Steel - Properties

History of Steel

Cast Iron

- Cast iron preceded wrought iron.
- It is brittle, has high carbon content with low tensile strength.
- It has excellent casting properties.
- It was mainly used to carry axial compression loads.

Wrough Iron

- It replaced cast iron, because of good tensile strength properties.

History of Steel

Steel

- Steel gradually replaced wrought iron until about 1890.
- Steel in commercial quantities is just over 100 years
- The chemistry of steel was not controlled until about 1960
- Strength and elongation were guaranteed but not the chemistry
- This was satisfactory for riveted structures but not for welded details

History of Steel

Steel

- Welding was first introduced in bridges in about 1936.
- During the World War, US produced a large number of welded cargo vessels.
- Many of these ships broke apart due to brittle fracture of steel adjacent to the welds.
- Welding contributes to brittle fracture because of introduction of severe cooling rates in the steel adjacent to the weld HAZ (Heat Affected Zone).

History of Steel

Failure of Steel Structures

- The St. Maurice Bridge at Quebec failed in January 1951. It was four years old.
- Byte Bend Bridge in Sacramento, California, failed in 1970 during construction.
- The Freemont Bridge in Portland, Oregon, had a failure in truss joint in 1971.
- In St. Paul, Minnesota, a girder in the Lafayette Street Bridge failed in 1975.

Iron

- Iron in the pure form is a soft, shiny metal like aluminum.
- However, it is never found in this state.
- Iron oxidizes extremely easily.
- In nature it is always found as an oxide.

What is Steel?

Alloy

- Metal prepared by adding other metals or non-metals to secure desirable properties.

Steel

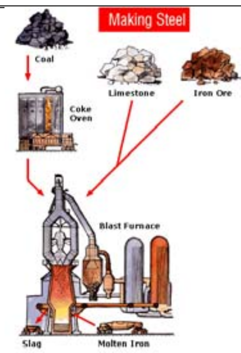
- It is an alloy of iron, carbon and other trace elements.

Steel Making Process

- Iron ore, coke and limestone are major raw materials.
- Coke is obtained by distilling coal.
- Raw material is charged into Blast furnace which has a temperature of 1600° C.
- Iron melts at the bottom.
- Solidified iron is called “Pig Iron”

Steel Making Process

- Molten metal from Blast furnace is taken into Basic Oxygen furnace
- Chemical analysis of the molten material is done
- Steel semis, billets are heated to 1200°C for rolling and finished products.



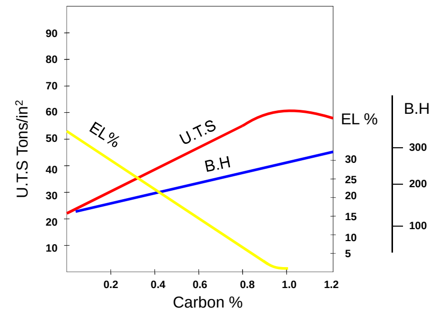
Effects of Carbon

- Increased carbon in steel:
  - Increases strength
  - Increases hardness
  - Increases hardenability
  - Reduces ductility
  - Reduces toughness
  - Reduces machinability

Effects of Carbon

% Carbon	Yield Strength (ksi)	% Elongation	Comments
4.0			Grey cast iron
2.5			White cast
1.1 to 1.7	90 – 100	0	Very high carbon steel
0.9 to 1.1	110 – 118	0	High carbon steel
0.7 to 0.9	94 – 118	8 – 14	Spring steel
0.55 to 0.7	75 – 94	14 – 19	Higher carbon steel
0.3 to 0.55	65 – 75	19 – 24	Medium carbon steel, weldable with care
0.15 to 0.3	48 – 65	24 – 28	Mild steel for bridges
0.05 to 0.15	40 - 48	28 - 34	Very mild steel, pure iron

Effects of Carbon



Effects of Other Alloying Elements

1. Sulphur:

   – Higher sulphur causes porosity and hot cracking in welding
   – Can cause brittleness in hot metal
   – Increases hardenability
   – It is not desirable and is kept as low as possible
   – Its ill effects are reduced by adding other alloying elements such as manganese.

Effects of Other Alloying Elements

2. Phosphorus
   – Like sulphur it is not desirable and is kept as low as possible
   – It increases strength and hardenability.
   – It reduces ductility and weldability.

3. Manganese
   – It is added to counteract the ill effects of sulphur
   – Increases strength, hardenability and notch toughness
   – It reduces weldability

Effects of Other Alloying Elements

4. Silicon:
   - It is used as de-oxidizer in steel making and produces fine grained steel.
   - 0.15 to 0.50 range is desirable and is known as "killed steel".
   - It increases strength and hardenability.

Effects of Other Alloying Elements

5. Aluminum
6. Chromium
7. Copper
8. Columbium
9. Molybdenum
10. Nickel
11. Tungsten
12. Vanadium

Basic Metallurgy

Grains

- The crystals of metals are referred to as grains.
- The smallest grain of a metal contains a large number of atoms.

Space-lattice

- All grains are composed of atoms bound together in a definite pattern or structure. This atomic structure is called space-lattice.

Basic Metallurgy

Structure of a Metal

The characteristics of the structure of a metal are due to:

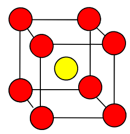
- The atoms making up the metal.
- The manner in which the atoms are arranged.

Space-lattice Types

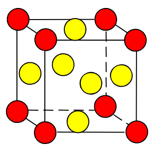
There are 14 possible space lattice types.

- The body centered cubic has 9 atoms.
- The face centered cubic has 14 atoms.

Space-Lattice Types

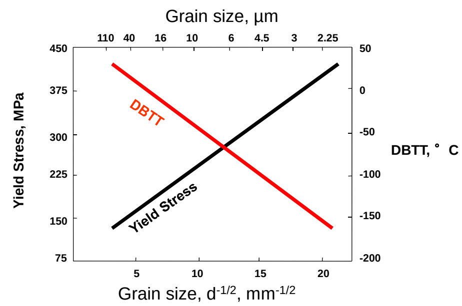


Body Centred

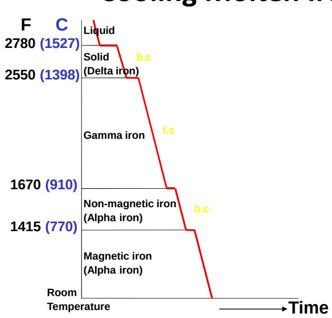


Face Centred

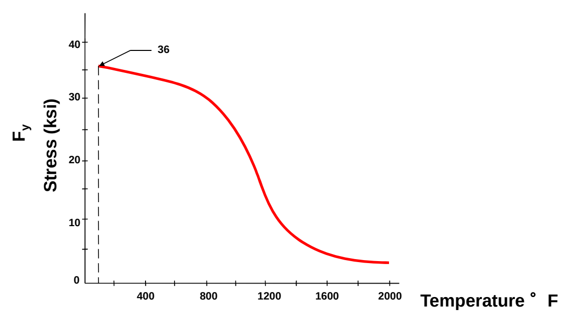
Grain Size



Cooling Molten Iron



Temp. Effect on Yield Stress



Definitions

Annealing:

Heating and holding at a suitable temperature and then cooling at a suitable rate. For such purposes as reducing hardness, improving machinability, facilitating cold working, producing a desired microstructure, or obtaining desired mechanical, physical, or other properties.

Hardenability:

Steel property which describes the depth to which the steel may be hardened during quenching.

Definitions

Hardness:

A measure of a material's resistance to localized plastic deformation.

Heat Treatment:

The way to produce particular microstructures and properties in steel by heating and cooling.

Killed Steel:

Steel deoxidized with a strong deoxidizing agent, such as silicon or aluminum, to reduce the oxygen content to such a level that no reaction occurs between carbon and oxygen during solidification.

Definitions

Normalizing:

In this process, the steel is heated to about 100 F above the transformation range, held there only briefly and then cooled in still air. This process refines the grain.

Quenching:

In heat treatment, the step of cooling metals rapidly in order to obtain desired properties.

Definitions

Stress Relieving:

Heating to a suitable temperature, holding long enough to reduce residual stresses and then cooling slowly to minimize the development of new residual stresses.

Tempering:

It is the process at which hardened steel is reheated at some point below the transformation range and cooled in air or water.

Definitions

Toughness:
An indication of steel's capacity to carry load and absorb energy, particularly in the presence of a notch or a crack.

Transformation Temperature:
The temperature at which a metal, when cooled, changes from one type of structure to another.

Physical Properties

- Strength
  - Compression
  - Tension
  - Fatigue
- Ductility
- Weldability
- Fire Resistant
- Corrosion Resistant
- Notch toughness
- Machinability
- Formability

Tensile Stress – Strain Curves

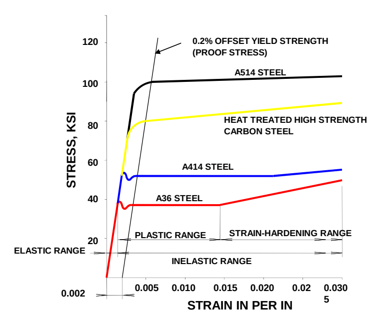
Elastic Range
Stress is proportional to strain. In this range there is no permanent deformation.

Plastic Range
In this strain increases without the appreciable increase of stress.

Strain Hardening Range
In this strain increase is accompanied with increase in stress.

Proof Stress
Stress required to cause a specified small , permanent extension.

Tensile Stress – Strain Curves



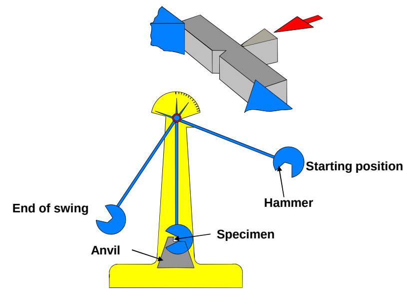
Charpy Test

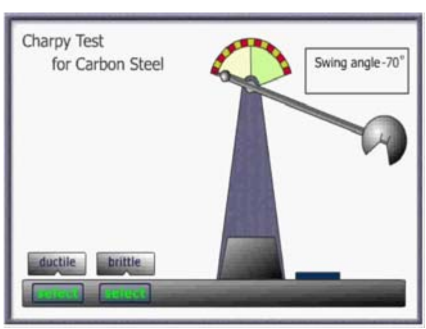
Charpy Test
Charpy test is used to determine metal toughness (i.e. impact strength).

Impact Energy
It is the work done to fracture the specimen as measured by the Charpy test.

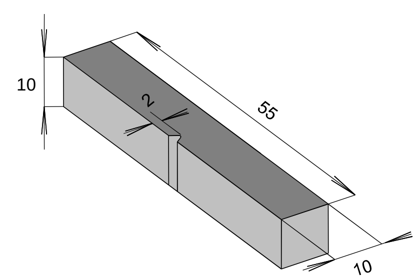
Impact energy = Elastic strain energy + Plastic work during yielding + Work done to create fracture.

Charpy Test





Charpy Test Specimen



Charpy Test

Charpy Test

Charpy Test

Factors Affecting Fracture Behavior

- Impact load
- Sub zero temperature range
- Notch

Common Steel Shapes

- Wires
- Cables
- Steel Plates
- Steel Bars
- Rolled Beams
- Built-up Shapes

Steel - Properties

Types of Steels

Steel Designation	Yield Strength (ksi)	Comments
OH Steel	26	Used until about 1905
EIC Steel	30	Used until about 1935
A7	33	Used until about 1960
A36	36	1960 to Present. (First steel with guaranteed chemistry)
G40.8 (A35)	40	Normalized and used by Alberta up-to 1968
G40.12 (A572)	44	Normalized and used by Alberta up-to 1968
A441	50	Normalized and used by Alberta up-to 1968

Steel - Properties

Current CSA G40.21 Steels

Nominal yield strength, MPa

Type	260	300	350	380	400	480	550	700
				Grade				
W	260W	300W	350W	380W*	400W	480W	550W	-
WT	260WT	300WT	350WT	380WT**	400WT	480WT	550WT	-
R	-	-	350R	-	-	-	-	-
A	-	-	350A	-	400A	480A	550A	-
AT	-	-	*350AT*	-	400AT	480AT	550AT	-
Q	-	-	-	-	-	-	-	700Q
QT	-	-	-	-	-	-	-	700QT

Steel - Properties

CSA Charpy Impact Requirements

Standard Charpy impact test temperature for specified category

Category	Standard test temperature °C
1	0
2	-20
3	*-30*
4	-45
5	To be specified by purchaser

CSA Charpy Impact Requirements

Standard Charpy impact energy for specified grade

Grade	Absorbed Energy (Joules)
260WT	20
300WT	20
350WT	27
400WT	27
480WT	27
350AT	*27*
400AT	27
480AT	27
700QT	34

What are the <u>three</u> most important properties for plate steel?

- Strength?
- Cost?
- Corrosion Resistant?
- Notch toughness?
- Machinability?
- Formability?
- Weldability?

<u>Strength</u>

✓*Yes* - **for structural applications strength is a very important property, a bridge member must support a given load without yielding.**

<u>Cost</u>

✗*No* - **Cost is always an issue with design and materials selection. In this case cost will need to be considered but is the fourth choice as there are other properties that are more critical.**

Corrosion Resistant

✗ ***No -*** **It is very important but is simply dealt with by painting. Also, the components can generally be checked visually for signs of corrosion and repairs made when appropriate.**

Notch Toughness

✓ ***Yes -*** **toughness is one of the top three properties to consider because we must guarantee structural components against sudden catastrophic failure.**

Machinability

✗ ***No -*** **This is not a very important property in this case because the steels are rolled to plate, flame cut and dressed to final size, then welded together.**

Formability

✗ ***No -*** **It is important that the steel can be rolled to produce plates, however little subsequent forming is required meaning that extremely good formability is not required.**

Weldability

✓*Yes -* **this is an extremely important property as ships, oil rigs, and bridge girders are constructed from a number of steel plates that are welded together to form the final product.**

Questions??