

Steel

The Framework of Our Civilization

L. M. DOUGHERTY

Los Alamos National Laboratory

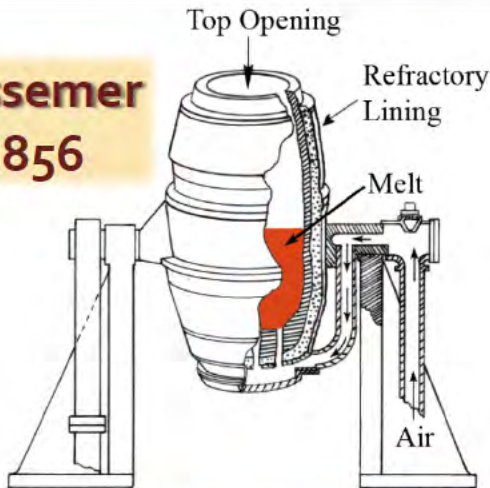
Steel & Modern Civilization



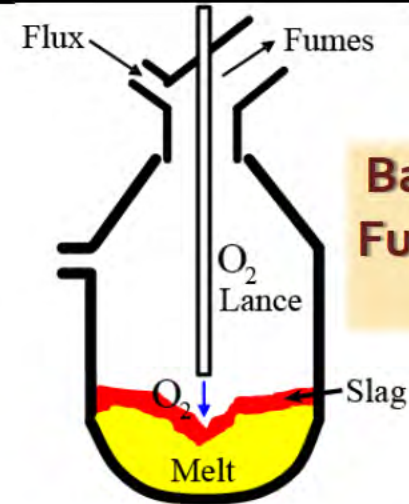
Energy
Structures
Transportation
Drinking Water
Waste Management

Modern Steelmaking

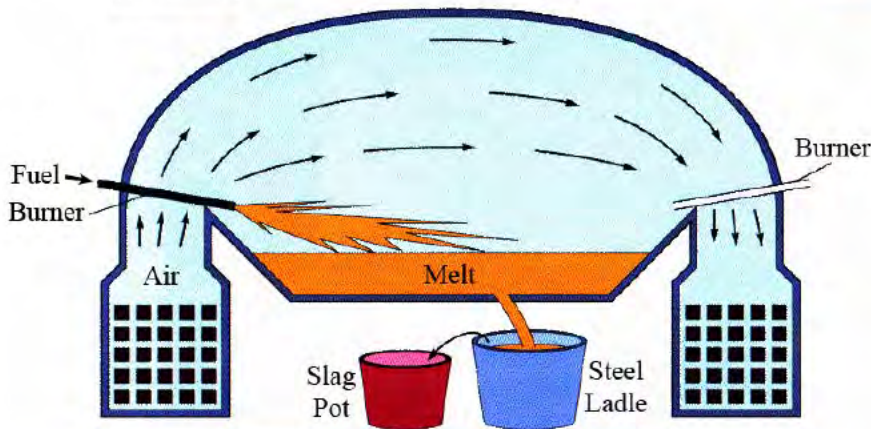
Bessemer
1856



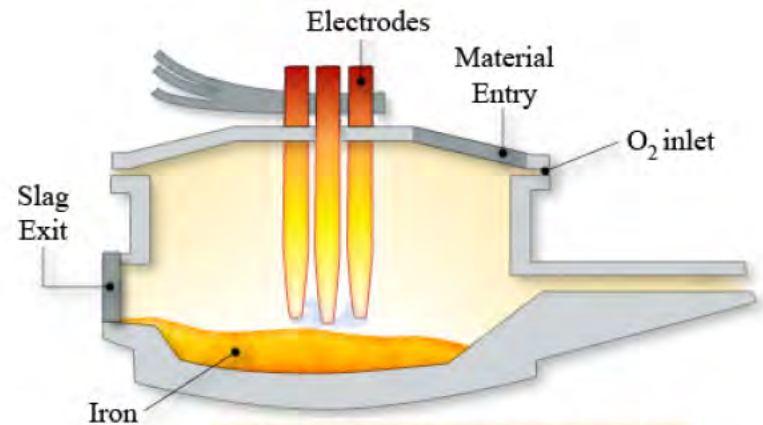
**High-Volume
Liquid
Steelmaking**



**Basic Oxygen
Furnace (BOF)**
1952



Siemens Open-Hearth Process
1858



Electric Arc Furnace
1907

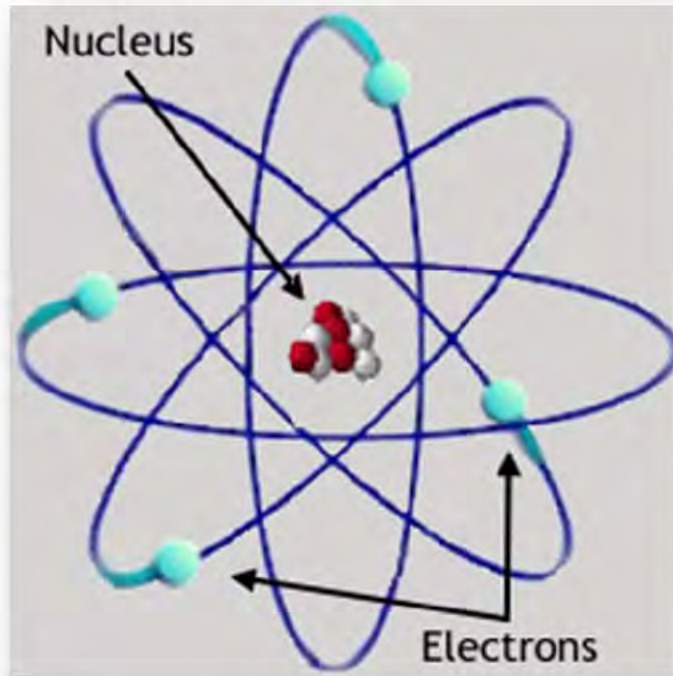
What Is a Metal?

Legend

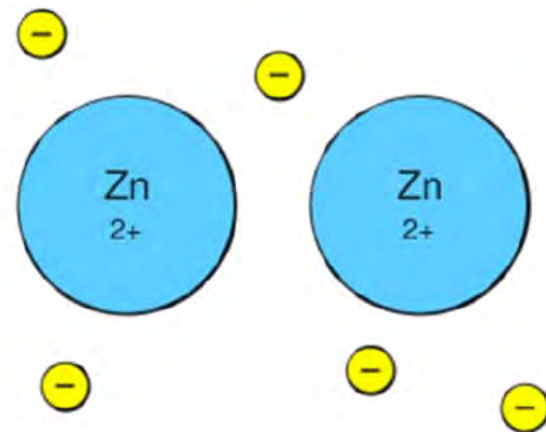
Metals	Metalloids
Non-Metals	Rare Gases

	IA s1	IIA s2	Transition elements										IIIA s2 p1	IVA s2 p2	VA s2 p3	VIA s2 p4	VIIA s2 p5	VIIIA s2 p6	0
1	1 H																		2 He
2	3 Li	4 Be	← VIII →										5 B	6 C	7 N	8 O	9 F	10 Ne	
3	11 Na	12 Mg	d1 s2	d2 s2	d3 s2	d5 s1	d5 s2	d6 s2	d7 s2	d8 s2	d10 s1	d10 s2	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
6	55 Cs	56 Ba	57 to 71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	
7	87 Fr	88 Ra	89 to 103	104 Ku	105 Ha	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub							
			← Inner Transition Elements →																
Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu				
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr				

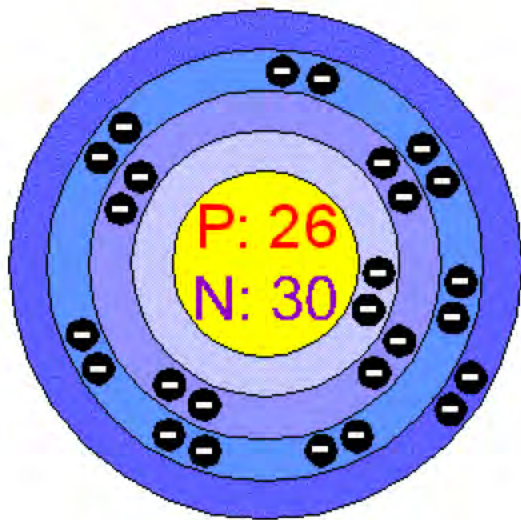
It's All About the Electrons



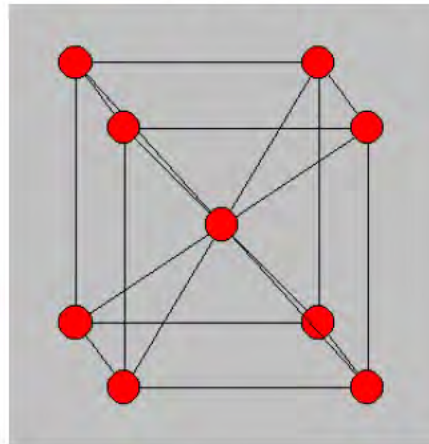
METALLIC BONDING



Phases of Iron



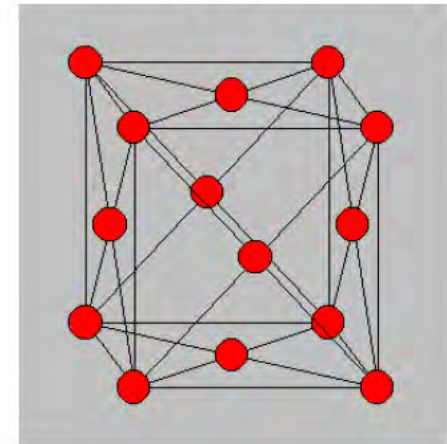
BCC



Room T

- Lower density
- Magnetic
- Stable

FCC



High T

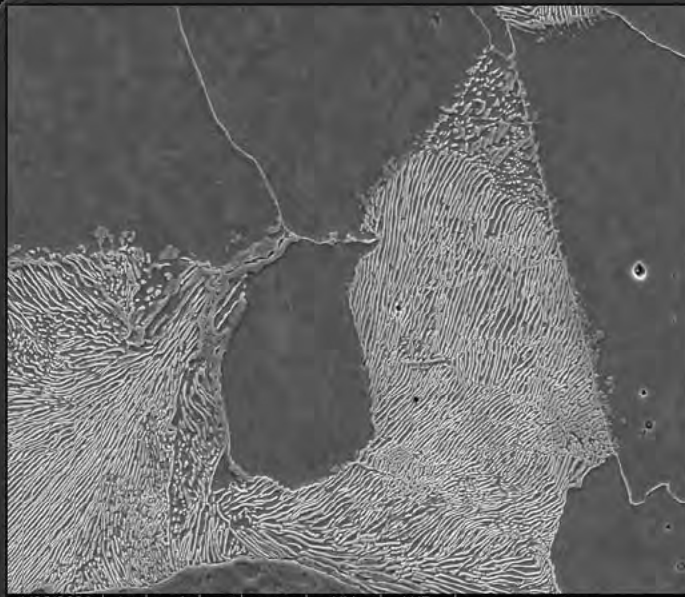
- Higher density
- Non-Magnetic
- Quasi-Stable

What is Steel?



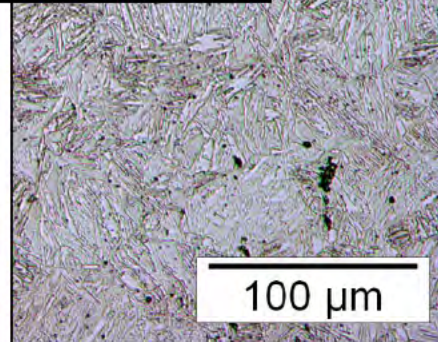
Plain Carbon Steel

Iron + Carbon
= A Mixture of Phases

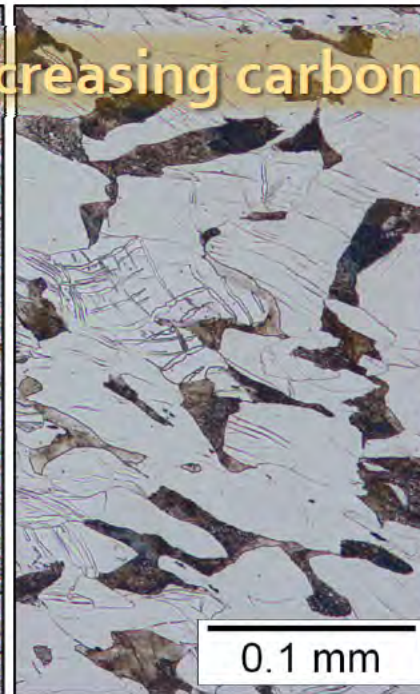


8/22/2008 | det | mode | spot | mag | HV | WD | 20 μ m
2:59:11 PM | ETD | SE | 3.0 | 5 000 x | 15.00 kV | 10.1 mm | K17

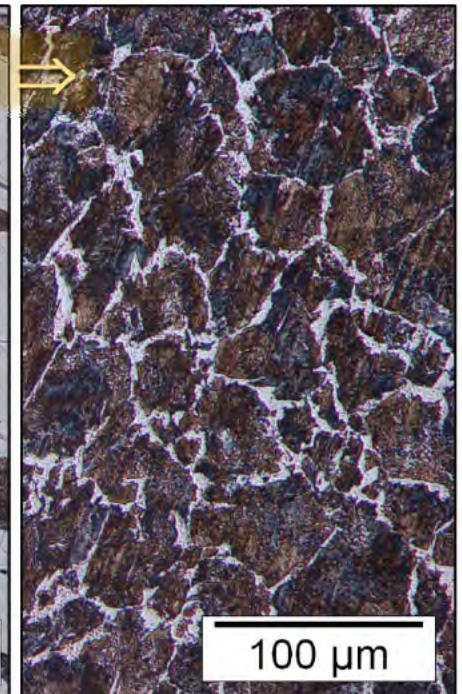
increasing carbon \Rightarrow



100 μ m



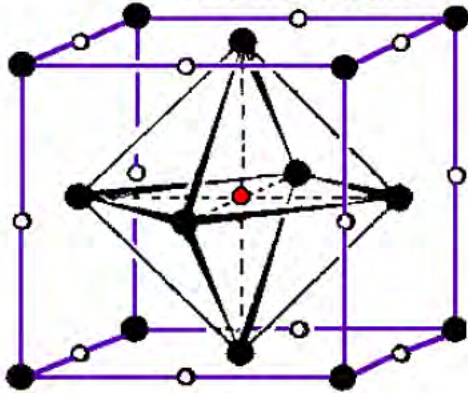
0.1 mm



100 μ m

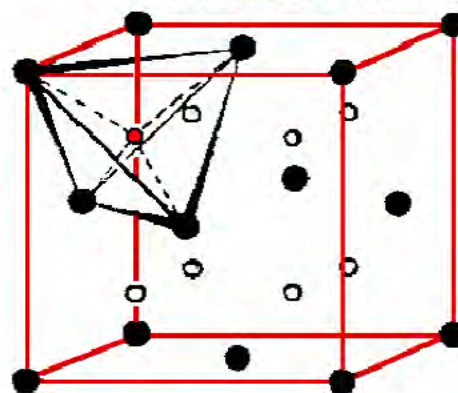
Where Does the Carbon Go?

octahedral
interstitials



FCC

tetrahedral
interstitials

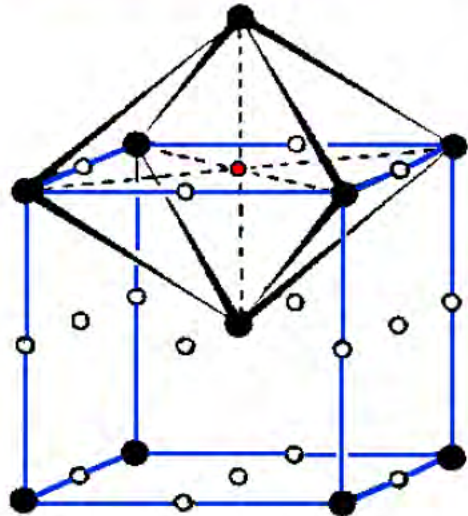


Low-Carbon
Up to 0.30 wt.% C

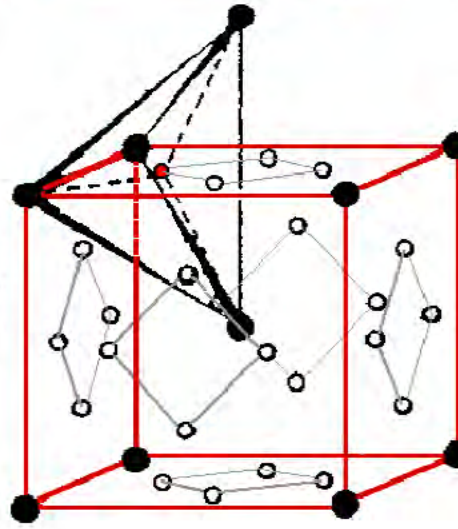
Medium-Carbon
0.3 to 0.60 wt.% C

High-Carbon
0.6 to 1.00 wt.% C

Ultrahigh-Carbon
1.25 to 2.0 wt.% C



BCC



Alloy Steel



Iron + other elements
= Special Properties



STAINLESS STEEL \Rightarrow Forms a protective oxide
10.5 to 30 wt.% chromium

How Does Steel Compare?

**SUPER
STEEL**

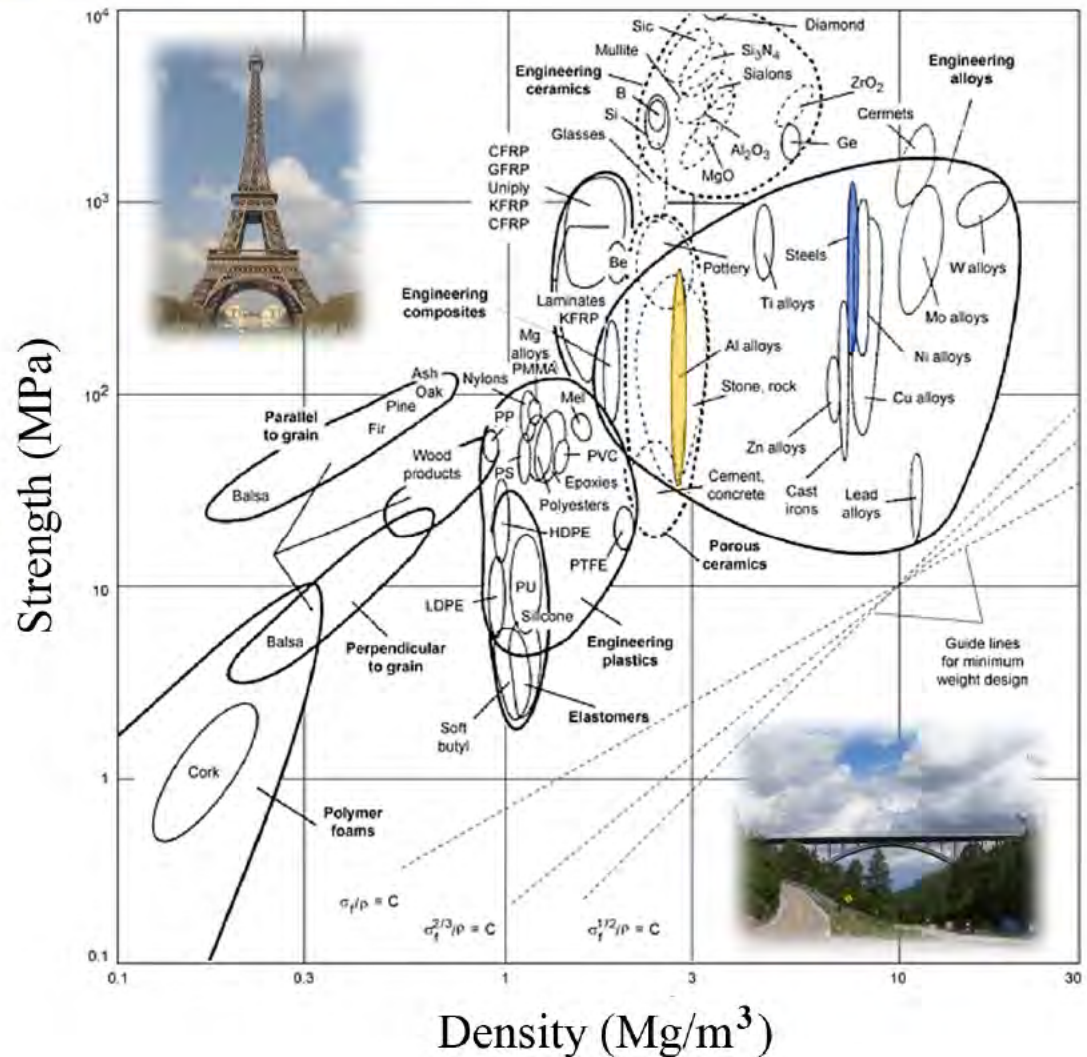


**ALUMINUM
MAN**



Structural Applications

- High strength
- Good ductility
- Fatigue resistant
- Cheap



Specialty Applications

- Nuclear reactor vessels
- Orthopedic implants
- Missile casings
- Tool steels

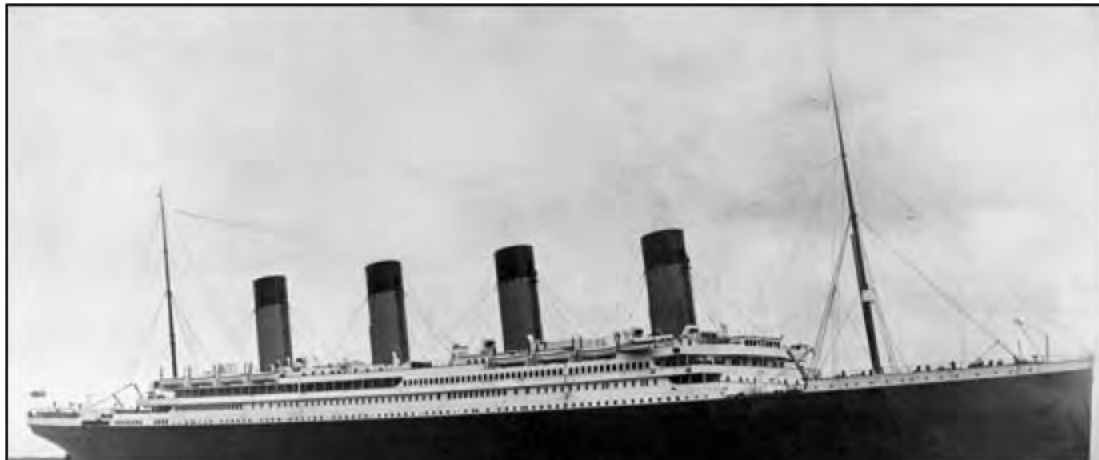


Why Does Steel Fail?



Impurities

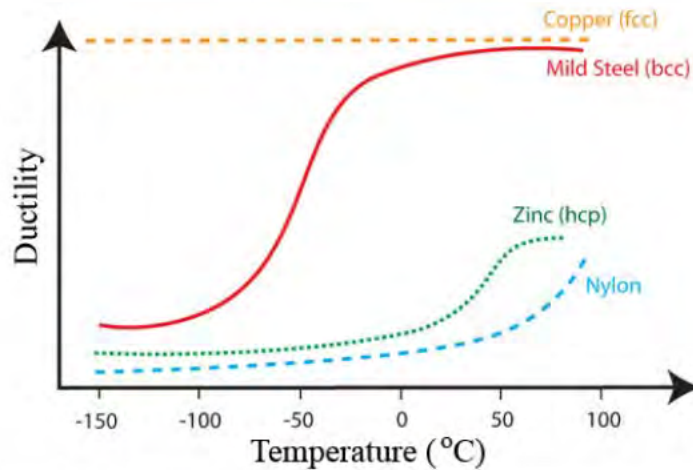
The Sinking of the Titanic
Too much slag in the rivets?



Sank in 1912 (1,517 dead)

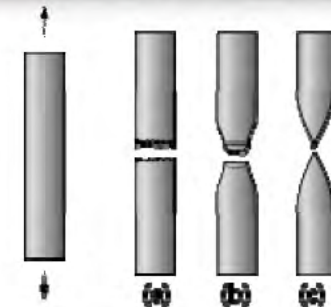
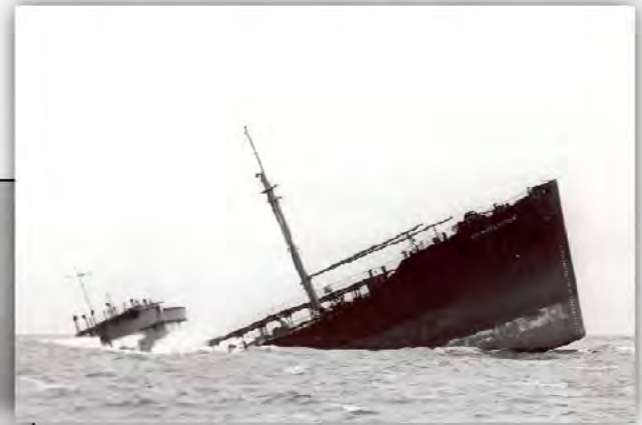


Wrong Type of Steel



Ductile to Brittle Transition

- Unique to ferritic steels
- Ductility lost at low temperatures
- 19 Liberty Ships sink in North Atlantic



Stress Corrosion Cracking



Collapse of pedestrian bridge in NC in 2000
(106 injured)



Mianus Bridge collapse in CT in 1983
(3 dead, 5 injured)

Steel Corrosion

- Salts & deicers
- Cyclic loads
- Sudden failure



Overloading



I-35 bridge over the Mississippi in 2007 (13 dead, 145 injured)

Too Much Traffic

- Aging bridges
- Increasing loads
- Insufficient maintenance



Our Declining Infrastructure

Infrastructure Category	1998 Report (Clark, 1998)	2001 Report (ASCE, 2001)	2003 Trends (ASCE, 2003)	2005 Report (ASCE, 2005)
Aviation	C-	D	No Progress	D+
Bridges	C-	C	No Progress	C
Dams	D	D	Dedining	D
Drinking Water	D	D	Dedining	D-
Energy	Not Graded	D+	Dedining	D
Hazardous Waste	D-	D+	No Progress	D
Mass Transit	C	C-	Dedining	D+
Public Parks	Not Graded	Not Graded	Not Graded	C-
Rail	Not Graded	Not Graded	Not Graded	C-
Roads	D-	D+	Dedining	D
Schools	F	D-	No Progress	D
Security	Not Graded	Not Graded	Not Graded	I
Solid Waste	C-	C+	No Progress	C+
Wastewater	D+	D	Dedining	D-
Waterways	Not Graded	D+	Dedining	D-
Overall Grade	D	D+	D+	D
Overall Need	\$1.3 Trillion	\$1.3 Trillion	\$1.6 Trillion	\$1.6 Trillion

Questions

1. What are things you do every day that you could not do without steel?
2. What are some ways that steel might have influenced societies ...
 - ... in transportation?
 - ... in exploration?
 - ... in architecture?
 - ... in warfare?
3. Why do you think the condition of our national infrastructure—much of which depends on steel—is in a poor or declining condition? What should be done about it? Why isn't it being done? What can you do about it?