Correlation of Micro-Macro Properties with Mechanical Properties in Rebar

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***Abstract*—Rebar owe their advantage to their composite microstructure; therefore, they have high yield strength combined with high ductility (the final structure consists of a combination of strong outer layer of tempered martensite and a ductile core of ferrite-pearlite). Mechanical Properties (Yield Strength, Ultimate tensile Strength, % Elongation) of rebar depend upon the macro-microstructure properties of rebar, which mainly includes: Macro Properties: Rim Uniformity, Rim Thickness, Rim Hardness, Core Hardness and Microstructure: Core microstructure (% of acicular ferrite & Pearlite, Bainite), Rim microstructure (Martensite, Bainite). The one of the major factors which affects the properties of rebar is its Hardness and Rim thickness. This is the conclusive result of experimental analysis based on correlation between micro & macro properties with mechanical properties of rebar, which admits Yield Strength is a function of Average Rim Thickness, Rim Hardness and Core Hardness. This correlation can be extremely helpful in finding out the Yield Strength when the Average Rim Thickness, Rim Hardness and Core Hardness are known. If we know the values of constants, we can particularly measure the Yield Strength of any particular Section during the manufacturing process. Through which we can produce the rebar of desired Yield Strength by controlling over Rim Thickness and Hardness of the rebar. In this project we are have experimented Rebar of section 25mm of Fe500D of various heat.**

Keywords*— Comparative Study, Hardness, Microstructure, Mechanical Properties, Rim Thickness, Reinforced Steel bar

I. INTRODUCTION

In TMT treatment, rebar of higher strength are produced by heat treatment of solid steel, mainly hot rolling followed by controlled cooling. The TMT process for rebar involves heating steel billets in a reheating furnace and 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. The finish rolling temperature of billets is maintained relatively on higher side (about 9500 ºC). The first stage of 'Quenching' begins when the hot rolled bar leaves the final mill stand and is rapidly quenched by a special water spray system. This converts the surface layer of the bar to a hardened structure called 'Martensite' while the core remains austenitic. The second stage of 'Self Tempering' begins when the bar leaves the quenching box with a temperature gradient through its cross section, the temperature of the core being 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 structure called 'Tempered Martensite' which is strong and tough. The core is still austenitic at this stage. The third stage of 'Atmospheric cooling' takes place on the cooling bed, where the austenitic core is transformed to a ductile ferrite-pearlite core. Thus, the final structure consists of a combination of strong outer layer of tempered martensite and a ductile core of ferrite-pearlite.

Such a structure gives optimum combination of high strength, good ductility as well as good bendability with improved corrosion resistance and fire resistance.

II. METHODOLOGY

A. Sampling

Various samples of Fe500D rebar of section 25mm of different heat were taken out from Merchant Mill of Tata Steel. The specification of Rebar is described in IS: 1786: 2008.

1) *Chemistry of Fe500D rebar:*
   a) Carbon (Max)= 0.3 %
   b) Sulphur (Max)= 0.05 %
   c) Phosphorous (Max)= 0.05 %
   d) Manganese (Max)= 0.05-1.2%
   e) Other Alloying Elements (Niobium, Tungsten, Titanium) = <0.3%
2) *Specified Mechanical Properties:*
   a) Min Yield strength = 500 MPa
   b) Min Ultimate Tensile Strength= 565 MPa
   c) Min % Elongation= 16

B. Tensile testing

The tensile test is a standard test which is conducted using a universal tensile testing machine (Make: MOHR & FEDERHAFF AG, MODEL: UPD -100, CAPACITY: 1000 KN, Standard Used: IS 1608: 2005). The prepared test specimen was position in the jaw of the universal tensile testing machine, as the machined started to stretched the rod readings of loads against extensions were recorded. At the yield point the extensometer was removed to prevent damage.

The experiment continued until the specimen fractured and the necking diameter was recorded. From the tests, the Yield Strength, Ultimate tensile strength, Young's Modulus, Percentage elongation in area was determined. The tensile strength was calculated using the following formulas of Olsen et al. (2007). Other properties were calculated from these fundamental parameters.

C. Metallography

The structure studied by metallography are indicative of the properties and hence the performance of material in service. In this technique, planar surface is prepared by sectioning followed by mounting in a thermosetting resin prior to grinding and polishing to obtain a reflective surface. In order to delineate the microstructure chemical or other etching method is employed prior to microscopy investigation. The etchant was prepared from 3% (3 vols.) of Nitric acid and 97% (97 vols.) of ethanol. Nital is normally used to see the grain boundaries, ferrite, and pearlite phases. The polished samples were agitated in the etchant for 40 seconds and quickly washed in water to stop the etchant from attacking more of the phases. The sample surfaces were then rinsed in ethanol and then dried by blowing with air. For microscopic analysis, a reflective surface is required. The etched samples analyzed by microscope. The desirable magnification was chosen by selecting one of the objective pieces. The focusing was adjusted until a good focus was found by looking into the eye piece. The image of the microstructure was captured by a digital camera connected to a computer. In Lab, Leica optical microscope is used to see the microstructures.

D. Hardness Testing

Micro samples were tested hardness using Vickers Hardness testing machine under 10kg load. Referred standard IS 1501:2002 for carrying out the test. Maximum permissible error is 2% for >300 HV at 30kg, and 3% for <300HV at 30Kg and all hardness at 10Kg.

E. Measurement of Rim Thickness

Minimum and Maximum thickness was measured and Average Thickness (mm) was considered in calculations as average rim thickness (mm).

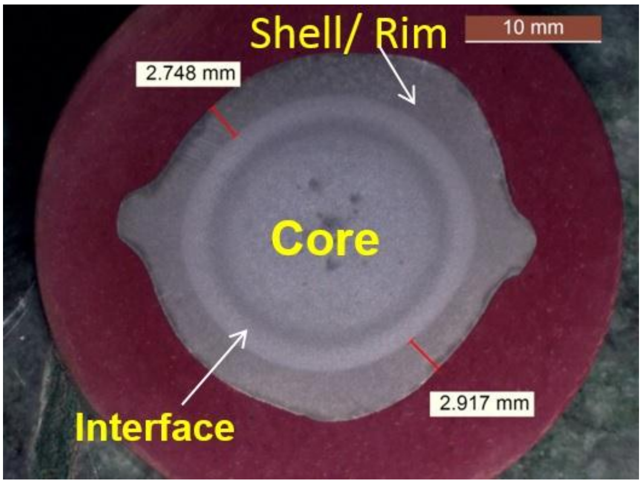

Fig. 1. Section of rebar showing layers and Rim thickness

III. EXPERIMENTAL RESULTS

TABLE I. REBAR OF SECTION 25MM, FE500D OF DIFFERENT CAST & MEASURED MECHANICAL PROPERTY

Sr. No.	Cast No.	Hardness (HV/10kgf)			Rim Thickness (mm)		
		Core	*Inter face*	*Rim*	*Min*	*Max*	*Aver age*
1	M56153-1	169	220	281	2.65	2.96	2.81
2	M57514	171	226	271	2.84	3.03	2.94
3	M36750	188	224	289	3.04	3.12	3.08
4	M59492-1	164	217	277	2.48	2.95	2.72
5	M60383	177	205	288	2.54	3.23	2.89
6	M62864	185	194	273	2.45	3.08	2.77
7	M62864	184	188	281	2.79	3.07	2.93
8	M62864	175	190	276	2.96	2.98	2.97
9	M62867	182	200	272	2.96	2.92	2.94
10	M62864	184	182	273	2.83	3.06	2.95
11	M62867	180	191	272	2.71	2.87	2.79
12	M62867	178	199	272	2.88	3.00	2.94
13	M62864	180	192	278	2.92	2.93	2.93
14	M62867	175	192	277	2.75	2.92	2.83
15	M62867	175	191	278	2.89	3.29	3.09
16	M 63187	170	208	278	2.85	3.60	3.22

TABLE II. REBAR OF SECTION 25MM, FE500D OF DIFFERENT CAST & MEASURED MICRO-MACRO PROPERTY

Sr No.	Measured Mechanical Property of Fe500D, 25 mm				
	Cast number	*YS (MPa)*	*UTS (MPa)*	*UTS/YS*	*% Elongation*
1	M56153-1	581	680	1.170	21
2	M57514	576	671	1.165	18
3	M36750	620	709	1.144	21
4	M59492-1	583	685	1.175	21
5	M60383	577	676	1.172	18
6	M62864	590	695	1.178	18
7	M62864	583	689	1.182	18
8	M62864	589	696	1.182	17.6
9	M62867	587	706	1.203	17.6
10	M62864	602	698	1.159	20
11	M62867	607	708	1.166	20
12	M62867	594	706	1.189	17.6
13	M62864	579	689	1.190	18
14	M62867	586	706	1.205	18
15	M62867	582	704	1.210	18
16	M 63187	598	692	1.157	19

IV. EXPERIMENTAL ANALYSIS

A. *Graph of YS (MPa) vs Core Hardness (HV/10kgf) of Samples*

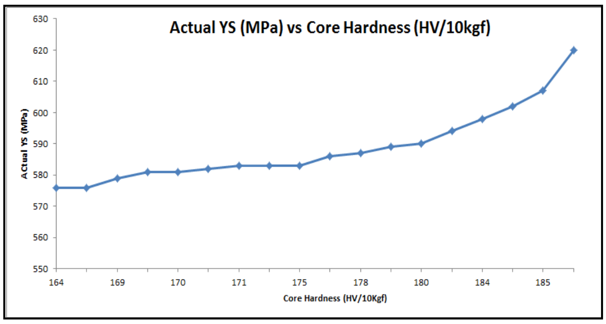

Fig. 2. Graph of Actual YS (MPa) (Y Axis) vs Core Hardness (HV/10kgf) (X Axis)

As the graph shows, YS (MPa) is directly proportional to Core Hardness (HV/10Kgf)

B. *Graph of YS (MPa) vs Rim Hardness (HV/10kgf) of Samples*

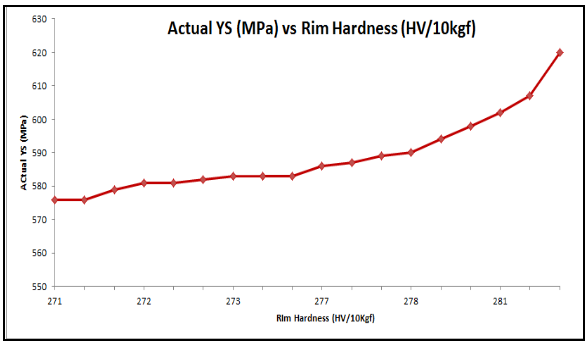

Fig. 3. Graph Actual YS (MPa) (Y Axis) vs Rim Hardness (HV/10kgf) (X Axis)

As the graph shows, YS (MPa) is directly proportional to Rim Hardness (HV/10Kgf)

C. *Graph of YS (MPa) vs Average Rim thickness (mm)*

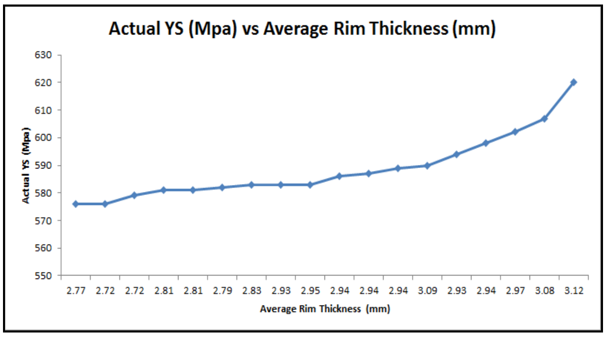

Fig. 4. Graph of Actual YS (MPa) (Y Axis) vs Average Rim Thickness (X Axis)

As the graph shows, Yield Strength (MPa) is directly proportional to Average Rim Thickness (mm).

D. *Correlating Measured Micro-Macro Properties & Mechanical Properties*

From the graph we concluded that

- Measured YS (MPa) ∞ Rim Hardness (HV/10kgf)
- Measured YS (MPa) ∞ Core Hardness (HV/10kgf)
- Measured YS (MPa) ∞ Average Rim Thickness (mm)

So, we remove the proportionality from above conclusions by introducing constants and rewrite the equations.

The Modified equations are

YS (MPa) = K_1** Rim Hardness (HV/10kgf)* (1)

YS (MPa) = K_2**Rim Hardness (HV/10kgf)* (2)

YS (MPa) = K_3**Average Rim Thickness (mm)* (3)

Summing above equations together,
Calculated Yield Strength = (K_1*Rim Hardness + K_2*Core Hardness + K_3* Average Thickness)/3

Applying this equation in Table

TABLE III. MEASURED VALUES

Sr No	Measured Values			
	Measured YS (MPa)	Rim Hardness (HV/10kgf)	Core Hardness (HV/10kgf)	Average Rim Thickness (mm)
1	576	271	171	2.935
2	579	278	180	2.925
3	581	281	169	2.805
4	581	281	169	2.805
5	582	278	175	3.086
6	583	281	184	2.93
7	583	277	164	2.715
8	586	277	175	2.833
9	587	272	182	2.941
10	589	276	175	2.973
11	590	273	185	2.766
12	594	272	178	2.942
13	598	278	170	3.12
14	602	273	184	2.947
15	607	272	180	2.792
16	620	289	188	3.08

TABLE IV. CALCULATED VALUES

Sr No	Calculated Values			
	K_1=Measured YS/Rim Thickness	K_2=Measured YS/Core Thickness	K_3=Measured YS/ Average Rim Thickness	Calculated YS (MPa)= (K_1*Rim Hardness+ K_2*Core Hardness +K_3* Average Thickness)/3
1	2.125	3.368	196.252	576
2	2.083	3.217	197.949	579
3	2.068	3.438	207.13	581
4	2.068	3.438	207.13	581
5	2.094	3.326	188.594	582
6	2.075	3.168	199.01	583
7	2.105	3.555	214.733	583
8	2.116	3.349	206.884	586
9	2.158	3.225	199.626	587
10	2.134	3.366	198.116	589
11	2.161	3.189	213.343	590
12	2.184	3.337	201.903	594
13	2.151	3.518	191.667	598
14	2.205	3.272	204.276	602
15	2.232	3.372	217.446	607
16	2.145	3.298	201.299	620

We can opt out that the Values for Constants K_1, K_2 and K_3 are 2.130, 3.350, 203.034 respectively by above data.

V. CROSS-VERIFICATION OF EXPERIMENT ANALYSIS

TABLE V. REBAR OF SECTION 25, FE500D OF DIFF CAST & COMPARISON OF MEASURED AND CALCULATED DATA

Sr No	Cast Number	Measured by Experiment				Calculated Outcome	
		YS (MPa)	Rim Hardness (HV/ 10Kgf)	Core Hardness (HV/ 10Kgf)	Average Thickness (mm)	Calculated YS (MPa)	Variation
1	M62798-1	499	255	160	2.04	497.8	-1.2
2	M03977	524	268	176	2.095	528.6	4.6
3	M02517	526	256	156	2.592	531.4	5.4
4	M02556	527	257	151	2.651	530.5	3.5
5	M02517	539	257	163	2.651	543.9	4.9
6	M02483	540	262	160	2.66	544.7	4.7
7	M02483	545	253	169	2.685	550.1	5.1
8	M03975	550	257	192	2.27	550.5	0.5
9	M02559	564	320	176	2.095	565.5	1.5
10	M02704	664	320	195	3.273	666.5	2.5
11	M02713	666	311	200	3.287	666.6	0.6
12	M02483	667	326	195	3.295	672.2	5.2
13	M02704	668	323	197	3.295	672.3	4.3
14	M02713	669	319	201	3.303	674.5	5.5

Note: Values for Constants K_1, K_2 and K_3 are 2.130, 3.35, and 203.034 respectively.

A. Graph of Actual YS (MPa) and Calculated YS (MPa) to study the variation

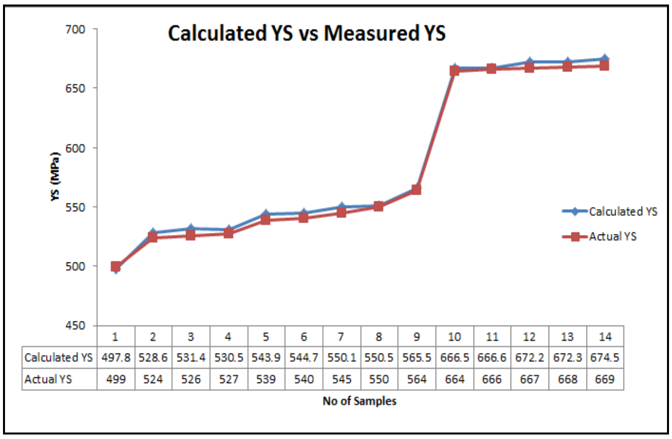

Fig. 5. Graph of Actual YS (MPa) (Y Axis) vs Calculated YS (MPa) (X Axis)

There is negligible variation in the Actual YS (MPa) and Calculated YS (MPa), which supports the equation.

VI. CONCLUSION

The Present study is helpful to estimate Yield Strength (MPa), with hardness (HV/10kgf) and average Rim thickness (mm) of rebar.

This system is useful for estimation of mechanical properties of Thermo-Mechanically Treated (TMT) bars produced in Merchant Mill for Fe500D, of Section 25mm. The system can predict the Yield strength (YS) of the bar.

Apart from predicting properties of rebar, this system is also useful to produce desired mechanical properties through proper process control. Thus, the system predicts and controls mechanical properties of the bars.

The assessment of properties helps proper monitoring, and thereby ensures control through corrective measures.

Prediction of properties helps to reduce the sampling size for mechanical testing.

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