SBQ Product Optimization of Thermomechanical Rolling Process

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ABSTRACT

Thermomechanical rolling (TMR), also known as controlled rolling, is a special hot rolling process feature in which the steel rolling temperature is controlled using water cooling to achieve desired as-rolled material characteristics and physical properties such as microstructure, grain size, hardness, tensile strength, and yield strength. Grain refinement is achieved when the rolling temperature is controlled and restricted from reaching the steel recrystallization temperature.

The TMR process requires rolling temperature control before reaching the final reducing stands. This is made by a loop temperature control that includes an online water box system with the finishing temperature control.

TMR is a product and application dependent process that considers characteristics such as steel grade, diameter, and material specifications. Standard operating practice is to roll without utilizing TMR water boxes. This practice results in an average finish temperature of 1740°F – 1830°F (950°C – 1000°C). When TMR is utilized, the target process control is the rolling finish temperature after final reduction. The temperature control capability of the TMR process is targeted between 1500°F – 1650°F (815°C – 900°C). The lower the finish temperature, the more water-cooling during rolling is required.

This research studies the effect of rolling mill finish temperature on material properties of grain size, microstructure, and hardness throughout the cross-section locations of surface (S), ½ radius (1/2R), to core (C) of round bar for medium carbon special bar quality (SBQ) grades and bar diameters, with an objective of increasing knowledge of the thermomechanical rolling process and optimizing SBQ product rolling practices to ensure best fit without compromising steel quality.

Keywords: thermomechanical rolling, SBQ carbon alloy steel, grain size refinement, microstructure, hardness properties, finish temperature, product and process optimization

INTRODUCTION

Thermomechanical rolling (TMR) manages steel temperature during rolling through water cooling to influence the final microstructure and mechanical properties. By maintaining rolling temperatures below the recrystallization threshold, as seen in Fig. 1, grain growth is suppressed[1,2], leading to grain refinement.

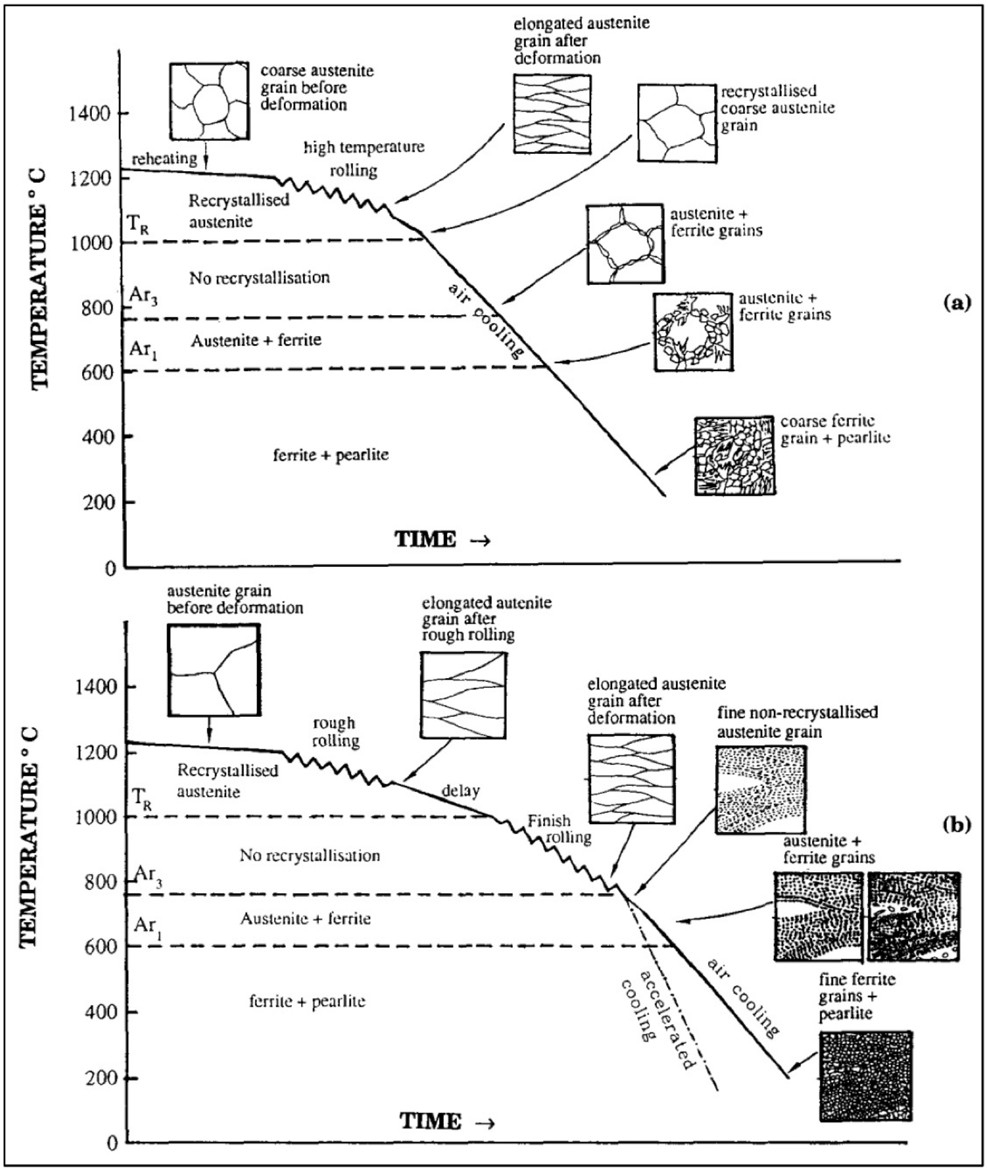

Figure 1. Schematic depictions of (a) hot rolling, (b) conventional thermomechanical or controlled rolling.[2]

Ar_3 = temperature at which austenite begins to transform to ferrite
Ar_1 = temperature at which transformation of austenite to ferrite is complete
T_r = recrystallization stop temperature

This processing approach modifies the as-rolled structure of the steel, which leads to improved material properties such as hardness, tensile strength, and yield strength[3]. Optimized properties result in better material performance. This includes material conditions that would otherwise require additional straightening and/or heat treatment. It is also ideal for subsequent operations such as machining and cold forming.

The Gerdau SBQ mill located in Monroe, Michigan has TMR capability for plain carbon and low-alloy steel grades with low to medium carbon content. Final hot-rolled diameters range from approximately 1 inch to 3 inches. The process begins by heating 240mm square blooms in a reheat furnace to a temperature of 2150°F–2250°F (1180°C–1230°C) and charged into the mill. After descaling, the blooms pass through a breakdown mill composed of five (5) horizontal-vertical (H-V) stands, reducing them to a 149mm pre-round bar. Subsequent reduction through a roughing mill of up to eight (8) H-V stands reduces the pre-round further to feed sizes of 50mm (8 roughing stands), 70mm (6 stands), 80mm (6 stands), or 90mm (4 stands) depending on final aim size. Immediately after the roughing mill stands, the TMR water boxes (Fig. 2) are located for rolling temperature control. Once passed through the water boxes, a series of up to eight (8) 3-roll reduction cassettes roll the feeder round to final prepared size which is dimensionally refined through a 3-roll precision sizing block (PSB) of three (3) cassettes. Hot- rolled bars are air cooled on a cooling bed to be cut to length and bundled. Refer to Fig. 3 for process flow schematic.

Figure 2. TMR water boxes

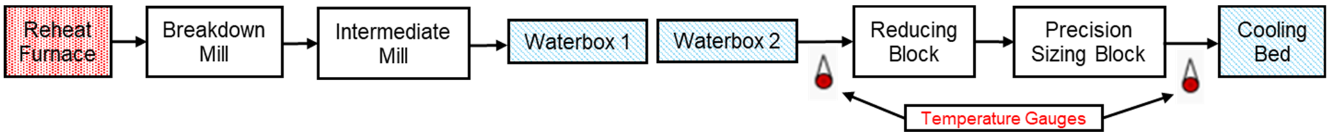

Figure 3. Gerdau Monroe rolling mill process flow

The primary TMR process control indicator is the temperature measurement taken at the PSB finish temperature gauge seen in Fig. 3 after final reduction and sizing just before cooling bed. Water box flows are set up to achieve target rolling mill finish temperatures accounting for other variables such as size and rolling mill speeds as well. When TMR for a product is required, a specific target PSB finish temperature is assigned as an aim to achieve. These target temperatures based on mill capabilities are available from a minimum of 1500°F (815°C) to a maximum of 1650°F (900°C), typically standardized by practice in increments of 50°F.

TMR by product up to this point is implemented based on several variables such as as-rolled customer requirements, grain size (minimum size 5 or finer in most cases), microstructure (ferrite/pearlite absent of duplex grains, reduced bainite, and reduced banding), hardness (minimum and maximum limits), and straightness (for product that is not machine straightened) considering theoretical benefits and best practices[3]. The specific target finish temperatures for each product have not previously been studied quantitatively in depth to understand the physical effect on the material. This study aims to optimize each product to the best finish temperature fit and compare to the baseline of standard hot rolling without TMR.

MATERIALS AND METHODS

The procedure for this study is to select a product of same grade, diameter range, and specifications and process to three (3) different rolling finish temperatures using TMR and non-TMR. Process data is then analyzed to ensure target temperatures are met in accordance with rolling practice. As-rolled bar samples for each roll condition are collected for an array of lab analyses and metallurgical testing described below.

a) Samples are sectioned and prepared via polishing and 2% Nital etching to contain transverse and longitudinal faces for full travel of cross-section surface to core.
b) Hardness is measured on transverse cross-section at surface (closest to OD), ½ radius, and core using Brinell[4] (BHN) and/or Rockwell B[5] (HRB) scales.
c) Physical properties of tensile strength, yield strength, elongation, and reduction of area are tested via 0.505 sample taken from ½ radius of the bar sample.[6,7]
d) Microstructure is analyzed via optical microscope taking micrographs of transverse and longitudinal directions at 100x magnification at surface, ½ radius, and core.
e) Grain size is quantified by analyzing the transverse 100x magnification micrographs at surface, ½ radius, and core.[8]
f) Certified heat chemistry is recorded from the melting and casting processes.[9]

This study focuses on SBQ products of SAE grade 10B38 with Titanium (Ti) and Boron (B) rolled to three (3) different rolling conditions (1, 2, 3) below. Three (3) experiments (A, B, C) below of different diameters were conducted for detailed results and six (6) experiments of data utilized to create overall average data trends at all three rolling conditions.

Experiment A) Grade 10B38 rolled to 1.22" (31mm) diameter. (50mm feeder size, 62% reduction) Experiment B) Grade 10B38 rolled to 1.457" (37mm) diameter. (70mm feeder size, 72% reduction) Experiment C) Grade 10B38 rolled to 1.484" (37.7mm) diameter. (70mm feeder size, 71% reduction)

1) TMR with average finish temperature of 1500°F-1600°F (815°C -870°C).
2) TMR with average finish temperature of 1600°F-1700°F (870°C -925°C).
3) non-TMR with average finish temperature of 1750°F-1850°F (955°C -1000°C).

RESULTS

Table 1. Chemistry ranges by element (wt%) for grade 10B38 with balance of Fe.

	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	Nb	Ti	B	N
Min	0.36	0.80	-	0.005	0.15	-	-	0.08	-	0.020	-	-	0.030	0.0005	-
Max	0.41	1.00	0.030	0.020	0.35	0.25	0.25	0.20	0.06	0.035	0.01	0.01	0.045	0.0030	0.0100

Note: C = carbon; Mn = manganese; P = phosphorus; S = sulfur; Si = silicon; Cu = copper; Ni = nickel; Cr = chromium; Mo = molybdenum; Al = aluminum; V = vanadium; Nb = niobium; Ti = titanium; B = boron; N = nitrogen

Table 2. Metallurgical data including grain size, hardness (HRB), and physical properties for Experiments A, B, and C at each rolling condition.

TMR?	Yes	Yes	No
Roll Finish Temp	1500-1600°F	1600-1700°F	1750-1850°F
Grain Size			
Experiment A – Grade 10B38 – 1.22" (31mm)			
Surface	8	7.5	6.5
½ Radius	7.5	6.5	6
Core	7	6.5	6
Experiment B – Grade 10B38 – 1.457" (37mm)			
Surface	7.5	7	6
½ Radius	6.5	6.5	6
Core	6	6	5.5
Experiment C – Grade 10B38 – 1.484" (37.7mm)			
Surface	8.5	6.5	6
½ Radius	7.5	6	6
Core	7	6	6
Hardness (HRB)			
Experiment A			
Surface	85	87	89
½ Radius	90	94	94
Core	93	94	95
Experiment B			
Surface	87	88	91

½ Radius	92	90	92
Core	96	97	91
Experiment C			
Surface	89	91	96
½ Radius	93	92	95
Core	93	94	97
Physicals			
Experiment A			
Tensile (ksi)	105	106	107
Yield (ksi)	58	60	60
Elong%	25	24	23
ROA%	49	46	49
Experiment B			
Tensile (ksi)	104	101	105
Yield (ksi)	56	54	58
Elong%	18	19	20
ROA%	30	36	37
Experiment C			
Tensile (ksi)	102	104	105
Yield (ksi)	58	59	61
Elong%	24	23	23
ROA%	50	44	44

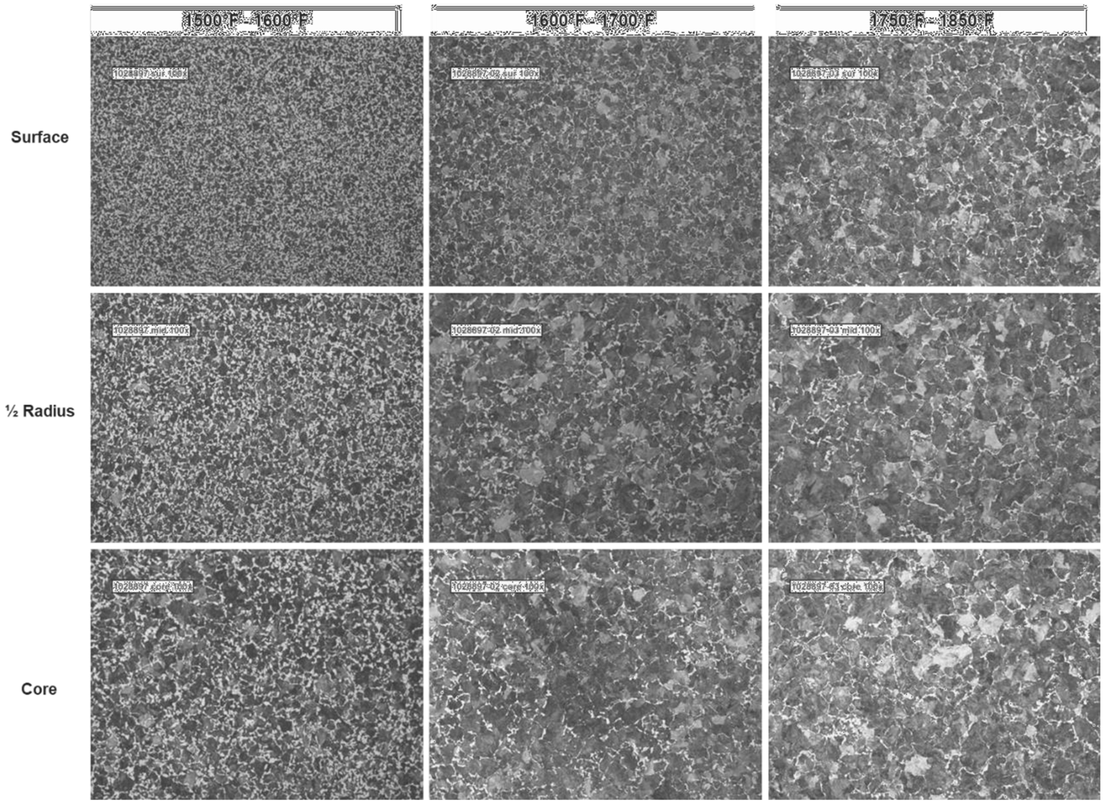

Figure 4. Experiment A transverse micrographs at 100x from surface to core for each rolling condition.

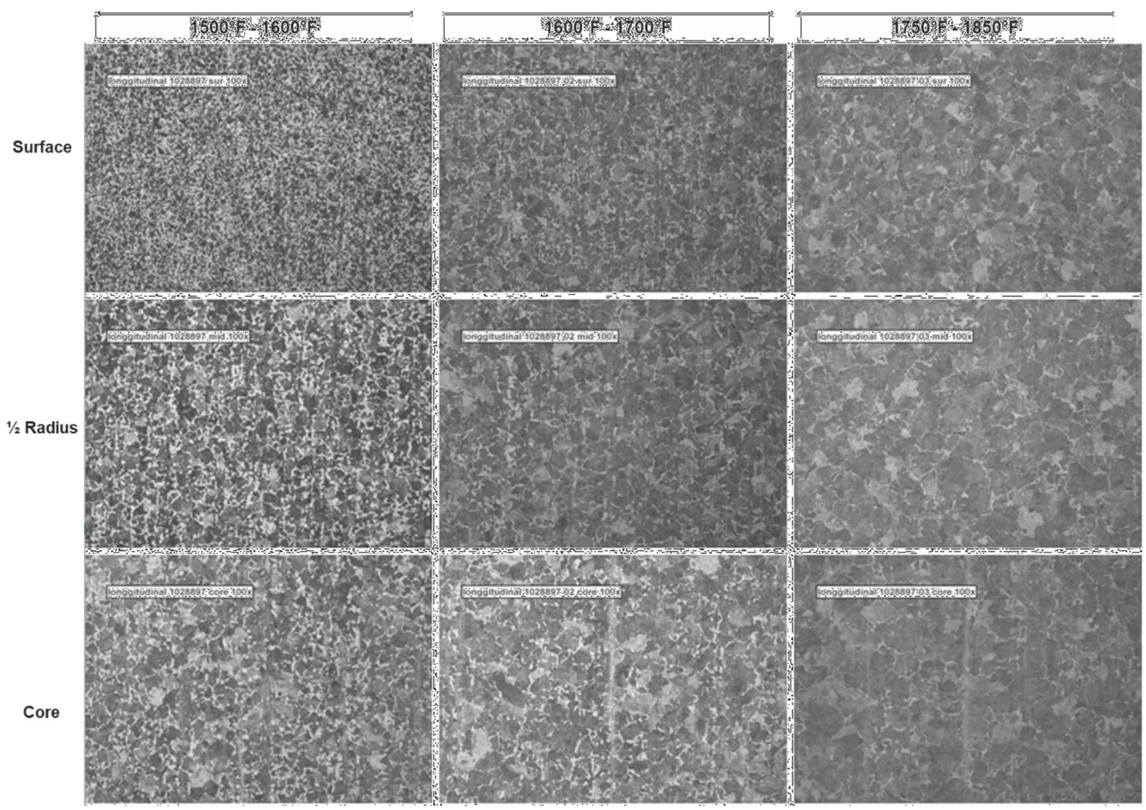

Figure 5. Experiment A longitudinal micrographs at 100x from surface to core for each rolling condition.

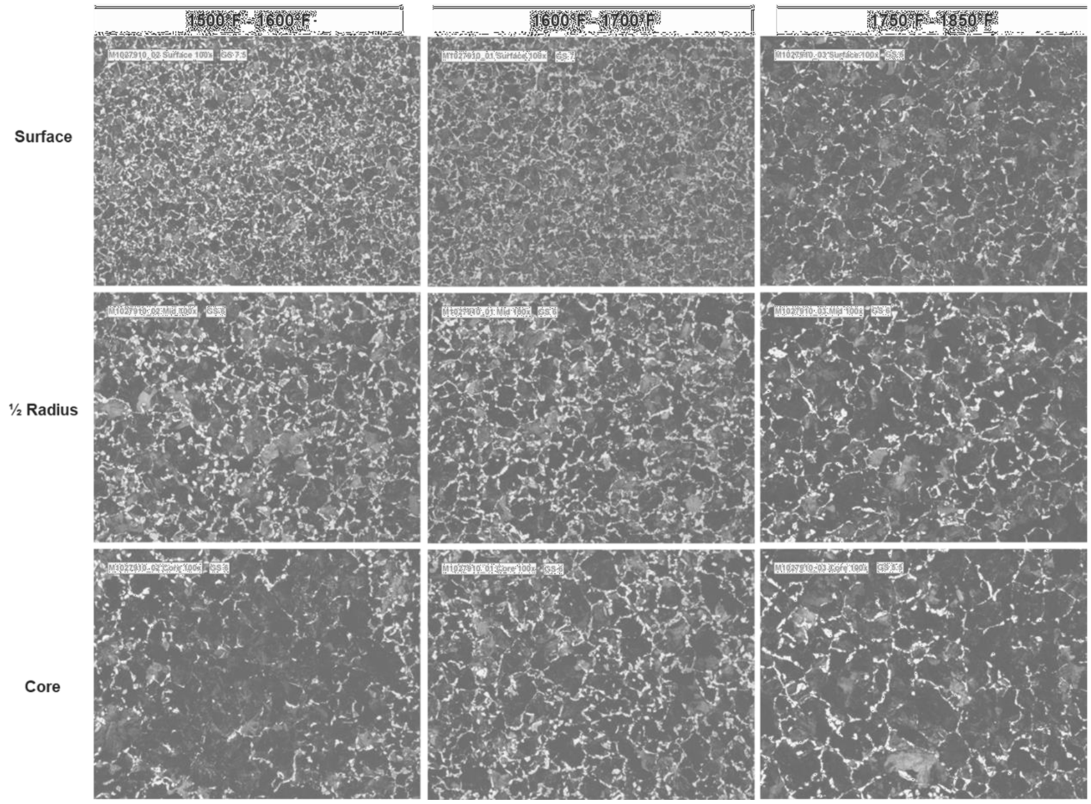

Figure 6. Experiment B transverse micrographs at 100x from surface to core for each rolling condition.

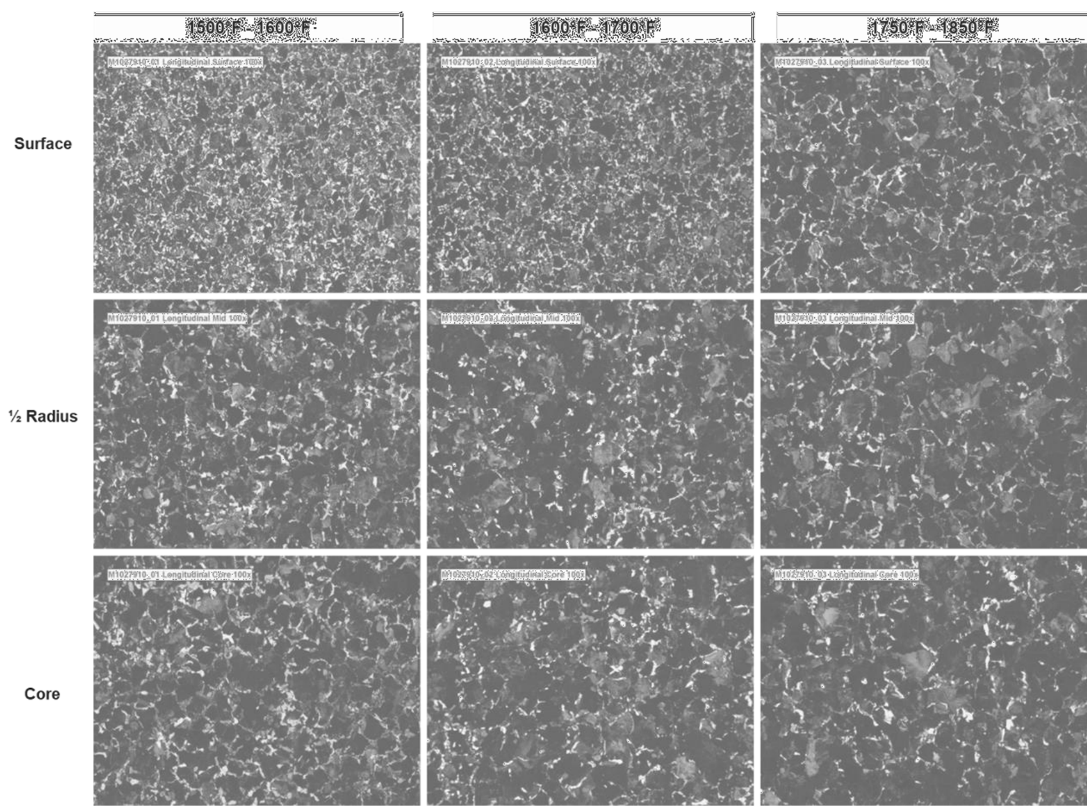

Figure 7. Experiment B longitudinal micrographs at 100x from surface to core for each rolling condition.

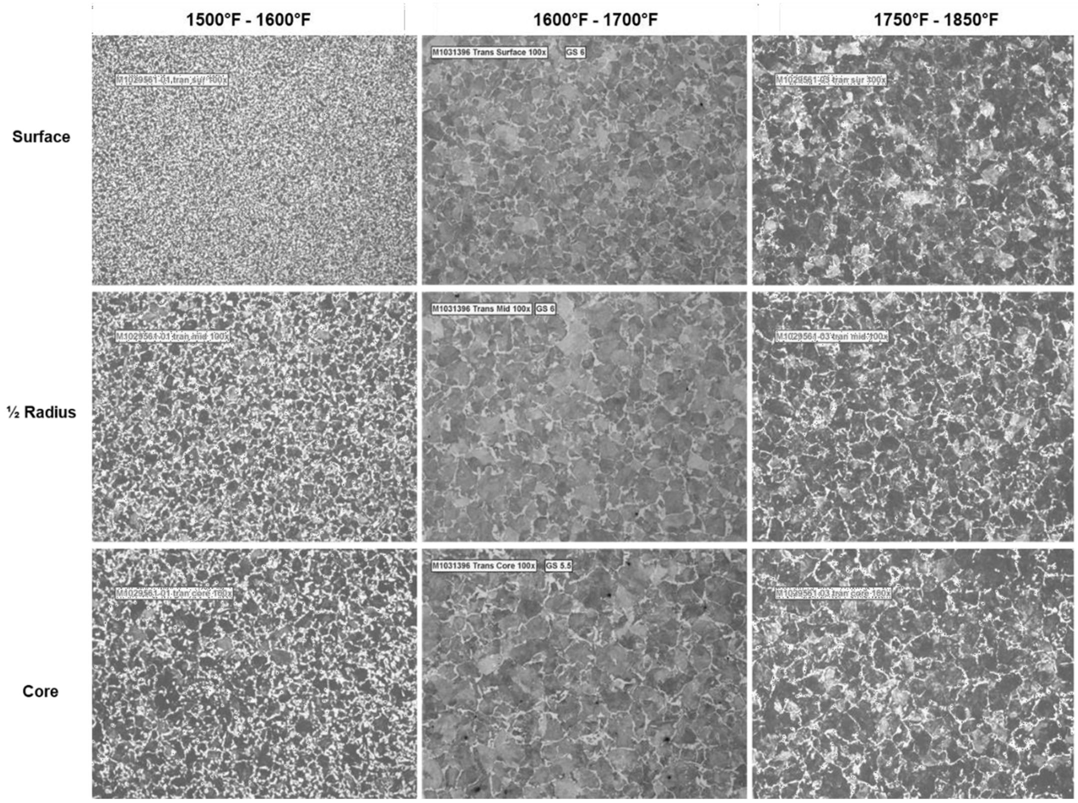

Figure 8. Experiment C transverse micrographs at 100x from surface to core for each rolling condition.

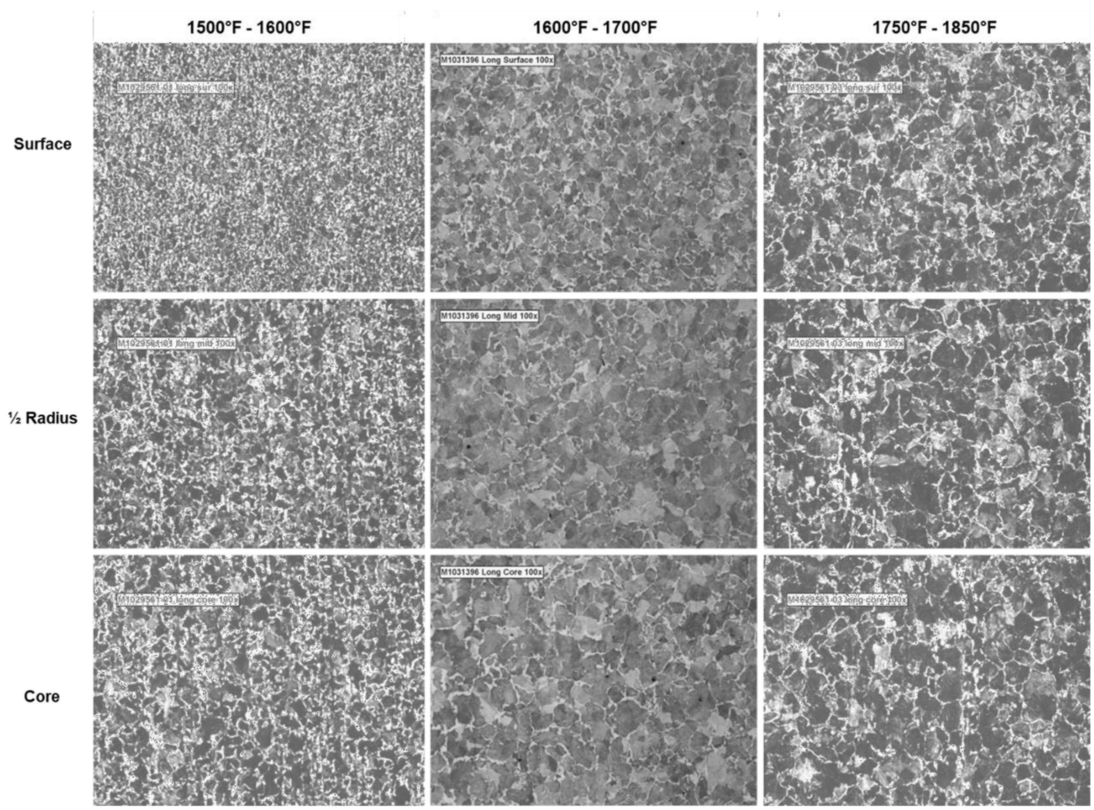

Figure 9. Experiment C longitudinal micrographs at 100x from surface to core for each rolling condition.

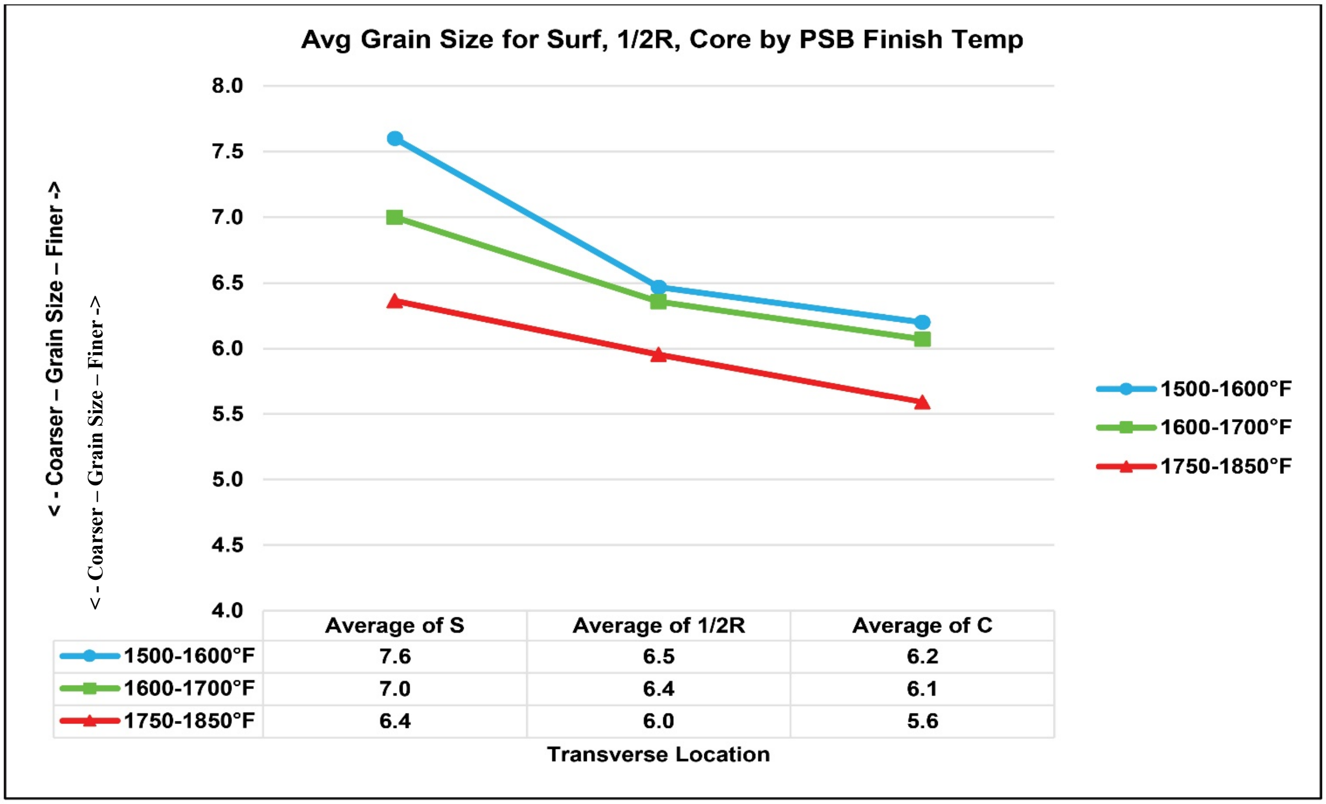

Figure 10. Average grain size trend by roll finish temp for each cross-section location. (n=6 trials)

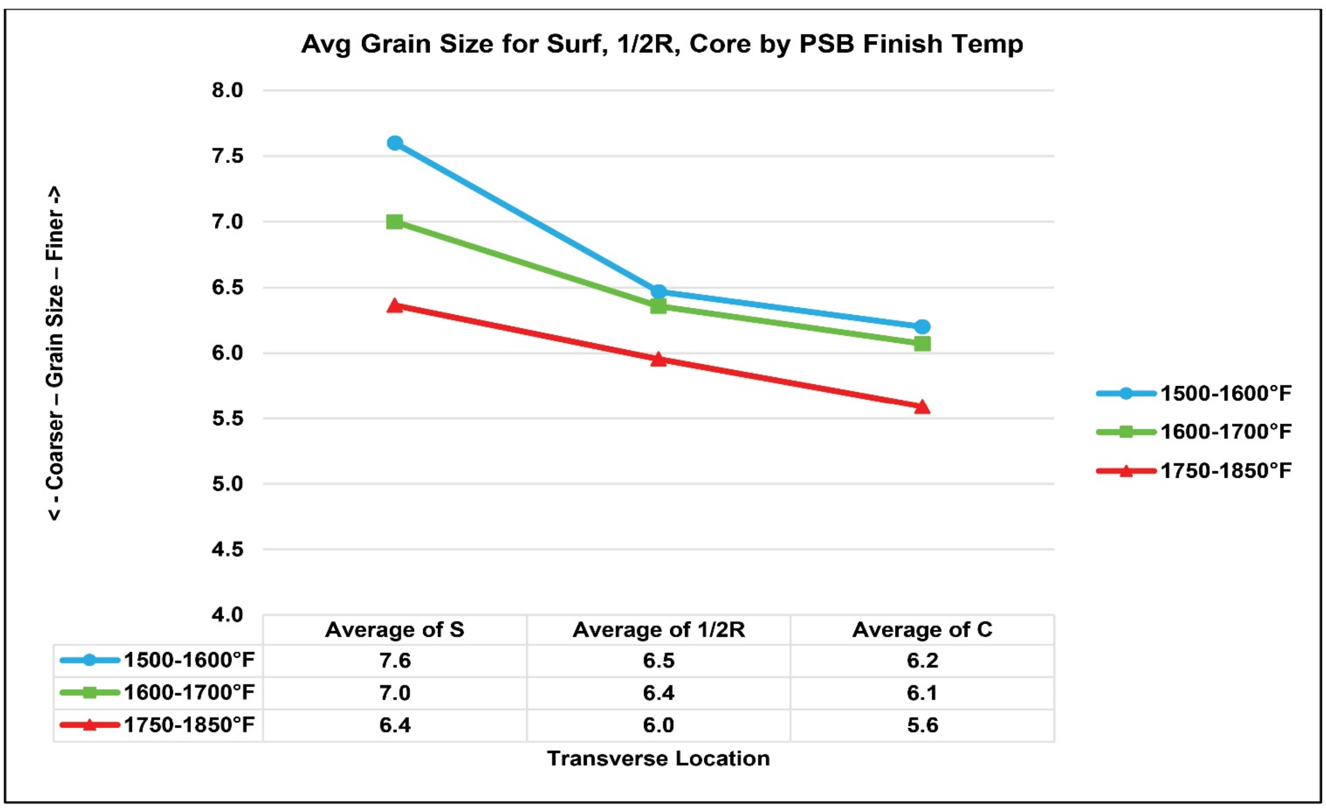

Figure 11. Average grain size trend by roll finish temp for each cross-section location. (n=6 trials)

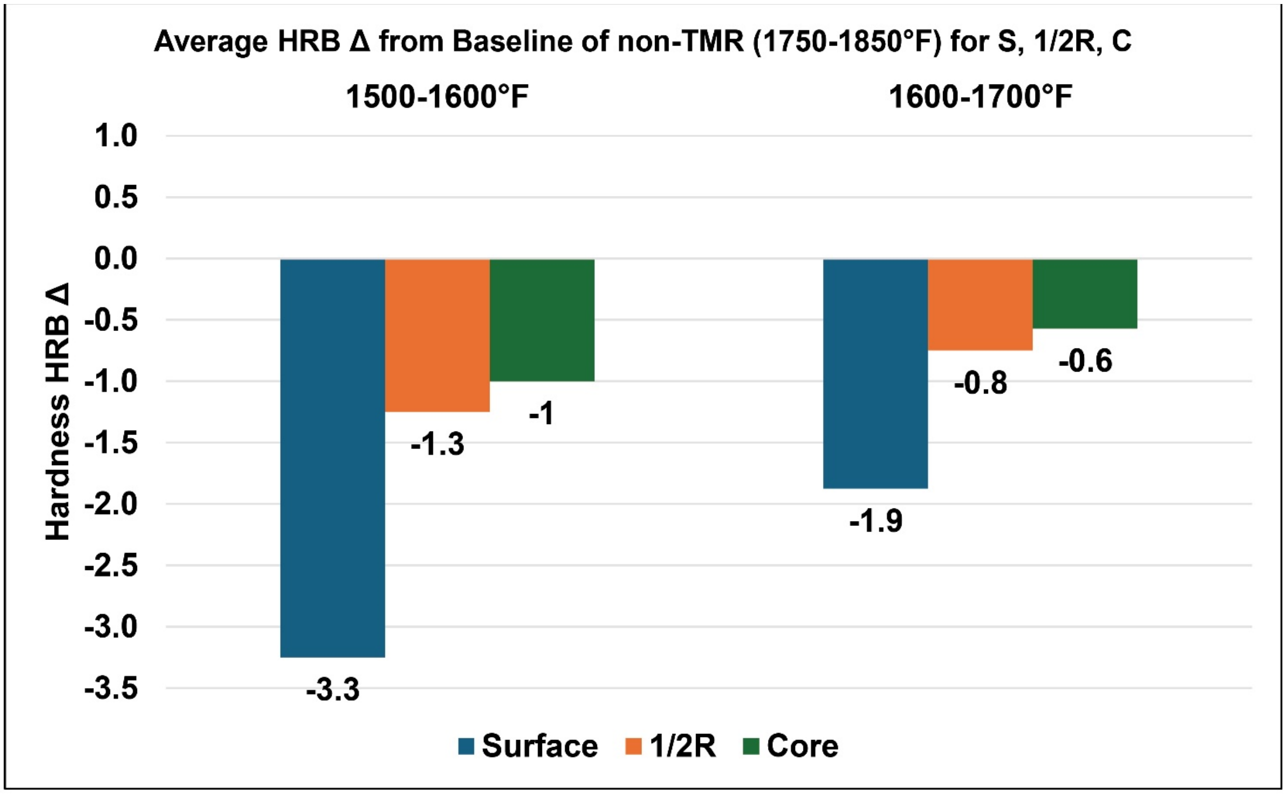

Figure 12. Average HRB delta for TMR practices compared to non-TMR from surface to core. (n=6 trials)

DISCUSSION

The grain size analysis resulted in an expected trend, that the lower the finish temperature, the finer overall grain size due to grain growth and recrystallization restriction[1]. This was observed from surface to core for all finish temperatures. It is noted that the grain refinement was most effective at the surface for TMR. This can be observed visually in the micrograph profiles in Figs. 4, 6, and 8.

The data also shows that distance from the surface results in a grain size refinement trend, as surface results had the finest average grain size, then ½ radius, then core. TMR results in a finer average grain structure overall, it also results in a slightly larger spread throughout the cross-section, the grain size spread for the TMR finish temperatures is wider than the grain size distribution for non-TMR, which has a marginally more homogenous microstructure from surface to core. This is supported by the data trends of Figs. 10 and 11. Non-TMR results in a grain size spread of 0.8 and maximum TMR capability results in a grain size spread of 1.4 from surface to core.

The longitudinal microstructure profiles did not show any evidence of differences in banding or duplexing of grains in Figs. 5, 7, and 9. Therefore, non-TMR practice for this grade of steel does not produce any harmful condition regarding microstructure, and only a difference in grain size.

The microstructure and grain size resulted in a hardness trend with hardness decreasing compared to the baseline with proximity to surface (closer) and with decreasing finish temperature as seen in Fig. 12.

There was no correlation of finish temperature compared to tensile test data, perhaps due to tensile specimen being machine from 1/2R where less of a grain size and hardness variation is observed, that is not significant enough to affect the overall tensile strength of the material.

CONCLUSION

Thermomechanical rolling process overall is successful in grain size refinement and reducing hardness. The magnitude of grain size refinement and hardness reduction increases as finish temperature decreases. No harmful microstructure results were observed in material rolled with or without controlled cooling.

Additional cooling time prior to the final reduction stands or an additional location of water box cooling after the PSB may be necessary to provide a more uniform cooling rate to result in increased microstructure homogeneity from surface to core, especially as the rolling finish temperature target decreases. It is not believed that the current average grain size spread across all rolling conditions is detrimental to material properties and performance.

Future studies to expand the analysis to alloyed and microalloyed steel grades are planned.

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