Steel Reinforcement for India

Relevance of Quenching & Tempering Technology

...Contd from the last issue

R. K. Markan
CMD, H&K (India)

TMT" REBARS IN INDIA

Thermo-mechanical treatment (TMT):

TMT is an acronym for the phrase 'thermo-mechanical treatment'. The Bureau of Indian Standards while issuing the new code IS: 1786-1985 was the first to use this phrase while making reference to the 'Technological advances during the last few years in the field of deformed bar production..... Microalloying .... and thermomechanical treatment process are worth mentioning in this field' in para 0.2.1 of its foreword.

The technological advances referred to in the IS code are the quenching processes 'Tempcore' and 'Thermex' which received world patents and quick global acceptance amongst civil engineers. It must be stressed for the benefit of all (and the civil engineers in particular) that neither of these two patented processes employs any mechanical treatment whatsoever. Instead, they obtain the unique properties in the rebars by "quenching and tempering" as explained earlier. After rolling, the deformed steel bar is passed through a quenching line whereby the periphery is subjected to intense water quenching in a short time whereas the core remains largely unaffected. On leaving the quenching system the core heat is utilised to temper the quenched outer surface. The resulting structure is a concentric tempered martensite periphery with a softer ferrite-pearlite core.

Thus, no mechanical treatment is involved in the technological advances referred to by B.I.S.

On their part the steel majors TISCO and SAIL, which were the first to employ the newly developed processes, exploited the same by a vigorous publicity of their "TMT" rebars. Thus, the innocent use of an incorrect phrase by BIS gained popularity in India and this is now looked upon by many civil engineers as an improvement on the old CTD bars and is often mistaken for a brand name. This is far removed from the truth.

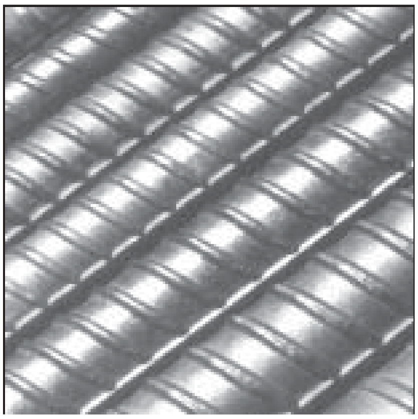
Every hot rolling mill for long products undertakes thermal and mechanical work in the normal course of rolling. Thus, each one of them genuinely and legally produces "TMT bars". Nothing stops them from claiming this and selling their products as 'TMT' bars even when they do not employ any Tempcore or Thermex process or for that matter any sort of quenching system, proven or unproven. And, there are about 2,500 rolling mills in India for long products.

The discerning customer must not blindly just ask for 'TMT' bars merely because it is fashionable to do so today, or because it is in vogue, so to speak. He cannot and should not assume that he is buying a product superior to the old rusty CTD rebars. All rebars must be purchased based on the properties of yield strength, tensile strength and elongation values. To ignore these will only be putting your construction at peril. Many civil engineers, even today, assume that 'TMT' bars have yielded strength of 415 N/mm^2 but better elongation than CTD bars. He should know that nothing in the current laws or regulations prevents the rolling mill to just sell untreated and untwisted deformed bars as TMT bars - even though the strength can be as low as only 300 N/mm^2.

Enough damage has already been done by use of the label 'TMT' and there is now an urgent need to use the correct phrase "Quenching & Tempering" as used globally – or any other suitable phrase which cannot be exploited by persons who do not have the proper technology – if we are to limit further damage. The consequences of not doing so are very frightening indeed in the years to come in view of the massive expenditure foreseen over the next decade in infrastructure and rural development.

Basic Objectives of developing Tempcore & Thermex Technologies

It must be clearly comprehended that both Tempcore & Thermex technologies were developed in the mid-eighties to produce rebars that had far superior properties to that available in CTD bars. They essentially aimed at meeting the then global demand for low cost rebars that had high yield strength of about 450 to 500 N/mm^2 (to effect saving in steel used) combined with good ductility so that adequate safety was feasible when used in high seismic zones. This means that these quenched and tempered rebars, as produced by Tempcore and Thermex Systems, genuinely gave civil engineers a product that was by far superior to CTD rebars.



The basic objective of this major technological advance would be defeated if India takes to the 'TMT' rebars as produced in the country, today. No major advantage would accrue to the civil engineer if they continue to use Fe 415 grade rebars as defined by IS 1786-1985 by merely choosing 'TMT' Fe 415 bars in place of the old CTD Fe 415 bars.

Sub-standard & Defective "TMT" Rebars

Dr. C. S. Vishwanath of Bangalore and his colleagues have done pioneering work in study of the various "TMT" rebars available in the country today and have published many articles on the subject. His team has already warned the users about how many mills are flooding the market with sub-standard and defective "TMT" rebars. They have found many "TMT" bars of the main producers and secondary mills with a Yield Strength in the range of only 350-390 N/mm^2. This only strengthens my worry that some civil engineers today assume all rebars are of Grade Fe 415 and so avoid testing.

Many a 'TMT' rebar manufacturer has approached the author for guidance and improvement in their 'TMT process' because the test results revealed that the minimum YS was about 350 to 390 N/mm^2 only as against 415 specified in IS: 1786-1985 for grade Fe 415. To save capital costs such mills have developed their own quenching lines in their rolling mill fitted with Edenborne coilers. Now, it is a well established fact that the rolled bar should be at about a minimum temperature of 730 to 760^{o}C for coiling with such coilers. On the other hand, for proper "Quenching & Tempering" to take place the equalising temperature should be in the region of 580 to 650^{o}C depending on the size and grade to be made. Thus it is clear that these mills cannot make proper "TMT" rebars of even Fe 415 grade let alone Fe 500. This has been pointed out every time we receive requests for guidance but unfortunately the production of such 'TMT' rebars continues even today and one such mill has become a sort of brand name in India! Such mills (with Edenborne coilers) merely carry out inadequate quenching and the important 'tempering' phase is almost non-existent.

Identifying Quenched & Tempered rebars (or "TMT" rebars as referred to in India)

Project site engineers and all civil engineers should be able to distinguish and identify good quality Q&T rebars. How does one ensure that the rebars have a concentric tempered martensite periphery with a softer ferrite-pearlite structure? A few guidelines are presented here :

a. Ensure the mill that has supplied the rebars has a genuine 'quenching & tempering' technology.

b. Check whether the Q & T technology supplied to the mill is by an authorised and competent organisation.

c. Check the licence, if any, issued to the mill for the specific Q & T rebars.

d. A Licence from B.I.S. is an added asset.

e. Always test the rebars for properties instead of merely relying on the name 'TMT'.

f. Field test the rebars at random. The first thing to be done is filing the surface of the rebars with the help of workers 'rough' hand file. A site worker will easily recognise if the surface is hard or soft. All Q & T rebars have a harder surface than unquenched bars.

g. Finally, random sample should be drawn. The cross-section is smoothened to a fine polished state by grinder and emery paper. The smooth end of sample is then pickled in nitrol solution (5 to10% nitric acid with balance ethyl alcohol). The result should show a uniform tempered martensite periphery with a softer core in case of good Q & T rebars.

A5 Elongation %	YS, N/mm2	Remark
36 - 45	265 - 300	'TMT' rebars without any treatment
32 - 40	360 - 390	'TMT' rebars with improper / inadequate Q & T treatment
Below 6%	600 or more	'TMT' rebars quenched in water tank after rolling

One must point out that elongation helps in identifying bad Fe415 "TMT" bars and based on data presented by Dr. C. S. Vishwanath, the following can be used for identifying such "TMT" bars:

Generally, good Q & T rebars will have elongation from 16 to 28% depending on final yield strength.

For the benefit of civil engineering fraternity an Illustrative Guide of the "TMT" rebars available in India of etched cross sections is presented through Fig 6 to 12. Besides photos received from various mills and HSE Germany, Dr. C. S. Vishwanath has kindly submitted some photographs of samples drawn and tested by his laboratory.. The explanatory notes alongside each illustration will serve as a good guide for a better understanding by the reader.

Illustrative Guide of the "TMT" rebars available in India :

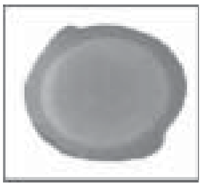


Fig 6: This photograph provided by HSE Germany, illustrates a good Q & T Thermex rebar. Note the uniform and concentric hardened periphery and the softer core. Such bars will have desired tensile strengths coupled with high elongation as required in seismic zones.

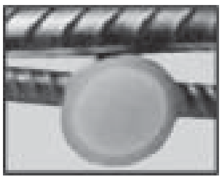


Fig 7: Photo of Thermex rebar provided by HSE Germany. The uniform tempered martensite periphery is clearly visible. Depending on the size and grade, the hardened periphery will be about 20 to 30 % of the bar cross sectional area for good Q & T rebars. Ideal rebar for civil construction.

Fig 8: A picture taken of a 25mm Thermex 500 rebar rolled by Metro Ispat, Maharashtra. Note the uniform tempered martensite periphery. Elongation measured was 19 %. A good rebar for civil construction.

Fig 9: This photograph provided by Dr. C. S. Vishwanath, Bangalore illustrates a highly over-quenched rebar. The hardened periphery is about 60% of the total crosssectional area. Produced by mill personnel who are not fully trained in quenching & tempering technology. Such bars will have high Yield Strength and very poor ductility and should never be used in civil construction.

Fig 10: This photograph provided by Dr. C. S. Vishwanath, Bangalore illustrates improper quenching treatment. Note non-uniform hard periphery signifying that the quenching has not taken place all round the periphery. Such bars are produced due to incorrect operation by mill personnel. Such bars should be used only after extensive testing.

Fig 11: This photograph provided by Dr. C. S. Vishwanath, Bangalore illustrates a bar produced by a bad quenching & tempering system. The quenching is not uniform and the test results will be anybody's guess. Such bars are produced mainly by 'hit-andtrial' "TMT" technology and systems. Such bars should never be used in civil construction as properties will vary from bar to bar.

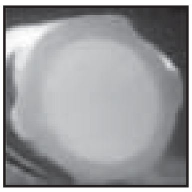


Fig 12: This photo, provided by HSE Germany, shows a typical Thermex rebar

– very uniform cross-section of hardened periphery with a soft core. An excellent rebar for civil construction.

SECTION 3: CODE FOR REBARS

It is imperative that the B.I.S. and the steel majors (TISCO, SAIL & RINL) combine with knowledgeable organisations to develop a code for rebars that fully benefits the country as a whole. If this is not done, the import of the Tempcore and Thermex technologies at high costs will really only mean a 'tick' on the list of jobs done instead of any meaningful benefit to the nation. We have already lost nearly 20 years on account of incorrect steps; we should not lose any more time.

It is heartening to note that the B.I.S. is seized of the matter and is considering a revision of the code for rebars and is even contemplating a separate code for what they still term as 'TMT' bars. The outcome is eagerly awaited. It is hoped that the correct phrase 'quenching and tempering' is used and that B. I. S genuinely take advantage of the global technological advances that have now been introduced in India by specifying properties as obtainable by quenched and tempered systems as per Thermex (used by Durgapur & Bhilai steel plants of SAIL and most secondary mills in India) and Tempcore (as used by TISCO & RINL). It must be noted that such rebars made by these two groups have a combined total market share close to 50% in the country. Surely, the interests of the common man and India as a whole should be the only consideration.

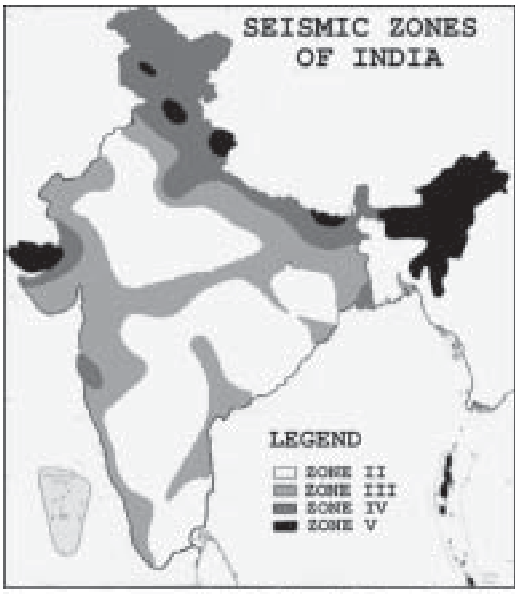


Fig13: Seismic Zones in India

What should the Indian Code specify?

One basic fact about India is that 50-60% of the country falls under the seismic 3, 4 & 5 categories. (See Fig.13: Seismic Zone Map). So, safety of construction is of prime importance and there is no place for casualness or complacency with regard to selection of rebars. The code in use must therefore take into account this basic need for India. Many countries are preparing special codes for rebars to be used in such areas whereas a few such as New Zealand have already done so through AS/NZS 4671:2001 – Steel Reinforcing Materials. Most countries are contemplating specifying elongation of 20 % or more. In India, as per IS: 13920, rebars for seismic zones 3, 4 &5 should have an elongation of 14.5% or more. This, I feel, is an extremely low minimum value and needs to be raised immediately to at least 16 % if not 18%.

Let us take the joint Code AS/NZS 4671-2001 developed by New Zealand and Australia and introduced recently. It replaced the old Code NZS 3402.

- In the new Code 4671, Grade 430 was withdrawn (adequate time was given for withdrawal of Grade 430) and replaced with Grade 500.
- The new Code covered three ductility classes – L, low ductility; N, normal ductility and E, high ductility for earthquake prone areas. These three classes of ductility are basically applicable for Grade 500 only. In case of Grade 250 only class N and for Grade 300 only class E is covered by the Code AS/NZS 4671. Class L includes cold worked steel wires & wire meshes.
- The concept of uniform elongation, Agt, was introduced as it was considered a more meaningful measure of ductility against the total elongation in the earlier code. Uniform ductility is the strain developed in the bar at maximum load while total elongation includes strain involved in the deformation at the necked region which is of no structural value. Limits are set not only for the yield strength, but also for the tensile (Rm) to yield (Re) ratio in both directions. The minimum value of the ratio Rm/Re is to ensure that yielding will not be confined to where it first commences, thereby permitting greater elongation of the

bar before fracture and hence greater ductility of the structural member. The maximum value is to ensure that when the steel commences to strain harden the stress in the bar does not lead to a significant over strength of the structural member.

• Yield Strength, Re, measure of the maximum load that the steel can carry in elastic manner. On exceeding this load steel is permanently elongated. The code has three grades – 250, 300 & 500.

• Ultimate Tensile Strength, Rm – no limits are specified. Instead limits of Rm:Re ratio have been specified and is fundamental to the ductile design concept in New Zealand.

It may be noted here that New Zealand follows the ductile design philosophy - to design for structures to yield but not fail during an earthquake. This facilitates absorption of the immense seismic forces allowing buildings to move and distort without complete catastrophic failure. Limits are set not only for yield strength, but also for the tensile to yield strength ratio in both directions. The minimum value of the ratio Rm/Re ensures yielding will not be confined to specific area, thereby permitting greater elongation of the bar before fracture and hence greater ductility. The maximum value is to ensure that the stress in the bar does not lead to significant over- strength.

Table-1: Properties as per old and new Codes of New Zealand

Property		AS/NZS 4671-2001					Old NZS 3402	
		250N	500L	500N	300E	500E	300	430
YS (MPa)	min	250	500	500	300	500	300	430
	max	-	750	650	380	600	355	500
Rm:Re	min	1.08	1.03	1.08	1.15	1.15	1.15	1.15
	max		-	-	1.50	1.40	1.50	1.40
Min. Uniform Elongation, %		5.0	1.5	5.0	15	10	-	-
Min. Total Elongation %		-	-	-	-	-	20	15

The brief properties of the old and new Grades of rebars in New Zealand are presented in Table-1 :

The new Code AS/NZS 4671-2001 is also specific about many issues that most standards are silent. It even spells out the identification for the different grades so that the site engineer has no difficulty in using the correct rebar grade. Further, it is mandatory for the rebar to carry unique marks to enable identification of the producer.

Many of the clauses in this Code are worth emulating by B. I. S. Since we are more conversant with total elongation the proposed code for India may continue to use total elongation as defined presently. However the values should be increased in light of the properties obtained through the quenching and tempering process now increasingly used in the country and the vast regions of high intensity earthquake prone areas in the country.

A summary of properties specified to Thermex Licensees and the typical properties as noted from Thermex rebars are given in Table 2 alongwith that specified in IS: 1786-1985.

The typical values of Thermex Grades 400 and 500 rebars mentioned in the Table-2 above do not include samples from the Durgapur and Bhilai Steel Plants of SAIL. Instead they are test results obtained in the period from August 2000 to April 2003 of 934 samples in the small mills of Thermex Licensees. Special importance is given in checking the Stress Ratio as this is a very significant factor when considering rebars for earthquake zones. Many Licensees get UTS / YS values in the range of 1.20 to 1.35 even for Grade 500 against the IS standard of only 1.08. Suggested IS Code Keeping in mind the above and that 50% of India falls are under seismic zones 3,4

Table 2: A comparison - IS Code 1786 and Properties of Thermex rebars.

Properties	IS 1786 Grade Fe415	Grade Thermex 400	Thermex 400 Typical Values	IS 1786 Grade Fe500	Grade Thermex 500	Thermex 500 Typical Values
Yield Strength, N/mm^2 min.	415	415	**430 – 460**	500	500	**520 – 560**
Min. Stress Ratio, (UTS:YS)	1.10	1.13	**1.15 – 1.25**	1.08	1.12	**1.15 – 1.24**
UTS, N/mm^2 min.	485	485	**500 – 570**	545	560	**590 – 630**
A_5 Elongation, min %	14.5	18	**20 - 25**	12	16	**18 - 22**

&5 the basic changes which may be considered, are as follows:

- The minimum elongation, A5, should not be less than 16% for any grade.
- Since CTD rebars will continue to be made, a grade 350 with 17% elongation can be added.
- Grade Fe 415 may be replaced by a grade of 450 to allow for savings in steel. Grade Fe 550 may be deleted as it is hardly ever used and does not exist in Codes of most countries.
- The mechanical properties to be specified should be restricted to Yield strength, Stress Ratio and elongation. Tensile strength need not be specified as limits for the same will be restricted by the Rm/Re Stress ratio.
- An upper and lower limit to be prescribed for both Yield Strength and Stress Ratio as is done in the new AS/NZS Code4671-2001.
- Special identifying marks to be evolved for identifying the rebar Grade. This will make the site engineer's job easier.
- It should be made mandatory for all rebars to have distinguishing marks to identify the producer.

Table 3: Suggested new IS Code.

Property		Grade			Future Seismic Grades		
		350	450	500	350E	450E	500E
YS (MPa)	min	350	450	500	350	450	500
	max	430	530	580	430	530	580
Rm:Re	min	1.15	1.15	1.15	1.15	1.15	1.15
	max	1.40	1.40	1.40	1.40	1.40	1.40
Min. Elongation %	Total	17	17	16	18	18	18

Other changes in line with the above could be incorporated. For example, B. I. S may consider reducing the C content to 0.25% as against the present 0.30%. The basic properties can be as tabulated below in Table 3. Grade 350 will be mainly for CTD bars.

Initially grades 350, 450 & 500 may be introduced and at a later date (after 2 years) the specific grades for seismic zones may be added – the change being mainly in ductility – with minimum 18% elongation.

Conclusion

It is estimated that that steel consumption will rapidly rise in the next 10-15 years to reach a level of 140 million tonnes per year by 2020 of which 55% (77mT) will be long products. Rebar demand will see a five-fold jump to around 35mT/year to allow for development of the vast hinterland. The best of quenching and tempering technologies are today available in the country and Q & T rebars have already made a dent in the market. By 2020 over 90% of the rebars used will be Q&T rebars. It is imperative that the B. I. S. put into place a relevant Code for rebars at the earliest so that the country utilises this technology to its full potential – savings in steel consumption and safety. The new Code could be on lines of the one adopted by New Zealand. It should make it mandatory for all rebars to have marks that make it easy for the Grade and name of producer to be identified. This will clean up the rebar sector and be beneficial to the entire construction industry.

References:

1. "TMT" Bars – The Best & the Worst of Times by R. K. Markan, 2002.
2. Reinforcement – Global & Indian Scenario by F. Tamm & R. K. Markan, 2003
3. Thermo-processing for High Strength rebars by R. K. Markan & F. Tamm, 2003
4. Properties of Thermo-processed Thermex HSD Rebars by R. K. Markan & R. S. Chavan , 2003
5. India: Steel 2020 & Relevance of Thermex Technology by R. K. Markan, 2004
6. Relevance of Quenching & Tempering Technology to India, by R. K. Markan, 2004
7. "TMT" Rebars & What Needs to be Done by R. K. Markan, 2004
8. The A, B, & C of 'TMT' Bars, Master Builder, 2004
9. The Australian/New Zealand Standard AS/NZS 4671-2001 "Reinforcing Steel Materials"
10. New Reinforcing Materials by K. Towl, Pacific Steel
11. L, N & E Grade 500 Reinforcing Steel by D. Bull & C. Allington, University of Canterbury
12. Welding Newly Developed, High Strength, Seismic Grade Reinforcing Bars by W. Scholz & B. Roberts
13. Sub-Standard Rebars in the Indian Market by Dr. C. S. Vishwanath and Others, 2004.

❑❑❑