International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 8, August - 2013

Studies on Properties of TMT Steels for Structural Applications

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***Abstract*— India is among the fastest developing nation in the world with major constructions like bridges, dams, airports, residential buildings etc. In a developing economy where infrastructure is getting boom, 'strength' of structural members is of great importance. This is where Thermo Mechanically Treated (TMT) bars scores over Cold twisted bars (or CTD bars). For understanding the proper behaviour of structural members, physical properties, chemical composition, mean projected rib area and macrostructure are very essential. Nowadays there are many companies which supply untreated and twisted deformed bars as TMT bars which would do much harm for structural stability. There is an urgent need to use the phrase "Quenching and Tempering" to label the TMT bars. This project is an effort to showcase the ways to identify good quality TMT bars.**

***Keywords*— TMT bars; strength; properties; quenching and tempering**

I. INTRODUCTION

Under Thermo Mechanical treatment, the steel bars are passed through a specially designed water cooling system where they are kept till the outer surface becomes colder while the core remains hot. This creates temperature gradient in the bars. When the bars come out of the TMT box to the cooling bay, the heat flows from the core to the outer surface, further tempering the bars, which helps them attain higher yield strength. The resulting concentric martenstic grain structure at the surface imparts superior strength and toughness to the bars. The microstructure of the core is a very fined-grained ferrite and pearlite. TMT bars are also known as 'quenched and tempered rebars', because of the quenching and tempering process involved in making the rebars, and thus TMT bars produced by the TMT process scores over Cold Twisted Bars(CTD) and TOR steels. The production of quality TMT bar depends on three major factors:

1. Quality raw materials
2. A properly designed and automated mill.
3. A well designed quenching and tempering technology.

Deciding the percentage of carbon content in steel has been a major challenge for engineers. While a minimum level of carbon content in steel is essential to achieve the required strength, excess carbon threatens its weld ability. In TMT bars, this problem has been eliminated by restricting the carbon content to 0.23% to attain weld ability and ensuring that its strength is not lost. The various grades of TMT bars are Fe 415, Fe 415D, Fe 500, Fe 500D. The following chemistry of steel is used for the production of TMT bars.

II. CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF STEEL BARS

CHEMICAL COMPOSITION OF STEEL BILLETS AND INGOTS AS PER IS 2831		
Constituent	Percent	
	Min	Max
Carbon	0.15	0.25
Manganese	0.32	0.6
Sulphur	----	0.055
Phosphorous	----	0.055
Carbon Equivalent= C+Mn/6	----	0.42

Table 1: Chemical composition of steel billets

CHEMICAL COMPOSITION OF TMT BARS AS PER IS 1786:2008				
Constituent	Percent, Maximum			
	Fe 415	Fe 415 D	Fe 500	Fe 500 D
Carbon	0.3	0.25	0.3	0.25
Manganese	0.6	0.45	0.5	0.4
Sulphur	0.06	0.045	0.05	0.04
Phosphorous	0.06	0.045	0.05	0.04
Sulphur and Phosphorous	0.11	0.085	0.10	0.07

Table 2: Chemical composition of TMT steel bars.

And the table 3 shows the mechanical properties of steel bars as IS 1786:2008.

MECHANICAL PROPERTIES OF HIGH STRENGTH DEFORMED BARS AS PER IS 1786:2008					
SR. NO.	PROPERTY	Fe 415	Fe 415D	Fe 500	Fe 500D
1	Yield Stress, Min, N/mm2	415	415	500	500
2	Elongation, Percent, Min	14.5	18	12	16
3	Tensile Strength, Min, N/mm2	485	500	545	565

Table 3: Mechanical properties of TMT bars

III. Experimental Method

A. Selection of Steel Samples

Samples of steel bars (Fe415) were obtained from three steel manufacturing companies randomly referred to as F1, F2 and F3. Samples of reinforcing steel bars 12mm in diameter were obtained from these three sources. From each source two samples (i.e. 6 samples) measuring 1m long were randomly selected from stock piled batches.

B. Testing of Physical Properties

Universal testing machine is used to perform mechanical tests such as Yield strength, Ultimate Tensile Strength and Percentage Elongation. The six samples were tested in the UTM and results were plotted on the stress-strain graph. The results so obtained were then compared with the IS 1786:2008. From each source and each sample mean value is taken by testing three samples. Obtained values of physical properties are shown in Table 4.

C. Testing of Chemical Properties

The six samples were then tested for the chemical properties of the steel using a Spectrometer. The results obtained were then compared with IS1786:2008. From each source and each sample mean value is taken by testing three samples. Values of chemical composition is shown in Table 5.

D. Testing of Mean Projected Rib Area

Third test involves one of the most neglected parts of structural engineering i.e. Mean Projected Rib Area. In order to determine the Mean Projected rib area (MPRA) we have to find out Depth of transverse Ribs (Dtr), Length of transverse rib (Ltr), spacing of transverse rib(Str) and Angle of inclination (θ). This is done manually, and using Standard formulas we can determine the Mean Projected Rib area. The results were then compared with the Indian standard. In the Standard procedure for the calculation of Mean Projected Rib area, the

Number of rows of transverse rib= 2 (two sides)

Area of transverse Ribs, Atr = ⅔ x Ltr x Dtr mm2 -------- (1)

Mean projected rib area, $Ar = \frac{Ntr \times Atr \times \sin\theta}{Str}$ mm2 -----(2)

Values of Depth of transverse rib(Dtr), Length of transverse rib(Ltr), Spacing of transverse rib(Str), Angle of inclination(θ) are shown in tabulated form.

Mill1 (Sample1)	Rib 1(mm)	Rib 2(mm)	Average(mm)
Dtr	Dtr1=0.88	Dtr2=0.92	Dtr=0.90
Ltr	Ltr1=19.30	Ltr2=19.43	Ltr=19.365
Str	Str1=7.38	Str2=7.35	Str=7.365
θ	θ=75	θ=76	θ=75.5

Table 6: Values of sample 1 from Mill 1

Putting the values in (1) and (2) we get,

Area of transverse rib (Atr) = 11.619mm2

Mean projected rib area (Ar) = 3.05mm2/mm

Mill1 (Sample 2)	Rib 1(mm)	Rib 2(mm)	Average(mm)
Dtr	Dtr1=1.11	Dtr2=1.08	Dtr=1.095
Ltr	Ltr1=19.45	Ltr2=19.49	Ltr=19.47
Str	Str1=7.39	Str2=7.39	Str=7.39
θ	θ=74	θ=74	θ=74

Table 7: Values of sample 2 from Mill 1

Putting the values in (1) and (2) we get,

Area of transverse rib (Atr)= 14.21mm2

Mean projected rib area (Atr)= 3.69mm2/mm

Mill2 (Sample 1)	Rib 1(mm)	Rib 2(mm)	Average(mm)
Dtr	Dtr1=1.20	Dtr2=1.21	Dtr=1.205
Ltr	Ltr1=20.54	Ltr2=22.57	Ltr=21.55
Str	Str1=6.642	Str2=6.10	Str=6.371
θ	θ=54	θ=56	θ=55

Table 8: Values of sample 1 from Mill 2

Putting the values in (1) and (2) we get,

Area of transverse rib (Atr)= 17.311mm2

Mean Projected rib area= 4.45 mm2/mm

Properties	Source F1		Source F2		Source F3	
Name	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Yield Strength	461.5 N/sqmm	481.5 N/sqmm	429.03 N/sqmm	426.3 N/sqmm	377.5 N/sqmm	383.1 N/sqmm
Ultimate Tensile Strength	569.3 N/sqmm	568.6 N/sqmm	555.9 N/sqmm	550.5 N/sqmm	542.6 N/sqmm	540.8 N/sqmm
Percentage Elongation	20.60%	20.80%	22.03%	22.10%	20.18%	20.92%

Table 4: Obtained values of physical properties

Table 5: Chemical composition obtained by testing TMT from various sources

CHEMICAL COMPOSITION OF TMT(sample 1) FROM SOURCE F1											
NAME	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu
	0.2062	0.0737	0.539	0.0562	0.033	0.1065	0.0084	0.0593	0.0010	0.0065	0.2492

CHEMICAL COMPOSITION OF TMT(sample 2) FROM SOURCE F1											
NAME	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu
	0.2374	0.0231	0.0126	0.0524	0.0351	0.1424	0.013	0.0732	0.0088	0.0085	0.3073

Values obtained by testing TMT steel bars from Source F1

CHEMICAL COMPOSITION OF TMT(sample 1) FROM SOURCE F2											
NAME	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu
	0.2199	0.3061	0.573	0.0502	0.0631	0.1004	0.0179	0.0758	0.0084	0.0092	0.1404

CHEMICAL COMPOSITION OF TMT(sample 1) FROM SOURCE F2											
NAME	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu
	0.2203	0.2897	0.576	0.0489	0.0635	0.1001	0.0171	0.0763	0.0092	0.0094	0.1417

Values obtained by testing TMT steel bars from Source F2

CHEMICAL COMPOSITION OF TMT(sample 1) FROM SOURCE F3											
NAME	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu
	0.2224	0.2247	0.4919	0.0696	0.0442	0.0652	<0.006	0.0588	0.0071	0.0061	0.1738

CHEMICAL COMPOSITION OF TMT(sample 1) FROM SOURCE F3											
NAME	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu
	0.2224	0.2247	0.4919	0.0696	0.0442	0.0652	<0.006	0.0588	0.0071	0.0061	0.1738

Values obtained by testing TMT steel bars from Source F3

Mill2 (Sample 2)	Rib 1(mm)	Rib 2(mm)	Average(mm)
Dtr	Dtr1=1.13	Dtr2=1.45	Dtr=1.29
Ltr	Ltr1=22.25	Ltr2=23.20	Ltr=22.725
Str	Str1=6.532	Str2=6.731	Str=6.631
θ	θ=56	θ=58	θ=57

Table 9: Values of sample 2 from Mill 2

Putting the values in (1) and (2)

Area of transverse rib (Atr) = 19.5 mm2

Mean Projected Rib area= 4.93mm2/mm

Mill3 (Sample 1)	Rib 1(mm)	Rib 2(mm)	Average(mm)
Dtr	Dtr1=0.66	Dtr2=0.95	Dtr=0.805
Ltr	Ltr1=19.71	Ltr2=18.88	Ltr=19.295
Str	Str1=8.10	Str2=7.98	Str=8.04
θ	θ=76	θ=78	θ=77

Table 10: Values of sample 1 from Mill1 3

Putting the values in (1) and (2), we get

Area of transverse rib(Atr) = 10.35mm2

Mean projected rib area = 2.507mm2/mm

Mill3 (Sample 2)	Rib 1(mm)	Rib 2(mm)	Average(mm)
Dtr	Dtr1=0.60	Dtr2=0.75	Dtr=0.675
Ltr	Ltr1=20.19	Ltr2=21.12	Ltr=20.655
Str	Str1=8.30	Str2=8.28	Str=8.29
θ	θ=77	θ=78	θ=77.5

Table 11: Values of sample 2 from Mill1 3

Putting the values in (1) and (2), we get

Area of transverse rib = 9.294 mm2

Mean projected rib area = 2.188mm2/mm

E. Testing of Macrostructure

D Now the last test is one of the most important i.e Macrostructure. Study of macrostructure is done by preparing a nitrol solution which contains 5 to 10% nitric acid with balanced ethyl alcohol. Before starting the test each sample should be grinded and polished properly otherwise the Macrostructure obtained will be of bad nature. After preparing the solution, smooth end of each sample is pickled in it for not less than 2 to 3 minutes, once the sample is taken out from the beaker we can clearly see the Macrostructure with the naked eye i.e uniform and concentric hardened Martensitic periphery on outer surface and soft fine grained ferrite pearlite at the core. Such bars will have desired tensile strengths coupled with high elongation as required in seismic zones. Depending on the size and grade, the hardened periphery will be about 20-30% of the bar cross-sectional area for good 'Quenching and tempering' bars. Hence the Macrostructure thus obtained is then compared with the Standard one and the differences are noted down.

IV. TEST RESULTS

1. Physical properties

The results obtained by testing the samples from three millers F1, F2 and F3 shows those samples from F1 and F2 have acceptable yield strength, ultimate tensile strength and percentage elongation. But the sample manufactured by source F3 shows yield strength of 380.35 N/mm2 which is far below the standard and hence cannot be accepted for constructional purpose.

2. Chemical Properties

The chemical analysis of steel bars from source F1, F2 and F3 shows that samples from F1 have average carbon content of 0.2%, manganese content of 0.525%, phosphorous content of 0.0549% and sulphur content of 0.039% which is well within the Indian standards and is acceptable for structural purposes in constructions. The samples of steel bars from source F2 have average carbon content of 0.22%, manganese content of 0.5745%, phosphorous content of 0.049% and sulphur content of 0.0633%. Here the sulphur content is beyond 0.06% which is totally unacceptable and is a case of rejection because increase in sulphur will increase the strength and hardness of the steel, and the same time will decrease the ductility and thus making it brittle. More over the increase in sulphur also decreases the weldability of steel. The samples of steel bars collected from source F3 have average carbon content of

0.22%, manganese content of 0.484%, phosphorous content of 0.069% and sulphur content of 0.045%. We see that phosphorous content has exceeded the permissible limit of 0.06% which is accepted maximum up to the range of 0.063%, and this is also a case of rejection because increase in phosphorous too increases the strength and hardness of steel but decreases the ductility (thus making it brittle) and notch impact toughness of steel.

Mean projected rib area

As per IS 1786:2008 mean projected rib area for 12mm bar should not be less than 1.8 mm2/mm. the samples being tested from three sources F1, F2 and F3 have rib area above the standard. Thus we can say all the samples are acceptable as far as Mean projected area is considered.

Macrostructure

From the test results, the samples when subjected to macrostructure from three millers F1, F2 and F3 shows those samples from F1 and F2 are having uniform and concentric hardened martenistic grain structure at the surface and fine grained ferrite pearlite at the core as shown in the figures. And the samples from source F3 cannot be considered at all because it is not showing any macrostructure when subjected to nitrol solution. Hence these types of TMT bar should never be used for structural applications.

V. CONCLUSIONS

Various physical and chemical tests, test for mean projected rib area and macrostructure conducted on TMT steel bars shows that out of the three TMT steel manufacturers only one miller exhibits all
properties as per IS 1786:2008. While TMT steels from other two millers failed due to either lower yield strength or increase in sulphur and phosphorous content. Based on the experiments conducted to test the various properties of TMT steel bars we suggest the following ways to identify and detect good quality TMT bars for structural applications.

1. We should check that the steel manufacturer who has supplied the TMT bar has proper and authentic quenching and tempering technology.
2. Depending on the brand name 'TMT' one must always check for the properties.
3. We must ensure that the quenching and tempering technology given to the steel manufacturer is through genuine and authorised firm.
4. By selecting the bars randomly test can be done at the field itself. This will require filing the surface of one end of the TMT bar using hand file. The worker engaged in the job everyday can easily recognise that the surface is hard or soft. Quenched bars have surface harder than the bars which are not properly treated.
5. We can ask for the license and check whether steel manufacturer has the same for making TMT bars.
6. A license from Bureau of Indian standard will be more advantageous.
7. Finally, we can make random selection of the samples. First thing to do is to grind and polish the cross section of each sample using grinder and then dip it in a solution of nitric acid and ethyl alcohol (4-9% nitric acid). After 2-3 minutes sample is taken out of the beaker and thus one can clearly see the macrostructure i.e tempered martensite at the periphery and fine grained ferrite-pearlite at the core. This is an effective method to identify good quality TMT bars.

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