Segregation, Banding, and Inclusions in AISI 1050 Carbon Steel

PURDUE MATERIALS ENGINEERING

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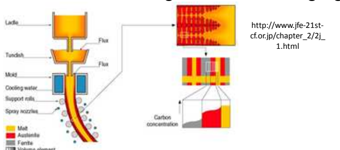
Three microstructural defects, banding, segregation, and the presence of inclusions, were studied in AISI 1050 steel from Nucor Crawfordsville to characterize the extent of these defects. It was determined that there was a change in the microstructure from the head to the tail of each coil. Through examination of microstructure, processing data, and the open literature, a small prior austenite grain size and slow cooling rate through the eutectoid transformation were found to be the main contributors to a banded structure. Banding proved to be the most prominent of the studied defects. The necessary steps to provide a uniform and defect-free microstructure involve large, uniform austenite grains and a fast cooling rate through the eutectoid transformation. These can be achieved through increased, uniform temperatures in the furnaces and a minimum of a ~400ºF temperature change on the run-out table.

This work is sponsored by Nucor, Crawfordsville , IN

Project Background

Segregation

- Microsegregation in continuously cast steel results from the differential solubility of the liquid and solid steel as it solidifies
- This microsegregation is an issue because it causes banding.
- Fluid flow in the liquid sump causes macrosegregation
- Fluid flow can be caused by thermal and solutal convection, residual flow from the submerged nozzle, suction due to shrinkage, and shell bulging



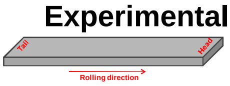
Banding

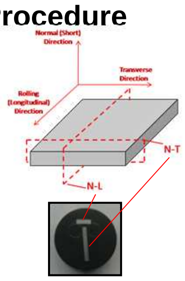
- In hypoeutectoid steels, alloying elements, such as Mn, exhibit "sluggish" substitutional-atom diffusivity
- Mn also stabilizes austenite and lowers the critical cooling temperature (A_{r3}) of the Fe-C phase diagram
- High Mn regions will be more stable as austenite, while low Mn regions will begin to form ferrite at higher temperatures
- Carbon is rejected from ferrite into high Mn regions

Inclusions

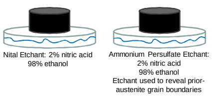
- Inclusions arise primarily from liquid steel coming in contact with foreign materials such as refractory brick and from the impurities in the scrap steel during melting and casting
- Inclusions affect overall mechanical properties

Experimental Procedure

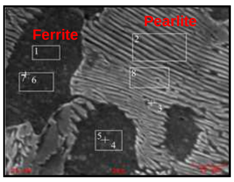




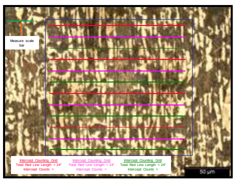
Sectioning performed along the rolling(N-L) and transverse(N-T) directions, with samples from the head and tail of coils



Metallography performed on all samples to evaluate phase fraction (Image J software), ASTM grain size, and for inspection of defects in the microstructure



EDS (electron dispersive spectroscopy) performed in conjunction with the SEM to obtain compositions of Mn across the different phases (ferrite, ferrite+cementite)



Heyn Lineal Intercept Procedure per ASTM E112-96 used for evaluation of ASTM grain size.

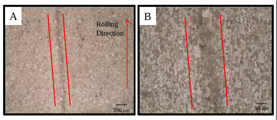
Microhardness performed on Leco AMH 43 unit across thickness of sample to determine effects of Mn segregation

Results & Discussion

Segregation

1400262H Centerline Segregation			
Area to the left of the CL		Area inside the CL	
Fe (wt.%)	Mn (wt.%)	Fe (wt.%)	Mn (wt.%)
98.936	1.064	98.684	1.316
98.956	1.044	98.764	1.236
98.934	1.066	98.588	1.412
98.942	**1.058**	**98.679**	**1.321**

Coil #1 shown below was the only coil out of the 18 evaluated to show a microstructural difference optically. The SEM image and table to the left and below show the variation in wt.% Mn in the ferrite/pearlite regions.

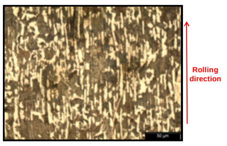


The EDS results consistently show an increase of ~0.3 wt.% Mn in the centerline of the Coil #1. This composition rise is within the uncertainty of these measurements which is no better than +/- 1wt%. No significant variation in composition was found in other coils, so it appears that macrosegregation is not typically an issue with Nucor's AISI1050 steel.

Banding

(Ref: L.E. Samuels, *Optical Microscopy of Carbon Steels*, ASM, pp.117-167: 1980.)

The extent of banding is affected by the prior austenite grain size and cooling rate through the eutectoid transformation. Large austenite grains inhibit impingement of the growth of proeutectoid ferrite grains and their combining into slabs. This means that the effect of Mn stabilization on austenite can be reduced. With this in mind the prior-austenite grain size was measured using an ammonium persulfate etchant and the cooling rate was also subsequently investigated through processing data provided by Nucor.



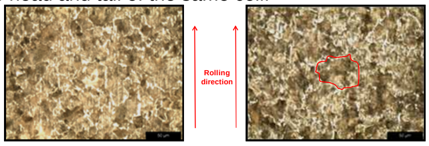
Coil #1 Head

Coil #1 exhibited a **banded** structure with ferrite and pearlite bands running parallel to the rolling direction. This particular sample contained 0.83 wt.% Mn and had a large ASTM grain size of 10, which correlates to small grains. Pearlite area fraction was 6-15 times the ferrite area fraction.

Coil Number	Longitudinal/ Transverse	Area Phase Fraction (Ferrite), %	Average Size (Ferrite), um^2	Diameter (Ferrite), um	Area Phase Fraction (Pearlite), %	Average Size (Pearlite), um^2	Diameter (Pearlite), um	ASTM Grain Size
1 H	L1	27.14	12.09	1.96	72.86	187.39	7.72	9.9
1 H	L2	32.85	18.35	2.42	67.15	139.67	6.67	11.6
1 H	L3	30.50	18.61	2.43	69.50	112.19	5.98	10.7

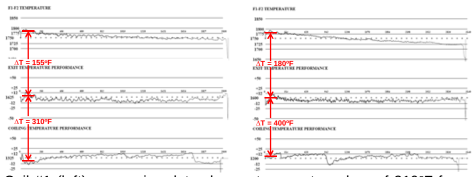
The prior-austenite grain boundaries were difficult to determine in coil #1 Head due to the banded structure. Large pearlite nodules resulted in a large average area for this region. The head and tail of the different coils exhibited different microstructures, with only the head having a banded structure. This was seen in every head/tail combination. Coil #2 exhibited ASTM grain sizes similar to Coil #1, but different pearlite area fraction. The tail of coil #2 had larger pearlite nodule diameters than the head of the same coil. This makes sense as the larger grains would restrict the impingement of the proeutectoid ferrite.

Samples below contain 0.65 wt.% Mn and are an example of the microstructural discrepancies between the head and tail of the same coil.



Coil #2 Head   Coil #2 Tail

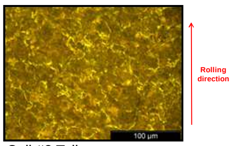
When comparing the heads of coil #1 and coil #2, it can be seen the severity of banding is much greater in coil #1, which experienced a lower cooling rate through the eutectoid transformation.



Coil #1 (left) processing data show a temperature drop of 310ºF from the exit of the hot rolling mill to the entrance to the coiling stand, while coil #2 (right) shows a cooling rate of 400ºF for the same area.

Coil Number	Longitudinal/ Transverse	Area Phase Fraction (Ferrite), %	Average Size (Ferrite), um^2	Diameter (Ferrite), um	Area Phase Fraction (Pearlite), %	Average Size (Pearlite), um^2	Diameter (Pearlite), um	ASTM Grain Size
2 H	L1	43.66	8.21	1.62	56.34	29.91	3.09	9.9
2 H	L2	39.21	6.36	1.42	60.79	46.03	3.83	9.6
2 H	L3	24.06	3.91	1.11	75.94	26.20	2.89	8.8
2 T	L1	17.07	3.10	0.99	82.93	59.04	4.34	9.3
2 T	L2	36.35	6.61	1.45	63.65	71.90	4.78	9.9
2 T	L3	26.64	4.77	1.23	73.36	47.44	3.89	10.1

Pearlite grain sizes were on average larger in the tail of each coil versus the head. The prior-austenite grain boundaries were determined essentially by the ferrite "skeleton" surrounding the pearlite grains.



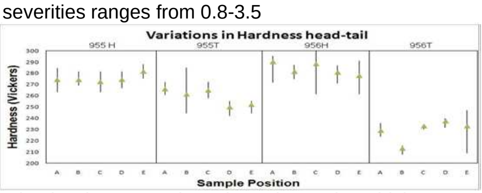
Coil #3 Tail

Sample exhibited a **non-banded** structure with ferrite and pearlite bands running parallel to the rolling direction. This particular sample contained 0.83 wt.% Mn.

Inclusions/Microhardness

Type A - Sulfide inclusions ranged from severities of 1.3 to 2.2 indicated by a presence in all steels

Type C – Silicates were found in six samples and their severities ranges from 0.8-3.5



Microhardness testing throughout the thicknesses showed a clear variation in hardness both within and between samples

Recommendations

To obtain a uniform desired microstructure:

1. A large austenite grain size is needed to restrict ferrite-ferrite impingement.
2. A fast cooling rate can reduce the effect of austenitic stabilization from inherent Mn segregation.

Our recommendations for Nucor are:

1. Increase the furnace (both tunnel and shuttle) temperature to grow austenite grains.
2. The temperature change on the run-out table should be at least a 400ºF drop from ~1600-1625ºF.
3. The time the head and tail of a given coil spend in the furnaces, hot rolling mill, and the run-out table should be measured. This duration should be monitored and kept as uniform as possible.