Process Flow

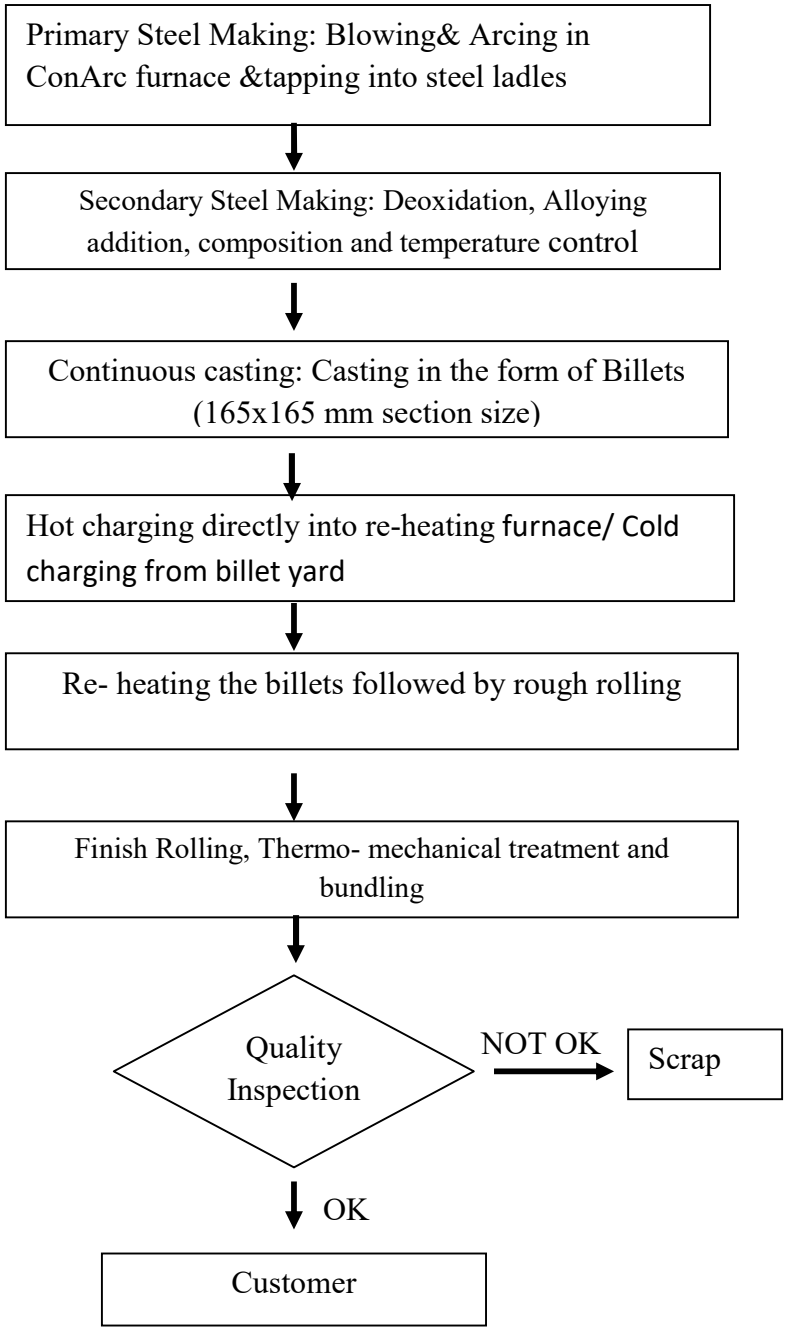
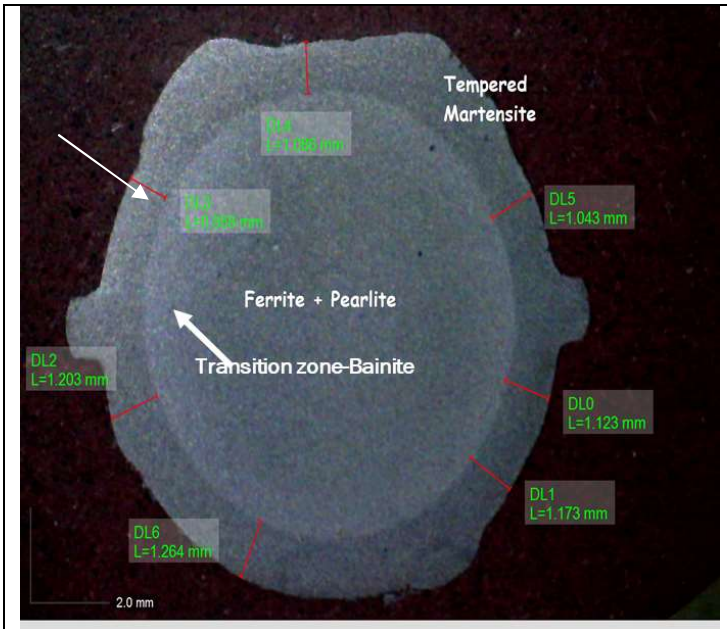
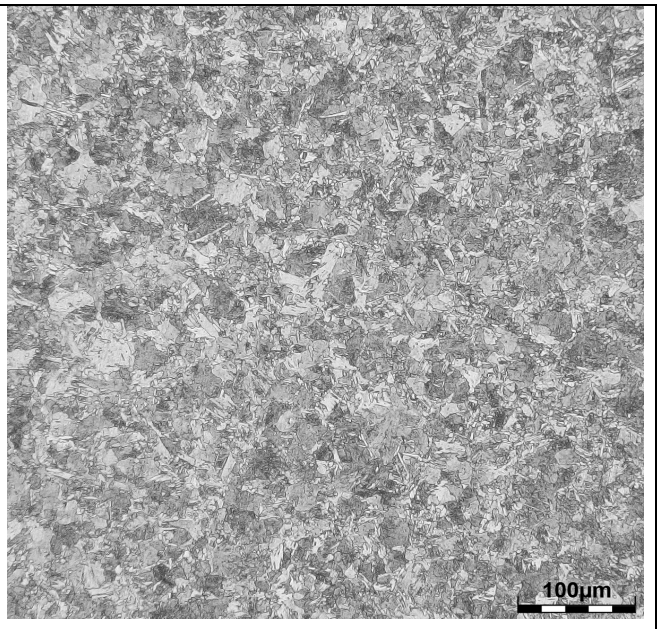


Figure 1

ANJAN SEN
(Applicants Agent of ANJAN SEN & ASSOCIATES)
IN/PA-199



(a) Macrostructure of invented TMT rebar (Ferrite +Pearlite Core, Tempered Martensite Rim and *Bainite Transition Zone*)



(b) Microstructure of core comprises ferrite +pearlite

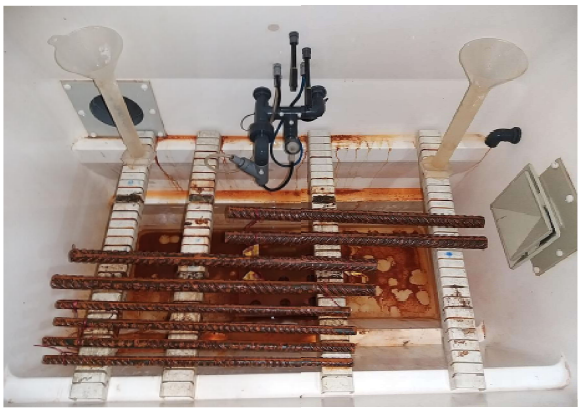
Figure 2

ANJAN SEN
(Applicants Agent of ANJAN SEN & ASSOCIATES)
IN/PA-199

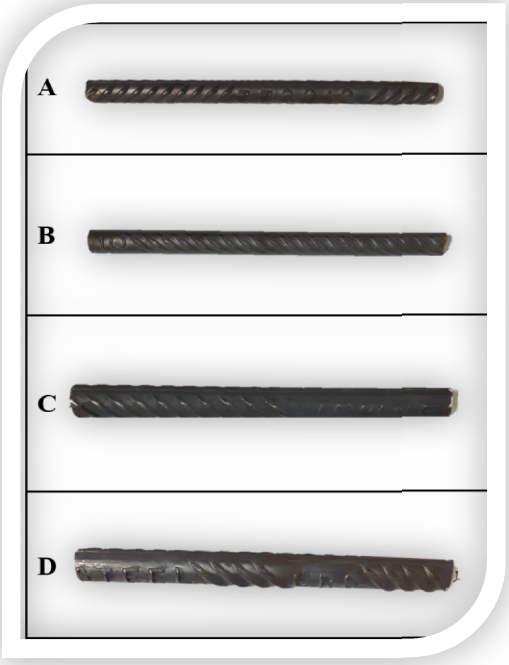
SALT SPRAY TEST (SST) SETUP

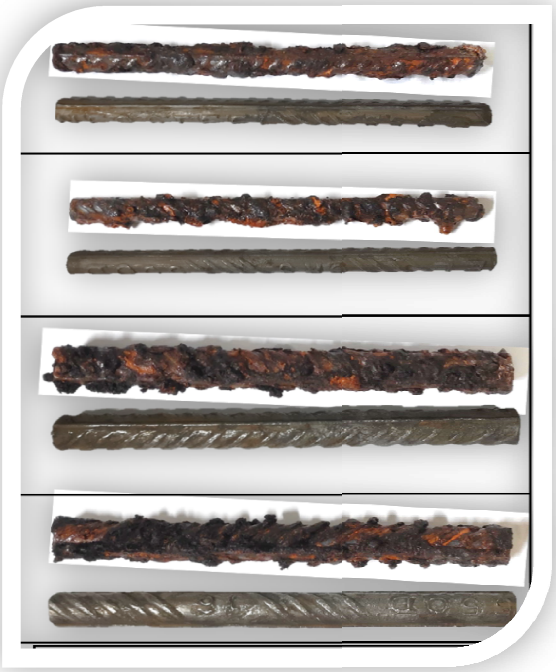


SALT SPRAY TEST (SST) SETUP



CRS AND NON-CRS TMT REBARS ON SALT SPRAY TEST BED





TMT Rebar samples before Salt spray test	TMT Rebar samples after 720 hrs Salt spray test

Figure 3

ANJAN SEN
(Applicants Agent of ANJAN SEN & ASSOCIATES)
IN/PA-199

Process Flow

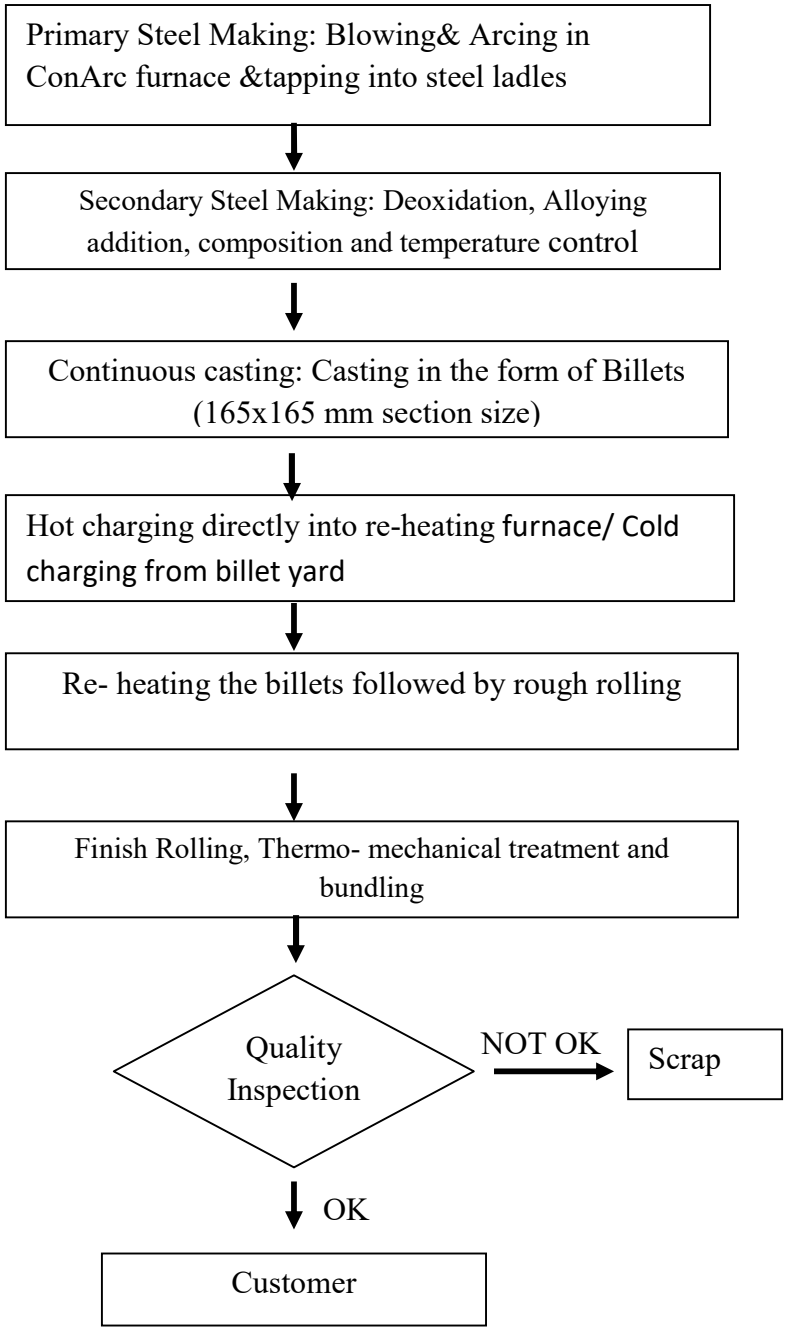
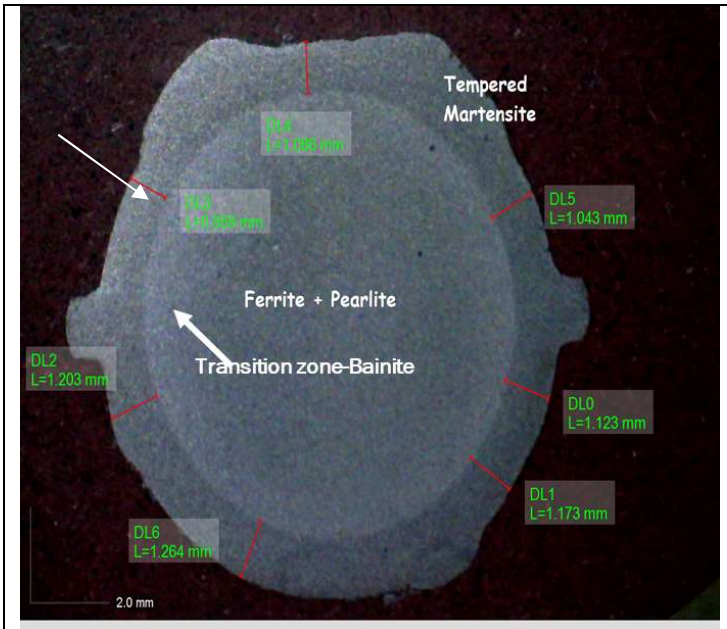
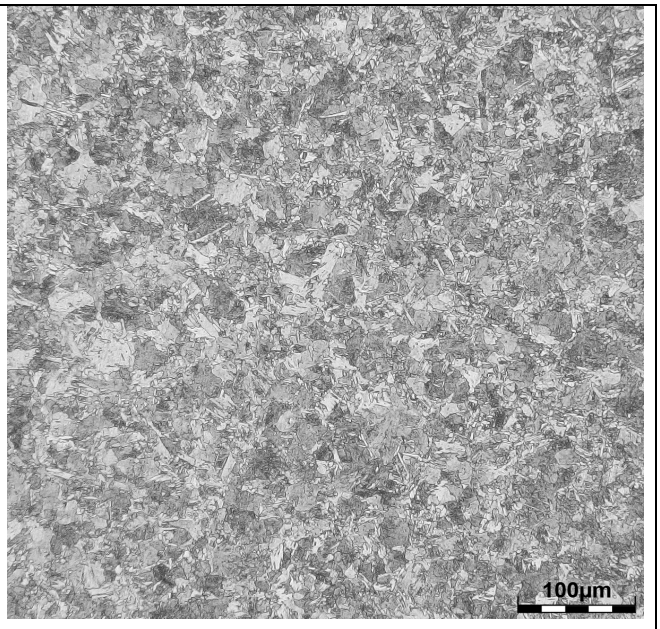


Figure 1

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(a) Macrostructure of invented TMT rebar (Ferrite +Pearlite Core, Tempered Martensite Rim and *Bainite Transition Zone*)



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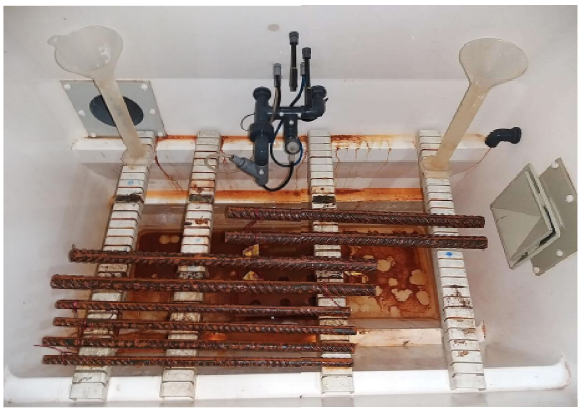
Figure 2

ANJAN SEN
(Applicants Agent of ANJAN SEN & ASSOCIATES)
IN/PA-199

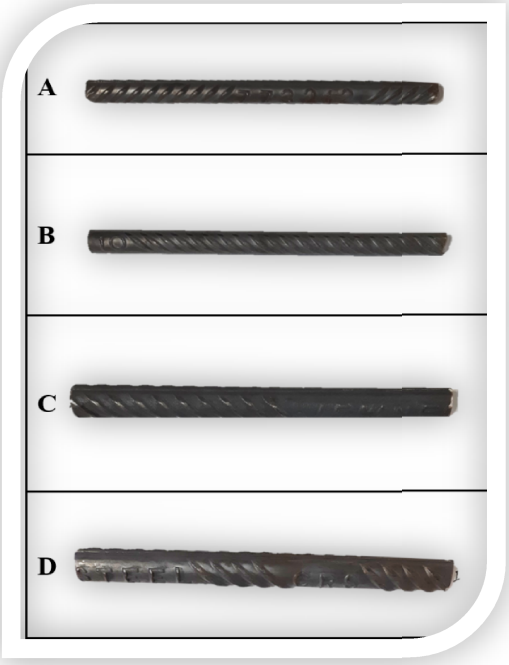
SALT SPRAY TEST (SST) SETUP

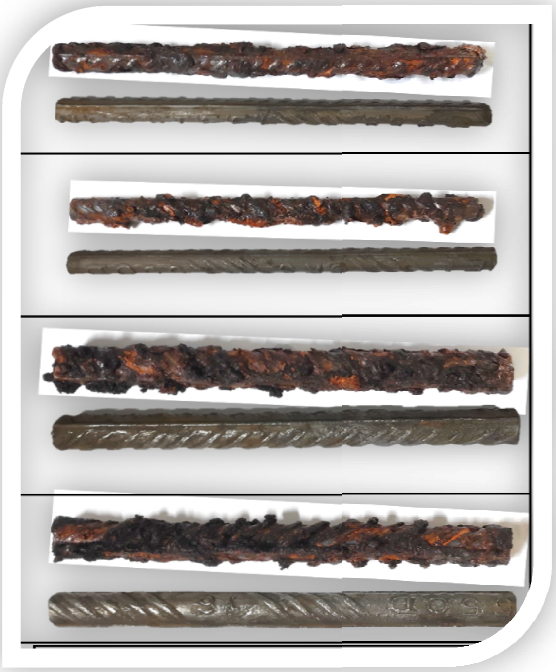


SALT SPRAY TEST (SST) SETUP



CRS AND NON-CRS TMT REBARS ON SALT SPRAY TEST BED





TMT Rebar samples before Salt spray test	TMT Rebar samples after 720 hrs Salt spray test

Figure 3

ANJAN SEN
(Applicants Agent of ANJAN SEN & ASSOCIATES)
IN/PA-199

FORM 2

THE PATENT ACT 1970
(39 OF 1970)
&
The Patent Rules, 2003

COMPLETE SPECIFICATION
(See Section 10 and Rule 13)

1 **TITLE OF THE INVENTION :**

HIGH STRENGTH HIGH DUCTILE THERMO-MECHANICALLY-TREATED (TMT) REBARS HAVING YIELD STRENGTH OF 550MPa(Min), HIGH CORROSION RESISTANCE INDEX (CRI)>=1.2, UTS/YS RATIO of 1.15 MINIMUM AND A PROCESS FOR ITS PRODUCTION.

2 **APPLICANT (S)**

Name : **JSW STEEL LIMITED;**

Nationality : An Indian Company.

Address : Dolvi Works, Geetapuram, Dolvi, Taluka Pen, Dist. Raigad, Maharashtra-402107,India; Having the Registered Office at JSW CENTRE,BANDRA KURLA COMPLEX,BANDRA(EAST), MUMBAI-400051, STATE OF MAHARASHTRA, INDIA.

3 **PREAMBLE TO THE DESCRIPTION**

COMPLETE

The following specification particularly describes the invention and the manner in which it is to be performed.

FIELD OF THE INVENTION:

Present invention relates to provide high-strength, extra ductile & corrosion-resistant Thermo-mechanically-treated(TMT) rebar having yield strength of 550MPa (Min) with total elongation >18%, elongation at maximum force (uniform elongation) >8% and UTS/YS ratio >=1.15 for reinforced concrete(RCC) application along with high **corrosion resistant Index(CRI)** of 1.20 min. More particularly, the present invention is directed to provide high-strength, corrosion resistant and high ductile TMT rebar of diameter 8-25mm conforming to IS 1786 Fe550D grade for concrete reinforcement application for corrosive environment, high seismic load condition and method of producing the same comprising selective uses of alloying elements such as Cu, Cr and the selective steps of water quenching and self-tempering. This can be produced in the form of straight bars and can be used for reinforcement in concrete and similar application. The high strength, extra ductile & corrosion resistant steel according to present invention is obtained by normal C-Mn steel composition with the addition of Chromium (Cr) & Copper (Cu) as a micro-alloy to achieve desired microstructure, mechanical properties and corrosion-resistant characteristics.

BACKGROUND OF THE INVENTION

Steel rebar are the backbone of any concrete reinforced construction segments. In RCC structure, steel rebar takes the tensile load whereas concrete takes the compressive load.Therefore, steel rebar is a vital material in any constructions whether they are high rise buildings, bridges or engineering projects.

The TMT rebar is produced by thermo mechanical treatment which includes, rolling through a sequence of rolling stands comprising roughing, intermediate, and finishing stands which progressively reduce the billet to the final size and shape of the reinforcing bar. In

the final rolling pass the bar is ribbed which leads to a good bonding between steel and concrete. The high strength and moderate elongation is achieved in TMT rebar by a process called QST (Quench & Self Tempering). After the hot rolling is finished the hot rebar is "Quenched" by passing through a series of water boxes which convert the surface layer of the bar to "Martensite" whereas the core remains as "Austenite". In the second stage of 'Self Tempering' when the bar leaves the water box with a temperature gradient through its cross section, the temperature of the core remains higher than that of the surface. This allows heat to flow from the core to the surface, resulting in tempering of the surface, giving a microstructure called 'Tempered Martensite' which is strong and tough as well. Upon cooling the core, the TMT rebar converts to (Ferrite + Pearlite) microstructure.

There are various loads which acts on a structure in different ways at different time includes dead load of the structure, live load on the structure, wind/storm load and seismic load. There are several regions in India which falls in the seismic zone II and III. To withstand sudden seismic load steel rebar must possess suitable mechanical properties such as high tensile to yield (UTS/YS) ratio and high elongation (both total and uniform). Although in BIS standard IS 1786:2008, there are seismic resistant rebar called Fe500S which is suitable for application in seismic zone IV & V, but there is no definite grade for application in seismic zone II & III. However, in BIS standard IS13920 (Ductile detailing of concrete reinforced structure), it is mandatory to have UTS/YS ratio of min 1.15. So with the rising incidence of earthquake, it is the need of the day to develop strong and ductile rebars which can withstand mild seismic load arising in zone II & III.

TMT rebar is naturally attacked by oxidizing agents like water & chlorides which corrode the steel and lead to the immature failure of the structure. The inherent corrosion-resistant characteristics which is

acquired by the formation of oxide layers of phosphorus, copper & chromium on surface, provides the protection to steel surface from such corrosive attack.

The allied properties- "Corrosion resistant" is achieved by addition of phosphorus, chromium and copper in the chemistry. These elements make a passive oxide layer on the steel surface which protects it from corrosion. However, with addition of Phosphorous (P), brittle phase Fe3P is formed which actually brittle in nature.

Evaluation of corrosion resistance index of TMT rebars is a non-standard method of corrosion resistance depiction using salt spray test, potentiodynamic polarisation test or sulphur dioxide test etc. Corrosion resistance Index (CRI) is defined as the ratio of corrosion rate of CRS grade and the corrosion rate of normal non CRS grade. The corrosion rate is measure by standard salt spray test and under two different conditions such as marine environment and polluted marine environment. For marine environment, the samples of TMT rebars are loaded in salt spray test chamber and 3.5% NaCl solution is sprayed on samples in the form of fog for the test duration of 72 hrs and 720 hrs. Similarly, for polluted marine marine environment test, samples from TMT rebars are loaded in salt spray chamber with 3.5 wt.% NaCl+ 0.01M NaHSO3 solution for 72 hrs. Amount of weight loss due to corrosion is then calculated from the initial and final weight difference of tested TMT rebars. Corrosion rate is then calculated as per the formula $\mathbf{Corrosionrate} = \mathbf{K} \times \mathbf{WA} \times \mathbf{T} \times \mathbf{D}\mathrm{mmpy}$. Corrosion resistance Index (CRI) is then calculated as (Corrosion rate of non−CRS TMT)/(Corrosion rate of CRS TMT). Where, K is 8.76x10^4 mm/year, W is weight loss in gms, A is area in cm2, T is time of exposure in hrs, D is density (7.85 g/cm3)

As per IS 1786:2008, there are several grades of high strength deformed steel bars for various applications in construction field. Depending upon the requirement of mechanical properties (mainly yield strength, YS), grades are designated as Fe415, Fe500, Fe550, Fe600, Fe650 and Fe700 (numbers such as 415, 500 etc. denote the minimum YS requirement) grades.
Fe550D is the grade incorporated in IS 1786:2008 to provide higher strength rebar for concrete reinforcement application. The required mechanical properties of IS 1786:2008 Fe550D are as follows:

YS: 550MPa (Min)

UTS / YS ratio: ≥ 1.08

Total Elongation>=14.5%

Uniform Elongation i.e elongation at maximum force >=5%

But no such grade is presently available in high strength, extra ductile as well as high Corrosion resistant for application in highly corrosive environment and seismic zone II and III.

The present invention is thus directed to develop a high strength equivalent to IS 1786: 2008 Fe550D grade in C-Mn steel with addition of Cu and Cr for enhanced corrosion resistance, strength and ductility. Its processing involves alloy design, suitable water quenching + self-tempering after thermo-mechanical rolling to achieve desired microstructure along with specified range of YS, UTS, UTS/YS ratio and elongation properties. This steel is named as Fe550D EDS-CRS (Extra Ductile Steel-Corrosion Resistant Steel) comprise following properties:
YS >=550 MPa
UTS/YS ratio >=1.15
% Total Elongation >=18 %
%Uniform Elongation >=8%
CRI>=1.20

OBJECTS OF THE INVENTION

The basic object of the present invention is directed to provide high strength, high ductility along with good Corrosion resistant TMT Rebars with minimum of 550 MPa, yield strength and UTS/YS ratio greater than 1.15 with minimum total elongation of 18 percent and minimum uniform elongation of 8 % and CRI greater than 1.20conforming to IS 1786 Fe 550Dand IS 13920 grade for construction applications and a method of its production.

Another object of the present invention is to provide a process of producing the said grade of reinforced steel rebar following selective chemical elements such as C-Mn steel with Cu,Cr micro alloying and selective process steps and parameters to achieve desired microstructure to ensure the required corrosion resistant, strength and ductility as per the applicable standard.

A still further object of the present invention is to provide a process of producing the said grade of reinforced steel rebar within the same set up such as mill speed and with minor adjustment in water flow so that mill set up is not hampered.

A still further object of the present invention is to provide a process of producing the said grade of reinforced steel rebar wherein billets casted to 165mm x 165 mm from steel melting shop are reheated in the reheating furnace and are subjected to different reduction ratios up to final diameter of 8-25 mm as per customer requirement in the Bar Rod Mill.

A still further object of the present invention is to provide a process of producing the said grade of reinforced steel rebar wherein selection of proper chemistry within BIS specification with combination of controlled cooling is the key to achieve the high yield strength along

with specified range of UTS/YS, minimum total elongation and uniform elongation.

SUMMARY OF THE INVENTION

The basic aspect of the present invention is directed to provide a high strength, extra ductile with corrosion-resistant thermo-mechanically treated(TMT) steel rebar having steel composition comprising by weight%:

C : 0.15-0.25%, preferably 0.20-0.23%;

Mn: 0.5- 1.0%, preferably 0.90-1.00%;

S: upto 0.04% max, preferably 0.007-0.020%;

P: upto 0.04% max, preferably 0.010-0.020%;

Si: 0.10-0.30%, preferably 0.15-0.20%;

Cr: 0.2-0.5 %, preferably 0.20-0.25%;

Cu: 0.2-0.5%, preferably 0.32-0.37%;

N: upto 0.012% max preferably 0.004 to 0.008 % and balance Fe,

having improved ductility, a microstructure of an outer peripheral tempered Martensite layer and a core of Ferrite and Pearlite structure with high YS>550 MPa min, preferably in the range of 570-650 MPa and UTS/YS>=1.15min, preferably 1.15-1.20 with total Elongation >=18 %min, preferably 18-21% and uniform elongation >=8%min, preferably 8-10% and **Corrosion Resistance Index (CRI)**>=1.2

A further aspect of the present invention is directed to said high strength high ductile thermo-mechanically treated(TMT) steel rebar comprising %Cr (0.20-0.25) and %Cu(0.32-0.37) as alloying elements for improved ductility and corrosion resistance of the steel at high strength in the range of YS 570-650 MPa, UTS 680-760 MPa, UTS/YS ratio 1.15-1.20, total elongation 18-21 % and uniform

elongation 8 to 10 %,and provide passive oxide layer resulting in better corrosion resistance (CRI>=1.20) as compared to normal TMT rebar.

Another aspect of the present invention is directed to said high strength thermo-mechanically treated(TMT) steel rebar wherein said rebar having diameter in the range of8-25mm.

A further aspect of the present invention is directed to a process for manufacture of high strength thermo-mechanically treated(TMT) steel rebar as described above comprising:

(i) providing said Cr and Cu microalloyed steel having composition in wt % comprising:

C : 0.15-0.25%, preferably 0.20-0.23%;

Mn: 0.5- 1.0%, preferably 0.90-1.00%;

S: up to 0.04% max, preferably 0.007-0.020%;

P: upto 0.04% max, preferably 0.010-0.020%;

Si: 0.10-0.30%, preferably 0.15-0.20%;

Cr: 0.2-0.5 %, preferably 0.20-0.25%;

Cu: 0.2-0.5%, preferably 0.32-0.37%;

N: up to 0.012% max preferably 0.004 to 0.008 % and balance Fe,

and continuously casting into billets;

(ii) subjecting said billets to processing including reheating in furnace, rough rolling and bar rod rolling in stages and water quenching and self-tempering for generating a controlled microstructure of a controlled peripheral tempered martensite and a ferrite-pearlite structure in the corehaving high YS>550 MPa in the range of 570 to 650 MPa and UTS/YS>1.15 in the range of1.15to 1.20with minimum 18% elongation in the range of 18 to 21% and uniform elongation 8% min in the range of 8 to 10%;

and

(iii) Enabling better corrosion resistance (CRI>=1.20)as compared to normal TMT rebar by adding Cu and Cr.

A still further aspect of the present invention is directed to said process comprising(i) providing said steel produced through primary steel making in ConArc furnace/LD converter followed by ladle heating, having composition in wt % comprising:

C : 0.15-0.25%, preferably 0.20-0.23%;

Mn: 0.5- 1.0%, preferably 0.90-1.00%;

S: up to 0.04% max, preferably 0.007-0.020%;

P: upto 0.04% max, preferably 0.010-0.020%;

Si: 0.10-0.30%, preferably 0.15-0.20%;

Cr: 0.2-0.5 %, preferably 0.20-0.25%;

Cu: 0.2-0.5%, preferably 0.32-0.37%;

N: up to 0.012% max preferably 0.004.. to 0.008 % and balance Fe,

and continuously casting into billets;

(ii) subjecting said billets to processing including reheating in furnace, rough rolling and bar rod rolling in stages and controlled water quenching and self-tempering following thermo mechanical treatment to generate said peripheral tempered martensite and a ferrite-pearlite structure in the core;

(iii) controlling said peripheral tempered Martensite layer thickness maintaining normal water flow rate under controlled quenching and tempering.

A still further aspect of the present invention is directed to said process wherein said peripheral tempered Martensite layer is formed free of any need for much altering the normal/conventional water flow in said water quenching.

A still further aspect of the present invention is directed to said process wherein said step of controlled water quenching includes quenching in water boxes with water flow rate in the range of 1000-2000 m^3/Hr depending on diameter of the rebar and said self-tempering comprise temperature in the range of 550-610°C.

A still further aspect of the present invention is directed to said process comprising said bar rod rolling is carried out involving the operating parameters comprising:

Furnace temperature (soaking) in the range of 1000-1070^{0}C;
Finishing rolling temperature < 1000^{0}C; and
Cooling bed temperature in the range of 550-610^{0}C;
Controlled cooling involving thermo-mechanical treatment under water flow in the range of 1000-2000m^3/hr for cooling in water box according to the diameter of the rebar.

The above and other objects and advantages of the present invention are described hereunder in greater details with reference to following accompanying non limiting illustrative drawings.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

Figure 1: Process flow chart for Fe550DEDS-CRS grade steel rebars according to present invention.

Figure 2: Comparative illustration of Macrostructure of the inventive high strength TMT rebars of Fe 550DEDS-CRSgrade steel having Cu and Cr as micro alloying element with improved corrosion resistance and ductility i.e. high UTS/YS ratio, total elongation and uniform elongation.

Figure 3: Salt Spray test set up and TMT Rebar samples before and after the test.

DETAILED DESCRIPTION OF THE INVENTION WITH REFERENCE TO ACCOMPANYING DRAWINGS

The present invention is directed to provide high strength TMT rebars conforming to IS 1786 Fe550Dgrade and IS 13920 standard with minimum of 550 MPa yield strength with minimum UTS/YS ratio 1.15, Total elongation >=18%, uniform elongation >=8% and Corrosion resistance index >=1.2 for concrete reinforcement application and method of producing the same. It is already known that with increasing yield strength ductility i.e. total elongation and uniform elongation decreases. Also in smaller diameter UTS/YS ratio decreases as YS tends to be on higher side n lower diameter. It is understood through various research that Yield strength (YS) of rebar depends more on thickness & strength of the tempered martensite rim whereas Ultimate tensile strength (UTS) and ductility depends upon the core microstructure and strength. So to improve the ductility and UTS/YS ratio, control of martensite rim thickness and strengthening of core with high hardness needs to be done. The hardness of the core can be little increase by addition of hardening elements such as Cu and Cr so that acicular ferrite and fine pearlite may be formed at the core.

The present invention relates to development of high strength, Corrosion resistance, high ductile TMT rebar complying to Fe550D in C-Mn steel with the addition of Cu and Cr, suitable water quenching & self-tempering after thermo mechanical rolling. The billets casted to 165mm x 165 mm from steel melting shop are reheated in the reheating furnace and are subjected to different reduction ratios up to final diameter as per customer requirement in the Bar Rod Mill. Selection of proper chemistry within BIS specification with combination

of controlled cooling is the key to achieve high strength along with high ductility even at lower diameter.

This new steel reinforced grade is made through ConArc furnace steel making and Ladle Heating Furnace (LHF) route. It is further cast into billets through continuous casting process. These billets are processed through reheating furnace and Bar Rolling Mill(BRM) followed by controlled Quenching. The hot rolled reinforced bars are inspected manually. Samples are collected from the bars. These samples are tested in laboratory for cleanliness of steel and mechanical properties.

Normally in TMT rebar, the strength is achieved by the peripheral tempered martensitic rim developed by fast water quenching in the water boxes and self-tempering in the cooling bed and ductility is achieved by ferrite-pearlite structure in the core. Martensite rim thickness increases with the increased water flow or by increase in the retention time in the water box or by decreasing the speed of the bar. More is the martensite rim thickness, more is the yield strength and less is the ductility (total elongation and uniform elongation) because of this hard martensite phase. To increase the uniform elongation, martensite layer thickness should be decreased which results in decrease of the yield strength. In this invention, the martensite thickness is optimized to get best properties in terms of elongation and uniform elongation. Also the P is used with very low quantity (<0.04) helps to reduce the brittleness which is due to formation of Fe3P.

Accordingly, the C-Mn steel composition with Cu and Cr as micro alloying element of new reinforced bar grade in weight % selected for the present invention is as presented in following table 1:

Table 1: (Composition in wt%)

C	Mn	S max.	P max.	Si	Cr	Cu	N max.

0.15-0.30	0.5-1.0	0.04	0.04	0.1-0.3	0.2 upto 0.5	0.2 upto 0.5	0.012

The balance is Fe and unavoidable impurities.

This combination of chemical composition and water flow gives YS>550 MPa, % UTS/YS ratio >=1.15, and total elongation>=18%, Uniform elongation >= 8% and Corrosion Resistance Index >=1.2

Now, the essential components of the steel grade for high strength TMT rebars according to present invention are described hereinafter with reasoning for selecting the respective concentration range in weight percent.

Carbon (C) :0.15% or more and less than 0.25% by weight

Carbon is an essential strengthening element that provides strength and hardness to steel further maintains ferrite and pearlite structure in the core. Strengthening from Carbon generally happens in two ways either by solid solution in austenite/ferrite phase or by formation of carbides(Fe3C) or Carbonitrides with microalloying elements such as Nb, V, Ti.

The carbon content needs to be more than 0.15wt% so that increased Carbon content will increase the hardness of tempered martensite and hence high YS will be achieved. Moreover, the hardenability of the steel increases with the increase in carbon content. The carbon content needs to be less than 0.25 as increased C content will reduce the ductility. The carbon content needs to be below 0.25% following (i) IS 1786 Fe550D standard requirement and also, (ii) Weldability will be poor. Accordingly, C content is kept in the range of 0.20-0.23

Silicon (Si): 0.10% or more and less than 0.30% by weight

Silicon is added as de-oxidizer for purity of Steel and has a strong solid solution strengthening effect. It retards softening during tempering and thus aids in the removal of quenching stresses without appreciable decrease in hardness.

Silicon needs to be contained within 0.30 % as excess of Silicon will deteriorate the surface quality of the rebar by making sticky scale during reheating of billet and difficult to remove during descaling. Also for better castability, Mn/Si to be maintained more than 3.5. Accordingly, the Si content is kept 0.10-0.5, preferably 0.20-0.25 % by weight.

Manganese (Mn): 0.5% or more and 1.0% or less by weight

Mn acts as solid solution strengthener. Further Manganese improves hardenability and access to critical alloying elements forming precipitate and acts pearlite stabilizer. Hence to ensure required strength, Mn content is kept as 0.5 % minimum. Increasing Mn content will increase the cost of the production. Also increased Mn has a high tendency of segregation so its content should not be very high. In this present invention, Mn content is kept as 0.65-0.75%

Phosphorus (P): 0.04% max or less by weight

Phosphorus acts as solid solution strengthener and improves the shape-forming workability of the steel, such as rib forming in rebars. But Phosphorous, when added in large amount deteriorates the toughness and weldability by formation of brittle phase Fe3P. In addition, the segregation of phosphorus at grain boundaries has been found to result in brittleness of the steel bar. For these reasons, the upper limit of phosphorus content in the present steel composition is kept as 0.04%wt by weight maximum. This is also requirement of IS1786 Fe550D grade. P is kept in the range of 0.010-0.020 %

Sulphur (S): 0.04% max or less by weight

As per standard requirement, sulfur content should not exceed 0.04%. It also causes hot shortness to the steel. Accordingly, the S content is restricted to less than 0.04% by weight. S is kept in the range of 0.007-0.020 %

Nitrogen (N): not more than 0.012% by weight

Nitrogen acts as solid solution strengthener. It also combines with micro alloy such as Nb/V/Ti to form Nitride/ Carbonitride precipitates and thus increase strength. Excess nitrogen causes a large amount of nitride to precipitate, thereby deteriorating ductility and hardenability and induces the phenomenon of room temperature ageing, which will cause the change of the mechanical properties of the steel and the restoration of the yield point elongation of the steel. Therefore, the amount of nitrogen should be no more than 0.012%. This is also requirement of IS1786 Fe550D grade.

Copper (Cu) :0.2or more and less than 0.50% by weight

Copper is an element that improves the atmospheric corrosion resistance of the structural steel material by formation stable oxide layer at the surface which restricts the non-uniform corrosion. Maximum limit is restricted because of cost. In this present case copper is added intentionally in the range of 0.32-0.37 range.

Chromium (Cr): 0.3% max by weight

Chromium increases the hardenability and increase the strength/hardness of core by formation of acicular ferrite / fine pearlite structure. Also Chromium increases the corrosion resistance and oxidation resistance. In this present case chromium is added intentionally and its maximal limit is restricted to 0.30% because of the cost. Cr is added in the range of 0.20-0.25%

Details of the process of manufacturing:

A high strength reinforcement steel having the composition described above is prepared by obtaining molten steel through primary & secondary steel making, followed by continuous casting in billets. To produce a high strength reinforcement steel having desired properties, the billet is subjected to reheating, descaling, rough rolling, bar rod rolling and thermal mechanical treatment, details of which will be described hereinafter.

The process route followed to produce the high strength TMT Rebars according to present invention comprising the steps of:

a) Primary Steel Making by ConArc or similar furnace

b) Secondary steel making: Ladle Heating Furnace.

c) Continuous billet of casting into (165mm x 165 mm) sections

d) Re-heating, bar rod rolling, controlled cooling and cut to length with set optimum processing parameters.

Accompanying **Figure 1** illustrates the process flow chart for producing Fe550D grade TMT Rebars according to present invention.

The Bar rod rolling parameters specified for processing are presented in the following Table 2:

Table 2:

1	Furnace Temperature (Soaking)	1000-1050 °C
2	Finish Rolling Temperature	< 1000 °C
3	Controlled cooling	Thermo Mechanical Treatment
4	Cooling bed Temperature	550-610 °C

The material specifications of the TMT Rebars produced according to above process of present invention in supply conditions are as presented in the following

Table 3:

1	Chemical Composition	As per Table 1
2	Rebar Diameter	8-25 mm
4	Yield Strength	550 MPa min (570-650 MPa)
5	UTS	680-760 MPa
6	UTS/YS	>=1.15 (1.15-1.20)
7	%Total El	>18% (18-21%)
8	%Uniform El	>8% (8.0-10.0%)
10	Bend Test	OK
11	Rebend Test	OK
112	Microstructure	Tempered Martensite + (Ferrite + Pearlite)

Trials were conducted with various steel composition with the Fe550D grade as per Table 4 (with or without Cr addition). According to present invention and the comparison of Normal and Invented Chemistry and Mechanical properties are presented in the following Table 4 wherein the samples marked as "invented" in remarks column conform to the specification and properties according to IS 1786 Fe550D grade:

Table 4:-

Chemistry (Wt %):

%C	%Si	%S	%P	%Mn	%Cr	%Cu	N2 ppm	Remarks
0.211	0.20	0.015	0.018	0.71	-	-	55	Conventional (Non CRS)
0.231	0.173	0.016	0.009	0.61	0.35	0.25	55	Conventional (CRS)
0.23	0.18	0.012	0.004	1.0	0.20	0.32	54	Invention
0.21	0.20	0.014	0.015	0.95	0.23	0.35	58	Invention

0.20	0.18	0.010	0.012	0.97	0.23	0.33	51	Invention

Mechanical Properties:

Dia	YS, MPa	UTS, MPa	UTS/YS ratio	% Total El	% Uniform El	CBT, Deg C	Remarks
8	657	735	1.12	17.8	7.8	580-590	Conventional (Non CRS)
10	645	729	1.13	17.5	7.4	580-590	
12	630	720	1.14	17.3	7.2	570-580	
16	640	730	1.14	17	7	560-570	
8	627	720	1.15	18.4	8.23	600-610	Conventional (CRS)
10	619	712	1.15	18.4	8.36	590-600	
12	610	706	1.16	18.7	8.28	580-590	
16	621	713	1.15	18.7	7.81	570-580	
8	590	695	1.18	18.1	8.4	570-590	Invention
8	*595*	*690*	*1.16*	*18.1*	*8.3*	*570-590*	
10	590	695	1.18	18.1	8.2	570-590	
10	*600*	*699*	*1.16*	*18.1*	*8.1*	*570-590*	
12	593	676	1.16	18.3	8.1	570-580	
12	*585*	*690*	*1.18*	*18.2*	*8.2*	*570-580*	
16	622	718	1.16	18	8.2	550-580	
16	*620*	*725*	*1.17*	*18.1*	*8.1*	*550-580*	

Corrosion Properties (Salt Spray Test)-

CRI (Corrosion rate of CRS grade /Corrosion rate of Non CRS grade)	Marine Environment 3.5% NaCl				Polluted Marine Environment (**(3.5 wt.% NaCl+ 0.01M NaHSO3)**	
	72 Hrs		720 Hrs		72 Hrs	
	Corrosion rate	CRI	Corrosion rate	CRI	Corrosion rate	CRI

	(mmpy)					
Conventional – Non CRS	*0.231*	-	*1.81*		*1.239*	
Conventional CRS	*0.211*	1.09	*1.77*	1.02	*1.214*	1.02
Invented CRS	*0.165*	1.40	*1.50*	1.21	*1.032*	1.20

Mechanical Tests, Corrosion Tests and Metallography

The tensile properties (yield strength and ultimate tensile strength) are measured using 600 mm long and gauge length = 5 d (where d is the nominal diameter of the rebar) test specimens on a universal testing machine. Bend and rebend tests are also conducted as per the standard requirement of IS1786. All tests are performed at room temperature.

Effects of marine environment on corrosion of steel is usually evaluated using salt spray test. It is thus possible by way of the present invention to provide high Corrosion resistance index >= 1.2 by adding small amount of Cu and Cr in C-Mn steel that is processed through controlled rolling, thermo-mechanical treatment involving selectively the steps of water quenching and self-tempering

Metallographic analysis is carried out to rate the cleanliness of steel. Metallographic samples prepared are polished and etched with 5% nital. A simple light optical microscope is used to record the core and outer microstructure of the rebar.

Accompanying Figure 2(a) shows the microstructure of invented steel rebar having peripheral tempered martensite rim of thickness in the range of 0.50mm to 1.50mm, and (b) ferrite plus pearlite core having distribution by volume of 75 to 80% ferrite and rest pearlite in core.

Referring to Figure 3, the photographs showing condition of TMT rebar after salt spray test and the difference can be found out after taking the weight loss and calculate the corrosion rate which is given in Table 4.

It is thus possible by way of the present invention to provide high strength , high ductile Thermo-mechanically-treated(TMT) rebars having yield strength of 550MPa (Min) conforming to IS 1786 Fe550D grade with UTS/YS ratio >=1.15(IS 13920 requirement), total elongation >=18%, uniform elongation >=8 % and Corrosion resistance index >= 1.2 for concrete reinforcement application under high tensile load and seismic condition and method of producing the same comprising providing normal C-Mn steel composition with the addition of Copper(Cu) and Chromium(Cr) as micro alloying element that is processed through controlled rolling, thermomechanical treatment involving selectively the steps of water quenching and self-tempering to achieve optimum microstructure to ensure desired strength and elongation properties.

We Claim:

1. A high strength thermo-mechanically treated(TMT) steel rebar having steel composition comprising by weight%:

C : 0.15-0.25%, preferably 0.20-0.23%;
Mn: 0.5- 1.0%, preferably 0.90-1.00%;
S: up to 0.04% max, preferably 0.007-0.020%;
P: upto 0.04% max, preferably 0.010-0.020%;
Si: 0.10-0.30%, preferably 0.15-0.20%;
Cr: 0.2-0.5 %, preferably 0.20-0.25%;
Cu: 0.2-0.5%, preferably 0.32-0.37%;
N: up to 0.012% max preferably 0.004.. to 0.008 % and
balance Fe,

having a microstructure of an outer peripheral tempered Martensite layer and a core of Ferrite and Pearlite structure with high YS>550 MPa in the range of .570. to 650..and UTS/YS>1.15 in the range of 1.15.. to 1.20..with minimum 18% elongation in the range of 18 to 21%, uniform elongation 8% min in the range of 8 to 10% and Corrosion resistance index >= 1.2.

2. The high strength thermo-mechanically treated(TMT) steel rebar as claimed in claim 1 comprising %Cr(0.20-0.25) and %Cu (0.32-0.37%) as alloying elements favouring ductility and corrosion resistance of the steel at high strength in the range of YS 570-650 MPa, UTS 680-760 MPa, UTS/YS ratio 1.15-1.20, total elongation 18-21%, uniform elongation 8 to 10 %and Corrosion resistance index >= 1.2.

3. The high strength thermo-mechanically treated(TMT) steel rebar as claimed in anyone of claims 1 to 2 of diameter in the range of 8-25 mm.

4. A process for manufacture of high strength thermo-mechanically treated(TMT) steel rebar as claimed in claims 1 to 3comprising:

(i) providing said steel composition in wt % comprising:

C : 0.15-0.25%, preferably 0.20-0.23%;

Mn: 0.5- 1.0%, preferably 0.90-1.00%;

S: up to 0.04% max, preferably 0.007-0.020%;

P: upto 0.04% max, preferably 0.010-0.020%;

Si: 0.10-0.30%, preferably 0.15-0.20%;

Cr: 0.2-0.5 %, preferably 0.20-0.25%;

Cu: 0.2-0.5%, preferably 0.32-0.37%;

N: up to 0.012% max preferably 0.004 to 0.008 % and balance Fe, and continuously casting into billets;

subjecting said billets to processing including reheating in furnace, rough rolling and bar rod rolling in stages and water quenching and self-tempering for generating a controlled microstructure of a peripheral tempered martensite and a ferrite-pearlite structure in the core having high YS>550 MPa in the range of 570 to 650MPa and UTS/YS>1.15 in the range of 1.15 to 1.20 with minimum 18% elongation in the range of 18 to 21% uniform elongation 8% min in the range of 8 to 10% and Corrosion resistance index >= 1.2.

5. The process as claimed in claim 4 comprising producing corrosion resistant said high strength steel rebars involving:

(i) providing said Cu and Cr added steel produced through primary steel making in ConArc furnace/LD converter followed by ladle heating, having composition in wt % comprising:

C : 0.15-0.25%, preferably 0.20-0.23%;
Mn: 0.5- 1.0%, preferably 0.90-1.00%;
S: up to 0.04% max, preferably 0.007-0.020%;
P: upto 0.04% max, preferably 0.010-0.020%;
Si: 0.10-0.30%, preferably 0.15-0.20%;
Cr: 0.2-0.5 %, preferably 0.20-0.25%;
Cu: 0.2-0.5%, preferably 0.32-0.37%;
N: up to 0.012% max preferably 0.004 to 0.008 % and balance Fe, and continuously cast into billets;

(ii) subjecting said billets to processing including reheating in furnace, rough rolling and bar rod rolling in stages and controlled water quenching and self-tempering following thermo mechanical treatment to generate said peripheral tempered martensite and a ferrite-pearlite structure in the core

(iii) controlling said peripheral tempered Martensite layer thickness maintaining normal water flow rate under controlled quenching.

6. The process as claimed in claims 4or 5wherein said peripheral tempered Martensite layer is formed free of any need for altering the normal/conventional water flow in said water quenching.

7. The process as claimed in anyone of claims 4 to 6 wherein said step of controlled water quenching includes quenching in water boxes with water flow rate in the range of 1000-2000 m^3/Hr depending on

diameter and said self-tempering comprise temperature in the range of 550-610°C.

8. The process as claimed in anyone of claims 4 to 7 comprising said bar rod rolling is carried out involving the operating parameters comprising:

Furnace temperature (soaking) in the range of 1000-1060^{0}C;
Finishing rolling temperature < 1000^{0}C; and
Cooling bed temperature in the range of 550-610°C;
Controlled cooling involving thermo-mechanical treatment under water flow in the range of 1000-2000m^3/hr for cooling in water box according to the diameter of the rebar.

Dated this 5th day of January, 2024

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ABSTRACT

TITLE: HIGH STRENGTH HIGH DUCTILE THERMO-MECHANICALLY-TREATED(TMT) REBARS HAVING YIELD STRENGTH OF 550MPa(Min), HIGH CORROSION RESISTANCE INDEX (CRI) >=1.2, UTS/YS RATIO of 1.15 MINIMUM AND A PROCESS FOR ITS PRODUCTION.

Present invention relates to provide high strength high ductile Thermo-mechanically-treated(TMT) rebars having yield strength of 550MPa (Min), conforming to IS 1786 Fe550D grade with high UTS/YS ratio>=1.15, total Elongation>=18%, Uniform Elongation>=8% and High Corrosion Resistance (CRI) >=1.2 for concrete reinforcement application under high tensile and seismic load condition and method of producing the same comprising selectively the steps of chemistry design, water quenching and self-tempering. The high strength along with high ductility of the said steel rebars according to present invention is obtained by normal C-Mn steel composition with the addition of Cu and Cr as alloying elements subjected to selective processing involving water quenching and self-tempering to have optimum tempered martensite at periphery and to achieve desired ferrite-pearlite microstructure at core favoring desired mechanical properties including high strength and high ductility. The TMT bars can be produced in the form of straight bars and can be used for reinforcement in concrete and similar application.

(Figure 1)