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Optimization of annealing cycle and Microstructural Characterization of cold rolled Titanium-stabilized Interstitial Free Steel

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Abstract –Interstitial free (IF) steels having carbon level at 30 ppm are extensively used for outer panel fabrication of four-wheeler. IF steel poses a mild strength with excellent elongation, high plastic strain ratio (r-bar; r) and excellent formability. After hot rolling, the Ti-stabilized IF grade steel having Carbon around 30 ppm are cold rolled and annealed at different annealing temperature. Mechanical properties i.e. YS, UTS & % El are evaluated at every step for understanding the change of material behaviour in terms of their strength and other formable parameters. Hardness in HRB scale evaluated and r (plastic strain ratio) is calculated by using resonant frequency method in modul- r drawability tester. Cold rolled and annealed at 650ºC, 700ºC & 725ºC samples shows the elongation 40% & above. Similarly, r are more than 2.0 for annealing temperature 650ºc, 700ºc & 725ºC. The best combination of properties achieved when cold rolled sheet was annealing at 700ºC i.e. % elongation is 48% and r is 2.25

Keywords - Interstitial free steels, Annealing, plastic strain ratio and formability

INTRODUCTION

Industrial production of Interstitial Free (IF) steels began around 50 years back and in last two decades, the demand increased for IF steel due to their superior formability over conventional extra deep drawing (EDD) steel. IF steels having C in the range of 20-40 ppm, are extensively used for outer panel fabrication in automotive segment. Heat of IF steel are made by keeping interstitial elements i.e C and N below 30 ppm by refining liquid steel in vacuum degassers, and stabilizing these interstitial elements by micro-Alloying addition of Titanium or Niobium or both. Carbide and nitride precipitates of these elements makes matrix almost free from interstitial elements.

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IF steel poses a typically non aging properties as no free C & N available and have mild strength with excellent elongation, high plastic strain ratio and excellent formability. For fully stabilization of C and [N] in IF Steel, the requirement of minimum Titanium are given by below mentioned equation [1]:

$Ti_{stab} = 4\times\%C + 3.42\times\%[N] + 1.5\times\%S$

Titanium precipitation took place in form of nitride and sulphide (TiN, TiS) at higher temperature and formed Ti-carbide and Ti-Carbo-Nitride at lower intercritical temperature region i.e austenite to ferrite transformation during hot rolling transform to $Ti_4C_2S_2$, Ti-CN & TiC by the absorption of titanium and carbon[2,3].

During Cold rolling, a favourable texture formation phenomena during annealing process which plays an important role in formability particularly elongation and r-bar (r *; however, has little effect on other properties [4,5]. Precipitate of Ti(CN) formed during hot rolling and coiling were not much interfere the formation of favourable texture during annealing. Also the extend of cold reduction, create a favourable condition for texture, so around 90% cold reduction shows highest r-bar (ٮ·) in all the IF or super extra deep drawing quality steels. However, such reduction is not possible in industrial practice, upto 80% reduction are more common for such streel.

EXPERIMENTAL

2 nos. of hot rolled coiled samples of size 200 mm X 300 mm has been cold rolled at Experimental rolling mill, RDCIS, Ranchi (fig-4a). The chemical composition of experimental IF steel (Table 3) was tested in Optical Emission Spectrometer (Model: Spectro-lab LAVMC05A).

Table-3: Chemical Composition of the IF steel

C	Mn	P	S	Si	Al	Ti
0.003	**0.080**	**0.012**	**0.006**	**0.008**	**0.040**	**0.053**

In both sheet, the reduction draft was kept 75% as per draft schedule shown in table-4. The cold reduced sheet was shown in fig-4b.

Table-4: Draft schedule of hot rolled IF sheet in Experimental rolling mill, RDCIS

Sample No.	Initial Thickness	Final Thickness	% Reduction
15	4.8	1.2	75.0
18	4.8	1.2	75.0

Annealing of cold rolled sheet was carried out at different temperature in muffle furnace (KANTHAL make as shown in fig-4c) as per chart given below in table-5:

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Table-5: Annealing Temperature given to IF cold rolled sheet

SN	Annealing Temp	Sample thickness	Sample Heating Rate	Holding time	Sample Cooling (f/c cooling)
1	550ºC	1.20 mm	12ºC/min	5 mnt.	10ºC/min
2	600ºC	1.20 mm	12ºC/min	5 mnt.	10ºC/min
3	650ºC	1.20 mm	12ºC/min	5 mnt.	10ºC/min
4	700ºC	1.20 mm	12ºC/min	5 mnt.	10ºC/min
5	725ºC	1.20 mm	12ºC/min	5 mnt.	10ºC/min

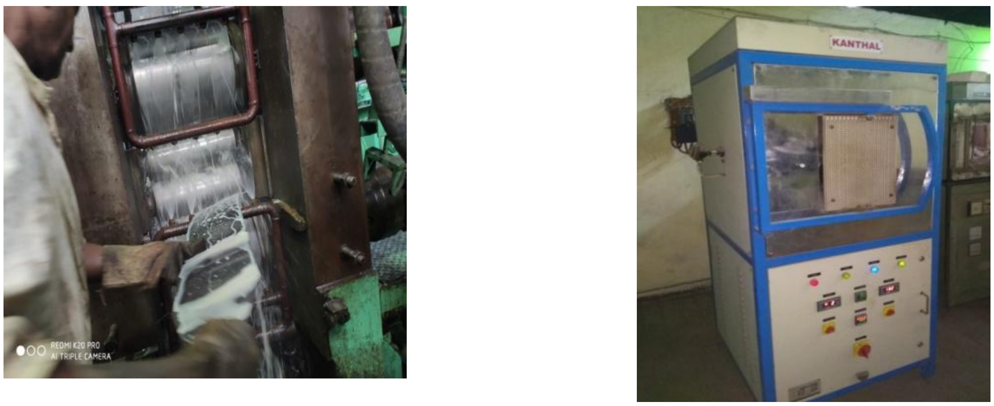

Fig-4: Experimental set-up (a) Rolling of IF grade steel at Experimental Rolling mill, RDCIS; (b) Muffle furnace for annealing, Kanthal Make.

The Tensile test was carried out in transverse direction of hot-rolled, unannealed cold rolled and annealed cold rolled sheets. Hardness of samples annealed at different temperature was taken Rockwell cum Rockwell Superficial Hardness Tester in HRB scale. Tensile tests were performed on 50 mm gauge length sample as per the ASTM E8 standard using UTM having 5 Ton capacity at ambient temperature. The tensile and hardness values are reported in Table 6. Plastic strain ratio r is calculated by using resonant frequency method in modul- r drawability tester (Make: Tinius Olsen). Sample for r is cut by modul-r punch press in rolling direction (0º), diagonal to rolling direction (45º) & transverse to rolling direction (90º). Specimens of hot rolled sheet, un-annealed cold rolled sheet and annealed cold rolled sheet were investigated in optical microscope (Model: Olympus GX 71). Fracture morphology observation was made using an ASPEX scanning electron microscope.

RESULTS AND DISCUSSION:

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Mechanical Properties:

The tensile strength of hot rolled IF grade steel was 308 MPa with around 40% elongation. The YS/UTS ratio is around 0.81. Cold rolled sample shows a 650 MPa of tensile strength with negligible elongation which is due to high stress developed in material during cold rolling. After annealing, the stress incurred in material was released during recrystallization and regain its ductility as shown in table-6 and Fig 5 & 6. The most interesting point is that in all annealing temperature, YS/UTS ratio are less than 0.60 with YS in the range of 121-136 MPa.

Table-6: Annealing Temperature given to IF cold rolled sheet

S N	Particulars	YS, MPa	UTS, MPa	% El	Hardness, HRB	Ͻˡ (r-bar)
1	Parent-HR	252	308	40%	52.0	----
2	Unannealed-CR	408	654	6%	86.6	----
3	CR-Annealing @ 550ºC	125	280	38%	36.2	1.61
4	CR-Annealing @ 600ºC	124	252	38%	36.8	1.47
5	CR-Annealing @ 650ºC	136	248	40%	28.3	2.20
6	CR-Annealing @ 700ºC	132	235	48%	24.7	2.25
7	CR-Annealing @ 725ºC	121	227	48%	24.9	2.23

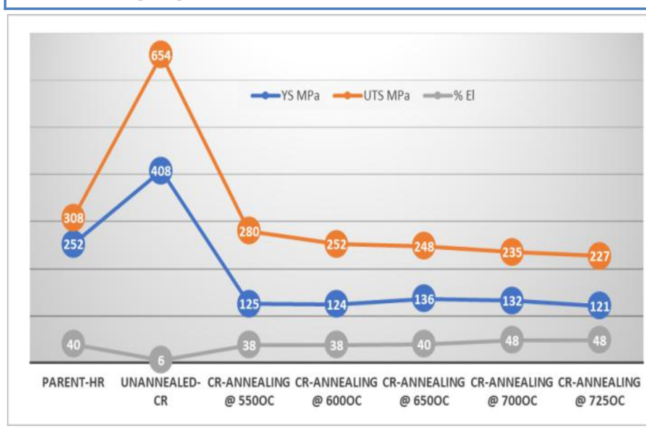

Fig-5: Variation of tensile properties w.r.t annealing time

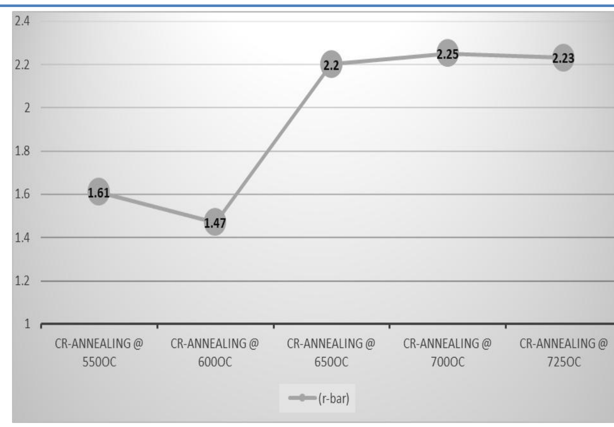

Fig-6: Variation of Ͻˡ w.r.t annealing time

Optical Microstructure:

Optical Microstructure of hot rolled sheet (as shown in fig-7) showing

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ferrite grains having a partially recovered, partially recrystallised and pancake microstructure, which evidenced a hot rolling in ferrite-region.

The cold rolled Unannealed sample shows an elongated grain of ferrite (in fig-8).

Fig-7: Optical Micrograph of hot rolled IF steel sheet X200

After annealing the recrystallization of elongated grains took place and observed in fig-9 to fig-13. The scattered grains are observed in lower temperature annealing i.e annealing at 550ºC, 600ºC & 650ºC. The size ferrite grains increased with increasing annealing temperature and almost equiaxed at 700ºC.

Fig-8: Optical microstructure of Cold rolled-Unannealed IF steel sheet X200

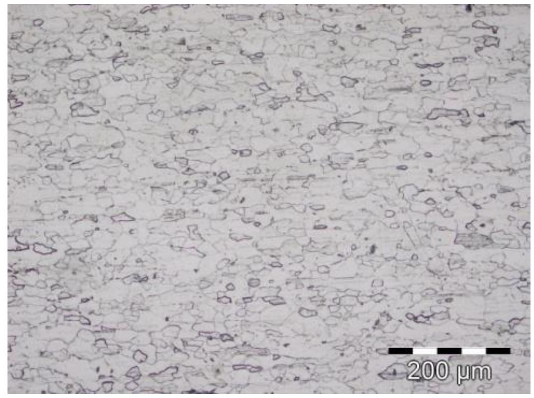

Fig-9: Optical microstructure of Cold rolled annealed at 550ºC X200

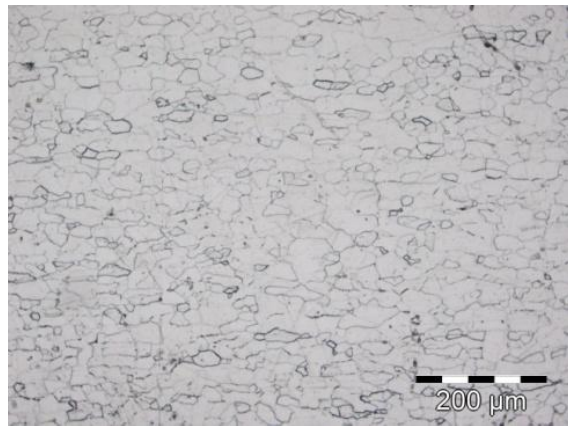

Fig-10: Optical microstructure of Cold rolled annealed at 600ºC X200

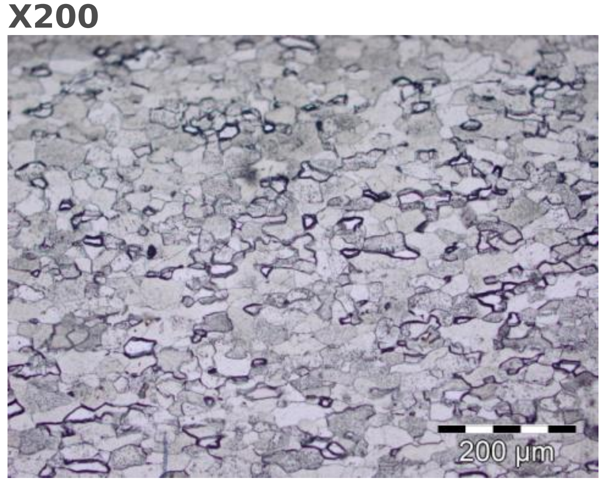

Fig-11: Optical microstructure of Cold rolled annealed at 650ºC X200

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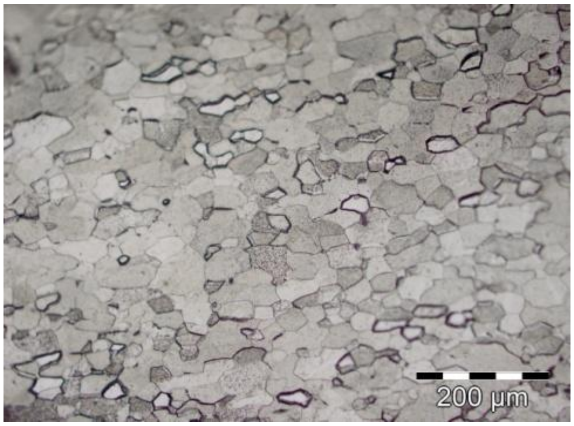

Fig-12: Optical microstructure of Cold rolled annealed at 700ºC X200

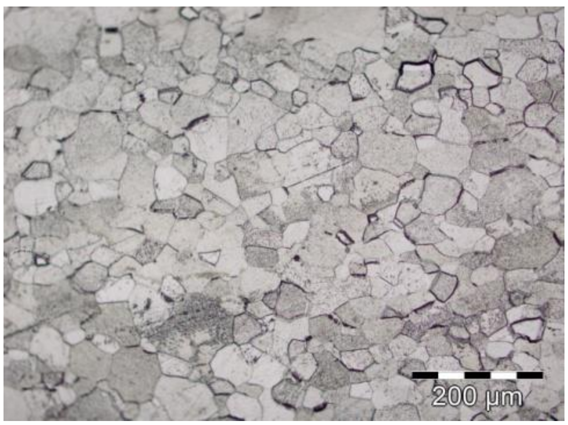

Fig-13: Optical microstructure of Cold rolled annealed at 725ºC X200

Scanning Electron Microscope Image:

Fracture morphology of tensile test sample of Hot rolled and cold rolled & annealed at 700ºC has been analysed and shown in fig-14 & 15. It is observed that the entire void formation is not of first generation but also smaller second-generation voids created in the matrix. In hot rolled sample the void size is as large as 117μm whereas void size in cold rolled annealed sample is smaller i.e. 32-38 μm.

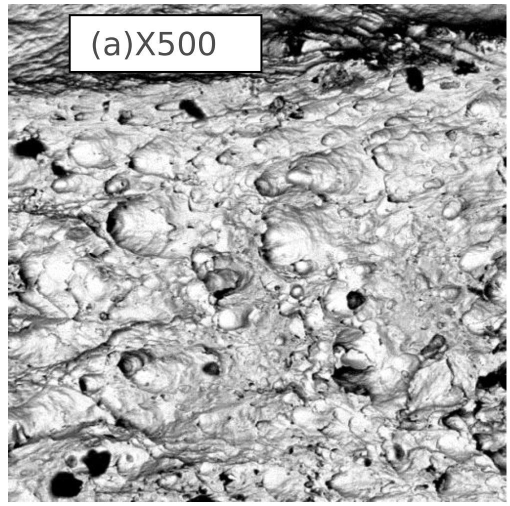

Fig-14: Fractographic image of tensile sample of Hot rolled steel

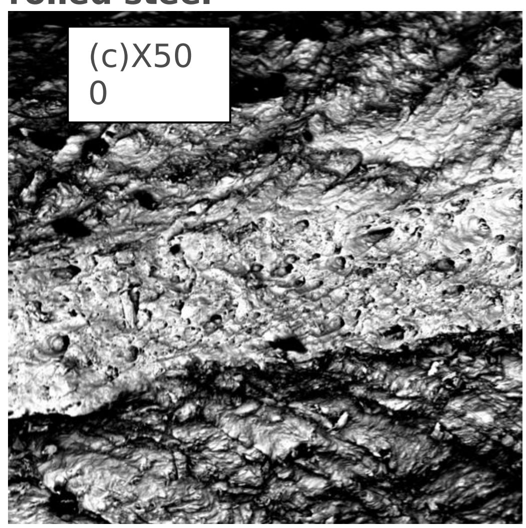

Fig-15: Fractographic image of tensile sample of Cold rolled-annealed at 700ºC

CONCLUSIONS:

Ti-stabilized interstitial free steel are applied for complex shaped part of inner and outer door panels, side parts etc in four wheeler. Carbon in the range of 20-40 ppm generally produced and stabilized by Ti for complete stabilization of carbon and nitrogen and formed precipitates of Ti-

Nitrides (TiN), Ti-carbides (TiC), or Ti-Carbo-nitrides (TiCN). This gives excellent formability, low yield points, and at the same time, high forming anisotropy.

Cold rolled and annealed at 650ºC, 700ºC& 725ºC samples shows the elongation 40% & above. Similarly, Ը· are more than 2.0 for annealing temperature 650ºC, 700ºC& 725ºC.

The optimized condition for annealing cycle was 700ºC, preceded by 75% cold reduction, which resulted in an Ը· of as high as 2.25 & 48% elongation.

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