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Development of Fe500S Earth Quake Resistance TMT Rebar

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Abstract – *Infrastructure development is the backbone of nation's growth. A major contribution to India's infrastructure has come from growth in the construction of residential/commercial buildings and high rise.. Steel is the key raw material used in India's predominantly RCC construction. Thermo mechanically treated rebars (TMT rebars) impart strength and ductility to RCC structure to withstand various kinds of loads impacting a building. In the demand for making such buildings safer, builders as well as individuals are focusing more on the quality of material used .These days a lot of focus is given in designing structures that have high earthquake resistance. TMT bars can have high resistance to Seismic loads due to its higher UTS/YS ratio. In view of these requirements, JSPL tookan efforts and initiatives to develop the seismic resistant grade/quality TMT – Re-bars. These rebars are produced as per Indian standard IS: 1786:2008.Developing this product, due consideration was given to the cost effective alloy design and optimization of process parameters with in mill capability of JSPL. Chemistry design and cooling parameters were major technological intervention that was judiciously used for achieving high UTS/YS ration (>1.25) in quake resistant TMT-Rebar.*

This present paper describes the technological details of earth quake resistant TMT rebars, recently developed at JSPL.

INTRODUCTION

In India, rebars account for one-fifth of total steel production and play an important role in national economic development. In recent years, the output and consumption of hot rolled rebars have both increased significantly to meet the requirements of fast growth of construction industry. Although the production of rebar has substantially increased in the last years, the product mix has been relatively backward. Currently, the domestic building market is dominated by grades Fe500D & Fe500S rebars with yield strength of 500 MPa. In a way the foray into the construction materials & solutions space comes naturally to JSPL due to its rich and diverse steel product mix which was being offered to this segment for many years. With a company that saw extensive expansion over the last decade, we had built significant in-house project management expertise to develop buildings and townships. These coupled with the focus on continuous innovation to develop new grades of steel and product lines offered immense potential to tap into this fast-growing market in a focused and concerted way.

TMT bars have improved properties such as yield strength, ductility and toughness and corrosion resistance bars. The multi-layered microstructure having soft ferrite-pearlite core of TMT bars enables them to have high strength with good ductility having YTS/YS ratio >1.25 can bear dynamic and seismic loads. With the above properties, TMT steel is also highly economical and safe for use and hence finds wide application in the areas of construction of roads, buildings, bridges etc.The mechanical properties of rebar (strength class 500 MPa), which is widely used abroad, are optimal for Ferro concrete structures without pre-liminary stress.For example, if conventional rebar (415Mpa Class) is replaced by 500_MPa rebar, the total saving of steel is 10–25%, according to different estimates. Therefore, construction enterprises are interested in the acquisition and use of such rebar, because it is reliable and economically expedient.
As we Know, Indian subcontinent is situated on a tectonic plate, which is more prone to earth quakes.Thermo mechanically treated rebars (TMT rebars) impart strength and ductility to RCC structure to withstand various kinds of loads impacting a building. These days a lot of focus is given in designing structures that have high earthquake resistance. TMT bars have high fatigue resistance to Seismic loads due to its higher UTS/YS ratio. This makes them most suitable for use in earthquake prone areas. Usage of TMT has enabled economy in design, construction of high risers with improved earthquake resistance along with added advantage of superior weldability, corrosion resistance, ductility and durability. Under such consideration JSPL took efforts and initiatives to developed seismic resistant TMT rebars. These rebars (Grade 500S) are produced as per Indian standard IS: 1786:2008. Steel reinforcement bars take care of tensile force acting on the civil structures. In order to make structure taller and heavier, there is greater demand of rebars of higher and higher strength. Apart of enhancing the yield strength of rebars there has been increasing concern to

provide better safety in the event of an earthquake in the seismic prone zone. According to BIS Specification IS1786 on high strength deformed steel bars was suitably revised in 2012 to include two grades of Fe415S and Fe500Swith enhanced UTS/YS ration of 1.25 min. and higher elongation in TMT rebars ensures greater energy absorption capacity in the civil structures in the event of an earthquake and minimize the risk of collapse and loss of human life. Jindal Panther™ TMT Rebars are thus able to withstand shock loading and cyclic loading conditions making them the choice of the designers for buildings in the high seismic areas.

Layout of JSPL – TMT Rebar Production

JSPL TMT Rebar mill at Patratu, Jharkhand supplied by Siemens of USA, the world leaders in rebar production technology. This mill produces high strength rebars conforming to BIS 1786:2008 Fe 500D, Fe 550D & 600 grade in normal, EQR & CRS quality. TMT production at Patratu uses the superior and clean steel billets produced at the company's Raigarh Plant through the BF + DRI ➔ EAF ➔ LRF ➔ Concast route with highly controlled steel chemistry & very low levels of sulphur and phosphorus (less than 0.035%). Patratu Mill uses superior HYQST (High Yield Quenching & Self Tempering) TMT technology for production of TMT rebars. HYQST technology produces rebars with high strength, high ductility, high bendability and high weldability surpassing the requirements of Fe 500D, Fe 550D & 600 CRS rebars.

Fig -1 – TMT Mill at JSPL Patratu

Achieving such high UTS/YS ratio and elongation is a challenge requiring optimization of steel chemistry and process parameters. Based on extensive literature survey revealed that, cooling of TMT within narrow temperature range is one of the optimal and economic solutions to get optimum UTS/YS ratio in rebars. JSPL, with its strong research expertise and advanced steel processing facilities has developed the earth quake resistance bars in different diameters.
This has been possible through proper alloying and microstructural engineering through repeated trials done at JSPL Patratu unit.

Theory of Design

While designing of seismic resistance rebars various attributes of alloying elements and their effect were kept in mind.Characterization of developed grades is very important to validate process design and its impact on various attributes of the desired product. To achieve the high strength TMT rebars at low cost the general practice is quench and self-tempering process (QST), which results in hard tempered martensite on the surface and soft pearlitic + ferritic core. While Martensite provides strength but at the same time it reduces the UTS/YS ratio as given in below figure. Our aim is to restrict the volume fraction of martensite to 10% by adjusting the cooling rate and finishing temperature and achieve the balance strength of around 50-60 MPa by addition of alloying elements. During early stages of development following hypothesis was suggested for development of this grade.

1 - On-line heat treatment of C-Mn steels by optimizing Quench and self-tempered (QST) Process -

2 – Addition of alloying elements (Nb, V, Ti, Mn, Cr, Cu, P & Si)

Alloy Design & Processing Approach

On the basis of above hypothesis, various attributes and their effect were kept in mind. The basic concept was to keep the structure in elastic limit in case of minor earthquake and well with in safe plastic zone (upto UTS) to avoid any catastrophic failure. The first requirement was enhance the UTS/YS ratio without hampering the yield strength. In first trials C-Mn base chemistry was selected & other microalloying element was suitable added to achieve desire strength with high UTS/YS ratio and allied properties. Process engineering was adopted to optimize cooling parameters to achieve desired properties. Accordingly in first trial below chemical composition was decided referred as ‘’Alloy A’’ given in below table-1. This is in line with basic requirements of IS1786:2008.

Trial -1: Table -1 –Chemical Composition

%C	Mn	%S	%P	Other alloying element
0.25 Max	1.10% Max	0.040 Max	0.040 Max	Nb + V + Ti

In first trial of 100 tonnes of steel of grade Fe500S steel was processed with microalloying given in Table-1. The steel billets with 130 x 130 mm cross-section were soaked at reheating furnace 1100 ◦C. The billets were hot rolled on 14 stands roll mill to a final dimension of 10mm diameter. Rolling was finished at 980–1000 ◦C and subsequent followed water cooling with in different temperature range and further followed air cooling.Processing conditions highly affect the mechanical properties of rebars. Table 2 represents standard tensile properties of grade Fe 500S (target) compared with the actual measured properties due to industrial trial.

Table – 2 - Standard (target) tensile properties of grade Fe 500S compared with the actual measured properties of Trial-1

Fe500S Standard requirement	500 Min	625 Min	1.25 Min	18 Min.	Finished Cooling regime
Billet No.	Yield strength (MPa)	Ultimate tensile strength (MPa)	UTS/YS Ratio	%Elongation	
1	534	634	1.17	23.6	610 - 630°C
2	543	634	1.17	22.22	
3	540	620	1.15	25.86	
4	533	624	1.16	23.78	
5	524	626	1.195	23.98	
6	473	585	1.23	25.48	650 - 670°C
7	482	595	1.23	23.12	
8	484	599	1.23	26.72	
9	486	601	1.24	25.21	
10	478	593	1.24	26.01	

As per above evaluated tensile results, it was observed that when finished cooling regime was at lower side (Billet No.1-5) having high cold mechanical strength compared to those billets which was finished at higher cooling regime but higher

cooling regimes enhance UTS/YS ratio .However, it is not good enough to meet the standard requirement of Fe500S Grade.
So further trial was planned with different chemical composition and predicts that modified chemistry with appropriate cooling practices results desired strength with high UTS/YS ratio under these consideration typical chemistry was proposed for trials (refer Table-3).

Trial -2: Table -3 – Modified chemical composition.

%C	Mn	%S	%P	Other alloying element
0.25 Max	1.10% Max	0.040 Max	0.040 Max	P, Cr, Cu &Si

The rolling parameters were designed in a manner to get the maximum benefit without further jeopardizing mill capability. During this trial following key parameters were kept as prime consideration for successful implementation of this trial. The reheating temperature was maintained 1100 - 1150°C during this campaign. The rolling speed was kept at 5-7 m/s. Accordingly the finished temperature was maintained around 960 - 1000°C and this was followed by optimum water quenching range using different combination of water header and valve opening.

Table-4 -Standard (target) tensile properties of grade Fe 500S compared with the actual measured properties of Trial-2

Fe500S Standard requirement	500 Min	625 Min	1.25 Min	18 Min.	Finished Cooling regime
Billet No.	Yield strength (MPa)	Ultimate tensile strength (MPa)	UTS/YS Ratio	%Elongation	
1	530	678	1.28	26.18	670 - 690°C
2	527	669	1.27	25.72	
4	531	664	1.25	24.78	
5	519	656	1.26	25.8	
6	511	650	1.27	26.1	
7	528	664	1.26	21.88	
8	507	656	1.29	28.12	
9	528	664	1.26	21.88	
10	529	671	1.27	21.92	

Performance Analysis of product with respect to Trials

Comparison of the performance analysis of product with respect to trials and the alloy compositions was carried out. TMT – Rebars were sampled for mechanical testing & graphical plot of trial -1,mechanical properties were drawn in below fig: 2.

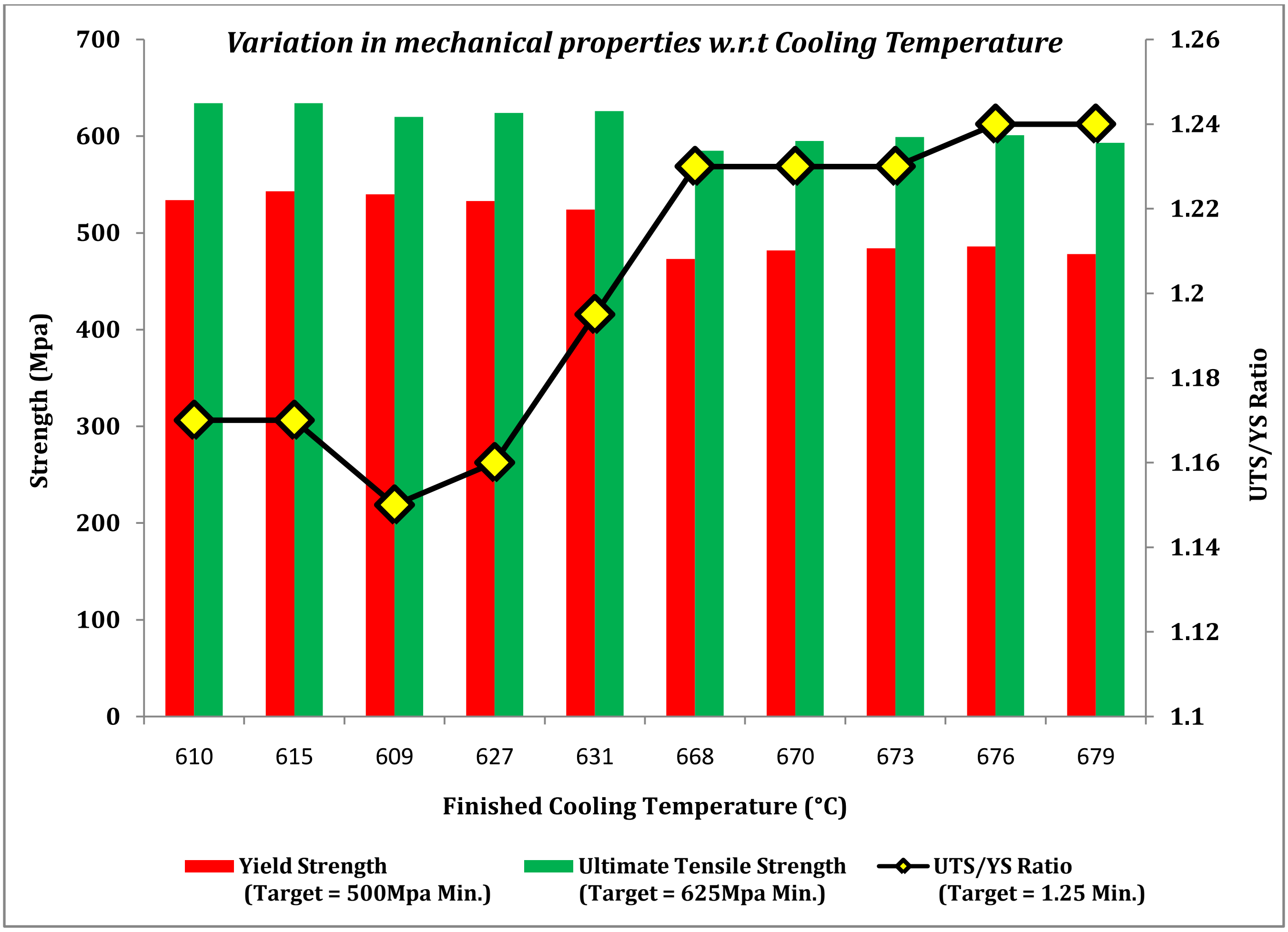


Fig – 2: Graphical plot of Mechanical Strength & UTS/YS Ratio with respect Finished Cooling Temperature (Trial-1)

As per above plotted graph of Trial -1, it can be seen that UTS to YS ratio increased significantly upto 1.23 by increasing the temperature from 610 to 680°C but the YS dropped below 500 MPa. Trial-1 has unsatisfied results with a poorer yield strength linked with higher UTS/YS due to finished in high cooling regime & appropriate Yield strength linked with lower UTS/YS ratio due to finished in lower cooling regime. In order to comparatively understand the impact of chemistry alteration on material behaviour under tensile loading, a graphical analysis of the trial-2 was done.The results obtained from the earlier campaign / Trial-1 was used to modify the chemical composition and cooling parameters in the subsequent campaigns.From figure:3, it clearly shows that the strength and UTS/YS ratio is higher side , much above the standard requirement while trial -1 the UTS/YS was not managed to touch the target line and Yield strength was also decreased when UTS/YS ratio increases above 1.25.

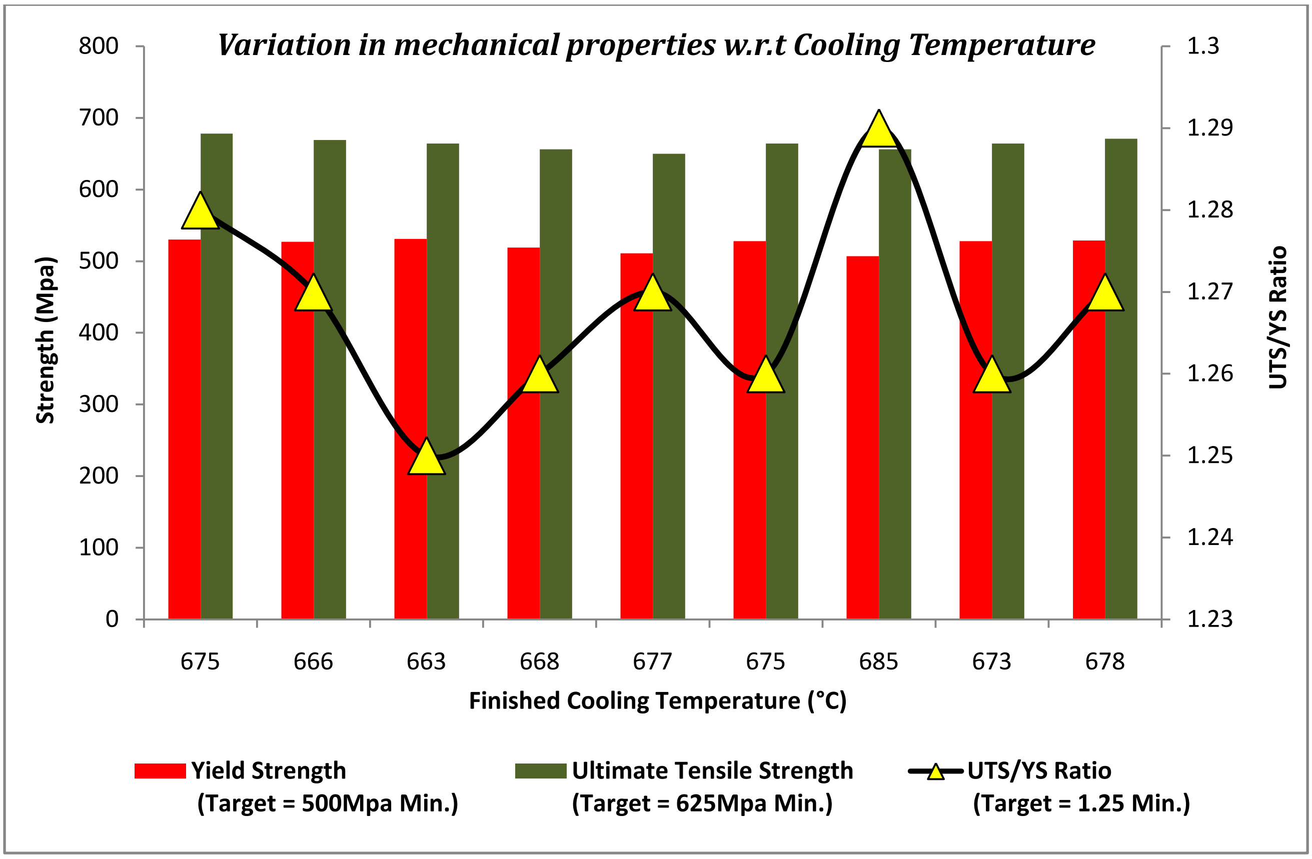


Fig – 3: Graphical plot of Mechanical Strength & UTS/YS Ratio with respect Finished Cooling Temperature (Trial-2)

Further this can be correlated that the addition of substitutional solid solution alloying (modified chemistry used in trial -2) and optimized cooling regime facilitated to achieve targeted UTS/YS ratio without significant drop in yield strength.

Product Characterization

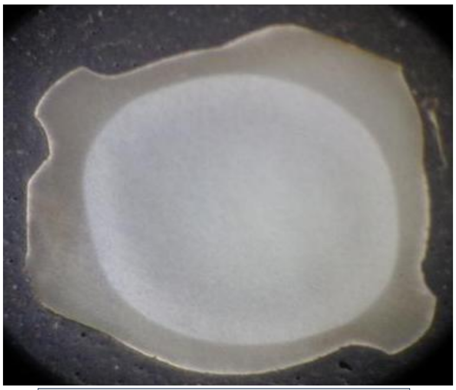
Microstructural examinations of the samples from both the trials were carried out by polishing the transverse section of rebars and etching them with freshly prepared 2% Nital solution. This was done to determine the phases present in the rim and core.

The purpose of these trials was to determine/optimize the cooling parameters so as to get the tempered martensite/bainite/ferrite+Pearlite volume fractions in such a way that it results in a UTS/YS ration is >1.25. Further to analyse the product characteristics of earth quake resistance TMT -Rebars.

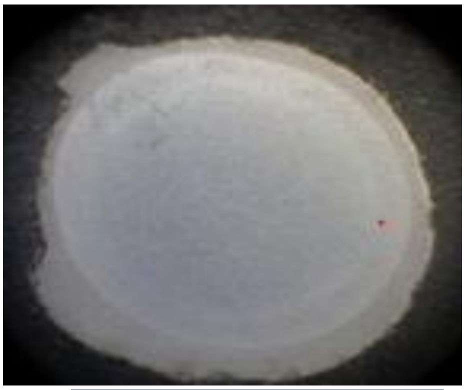
Macrostructure of Rebars

The variation of the radial ring formation of martensitic layer of TMT bars was studied to determine the variation of martensitic layer on mechanical properties. A typical macrostructure of rebar clearly revealed the tempered martensite rim on the surface. In Trial -1 low cooling regime increased the fraction of tempered martensite to more than 30% leading to higher yield strength with lower UTS/YS Ratio, but in the same trials rebars finished at higher cooling temperature (650 - 680°C) fraction of martensitic layer was reduced but obtained mechanical was not enough good to meet the specification requirement. In comparison trial -2 the partial ring formation is there but achieved mechanical properties satisfactorily meet the requirements.The case depth has been measured of these steel rebars with a micrometer fitted microscope.

Trial -1

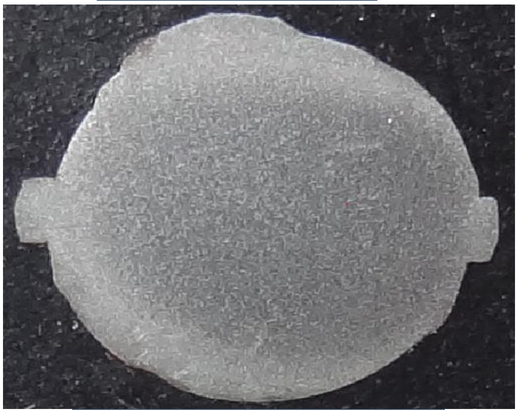


Cooling Temperature = 615°C



Cooling Temperature = 660°C

Trial -2



Cooling Temperature = 685°C

Fig – 4: Macrostructure of TMT Bar with respect to Trials

To know the case depth of the hardened zone of the TMT steel bars, case depths from different places are measured and their average is considered as the representative value given in table no.5.

Table No.5:-

Case depth and area fraction of case and core of steel rebars.				
Trial No.	**Sample No.**	**Cooling regime(°C)**	**Case Depth (in mm)**	**Case Area (Sq.mm)**
1	**1**	**610 - 620**	**2.2**	**31**
	2	**660 - 670**	**1.5**	**22**
2	**3**	**680 - 700**	**0.7**	**11**

A case depth of TMT rebar w.r.t to cooling regime and chemical composition , In trial -1 , sample -1 was finished at low cooling regime having a higher case depth leads a higher YS and low UTS/YS Ratio but in sample -2 finished in high cooling regime leads a high UTS/YS ratio and less yield strength. As comparatively in trial -2 finished the material in high cooling regime (680 - 700°C) having a very less case depth equivalent to air cooled rebar leads a high UTS/YS ratio with required yield strength.

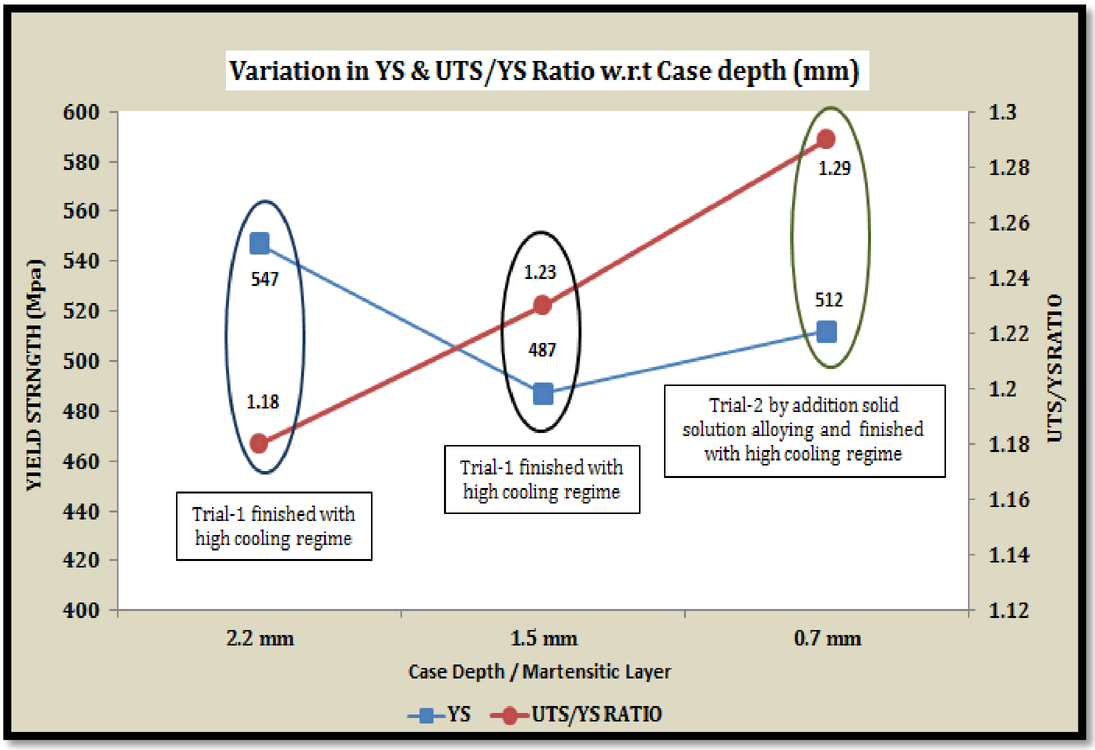


Fig – 5: Graphical plot of Mechanical Strength & UTS/YS Ratio with respect to case depth / Martensitic layer

The plot clearly shows that in Trial- 2 (by addition of substitutional element), the mechanical properties is obtained at higher side, much above the standard requirement while in Trial -1 (with microalloying element) the UTS/YS ratio is linearly increase with increasing cooling temperature but the obtained value of yield strength & UTS/YS ratio plot has not managed to touch the targeted line. Further this can be correlated that the addition of solid solution alloying elements has facilitated to achieve higher UTS/YS ratio.

Microstructure of Rebars

The polished samples of steels were etched to observe their microstructures under the optical microscope in large magnification. Microstructures of different zones (case, & core) of each trial were observed. The following figures present those structures of different steel bars.

Trial – 1 -

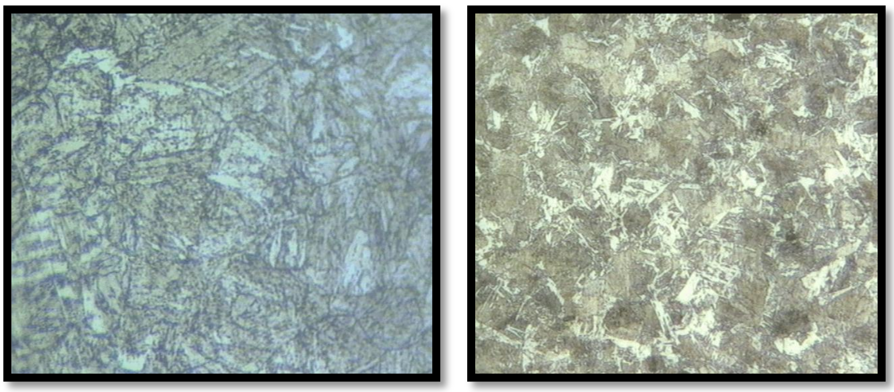


Fig: 6- (a) - Sample No.1, Cooling regime = 610 - 630°C

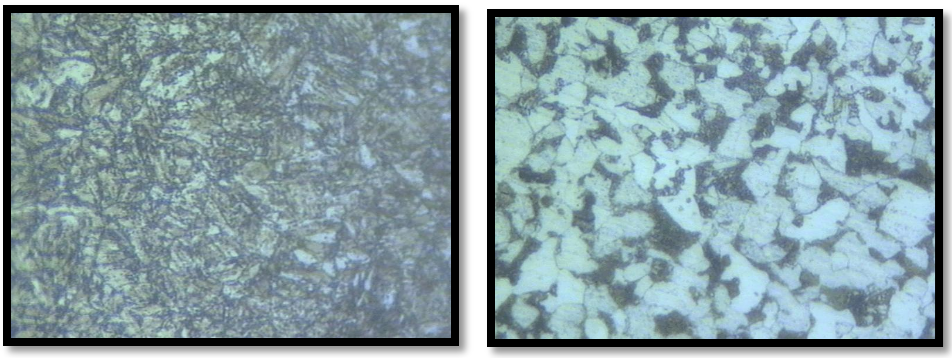


Fig: 6 (b) - Sample No.2, Cooling regime = 650 - 670°C

<u>Trial – 2 –</u>

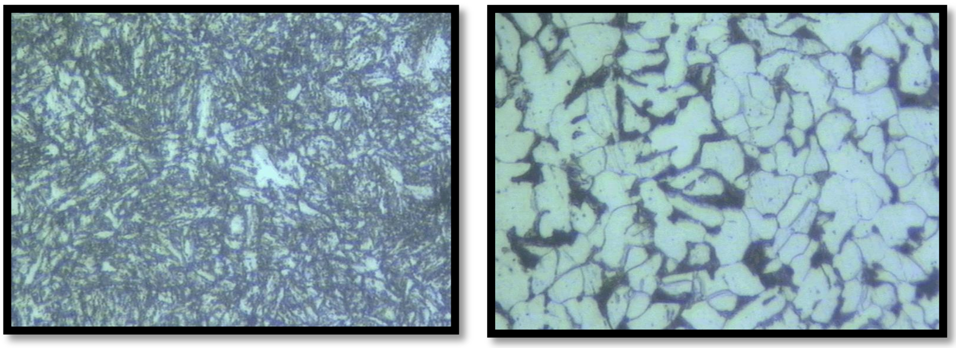


Fig: 6 (c) - Sample No.3, Cooling regime = 675 - 685°C

It is revealed that case areas of sample -1 are differing from the sample -2 & sample-3. However, in those areas, the microstructures are significantly different. In core areas, microstructure of steel 1 is composed of mixed grain structure which having fine ferrite with tempered martensite in steel. This significantly deviated from the standard TMT microstructures. In sample 2 & 3, the core microstructures should be fully composed of well-developed ferrite and pearlite grains but sample-3 (Trial-2) having acoarser ferrite grains compared to sample-2 (Trial-1, high cooling regime) and contribute higher UTS /YS Ratio.

Conclusion

From the above comprehensive analysis, it can be determined that adding the substitutional alloying elements and subsequent experiment with finished rolling temperature leads an optimum strength with desired UTS/YS ratio of >1.25.

1 – The subsequent experiment with is used to refine the microstructure by adjusting or optimize the finished quenching temperature and achieved a best equalizing martensitic layer by the slow cooling of bars.

2 - The steel is only microalloyed did not give the encouraging results; but by addition Si, P, Cr, Cu & Mn gives desired UTS/YS ratio with high mechanical strength.

With the proper control of alloy design, & final quenching temperatures, leads optimum strength with high UTS/YS ratio. The key to this success is a thorough understanding of the metallurgy involved, particularly the proper use of alloy designing & final quenching temperature.

These trials have helped in identifying the chemistry and process parameters that can result in the desired product (with specified UTS/YS Ratio>1.25). Considering the practical problem of processing material in high speed mill at a finishing quench temperature of 700°C, it is decided to further fine tune the chemistry so that commercial production can be started without adversely affecting the productivity of mill at economical price.

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