Attributes of Ductile Reinforcing Steel

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Introduction

Reinforced concrete is a composite material. By definition a material is composite if it is made of 2 different materials with highly divergent and even opposite properties. Manufactured concrete is excellent in compression and a lightweight material but brittle which make it useless in any member subjected to tensile forces. To overcome this steel bars are placed in concrete member zones where tensile forces are present. Steel has excellent tensile properties and highly ductile compared to concrete. Therefore a combination of steel and concrete confers unique properties to RCC which retains the most desirable characteristics of both the materials.

As reinforced concrete is the mainstay of infrastructure and housing construction throughout the world, cement and reinforcing steel has emerged as major manufacturing industries in every country. This has led to codification of RCC construction practice throughout the world to simplify and streamline the design and construction process. This in turn has led to the standardization of material specifications for the construction industry. Reinforcing steel production is a major industrial segment in every country of the world. It is generally produced to national standards specification. As international trade has grown in volume and scope the demand for a material specification across major national standards has grown. The Geneva based International Standards Organization (ISO) under the tutelage of the World Trade Organization (WTO) played a pivotal role in the internationalization of material standards. Today the European Community nations follow common material specifications for thousands of items and reinforcing steel is no exception. Standardization of products to national and international specifications serves 3 useful purposes. First, it simplifies the exchange of goods as buyers and sellers have a common specification. Further, legal enforcement of contract specifications becomes easier and transparent. Most important the design profession can prescribe material specification as per well defined norms which are available in the area.

The international standard for reinforcing bar specification is ISO 6935. It has been adopted by the national reinforcing steel standards of the entire European Community of nations as well as Russia and all the CIS nation states. In Asia India, China and Japan along with the ASEAN nations has adopted the ISO based standards for steel and many other material standards as well. Bangladesh adopted the ISO standard in 2006. The strongest motivation, for this move is to remain globally competitive, by making a product for both the domestic and international market. It is worth mentioning that many of the nations adopting the ISO based standard are in the high seismic category. Among them are Turkey, Italy, and New Zealand. China and India both have areas of intense seismic activity.

ISO and ASTM Standards Compared

Since many practicing engineers in Bangladesh are usually accustomed to using the U.S. based ASTM A-615 re-bar standard the various grades in both the standards are compared for easy understanding.

Table. 1 Strength comparisons of steel standards

ASTM 615	ISO 6935
Grade 40 [40,000 psi = 275 MPa]	Grade 300 [300 MPa = 43,500 psi]
Grade 60 [60,000 psi = 415 MPa]	Grade 400 [400 MPa = 58,000 psi]
Grade 75 [75,000 psi = 520 MPa]	Grade 500 [500 MPa = 72,500 psi]

There is another distinguishing feature of the ISO 6935, its restricted chemistry versus the open chemistry of the ASTM A-615 standard which is tabulated below.

Table.2 Chemistry of ASTM and ISO Standards

Chemical Composition	ASTM A 615 Grade 60	ISO 6935 Grade 500W
Carbon %	No limit	0.24% Max
Manganese %	No limit	1.65% Max
Silicon %	No limit	0.60% Max
Phosphorous%	0.06% Max.	0.06% Max
Sulphur %	No limit	0.06% Max
Carbon Eqv.	No limit	0.51% Max

Ductile Grades of Steel

Within the umbrella of the ISO 6935 standard a new generation of high strength reinforcing steels has been developed which is used in all high grade construction with safety and performance under adverse conditions of prime concern. The distinguishing feature of these steels is both the yield strength and ultimate strength have a minimum lower limit and maximum upper limit. This is clearly shown in the table below. <u>In contrast the ASTM 615 bars had only minimum yield and ultimate strength requirements with no specified upper limits.</u> The leading ductile or earthquake bar standards of several countries are compared below:

Table. 3

SEISMIC STANDARDS

Country	Standard	Quality	Yield	Tensile	Elongation	% Agt	Re/Rm	Carbon %	Carbon Eq. %
USA	ASTM A 706	Gr 60	420-540	550	14		>1.25	0,30	0,55
Australia	AS 4671	GR 500 E	500-600			10	>1.15 - 1.40	0,22	0,50
U.K.	BS 4449	B 500 C	500-650			7,5	>1.15 - <1.35	0,22	0,50
Norway	NS 3576-3	B 500 C	500-650			7,5	>1.15 - <1.35	0,22	0,50
Greece	Elot 1421-3	B 500 C	500-625			7,5	>1.15 - <1.35	0,22	0,50
Italy	UNİ 6407	FeB 44 K	450-560			7	>1.13 - <1.35	0,22	0,50
Spain	UNE 36065	B 400 SD	400-480	480	20	9	>1.15 - <1.35	0,22	0,50
		B 500 SD	500-625	575	16	8	>1.15 - <1.35	0,22	0,50
Portugal	E 455	A 400 NR SD	400-480			8	>1.15 - <1.35	0,22	0,50
	E 460	A 500 NR SD	500-600			8	>1.15 - <1.35	0,22	0,50
New Zealand	NSZ 4671	GR 500 E	500-600			10	>1.15 - 1.40	0,22	0,50
Canada	CSA.G.30.18-M92	Gr 400	400-525	560	13		>1.15	0,30	0,55
		Gr 500	500-625	625	12		>1.15	0,30	0,55
Colombia	NTC 2289	Diaco 60	420-540	550	14		>1.25	0,30	0,55
Israel	SI 4466-3	400 W	400-520	500	12		>1.25	0,24	0,55
Venezuela	Covenin 316	W60	415-540	620	14		>1.25	0,30	0,55
		W70	490-637	620	14		>1.25	0,30	0,55
EKSISMIK			500-650	600		8	>1.15 - <1.35	0,22	0,50

Agt = Percentage total elongation at maximum force

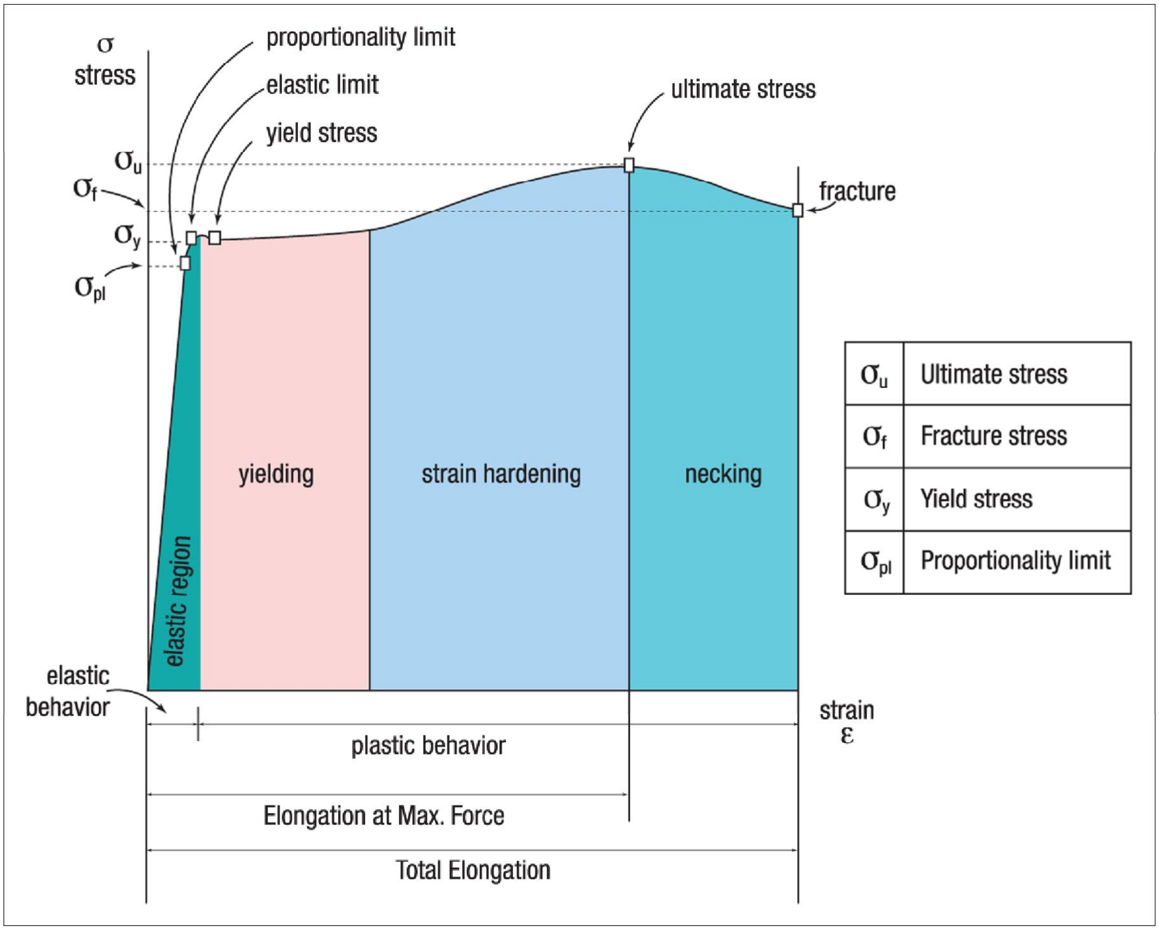
Some of the more internationally recognized 'Ductile' also literally known as earthquake grades of steel are shown below

Attribute	ASTM 706 Grade 60	AS/NZS 4671 Grade500E	BS4449 Grade 500C	JIS G3112 SD 490
ORIGIN	**U.S.A.**	**Australia-New Zealand**	**U.K.**	**Japan**
Yield strength, Fy,Mpa	**540≥Fy≥420**	**600≥ Fy ≥500**	**650≥ Fy≥ 485**	**625≥Fy≥490**
Ultimate strength Ts, Mpa	**550 Min ≥1.25Fy**	**1.40Fy ≥Ts≥1.15Fy**	**1.38Fy≥Ts≥1.13Fy**	**620 Min**
Elongation Gauge	**200 mm**	**5d**	**5d**	**5d**
Elongation: Fracture	**10% – 14%**	**--**	**--**	**12% Min.**
Elongation: Max. Force	**--**	**≥10%**	**6% Min.**	**--**

The 5 Measures of Ductility

The elongation at fracture is the most common and easily understood measure of ductility. It measures the total strain which the test specimen undergoes from the onset of loading to the point of rupture on a Universal Testing Machine (UTM). The elongation at maximum force is another measure of ductility which has gained currency in recent years. The elongation at maximum force is best understood by referring to the stress-strain graph shown below. It refers to the highest stress level shown on the y-axis of the graph. The corresponding strain on the x-axis of the graph is the elongation at maximum force. The 3rd measure of ductility is the ratio of tensile stress to yield stress, which is a measure of strain hardening, under plastic deformation.

Fig.1 Stress-Strain Graph of Ductile Grade of Steel



The last 2 measures of ductility are the simple bend and re-bend tests. All bar standards of the world have some requirements for this test. It is the most simple and direct measure of ductility and requires inexpensive equipment to perform the test. Despite the apparent simplicity of the bend test it is a very crucial test as it reveals manufacturing and processing defects in the steel which is not apparent from the yield and tensile strength of the steel. A steel bar may easily pass the tensile test yet completely fail in the bend / re-bend test which reveals its true brittle structure. In the bend test the bar specimen undergoes tensile deformation on the outer surface and compression deformation in the inner surface.

Fig.2 Bending Test

Fig. 3 Ductile Rupture

One of the most notable features of ductility is the reduction in cross-sectional area of the test specimen in rupture. A ductile material undergoes complex tri-axial deformation after the ultimate tensile stress and the failure is a combination of tensile and shear forces. While the reduction in area is not a requirement in any of the worldwide bar standards it is a very direct indicator of material ductility.

Design Consideration

Performance based RCC design dictates that structural elements form a plastic hinge under overload conditions. Further, the plastic hinge must be capable of undergoing large inelastic deformation with no significant reduction in load carrying ability. Structural designers would like to know the maximum strength of a plastic hinge zone so that other elements of a structure can be designed to remain elastic. For example, designers of RCC buildings would want the beam to 'fail' by forming plastic overload hinges, in dissipating earthquake forces but not the columns. This is known as 'strong column weak beam' design to minimize loss of life in an earthquake. For such design the design engineers must know the minimum and maximum yield strength and the minimum and maximum tensile strengths of the reinforcing steels. Further, the use of higher strength steel relieves bar congestion in beam and column intersections, which is the most critical zone for safety from earthquakes. As the above ISO based bar standards place a definite lower and upper limit to the yield and tensile strength of the bar, probable over strength capacity of a plastic hinge can be inferred from test properties of the reinforcing steel manufactured to ISO standards.

The U.S. government's Federal Emergency Management Agency (FEMA) has advocated the following design strategy for improving the overall ductility of framed RC structures:

Strategies to Improve Ductility

- **Use low flexural reinforcement ratio**
- **Add compression reinforcement**
- **Add confining reinforcement**

<u>The Ductile bar Manufacturing Process</u>

The mechanical properties of the new generation ductile grade high strength reinforcing bar are derived from the restricted chemistry steel billets and by a unique in-line heat treatment in the bar rolling mill.

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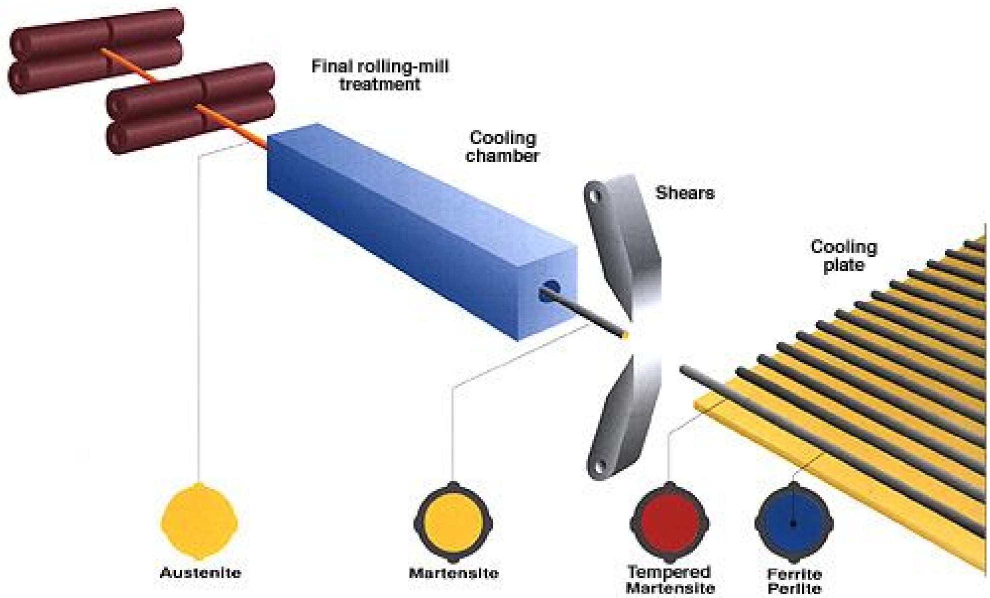


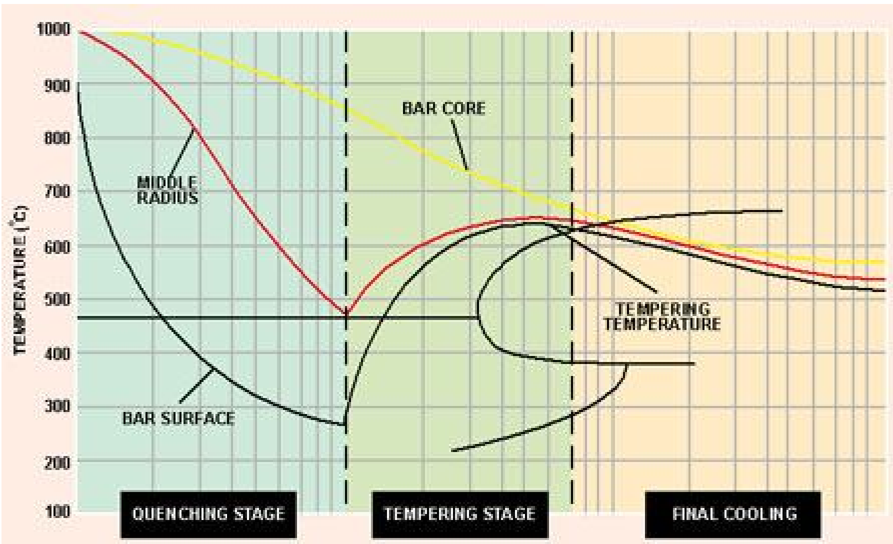
The above schematic diagram illustrates the **Quench & Temper** process which converts low carbon steel into 500 MPa high strength bars with a guaranteed yield strength of 500 MPa.

It consists in subjecting the hot rolled steel to an in-line heat treatment in 3 successive stages:

- As soon as it leaves the final mill stand, the product is rapidly and energetically cooled through a short cooling installation, where it undergoes surface hardening (martensite layer)
- As soon as this quenching operation is stopped, the surface layer is TEMpered by using the residual heat left in the CORE of the bar (self tempering of the martensite layer).
- The third stage takes place while the product lies on the cooling bed where the bar is subjected to normal cooling down to ambient temperature (transformation of the residual austenite in the core)

- The TTT diagram graphically explains the internal transformation in the micro-structure of the steel as it is rapidly cooled “quenched” for a precise interval and then naturally cooled at room temperature.

Time Temperature Transformation (TTT) Diagram of the Q&T process.



The above process requires precise process control in the rolling mill as the quench process is time and temperature sensitive. The Quench and Temper process has clearly emerged as the preferred manufacturing route for reinforcing steel throughout the world due to the excellent combination of high strength and ductility of the steel which is obtained through this process.

The heat treated steel has a dual metallurgical structure, a soft inner core and a hard outer casing.

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Economy and Safety

As the construction industry demands greater economy and cost reductions in the face of ever rising price of all types of construction material including steel reinforcements the demand for higher strength steel has gone up worldwide.

All buildings and structures in the developed world and in the Middle East and in the ASEAN region are designed and built on high strength reinforcing steel manufactured through the heat treatment process. The reason is not only economic but better performance of the structure under adverse conditions of earthquakes and storms.

Ductile Steel Grades in Bangladesh

In Bangladesh BSRM Steels Ltd. was the first to introduce high strength ductile Grade 500 MPa yield strength steel reinforcement. The Grade 500 steel produced by BSRM is of the ductile or earthquake variety with controlled lower and upper limit yield strengths and the lower and upper limits in tensile strengths as well. It fully conforms to the internationally accepted U.K. bar standard B.S. 4449 Gr.500 and the Australia-New Zealand AS-ANZ 4671 Grade 500E and meets the major requirements of both the U.S. standard ASTM 706 and the Japanese standard JIS G3112 SD 490 (typical Mill Test Reports enclosed)

Traditionally construction in Bangladesh has relied on Grade 60 or 400 MPa strength steel for all types of construction. The scenario changed rapidly with the introduction of Grade 500 steel last year by BSRM Steels Ltd. As the use of Grade 500 steel reduces steel consumption by up to 15% compared to Grade 60 steel the introduction was an instant success. Many of the country's top developers and designers of high rise buildings switched to Grade 500 for the inherent economy in the use of this grade of steel.

It is worth mentioning that the monumental Bangabandhu Bridge over the mighty Jamuna River was built with a ductile grade of re-bar conforming to U.K. standard B.S. 4449. At the time no manufacturer in Bangladesh had the means to produce any type of ductile reinforcements; the entire steel for the bridge was imported from Belgium and Turkey. In 2008 the cable stayed bridge over the river Karnafuli was built using BSRM ductile bar conforming to Grade 500

Comments on this article
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