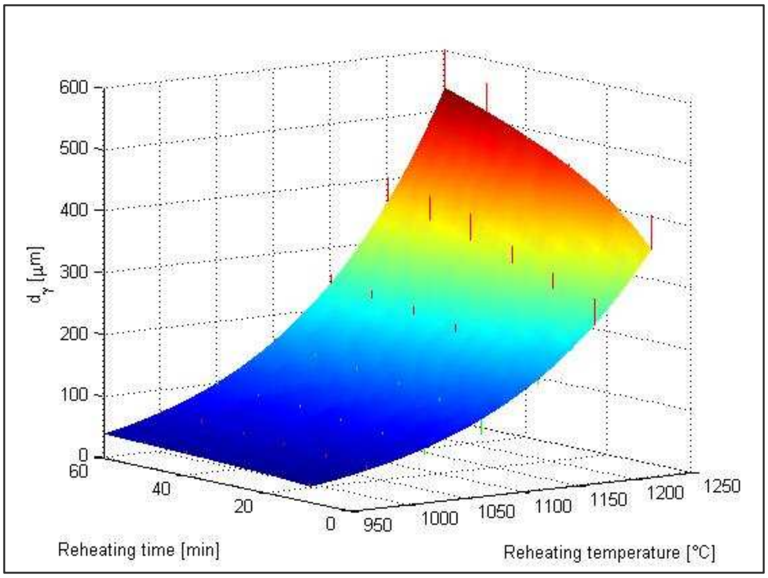

Fig.2 Graphical characterization of the equation (1)

From graphical description results a good coincidence of measured and calculated data, whereby deviations are showed at temperature above 1200ºC.

Dutta-Sellars model of AGS development during reheating conditions has form:

$$d_\gamma^n - d_{\gamma,0}^n = A.\exp\left(\frac{-Q}{R.T_{heat}}\right).t_{reheat} \qquad [-] \qquad (2)$$

Explanatory notes:

d_γ	[µm]	- output diameter of AGS
$d_{\gamma,0}$	[µm]	- input diameter of AGS
n = 2 - 10	[-]	- coefficients dependence on chemical
$A = 1{,}44.10^{12} - 5{,}02.10^{53}$	[-]	composition and processing condition
Q = 280 - 914	[kJ/mol]	- activation energy of grain growth
$R = 8{,}314.10^{-3}$	[kJ/mol.K]	- universal gas constant
T_{reheat}	[K]	- reheating temperature
t_{reheat}	[min]	- reheating time

At the explanation of output AGS diameter from this model, the following equation is obtained:

$$d_\gamma = \sqrt[n]{\left[d_{\gamma,0}{}^n . A.\exp\left(\frac{-Q}{R.T_{reheat}}\right).t_{reheat}\right]} \qquad [\mu m] \qquad (2a)$$

Coefficients in equation (2a) represent unknown variables, which were consequently derived by multi-regression method for reheating condition described by laboratory experiment at interval T_{reheat} = 950-1250º and t_{reheat} = 10-60min. Resultant form of equation (2a) for C-Mn-Nb-V steel and researched reheating condition is following:

$$d_\gamma = \sqrt[3]{\left[40^3 + \left(3{,}28725.10^{22}\right).\exp\left(\frac{-460}{8{,}314.10^{-3}.T_{reheat}}\right).t_{reheat}\right]} \qquad [\mu m] \qquad (2b)$$

Dutta-Sellars model has been widely used to predict the precipitation in HSLA steels upon isothermal holding [9].

3.2 Influence of holding time on growth of AGS

Prediction of AGS growth behavior for other time-temperature conditions was calculated and displayed in **Fig.4**, which base was equation (2a). From Fig.4 resulting that with increasing temperatures and input AGS average output AGS increased with dependence on reheating temperature and time. Strong rising of AGS is possible to observe at temperature 1150ºC.

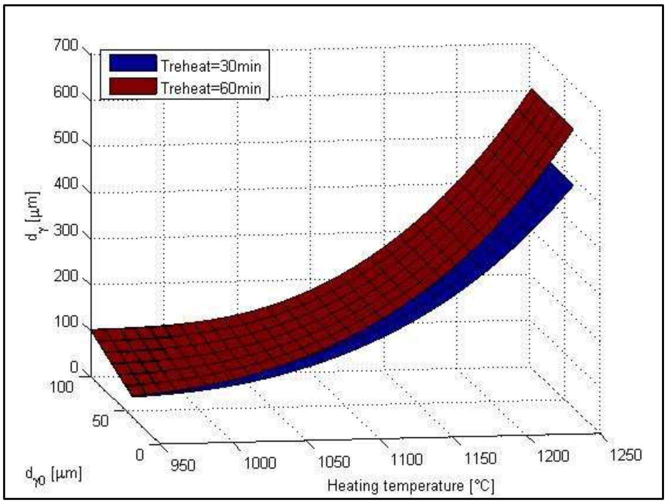

Fig.4 Influence of reheating time on growing of AGS

3.3 Comparison of measured and calculated data

Comparison of equation (1) and equation (2a) is shown in **Fig. 3**, and displays together with measuring data a good coincidence and easy application for given heating conditions.

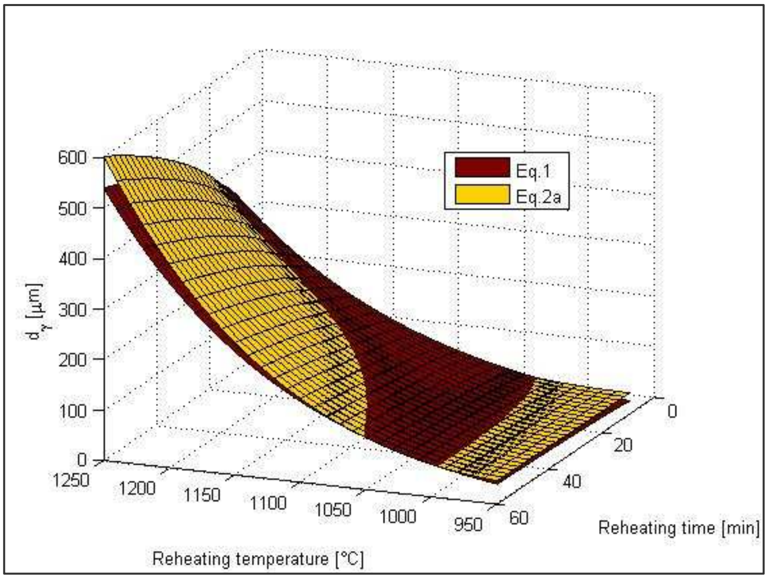

Fig.3 Graphical comparation of equation (1) and equation (2a)

3.4 Deviations comparison of measured and calculated data

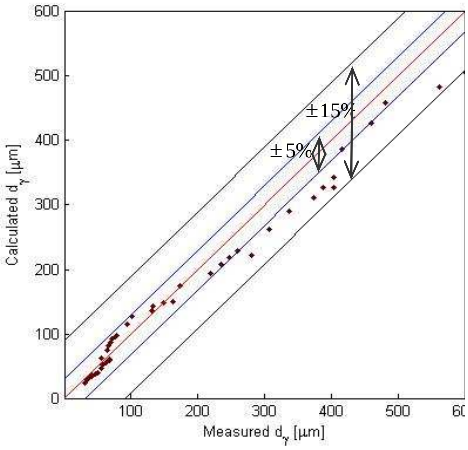

Fig.5 Deviations of data from Eq.2a

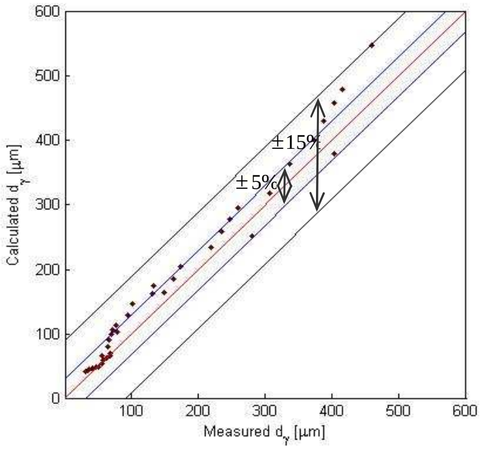

Fig.6 Deviations of data from Eq.2a

Deviations of ±5% and ±15% from average valueares shown in **Fig.5** that considerable part of data is in the interval of ±5%, middle part is between -5% to -15% deviations, but the end points are further from begining and the last one is on the boundary of -15% deviatons.

In opposite case is shown in **Fig.6**, where initial values are in a narrow interval of $\pm 5\%$ deviations, the middle part is between +5 and +15% deviation, and last points are near the boundary of these deviations.

Conclusion

On the basis of experimental study of influence of reheating conditions on average AGS changes it is possible to make following conclusions:

1) the reheating conditions are important from the view of mechanical and metallurgical technology
2) description of experimental data was made by two equations, one is regression and other is Dutta-Sellars model with new derived coefficients valid for investigated steel chemical composition and investigated reheating conditions:
   a) very good coincidence of measured and calculated data was achieved
   b) from graphical and mathematical dependences are resulting dominant influence of reheating temperature and weakly effect of reheating time on change in AGS diameter.

   Initial conditions for dominant grain growth of AGS are:

   - $T_{reheat} \geq 1100^{o} C \quad for \quad t_{reheat} \leq 30\,\text{min}$
   - $T_{reheat} \geq 1050^{o} C \quad for \quad t_{reheat} \rangle 30\,\text{min}$

Literature

[1] available on the web-site: <http://www.autosteel.org/AM/TemplateRedirect.cfm?Template=/CM/ContentDisplay.cfm&ContentFileID=9298>

[2] Deardo A.J.: Microalloyed strip steels for 21st century, Materials Science Forum Vols. 284-286 (1998), p. 15-26

[3] Korchynsky M.: Advanced Metallic Structural Materials and a new role for microalloyed steels, Materials Science Forum Vols.500-501 (2005), p.471-480

[4] Rodriguez-Ibabe, J.M.: Thin slab direct rolling of microalloyed steels, Materials Science Forum Vol. 500-501 (2005), p. 49-62

[5] available on the web-site: <http://www.oulu.fi/elme/ELME2/PDF/Diplomityot/Masters_Thesis_Albert_Satorres%20.pdf>

[6] Kvačkaj T: Vplyv riadeného valcovania na vlastnosti konštrukčných mikrolegovaných ocelí, KDP, Košice, október 1982

[7] Zemko M.: Výskum plastických deformácií pomocou MKP, PhD. práca, jún 2006

[8] Klein M., Spindler H., Luge A., Rauch R., Stiaszny P., Eibelsberger M.: Thermomechanically hot rolled high and ultra high strength steel grades – processing, properties and applications, Material Science Forum Vols. 500-501 (2005), p. 543-550

[9] Chakrabarti D. PhD.Thesis, University of Birmingham

[10] Tither G.: In *Proc. 2nd Int. Conf. on HSLA steels: processing, properties and applications*, Baijing, China, (1992), TMS, Warrendale, p. 61

[11] Kundu A., Davis C.L., Strangwood M.: Grain structure development during reheating and deformation of niobium-microalloyed steels, In *Proc. 3rd Int. Conf. on Thermomechanical processing of steels*, Padua, Italy, 10.-12.September 2008, (CD)

[12] Sellars C.M.: Modeling strain induced precipitation of niobium carbonitrides during hot rolling of microalloyed steel, Materials Science Forum Vols. 284-286 (1998), p. 73-82