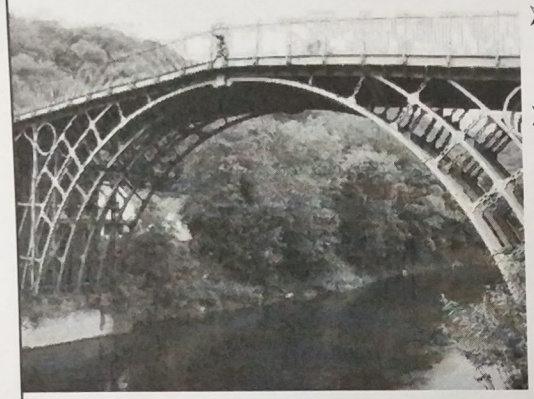
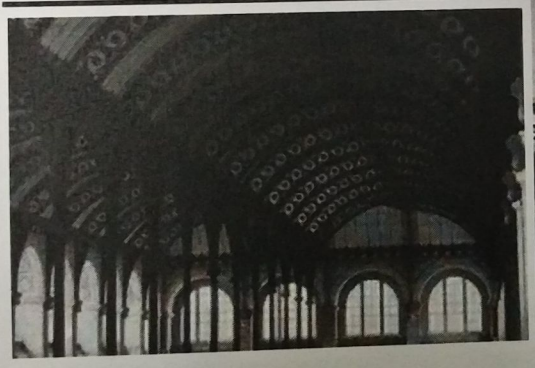
Historical Development Steel

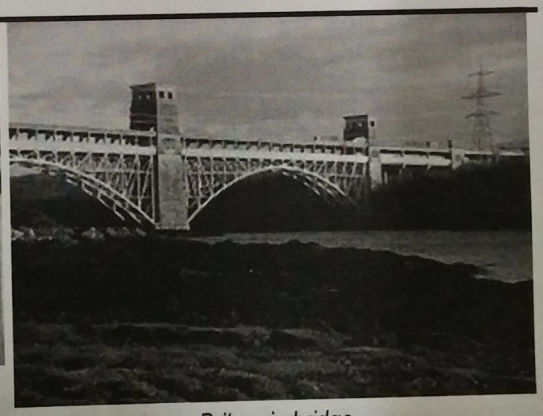


Coalbrookdale Arch Bridge
First major cast iron structure

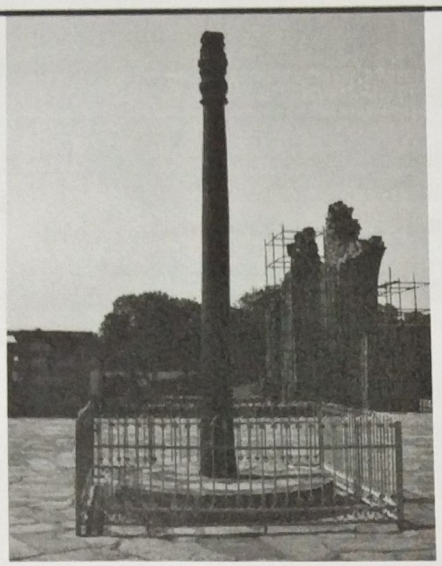
- **Human first developed metal copper alloy– Bronze**
- **Indus Valley, Greeks and Egyptians (1000 BC)**
- **Cast Iron – week in tension: 30.4—m Coalbroakadle Arch Bridge (Abraham Darby, England, 1779)**
- **Henry Cort (1784) invented Wrought Iron -- stronger, flexible, higher tensile strength than cast iron**



Cast iron supporting structure, ceiling of the reading room of the Bibliothèque Sainte-Geneviève, Paris.



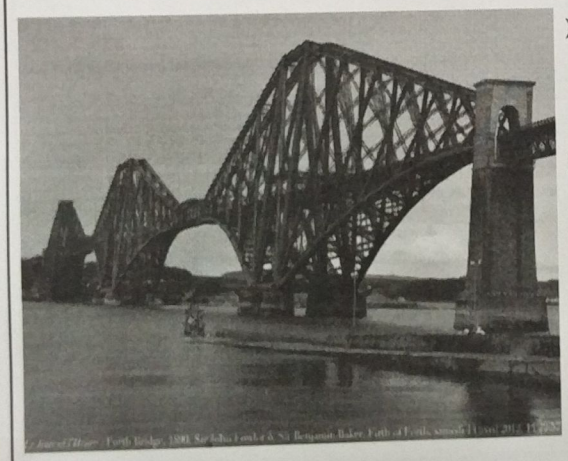
Britannia bridge
First box girder wrought iron bridge between island of Anglesey and the mainland of Wales



Iron Pillar of Mehrauli

It is notable for the rust-resistant composition of the metals used in its construction. Built during Gupta monarchs in approximately 402 CE.

The corrosion resistance : an even layer of crystalline iron hydrogen phosphate hydrate forming on the high-phosphorus-content iron, which serves to protect it from the effects of the Delhi climate.



First Steel Bridge
Fowler and Baker's railway bridge at Firth of Fourth, east Scotland

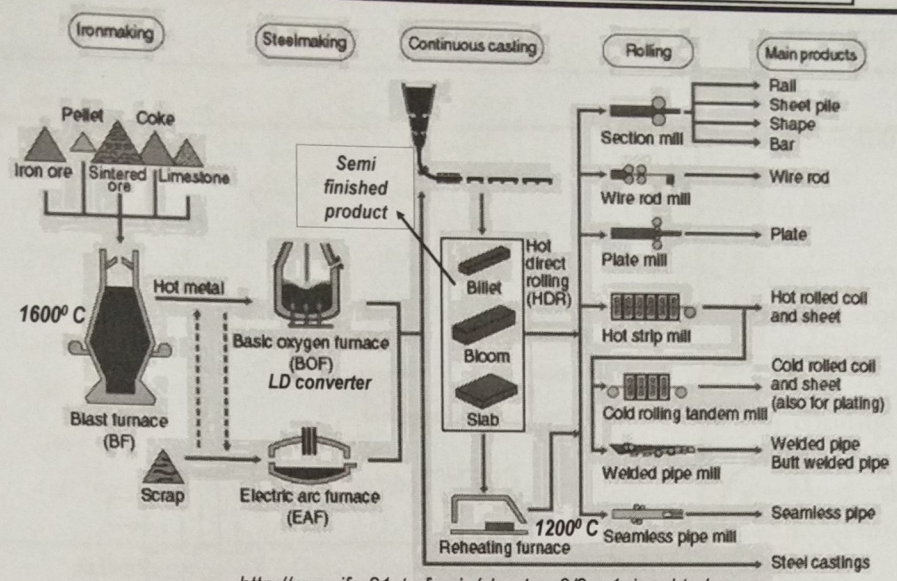
- **Steel – Henry Bessemer, England, 1855 – patented process of making steel**
- **Seimens & Martin 1865 -- open-hearth process used extensively**
- **Carbon content less than Cast iron but normally more than Wrought iron in steel**
- **High tensile strength, ductility, toughness in steel**
- **Wrought iron, steel rust easily, cast iron does not**

length. In the
λ < 730 nm (410
length light is absorbed by
penetrate to the troposphere. Long
break chemical bonds.

Atmospheric Lifetime of Air Pollutants

atmospheric lifetime of air pollutants varies markedly among
exist for less than one second. Moderately reactive species
ide have lifetimes of a few minutes during daylight hours.
spheric lifetime of weeks, methane lasts many months,
in the atmosphere for decades. The characteristic

Steel making



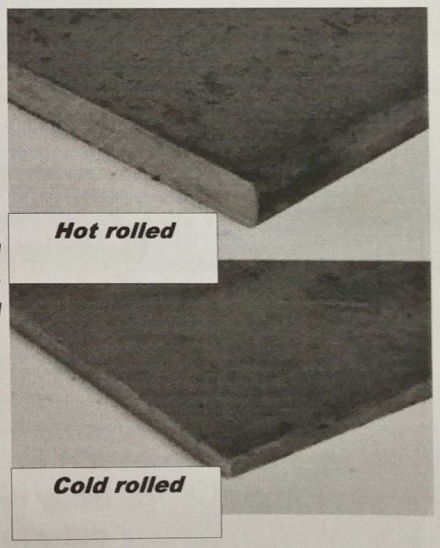
http://www.jfe-21st-cf.or.jp/chapter_2/2a_1_img.html

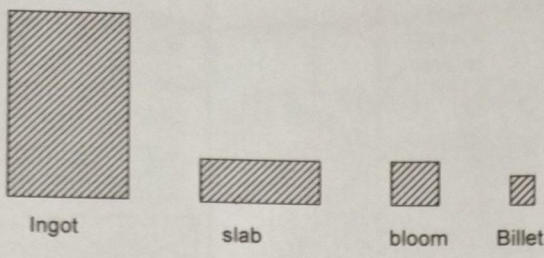
Hot rolling: *Semi finished products – billets, blooms and slabs are heated 1200⁰ C– make metal malleable and rolled into finished product – plates. Structural sections. Bars. Strips*

- *reduction in size increase hardening*
- *variation in cooling rates for different thickness introduces residual stresses*

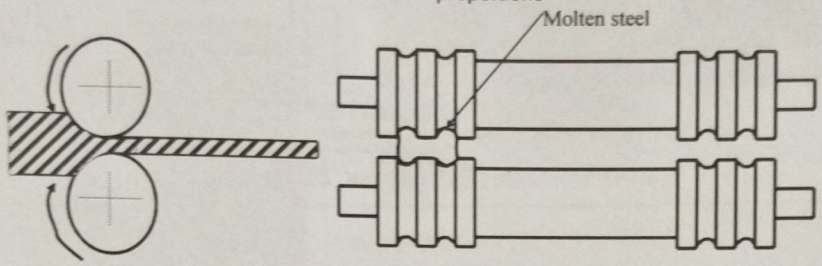
Cold rolling: *hot rolled steel processed in cold reduction mills -- material cooled (at room temperature) followed by annealing and/or tempers rolling. Cold Rolled refers to the rolling of flat rolled sheet and coil products.*

- *increases the yield and tensile strengths, eliminates costly thermal treatments.*
- *Turning gets rid of surface imperfections.*
- *Grinding narrows the original size tolerance range.*
- *Polishing improves surface finish.*





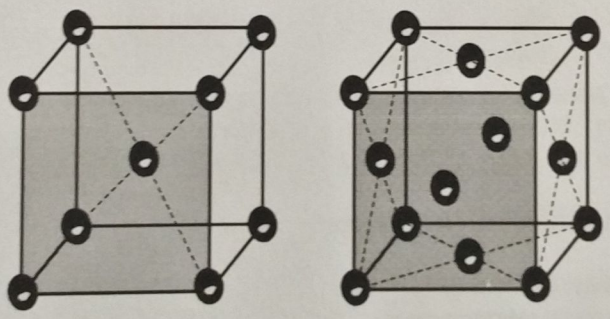
Basic shapes and their relative proportions



Primary rolls for plates

Primary rolls for structural shapes

Steel metallurgy

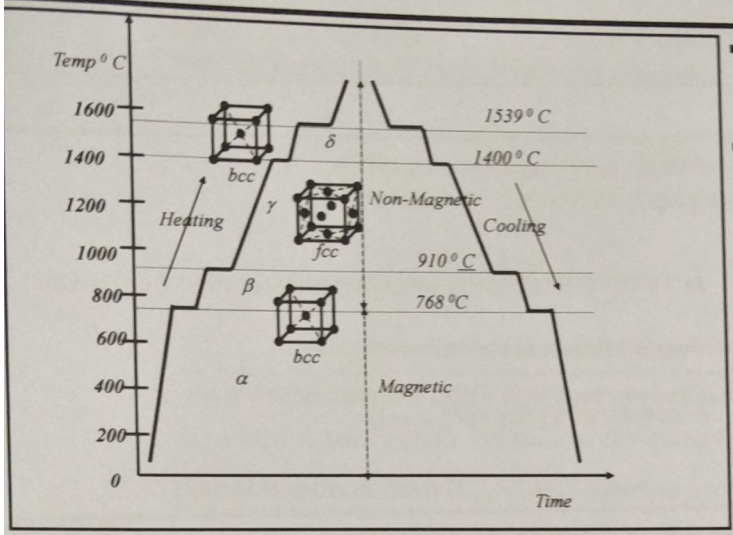


(a) Body centred cube (bcc)

(b) Face centred cube (fcc)

Crystal structure of Iron

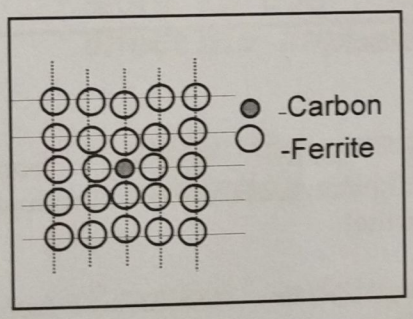
typically per
and nitrogen dioxide have lifetim
monoxide has an atmospheric lifetime of weeks,
hydrocarbons persist in the atmosphere for decades. The chara



Allotropy of Iron (existence of two or more different physical forms of a chemical element)

- Up to temp 910⁰C iron bcc crystalline structure
- 910⁰C--1400⁰C transforms to austenite having fcc structure
- 1400⁰C--1539⁰C (melting temp) iron reverts bcc structure
- On cooling it back to room temp with transformations reversed almost at same temp when heated

Steel is alloy of Iron and Carbon !
(Point to think about)



Interstitial solid solution of Carbon in Iron

More Carbon more strength? - Yes

But what happens to ductility?

Adding Carbon - Is it the only way to get strength?

Is there a limit for carbon content in structural steel?

Carbon content in Structural steel- 0.12-.25%

Wrought iron – up to 0.2%

Cast iron - 2.5 - 4.5%

length ng...
penetrate to the tro...
break chemical bonds.

Atmospheric Lifetime of Air Pollutants

The atmospheric lifetime of air pollutants varies markedly among speci...
...nically persist for less than one second. Moderately reactive species such as ozo...
... dioxide have lifetimes of a few minutes during daylight hours. Carbon
...ospheric lifetime of weeks, methane lasts many months, and
...the atmosphere for decades. The characteristic resi-

Are there any their any parameters which increases strength of steel? *Yes, Grain size*

$$f_y = f_0 + \frac{k}{\sqrt{d}}$$

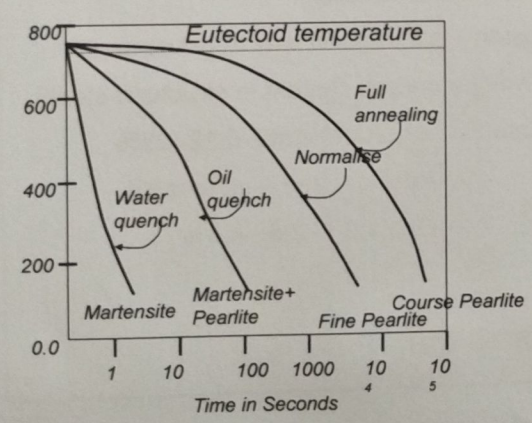
f_0 – yield strength very large crystals (for mild steel 5 Mpa)

d- grain size in mm

k- constant (38 for mild steel)

- With temperature control we can achieve small grain size
- With Mechanical pressure during rolling we can get smaller grain size

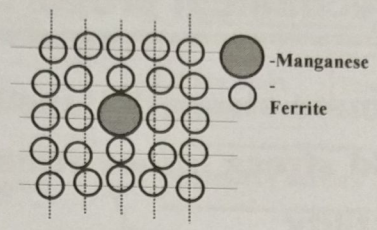
Heat treatment of steel



Variation of microstructure as a function of cooling

- Annealing (slow cooling from austenitizing temperature 723⁰C. Product: coarse pearlite)
- Normalizing (air cooling from austenitizing temperature 723⁰C. Product: fine pearlite)
- Quench & Temper. Quench (fast – water or oil – cooling from austenitizing temperature 723⁰C. Product: martensite)

Are there any their any parameters which increases strength of steel? *Yes, Additive metals*



Substitution solid solution of Manganese in Iron

How much can we add? ***It Should not exceed C_{eq}(0.45)***

C_{eq} =%C + % Mn/6 + (% Cr + % Mo + % V)/5+(% Ni + % Cu)/15

What happens then (C_{eq} >0.45)? ***Welding becomes a problem !!***

Points to Consider about steel!

- ***More carbon : more strength; but negatively affect the important property of ductility!***
- ***Smaller the grain size greater the strength (Production control)***
- ***Smaller additive metals also increases the strength of steel - HSLA steels***

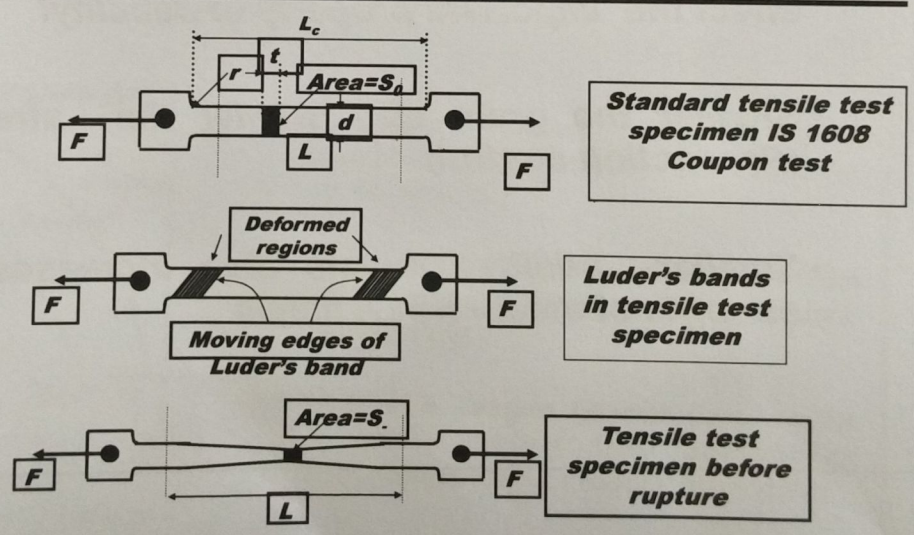
Atmospheric Lifetime of Air Pollutants
The atmospheric lifetime of air pollutants varies
typically persist for less than one second. Moderately
gen dioxide have lifetimes of a few minutes during
atmospheric lifetime of weeks, methane lasts
ist in the atmosphere for decades. The charac

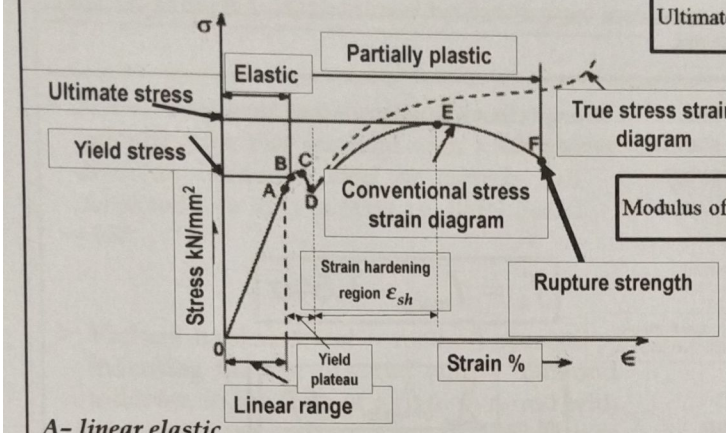
Mechanical properties

- Ultimate strength (tensile strength)
- yield stress (proof stress)
- ductility
- weldability
- toughness
- corrosion resistance
- machinability

Factors: chemical composition, rolling methods, rolling thickness, heat treatment, stress history

Tensile strength of steel





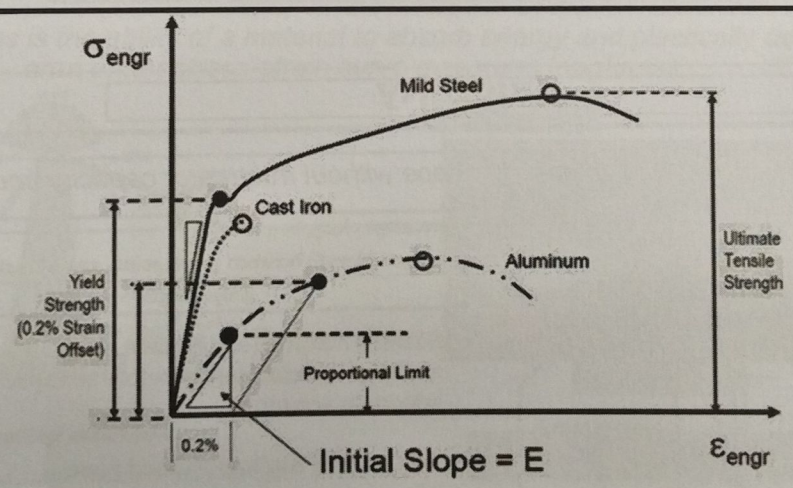
$$\text{Ultimate tensile strength} = \frac{\text{Ultimate tensile load}}{\text{original area of cross section}}$$

$$\text{True stress} = \frac{\text{Ultimate tensile load}}{\text{actual area of cross section}}$$

$$\text{Modulus of elasticity} = \frac{\text{stress within th e proportion al limit}}{\text{strain}}$$

- *E – 200,000 – 210,000 Mpa*
- *obey Hook's law within linear range*
- $\varepsilon_y = f_y / E$ *mild steel 0.125%*
- *hardening strain* ε_{sh} *varies* $5\varepsilon_y$--$10\varepsilon_y$
- E_{sh} *strain hardening modulus – initial slope strain hardening part*

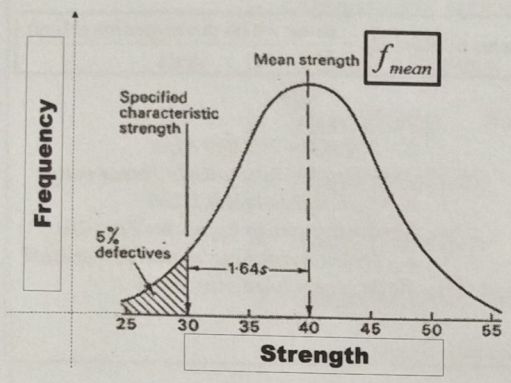
A– linear elastic
B– nonlinear elastic
C– upper yield point
D– lower yield point



Stress-strain characteristics for different types of iron

tively
cies under relatively
The rates of photolytic reacti
length. In the troposphere, photolysis is caus
nm (410 nm < λ < 650 nm defines the visi
bed by stratospheric ozone and oxygen molecules
Longer-wavelength light has insufficient energy

Characteristic strength f_k This is the strength that has particular probability (often 95%) of being exceeded in any standard tension test



Normal distribution curve

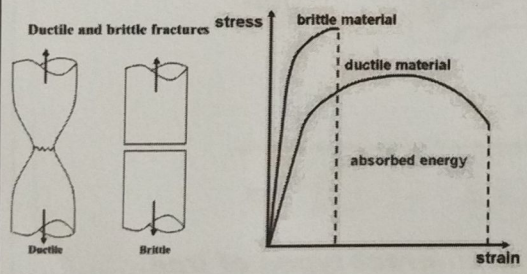
$$f_k = f_{mean} - 1.64\sigma$$

$$\sigma = \left[\frac{\sum (f_{mean} - f)^2}{(n-1)^{0.5}}\right]$$

Ductility

Ductility: *ability material to change its shape without fracture or capacity undergoing large inelastic deformation*

$$\text{Percentage elongation} = \frac{(\text{elongated length between gauge point} - \text{gauge length}) \times 100}{\text{gauge length}}$$



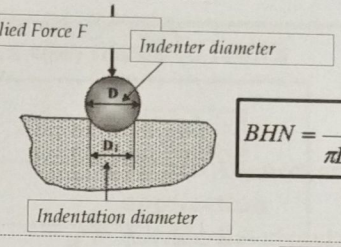
- Sudden loading (earthquake blast) structure undergoes deformation before collapse – adequate warning
- Help avoid fracture welded zone
- Absorbs local deformation, deformation during handling fabrication and transportation
- absorbs strain bending or straightening avoids crack during fabrication

Hardness

Hardness is regarded as the resistance of a material to indentations and scratching. This is generally determined by forcing an indenter on to the surface

- **Brinell hardness test** – method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. BHN Fe410 - 152

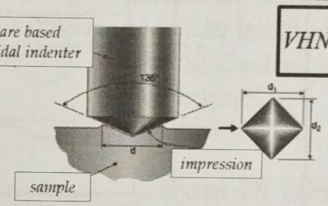
Brinell Hardness Test



$$BHN = \frac{0.204F}{\pi D\left[D-(D^2-D_i^2)\right]}$$

D In mm

- **Vickers hardness test** -- method consists indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. VHN, Fe410 - 157



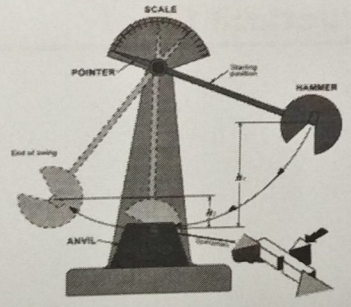
$$VHN = \frac{0.189P}{d^2}$$

$$d = \frac{d_1 + d_2}{2}$$

d In mm

Toughness

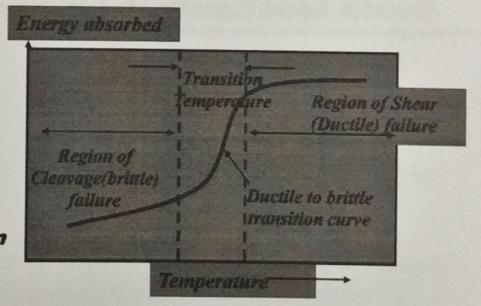
Toughness is the ability of a material to absorb energy and plastically deform without fracturing– area under stress-strain curve measures toughness



Charpy testing machine

Provides qualitative measure whether the material ductile or brittle

Test specimen

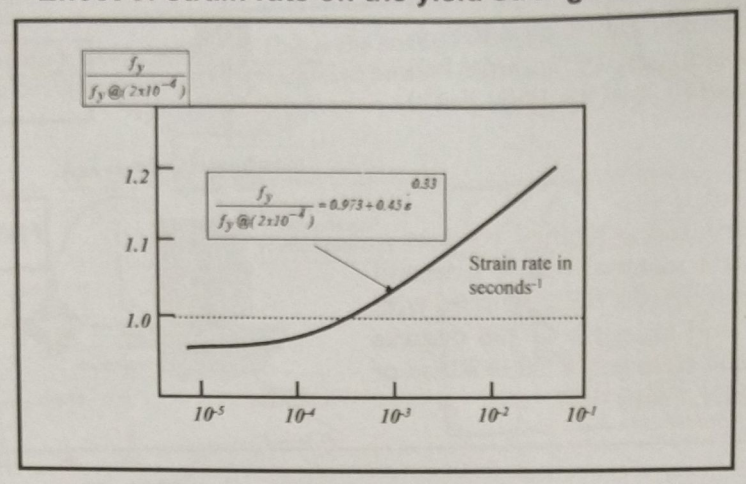


Energy temperature curve of steel

Experimental set up for notch toughness test

The atmospheric ... typically persist for less than one ... and nitrogen dioxide have lifetimes of a few minut... monoxide has an atmospheric lifetime of weeks, methane last... chlorofluorocarbons persist in the atmosphere for decades. The characte...

Effect of strain rate on the yield strength of steel



yield strength increases with strain rate

Some Mechanical properties of structural Steel

STEEL DESIGNATED INDIA – Fe 410 WA

Characteristic ultimate tensile strength

weldable

- Grade A – non critical application
- Grade B – structural part prone to brittle failure
- Grade C – low temperature and impact

from IS 2062

Special steels

- Stainless steels

Ni : 10-14%

Ni : 8-10.5%

Ni : 0.75%

Ni : 0.5%

Cold rolled steel and cold forming of steel

- Unheated slabs are rolled at ambient temperature into thin sheets (.3mm-8mm)
- Results in smooth surface and improved mechanical properties
- Cold forming of hold /cold rolled sheets
- CF sheets are basically low carbon steels which are reheated to 650^0C to recrystalise ferrite to get finer grain size

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TMCP steels and HSLA steels

- Thermo-Mechanically Controlled Process (TMCP) steels are becoming popular in obtaining high strength steels of yield strength of 800 MPa and thickness even beyond 40 mm.
- High Strength Low Alloy (HSLA) also are very popular which requires very good process control.

28

Fire resistant steels

Chemical composition of fire resistant steel

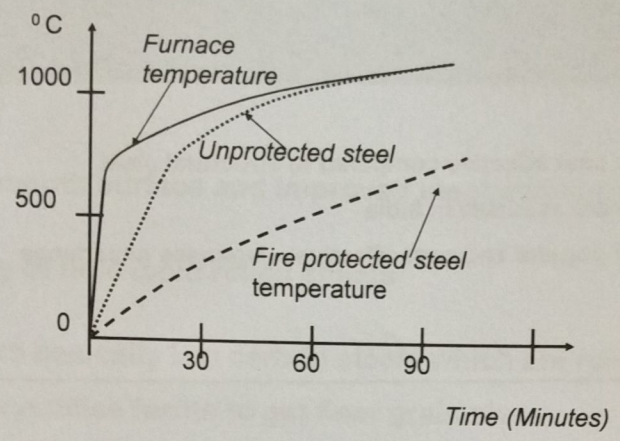
	C	Mn	Si	S	P	Mo+Cr
FRS	≤0.20 %	≤1.50 %	≤0.50 %	≤0.040 %	≤0.040 %	≤1.00 %
Mild Steel	≤0.23 %	≤1.50 %	≤0.40 %	≤0.050 %	≤0.050 %	-

- Very cost effective compared to structural steel
- FRS are available in India
- Very popular and cost effective - Japanese experience

Steel as a construction material under fire

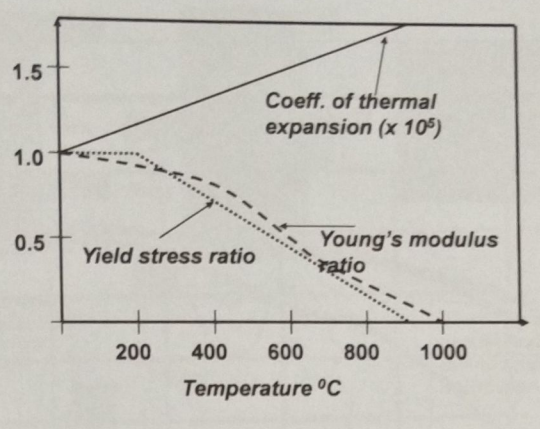
- Damage to strength of steel due to fire is reversible in most of the cases
- Using the principle " if the member is straight after the fire - the steel is O.K" many of the members could be salvaged.
- Up to about 215^{0}C steel retains its strength
- In the case of concrete, at 235^{0}C turns pink; 590^{0}C turns red and irreversible damage after 600^{0}C
- Steel exposed to 600^{0}C could be strengthened and reused.

Typical fire loads and behavior of steel under fire



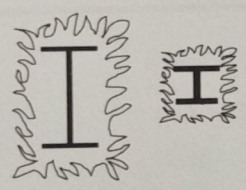
Examples of fire load in various structures

Type of steel structure	Kg wood / m^2
School	15
Hospital	20
Hotel	25
Office	35
Department store	35
Textile mill / Show room	200



Mechanical properties of steel at elevated temperatures

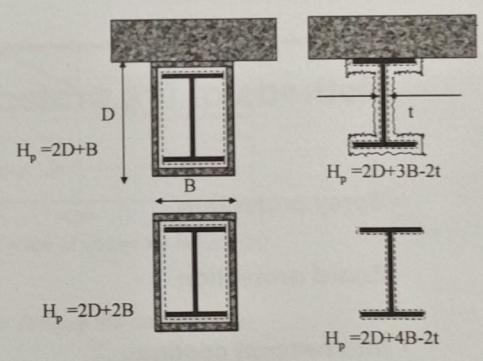
Fire Engineering of steel structures- very well developed in the literature



High H_p / A Value

Low H_p / A Value

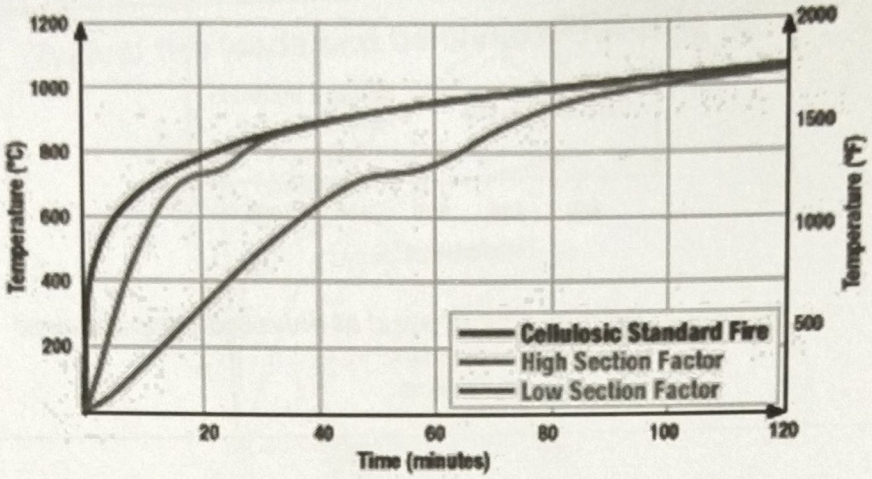
The section factor concept



Some typical values of H_P of fire protected steel sections

Low factor is desirable

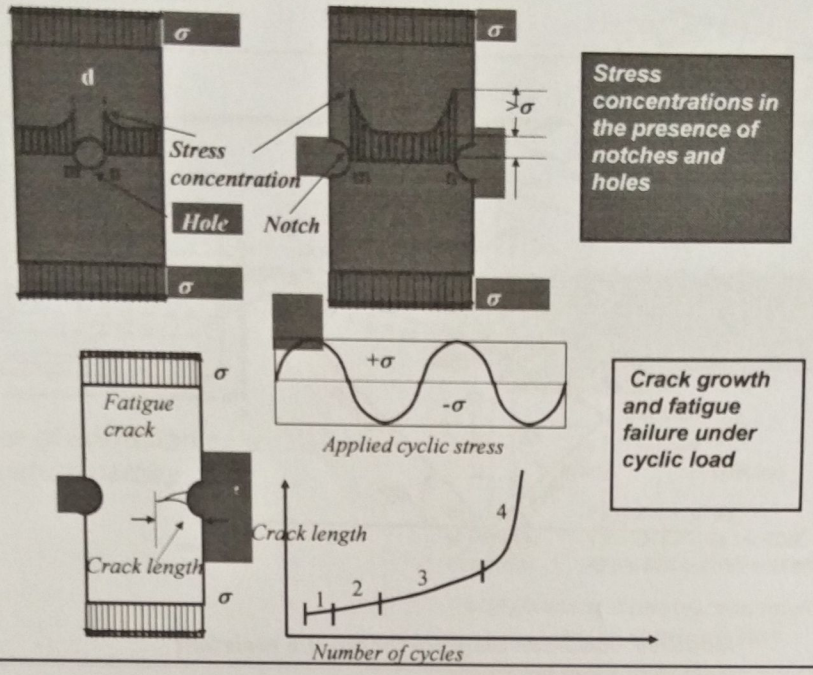
Section Factors: Rates of Heating



http://www.international-pc.com/products/fire-protection/fire-protection-technical-information.aspx

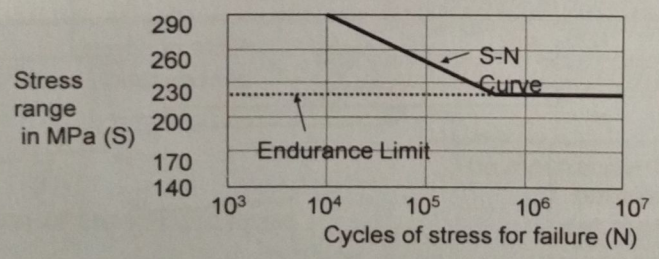
Methods of fire protection

- Spray protection
- Board protection
- Intumescent coatings
- Concrete encasement?

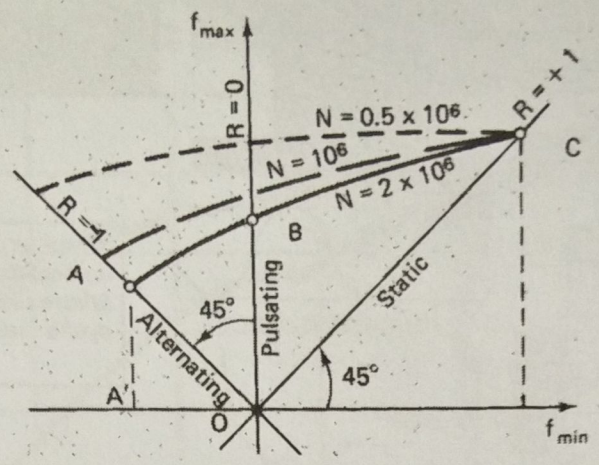


Stress concentrations in the presence of notches and holes

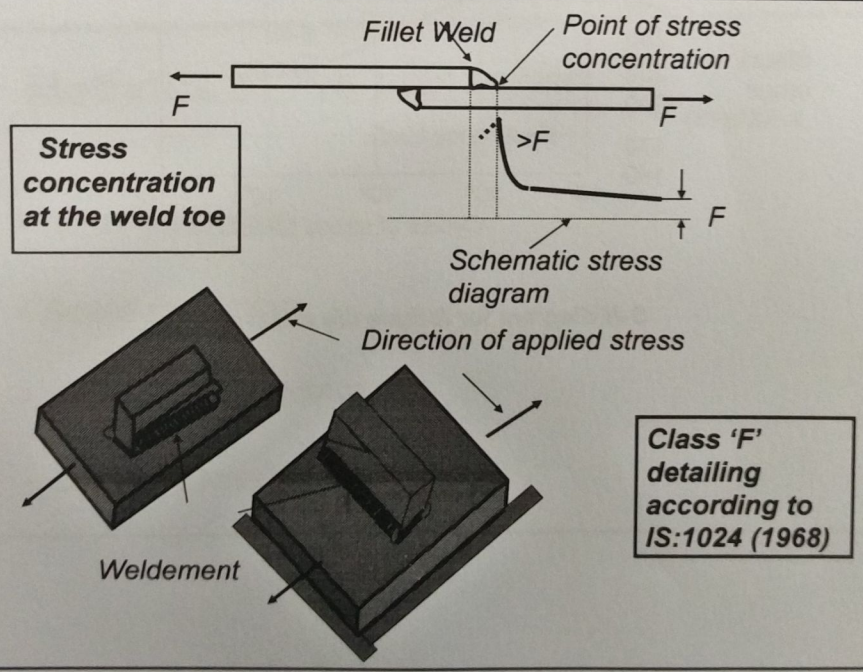
Crack growth and fatigue failure under cyclic load



S-N diagram for fatigue life assessment



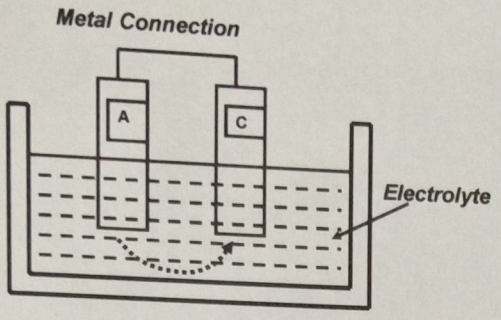
Modified Goodman diagram for fatigue resistant design of steel structures



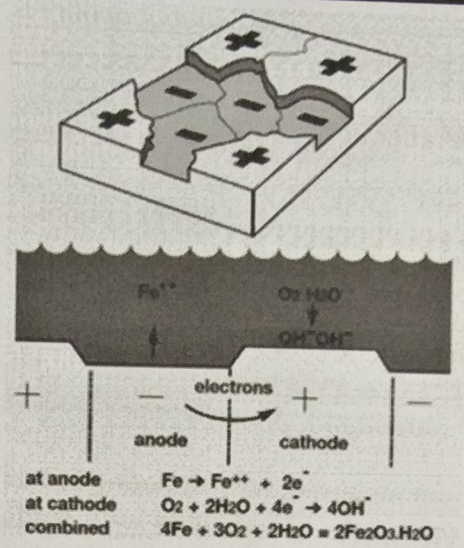
Stress concentration at the weld toe

Class 'F' detailing according to IS:1024 (1968)

Steel Corrosion

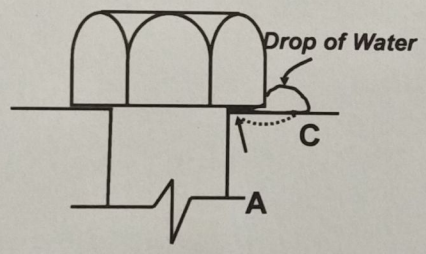


Mechanism of corrosion as a miniature battery

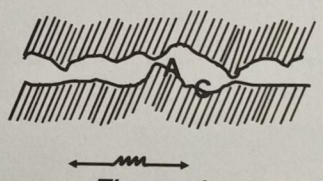


http://www.steelconstruction.info/Corrosion_of_structural_steel

Types of corrosion

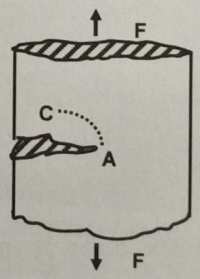


Mechanism of crevice corrosion



The mechanism of fretting corrosion

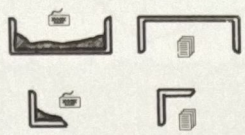
- Galvanic corrosion
- Hydrogen embritlement
- Bacterial corrosion



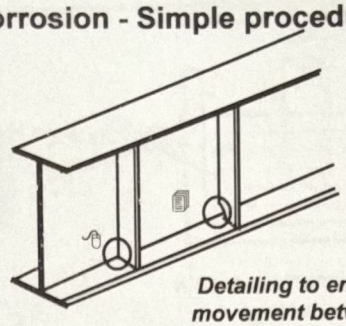
Mechanism of stress corrosion

monoxide
chlorofluorocarbons

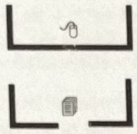
Methods of prevention corrosion - Simple procedures



Simple orientation of members



Detailing to enhance air movement between joints



Simple rule:

- **Eliminate the electrolyte**
- **Avoid simultaneous presence of water and oxygen**

Is Corrosion a real Problem?

- **Indian designers feel that steel corrodes most in India. Is it true?**
- **Steel corrodes all over the world! But they are better managed in the western countries!**
- **Excellent protective coatings which retain their life even up to 20 years are available!**
- **Corrosion-where does it matter? Normal inland there is no problem! Exposed conditions of course do need attention.**
- **Corrosion is no more a disincentive for not using steel in housing sector!**