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Prediction of Austenite Grain Growth During Hot Rolling of 0.028% Nb Steel

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Abstract

Effects of rolling temperatures and deformation on the grain growth predictions of hot rolled Nb Steel (A572 Grade 50) were investigated. Hot rolling process was conducted by using a laboratory hot rolling mill, in which three different kinds of rolling temperatures and strain were applied. Then microstructure studies are performed and the effects of process parameter are studied. The results showed that increase the temperature and strain will decrease the austenite grain size with a non significant affect of delay time prior to quenching after deformation.

1. Introduction

It is well established that grain growth is the evolution of microstructure by motion of grain boundary driven by the reduction in grain boundary interfacial energy[1]. Given a sufficiently high temperature and no factors impede grain boundary migrations, a polycrystalline material will evolve towards a single crystal. In reality, this goal is rarely attended due to the unavoidable defects and impurities in materials even for high purity zone refined metals. The grain growth is characteristic of growth of larger grain at the expense of smaller ones, leading to an increase in average grain size[1].

Grain growth control in micro alloyed steels during hot rolling processing, critically depends on second phase particles[2]. The appropriate employment of micro alloying elements in high strength low alloy (HSLA) steels, coupled with hot roll processing, can provide improvements in both strength and toughness[3]. This is achieved by suitable manipulation of the recrystallization and precipitation phenomena that take place during deformation. Austenite grain growth in micro alloyed steels is influenced by numerous factors, including austenitizing time and temperature, alloy composition, hot deformation history, initial grain size distribution, and rate of heating to the austenitizing temperature[2]. By suppressing austenite recrystallization, these elements act as ferrite grain refiners, thus increasing the yield strength and decreasing the impact transition temperature3].

The key to obtaining tailored microstructures and, hence, optimum properties is through obtaining a proper understanding of the microstructure evolution phenomenon during the processing, and evaluating the role of the different process parameters[4]. The aim of this study, in terms of the microstructure, was to examine the effect of temperature and deformation on the interaction between recrystallization and austenite grain growth in a 0,028% of Nb micro alloyed steels.

2. Emperical Predictions

Beck et al. showed that experimentally determined values of grain sizes during normal grain growth under isothermal conditions fitted a power relation such as :

$$d^n - d_o^n = C\cdot t \qquad (1)$$

where d is the final grain diameter, d_o is the initial grain diameter, t is the annealing time and n and C are constants which depend on alloy composition and annealing temperature but are independent of the grain size[5].

Sellars et al.[5] analysed previously published grain growth data on low carbon-manganese steels and arrived at the following general expression for evaluating the constant C in (1) :

$$d^n - d_o^n = [A.\exp(-Q_{gg}/RT)]\cdot t \qquad (2)$$

where n and A are constant which depend on material composition and processing conditions, Q_{gg} is the activation energy for grain growth, R is the universal gas constant and T is the temperature in degree

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absolute. Majority of the current available empirical models which describe grain growth behavior of austenite are based on (1).

In general, austenite grain size evolution describes the change in austenite grain size by recrystallization and grain growth. During hot roll processing, grain is refined by recrystallization under the certain strain and temperature. Further grain growth may take place even in short inter pass time, when recrystallization is completed [6].

The rate of recrystallization is only one of important aspects when modeling the microstructural evolution, occurring during inter pass between deformation and during cooling from the lass past to the transformation temperature. The recrystallized volume fraction is expressed as a function of the holding time after deformation as :

$$X = 1 - \exp[C\cdot (t/t_x)^k] \qquad (3)$$

where t is the holding time, t_x is the time for a given volume fraction X to recrystallize, C=ln(X), and k is the Avrami exponent.

The ability to predict the recrystallized grain size is also necessary. General observation for C-Mn-Nb steels regarding the influence of strain, strain rate and temperature on the fully recrystallized grain sized are given by Sellars[7], and the model for statically recrystallize grain size can describe as :

$$d_{RX} = 0.9^{0.33}\cdot d_o^{0,67}\cdot \varepsilon^{-0.67} \qquad (4)$$

where d_{RX} is the recrystallized grain size, d_o is the austenite prior grain size and ε is the strain.

Following complete static or meta dynamic recrystallization, the equiaxed austenite microstructure coarsens by grain growth. Since there is a lack of models dealing with an abnormal grain growth, the assumption of uniform growth is made. The models for uniform growth are, in general, based on the isothermal law :

$$d(t)^n = d_{RX}^n + A\cdot t\cdot \exp(-Q_g/RT) \qquad (5)$$

where d_{RX} is the fully recrystallized grain size, t is the time after complete recrystallization, Q_g is the apparent activation energy for grain growth, and n and A are constants[7].

Mathematical models describing isothermal grain growth of statically or meta dynamically recrystallized austenite in C-Mn and C-Mn-Nb steels are summarized in Table 1.

Looking for the empirical model that will be used for this experience, the models compare each other to observe the relation of each other. Assuming a hypothetical but typical value for d_{RX} of 60µm and solving all above models by substituting T = 1133, 1233 and 1333°K, for holding time t = 10s and t=1000s the results obtained are given in Fig. 1.

Table 1. Summary of empirical models describing austenite grain growth[5], [7]

Source	Steel	*n*	k_g	Q_g, J/mole
Sellars et al., (1979)	C – Mn	10	$3.87\cdot10^{32}$ for T>1273°K $5.02\cdot10^{53}$ for T<1273°K	400000 for T>1273°K 914000 for T<1273°K
Namba et al., (1979)	Low C-Mn	2	$4.27\cdot10^{12}$	66600
Hodgson and Gibbs (1992)	C-Mn and C-Mn-V	7	$1.45\cdot10^{27}$	400000
Hodgson and Gibbs (1992) Beynon and Sellars (1992)	C-Mn-Nb	4.5	$4.1\cdot10^{23}$	435000

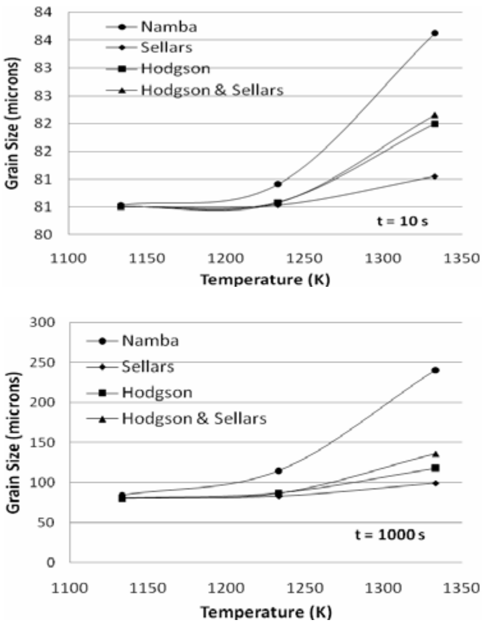

Fig. 1. Predicted austenite grain growth in C-Mn Steels from (a). t=10 s and (b). t=1000 s

It can be seen in Fig.1 that the prediction models for grain growth of austenite in C-Mn steels do not match each other. It will be see that the model for C-Mn steel by Sellars will be constant trend line for the gradual time inter pass and will be fit with the model C-Mn-Nb by Hodgson and Sellars for the long time inter pass.

So, this research will be use the prediction of Hodgson and Sellars model to observe the grain growth evolution after deformation.

3. Experimental Procedures

A commercial Nb-micro alloyed steel was used for these study and the detailed composition of the steel is given in Table 2. A relatively high concentration of manganese was used in order to provide added harden ability to minimize the amount of pro eutectoid ferrite formation during quenching.

Table 2. Steel composition (percent of weight)

C	Si	Mn	P	S	Al	Nb	Cu	Fe
0,085	0,222	1,45	<0.003	<0,003	0,049	0,028	0.045	98,14

The hot rolling was carried out in a laboratory hot rolling mill having 20 kN rolling load capacity with constant rolling speed. Rectangular samples in 30 mm width and 60 mm length (parallel to the rolling direction) were machined from HRC material. A hole of 2 mm in diameter was drilled in the center of longitudinal-transverse (L-T) section of sample, for insert a thermocouple.

Heat treatment of the sample fitted with the thermocouple was performed by heating at a constant rate of 0.3 °C.s^{-1} to temperatures of 1150 °C, followed by holding for 10 minutes to permit full austenitization of the material. Then the specimens hot rolled at three different temperatures of about 860°C, 960°C and 1060°C to study the influence of the rolling temperature on the grain refinement. To investigate the influence of the reduction, the rolling reduction was varied about 10%, 20% and 30% in one pass. After rolling, the specimens was delay in a few second with air cooling and then water quench to view the austenite boundary. Light microscopy of steel plates was conducted in a Olympus metallurgical microscope, on 4 pct picral–etched specimens.

4. Results and discussion

Strain during rolling (ε) were predicted by measured the altering of the plate thickness and count by using the plane strain rolling. Compare the strain with the critical strain (ε_c) by using Djaic and Jonas critical strain model ($\approx 0.8\varepsilon_p$)[8], observed that static recrystallization and fully recrystallize take place after deformation.

Table 3. Strain and evolution condition after deformation

No	Reduction	T_{def} (°C)	ε	ε_p	ε_c	$\varepsilon < \varepsilon_c$	$X_{0,95}$	X
1	0.110	1060	0.135	0.471	0.377	static	1.00	Fully
2	0.149	1060	0.186	0.480	0.384	static	1.00	Fully
3	0.313	1060	0.434	0.541	0.433	static	0.99	Fully
4	0.109	960	0.133	0.660	0.528	static	1.00	Fully
5	0.196	960	0.252	0.695	0.556	static	1.00	Fully
6	0.283	960	0.385	0.729	0.583	static	1.00	Fully
7	0.100	860	0.134	0.985	0.788	static	1.00	Fully
8	0.197	860	0.254	1.045	0.836	static	1.00	Fully
9	0.287	860	0.390	1.085	0.868	static	1.00	Fully

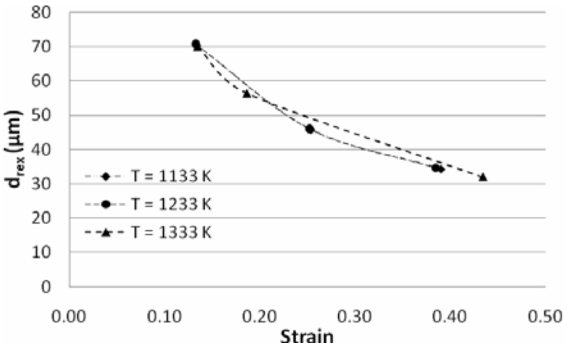

Fig. 2. Recystallized grain size with respect to deformation at various temperature

Table 3 present that the recrystallization controlled rolling (RCR) is carried out because the temperatures where the austenite microstructure is completely recrystallized (*e.g., >T*95pct).

Then microstructure model determination by Olympus metallurgical microscope, it was transformed to be grain size by using Heyn Interceipt Method and ASTM E 112. Using the grain size of austenite prior (80,5 μm) on the reheating condition, the deformation and temperature condition have been transformed to the recrystallization grain size according to the Sellars model and plotted the statistical recrystallization model with the strain deformation in Fig. 2.

It is clear that the static recrystallize grain size decrease with increasing strain with a significant affect in the slope. Increased the strain level will decrease the slope of recrystallize grain size[12]. It cause by a sufficient amount of precipitate-induced grain-boundary pinning prevents a further grain growth and retains the fine recrystallized grain size and the size of recrystallization grains in coarse grain materials becomes constant when the plateau of recrystallization is reached [13]. The recrystallization grain size reported in Fig. 2 is the value at the plateau in these cases.

Fig. 2 present that at strain below the critical value the deformation temperatures don't have a significant effect on recrystallice grain size[8]. It would be showed that there is no effect of increase deformation temperature from 860°C to 960°C. It cause by incomplete dissolution of NbC. Above 1000°C showed that the recrystallization will increase with a lower magnitude cause the retardation of recrystallization is reduced[8].

It could be explained by observe the austenite grain growth after fully recrystallize and plotted them in Fig. 3 and Fig. 4. The figure showed the correlation between the grain growth with a delay time prior to quenching after deformation and the deformation temperature in the similar strain. It showed that increase the deformation temperature will increase the austenite grain size slowly. Compared to the empirical model, it would be like an equal fit on the lower strain, but a different prediction with the empirical model on the higher strain. It might be due to the kinetic model used on simulations in this case that observed the C-Mn steels without micro alloyed.

Refer to the condition, empirical model based on Hodgson and Sellars model that predicted in Fig. 1was used. It's carried out to predict grain growth behavior of 0,028 Nb Steel.

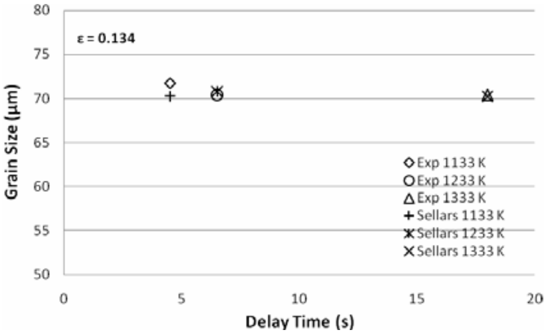

Fig 3. Austenite grain size respect to temperature at ε = 0.134

The experimental grain growth of samples on hot rolled 0,028 Nb steel at different reduction grades (10%, 20% and 30%) and holding at different time after deformation are showing in Fig. 5 together with the values predicted by the empirical model.

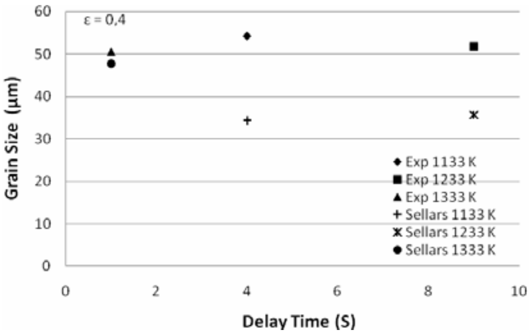

Fig. 4. Austenite grain size respect to temperature at ε = 0.4

It was looking that increase deformation will decrease the grain growth, but increase temperature will decrease the grain growth accept for 10% deformation. The experimental data showed that increase temperature will decrease the grain growth, and it doesn't have a significant tendency with the empirical model. It might be effect of many reasons.

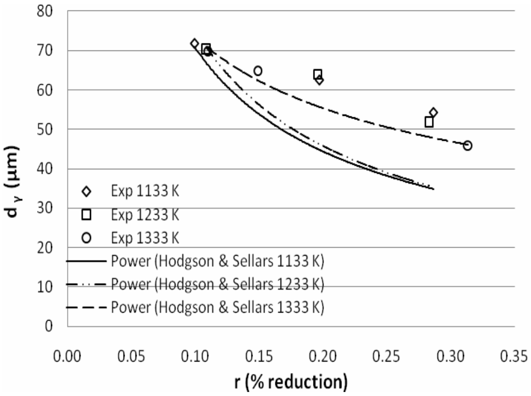

Fig 5. Comparison of predicted and experimental grain growth behavior in 0,028 Nb Steel

To reduce the dissimilar tendency, the empirical model will be modification. Equation (2) will modification according to the regression analysis of data on Fig. 5 and prediction model on table 1, produce the constant n = 9,7 and A = $1{,}7\cdot10^{34}$ and Q=463000. Then (2) will become :

$$d^{9.7} - d_o^{9.7} = [1.7\cdot10^{34}\cdot\exp(-463000/RT)]\cdot t \qquad (6)$$

This equation will produce the experimental model similar with Hodgson and Sellars prediction model, that could be looked in Fig. 6.

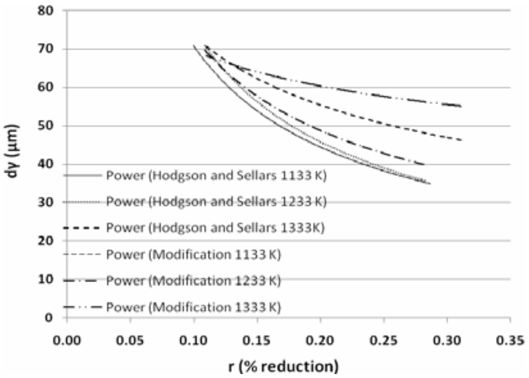

Fig 6. Prediction and Experimental Model of Austenite Grain Growth

5. Conclusions

1. Increasing the strain appears to accelerate the recrystallization kinetics, so there was decreased recrystallized grain growth.
2. Grain growth of 0,028% Nb steels is influenced by heating and deformation conditions. Grain sizes increase with increasing temperature and holding time.
3. The austenite grain size growth slowly after reach fully recrystallization
4. Grain growth predictions for Nb steels compare well with the experimental grain growth data for these steels, by modification the predictions model to become :
   $d^{9.7} - d_o^{9.7} = [1.7\cdot 10^{34}\cdot \exp(-463000/RT)]\cdot t$

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References

[1]. H.R. Wang, W. Wang: Materials Sciences and Technology, **24** (2008), 228.

[2]. K.A. Alogab, D.K. Matlock, J.G. Speer and H.J. Kleebe: ISIJ Int., **47** (2007), 1034.

[3]. L. Jiang, A.O. Humphreys & J. J. Jonas: ISIJ Int., **44** (2004), 381.

[4]. B. Dutta and E.J. Palmiere: ISIJ Int., Mettallurgical and Materials Trans. A, **34A** (2003), 1237.

[5]. P.A. Manohar, D. P. Dunne, T. Chandra, C. R. Killmore: *ISIJ Int*., **36** (1996), 194.

[6]. H. W. Lee, H. C. Kwon, Y. T. Im, P. D. Hodgson, S. H. Zahiri: *ISIJ Int*., **45** (2005), 706.

[7]. J.G. Lenard, M. Pietrzyk, L. Cser: Mathematical and Physical Simulation of The Properties of Hot Rolled Products, 1st ed., Elsevier, (1999), 167.

[8]. C. M. Sellars: The physicals metallurgy of hot working.

[9]. J. H. Beynon and C. M. Sellars: ISIJ Int., **32** (1992), 359.

[10]. P.D. Hodgson and R.K. Gibbs: ISIJ Int., **32** (1992), 1329.

[11]. J. H. Beynon and C. M. Sellars: ISIJ Int., **32** (1992), 359.

[12]. M. Militzer, E.B. Hawbolt, T.R. Meadowcroft: *Metallurgical and Materials Trans*. *A*, **31A**, (2000), 1247.

[13]. S. Akta, G. J. Richardson, C. M. Sellars: ISIJ Int., **45** (2005), 1686.