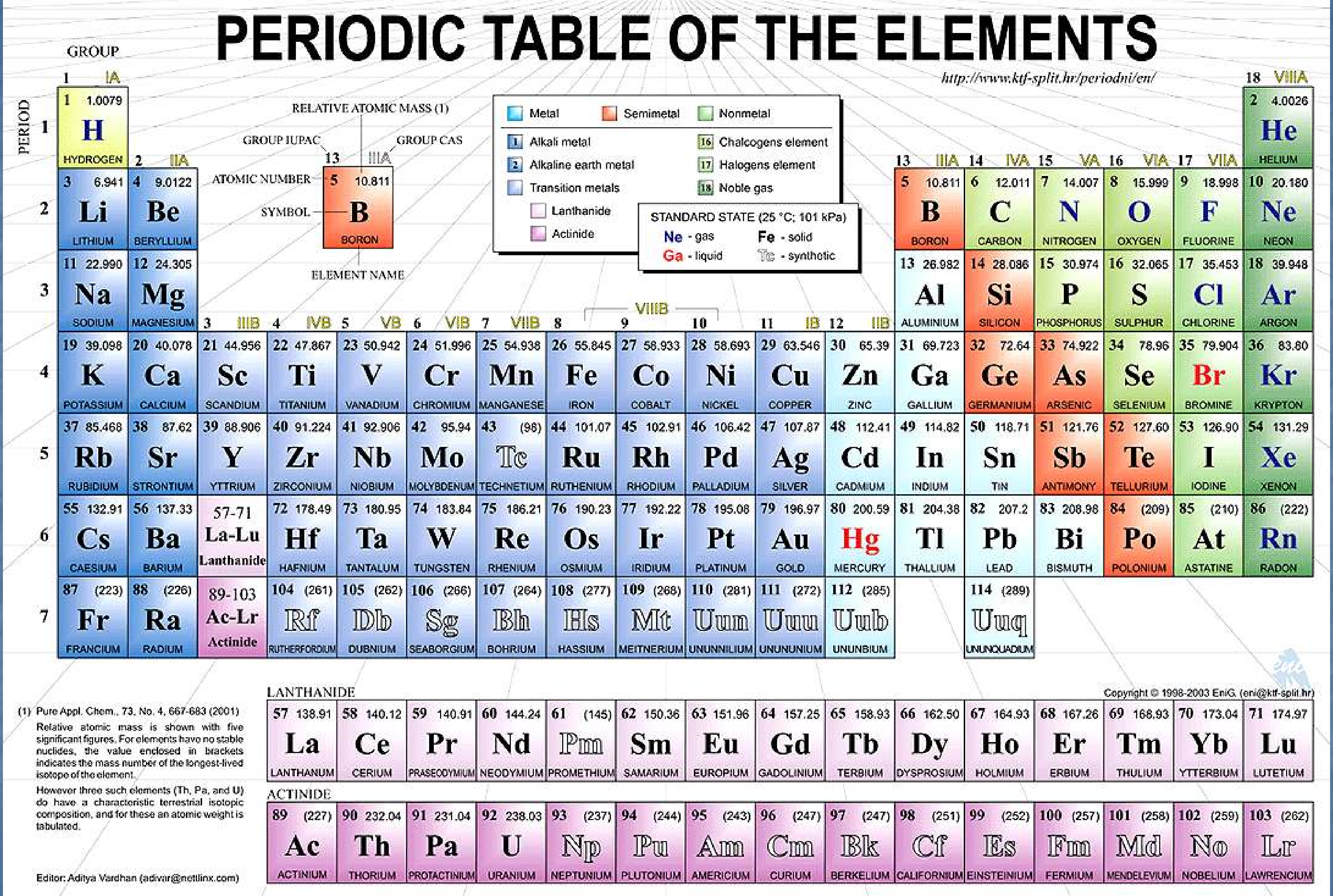
Basic Engineering Materials

Elements

- Elements are the smallest particles of any substance that can be found.
- There are about 90 elements occurring naturally and all materials are made from ELEMENTS.
- A material consisting of only one element is said to be pure.
- Most materials in their natural state are mixtures of many elements and are known as RAW MATERIALS.
- The materials of most interest to engineers are plentiful and have properties suitable to tooling and manufacturing.
- 2 basic types of materials used extensively on engineering METALS and NON METALS. They are classified into 3 main groups:
- FERROUS (Contains Iron)
- NON-FERROUS (Does not contain Iron)
- NON METALIC (Contains no metals)



PERIODIC TABLE OF THE ELEMENTS

http://www.ktf-split.hr/periodni/en/

RELATIVE ATOMIC MASS (1)
GROUP IUPAC 13
GROUP CAS IIIA
ATOMIC NUMBER 5
10.811
SYMBOL B
ELEMENT NAME BORON

🟦 Metal	🟥 Semimetal	🟩 Nonmetal	
1 Alkali metal		16 Chalcogens element	
2 Alkaline earth metal		17 Halogens element	
Transition metals		18 Noble gas	
Lanthanide			
Actinide			

STANDARD STATE (25 °C; 101 kPa)
Ne - gas
Fe - solid
Ga - liquid
Tc - synthetic

PERIOD	GROUP 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 1.0079 H HYDROGEN																	2 4.0026 He HELIUM
2	3 6.941 Li LITHIUM	4 9.0122 Be BERYLLIUM											5 10.811 B BORON	6 12.011 C CARBON	7 14.007 N NITROGEN	8 15.999 O OXYGEN	9 18.998 F FLUORINE	10 20.180 Ne NEON
3	11 22.990 Na SODIUM	12 24.305 Mg MAGNESIUM											13 26.982 Al ALUMINIUM	14 28.086 Si SILICON	15 30.974 P PHOSPHORUS	16 32.065 S SULPHUR	17 35.453 Cl CHLORINE	18 39.948 Ar ARGON
4	19 39.098 K POTASSIUM	20 40.078 Ca CALCIUM	21 44.956 Sc SCANDIUM	22 47.867 Ti TITANIUM	23 50.942 V VANADIUM	24 51.996 Cr CHROMIUM	25 54.938 Mn MANGANESE	26 55.845 Fe IRON	27 58.933 Co COBALT	28 58.693 Ni NICKEL	29 63.546 Cu COPPER	30 65.39 Zn ZINC	31 69.723 Ga GALLIUM	32 72.64 Ge GERMANIUM	33 74.922 As ARSENIC	34 78.96 Se SELENIUM	35 79.904 Br BROMINE	36 83.80 Kr KRYPTON
5	37 85.468 Rb RUBIDIUM	38 87.62 Sr STRONTIUM	39 88.906 Y YTTRIUM	40 91.224 Zr ZIRCONIUM	41 92.906 Nb NIOBIUM	42 95.94 Mo MOLYBDENUM	43 (98) Tc TECHNETIUM	44 101.07 Ru RUTHENIUM	45 102.91 Rh RHODIUM	46 106.42 Pd PALLADIUM	47 107.87 Ag SILVER	48 112.41 Cd CADMIUM	49 114.82 In INDIUM	50 118.71 Sn TIN	51 121.76 Sb ANTIMONY	52 127.60 Te TELLURIUM	53 126.90 I IODINE	54 131.29 Xe XENON
6	55 132.91 Cs CAESIUM	56 137.33 Ba BARIUM	57-71 La-Lu Lanthanide	72 178.49 Hf HAFNIUM	73 180.95 Ta TANTALUM	74 183.84 W TUNGSTEN	75 186.21 Re RHENIUM	76 190.23 Os OSMIUM	77 192.22 Ir IRIDIUM	78 195.08 Pt PLATINUM	79 196.97 Au GOLD	80 200.59 Hg MERCURY	81 204.38 Tl THALLIUM	82 207.2 Pb LEAD	83 208.98 Bi BISMUTH	84 (209) Po POLONIUM	85 (210) At ASTATINE	86 (222) Rn RADON
7	87 (223) Fr FRANCIUM	88 (226) Ra RADIUM	89-103 Ac-Lr Actinide	104 (261) Rf RUTHERFORDIUM	105 (262) Db DUBNIUM	106 (266) Sg SEABORGIUM	107 (264) Bh BOHRIUM	108 (277) Hs HASSIUM	109 (268) Mt MEITNERIUM	110 (281) Uun UNUNNILIUM	111 (272) Uuu UNUNUNIUM	112 (285) Uub UNUNBIUM		114 (289) Uuq UNUNQUADIUM				

LANTHANIDE

57 138.91 La LANTHANUM	58 140.12 Ce CERIUM	59 140.91 Pr PRASEODYMIUM	60 144.24 Nd NEODYMIUM	61 (145) Pm PROMETHIUM	62 150.36 Sm SAMARIUM	63 151.96 Eu EUROPIUM	64 157.25 Gd GADOLINIUM	65 158.93 Tb TERBIUM	66 162.50 Dy DYSPROSIUM	67 164.93 Ho HOLMIUM	68 167.26 Er ERBIUM	69 168.93 Tm THULIUM	70 173.04 Yb YTTERBIUM	71 174.97 Lu LUTETIUM

ACTINIDE

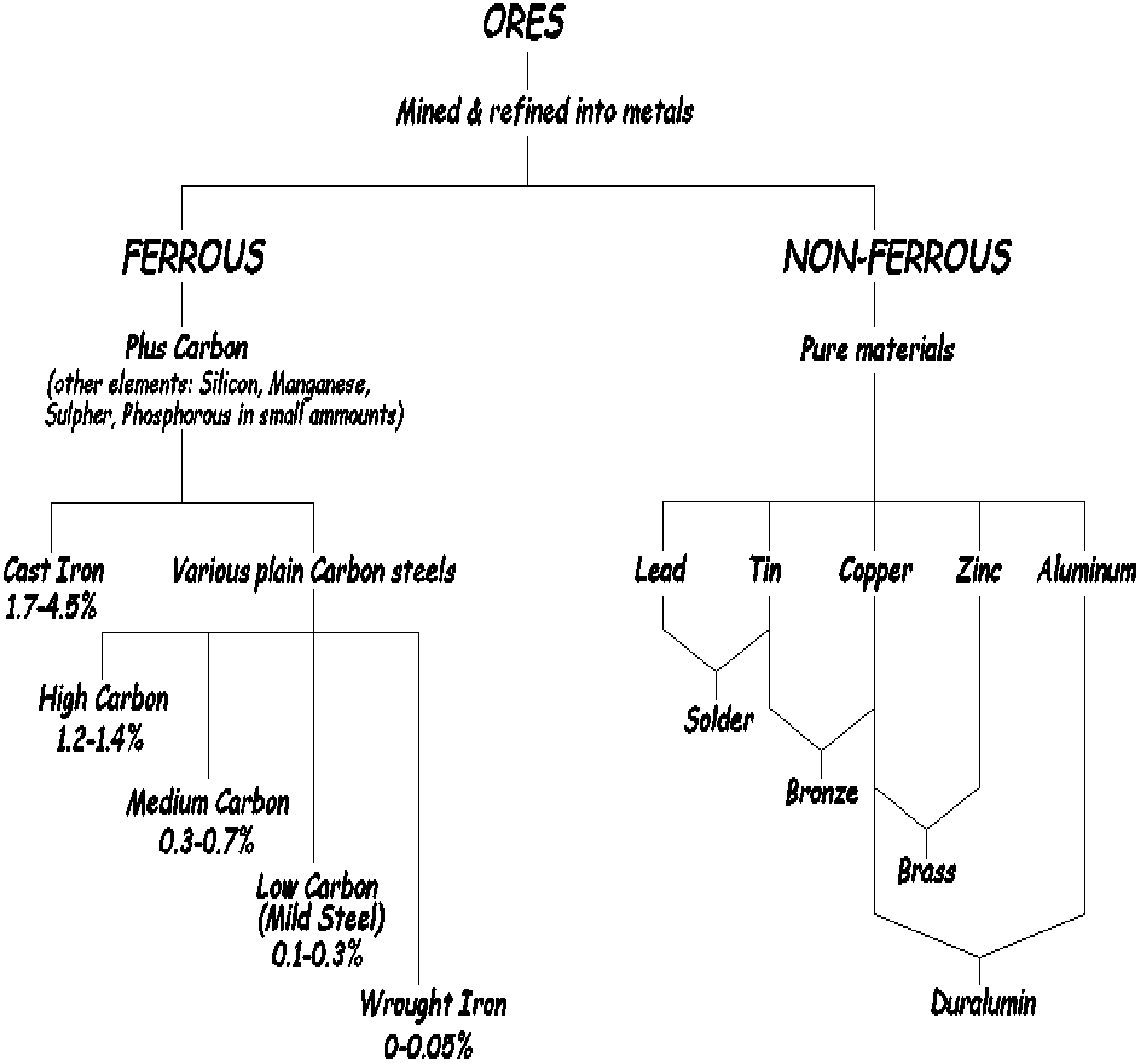
89 (227) Ac ACTINIUM	90 232.04 Th THORIUM	91 231.04 Pa PROTACTINIUM	92 238.03 U URANIUM	93 (237) Np NEPTUNIUM	94 (244) Pu PLUTONIUM	95 (243) Am AMERICIUM	96 (247) Cm CURIUM	97 (247) Bk BERKELIUM	98 (251) Cf CALIFORNIUM	99 (252) Es EINSTEINIUM	100 (257) Fm FERMIUM	101 (258) Md MENDELEVIUM	102 (259) No NOBELIUM	103 (262) Lr LAWRENCIUM

(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)

Relative atomic mass is shown with five significant figures. For elements have no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.

However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (adivar@netlinx.com)



ORES

Mined & refined into metals

FERROUS

Plus Carbon
(other elements: Silicon, Manganese,
Sulpher, Phosphorous in small ammounts)

Cast Iron
1.7-4.5%

Various plain Carbon steels

High Carbon
1.2-1.4%

Medium Carbon
0.3-0.7%

Low Carbon
(Mild Steel)
0.1-0.3%

Wrought Iron
0-0.05%

NON-FERROUS

Pure materials

Lead

Tin

Copper

Zinc

Aluminum

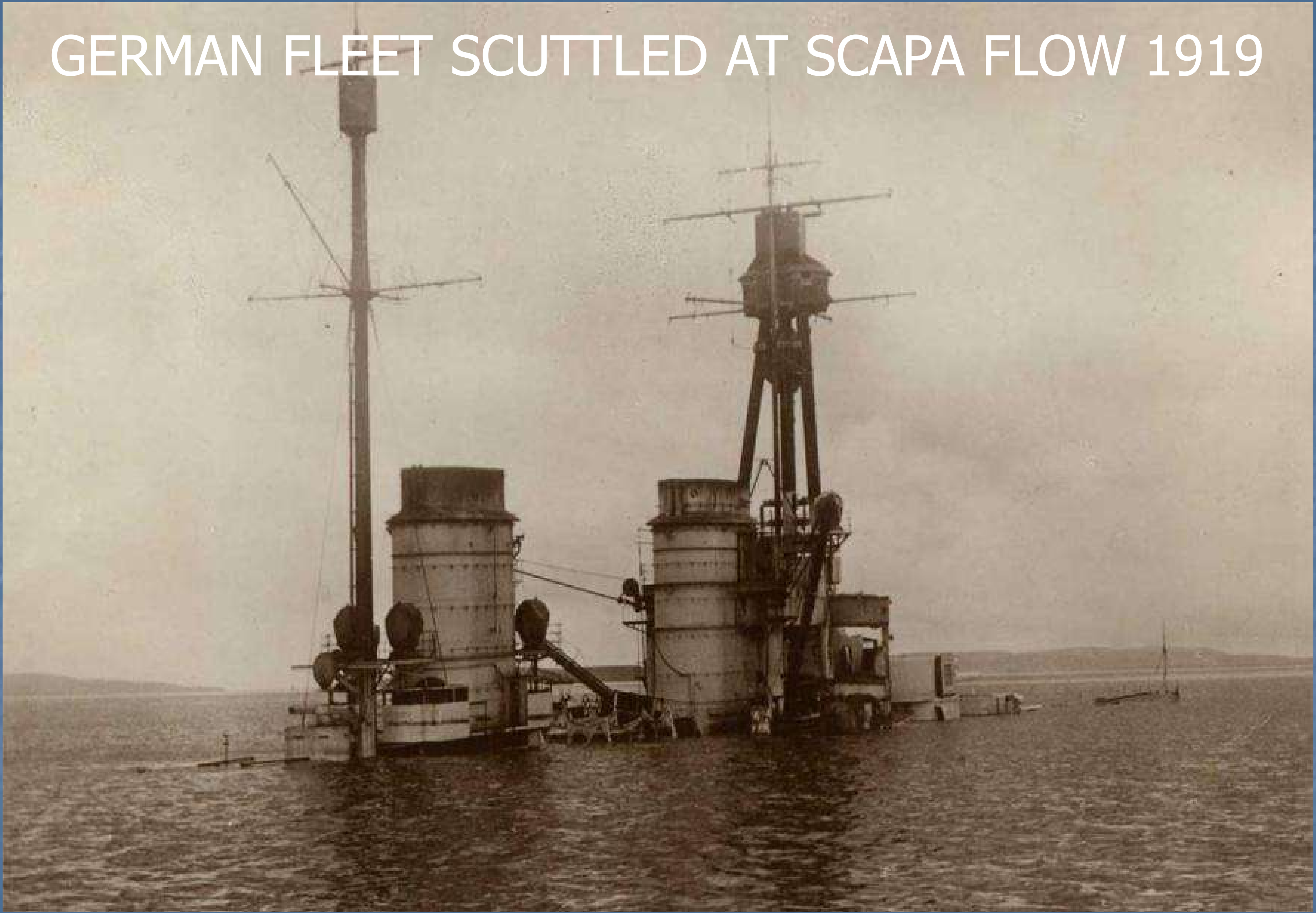
Solder

Bronze

Brass

Duralumin

GERMAN FLEET SCUTTLED AT SCAPA FLOW 1919



THINGS CAN NEVER BE THE SAME AGAIN

Interesting Facts

- Did you know that the steel produced before 1940 is the purest form known to man
- To our detriment it can never be this pure ever again! And eventually will be depleted
- Why?
- Radiation contamination due to Nuclear detonations during WW2 and further weapons testing and radiation leaks hence all steel is now radioactive
- What is the significance of sunken shipwrecks in Scapa flow in the Orkneys ?
- They constitute the world’s largest and best reserve of non-radioactive steel.
- Non-radioactive steel currently allows us to build airliners and space craft, without it we can't make accurate radiation instrumentation - vital to the maintenance and manufacture of Airliners and space craft, for example, the Voyager space craft was built using steel from Scapa

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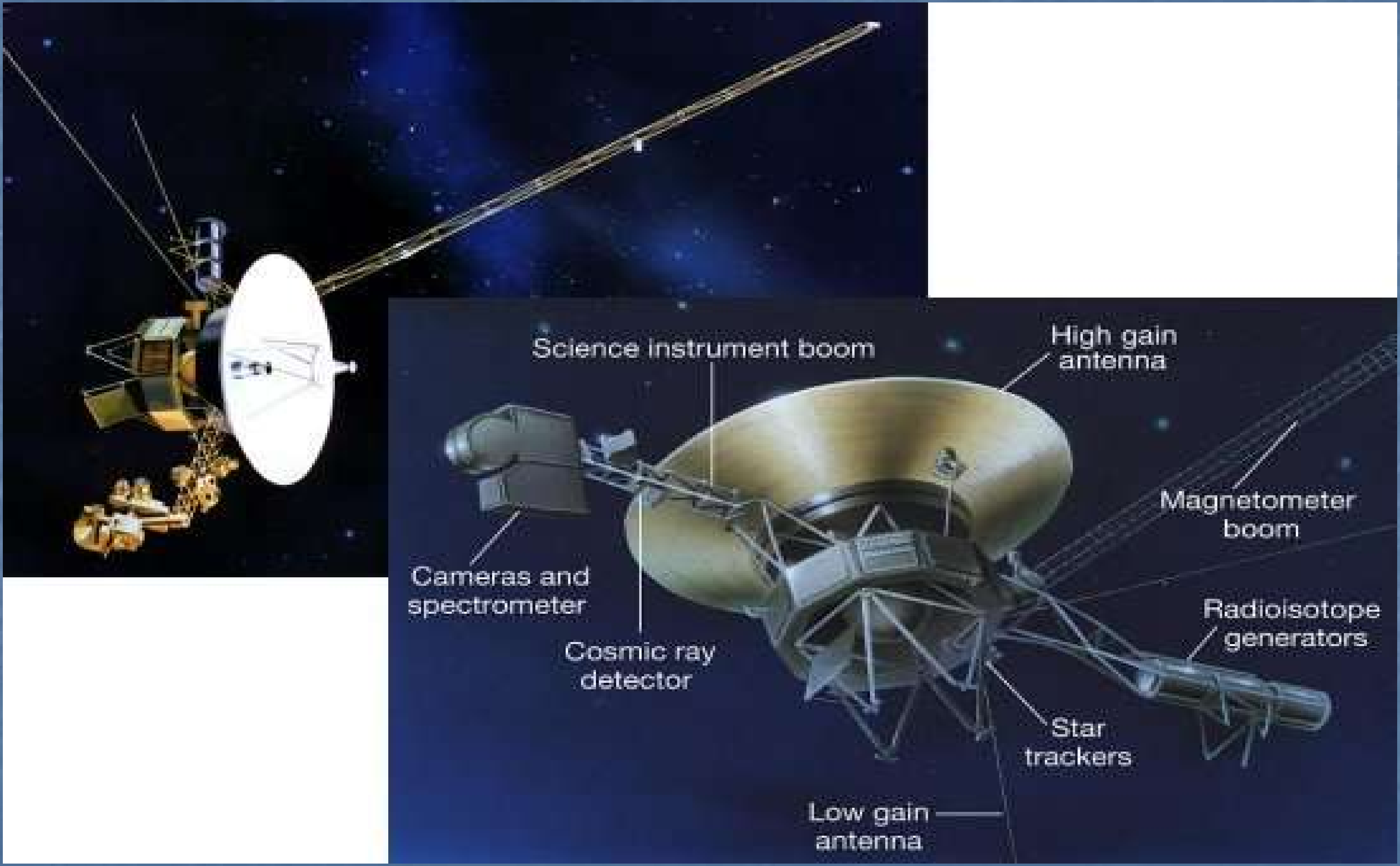
VOYAGER SPACE CRAFT



METALS

- A metal is a raw material mined from the ground as an ore.

- After being solidified from the molten state they develop a crystalline structure and become good electrical conductors.

- Metals are not generally used in their pure state but mixed to form ALLOYS.

- Mixing, or alloying is to enhance certain properties or to make an alloy easier to work e.g. to cut, bend or shape.

- Metals can be divided into two categories FERROUS and NON-FERROUS.

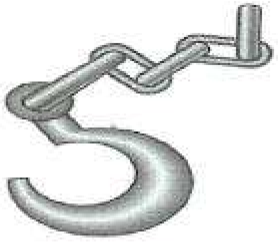
- Ferrous metals and alloys contain the element iron.

- Steels are ferrous alloys made up of iron and smaller amounts of carbon and other elements.

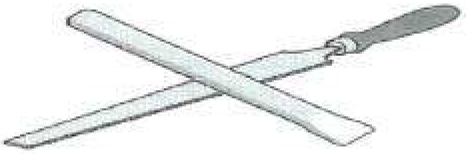
Ferrous Metals

Common name	Carbon %	Common uses
Mild Steel (or Low Carbon	0.1 - 0.3	General-purpose, used throughout engineering
Medium carbon steel	0.3 - 0.7	Hammers and bolts, high stress components
High Carbon steel (or tool steel)	1.2 -1.4	Metal cutting and forming tools

Mild steel
Sheet metal tool box



Medium carbon steel
Lifting hooks and chains

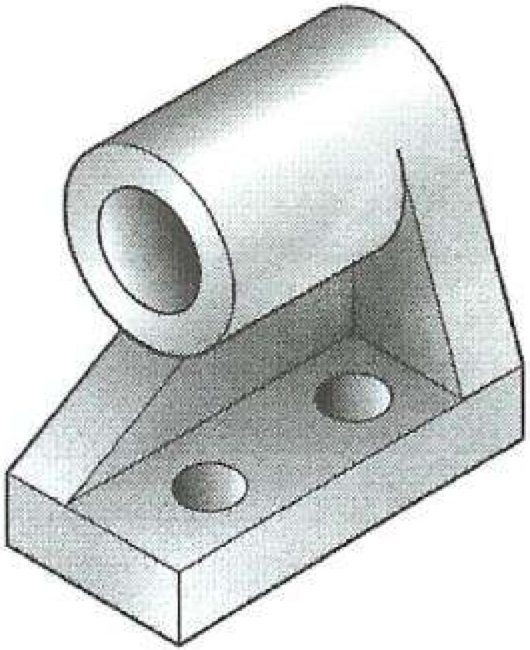


High carbon steel
Hand cutting tools

Cast iron

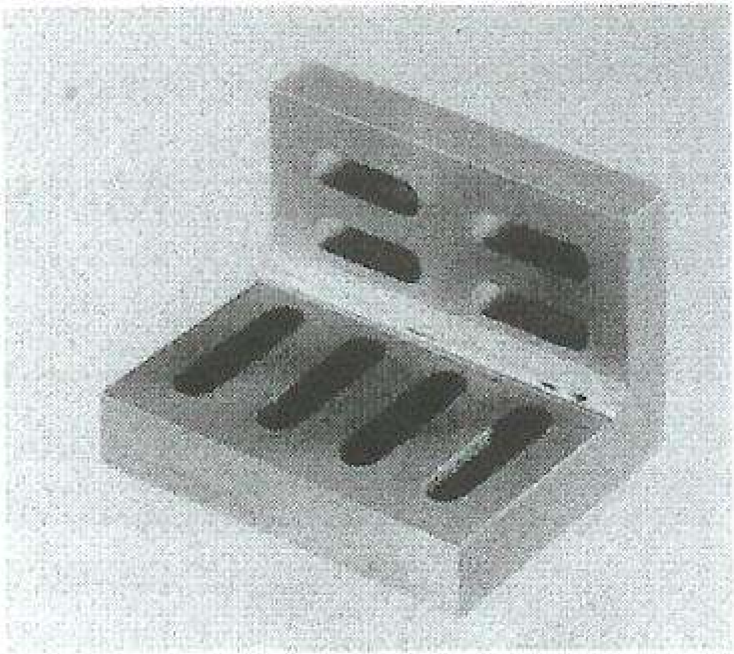
- Cast iron is iron mixed with larger amounts of carbon than plain carbon steels.
- Grey cast iron is the most common type and has a carbon content between 1.7-4.5% together with other elements in smaller proportions.
- Cast iron is used as a fluid when molten, enabling large and intricate castings to be produced.
- Cast iron is quite brittle and has the quality of self-lubrication. These properties are caused by the excess carbon I it’s structure.
- Grey cast iron is used for the production of pre-machined parts e.g. motor-car engines and machine-tool frames. Also for marking out equipment e.g. vee blocks and angle plates.

Cast Iron



Cast Iron

Pulley mounting bracket



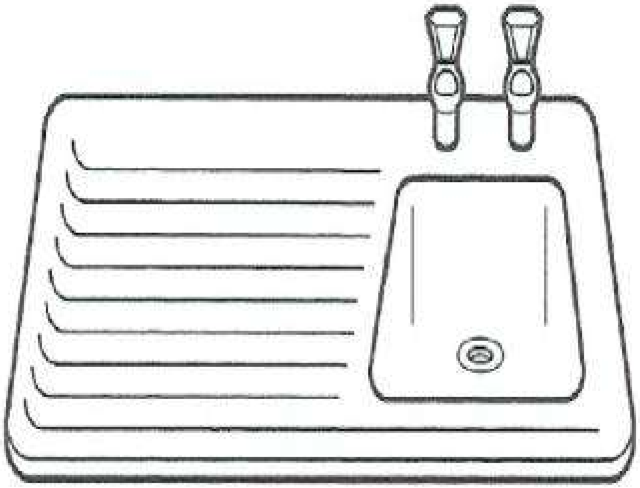
Cast Iron

Angle Plate

Alloy Steels

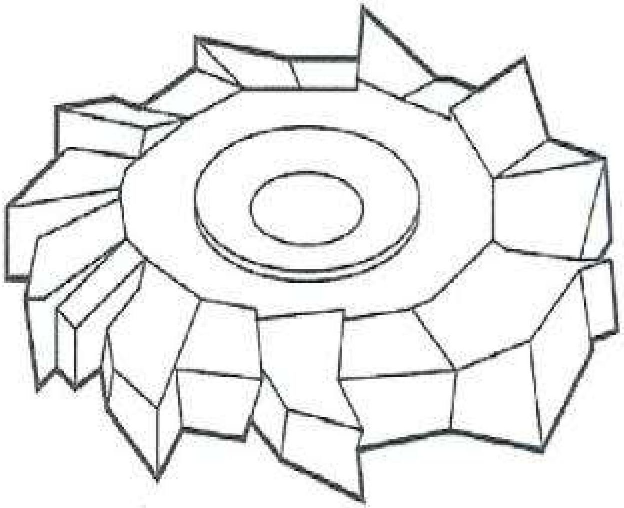
- Alloy steels are steels that have larger amounts of other metals in their composition than cast iron or plain carbon steels.
- These frequently contain such elements as chromium, nickel, molybdenum and vanadium.
- They are usually developed for special purposes e.g. stainless steel is resistant to corrosion and is used in food processing and chemical industries.
- High speed steel (HSS) is a special alloy steel developed for its hardness and toughness, and is used for the manufacture of metal-cutting tools e.g. twist drills and milling cutters.

Alloy steels



Stainless steel

Domestic sink unit



High speed steel

Milling cutters

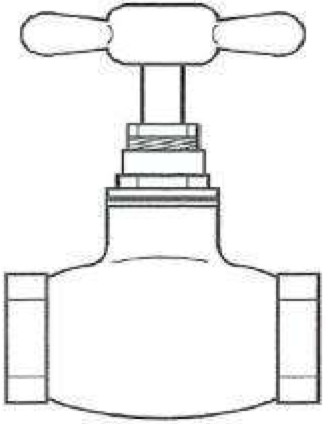
Wings made at Broughton

Non-ferrous metals

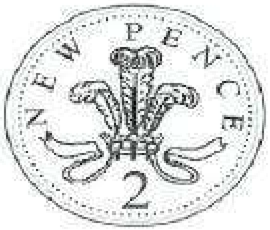
- Non-ferrous metals are metals and alloys that do not contain iron.
- E.g. aluminium, copper, tin, lead and zinc.
- Each metal has its own properties and uses, and although copper is used for electrical wires and water pipes, non-ferrous metals are generally mixed together to form alloys.
- Many non-ferrous metals and alloys are corrosion resistant.

Non-ferrous metals

Duralumin
Aluminium step ladder

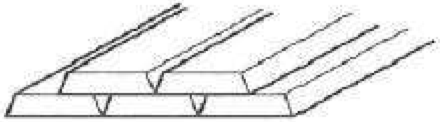


Cast brass
Pipe fittings

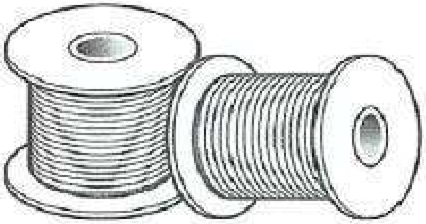


Coin bronze
1p and 2p coins

Phosphor bronze
Bearing bush



Tinman's solder
Stick for sheet steel solder



Electrical solder
Solder for electronic circuits

Non-ferrous metals

The table below shows the composition of some common non-ferrous alloys used in engineering

Metals alloyed	**Common composition(%)**	**Name of alloy**
Aluminium Copper	96 4	Duralumin
Copper Zinc	40 60	Cast brass (Muntz metal)
Copper Zinc Tin	96 2.5 0.5	Coin bronze
Copper Tin Phosphorous	94 5 1	Phosphor bronze
Tin Lead	40 60	Tin man's solder
Tin Lead	30 70	Electrical solder

Non-metals are diverse in their make-up. They can be:

Organic

Mineral

Plastic

Non-metals

- **Organic** - derived from plants and animals e.g. rubber and wood
- Rubber - has many uses in engineering for example a rubber washers is used to form a watertight / airtight joint other uses include ejection springs for press tools
- Wood - we think of Joiners but wood has its uses in engineering, prototype parts are often made from wood, file handles and mould patterns in foundry work

Non-metals **Cont'd**

- **Mineral** – Oils, Stone, Diamond/Carbon & Glass/Ceramics
- These materials are widely used within engineering some examples are:
- Oils - used in cutting compounds also impregnated into bronze bushes which are self lubricating
- Stone - widely used for abrasives
- Diamonds - commonly used for cutting tools
- Glass fibre - used in many applications of engineering materials for example glass filled nylon , Fibre glass
- Ceramics - moulded into parts for engineering applications which are required to resist high temperatures; also cutting tools

Non-metals Cont'd

- **Plastic** – the most common non-metals used in engineering, they tend to be:
  a) lightweight
  b) strong in relation to their weight
  c) good insulators
  d) resistant to corrosion from acids

- Plastic materials have been synthetically made by processing organic and/or mineral materials.

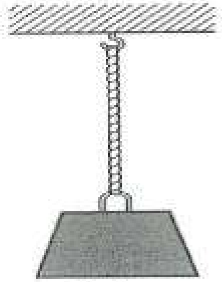
- They have giant molecules which bond together in different ways to produce two distinct types of materials.

- The two types of plastics are recognised by how they behave when treated.

Thermoplastics

- These are materials that are usually moulded while hot as they can be reshaped by heating.
- The molecular structure is long-chain or branched.
- Some common thermoplastics are Perspex, Acetal, nylon, polyvinyl chloride (PVC) and polythene.
- Some common uses are illustrated below:

Perspex
Safety glasses to BS 2092.2

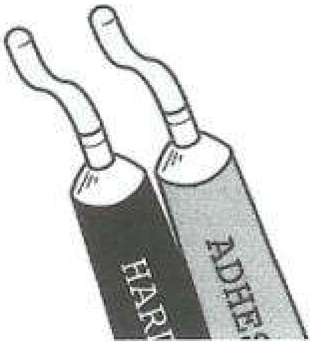


Nylon
Rope

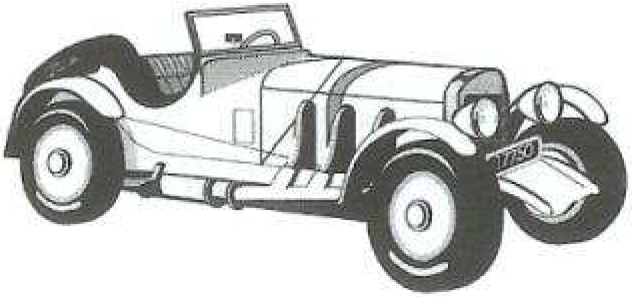
PVC
Wire insulation

Thermosetting plastics

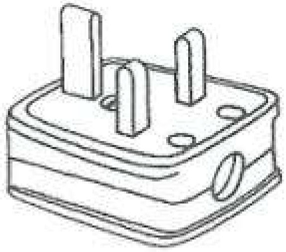
- These are shaped by chemical action and harden on heating.
- Their molecular structure is *cross linked* which gives the material hardness and rigidity.
- Some common e.g. are epoxy resin, glass fibre and urea formaldehyde. Common uses for these hard rigid materials are illustrated below:



Epoxy resin
Adhesive



Glass fibre
Kit-car body



Urea formaldehyde
Electrical

Tufnol – A High Performance Material

- Tufnol - A combination Organic, Mineral & Plastic

  A non - metallic engineering material made from layers of fibrous reinforcement, such as cotton cloth, paper or woven glass cloth, which are bonded together with high quality thermosetting plastic resins.

- The use of Tufnol has many advantages including:
- The use in machines as 'safety critical items'.
- Excellent wear resistance with high strength.
- Resistance to corrosion.
- Large amounts of lubrication are not required

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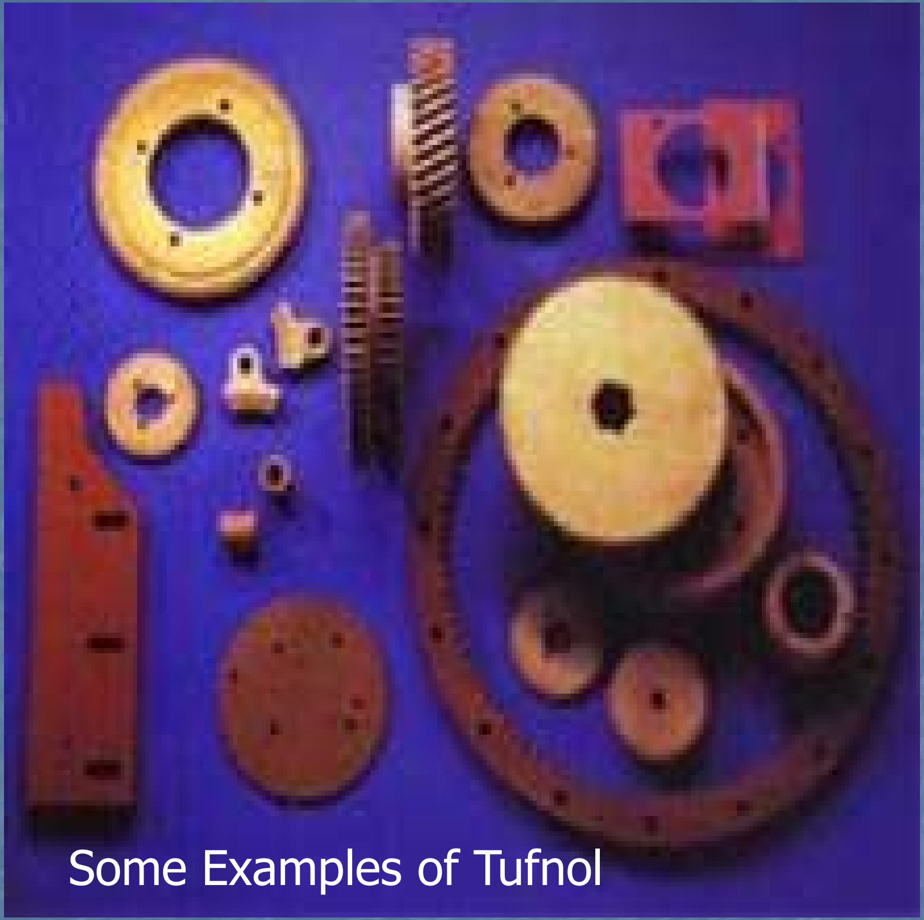
Tufnol

- Tufnol laminates are unaffected by oil, grease or petrol, are generally suitable for use in corrosive atmospheres and can be stored indefinitely without deterioration. Their mechanical strength, toughness, and temperature resistance exceed those of many commonly used thermoplastics materials and enable them to withstand extremely arduous working conditions, as well as the more delicate precision situations. Their resilience provides good resistance to shock loads and their light weight - one sixth of the weight of steel - reduces inertia, which leads to lower power requirements

- These high performance materials are used for a very wide variety of applications where high strength, rigidity dimensional stability and electrical performance are required. Applications such as insulation in large turbine generators, components for cryogenic superconducting magnets, high strength bolt insulation in structures, jigs for electro-chemical machining and structural insulation for high performance electronic equipment, these are typical of the many uses to which this material is put.


Some Examples of Tufnol

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Plastics In Engineering

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Identification of properties

- The properties of materials, particularly metals, can be enhanced by alloying them, e.g. the addition of magnesium into steel makes it easier to forge and roll.
- The addition of Sulpher and Lead to steel can make machining easier
- These are very few metals used in their pure state, most are alloyed with other elements to enhance the properties of the material or to make it easier to manufacture.
- A designer chooses the material for a product and plans its manufacturing process. To do this, the designer must understand the properties of a wide range of materials.

Forms of supply

- Raw materials can be supplied in many different forms.
- The choice allows companies to order their materials in a condition which will enable them to undertake their processing more efficiently.
- This results in savings to be made because the material is bought in the most appropriate form.
- It is therefore important to know and identify the forms in which materials can be supplied.

Commonly Supplied Forms

- Bar
- Plate
- Sheet
- Casting
- Extrusion
- Tube
- Section

Defects in materials

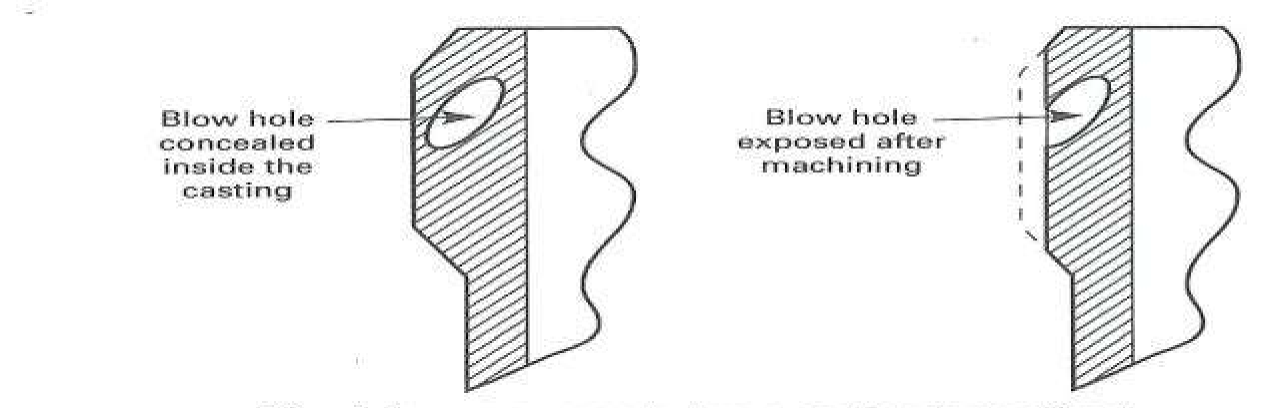
- On delivery, before any materials are accepted it is good practice to visually examine the material for defects.
- Material suppliers can often supply a certificate of conformity guaranteeing that the material meets the necessary standards.
- Some common defects are described next, together with some simple methods of detection.
- The effect of the defect on the serviceability of the materials is also introduced.

Cracks

- If bright rolled steel bar contains excessive sulphur it is prone to cracking.
- Forged components can crack if they have been hammered while not hot enough.
- This can also occur if a component has been cooled too quickly during heat treatment.
- Cracks weaken materials and should be avoided in all highly stressed components.
- A reliable methods of testing is to spray a penetrating die over the surface being tested. When the die has soaked in, it is wiped dry and a developer powder is dusted on the surface. If a crack exists, the penetrating fluid is drawn out by the developer and shows a strain.
- More reliable methods of detection are to use X-ray or ultrasonic equipment.

Blowholes

- These are large voids inside castings; caused by poor venting during manufacture.
- Blowholes can cause weakness and are unsightly
- Although they are invisible immediately after casting, it can become exposed during machinery. The component would then be scrapped.

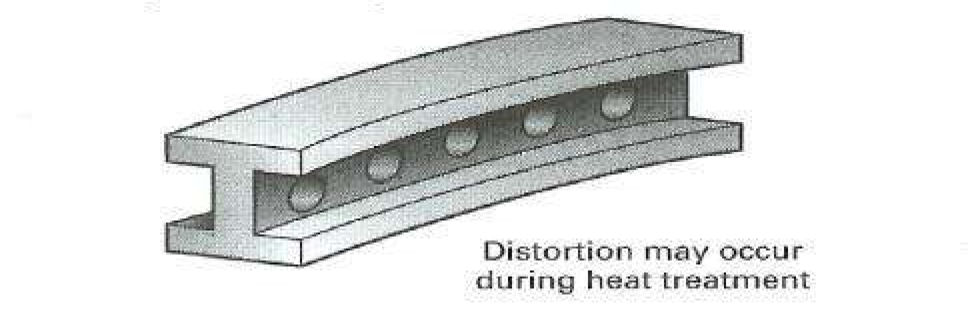


Blowholes are exposed when a casting is machined

- To test for blowholes, samples of the casting can be sawn into pieces and visually inspected by X-ray or ultrasonic equipment

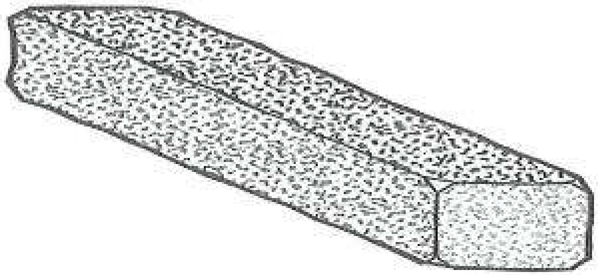
Distortion

- If a component has been incorrectly quenched after heat treatment, or machined without first being stressed relieved, it may become warped.
- Distorted components can be straightened but this is time consuming and may cause internal stress to develop in the component
- Distortion in a bar stock can be detected by comparing the component surface with a straight edge or flat reference surface

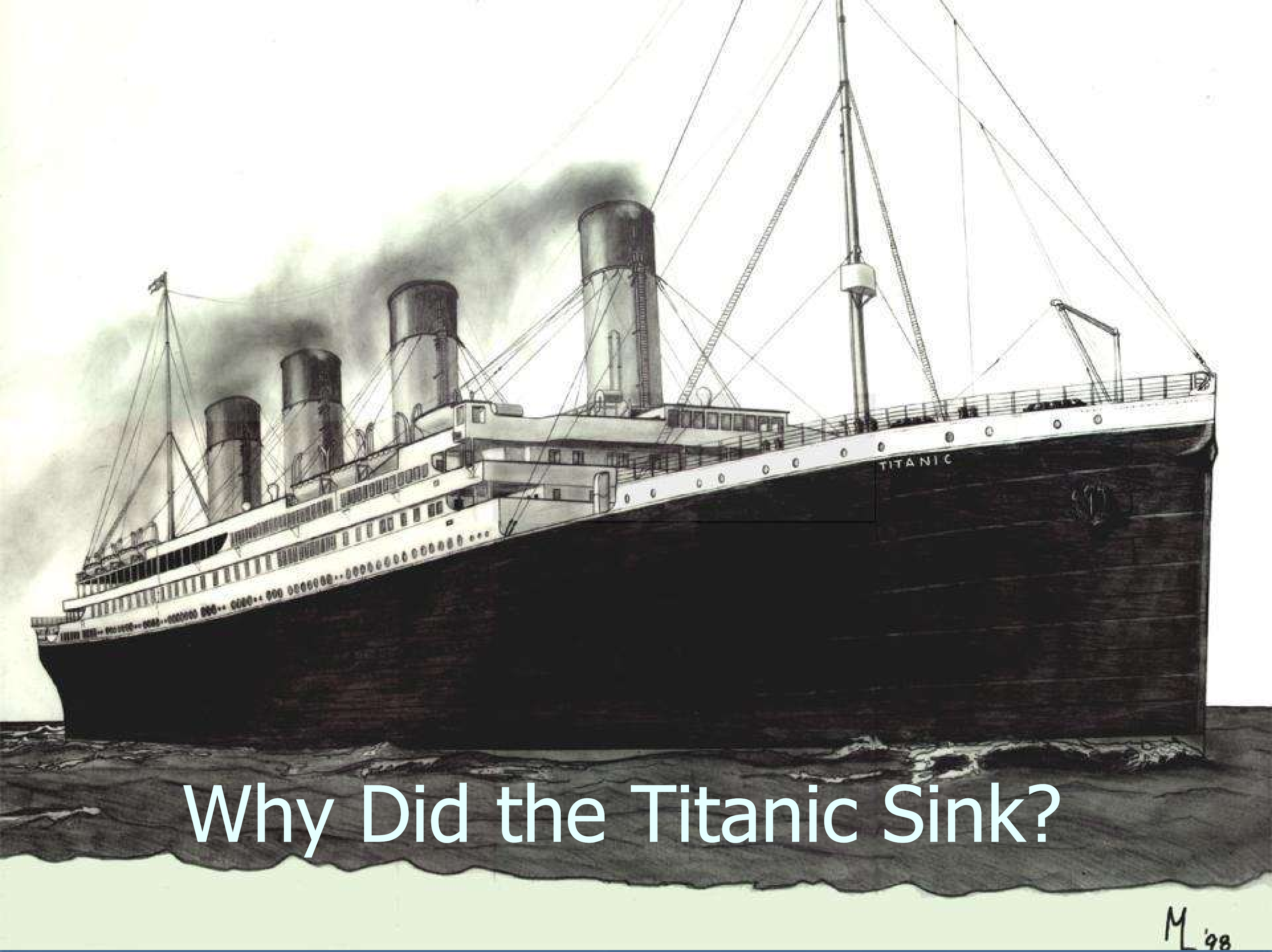


Scale

- This is the term used for hard areas on the surface of cast or forged components and can appear as flakes which are removed with a wire brush of file
- If it is embedded in the skin, it cannot easily be removed.
- Scale can conceal small surface cracks and can cause excessive wear on cutting tools.
- Scale can easily be seen and should be removed with a wire brush to expose any defects on the materials surface. In large steelworks, it is removed by sulphuric acid.



Loose scale should be removed with a wire brush



Why Did the Titanic Sink?

Material Defects
Titanic

When the Titanic collided with the iceberg, the hull steel and the wrought iron rivets failed because of brittle fracture. A type of catastrophic failure in structural materials, brittle fracture occurs without prior plastic deformation and at extremely high speeds. The causes of brittle fracture include low temperature, high impact loading, and high sulphur content. On the night of the Titanic disaster, each of these three factors was present: The water temperature was below freezing, the Titanic was travelling at a high speed on impact with the iceberg, and the hull steel contained high levels of sulphur.

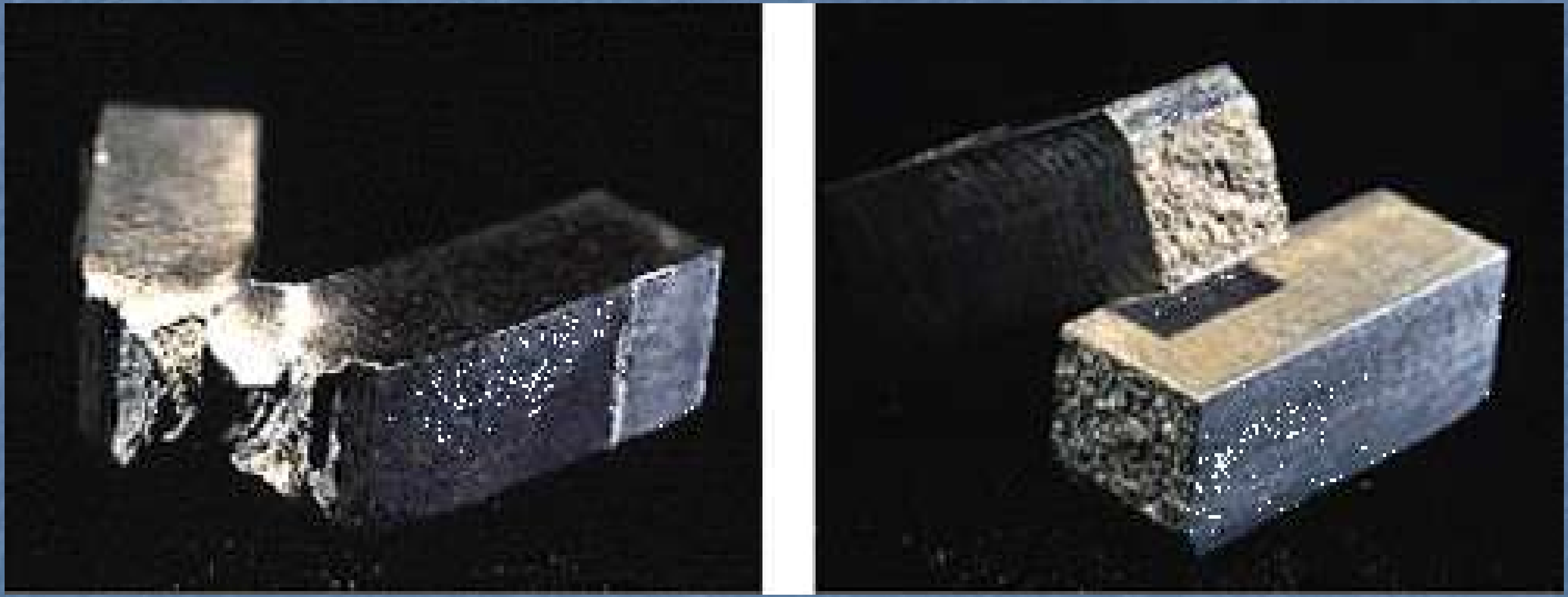
The Titanic - Hull Steel

The first hint that brittle fracture of the hull steel contributed to the Titanic disaster came following the recovery of a piece of the hull steel from the Titanic wreck. After cleaning the piece of steel, the scientists noted the condition of the edges. Jagged and sharp, the edges of the piece of steel appeared almost shattered, like broken china. Also, the metal showed no evidence bending or deformation. Typical high-quality ship steel is more ductile and deforms rather than breaks

The Titanic - Hull Steel **Cont'd**

A micro-structural analysis of the Titanic steel also showed the plausibility of brittle fracture of the hull steel. The test showed high levels of both oxygen and sulphur, which implies that the steel was semi-kilned low carbon steel, made using the open-hearth process. High oxygen content leads to an increased ductile-to-brittle transition temperature, which was determined as 25 to 35°C for the Titanic steel. Most modern steels would need to be chilled below -60°C before they exhibited similar behavior. High sulphur content increases the brittleness of steel by disrupting the grain structure The sulphur combines with magnesium in the steel to form stringers of magnesium sulphide, which act as "highways" for crack propagation. Although most of the steel used for shipbuilding in the early 1900s had a relatively high sulphur content, the Titanic's steel was high even for the times

The Results of the Charpy test for modern steel and Titanic steel. When a pendulum struck the modern steel, on the left, with a large force, the sample bent without breaking into pieces; it was ductile. Under the same impact loading, the Titanic steel, on the right, was extremely brittle; it broke in two pieces with little deformation



Charpy test: a common test of brittleness in structural materials. A Charpy test is run by placing a specimen against a steel backing and striking it with a large pendulum

The Titanic - The Rivets

The wrought iron rivets that fastened the hull plates to the Titanic's main structure also failed because of brittle fracture from the high impact loading of the collision with the iceberg and the low temperature water on the night of the disaster. Figure 2 shows the Titanic during her construction, with the riveted hull plates of her stern visible. With the ship travelling at nearly 25 mph, the contact with the iceberg was probably a series of impacts that caused the rivets to fail either in shear or by elongation. As the iceberg scraped along sections of the Titanic's hull the rivets were sheared off, which opened up riveted seams.

Also, because of the tremendous forces created on impact with the iceberg, the rivet heads in the areas of contact were simply popped off, which caused more seams to open up. Normally, the rivets would have deformed before failing because of their ductility, but with water temperatures below freezing, the rivets had become extremely brittle.

As outlined above we can see how defects can become catastrophic

TTE

En numbers and BS 970

- During the second world war there was rapid movement in the development of steels.
- These new materials were given emergency numbers (En) for identification.
- In 1955 BS 970 was introduced to catalogue all materials.
- BS 970 was updated to enable easy identification of materials in 1983 and 1991; It is a four-part document and recommends specifications for wrought steels for mechanical and allied engineering purposes.
- The section of most interest to engineers is Part 1 which deals with inspection and testing procedures and specific requirements for carbon, carbon-manganese, alloy and stainless steel.

En numbers and BS 970 (cont)

- The recommendation in BS 970 is to use a six-digit code to describe the steel specification. The code is used as follows

- The first three numbers represent the type of steel:

- 000-199 indicates a plain carbon steel
  (the number is 100 times the manganese content)
- 200-249 indicates a free cutting carbon steel
  (the number is 100 times the sulphur content)
- 250 indicates a particular type of silicon-manganese spring steel
- 251-299 indicates a free-cutting alloy or stainless steel
- 300-499 indicates a particular type of stainless or valve steel
- 500-999 indicates a particular type of alloy steel

En numbers and BS 970 (cont)

- One of four letters follow:

  A for steel supplied to chemical composition requirements
  H for steel supplied to harden ability requirements
  M for steel supplied to mechanical property requirements
  S for a type of stainless steel

- The fifth and sixth numbers correspond to 100 times the amount of carbon in the steel.

Example of the BS 970 coding could be a steel specification BS 970: 070M 26. This steel can be defined as:

- A manganese steel with 0.70% manganese content (070 ÷ 100)
- Supplied on mechanical property specification (letter M)
- A carbon content of 0.26% (26 ÷ 100)

Colour codes and abbreviations

- Some steel suppliers paint a colour on steel bars to enable easy and quick identification. This code is not a BS recommendation for steels, so most companies use their own codes (see table below).

- Draughtsperson may use any of the following to describe a material.

- Most of the following are not specific to a material but describe the material in loose or general terms:

MS = mild steel
BMS = bright mild steel
CI = cast iron
HCS = high carbon steel
Ally = aluminium alloy

Colour codes and abbreviations (cont)

Shown below is the BS 970 specification and old En equivalent of some steels, together with the code used by a leading UK steel stockholder.

Material type	**New BS 970:1991 spec**	**Old BS 970:1955 (En) spec**	**Common colour code**
Low carbon steel	**080 A 15**	**En3B (equivalent)**	**blue**
(or mild steel	**070 M 20**	**En3B**	**blue/red**
	080 M 15	**En32B**	**red**
Free-cutting steel	**230 M 07**	**En1A**	**green**
	230 M 07 (leaded)	**En1A (leaded)**	**magenta**
Medium carbon steel	**080 M 40**	**En8**	**yellow**
Alloy steels	**605 M 36**	**En16**	**white**
	708 M 40	**En19**	**yellow/white**
	817 M 40	**En24**	**white/blue**