Structural Steels and Their Weldability

Chitoshi Miki
Department of Civil Engineering
Tokyo Institute of Technology

Contents

Historical Review of Steels

Iron and Steel

Iron

Fe Ductile Material, Tensile Strength=200-300MPa

Steel

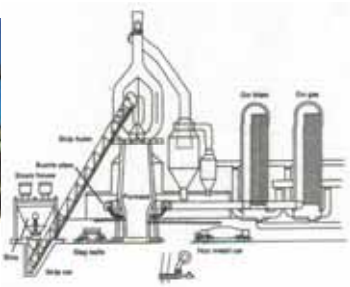
Fe+C+Mn+Si+Cr+...

Additional Chemical Elements

⇨ Improved Properties

Production of Iron

Reducing iron ore in a blast furnace



Pig Iron and Slag

Iron Bridge (1779, UK)

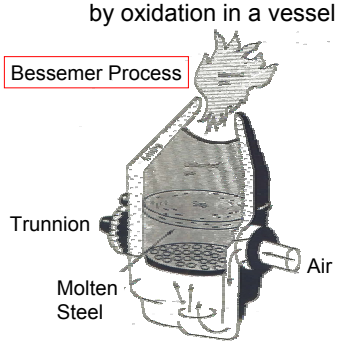
The First Iron Bridge

Iron Bridge (1779, UK)

Coalbrookdale Bridge UK 1779 SPAN=30.5m

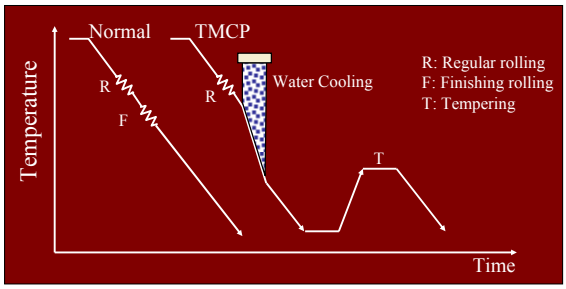
Production of Steels

Impurities in pig iron are removed
by oxidation in a vessel called a converter



Pig Iron C:2.5-4.5%
⇨ Cast Iron

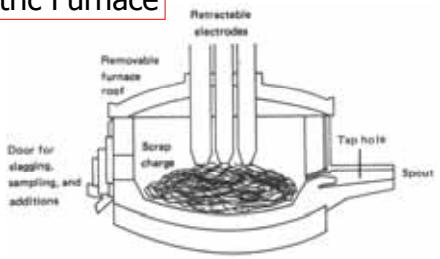
Temperature Control during Rolling



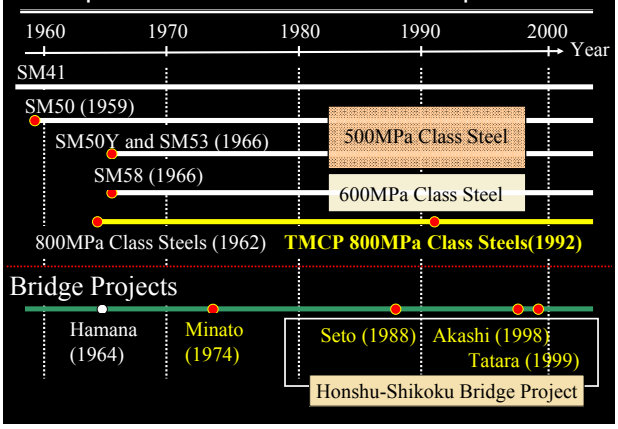
Normalizing Quenching
Annealing Tempering
TMCP (Temperature Mechanical Control Process)

Recycling Steels from Scrap

Electric Furnace



Development of Structural Steels in Japan



Effects of Impurities and Alloy Metals

Chemical Composition Example: JIS-SM490YB,SM570Q

	C	Si	Mn	P	S	Cu	Ni	Cr	V
SM490YB	0.14	0.46	1.56	0.020	0.005	0.01	0.01	0.02	0.04
SM570Q	0.14	0.23	1.44	0.012	0.005				

Carbon, C

Very Influential Element

Carbon acts as Hardener and Strengthener,
but reduces the Ductility

Silicon, Si

Less 0.2%: Slight Effects on Strength and Ductility
0.3-0.4%: Elastic Limit and Strength are Raised

Effects of Impurities and Alloy Metals

Chromium, Cr

Hardening Agent, Intense Hardness after quenching with very high strength
Chromium improves corrosion resistance

Nickel, Ni

Nickel-Chromium Steels have a very high tensile strength with considerable toughness and ductility
Stainless Steels

Copper, Cu

Increases the resistance of steels to atmospheric corrosion
Weathering Steels

Effects of Impurities and Alloy Metals

Sulfur, S

Less than 0.1% : No appreciable effects
It has a very injurious effects upon the hot metal,
Lessening its malleablility and weldability

Phosphorus, P

The Most undesirable impurity
It is detrimental to toughness, ductility, and weldability
It Improves Corrosion Resistance

Manganese, Mn

Improves the strength of carbon steels

Steels

Iron ⇨ Steel

Chemical Composition

Improvement of Mechanical Properties
- High Strength
- High Ductility
- Mass Production
- High Quality

Steels:
Tensile Strength: 400, 500, …., 800MPa

Cables:
….., 1100, ….., 1600, 1800 MPa

Mechanical Properties of Steels

Governed by Chemical Composition

- Strength
- Ductility
- Toughness
- Hardness
- Corrosion Resistance
- Weldability
  - Prevention of Weld Cracks

Weld Cracks

Hot Cracks

Cold Cracks

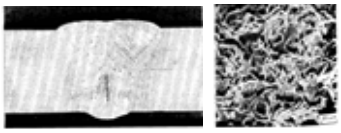
Lamellar Tearing

Hot Cracks

Cracks occur near melting temperature during welding or after welding

Hot Cracks can be eliminated by designing the material composition of weld metal and base metal.

$$HCS = \frac{C(S + P + Si/25 + Ni/100)}{3Mn + Cr + Mo + V} \times 10^3 < 4$$



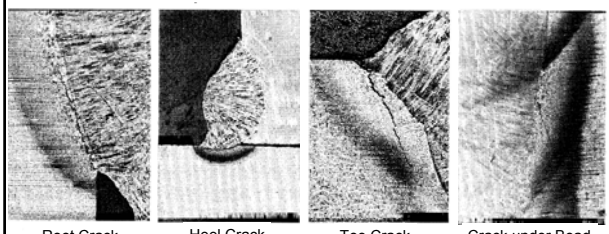
Cracks occurred during solidification

Cold Cracks

Generally, Tran-granular cracks

Short time cracking: during cooling process
Delayed cracking: after some time lapse at room temperature

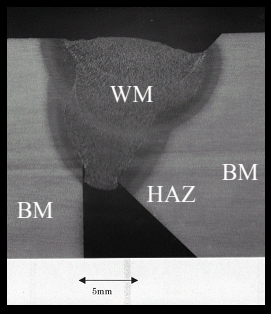
Hydrogen is responsible for cold cracks



Root Crack | Heel Crack | Toe Crack | Crack under Bead

HAZ (Heat Affected Zone)

HAZ in Welded Joints



K-Groove
Butt-Welding

Heat Cycle
and Microstructure Change

Resistance Performance of HAZ against Cold Crack

Carbon Equivalent

$$C_{eq} = C + \frac{Mn}{6} + \frac{Si}{24} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{V}{14} + \left(\frac{Cu}{13}\right)$$

$$P_{CM} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B$$

IIW

$$CE_{IIW} = C + \frac{Mn}{6} + \frac{Cu + Ni}{15} + \frac{Cr + Mo + V}{5}$$

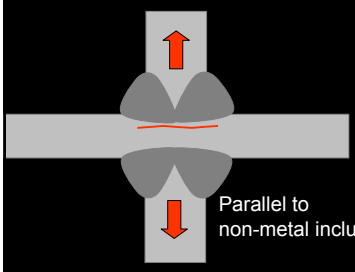
Prevention of Cold Cracks

The Use of Low Hydrogen Processes

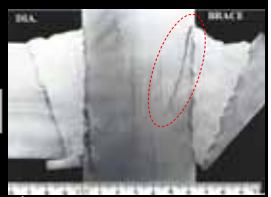
Preheating

Reduced Joint Restraint

Lamellar Tearing



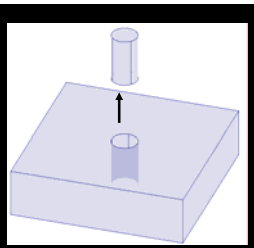
Parallel to
non-metal inclusions

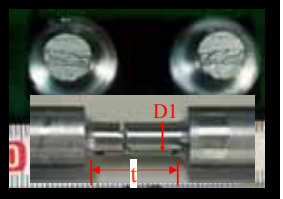


High Constraint Condition
Large Deposited Weld
Ductility in Plate Thickness Direction

Z-tension tests

- Φz: Reduction of Area in Thickness Direction (Z-Direction) Tension tests





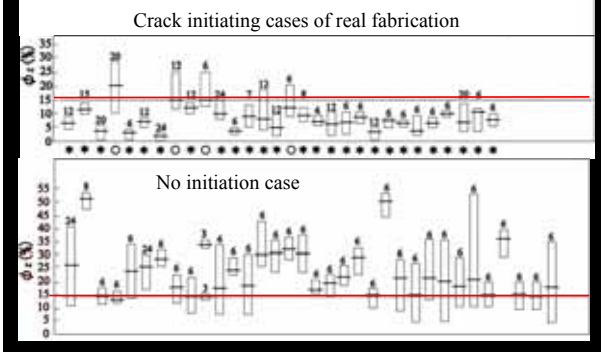
thickness

D2 D1

$$\phi_z = \frac{\left(D_1^2 - D_2^2\right)}{\left(D_1\right)^2}$$

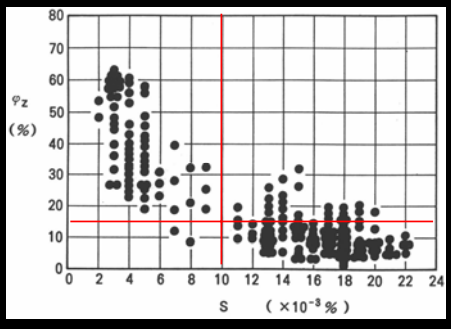
Lamellar tearing and ϕz

- ϕ_z<15%, High risk of Lamellar tearing

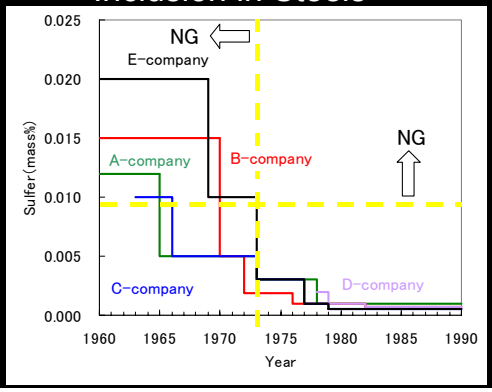


Φz and Sulfur Inclusion in Steels

- If S>0.01% then many of the z-tension test results are ϕ_z<15%.

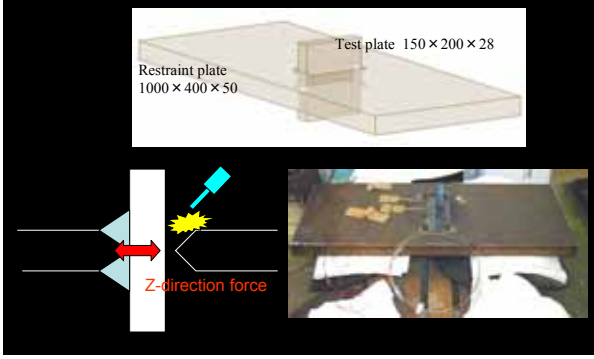


Historical Review of Sulfur Inclusion in Steels



Z-Window Welding Tests

To Evaluate the possibility of Lamellar Tearing



Lamellar Tearing Resistant Steels