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Optimization of Parameters to Investigate the Effect of Annealing Heat Treatment on SS431 Grade Martensitic Stainless Steel Material Using JmatPro Software

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Abstract: Martensitic stainless steels are widely used in industrial applications due to their ability to be heat treated to different strength levels, added with good corrosion and oxidation resistance. By applying suitable heat treatment procedures, the properties of martensitic stainless steels are greatly modified. The scope of the work is to develop a heat treatment for SS431 martensitic stainless steel to get pearlite microstructure of the same, this is achieved by controlling rate of cooling of SS431 MSS done by using annealing heat treatment. The simulations carried out by changing various alloying elements and their influence on microstructure and hardness in JmatPro software are discussed below.

Index Terms - Martensitic stainless steel (MSS), Heat Treatment, Annealing, MSS431, JmatPro.

I. Introduction

Stainless Steel 431 is a martensitic stainless steel it's a heat-treatable grades with excellent corrosion resistance, high toughness, torque strength, and tensile properties. Its properties make them ideal for bolt and shaft applications. Grade 431 steels, are suitable for operations mainly spinning, deep drawing, bending or cold heading. Hence it can't be cold-worked due to their high yield strength. Hardening and tempering treatments and poor weldability techniques are generally applied for the fabrication of martensitic steels. Grade 431 steels corrosion resistance properties are less than that of austenitic grades. By the loss of strength at high temperatures, the operations of grade 431 are limited, because of over-tempering, and loss of ductility at negative temperatures. It is less resistant to tropical water in comparison with of grade 316 steels, but it has considerable resistance to salt water. It has overall corrosion resistance similar to, or slightly less than, that of grade 304 steels. 431 stainless-steel, with a smooth surface finish performs well in tempered and hardened conditions. Grade 431 martensitic stainless steel, in intermittent conditions, and 870°C during continuous operations are resistant to scaling at temperatures of 925°C. This grade gets hardened even during slow cooling. Corrosion Resistance: Grade 431 stainless steels have considerable resistance to salt water, but they're less immune to tropical water in comparison with of grade 316 steels. Grade 431 steels have overall corrosion resistance the same as, or slightly lower than, that of grade 304 steels. Grade 431 steels with a smooth surface finish perform well in tempered and hardened conditions. Heat Resistance: Grade 431 steels are immune to scaling at temperatures of 925°C in intermittent conditions, and 870°C during continuous operations. In general, these steels aren't to be used at temperatures above standard tempering temperatures, due to loss of mechanical properties. Applications: Laboratory equipment, Marine systems, Beater bars, Pump and propeller shafts, Nuts and bolts.

Annealing is a generic term denoting a treatment that consists of heating to and holding at an appropriate temperature followed by cooling at an appropriate rate, primarily for the softening of metallic materials. Generally, in plain carbon steels, annealing produces a ferrite-pearlite microstructure. Steels can be annealed to facilitate cold working or machining, to extend mechanical or electrical properties, or to increase dimensional stability. The choice of an annealing treatment which will provide an adequate combination of such properties at minimum expense often involves a compromise. Terms which are used to denote specific kind of annealing applied to steels are descriptive of the methodology used, the equipment used, or the condition of the material after treatment. In this study various specimens are tested using different conditions. One of the conditions will be going through different austenitizing temperature and other condition is different cooling temperature. Controlling the variable help us understanding of the temperature on the heat treatment process of the product.

II. SIMULATIONS USING JMATPRO

The methodology section outline the plan and method that how the study is conducted. This includes Universe of the study, sample of the study, Data and Sources of Data, study's variables and analytical framework. The details are as follows;

2.1 JmatPro

JMatPro is a simulation software which calculates a wide range of materials properties for alloys and is particularly aimed at multi-component alloys used in industrial practice. Using JMatPro you can make calculations for:

- Stable and metastable phase equilibria
- Solidification behaviour and properties
- Mechanical properties
- Thermo-physical and physical properties
- Phase transformations.

2.2 Chemical Composition of MSS431

Table below shows chemical composition of MSS 431 according to ASTM A276 standard.

Table 2.1 Chemical Composition of SS 431 grade

C	Mn	Si	P	S	Cr	Ni
0.2	1	1	0.04	0.03	15-17	1.25-2.5

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2.3 Alloying Element Variation

Influence of alloying elements on SS431 martensitic stainless steel is visible in the simulations carried out by varying alloying elements such as chromium (Cr), Nickel (Ni) and Carbon(C) by weight percentage keeping austenizing temperature constant in the martensitic stainless steel. (varied values in wt% as per ASTM A276 standard)

- Chromium from 15 to 17
- For Nickel 1.25 to 2.5
- Carbon from 0.1 to 0.2

III. RESULTS AND DISCUSSION

In this section the results from JmatPro software are shown by varying chromium, carbon and nickel content by weight percentage.

3.1 Chromium

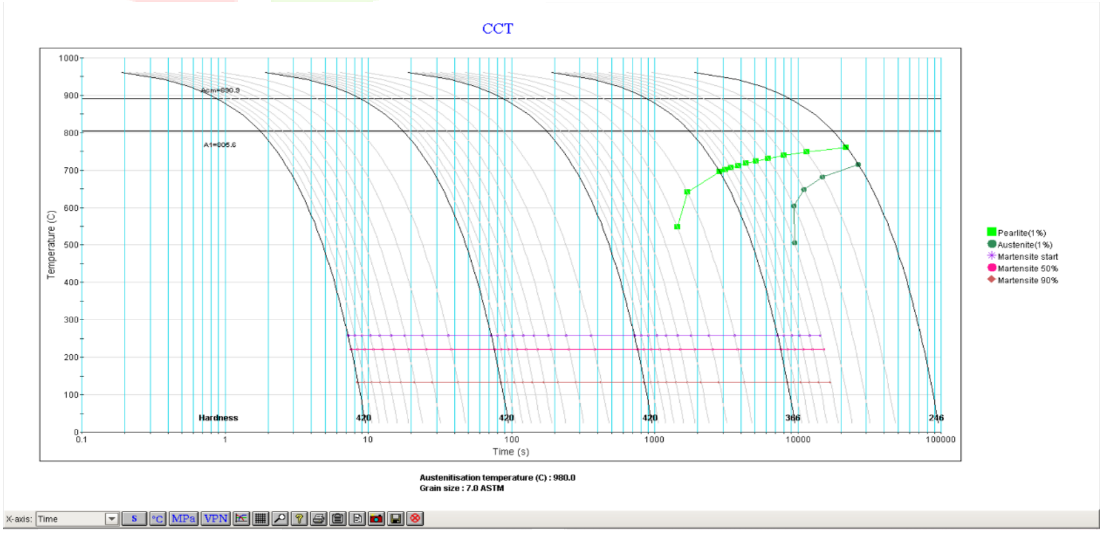

Fig.3.1 Continuous Cooling Transformation Curve at 15% Chromium

As seen from Fig. 3.1 the phase transformation of 15% Cr here on X axis we have time in seconds(s) and on Y axis has Temperature in ºC. From this CCT curve we get that as cooling rate changes there is observable change in following properties as well: Phase fractions, Tensile Stress and Hardness. Desired pearlite microstructure get when cooling rate is kept below 1℃/s.

Table 3.1 Change in properties with cooling rate at 15% Chromium

Cooling Rate (ºC/s)	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
0.01	1	0	0	777.553	245.96
0.1	0.350145	0.641072	0.008782	1145.9	365.577
1	0.000615	0.98588	0.013505	1312.94	419.5
10	0	0.986479	0.013513	1313.21	419.585
100	0	0.986486	0.013513	1313.21	419.587

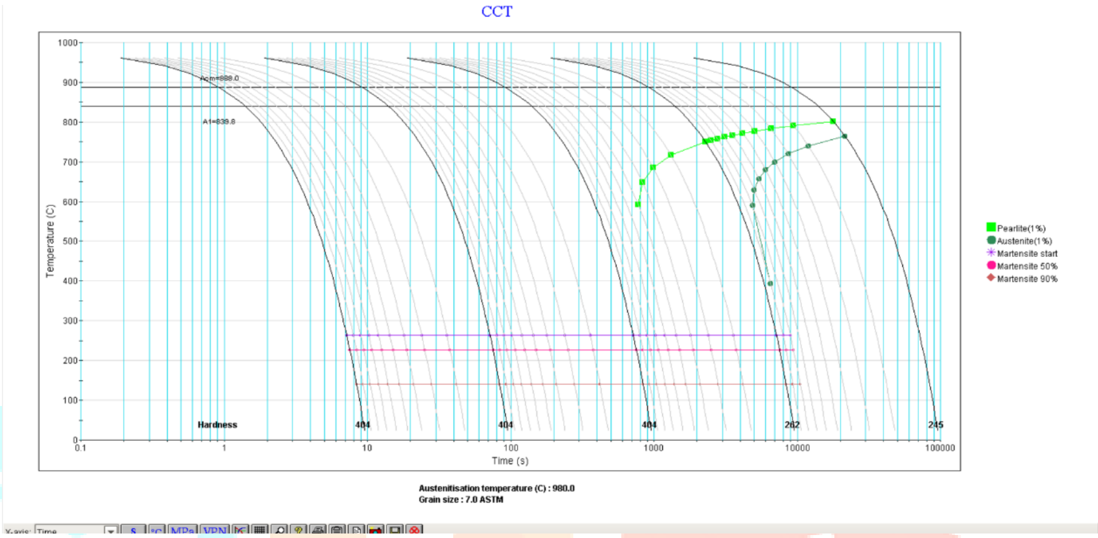

Fig. 3.2 Continuous Cooling Transformation Curve at 16% Chromium

As seen from Fig. 3.2 the phase transformation of 16% Cr here on X axis we have time in seconds and on Y axis have Temperature in ºC. From this CCT curve we get that as cooling rate changes there is observable change in following properties as well: Phase fractions, Tensile Stress and Hardness. Desired pearlite microstructure get when cooling rate is kept below 1°C/s.

Table 3.2 Change in properties with cooling rate at 16% Chromium

Cooling Rate (°C/s)	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
0.01	1	0	0	775.568	245.316
0.1	0.959382	0.040136	0.000482	826.678	261.906
1	0.002308	0.98586	0.011832	1263.95	403.726
10	0	0.988124	0.011859	1264.85	404.018
100	0	0.98814	0.011859	1264.87	404.024

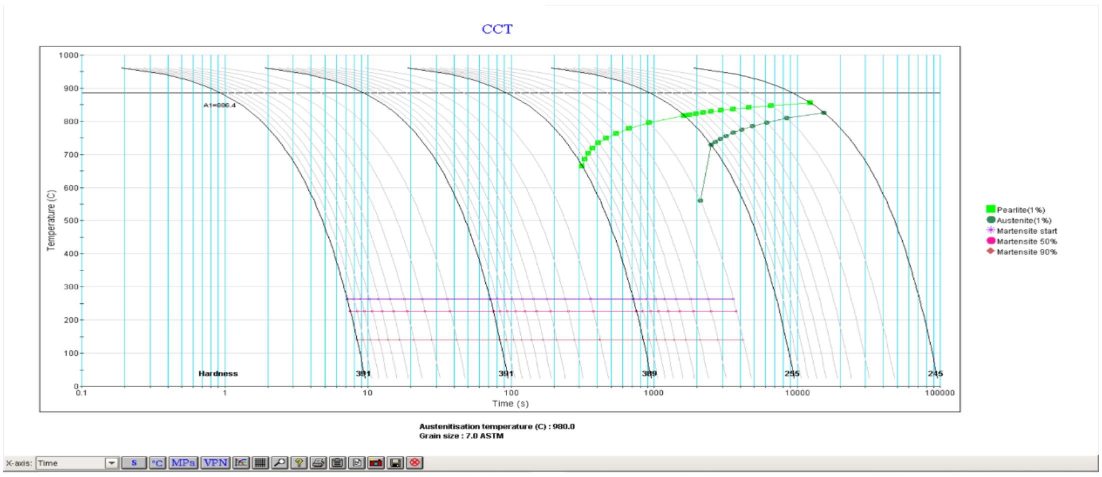

Fig. 3.3 Continuous Cooling Transformation Curve at 17% Chromium

As seen from Fig. 3.3 the phase transformation of 17% Cr here on X axis have time in seconds and on Y axis has Temperature in °C. CCT curve shows that as cooling rate changes there is observable change in following properties as well: Phase fractions, Tensile Stress and Hardness. Desired pearlite microstructure get when cooling rate is kept below 1°C/s.

Table 3.3 Change in properties with cooling rate at 17% Chromium

Cooling Rate (°C/s)	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
0.01	1	0	0	774.618	245.008
0.1	0.999974	0	0	805.418	255.003
1	0.021295	0.967133	0.011562	1217.94	388.88
10	0	0.988118	0.011812	1225.67	391.378
100	0	0.988184	0.011813	1225.74	391.398

3.2 Carbon

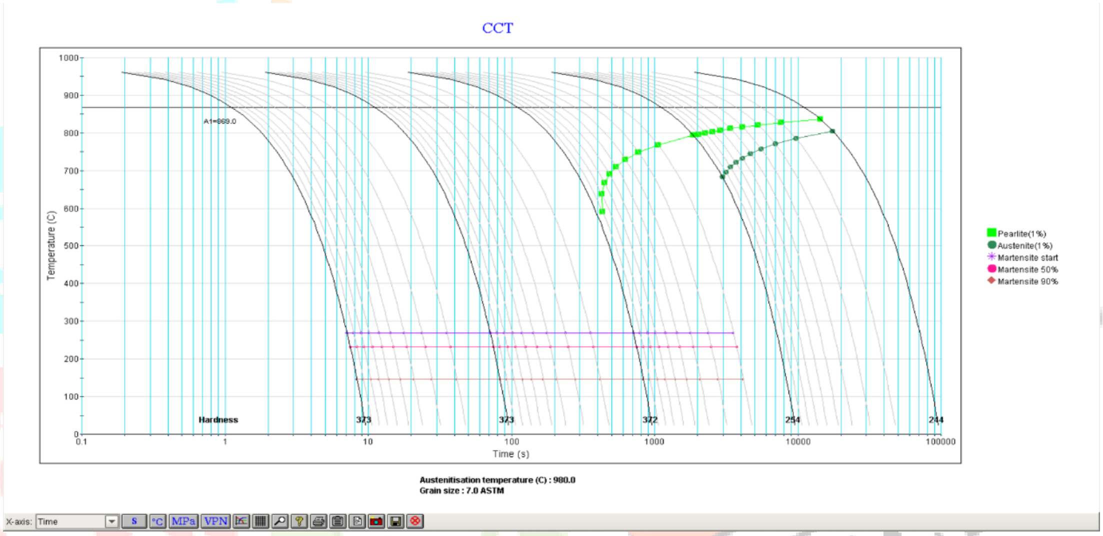

Fig. 3.4 Continuous Cooling Transformation Curve at 0.1% Carbon

As seen from Fig. 3.4 the phase transformation of 0.1% C here on X axis has time in seconds and on Y axis has Temperature in °C. CCT curve shows that as cooling rate changes there is observable change in following properties as well: Phase fractions, Tensile Stress and Hardness. Desired pearlite microstructure get when cooling rate is kept below 1°C/s.

Table 3.4 Change in properties with cooling rate at 0.1% Carbon

Cooling Rate (°C/s)	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
0.01	0.999858	0	0	771.758	244.08
0.1	0.999932	0	0	802.847	254.168
1	0.009582	0.98006	0.010345	1165.07	371.784
10	0	0.989514	0.010444	1168.06	372.753
100	0	0.989553	0.010445	1168.1	372.764

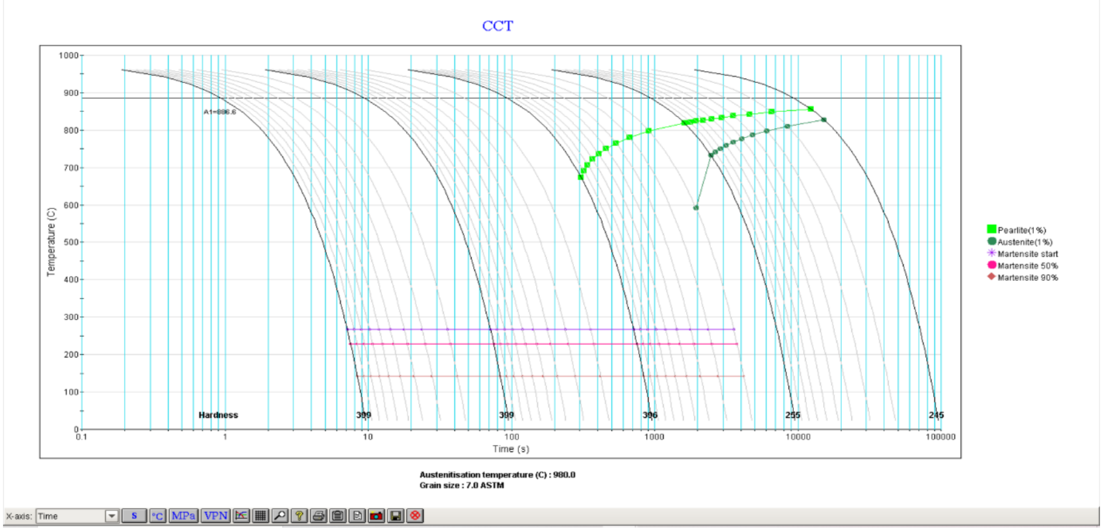

Fig. 3.5 Continuous Cooling Transformation Curve at 0.15% Carbon

As seen from Fig. 3.5 the phase transformation of 0.15% C here on X axis has time in seconds and Y axis has Temperature in °C. CCT curve shows that as cooling rate changes there is observable change in following properties as well: Phase fractions, Tensile Stress and Hardness. From this simulation desired pearlite microstructure get when cooling rate is kept below 1°C/s.

Table 3.5 Change in properties with cooling rate at 0.15% Carbon

Cooling Rate (°C/s)	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
0.01	1	0	0	774.831	245.077
0.1	0.999972	0	0	805.63	255.071
1	0.023764	0.965258	0.010967	1239.49	395.837
10	0	0.988693	0.011233	1248.61	398.78
100	0	0.988764	0.011233	1248.68	398.802

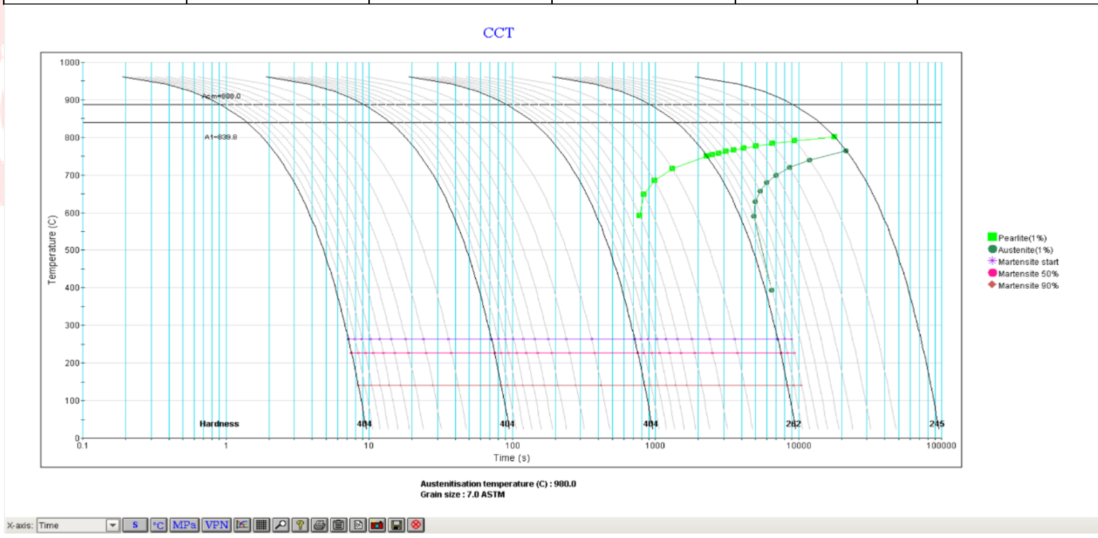

Fig. 3.6 Continuous Cooling Transformation Curve at 0.2% Carbon

As seen from Fig. 2.6 the phase transformation of 0.2% C here on X axis has time in seconds and on Y axis has Temperature in °C. CCT curve shows that as cooling rate changes there is observable change in following properties as well: Phase fractions, Tensile Stress and Hardness. Desired pearlite microstructure get when cooling rate is kept below 1°C/s.

Table 3.6 Change in properties with cooling rate at 0.2% Carbon

Cooling Rate (°C/s)	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
0.01	1	0	0	775.568	245.316
0.1	0.959382	0.040136	0.000482	826.678	261.906
1	0.002308	0.98586	0.011832	1263.95	403.726
10	0	0.988124	0.011859	1264.85	404.018
100	0	0.98814	0.011859	1264.87	404.024

3.3 Nickel

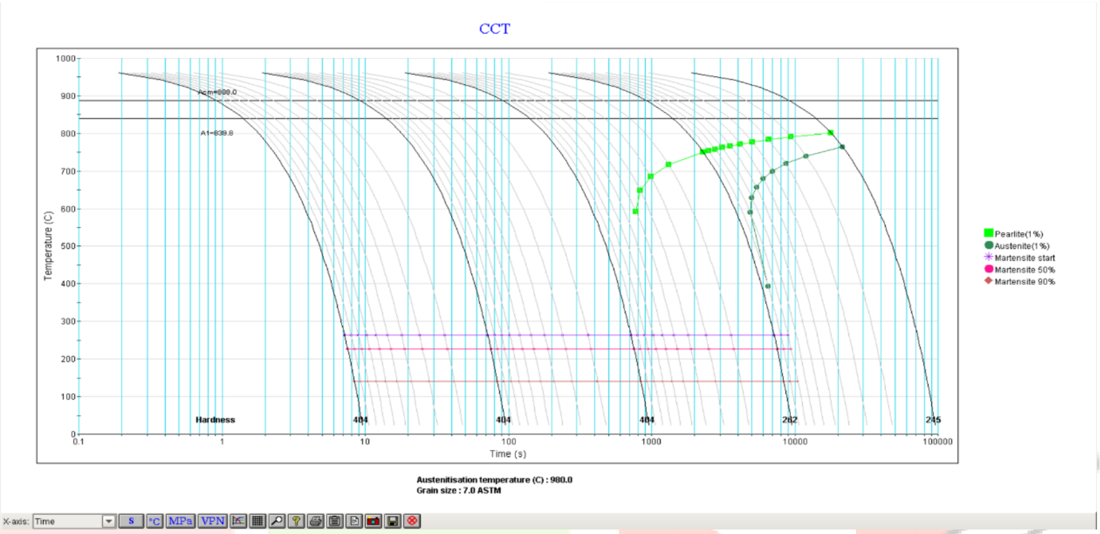

Fig. 3.7 Continuous Cooling Transformation Curve at 1.25% Nickel

As seen from Fig. 3.7 the phase transformation of 1.25% Ni here on X axis has time in seconds and on Y axis has Temperature in °C. From this CCT curve we get that as cooling rate changes there is observable change in following properties as well: Phase fractions, Tensile Stress and Hardness. Desired pearlite microstructure get when cooling rate is kept below 1°C/s.

Table 3.7 Change in properties with cooling rate at 1.25% Nickel

Cooling Rate (°C/s)	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
0.01	1	0	0	775.568	245.316
0.1	0.959382	0.040136	0.000482	826.678	261.906
1	0.002308	0.98586	0.011832	1263.95	403.726
10	0	0.988124	0.011859	1264.85	404.018
100	0	0.98814	0.011859	1264.87	404.024

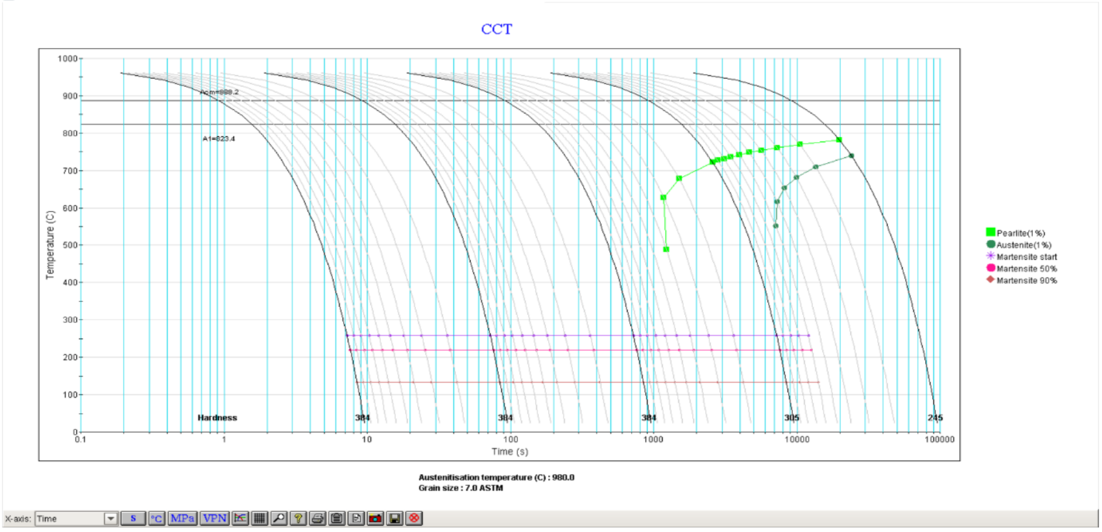

Fig. 3.8 Continuous Cooling Transformation Curve at 1.5% Nickel

As seen from Fig. 3.8 the phase transformation of 1.5% Ni here on X axis have time in seconds and Y axis have Temperature in °C. From this CCT curve we get that as cooling rate changes there is observable change in following properties as well: Phase fractions, Tensile Stress and Hardness. Desired pearlite microstructure get when cooling rate is kept below 1°C/s.

Table 3.8 Change in properties with cooling rate at 1.5% Nickel

Cooling Rate (°C/s)	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
0.01	1	0	0	775.364	245.25
0.1	0.631177	0.363769	0.005053	959.338	305.018
1	0.001008	0.985305	0.013686	1202.18	383.788
10	0	0.98629	0.0137	1202.52	383.898
100	0	0.986299	0.0137	1202.53	383.9

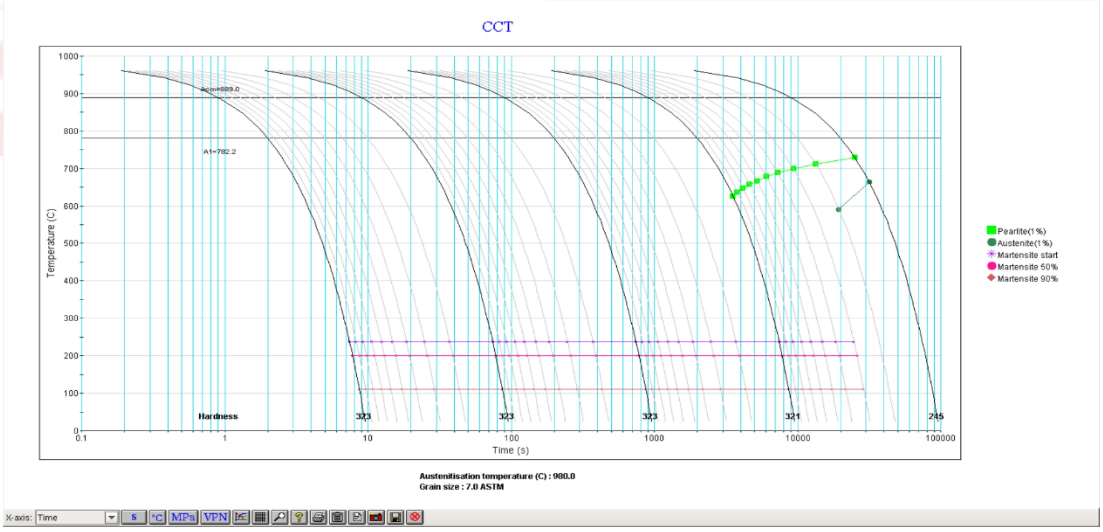

Fig. 3.9 Continuous Cooling Transformation Curve at 2.25% Nickel

As seen from Fig. 3.9 the phase transformation of 2.25% Ni here on X axis has time in seconds and on Y axis has Temperature in °C. CCT curve shows that as cooling rate changes there is observable change in following properties as well: Phase fractions, Tensile Stress and Hardness. Desired pearlite microstructure get when cooling rate is kept below 1°C/s.

Table 3.9 Change in properties with cooling rate at 2.25% Nickel

Cooling Rate (°C/s)	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
0.01	1	0	0	774.758	245.053
0.1	0.040645	0.938905	0.02045	1007.76	320.755
1	0.000105	0.978581	0.021314	1015.96	323.419
10	0	0.97868	0.021317	1015.97	323.423
100	0	0.978683	0.021317	1015.98	323.424

IV. CONCLUSION

These are few the conclusions we got from above simulations that are executed in JmatPro Software:

1. To get the desired pearlite microstructure keep the cooling rate below 1°C/s. So, we considered cooling rate below 1°C/s and increased Cr wt% from 15% to 17 %, the pearlite phase fraction also increases, but the hardness value decreased from 365 to 255 on Vickers scale. This shows as chromium wt% increases hardness value decreases. Similarly, tensile strength also decreases from 1312 MPa to 1217 MPa.
2. To get the desired pearlite microstructure keep the cooling rate below 1°C/s. So, we considered cooling rate below 1°C/s and increased C wt% from 0.1% to 0.2 %, the pearlite phase fraction remains constant, but the hardness value increased from 371 to 403 on Vickers scale. This shows as carbon wt% increases hardness value increases. Similarly, tensile strength also increases from 1165 MPa to 1263 MPa.
3. To get the desired pearlite microstructure keep the cooling rate below 1°C/s. So, we considered cooling rate below 1°C/s and increased Ni wt% from 1.25% to 2.25 %, the pearlite phase fraction also decreases, but the hardness value decreased from 403 to 323 on Vickers scale. This shows as nickel wt% increases hardness value decreases. Similarly, tensile strength also decreases from 1264 MPa to 1015 MPa.

REFERENCES

[1] Rajasekhar, A., Madhusudhan Reddy, G., Mohandas, T., & Murti, V. S. R. (2009). Influence of austenitizing temperature on microstructure and mechanical properties of AISI 431 martensitic stainless-steel electron beam welds. *Materials & Design, 30(5), 1612–1624.* https://doi.org/10.1016/j.matdes.2008.07.042

[2] Liu, Y., Li, A., Cheng, X., Zhang, S. Q., & Wang, H. M. (2016). Effects of heat treatment on microstructure and tensile properties of laser melting deposited AISI 431 martensitic stainless steel. *Materials Science and Engineering: A, 666, 27–33.*https://doi.org/10.1016/j.msea.2016.04.014

[3] A. Rajasekhar (2015) Heat treatment methods applied to AISI 431 martensitic stainless steels. International Journal of Scientific & Engineering Research, Volume 6, Issue 4, April-2015 547 ISSN 2229-5518

[4] Mabruri, E., Prifiharni, S., Anwar, M. S., Romijarso, T. B., & Adjiantoro, B. (2018). Mechanical properties optimization of the modified 410 martensitic stainless steel by heat treatment process. *Materials Today: Proceedings, 5(7), 14918–14922.* https://doi.org/10.1016/j.matpr.2018.04.030

[5] L. F. Alvarez, C. Garcia and V. Lopez (1994) Continuous Cooling Transformations in Martensitic Stainless steels. ISIJ International, Vol. 34 (1994), No. 6, pp. 516-521

[6] Cronin, K., & Cocker, R. (2011). Plant and Equipment | Materials and Finishes for Plant and Equipment. Encyclopaedia of Dairy Sciences, 134–138. doi:10.1016/b978-0-12-374407-4.00401-5

[7] Garrison, W. M., & Amuda, M. O. H. (2017). Stainless Steels: Martensitic. Reference Module in Materials Science and Materials Engineering. doi:10.1016/b978-0-12-803581-8.02527-3

[8] ASTM E140-12B (2019) e1, Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness, ASTM International, West Conshohocken, PA, 2019, www.astm.org

[9] ASTM A276 / A276M-17, Standard Specification for Stainless Steel Bars and Shapes, ASTM International, West Conshohocken, PA, 2017, www.astm.org

[10] ASTM A479 / A479M-20, Standard Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels, ASTM International, West Conshohocken, PA, 2020, www.astm.orgM. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.