ABSTRACT

TITLE: HIGH STRENGTH (YS : 640 MPa Min.) THERMO MECHANICALLY TREATED (TMT) BAR AND A PROCESS FOR ITS PRODUCTION.

The present invention relates to developing high strength (YS:640MPa Min.) Thermo Mechanically Treated (TMT) bar and a process for its production. The TMT bars of the invention is having yield strength above 640MPa, UTS/YS ratio of 1.15 Min., with super toughness (18% elongation Min.) properties of said TMT rebars through selective alloy design and optimizing process parameters. The alloy design comprising C-Mn chemistry wherein manganese content of steel is maintained in the range of 0.8-1.3 wt %, and no micro-alloying element is added so that cost of production remains competitive. The process parameters for the instantaneous quenching by accelerated cooling of the hot deformed rebars are adapted to provide thick martensitic structure at the periphery and the core containing predominantly acicular ferrite/bainite structure along with pearlite ensuring desired combination of strength and ductility properties, favoring wide scale application in RCC structures or as rock bolts for effective roof support in tunnel construction and the like.

We claim:

1. High strength (YS;640MPa Min.) TMT bars comprising:
   a chemical composition
   C:0.18 to 0.3 wt % preferably o.2;
   Mn:0.8 to 1.5 wt% preferably 1.1;
   Si: 0.05 to 0.10 wt %;
   S:0.025 to 0.042 wt %;
   P:0.025 to 0.042 wt%; & rest Fe.

2. High strength TMT bars as claimed in claim 1 comprising:

   YS(MPa) 640 to 740 and preferably 650;
   UTS(MPa) 750 to 850 preferably 780;
   UTS/YS: 1.12 to 1.2 preferably1.2; and
   %El: 18 to 24;

3. High strength TMT bars as claimed in anyone of claims 1 or 2 having very hard martensite rim of higher thickness at periphery and acicular ferrite/bainite along with relatively soft pearlite at core ensuring excellent combination of strength and ductility.

4. High strength TMT bars as claimed in anyone of claims 1 to 3 wherein hardness profile of the bar comprises hardness of martensitic rim of around 290 VHN and core area hardness around 240 VHN.

5. A process for producing high strength TMT bar as claimed in anyone of claims1 to 4 comprising the steps of:

(i) producing the steel maintaining C-Mn chemistry free of micro alloying such as to obtain steel composition comprising
   C:0.18 to 0.3 wt % preferably o.2;
   Mn:0.8 to 1.5 wt% preferably 1.1;
   Si: 0.05 to 0.10 wt %;
   S:0.025 to 0.042 wt %;
   P:0.025 to 0.042 wt%; & rest Fe.

(ii) producing billet therefrom;

(iii) hot rolling with controlled parameters to produce TMT bars from billet; and

(iv) instantaneous quenching of hot deformed bars under controlled cooling parameters such as to achieve desired microstructure and combination of strength with yield strength of 640MPa min and super tough with eleongation 18% min.

6. A process for producing high strength TMT bar as claimed in claim 5 wherein, said rolling parameters comprising

soaking temperature:1100-1280°C;
bar dia:20,22,25mm;
mill speed:4.8-5.2m/s;
water Pressure:9.5-10.7kg/cm2;
water Flow:535-550m3/hr;
equalization temperature:480-520°C.

7. A process for producing high strength TMT bar as claimed in claims 5 wherein cooling parameters for instantaneous quenching of hot deformed bars comprising cooling Water flow rate;535 to 550 m3/hr; inlet water temperature: 15 to 30oC; retention time in cooling chamber: 1.8 to 2.5 sec which are varied according to the size of the bar.

8. High strength (YS: 640MPa Min.) and super tough (Elongation 18% Min.) TMT bars and a process for its production as hereindescribed with reference to the accompanying non limiting examples.

Dated this the 12th day of January, 2010

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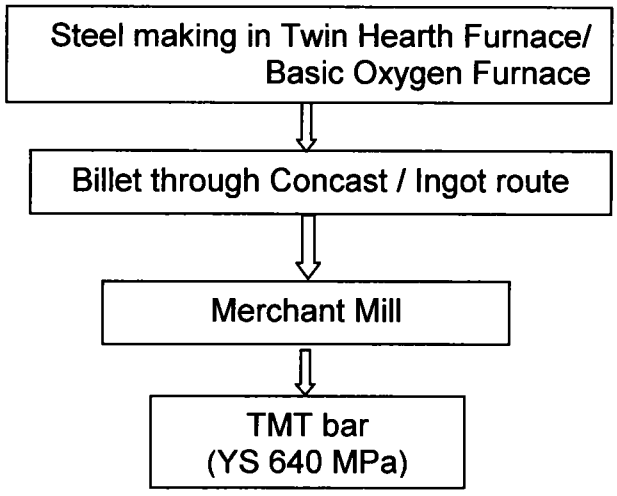

Figure 1

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Figure 2(a)



Figure 2(b)

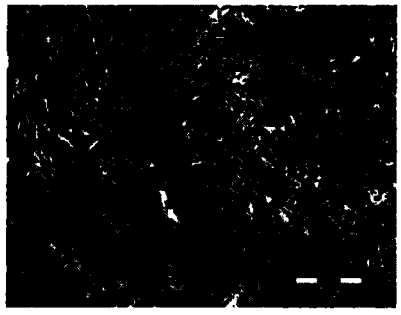

Figure 2(c)

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FIELD OF THE INVENTION

The present invention relates to developing high strength (YS:640MPa Min.) Thermo Mechanically Treated (TMT) bar and a process for its production. More particularly, the present invention is directed to developing TMT bars having yield strength above 640MPa, UTS/YS ratio of 1.15 Min., with super toughness (18% elongation Min.) properties of said TMT rebars through selective alloy design and optimizing process parameters. The alloy design of the high strength TMT rebars of the invention is obtained with C-Mn chemistry for the developmental heats wherein manganese content of steel is maintained on moderately higher side in the range of 0.8-1.3 wt %, and no micro-alloying element is added so that cost of production remains competitive. Importantly, the process parameters for the instantaneous quenching by accelerated cooling of the hot deformed rebars according to the present invention are adapted to provide thick martensitic structure at the periphery and the core containing predominantly acicular ferrite/bainite structure along with pearlite ensuring desired end properties. The high strength TMT bar according to the invention thus ensuring high strength to weight ensure favouring wide scale application such as reinforcement bar in RCC structures or as rock bolts for effective roof support in under ground mines or tunnel construction.

BACKGROUND ART

It is well known in the related art that thermo mechanically treated steel reinforcement bars of Fe 500 grade are being used conventionally as rock bolts for active roof support system in underground coal mines as well as tunnel construction. It has also been experienced in the art that considering the safety aspect of such construction, there had been a need to develop steel materials with even higher strength to weight ratio with same section for the TMT bars associated with higher toughness properties to suit application in RCC/tunnel structures.

It is thus the intent of the present invention to overcome the limitation of the existing TMT bars used for RCC structures and rock bolts for mines or roof support system or the like, by developing a new grade of steel rebar capable of ensuring higher strength and toughness as also the desired improved strength to weight ratio of said TMT rebars. Such high strength rebars (YS:640MPa Min.) is developed and produced by selectively controlling on one hand

the chemistry of the steel material and on the other hand optimizing the process parameters for rolling and instantaneous quenching by accelerated cooling of the hot deformed rebars to thereby obtain desired microstructure favouring achieving desired superior strength/physical properties in the end products.

OBJECTS OF THE INVENTION

The basic object of the present invention is thus directed to developing a high strength (YS: 640 MPa minimum) Thermo Mechanically Treated (TMT) rebar for application as reinforcement bar in RCC structure and as rock bolt bar in roof support system for underground mines and tunnel construction and the like.

According to yet another object of the present invention is directed to developing a TMT rebar with desired higher physical strength properties wherein C-Mn chemistry for developmental heats for steel material maintained with Mn in the moderately higher range.

A further object of the present invention is directed to developing a TMT rebar which would be capable to providing high strength, high toughness with moderate elongation properties suitable for RCC reinforcement or rock bolts in tunnel structures.

A still further object of the present invention is directed to developing a TMT rebar with desired higher physical strength properties obtained by selective control of chemistry as well as optimizing the process parameters for rolling and rapid cooling of hot rolled bars such as controlling cooling water flow, inlet water temperature, retention time in cooling chamber (cooling chamber length and mill speed) etc. which is selectively varied according to the size of the bar.

A still further object of the present invention is directed to developing a TMT rebar with desired higher physical strength properties wherein a preferred microstructure is obtained by control of chemistry and process parameters to ensure very hard peripheral rim of rebars with higher thickness of martensite with core relatively soft comprising ferrite/bainite alongwith pearlite thereby ensuring excellent combination of strength and ductiliy.

A still further object of the present invention is directed to developing a TMT rebar with desired higher physical strength properties wherein no micro-alloying element is added to keep the cost of production competitive.

A still further object of the present invention is directed to developing a TMT rebar with desired higher physical strength properties wherein the developed steel rebar ensure higher safety of RCC or tunnel structure using such TMT rebars and favour cost advantage by way of material saving on account of ensuring improved strength to weight ratio for same steel sections.

SUMMARY OF THE INVENTION

The basic aspect of the present invention is directed to High strength (YS;640MPa Min.) TMT bars comprising:

a chemical composition
C:0.18 to 0.3 wt % preferably o.2;
Mn:0.8 to 1.5 wt% preferably 1.1;
Si: 0.05 to 0.10 wt %;
S:0.025 to 0.042 wt %;
P:0.025 to 0.042 wt%;
& rest Fe.

Another aspect of the present invention is directed to said High strength TMT bars comprising:

YS(MPa) 640 to 740 and preferably 650;
UTS(MPa) 750 to 850 preferably 780;
UTS/YS: 1.12 to 1.2 preferably1.2; and
%El: 18 to 24;

A further aspect of the present invention is directed to said High strength TMT bars having hard martensite rim of higher thickness at periphery and acicular ferrite/bainite along with relatively soft pearlite at core ensuring excellent combination of strength and ductility.

A still further aspect of the present invention is directed to said High strength TMT bars wherein hardness profile of the bar comprises hardness of martensitic rim of around 290 VHN and core area hardness around 240 VHN.

According to yet another aspect of the present invention is directed to a process for producing high strength TMT bar comprising the steps of:

(i) producing the steel maintaining C-Mn chemistry free of micro alloying such as to obtain steel composition comprising

C:0.18 to 0.3 wt % preferably o.2;
Mn:0.8 to 1.5 wt% preferably 1.1;
Si: 0.05 to 0.10 wt %;
S:0.025 to 0.042 wt %;
P:0.025 to 0.042 wt%; & rest Fe.

(ii) producing billet therefrom;

(iii) hot rolling with controlled parameters to produce TMT bars from billet; and

(iv) instantaneous quenching of hot deformed bars under controlled cooling parameters such as to achieve desired microstructure and combination of strength with yield strength of 640MPa min and super tough elongation 18% min.

A still further aspect of the present invention is directed to a process for producing high strength TMT bar wherein, said rolling parameters comprising

soaking temperature:1100-1280°C;
bar dia:20,22,25mm;
mill speed:4.8-5.2m/s;
water Pressure:9.5-10.7kg/cm^2;
water Flow:535-550m^3/hr;

equalization temperature:480-520°C.

A still further aspect of the present invention is directed to a process for producing high strength TMT bar wherein cooling parameters for instantaneous quenching of hot deformed bars comprising cooling water flow 520 to 560 m^3/hr; inlet water temperature 15 to 30°C; retention time in cooling chamber 1.8 to 2.5 s which are varied according to the size of the bar.

The present invention and its objects and advantages are described in greater details with reference to the following accompanying non limiting illustrative figures and example.

BRIEF DESCRIPTION OF THE ACCOMPANYING FIGURES

Figure 1: is the process flow chart showing the processing route involving the basic steps for developing the TMT bars.

Figure 2a: is the image of micro structure of the core of the TMT rebar developed according to the process of the invention showing acicular Ferrite/Bainite structure at core.

Figure 2b: is the image of micro structure showing Ferrite/Pearlite interface between core and rim of TMT bars developed according to the present invention.

Figure 2c: is the micrograph showing dendritic tempered Martensite structure at the rim/periphery of TMT bars developed according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION WITH REFERENCE TO THE ACCOMPANYING FIGURES

The present invention is directed to developing high strength (YS: 640 Mpa Min.) super tough (Elongation 18% Min.) TMT rebars for application in reinforcement of RCC structure or as rock bolts used in tunnel structures. The TMT bars is developed following the process according to the invention involving selective alloy design comprising C-Mn chemistry with

moderately high Mn content in the range of 0.8-1.3 wt% and avoiding any micro alloying and also involving controlling/optimizing process parameters for hot rolling as well as accelerated cooling/instantaneous quenching of hot deformed rebars to achieve desired microstructure in said TMT rebars comprising hard martensite rim of increased thickness with relatively soft and tough core formed of acicular ferrite/bainite along with pearlite.
The objects and advantageous aspects of the high strength TMT rebars and the process for its production is described in further details with reference to the following non limiting figures and example.

Reference is first invited to the accompanying **Figure 1** that illustrate the basic steps involved in the developments of TMT bars. It is clearly apparent from the process route shown in the accompanying Figure 1, that in the first step making of steel having desired chemistry is carried out in Twin hearth furnace or Basic Oxygen furnace. Heat making for steel production is adopted wherein alloy design with C-Mn chemistry is maintained for the developmental heats. No micro alloying is added to keep the cost of production competitive. The manganese content is maintained relatively on higher side preferably in the range of 0.8-1.3 wt %.

The steel is then cast into billet in continuous casting mill or made in ingot casting route. The cast billet obtained is then subjected to hot rolling in Merchant mill for reduction of section through successive roll passes to desired TMT bar section, preferably obtained in the sizes of 20mm, 22mm and 25mm bar diameters. Rolling parameters and the water quenching of the hot deformed bars comprised the variables like the soaking temperature, mill speed, cooling water pressure and flow rate, inlet water temperature, retention time in cooling chamber equalization temperature. The parameter values selected/varied based on the size of the bars. The parameters are optimized through trials and standardized till a desired micro structure is achieved ensuring the desired strength (YS: 640 MPa min) and toughness properties(18% El min) of the rolled and quenched TMT bars. Necessary testing of the rolled and quenched TMT rebars is carried out to ensure desired micro structure and strength properties.

The steps involved in the process according to the invention for production of TMT bars of desired strength properties is further illustrated with the help of following example.

Example I:

1. Alloy design for steel manufacturing is maintained with C-Mn chemistry for the developmental heats, free of any micro alloying and Mn content at relatively higher range. The composition of steel obtained in Twin hearth/Basic Oxygen furnace is as follows:
   C:0.18 to 0.3 wt %;
   Mn:0.8 to 1.3 wt%;
   Si: 0.05 to 0.10 wt %;
   S:0.025 to 0.042 wt %;
   P:0.025 to 0.042 wt%;& rest Fe.

2. The steel so produced is cast into billets either in concast (continuous casting) plant or through ingot casting route.

3. The cast billet is then subjected to hot rolling in Merchant mill following the selective rolling parameters as follows:
   Soaking temperature:1100-1280°C;
   Bar dia.: 20mm, 22mm and 25mm;
   Mill speed:4.8 to 5.2 m/s;

4. Hot deformed rebars are subjected to instantaneous quenching following the cooling parameters comprising cooling water flow, inlet water temperature, retention time in cooling chamber determined by cooling chamber length and mill speed and such aparemeters are varied according to the size of the bar. The cooling parameters are as follows:
   Water pressure: 9.5 to 10.7 kg/cm^2;
   Water flow rate: 535 to 550 m^3/hr;
   Inlet water temperature: 15 to 30°C;
   Equalisation temperature:480-520°C;
   Mill speed:4.8-5.2m/s;
   Cooling chamber length: 10m approx;
   Retention time in cooling chamber: 1.8 to 2.5 sec;

5. Accelerated cooling of hot rolled TMT rebars according to the process of the present invention ensure developing a micro structure with increased thickness of very hard martensite rim at periphery of bars and a relatively soft and tough core having predominantly acicular ferrite/ bainite structure along with pearlite. Accompanying **Figure 2a** shows the micro structure of the core of the TMT rebar having acicular Ferrite/Bainite structure at core. Accompanying **Figure 2b** shows the micro structure having Ferrite/Pearlite interface between core and rim of TMT bars and **Figure 2c** is the micrograph showing dendritic tempered Martensite structure at the rim/periphery of TMT bars of increased thickness developed following the process of the present invention.

6. The testing of the TMT bars obtained with controlled C-Mn chemistry and optimized rolling/ cooling parameters are carried out to determine and ensure the desired physical properties to meet the objective of application in RCC reinforcement or rock bolts for tunnel/roof support structure.

7. Test Results obtained are as follows:

    a. Yield strength of bar is above 640 Mpa with 18% El and UTS/YS ratio of 1.15min.

    b. Tensile properties:
    Guaranteed: YS(MPa)-640Min.;UTS(MPa)-736Min.; %El 15 min.;
    Typical: YS(MPa):666; UTS(MPa)-793; %El 19;

    c. Hardness profile of the bar shows that hardness of martensite rim is of the order of 290VHN whereas the core area has attained a hardness of around 240VHN.

    d. The excellent combination of strength and ductility obtained due to the microstructure evolution in the bar such as the core microstructure of acicular ferrite plus pearlite combined with martensitic rim of increased thickness has resulted in the favoured combination properties of strength and toughness as well as ductility.

It is thus possible by way of the present invention to developing a high strength (YS: 640 MPa min.) TMT rebar with improved toughness and moderate elongation (18% El) properties for application as reinforcement in RCC structures or as rock bolts in roof support system and a process for its production involving selective C-Mn composition with relatively high Mn content in the range of 0.8 to 1.3 wt% and optimizing rolling as well as water quenching parameters to ensure desired micro structure and strength properties in the resulting hot rolled and quenched TMT rebars. Importantly, the process of production of the TMT rebars according to the invention eliminates any micro alloying element addition to keep the cost of production low. The high strength TMT rebars according to the present invention is advantageously providing improved weight to strength ratio favoring material saving and resultant cost saving while ensuring safety and security of support structures. The instantaneous cooling of the hot deformed bars as of the invention results in evolution of a micro structure of said rebars comprising acicular ferrite/bainite along with pearlite at core and a very hard dendritic martensite of higher thickness at the periphery favoring excellent strength and ductility combination in the TMT rebars and thus favoring wide scale application of this grade of steel rebars in variety of structures and industrial application of the process technology for their production in steel plants.

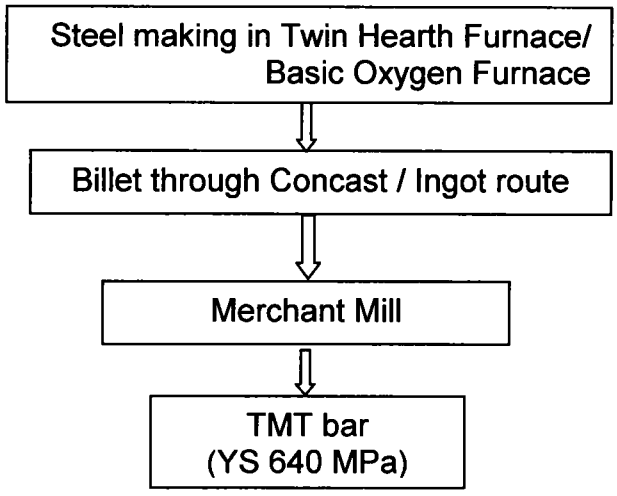

Figure 1

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Figure 2(a)



Figure 2(b)

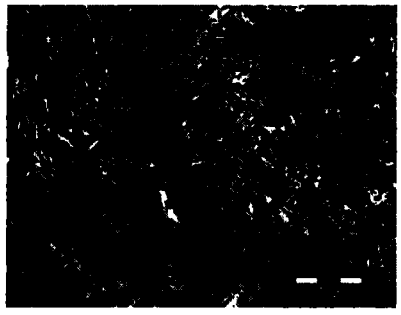

Figure 2(c)

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