"Investigation on Effect of Annealing Treatment on Type SS410 grade Martensitic Stainless Steel Material using JMAT Pro Software"

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Abstract : This paper report the optimization of mechanical properties and microstructure of the developed steels by annealing heat treatment process. Annealing is one among the foremost important processes of warmth treatment Annealing is defined as the softening process. Analyze role of different alloying element in SS410 Martensitic Stainless Steel over microstructure and mechanical properties of 410 grade Martensitic Stainless Steel by using JMAT PRO Software. The scope of the work is to develop a heat treatment for SS410 martensitic stainless steel to get pearlite microstructure of the same; this is achieved by controlling rate of cooling of SS410 MSS done by using annealing heat treatment. Martensitic stainless steels (MSS) used in cutlery, surgical instruments, scissors, springs, valves, shafts, ball bearings, turbine equipment, and petrochemical equipment.

Keywords- Martensitic stainless steel, heat treatment, Annealing, SS410

I. INTRODUCTION

Martensitic stainless steels are basically ternary alloys of chromium, iron and carbon that possess a martensitic crystal structure in the hardened condition. Harry Brearley was invented basic grade 410 in 1913. 410 grade is the basic grade of martensitic stainless steel. With the presence of additional alloying elements various grades of martensitic stainless steel get.(grade416,grade420,grade414,grade440,grade431)

AISI 410 stainless steel can virtually fully transfer to dislocated lath martensite at a very low cooling rate by air cooling. It is found that at an equivalent cooling rate the specimen austenitized at the upper temperature features a lower martensite start temperature (Ms); besides, the difference of Ms becomes much larger at the higher cooling rate. Within the continuously cooled specimens investigated, significant amounts of inter-martensite retained austenite film could also be imaged, where the martensite laths tend to be within the same crystallographic orientation [3].

It is well-known that the microstructure and mechanical properties of the martensitic stainless steels is strongly depend upon the warmth treatment process. The heat treatment of the martensitic stainless steels consists of austenitizing and quenching to facilitate formation of hard martensite structure and subsequent tempering to enhance ductility and toughness. The austenitizing is performed at high temperature of austenite phase and determines the extent of carbide dissolution, dissolved alloying elements, grain growth and martensite characteristic [1] .

The purpose of annealing on martensitic stainless steel is improve its machinability, to refine grain size and remove gases, removes the internal stresses developed during the previous process. Although martensitic stainless steel materials are not used in large quantities compared to austenitic and ferritic grades, they play a huge and often unseen part in our modern world due to their combination of strength, toughness and moderate corrosion resistance.[2] Martensitic stainless steels used in cutlery, cookware, surgical and dental instruments, springs, scissors, industrial blades, vehicle stampings, screwdrivers, pliers, and staple guns.

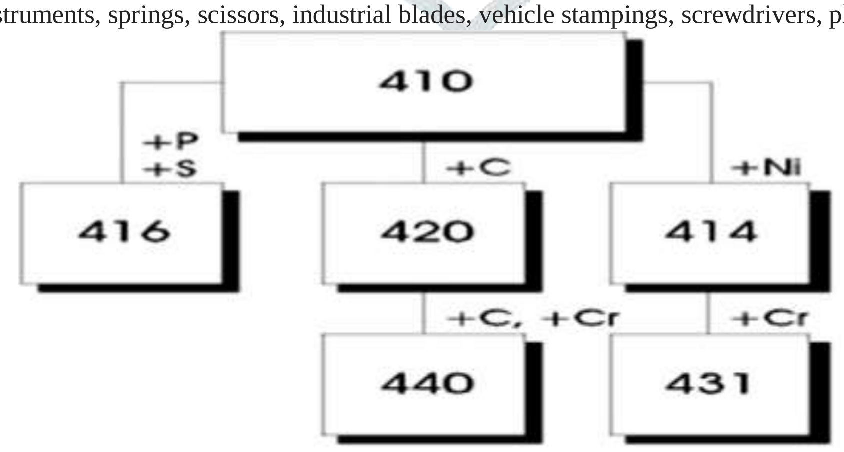

Figure 1. Grades of martensitic stainless steel from the 410 grade

II. SIMULATION

JMAT PRO 7.0

JMAT PRO is simulation software wont to calculates a good range of materials properties for alloys and is especially aimed toward multi-component alloys utilized in industrial practice. Using JMAT Pro you'll make calculations for:

- Mechanical properties

  In this involve calculation of following quantities

  a) Strength and hardness

  b) Flow stress curves

  c) Creep and rupture life/strength

  d) Conversion between strength and hardness

- Thermo-physical and physical properties

  In this involve calculation of following properties

  a) specific heat and enthalpy

  b) density and thermal expansion coefficient

  c) thermal conductivity

  d) electrical conductivity/resistivity

  e) liquid viscosity/diffusivity

  f) Poisson's ratio

- Phase transformations

  In this involve following

  a) TTT/CCT/TTA diagrams

  b) Microstructure evolution and properties during heating, cooling and isothermal holding.

- Solidification behaviour and properties

  In this involve calculation of thermo-physical and physical property during solidification.

Table2.1 Chemical Composition for SS 410 grade

ELEMENT	Maximum Concentration (%)
C	0.08-0.15
Mn	1.0
S	0.030
P	0.040
Si	1.0
Cr	11.5-13.5

Alloying Element and austenizing temperature Variation for SS 410Grade

Influence of alloying elements on SS410 martensitic stainless steel is visible in the simulations carried out, we varied alloying elements such as chromium (Cr), and Carbon (C) by weight percentage varying austenizing temperature in the martensitic stainless steel

Table2.2 alloying element and austenizing temperature Variation Range for SS410 grade

Variation (%)	Low	Medium	High
Austenizing Temp.(^{0}C)	925	970	1010
Carbon (%)	0.08	0.12	0.15
Chromium	11.5	12.5	13.5

As visible from table we varied values (wt %) as per ASTM standard

- Chromium from low (11.5) to high (13.5)
- Carbon from 0.08 to 0.15

III. RESULT

A) Austenizing Temperature Variations

INPUT PARAMETERS	
Austenizing Temp.(^{0}C)	925
Composition (%)	C-0.15 Cr-12.5

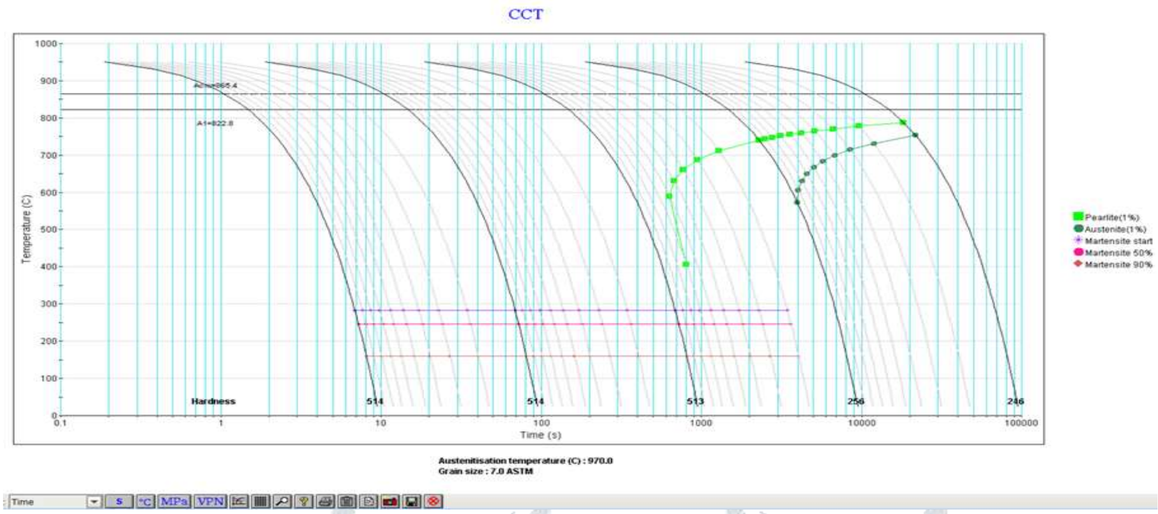

Fig. 3.1 Continuous Cooling Transformation Curve at 925^{0}C

As seen from Fig.1 we see the phase transformation of Austenizing Temp .925^{0}C here on X axis we have time in seconds(s) and on Y axis we have Temperature in ^{o}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. To get the desired pearlite microstructure we need to keep the cooling rate below 1℃/s

Table 3.1 change in properties with cooling rate at 925 austenizing temperature

Austenizing temp(C)	Cooling Rate (^{0}C/s)	Ferrite fraction	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
	0.01	0.000551	0.999449	0	0	774.283	244.899
	0.1	0.001371	0.998629	0	0	804.891	254.832
925	1	0.000662	0.004314	0.988484	0.00654	1520.03	485.684
	10	0	0	0.993374	0.006568	1522.97	486.617
	100	0	0	0.993427	0.006569	1523.02	486.632

INPUT PARAMETERS	
Austenizing Temp.(^{0}C)	970
Composition (%)	C-0.15 Cr-12.5

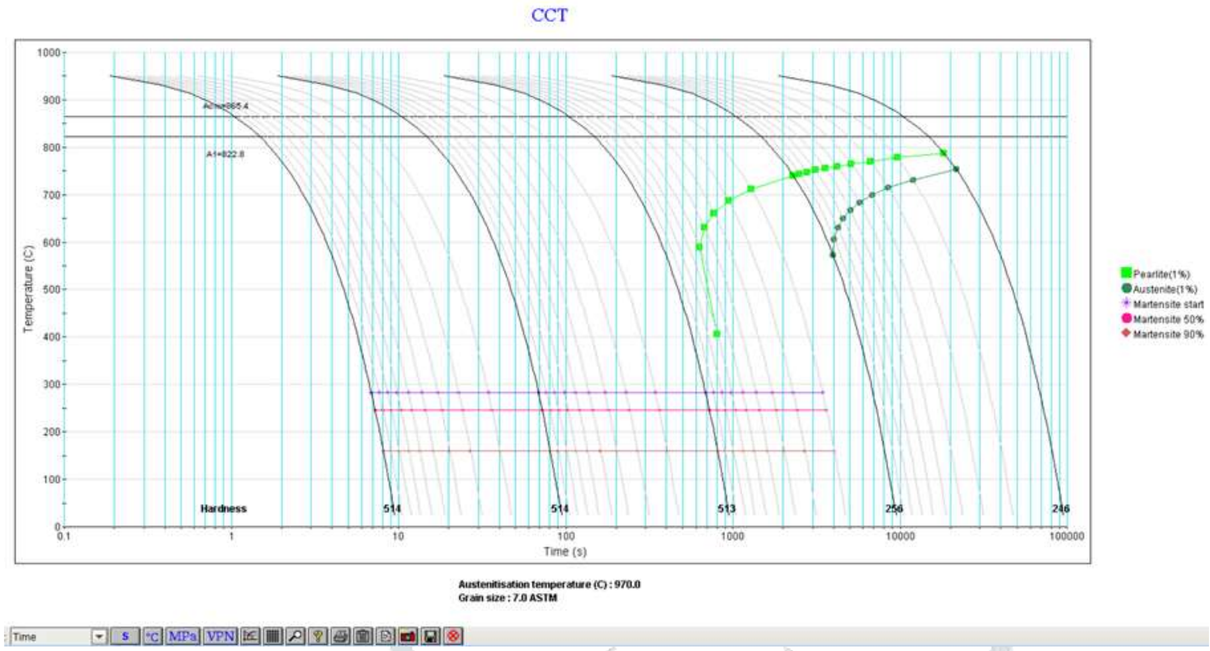

Fig. 3.2 Continuous Cooling Transformation Curve at 970^{0}C

As seen from Fig.2 we see the phase transformation of Austenizing Temp. 970^{0}C here on X axis we have time in seconds(s) and on Y axis we 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. To get the desired pearlite microstructure we need to keep the cooling rate below 1℃/s

Table. 3.2 change in properties with cooling rate at 970 austenizing temperature

Austenizing temp(C)	Cooling Rate (^{0}C/s)	Ferrite fraction	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
	0.01	0	0.999924	0	0	777.834	246.051
	0.1	0.000574	0.999426	0	0	808.56	256.023
970	1	0.000381	0.003984	0.987874	0.00776	1607.02	513.216
	10	0	0	0.992164	0.007791	1609.95	514.141
	100	0	0	0.992206	0.007791	1609.99	514.154

INPUT PARAMETERS	
Austenizing Temp.(^{0}C)	1010
Composition (%)	C-0.15 Cr-12.5

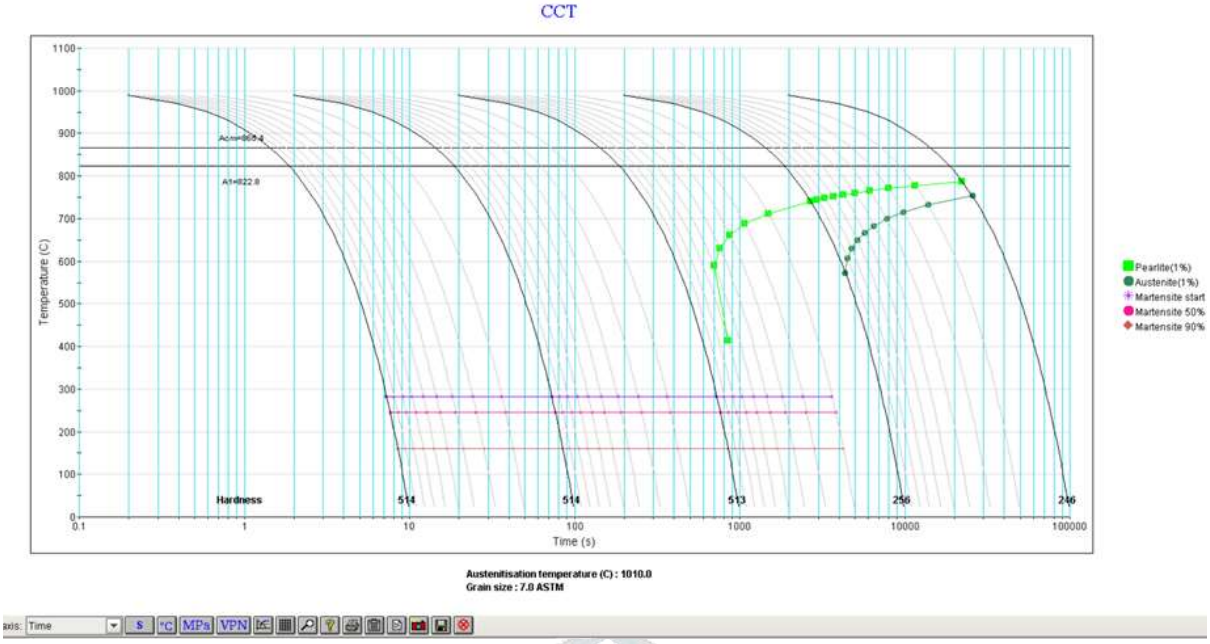

Fig.3.3 Continuous Cooling Transformation Curve at 1010^{0}C

As seen from Fig.3 we see the phase transformation of Austenizing Temp.1010^{0}C here on X axis we have time in seconds(s) and on Y axis we 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. To get the desired pearlite microstructure we need to keep the cooling rate below 1℃/s

Table.3.3 change in properties with cooling rate at 1010 austenizing temperature

Austenizing temp(C)	Cooling Rate (^{0}C/s)	Ferrite fraction	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
	0.01	0	0.999924	0	0	777.834	246.051
	0.1	0.000574	0.999426	0	0	808.56	256.023
1010	1	0.000381	0.003984	0.987874	0.00776	1607.02	513.215
	10	0	0	0.992163	0.007791	1609.95	514.14
	100	0	0	0.992206	0.007791	1609.99	514.153

B) Carbon Variations

INPUT PARAMETERS	
Austenizing Temp.(^{0}C)	925
Composition (%)	C-0.08 Cr-12.5

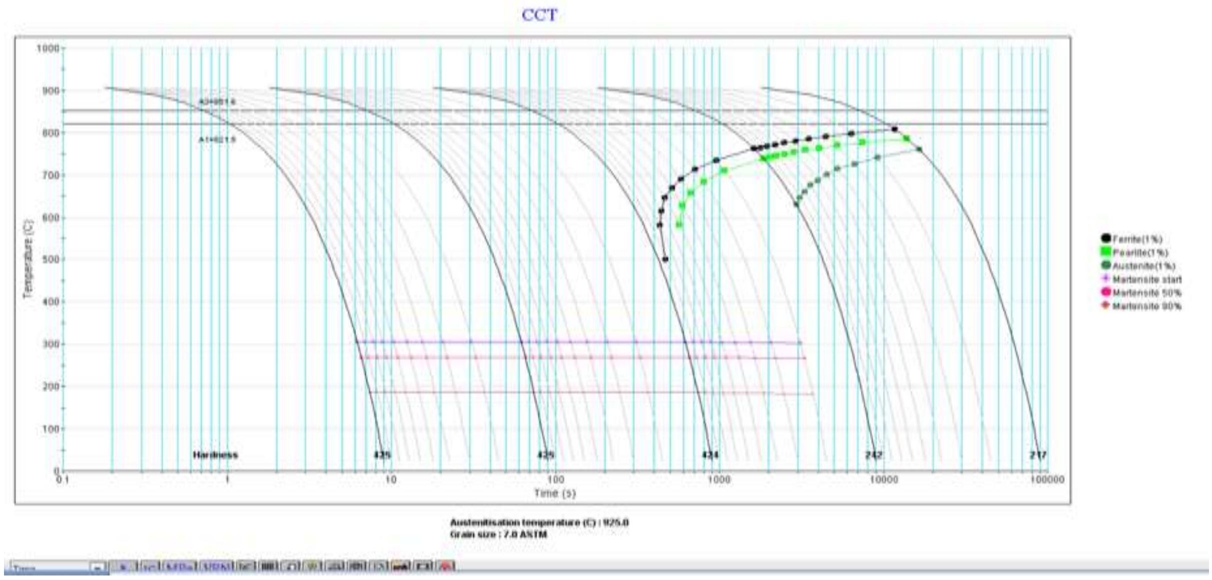

Fig. 3.4 Continuous Cooling Transformation Curve at 0.08% Carbon

As seen from Fig.4 we see the phase transformation of 0.08%C here on X axis we have time in seconds(s) and on Y axis we 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. To get the desired pearlite microstructure we need to keep the cooling rate below 1℃/s .

Table.3.4 change in properties with cooling rate at 0.08% carbon

Austenizing temp.(C)	Cooling Rate (^{0}C/s)	Ferrite fraction	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
	0.01	0.379508	0.620492	0	0	686.663	216.517
	0.1	0.13369	0.86631	0	0	766.381	242.336
925	1	0.007529	0.003664	0.984304	0.004503	1326.82	423.961
	10	0.000123	0	0.995321	0.004534	1331.37	425.423
	100	0	0	0.995455	0.004534	1331.43	425.443

INPUT PARAMETERS	
Austenizing Temp.(^{0}C)	925
Composition (%)	C-0.10 Cr-12.5

As seen from Fig.5 we see the phase transformation of 0.10%C here on X axis we have time in seconds(s) and on Y axis we 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. To get the desired pearlite microstructure we need to keep the cooling rate below 1℃/s.

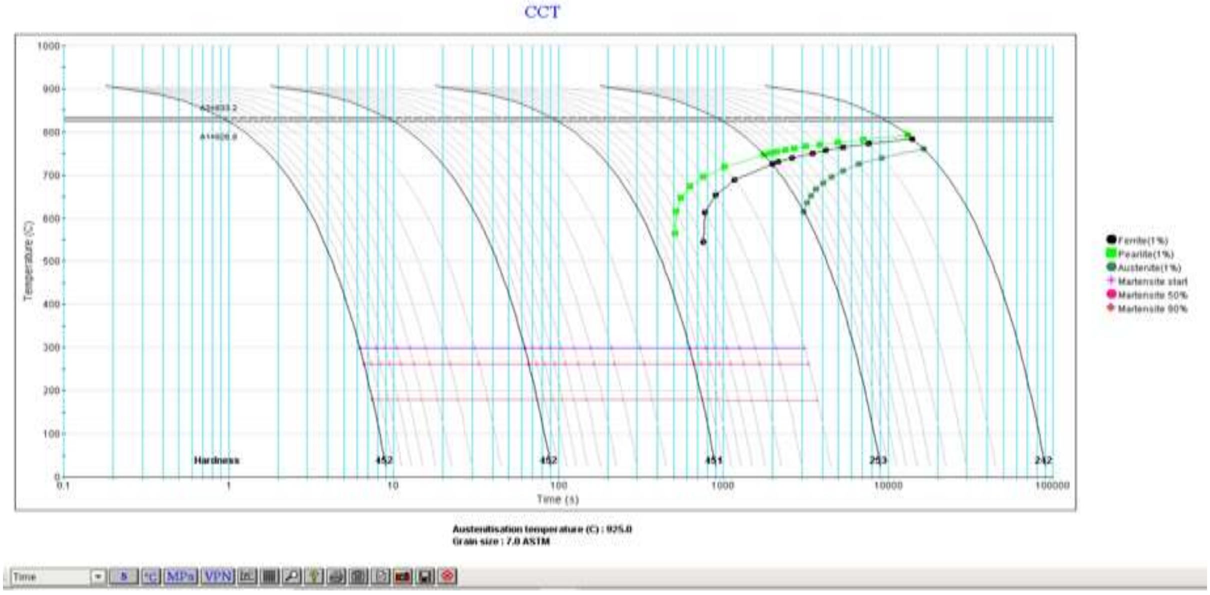

Fig. 3.5 Continuous Cooling Transformation Curve at 0.10% Carbon

Table.3.5change in properties with cooling rate at 0.10% carbon

Austenizing temp.(C)	Cooling Rate (^{0}C/s)	Ferrite fraction	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
	0.01	0.017378	0.982622	0	0	766.488	242.371
	0.1	0.010717	0.989283	0	0	798.465	252.746
925	1	0.002069	0.004891	0.987772	0.005267	1410.1	450.656
	10	0	0	0.994612	0.005296	1413.45	451.727
	100	0	0	0.994697	0.005296	1413.52	451.75

INPUT PARAMETERS	
Austenizing Temp.(^{0}C)	925
Composition (%)	C-0.15 Cr-12.5

As seen from Fig.6 we see the phase transformation of 0.15%C here on X axis we have time in seconds(s) and on Y axis we have Temperature in ^{o}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. To get the desired pearlite microstructure we need to keep the cooling rate below 1℃/s .

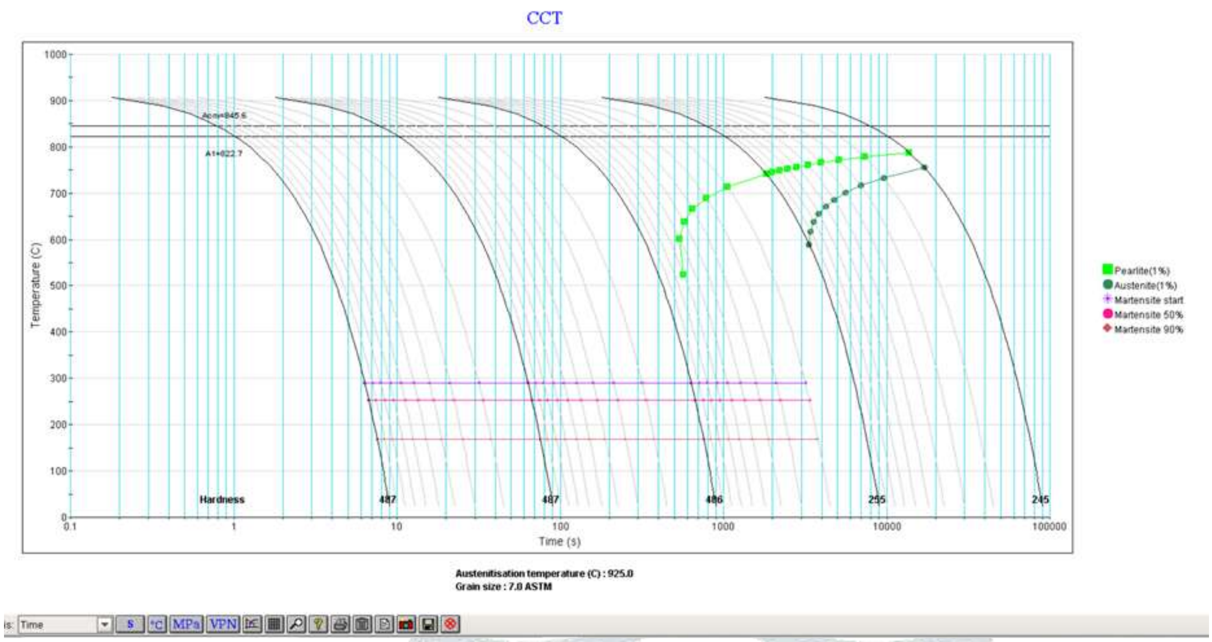

Fig. 3.6 Continuous Cooling Transformation Curve at 0.15% Carbon

Table.3.6 change in properties with cooling rate at 0.15% carbon

Austenizing temp(C)	Cooling Rate (^{0}C/s)	Ferrite fraction	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
	0.01	0.000551	0.999449	0	0	774.283	244.899
	0.1	0.001371	0.998629	0	0	804.891	254.832
925	1	0.000662	0.004314	0.988484	0.00654	1520.03	485.684
	10	0	0	0.993374	0.006568	1522.97	486.617
	100	0	0	0.993427	0.006569	1523.02	486.632

C) Chromium variations

INPUT PARAMETERS	
Austenizing Temp.(^{0}C)	925
Composition (%)	C-0.15 Cr-11.5

As seen from Fig.7 we see the phase transformation of 11.5%Cr here on X axis we have time in seconds(s) and on Y axis we have Temperature in ^{o}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. To get the desired pearlite microstructure we need to keep the cooling rate below 1℃/s.

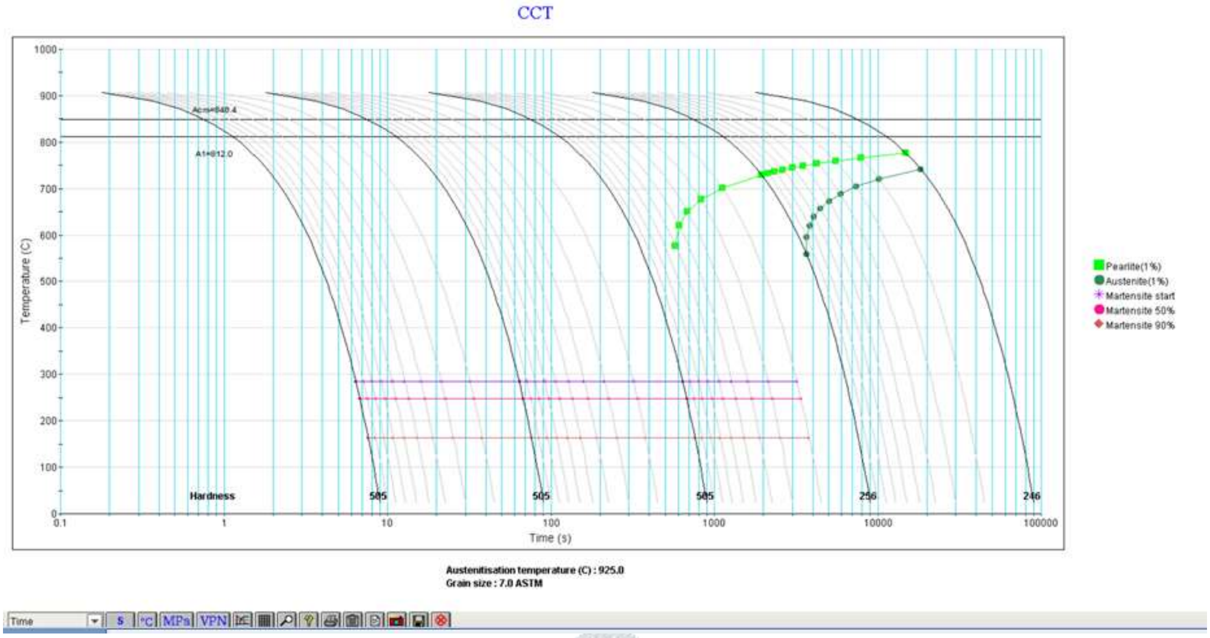

Fig. 3.7 Continuous Cooling Transformation Curve at 11.5% Chromium

Table 3.7change in properties with cooling rate at 11.5% chromium

Austenizing temp.(C)	Cooling Rate (^{0}C/s)	Ferrite fraction	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
	0.01	0.000149	0.999851	0	0	776.728	245.692
	0.1	0.000747	0.999102	0	0	807.462	255.666
925	1	0.000367	0.003833	0.988538	0.007262	1579.59	504.553
	10	0	0	0.992666	0.00729	1582.32	505.416
	100	0	0	0.992707	0.00729	1582.36	505.429

INPUT PARAMETERS	
Austenizing Temp.(^{0}C)	925
Composition (%)	C-0.15 Cr-12.5

As seen from Fig.8 we see the phase transformation of 12.5%Cr here on X axis we have time in seconds(s) and on Y axis we have Temperature in ^{o}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. To get the desired pearlite microstructure we need to keep the cooling rate below 1℃/s.

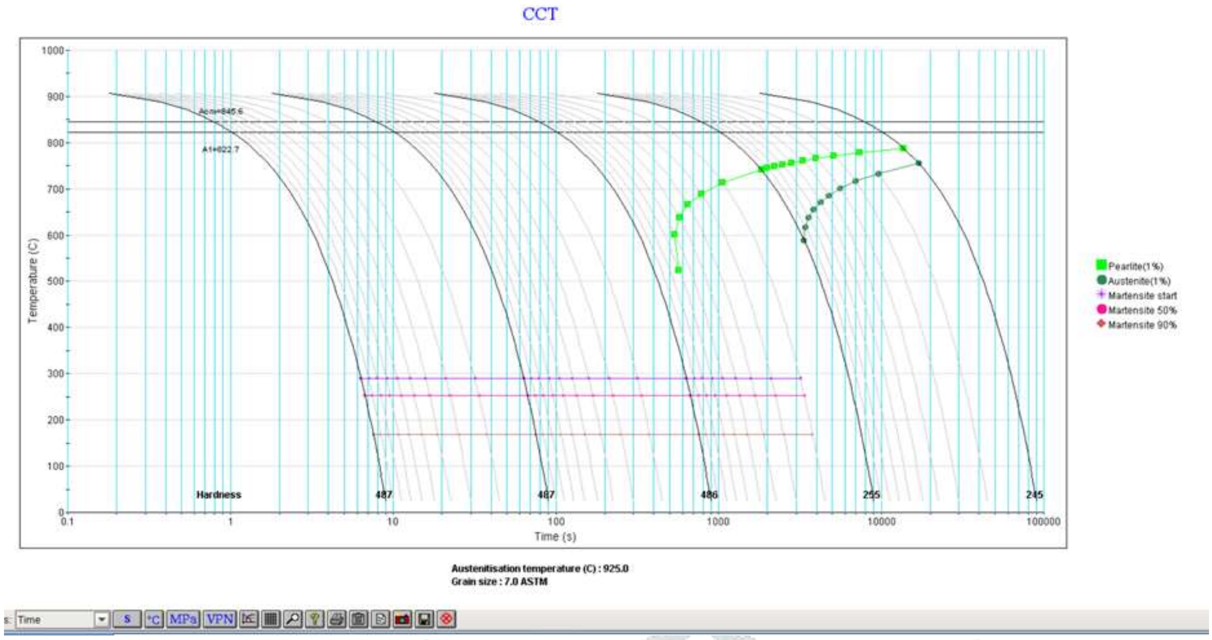

Fig. 3.8 Continuous Cooling Transformation Curve at 12.5% Chromium

Table.3.8 change in properties with cooling rate at 12.5% chromium

Austenizing temp.(C)	Cooling Rate (^{0}C/s)	Ferrite fraction	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
	0.01	0.000551	0.999449	0	0	774.283	244.899
	0.1	0.001371	0.998629	0	0	804.891	254.832
925	1	0.000662	0.004314	0.988484	0.00654	1520.03	485.684
	10	0	0	0.993374	0.006568	1522.97	486.617
	100	0	0	0.993427	0.006569	1523.02	486.632

INPUT PARAMETERS	
Austenizing Temp.(^{0}C)	925
Composition (%)	C-0.15 Cr-13.5

As seen from Fig.9 we see the phase transformation of 13.5%Cr here on X axis we have time in seconds(s) and on Y axis we 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. To get the desired pearlite microstructure we need to keep the cooling rate below 1℃/s.

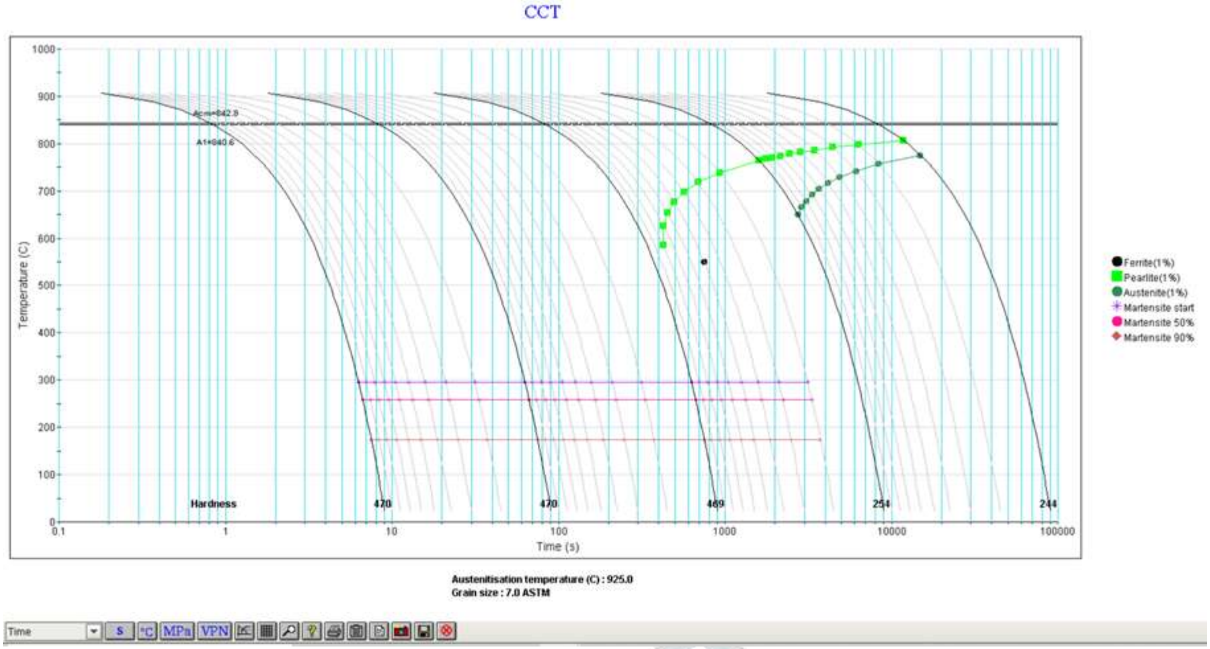

Fig. 3.9 Continuous Cooling Transformation Curve at 13.5% Chromium

Table3.9 change in properties with cooling rate at 13.5% chromium

Austenizing temp.(C)	Cooling Rate (^{0}C/s)	Ferrite fraction	Pearlite fraction	Martensite fraction	Austenite fraction	Tensile Stress (MPa)	Hardness (VPN)
	0.01	0.004281	0.995719	0	0	771.515	244.001
	0.1	0.004688	0.995312	0	0	802.141	253.939
925	1	0.002063	0.007345	0.984855	0.005736	1466.74	468.735
	10	0	0	0.99412	0.00578	1471.77	470.336
	100	0	0	0.994212	0.005781	1471.85	470.362

IV.CONCLUSION

These are few work-related results and conclusions we have reached at from this study till now:

- To get the desired pearlite microstructure we need to keep the cooling rate below 1^{0}C/s. So, we considered cooling rate below 1^{0}C/s and increased austenizing temperature from 925^{0}C to1010^{0}C the pearlite phase fraction also increases, the hardness value increased from 485 to 513 on Vickers scale. This shows as austenizing temperature increases hardness value increases. Similarly, tensile strength also increases from 1520 MPa to 1607MPa.
- To get the desired pearlite microstructure we need to keep the cooling rate below 1^{0}C/s, So, we considered cooling rate below1^{0}C/s. and increased C wt% from 0.08% to 0.15 %, the pearlite phase fraction also increases, the hardness value increased from 423 to 485 on Vickers scale. This shows as carbon wt% increases hardness value increases. Similarly, tensile strength also increases from 1326 MPa to 1520 MPa.
- To get the desired pearlite microstructure we need to keep the cooling rate below 1^{0}C/s. So, we considered cooling rate below1^{0}C/s and increased Cr wt% from 11.5% to 13.5 %, the pearlite phase fraction also increases,

but the hardness value decreased from 504 to 468 on Vickers scale. This shows as chromium wt% increases hardness value decreases. Similarly, tensile strength also decreases from 1579 MPa to 1466 MPa.

V. REFERENCES

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