Q. Which high strength deformed steel rebar is better for RC Construction?

TOR steel (Fe 415) or TMT (Fe 500)

Comments

These days, high yield strength deformed **(HYSD) TOR 415 & TMT 500** steel rebars are widely used in the construction of Reinforced Concrete (**RC)** structures. Following major parameters should be checked & compared while determining the quality of any steel rebars;

- **Tensile Strength**
- **Ductility**
- **Bendability**
- **Weldability**
- **Durability**
- **Behavior Under Cyclic Loading**

At first, the manufacture process and configuration of the TOR & TMT Steel rebars should be thoroughly understood which have been described in detail below;

(A) Manufacture Process and Configuration

TOR Rebars

Conventionally, Rebar's are produced by two different methods of production. In the first type, the bars possessing ribs at their surface are hot rolled from steel billets along with definite chemical composition to achieve desired strength.

Another one is produced by "Cold Working Process" that involves the stretching and twisting of the Mild Steel (MS) bar of **250 MPa** in a repeated manner. Rebars such produced are **Cold Twisted Deformed (CTD)** rebars

On loading, Steel will follow a linear elastic path similar to that of original mild steel till it reaches the point where unloading starts; which also becomes a new "yield point". Please refer FIG-1. The required increase in yield strength is achieved by appropriate selection of unloading point. These rebars are commercially manufactured under the trade name of **"TOR Steel". TOR** Steel of Fe 415 grade is widely manufactured in our country.

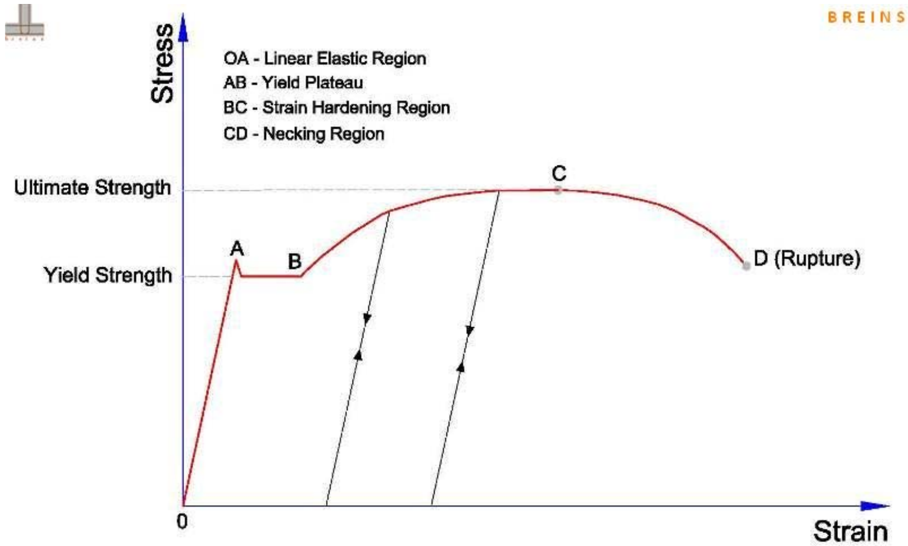

FIG-1 (Typical Stress-Strain Curve for Mild Steel Rebars; Showing Loading /Unloading Path)

TMT Rebars

TMT stands for **"Thermo Mechanically Treated"** steel rebars are produced by applying latest advanced technologies resulting in far more superior properties than conventional **CTD /TOR** rebars.

Thermo mechanical treatment is an advanced heat treatment process in which hot bars coming out of last rolling mill stand are rapidly quenched by a special water spray system. Rapid quenching provides intensive cooling that converts surface layer of the bar to a hardened structure called "Martensite" and with hot core; austenitic.

FIG-2, (Longitudinal View of TMT Steel Rebars)

The rebars cross-section with a temperature gradient is then allowed to cool in ambient conditions called “Self tempering”. Up-to this stage temperature of core is higher than that of the surface. Heat is then allowed to flow from the core to the surface resulting in tempering of the surface that gives outer surface a strength and toughness while core is turned into a “Ductile Ferrite Pearlite”.

Special Heat Treatment of Quenching & Tempering thus changes the structure of material to a composite structure of ductile inner core having a structure of “Ferrite Pearlite” and with strong, tough outer surface of “Tempered Martensite”.

This is how TMT rebars provide the unique combination of strength and ductility.

FIG-3, (Cross Sections of Various Steel Rebars Showing their Configuration)

Following describes the parameters those are to be considered in the determination of the quality structural steel rebars;

(B) Quality of Structural Steel Rebars

Tensile Strength

Obviously**, TMT 500** has higher value of yield strength of **500 MPa** to that of the **TOR 415** which has yield strength of **415 MPa** only. For an applied load on the structural element, definitely, use of **TMT 500** grade results in lower steel quantity. It has been found that use of **TOR 415 grade** almost increases the steel quantity by **20 %** to that of the **TMT 500** grade.

That also means if the total steel consumption in a project using **TMT 500** grade was **200 tons** then by using **TOR 415** grade total consumption would be **240** tons. There would be huge saving in steel of **40** tons by using **TMT 500** grade. Refer Appendix for more detail.

Ductility

Ductility is an ability of any material / structural element to deform, without collapse, even after reaching the failure load. This property protects the rupture / structural collapse or prolongs the rupture / collapse process. Materials with no ductility are brittle ones. Also, Structures with no ductility collapse almost suddenly/ immediately. It can't resist the failure load without sudden collapse. Mathematically, Ductility is expressed as ratio of Ultimate Deformation to Yield Deformation. Refer FIG-4.

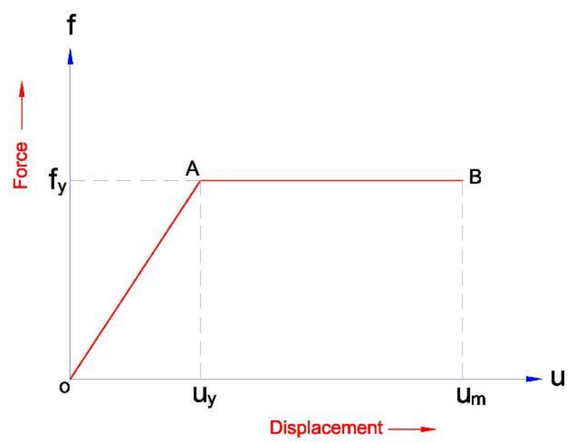

FIG-4, (Load Deformation Curve of an Elasto-Plastic System)

$$Ductility = \frac{u_m}{u_y}$$

$$u_m = Ultimate\ deformation$$

$$u_y = Yield\ deformation$$

Elongation along with its **Yield Strain/Deformation** (**u_y**) of a steel rebar plays a major role in its ductility. Elongation of a steel rebar refers to ability to elongate before failure. It is an ultimate strain/deformation (**u_m**) at fracture. Yield strain/deformation corresponds to the Yield Strength (**f_y**); which is maximum load that an element can undertake. Refer FIG-4.

Higher elongation value provides higher ductility in general. Also, Low yield strain value of steel rebars provides higher ductility. Steels permitted to use as reinforcement bars as per the **IS Codes; IS : 432-1982, IS : 1786-1985** along with their characteristics are as follows:

Type of Steel	Yield Stress	Yield Strain	Minimum Elongation
Mild Steel (MS)	250 MPa	0.0031	23 %
HYSD	415 MPa	0.0038	14.5 %
	500 MPa	0.0042	8 %
	550 MPa	-	6%

Recent codes demand for the higher elongation values with a minimum elongation of **14.50 %** in all types of steel rebars.

TMT rebars with its soft ductile core of "Ferrite Pearlite" exhibit excellent ductile behavior with an elongation value of 16.0%. Commercially available **TMT** brands even claim to have elongation value of 18-25 %.

Though the Yield Strain of **TMT** rebars is higher than that of **HYSD-415**; sufficient ductility can be achieved because of its higher elongation values in Reinforced Concrete (RC) Structures. In RC technology, it's not only the yield/elongation values of a steel rebar that improves its ductile behavior. ***In fact in RC elements, it's the interplay between the steel rebars and concrete properties that determines the ductility***.

By means of proper design and maintaining other detailing factors sufficient ductile value can be easily achieved even with the steel rebars having lower elongation values and higher yield strain.

Bendability

Bendability is required to give steel rebars a desired shape; such as at the end connections of Beam-Column Joints.

TMT rebars with its soft inner core results in good bendability to achieve various shapes. **TOR** steel has proven track of its bendability.

Weldability

TMT rebars with low carbon content are highly weldable. Appropriate Carbon content is necessary to impart strength in rebars. However higher carbon content hinders the weldability.

Various codes allow maximum Carbon content of 0.30 %. However keeping in view of the superior weldability characteristics, the maximum Carbon content should be less than 0.25%.

Some of the available commercial brands in Nepal claim to have their **TMT** rebars with Carbon content 0.17% - 0.25%.

Durability

Resistance against the corrosion of steel rebars is the key parameter in durability of structure.

Resistance of rebars against corrosion depends upon its chemical composition. Though good quality concrete is a pre-requisite for the corrosion resistance of RC structure, the quality of rebars has also a significant influence on it.

During the cold twisting process a part of residual strain is withheld in the periphery of the **CTD** bars. This residual strain in **TOR** initiates the corrosion process faster than in **TMT** rebars that doesn't include and twisting and stretching process.

Behavior Under Cyclic Loading

Earthquake imposes repetitive loading for number of cycles or cyclic loading in a structure. In such, load that doesn't cause failure in a single application can result in failure when applied for number of cycles. This process of failure under the repeated loading is also termed as **"Fatigue"**.

Thus behavior of materials under the cyclic loading should also be checked. It has been found that the stress-strain behavior of materials like steel is also a **history dependent**.

TMT 500, Thermo-Mechanically Treated rebars are intrinsically hard and strong than **TOR 415**. Materials those are initially hard and strong show **Softening Behavior**, whereas initially soft materials show **Strain-Hardening** under cyclic loading.

Both **TOR 415** & **TMT 500** rebars with their higher elongation values in minimum of **14.50%** can accommodate inelastic strains imposed by cyclic loading; if proper ductility factor is maintained in a RC structure.

Conclusion

TMT rebars produced from latest thermo-mechanical treatment possess far better qualities than conventional **TOR** rebars in much ways as discussed above. It also results in huge saving in cost of steel by almost 20%. Please refer Appendix for calculation.

Nevertheless, only Genuine **TMT** rebars made from the Steel Billets obtained from primary source, Iron ores, should be used. **TMT** rebars are often manufactured from the secondary sources as scrap metals.

Also the process of **TMT** manufacture is sophisticated & advanced process that changes the atomic structure in metal to give its enough strength along with the desired ductility. It is not ensured that all the steel mills from the various companies could perform these processes in a specified manner as they claim.

If **TMT** rebars obtained from secondary sources and manufactured in technically sub-standard steel mill are used; then such **TMT 500** rebars could have lower strength than **TOR 415**. It also could impart high degree of hardness due to high carbon content and other defective chemical compositions resulting in lower ductility and other kinds of defects that will put infrastructures in peril.

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APPENDIX

Comparative Study on Strength & Ductility

Example-1 on Flexural Elements, BEAMS

Let's Consider,

Beam Size

Depth of Beam = 600.00 mm

Width of Beam = 230.00 mm

Applied Moment = 150.00 Kn-m

Grade of Concrete = M20

Design of the above mentioned Beam yields following results.

Grade of Steel	Area of Tensile Steel Required	Depth of Neutral Axis	Rotational Ductility Factor
TOR 415	857.27 sq.mm.	186.91 mm	1.85
TMT 500	711.54 sq.mm.	186.91 mm	1.68

It is quite clear from the above example that use of **TOR 415** results in higher area of steel reinforcement. But its ductility is higher than that of beam section reinforced with **TMT 500**. Though the ductility factor of beam section reinforced with **TOR 415** is higher, it all depends how much of ductility factor is required. Suppose if the ductility factor to be maintained is just 1.5 only, then use of **TMT 500** steel rebars would be quite beneficial.

Also, in the above example, ductility factor in case of **TMT 500** could be enhanced to 1.85 by meager increase in beam depth by 15 mm; that again lowers its steel quantity from 711.54 sq.mm to 686.40 sq.mm due to increase in beam depth to 615 mm.

From this example it is quite clear that in order to achieve the **required Strength for a given Ductility Demand**, use of **TOR 415** grade results in increase in steel quantity along with meager decrease in concrete quantity in comparison to use of **TMT 500 grade** steel rebars by the following percentages:

% Increase in steel quantity in using TOR 415 over TMT 500 = + 24.89 %

% Decrease in concrete quantity in using TOR 415 over TMT 500 = - 2.44 %

<u>Example-2 on Axial-Bending Elements, COLUMNS</u>

Let's Consider,

Column Size

Width of Column = 300.00 mm (X-dir.)

Depth of Column = 400.00 mm (Y-dir.)

Applied Loads

P_u = 905 Kn

M_x = 68.00 Kn-m

M_y = 110.00 Kn-m

Grade of Concrete = M25

Biaxial Design of the above mentioned column with reinforcement distributed equally on two sides yields following results.

Grade of Steel	% of Steel Required	Area of Tensile Steel Required	Rebar Detailing
TOR 415	2.38%	2856 sq.mm.	4-20Φ+8-16Φ
TMT 500	2.00%	2400 sq.mm.	4-20Φ+6-16Φ

% Increase in steel quantity in using TOR 415 over TMT 500 = + 19.00 %