OPTIMIZATION OF RETENTION TIME IN REHEATING FURNACE FOR MICROALLOYED STEEL GRADES

PATIL Milind[1], AlSHAHRANI Abdullah[1], ALMALKI Othman[1], ALGHADEER Yousuf[2], ARIKERE Bharath[3], AKHTAR Jamil[3], RO KS[4], SARNA Amitabh[5]

[1]Metal Technology - Hadeed SABIC, Al-Jubail, KSA; [2]Regional Analytical Laboratory, SABIC, [3]Hot Strip Mill- Hadeed, SABIC; [4]Metals SBU- Product Support, SABIC, [5]Technology Programming, SABIC; Jubail Industrial City, Saudi Arabia

patilm@sabic.com

Abstract

Slab thermal homogenization during reheating in furnace is temperature and retention time dependent. Dissolution of microalloying element like niobium in austenite at soaking temperature is important to achieve desired strength and toughness in final rolled product. Under soaking and low set temperature may not dissolve microalloying elements and on other hand over soaking and higher temperature may lead to austenitic grain growth. In both cases, it affects, strength and toughness of the final product. The optimum temperature and retention time allows micro-allying elements to dissolve in austenite and controls austenite grain growth. These conditions are favorable to achieve both high strength and toughness in the rolled strip.

Gleeble 3000 physical simulator was used to conduct trials with combination of various soaking temperatures and time. Prior austenitic grain size and dissolution of micro-alloying was evaluated. To validate experiment and check relevance of experiment with actual rolling during production, laboratory muffle furnace was used and same plant process conditions of soaking temperatures and time were used to simulate actual plant conditions. The results of validation trials were encouraging. Temperature of 1220°C and soaking for 15 and 30 Seconds in Gleeble experiments, had shown similar results, this was deciding factor for the optimizing retention time in reheating furnace. Based on laboratory trials results, plant trials were conducted with reduced furnace retention time of 160 minutes minimum against 170 minutes earlier. The test results of plant trials were satisfactory and meeting specification requirements. Special technique of micro etching was used to reveal prior austenitic grain size.

With 10 minutes reduction in retention time for group of steel grade, around 6% more time will be available for rolling, contributing to increment in production and financial benefits.

Keywords: Retention time, dissolution of micro-alloying elements, Austenite grain size

1. INTRODUCTION

Rolling of coils with Thermo-mechanical controlled practice (TMCP) helps in achieving strength and toughness in micro-alloyed steel grades. Optimum setting of rolling parameters like Re-heating temperature and retention time, drafting, temperatures at every stage of rolling and most importantly cooling rates is a success story of TMCP. Reduction in retention time in furnace adversely affects the strength of material on the other hand increment in retention time for entire quantity micro-alloyed grades affects badly on productivity. Striking optimum balance between productivity and the product quality is necessary in industrial conditions.

Dissolution temperature of micro-alloying elements without austenitic grain growth were evolved by conducting experiments in Gleeble 3500 and laboratory muffle furnace. Based on experimental results, plant trials were conducted with combination of reduction in retention time by 10 minutes with increment in reheating temperatures. The results of mechanical properties were satisfactory for API grades J-55, X60 and X65.

2. BACKGROUND

Drop in strength from coil to spiral pipe due to Bauschinger effect is usual concerned of pipe manufacturers. However, unusual drop in strength in hot rolled coil was observed. Detailed investigation revealed strong influence of retention time on mechanical properties of the strip. Dissolution of alloying elements and microalloying elements is a function of time and temperature. If the micro-alloying element like Niobium is not dissolved completely in the austenite, the resultant microstructure influences the strength of material. To optimize retention time for API linepipe steel grades, moderately microalloyed grades were selected.

3. IMPORTANCE OF REHEATING TEMPERATURE AND CALCULATIONS FOR DISSOLUTION TEMPERATURE

3.1. Importance of reheating temperature

Re-heating of slabs is a critical parameter to maintain yield and quality of the product. Optimum reheating temperature facilitates (1) increase in plasticity of material to for smooth rolling (2) homogenization of temperature and to some extent chemical composition (3) Transformation of ferrite to austenite without unreasonable grain growth (4) dissolution of precipitates [4]. During reheating, ferrite to austenite transformation without grain growth and dissolution of precipitates are very important parameters to achieve strength and ductility in micro-alloyed steel grades. Both transformation of ferrite to austenite and dissolution of microalloying elements in austenite are time and temperature dependent. With lower Carbon, the solubility of microalloying elements like niobium is more even at low temperature compared to high carbon content composition [2]. However, re-heating temperature and retention time are govern by furnace heating capacity and the percentage of other elements in steel grade.

3.2. Calculations for dissolution temperatures

Conventionally, slabs are usually cooled to ambient temperature before charging to reheating furnace. Slabs are heated to temperatures to which precipitates of niobium will be dissolved. Dissolution temperatures for various grades in low microalloyed group are calculated using empirical formula. The chemistries selected for the calculations are from particular with less microalloying element contents. The empirical formulae used for the calculation of amount of various niobium, component formations like Niobium carbide, Niobium nitride and niobium carbonitride in solution at particular temperature for varying carbon and nitrogen content [1] [3] in chemical composition, following empirical formulae were used

For calculating the availability of

Niobium carbide: $\log [Nb][C] = 2.78-7407/T$ (1)

For Niobium nitride: $\log [Nb][N] = 2.89-8500/T$ (2)

For Niobiumcarbonitride: $\log [Nb][C+12/14N] = 2.26-6770/T$ (3)

By using empirical formulae, reference tables for Solubility of NbC in austenite at various temperatures **(Table 2)**, for solubility of NbN in austenite at various temperature **(Table 3)** and for solubility of NbCN in austenite at various temperature **(Table 4)** were prepared to understand the amount of precipitate formed at various temperature for each chemistries under trials. Using above formulae solubility of various niobium components was calculated for X60, X65 API grade and J-55 grade. Chemical composition of these grades is mention below in **Table 1.**

Table1 Chemical composition in weight % for the two grades from selected group

Grade	C	Si	Mn	P	S	Al	V	Ti	Nb	N_2
X60/X65	0.06-0.16	0.20 - 0.35	1.30 - 1.70	0.015 max	0.015 max	0.050 max	0.030-0.050	0.010-0.020	0.030-0.050	0.006 max
J-55	0.10-0.25	0.20 - 0.35	1.00 - 1.50	0.015 max	0.015 max	0.050 max	-	-	-	0.006 max

Table 2 Reference table for Solubility of NbC in austenite at various temperatures

T [°C]	T [K]	log [Nb][C]	[Nb][C]	%Nb solute
1000	1273	-3.04	0.0009	0.0092
1050	1323	-2.82	0.0015	0.0152
1100	1373	-2.61	0.0024	0.0243
1150	1423	-2.43	0.0038	0.0376
1200	1473	-2.25	0.0056	0.0564
1250	1523	-2.08	0.0083	0.0825
1300	1573	-1.93	0.0118	0.1178

Table 3 Reference table for Solubility of NbN in austenite at various temperatures.

T [°C]	T [K]	log [Nb][N]	[Nb][N]	%Nb solute
1000	1273	-3.79	0.0002	0.0270
1050	1323	-3.53	0.0003	0.0490
1100	1373	-3.30	0.0005	0.0830
1150	1423	-3.08	0.0008	0.1380
1200	1473	-2.88	0.0013	0.2190
1250	1523	-2.69	0.0020	0.3390
1300	1573	-2.51	0.0031	0.5110

Table 4 Reference table for Solubility of NbCN in austenite at various temperatures.

T [°C]	T [K]	log [Nb][C,N]	[Nb][C,N]	%Nb solute
1000	1273	-3.06	0.0009	0.0083
1050	1323	-2.86	0.0014	0.0132
1100	1373	-2.67	0.0021	0.0203
1150	1423	-2.50	0.0032	0.0302
1200	1473	-2.34	0.0046	0.0439
1250	1523	-2.19	0.0065	0.0621
1300	1573	-2.04	0.0090	0.0860

4. DESIGN OF EXPERIMENT IN MUFFLE FURNACE AND GLEEBLE 3500 PHYSICAL SIMULATOR

The objective of experiment is to reduce reheating time during slab reheating. The heat transfer from slab surface to core is by conduction which is time and temperature dependent. Reduction in time with homogeneity in temperature is only possible, if temperature is raised. It should be also be noted that too high temperature will lead to grain growth and deteriorate the toughness and strength. Grade X60/X65 was selected for the experiment in muffle furnace. Samples from slabs of X60/X65 were cut in half an inch cube and heated to 4 different temperatures in controlled way. These samples were soaked for 3 different period. After soaking at pre-defined temperatures, samples were quenched in to brine water and stirred continuously to achieve fastest possible cooling rate. These samples are then studied for metallographic examination. The austenitic grain size and temperature at which grain growth is taking place is checked.

4.1. Physical Simulation study on Gleeble

The experiment conducted in Gleeble 3500 was of two folds. The first was to identify the temperature at which the austenite grain is stable without grain growth and the second is to identify the soaking/holding time, which is sufficient to dissolve the micro-alloying elements without austenitic grain growth. The temperatures selected for the experiment were 1200, 1220, 1240 and 1260°C. These samples were simulated at these temperatures with varying holding time of 5, 10, 15 and 30 second in Gleeble.

The austenitic grain was measure by special etching technique with hot picric acid. The grain size distribution analysis was carried out on the samples, which were etched with special technique for each holding time at particular temperature. Dissolution of micro-alloying elements were evaluated based on the hardness of the sample as very fine precipitated of Niobium could not be seen by Scanning Electron Microscope (SEM).

4.2. Plant Trials

Based on the metallographic studies on samples from muffle furnace experiment and gleeble simulation, it was noticed, that slab reheating temperature of 1220°C would be optimum without grain growth. Plant trials were conducted by reducing 10 minutes in retention time compensating with increment of 20°C in re-heating temperature.

From the graph in **Figure 1**, it can be seen that the homogeneity in the temperature at the end of re-heating furnace is a function of time and temperature. Homogeneity in temperature can be achieved earlier by raising temperature. However minimum period of soaking is necessary when the chemistry is microalloyed and alloyed with other elements like Manganese (other major alloy being Manganese).

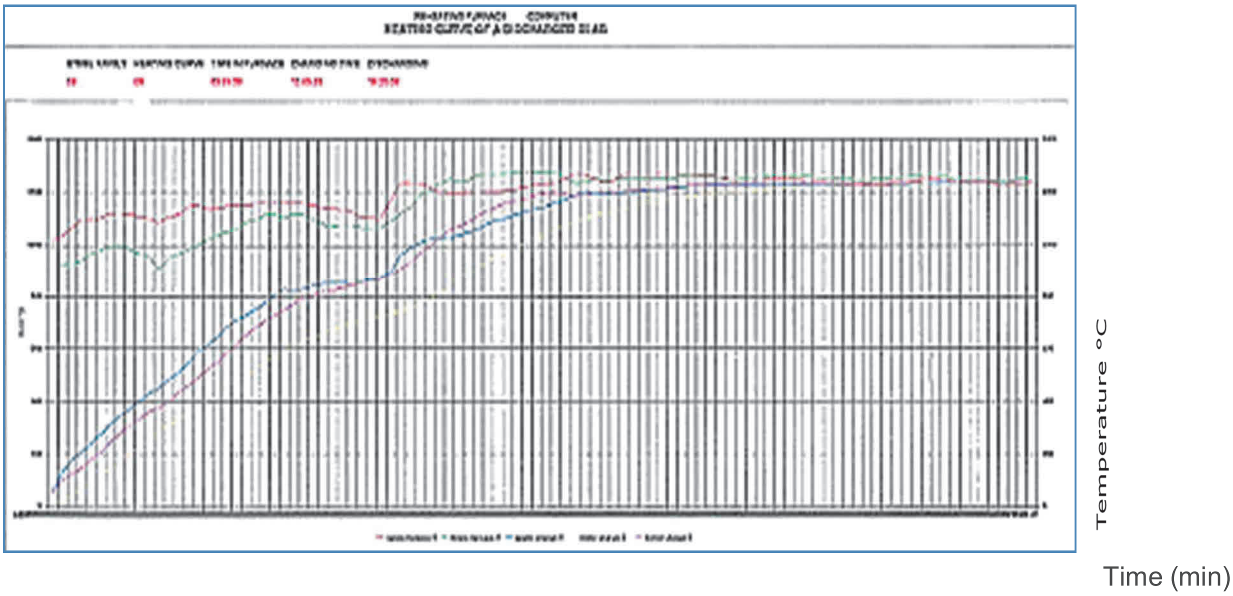

Figure 1 Showing graphs with proper homogeneity in temperature at soaking zone in reheating furnace

Plant trials were planned with reheating temperature of 1220°C with minimum retention time of 160 minutes. It was necessary to ensure the soaking time of around 30-35 minutes to dissolve all micro-alloying elements in austenite and maintain temperature homogeneity. The trial was restricted for only one rolling schedule comprising of around 100 slabs. First trial was conducted on two different chemistries viz. X65 & J55. The mechanical properties test results were encouraging for grade J55 and slight improvement in strength was observed, however in chemistry for grade X60/X65 minor drop in yield strength was observed. To validate these results one more trial was conducted. In validation trials, the results of X60/X65 were also satisfactory. The results of each trials with their retention time are mentioned in **Table 5.**

5. RESULTS OF EXPERIMENTS AND PLANT TRIALS

5.1. Evaluation of Gleeble Simulation

Simulation in gleeble was done for 4 different temperature 1200, 1220, 1240 and 1260°C and with 4 different soaking/holding period as 5, 10, 15 and 30 Seconds. These samples were etched with hot picric acid to reveal the austenitic grain size. **Figure 2** shows the metallographic results of these experiment and austenitic grain size in micrographs. It was seen that at 1220°C when soaked for 15 sec no growth or minimum growth of austenitic grain occurred. This was considered as the optimum temperature for the heating of slabs of X60/X65 and J55 grades.

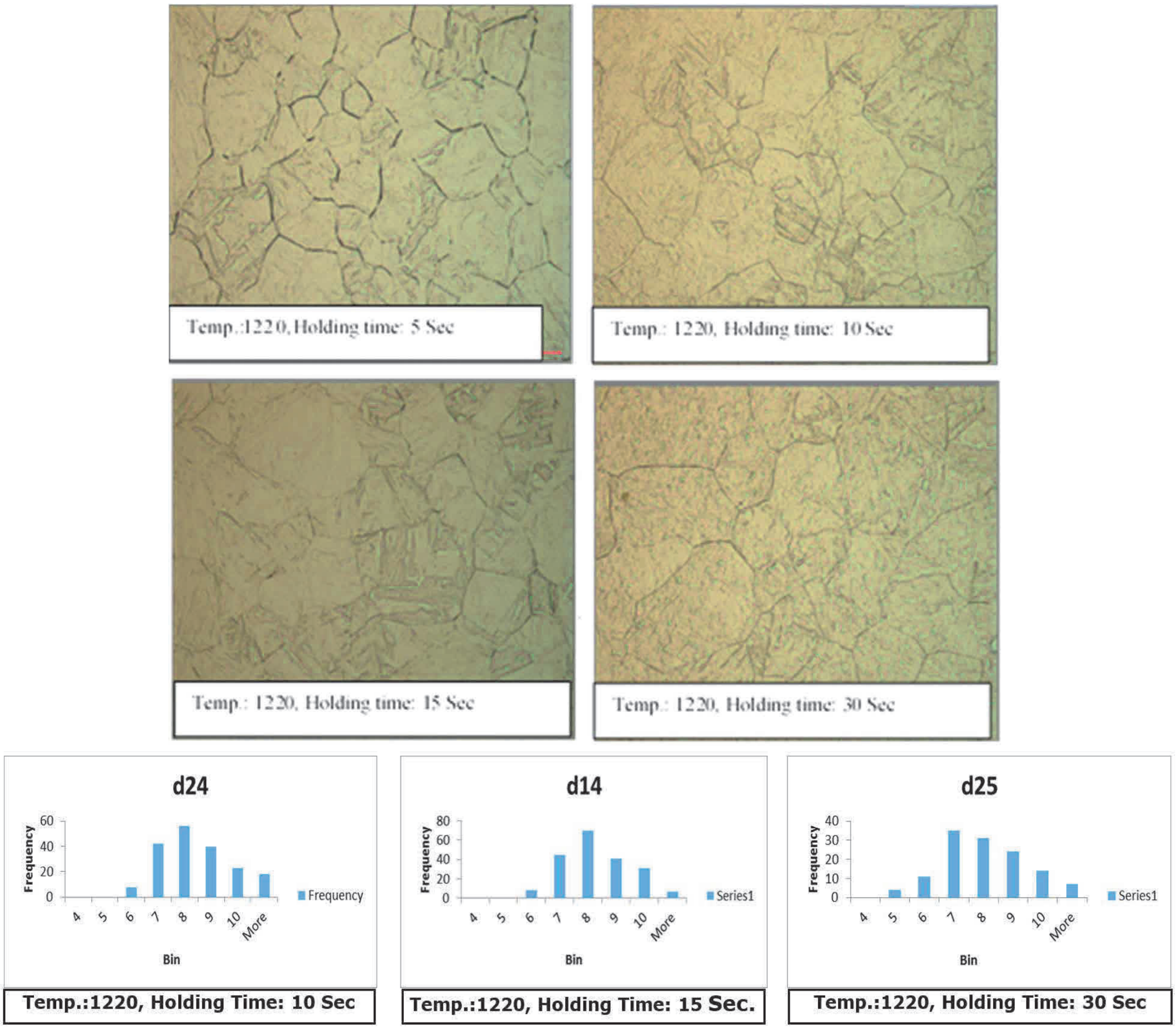

Figure 2 Shows austenitic grains when heated at 1220°C and the actual austenitic grain size at different holding times

Since SEM does not reveal precipitate percentage, the hardness of the sample was taken as a measure to estimate the dissolution of micro-alloying elements. The higher hardness was indicative for the complete or maximum dissolution of micro-alloying elements in austenite, **Figure 3**. The drop in the hardness at 1240°C indicates increment in precipitation size due to coagulation. Further increment in hardness at 1260°C can be seen, which indicates complete dissolution of microalloying elements in austenite however, grain growth is also observed which is detrimental for toughness.

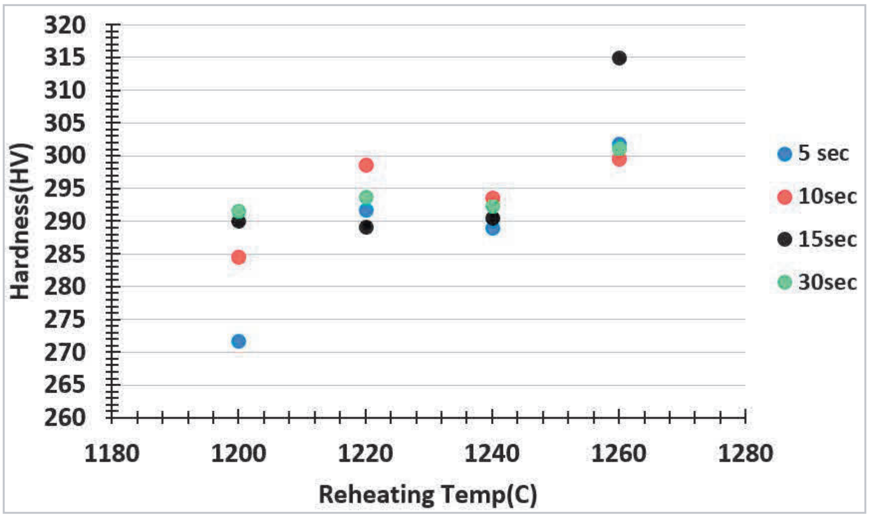

Figure 3 Shows Hardness at various temperature at defined holding time

5.2. Evaluation of Plant Trials

Only one rolling schedule of around 100 slabs was planned with increased reheating set point temperature of 1220°C & retention time of minimum 160 minutes In first trial two grades X60/X65 and J55 were tried. Grade X65 was for the spiral pipe manufacturing whereas grade J55 was for ERW pipe manufacturing and hence the sample orientation was in 30° to rolling and longitudinal direction to rolling for spiral and ERW pipes respectively. The comparison of the tensile results of the coils under trial was done in respective grades in same sample orientation.

Table 5 Mechanical properties in coils under 1st plant trial

Coil Id	Chem Id	Retention Time (min)	Sample Direction	YS (MPa)	TS (MPa)	% El.
831	X60/X65	161	30	493	612	42
828	X60/X65	161	30	480	609	44
829	X65	164	30	507	609	41
716	J55	168	L	467	588	40
717	J55	161	L	481	580	40
721	J55	161	L	497	592	42

Validation (Second) trial was conducted as a validation trial and specifically X65 grade was rolled. The retention time was maintained in range of 160 to 170 minutes. The sample location was 3 m from tail end of coil and orientation of sample was at 30°. Test results coils of validation trials are shown in **Table 6** and meeting of X60/X65 grade specification requirements.

Table 6 Mechanical properties in coils under validation trial

Coil ID	Chemical ID	Retention Time group	Actual Retention Time	YS (MPa)	TS (MPa)
1011	X65	160min < RT< 170 min	165	528	617
1038	X65	160min < RT< 170 min	168	531	623
1021	X65	160min < RT< 170 min	165	528	614

6. CONCLUSIONS

The study on retention time in re-heating furnace was successfully concluded by conducting plant trials with reduced retention time.

With reduced retention time in reheating furnace, for low microalloyed grades, the estimated increment in productivity is around 6 percent.

From trial, it can be concluded that the combination of 1220°C as reheating time and minimum 160 minutes retention time will not affect mechanical properties of grades in J55 through X65 for certain thickness-width combination.

ACKNOWLEDGEMENTS

Authors are thankful to Metal Technology management to accept challenge of optimization of retention time in reheating furnace for microalloyed steels and allow team to work on it. Thanks to Hadeed HSM and MT Gleeble team for conducting trials. Thanks authors in references without which paper could not have been technically completed and also thanks to organizing team of METALS 2017 for giving opportunity to present in conference.

REFERENCES

[1] GLADMAN,T. *The Physical Metallurgy of Microallyed Steels.* Institute of Materials, 1997.

[2] PANIGRAHI, B. K. Processing of low carbon steel plate and hot strip-an overview. *Bull Mater. Sci.*, 2001, Vol. 24, No. 4, pp. 361-371.

[3] DEARDO, A. J. Nobium in Modern Steels. *J. International Materials Reviews,* 2003, Vol. 48, No.6, pp.371-402.

[4] GINZBURG, V. B., BALLAS, R. *Flat Rolling Fundamentals*. Marcel Dekker Inc. New York, 2000.