STEEL

Lecture - 2

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Content

1. Market Form of Steel
2. Types and Grades of Reinforcing Steel
3. Significance of corrosion resistance in reinforcement
4. Type of Reinforcing Bar
5. Influence of Different Chemical Ingredients on Properties of Rebars
6. Stress Strain Curve of Mild and CTD Bar

Market Form of Steel

Reinforcement Steel

Structural Steel

Significant Reason

Concrete is strong in resisting the compression force but weak to resist the tension
steel is strong in tension and makes a good bond with concrete

A sufficient strength in all aspect and safe to carry the load. Use to construct the building in mono and hybrid form.

Types and Grades of Reinforcing Bars

Types of Steel	Bar Diameter	0.2% Proof Stress	Elongation
Mild Steel Grade -I	Up to and including 20 mm Over 20 mm up to and including 50 mm	250 N/mm^2 250 N/mm^2	23% 23%
Mild Steel Grade –II	Up to and including 20 mm Over 20 mm up to and including 50 mm	225 N/mm^2 215 N/mm^2	23% 23%
Medium Tensile Steel	Up to and including 16 mm Over 16 mm up to and including 32 mm Up to and including 50 mm	350 N/mm2 340 N/mm2 330 N/mm2	20% 20% 20%
High Strength Deformed Steel Bars	All Sizes	415 N/mm2 500 N/mm2 550 N/mm2	14.5% 8% 6%
TMT Bars	All Sizes	415 N/mm2 500 N/mm2 550 N/mm2	22% 20% 18%

Types and Grades of Reinforcing Bars

Good steel should not have carbon content of more than 0.25%, sulphur content of more than 0.05% and phosphorus content of more than 0.05%. Effectiveness of concrete reinforcement may be enhanced by the use of low-alloy steel, or by mechanical strengthening, or by heat treatment.

Mechanical strengthening of steel is done by drawing, stretching, twisting; the yield point of steel rises by about 30%.

Heat treatment increases strength and improves mechanical properties of steel and effects 30 to 40% savings on reinforcement.

Types and Grades of Reinforcing Bars

Steel bars can also be strengthened by cold drawing after rolling. Mild steel has a definite yield point. *Cold working* increases the yield stress of mild steel. Higher yield strength of reinforcing steel bars lowers the steel requirement and thus the cost of reinforcement and its fixing is reduced. The major drawback of cold working is the introduction of internal stresses in steel bars. Some of the other disadvantages of cold working are reduced ductility of steel, and reduced shear strength of RCC beams; the longitudinal tensile reinforcement is reduced. Heating of cold worked steel to high temperatures results in annealing of steel causing loss of increased strength due to cold working.

Types and Grades of Reinforcing Bars

Mild Steel Bar

For impacts and suddenly applied loads mild steel reinforcement may prove to be a better choice since high yield steels are more brittle and may fail under such conditions.

High yield Strength Deformed Bar

HYSD bars have lugs, ribs, or deformations on the surface *which inhibit longitudinal movement of the bar relative to the surrounding concrete*. Thus, the deformed surface ensures better bond between reinforcement and concrete. These bars do not have a **definite yield point**. HYSD bars result in a considerable increase in yield, tensile and bond strength when twisted hot or cold.

Cold twisted deformed (CTD) bars are most suitable for building purposes and are widely used in India. CTD bars with trademark TOR are called TOR-steel. Tor-steel is high strength deformed bars with high yield and bond strength. These bars result in almost 40% economy.

Duggal SK, Building Material

Types and Grades of Reinforcing Bars

Thermo Mechanically Twisted Bar

These are extra high strength reinforcing bars, *which eliminate any form of cold twisting*. In this process, the steel bars receive a short intensive cooling as they pass through a water cooling system after the last rolling mill stand. The reduction in temperature converts the surface layer of the steel bar into a hardened structure.

This phase of intensive cooling is further followed by cooling in atmosphere, so that the temperature of core (which is still hot) and the temperature of the cooled surface is equalized. ***Hence, the surface layer gets tempered by the heat form the core***. The resulting structure is a tempered **martensite zone** at the periphery and a fine grain ***ferrite pearlite*** structure in the *centre zone*.

Types and Grades of Reinforcing Bars

Thermo Mechanically Twisted Bar

Due to the improved properties of *high strength* combined with *toughness and ductility*, *TMT bars score over mild steel plain and CTD steel bars*. **TMT steel exhibits a definite yield point**. It can resist high temperature up to 500°C with no loss of strength. These are more ductile compared to CTD bars. TMT bars possess excellent bendability due to the unique feature of uniform elongation.

TMT bars have very good **weldability**. They do not suffer loss of strength at the weld joints. These bars can also be easily welded with cold twisted bars. No pre-heating or post-heating is required during welding.

Types and Grades of Reinforcing Bars

Thermo Mechanically Twisted Bar

The unique feature of these bars is their high fatigue resistance on dynamic loading on account of the high strength of the surface layer. The thermally hardened reinforcing steel bars are more suitable for use in places prone to fire hazards, because of the thermal stability of the heat treated structure of the bars and a total absence of a cold worked structural zone. TMT bars have high percentage of uniform elongation, thus high formability.

These bars can be used for general concrete reinforcement in buildings, bridges and various other concrete structures. They are highly recommended for use in high-rise buildings because of the saving in steel due to the higher strength

Types and Grades of Reinforcing Bars

Saving in steel using TMT Bars

	TMT 415	TMT 500	TMT 550
Yield Strength, Mpa, Min	415	500	550
Saving in steel compared to Plain bar	40%	44%	47%
Saving in steel compared to Fe-415 CTD	-	14%	19%

The latest development is steel reinforcing bars is thermo-mechanically treated high-strength corrosion resistant (TMT-HCR) rebars. The TMT-HCR rebars are concrete embedded bars, which have superior resistance to aggressive weather conditions.

The chemistry of TMT-HCR rebars is appropriately designed for **substantially reducing atmospheric and marine corrosion**.

Types and Grades of Reinforcing Bars

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Is really Corrosion a big threat for the life of structure ?

Money Invested on Corrosion Remedy

In 2014, the direct cost of corrosion in India was Rs. 4 lakhs crores/year
Equivalent to 3 to 4% of GDP

Up to 50% of corrosion budgets
50% of structures hit a repair in about 10 years
30% of steel is used for repair
40% of cement is used for repair

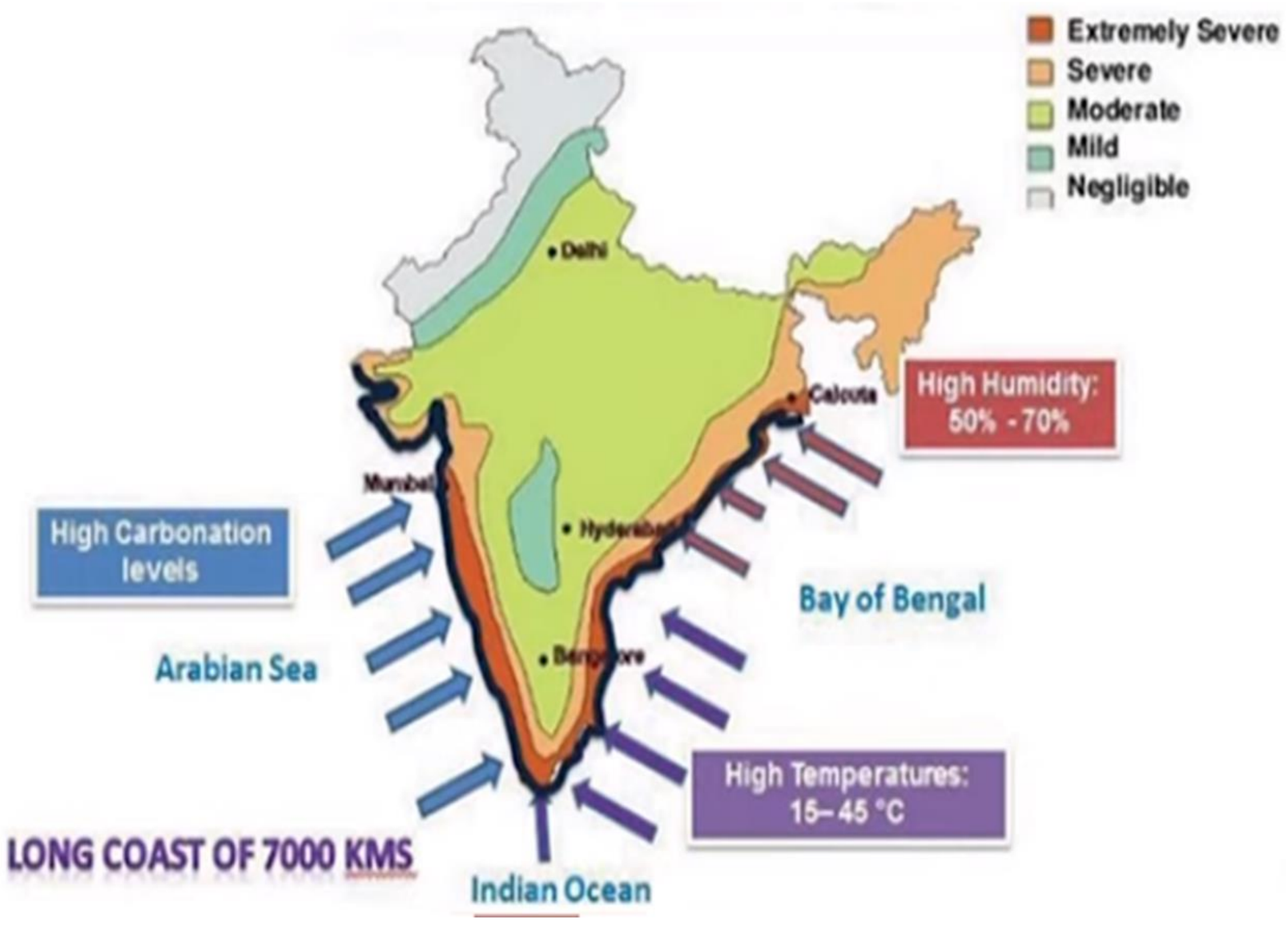
A corrosion protection strategy to minimise the repair and maintanance cost is a must.
No technology is available to achieve long corrosion free service life

Chloride induce corrosion map of India

- ✓ Structures constructed *along the coastline* is mainly subjected to *chloride induced corrosion* .

- ✓ However, *humidity* in the range of *60%-70%* is favourable for *carbonation induced corrosion.*

- ✓ Always consider *local effect* for the *structures* constructed *away* from the *coastal line*



Service life of structure affected due to corrosion

Spalling of concrete and rusting of reinforcement.

ACI 201.1R-08, Guide for Conducting a Visual Inspection of Concrete in Service

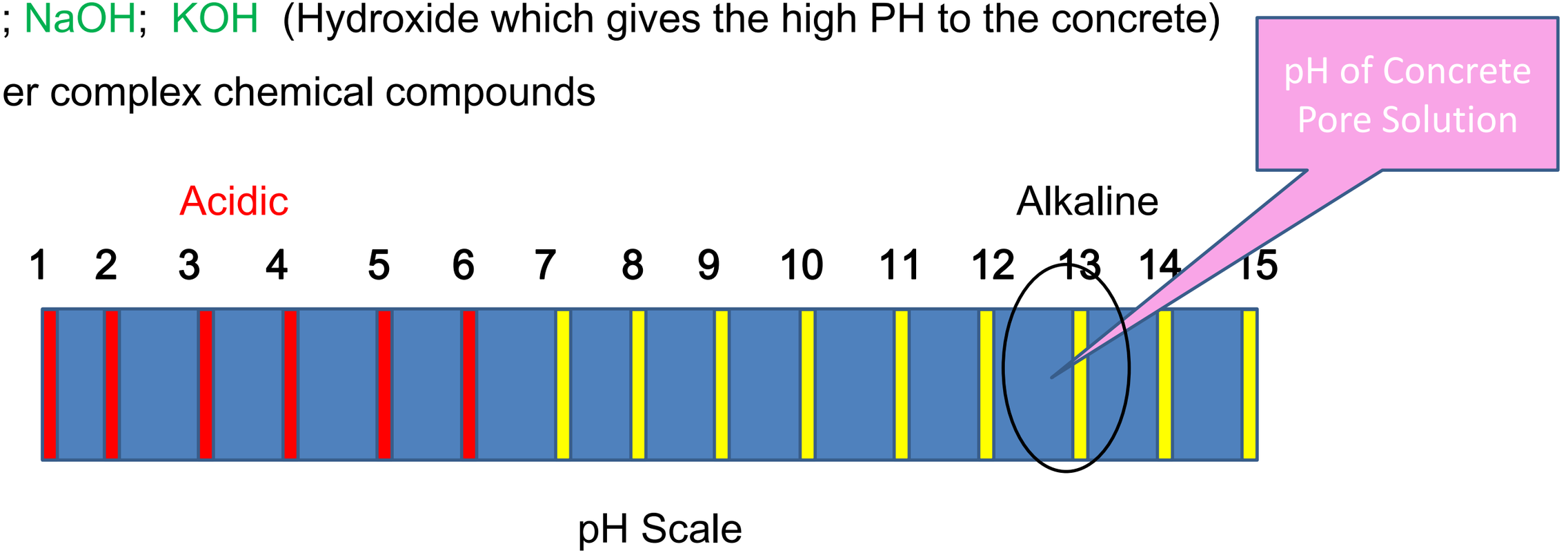
Concrete and Steel

Concrete microstructure and pore solution

C-S-H

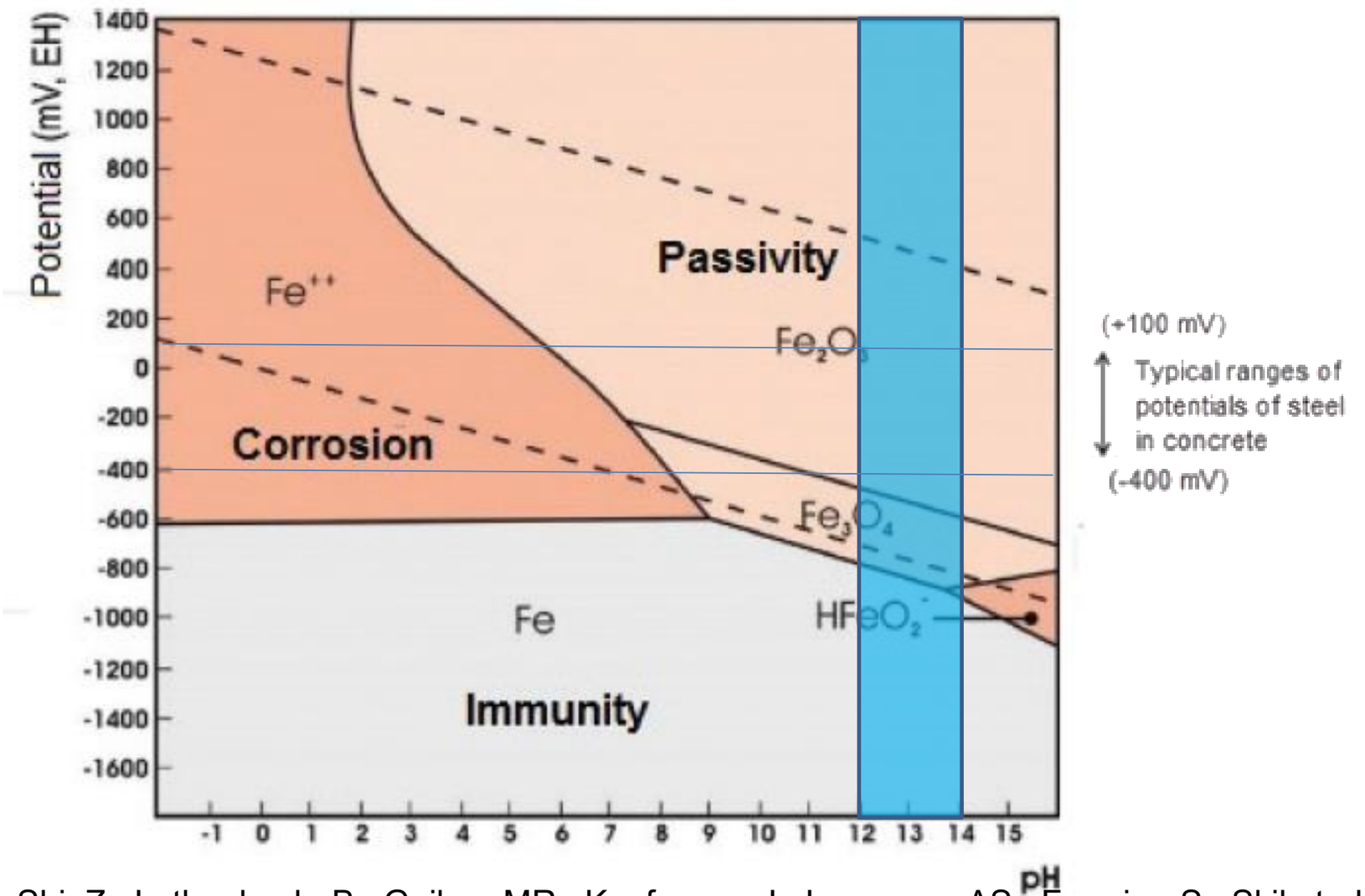
$Ca(OH)_2$; NaOH; KOH (Hydroxide which gives the high PH to the concrete)

Many other complex chemical compounds



How Steel Inside of Concrete Free From Corrosion

If Steel is embedded in concrete having a range of pH 12 above, the passivity formed which neglect the occurrence of corrosion. That is the reason why steel perform long in concrete

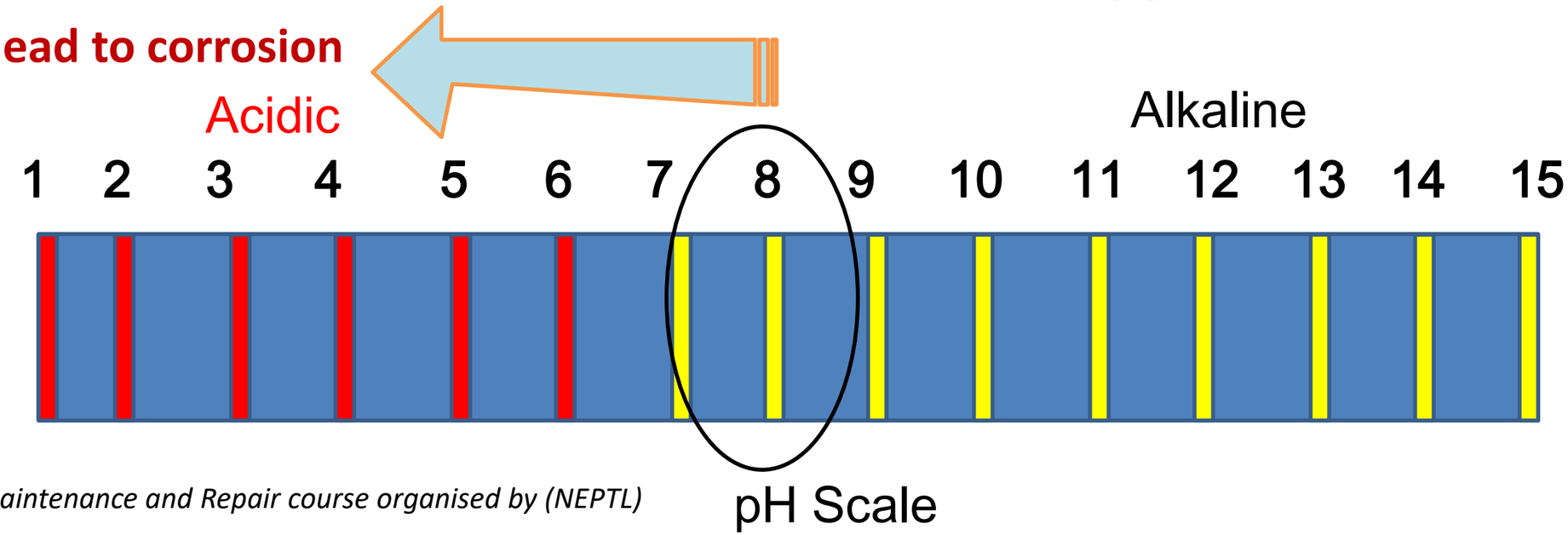


Shi Z, Lothenbach B, Geiker MR, Kaufmann J, Leemann AS, Ferreiro S, Skibsteda J. Experimental studies and thermodynamic modeling of the carbonation of Portland cement, metakaolin and limestone mortars. Cement and Concrete Research. 2016;88:60-72. DOI: 10.1016/2016.06.006

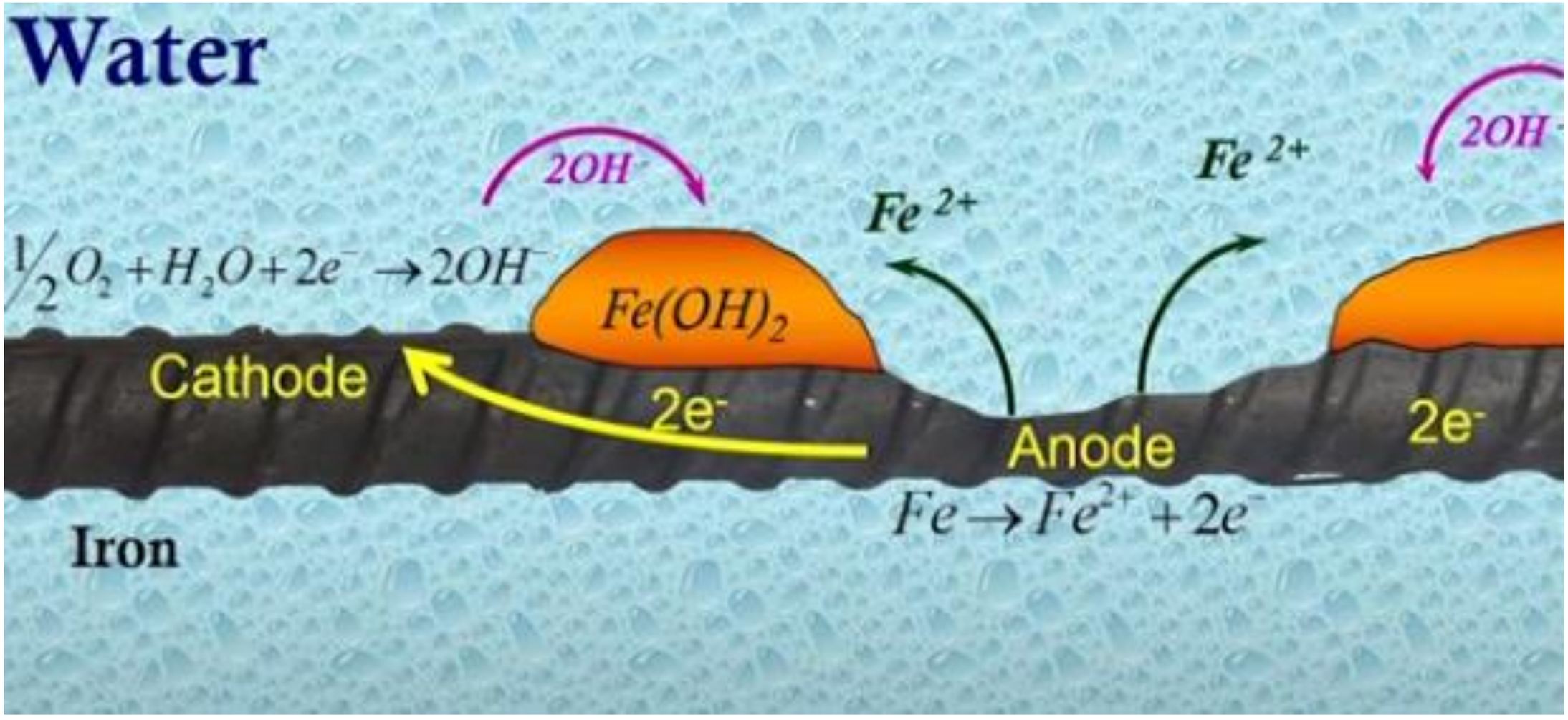
Concrete and Steel

- Steel does not corrode due to high pH of concrete pore solution.
- A protective layer (“Passive layer”) is formed
- A thin, invisible and stable layer of initial corrosion products (i.e., iron oxides and hydroxide)
- However, corrosion can occur when exposed to aggressive condition

> 9 Mpa lead to corrosion

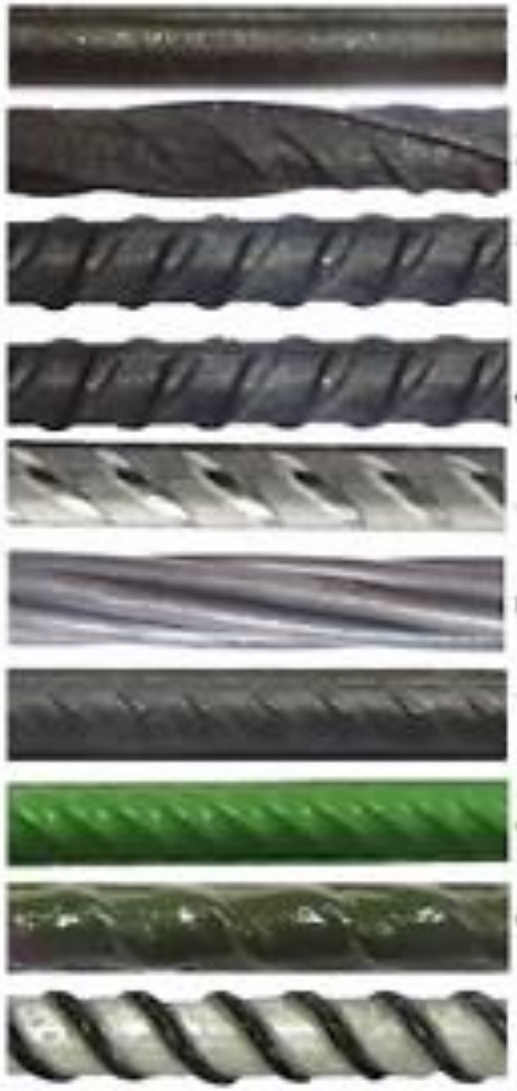


Concrete and Steel



Anode and Cathode can exist on the same piece of metal

Type of Reinforcing Steel



Plain and Ribbed (hot rolled) mild steel bars

Cold twisted deformed (CTD) steel bars

Thermo mechanically treated (TMT) or Quenched and Self-tempered (QST) Steel Bars

Corrosion-resistance Steel Bars

Stainless Steel Bars

Prestressed Steel Strands

Galvanized Steel Bars

Fusion Bonded Epoxy Coated (FBEC) Steel Bars

Cement Polymer Composite Coated (CPCC) Steel Bars

Fiber Reinforced Polymer Composite (FRP) Steel Bars

Plain and Ribbed (Hot Rolled) Mild Steel Bar

- **Plain bars**

First type of hot rolled bars (after the flat and strip reinforcement)

More resistant against corrosion than the cold-rolled steels

Not very much used in construction – due to the demand for higher strength

- **Ribbed bars**

Enhanced Bond Strength

Cold Twisted Deformed (CTD) Bar

- Ribbed steel bars, twisted to increase the yield strength

  Cold working or work hardening

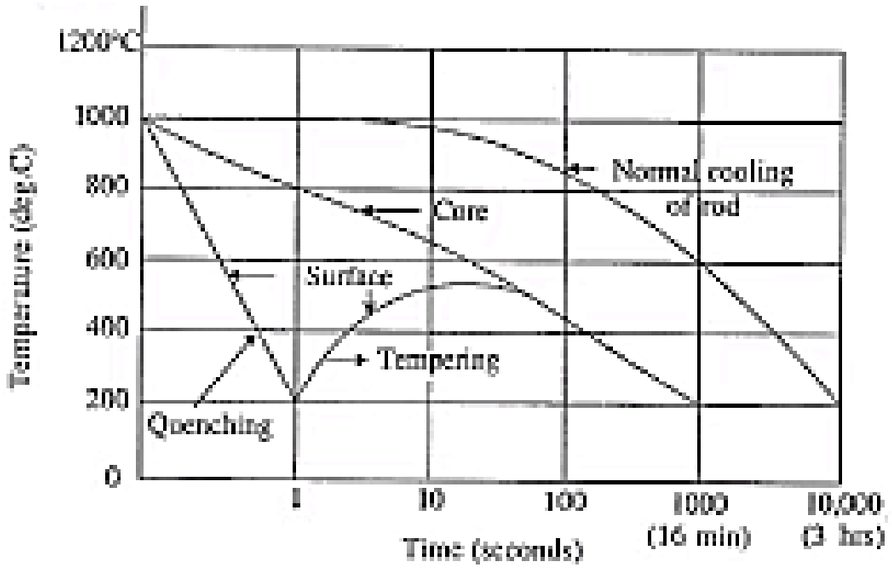
  Cold : at a temperature below the recrystallization temperature (Ususally between 400 – 700 C)

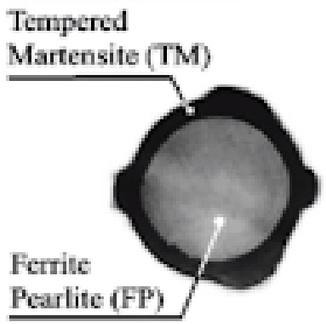
  Residual Stress have higher energy level

  Resistance to corrosion decreases due to residual stresses

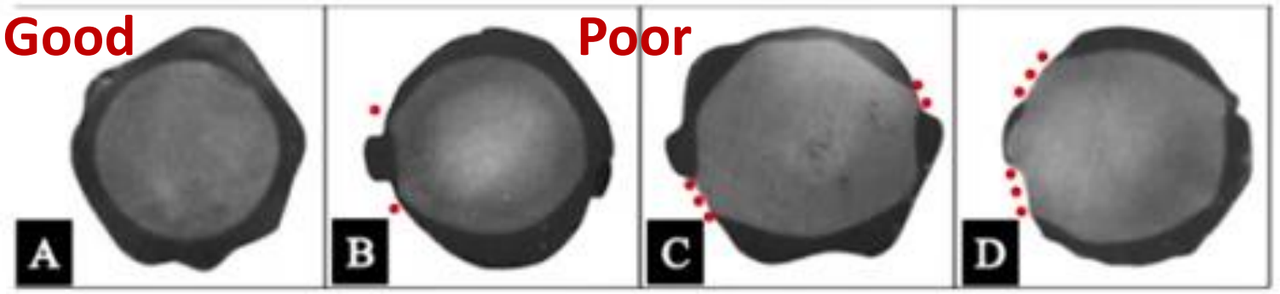
CTB bars no longer used due to poor corrosion resistance

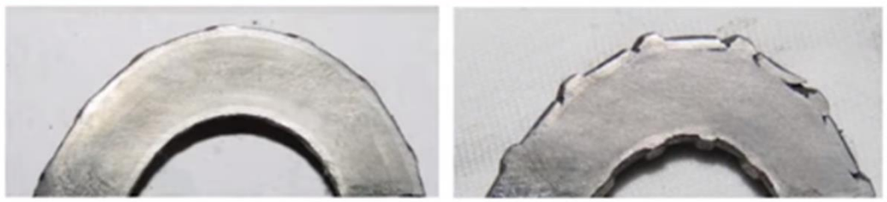
Thermo mechanically treated (TMT) or Quenched and Self-tempered (QST) Steel Bars

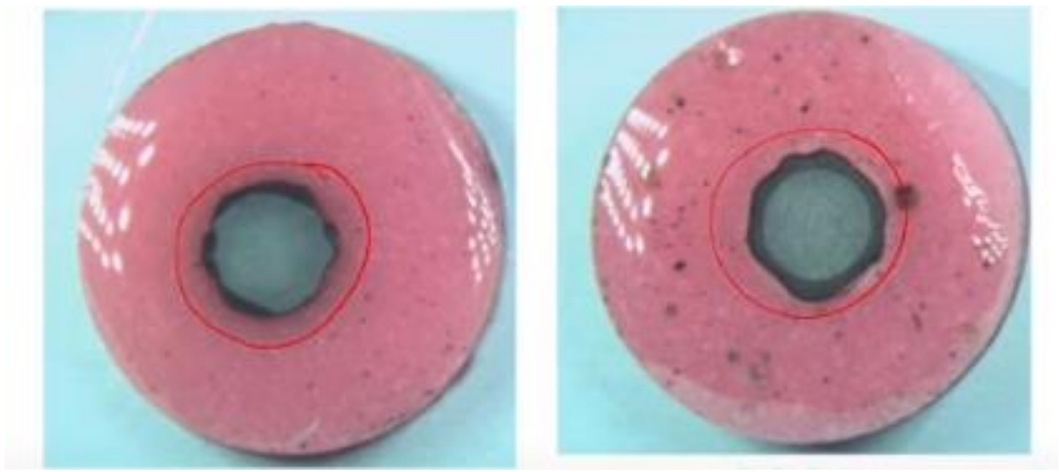




- **Advantage**
- Low Cost and High Strength
- High Ductility (Good for earthquake resistance structure)
- Elongation around 18-30%
- Excellent Weldability
- No cold working (better corrosion resistance)







Poor **Good**

Nital test

Corrosion Resistant Steel

- Bars with small quantities of copper and chromium, and higher than usual percentage of phosphorus
- Carbon -0.15%
- Manganese – 1%
- Sulphur – 0.04%
- Phosphorous – 0.10%
- Silicon – 0.45%
- Corrosion Resistant Elements – 0.50% (minimum)
- Test the chloride threshold of CRS cementitious systems and ensure that the desired service life can be achieved.

Stainless Steel

- > 11% chromium +Nickel and molybdenum
- Molybdenum are the alloys which provide long term corrosion resistance when concrete is exposed to chloride containing environment e.g., road salts and sea water.
- Passive film – mainly chromium oxide
- There are four type of stainless steel; Martensitic stainless steel, Ferritic stainless steel, Austinitic stainless steel, Duplex Stainless steel. Third and fourth type of rebar used in construction

French bridge using Mo-containing stainless steel (Courtesy of Dunkirk Specialty Steel)

Prestressing Steel Strands

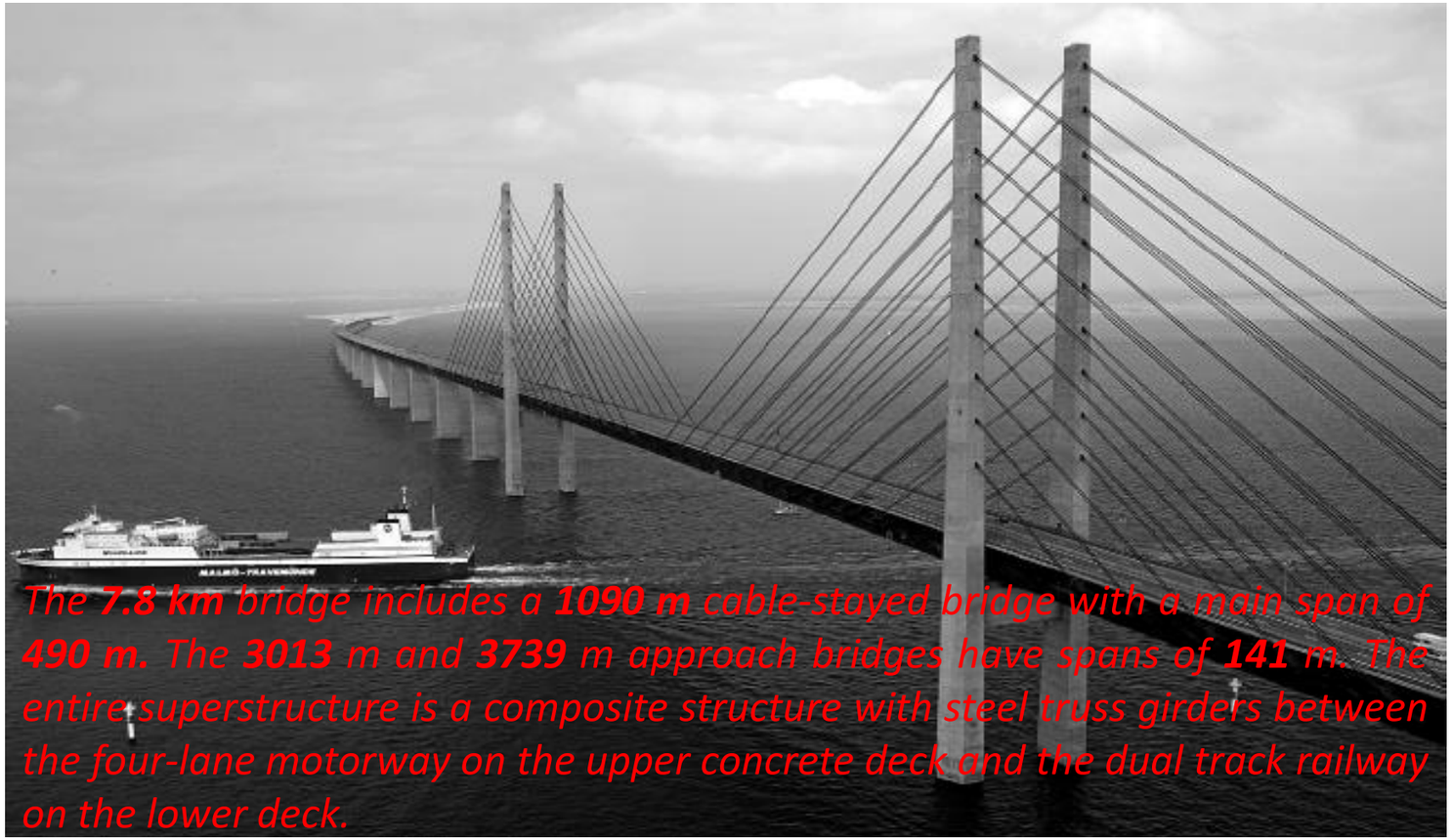
- These strands having a higher tensile strength and used in reinforced concrete bridges, building rail sleepers, electric pole etc.,

Prestressing Steel Strands

- Overstressing can decrease the corrosion resistance
- Reduced number of corrosion cells can also lead to faster growth of the existing corrosion pits

High Strength Steel Cables and Strands

- Metro Rail Projects
- Long Span Bridges
- High Rise building
- And many superior structures



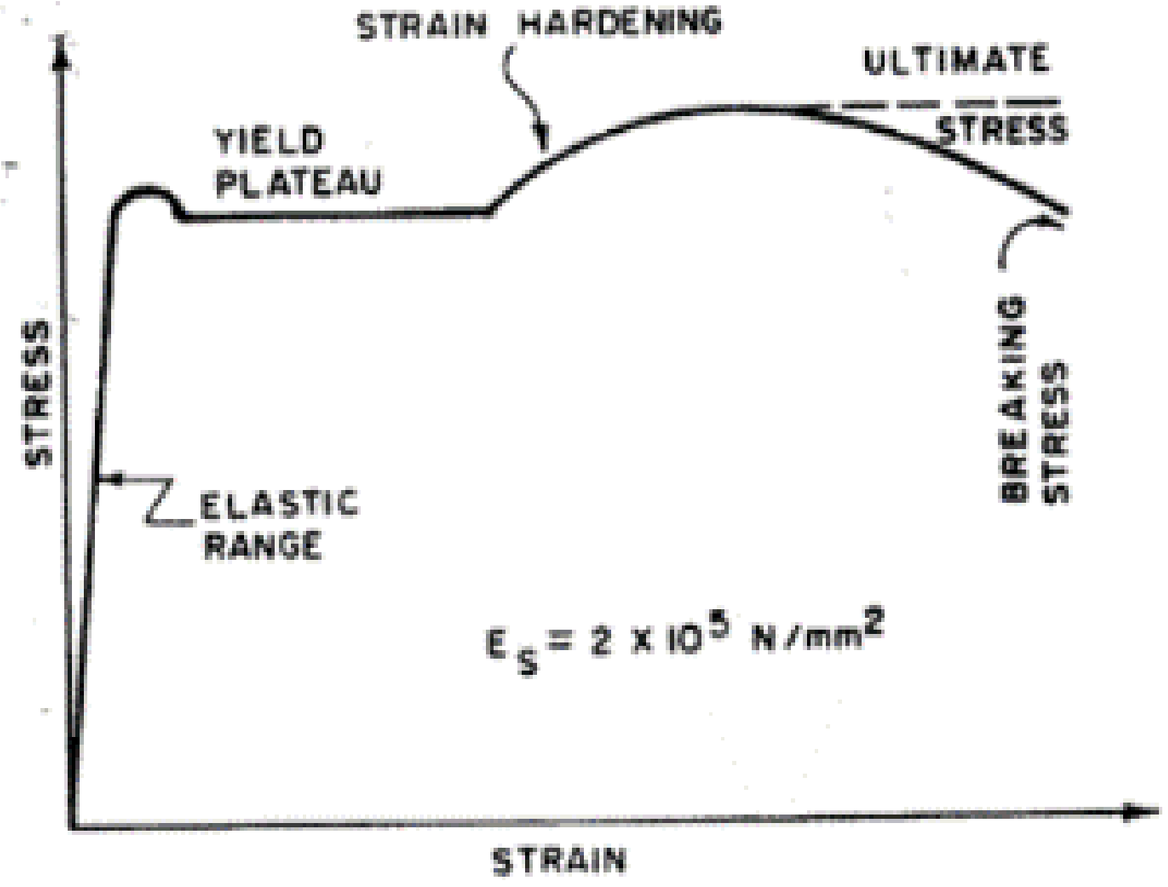
*The **7.8 km** bridge includes a **1090 m** cable-stayed bridge with a main span of **490 m.** The **3013** m and **3739** m approach bridges have spans of **141** m. The entire superstructure is a composite structure with steel truss girders between the four-lane motorway on the upper concrete deck and the dual track railway on the lower deck.*

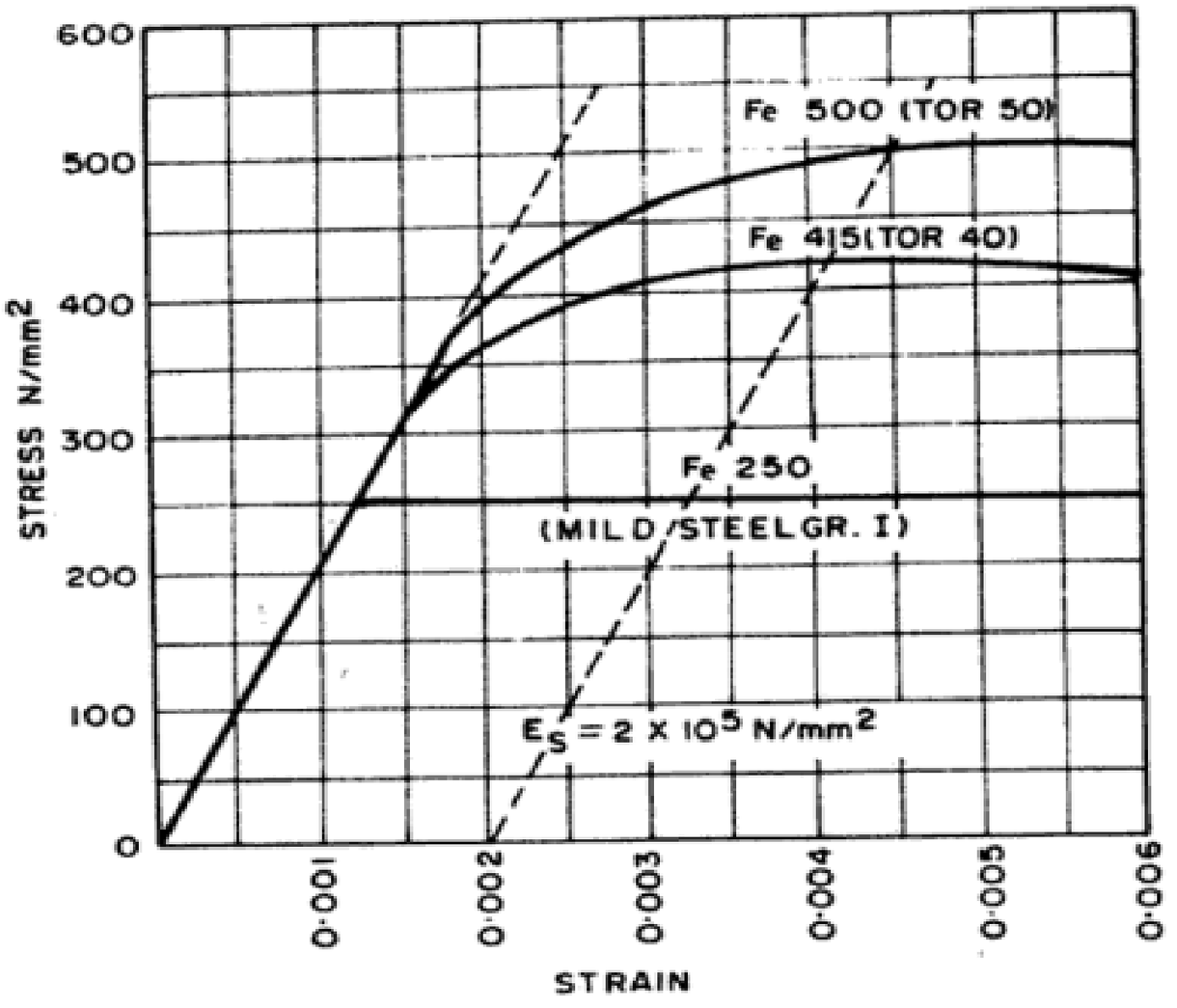
Influence of Different Chemical Ingredients on Properties of Rebars

Sr. No.	Chemicals	Effect on Rebars Controlling Property When at Suitable Concentration
1	Carbon (C)	Influence the Hardness, Strength, Weldability and Brittleness < 0.1% carbon reduced the strength > 0.3% carbon led to make unweldable and brittle
2	Manganese (Mn)	Yield Strength
3	Sulphur (S)	Brittleness
4	Phosphorous (P)	Strength and Brittleness + Corrosion
5	Copper (Cu)	Strength and Corrosion Resistance
6	Chromium (Cr)	Weldability and corrosion resistance
7	Carbon equivalent	Hardness, tensile strength and weldability

Basu et al. 2004

Stress Strain Curve of Mild Steel and CTD Bar





Thank You