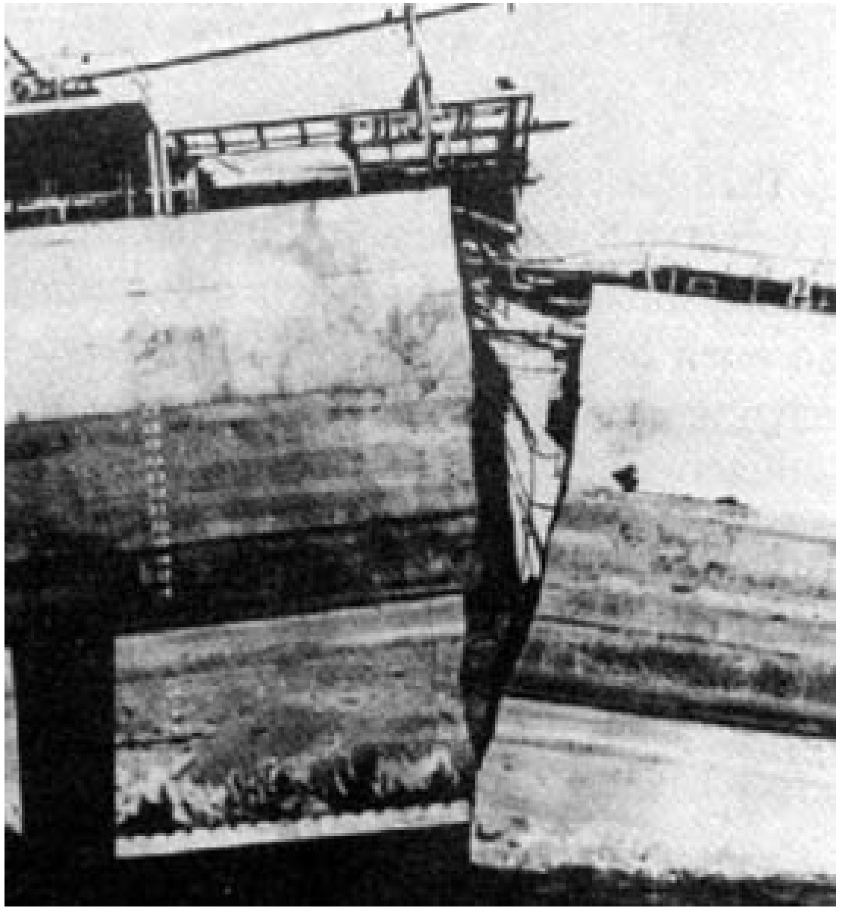
Impact Testing [4]

- **Liberty ship: class of cargo ship built in the U. S. during World War II (2,710 units between 1941-1945).**

Displacement: 14,474 t
Length: 134.57 m
Beam: 17.3 m
Draft: 8.5 m
230 days → 42 days

SS John W. Brown (2000)

Liberty class ship lost during WW2



Impact Testing

- **Fracture:**
  - Cracking to the extent that component to be separated into pieces
  - Steps in fracture:
    - crack formation
    - crack propagation
- Depending on the ability of material to undergo plastic deformation before the fracture two fracture modes can be defined - **ductile or brittle**
  - **Ductile fracture** - most metals (not too cold):
    - Extensive plastic deformation ahead of crack
    - Crack is "stable": resists further extension unless applied stress is increased
  - **Brittle fracture** - ceramics, ice, cold metals:
    - Relatively little plastic deformation
    - Crack is "unstable": propagates rapidly without increase in applied stress

➢ Crack formation mechanisms:

- **Metals** typically form cracks by the accumulation of dislocations at a crack nucleation site (grain boundaries, precipitate interface, free surface, etc.)

- **Ceramics, semiconductors, some plastic**s (hard and brittle, eg., thermosetting plastics) and intermetallic compounds form cracks by planar defects (grain boundaries, two-phase interfaces, etc.)

- **Soft plastics** crack by the sliding of the long polymer chairs across each other by breaking the Van der Wall bonds.

Fracture of Materials

➢ **Fracture can be classified according to the path of crack propagation:**

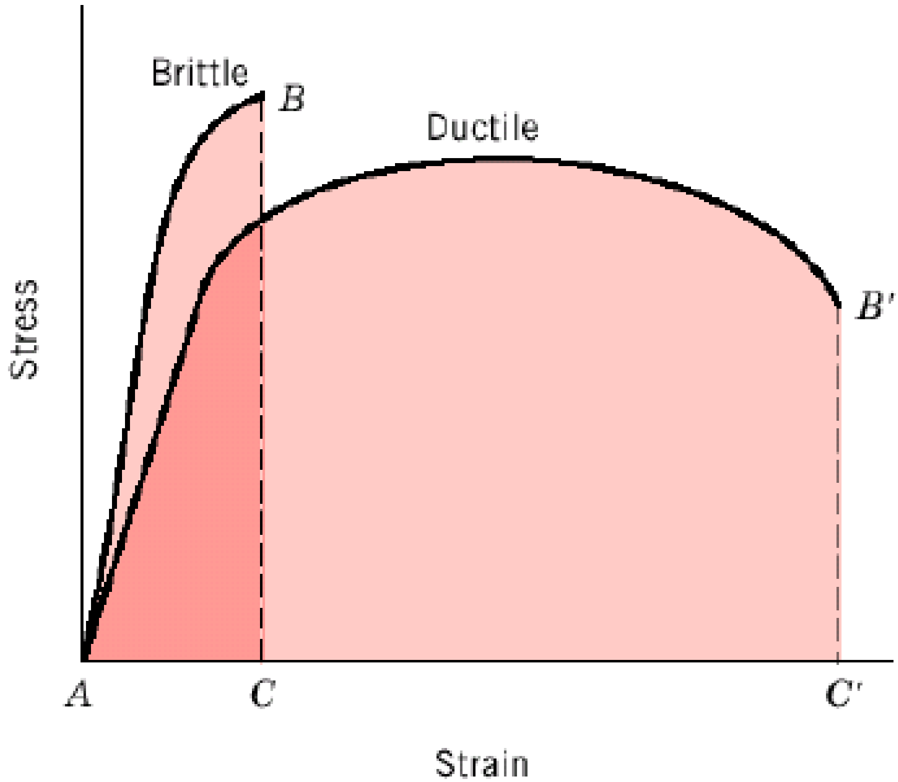
• **Transgranular – the crack travels directly through the grains of the material (sometimes called cleavage because it occurs along certain crystallographic planes). It can be ductile or brittle.**

• **Intergranular – the crack propagates along grain boundaries. This is primarily brittle fracture.**

➢ **A variety of loading conditions can lead to fracture:**

• **Static Overloading (σ > Tensile Strength)**
• **Dynamic Overloading (impacting)**
• **Cyclic loading (fatigue)**
• **Loaded at elevated temperatures (creep)**
• **Loading at cryogenic temperatures (ductile to brittle transition)**
• **Loading in a corrosive environment (stress corrosion)**

Brittle vs. Ductile Fracture



- **Ductile materials** - extensive plastic deformation and energy absorption ("toughness") before fracture
- **Brittle materials** - little plastic deformation and low energy absorption before fracture

Impact Fracture Testing

➢ **Fracture behavior depends on many external factors:**

- **Strain rate**
- **Temperature**
- **Stress rate**

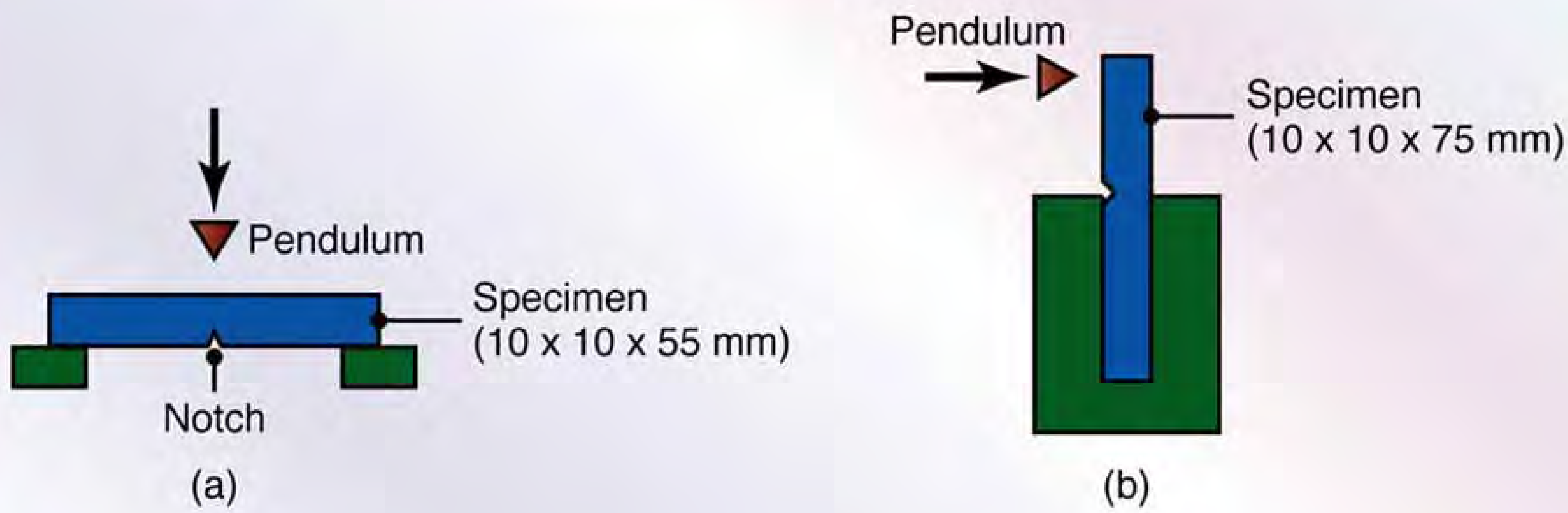
➢ **Impact testing is used to ascertain the fracture characteristics of materials at a high strain rate and a triaxial stress state.**

➢ **In an impact test, a notched specimen is fractured by an impact blow, and the energy absorbed during the fracture is measured.**

➢ **There are two types of tests – Charpy impact test and Izod impact test.**

ASTM Impact Test Standards

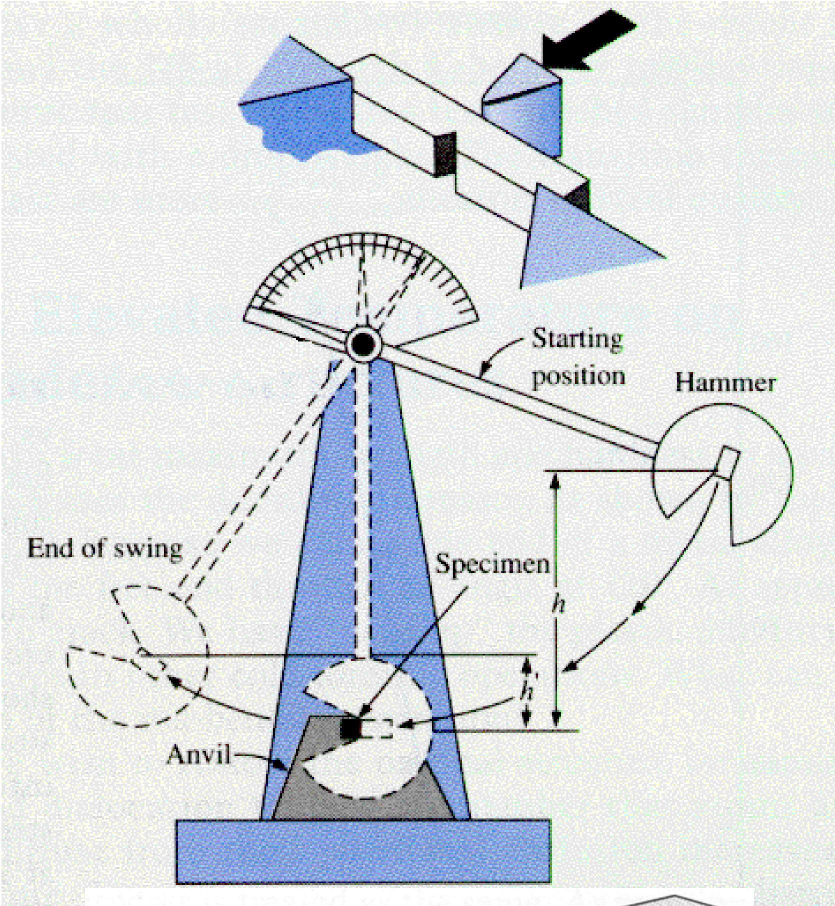
- **E23 - Standard Test Methods for Notched Bar Impact Testing of Metallic Materials (2016)**
- **E1823 - Standard Terminology Relating to Fatigue and Fracture Testing (2013)**
- **E2298 - Standard Test Method for Instrumented Impact Testing of Metallic Materials (2015)**

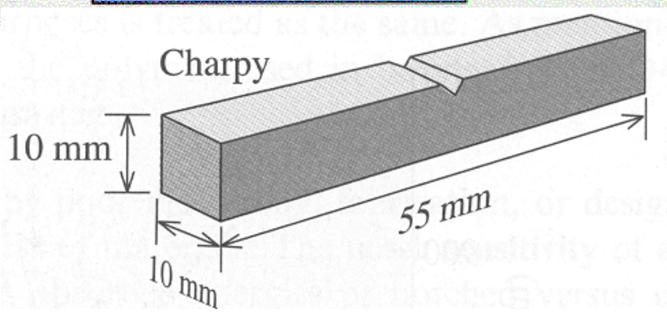


(a) Charpy **(b) Izod.**

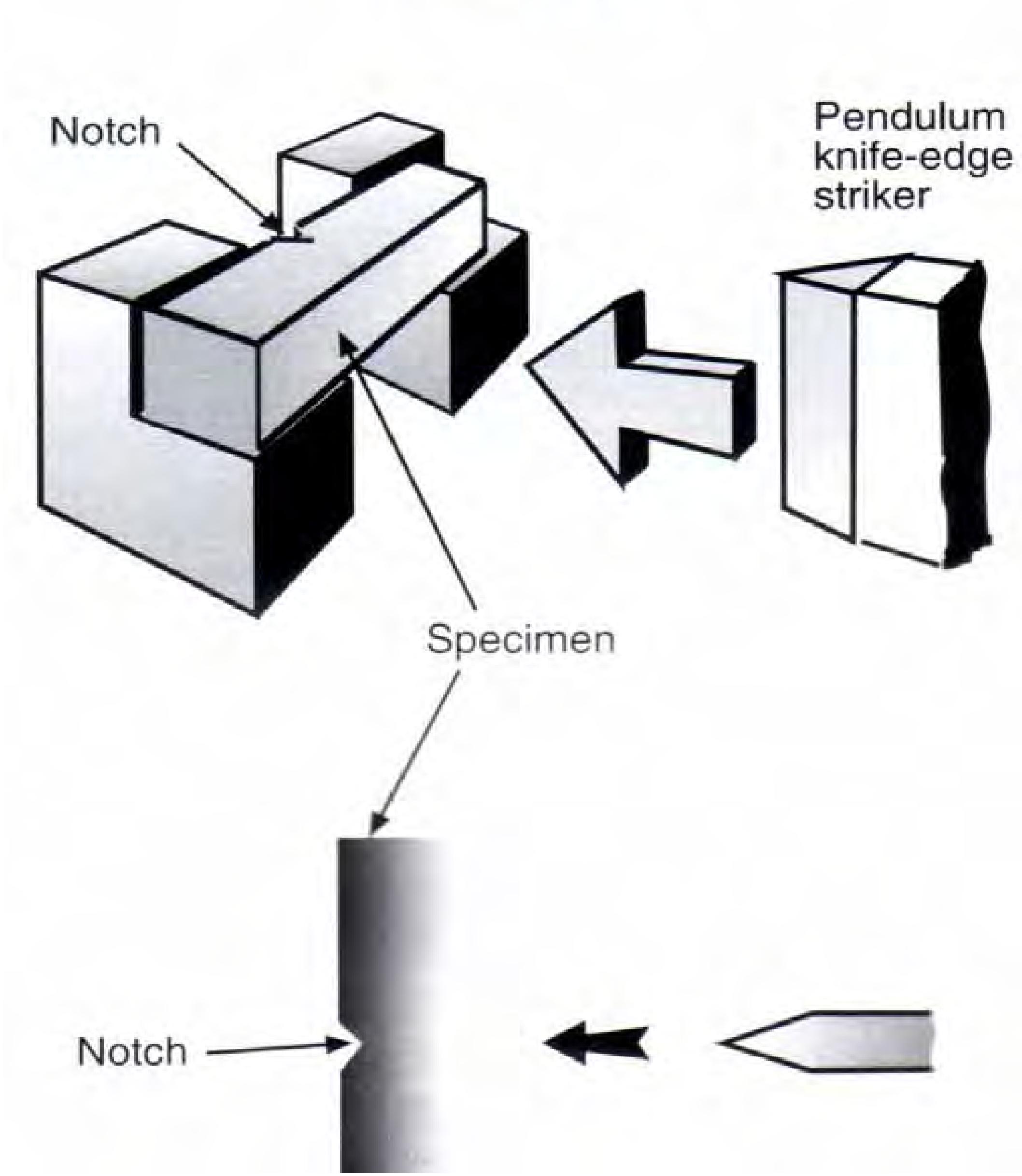
Charpy Test Machine

- energy absorbed by a material during fracture.



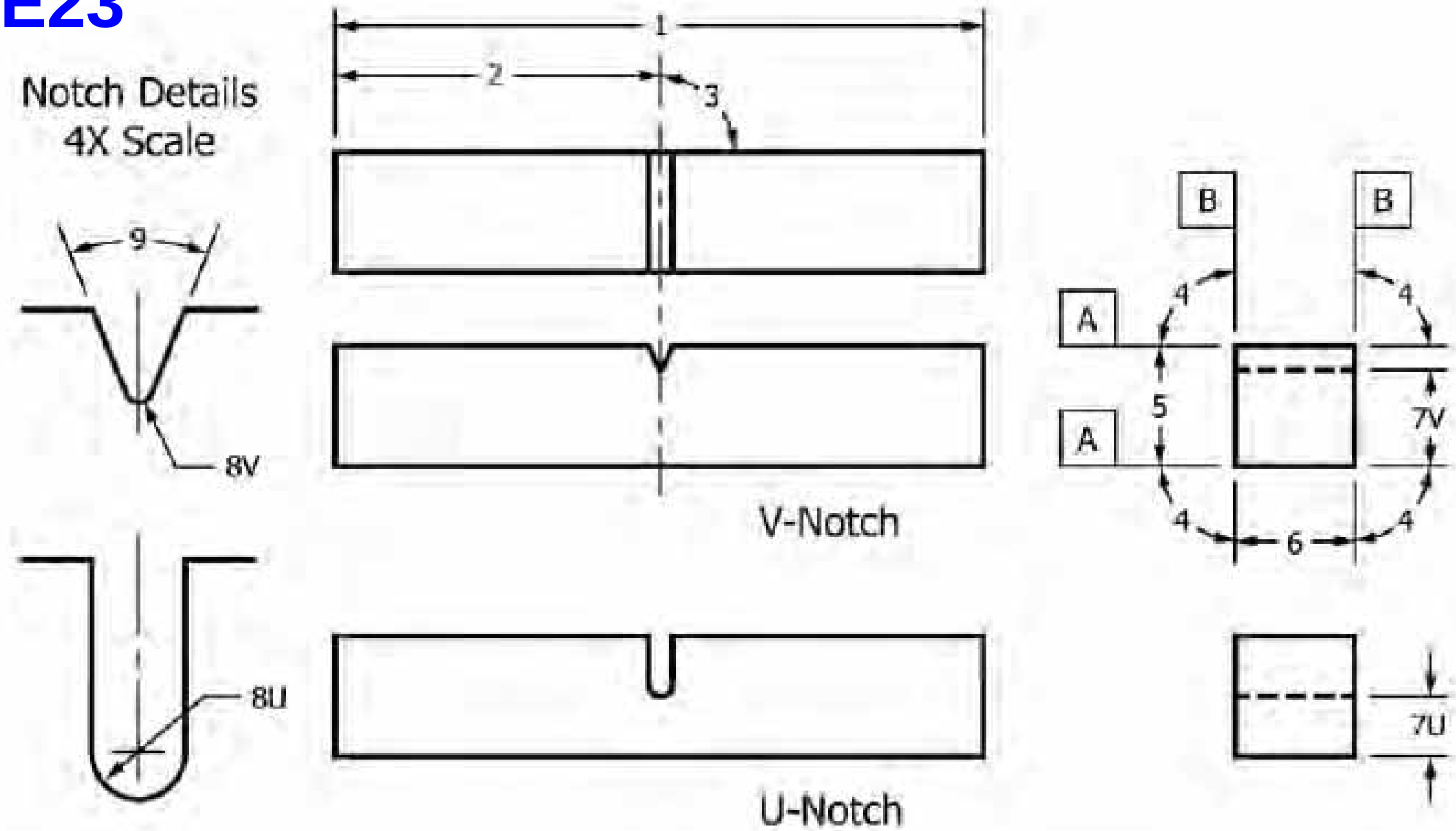


The Charpy test



Charpy Impact Test Specimens

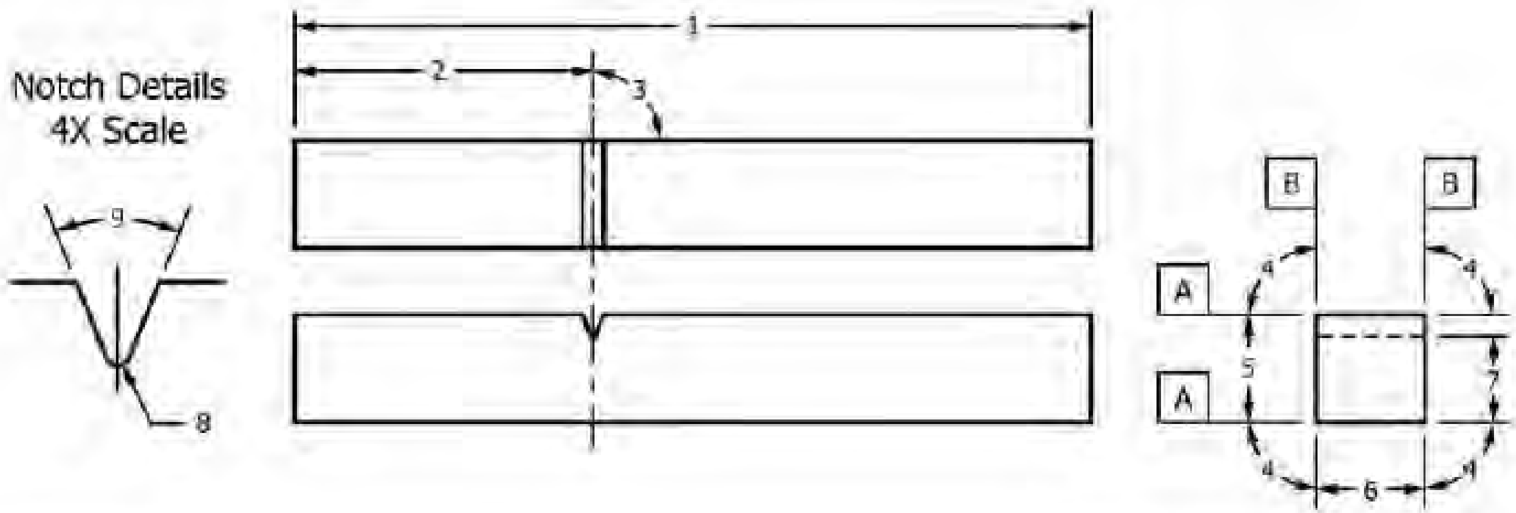
- **ASTM E23**



ID Number	Description	Dimension	Tolerance
1	Length of specimen	55 mm	+0/-2.5 mm
2	Centering of notch		±1 mm
3	Notch length to edge	90°	±2°
4	Adjacent sides angle	90°	±0.17°
5	Width	10 mm	±0.075 mm
6	Thickness	10 mm	±0.075 mm
7V	Ligament length, Type V	8 mm	±0.025 mm
7U	Ligament length, Type U	5 mm	±0.075 mm
8V	Radius of notch, Type V	0.25 mm	±0.025 mm
8U	Radius of notch, Type U	1 mm	±0.025 mm
9	Angle of notch	45°	±1°
A	Surface finish requirements	2 µm (Ra)	≤
B	Surface finish requirements	4 µm (Ra)	≤

Izod Impact Test Specimens

➢ ASTM E23



ID Number	Description	Dimension	Tolerance
1	Length of specimen	75 mm	+0/-2.5 mm
2	Notch to top	28 mm	
3	Notch length to edge	90°	±2°
4	Adjacent sides angle	90°	±0.17°
5	Width	10 mm	±0.025 mm
6	Thickness	10 mm	±0.025 mm
7	Ligament length	8 mm	±0.025 mm
8	Radius of notch	0.25 mm	±0.025 mm
9	Angle of notch	45°	±1°
A	Surface finish requirement	2 µm (Ra)	≤
B	Surface finish requirement	4 µm (Ra)	≤

Some Results from Charpy Test

	Alloy	Impact energy [J (ft·lb)]
1.	1040 carbon steel	180 (133)
2.	8630 low-alloy steel	55 (41)
3.	c. 410 stainless steel	34 (25)
4.	L2 tool steel	26 (19)
5.	Ferrous superalloy (410)	34 (25)
6.	a. Ductile iron, quench	9 (7)
7.	b. 2048, plate aluminum	10.3 (7.6)
8.	a. AZ31B magnesium	4.3 (3.2)
	b. AM100A casting magnesium	0.8 (0.6)
9.	a. Ti–5Al–2.5Sn	23 (17)
10.	Aluminum bronze, 9% (copper alloy)	48 (35)
11.	Monel 400 (nickel alloy)	298 (220)
13.	50:50 solder (lead alloy)	21.6 (15.9)
14.	Nb–1 Zr (refractory metal)	174 (128)

Table 8.1

Impact Test (Charpy) Data for Some of the Alloys of Table 6.1.

Charpy Test Conditions

- The impact data are sensitive to test conditions. Increasingly sharp notches can give lower impact-energy values due to the stress concentration effect at the notch tip
- The FCC alloys→ generally ductile fracture mode
- The HCP alloys→ generally brittle fracture mode
- Temperature is important
- The BCC alloys→ brittle modes at relatively low temperatures and ductile mode at relatively high temperature

Transition Temperatures

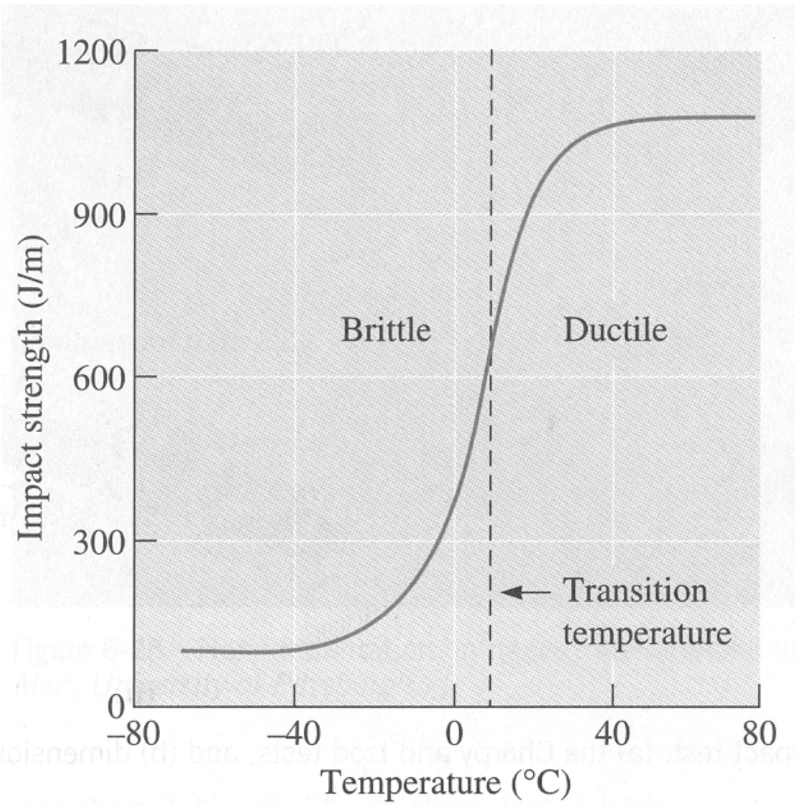
- As temperature decreases a ductile material can become brittle. So, there is a ductile-to-brittle transition temperature also called DBTT.

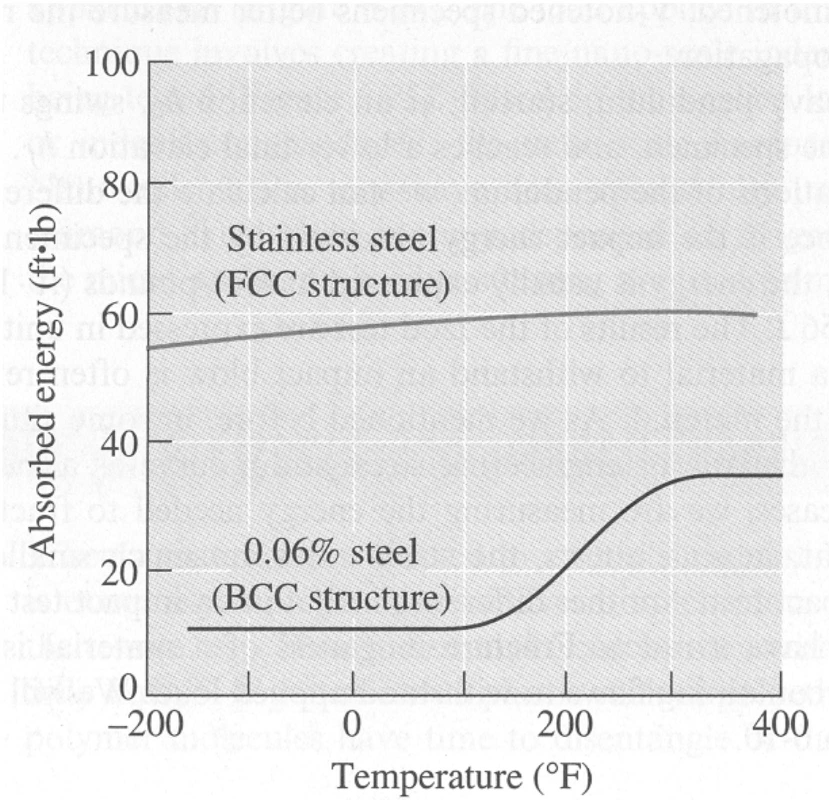
- Alloying usually increases the ductile-to-brittle transition temperature. FCC metals remain ductile down to very low temperatures. For ceramics, this type of transition occurs at much higher temperatures than for metals.

- The ABSORBED ENERGY vs. TEMPERATURE curves for many materials will show a sharp decrease when the temperature is lowered to the ductile to brittle transition temperature (DBTT) .

Transition Temperatures

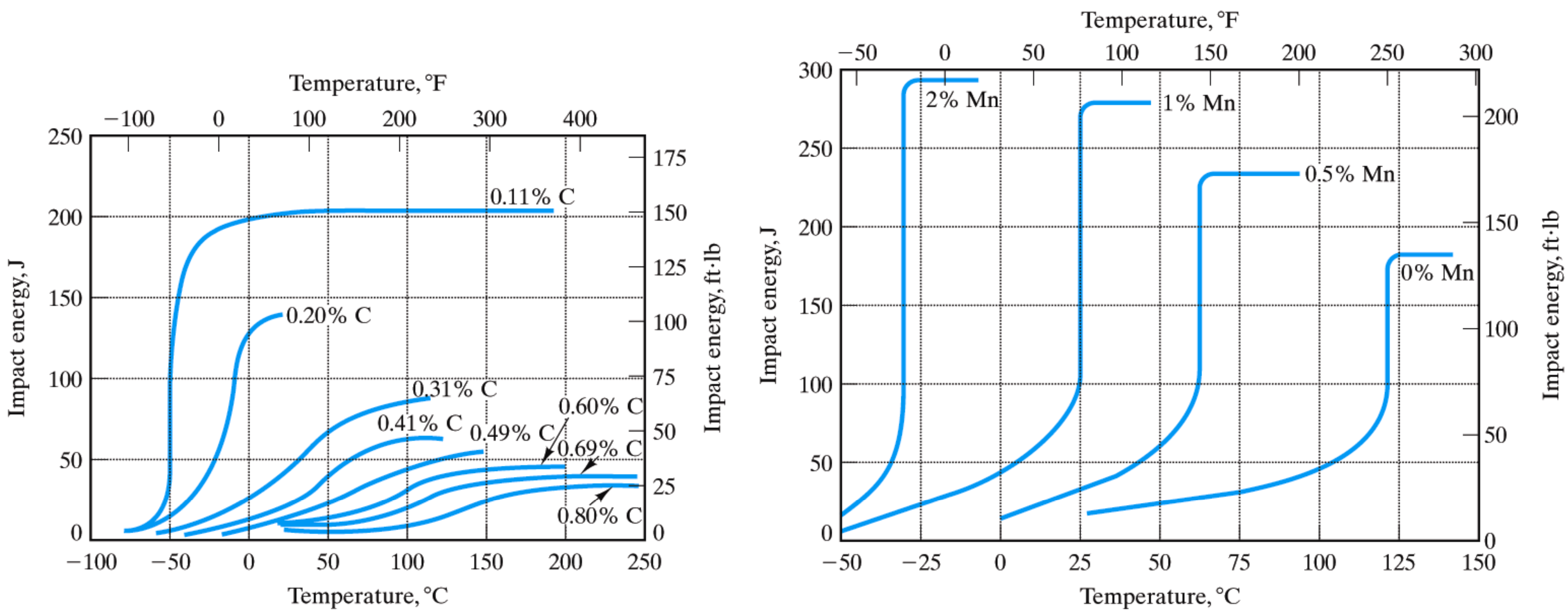
A typical ductile to brittle transition as a function of temperature. The properties of BCC carbon steel and FCC stainless steel, where the FCC crystal structure typically leads to higher absorbed energies and no transition temperature.





- **BCC metals have transition temperatures**
- **FCC metals do not**

Transition Temperatures

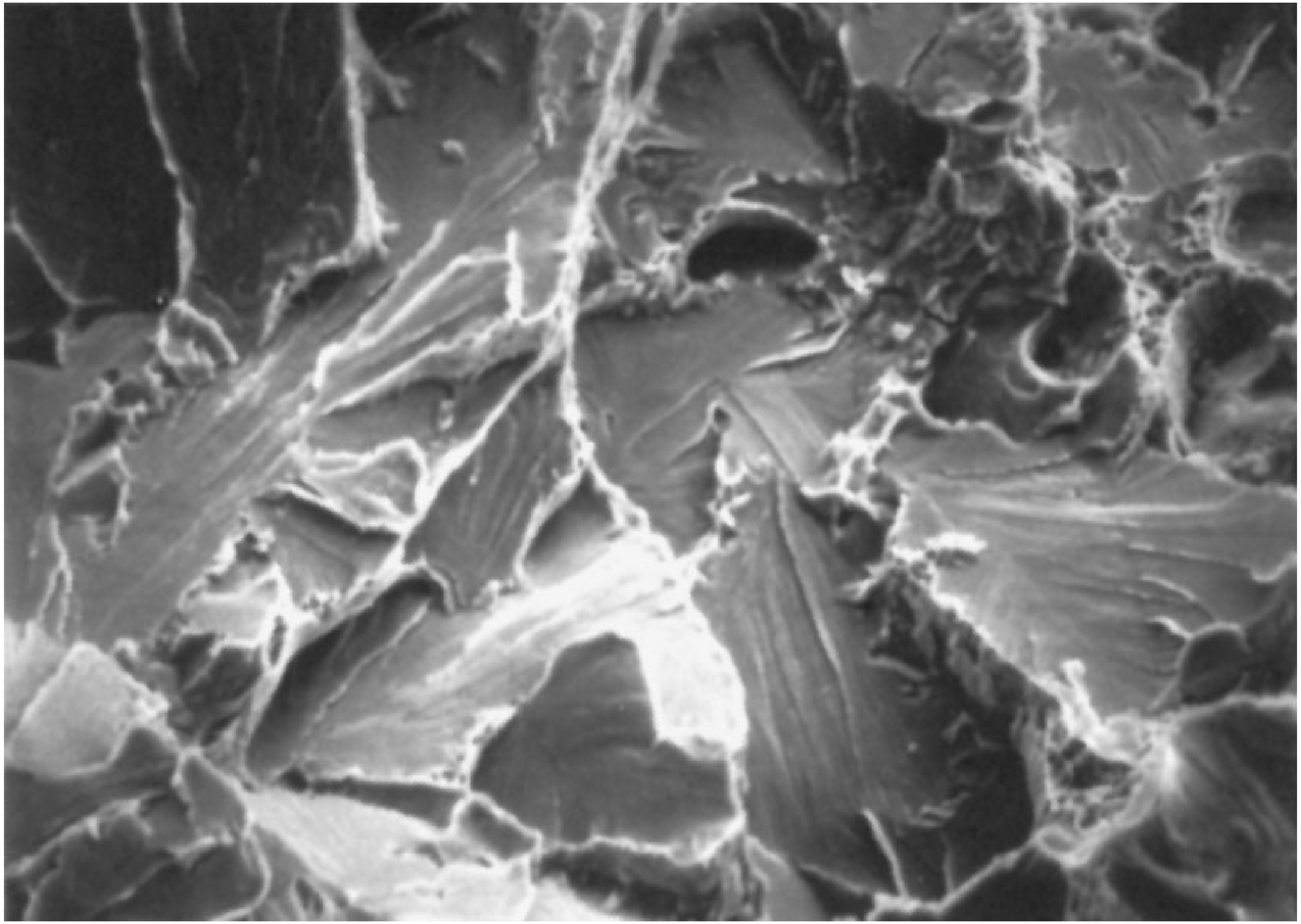


↑ Carbon → ↑ brittleness / ↑ Manganese → ↓ brittleness

Figure 8.3

Variation in ductile-to-brittle transition temperature with alloy composition. (a) Charpy V-notch impact energy with temperature for plain-carbon steels with various carbon levels (in weight percent). (b) Charpy V-notch impact energy with temperature for Fe–Mn–0.05C alloys with various manganese levels (in weight percent). (From Metals Handbook, *9th ed., Vol. 1, American Society for Metals, Metals Park, OH, 1978.)*

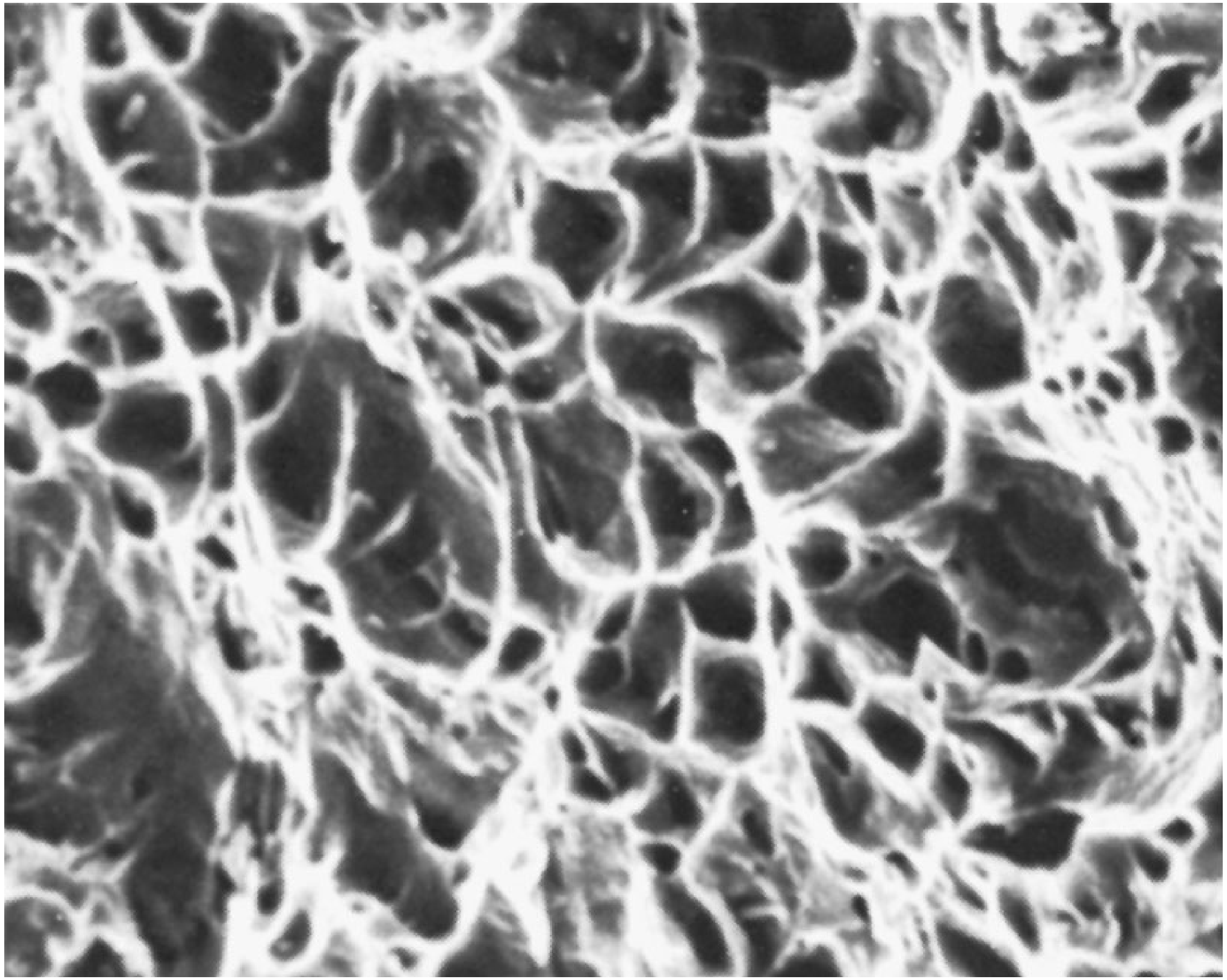
Fracture Surfaces



Fracture surface of steel that has failed in a **brittle mode (cleavage)**. The fracture path is transgranular (through the grains).

after Kalpakjian & Schmid (2009)

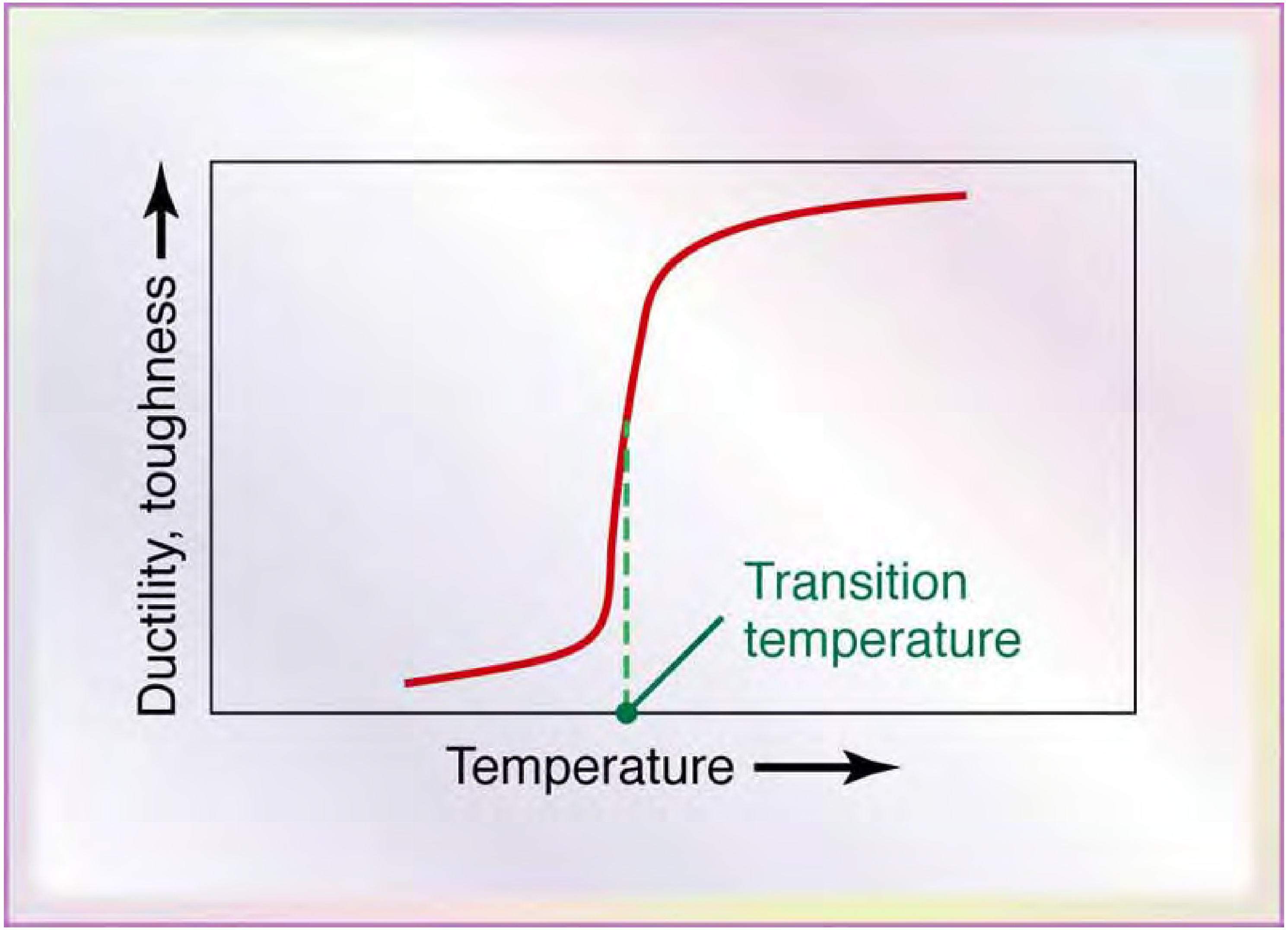
Fracture Surfaces



Surface of ductile fracture in low-carbon steel, showing dimples. Fracture usually is initiated at impurities, inclusions, or preexisting voids (microporosity) in the metal.

after Kalpakjian & Schmid (2009)

Fracture Surfaces

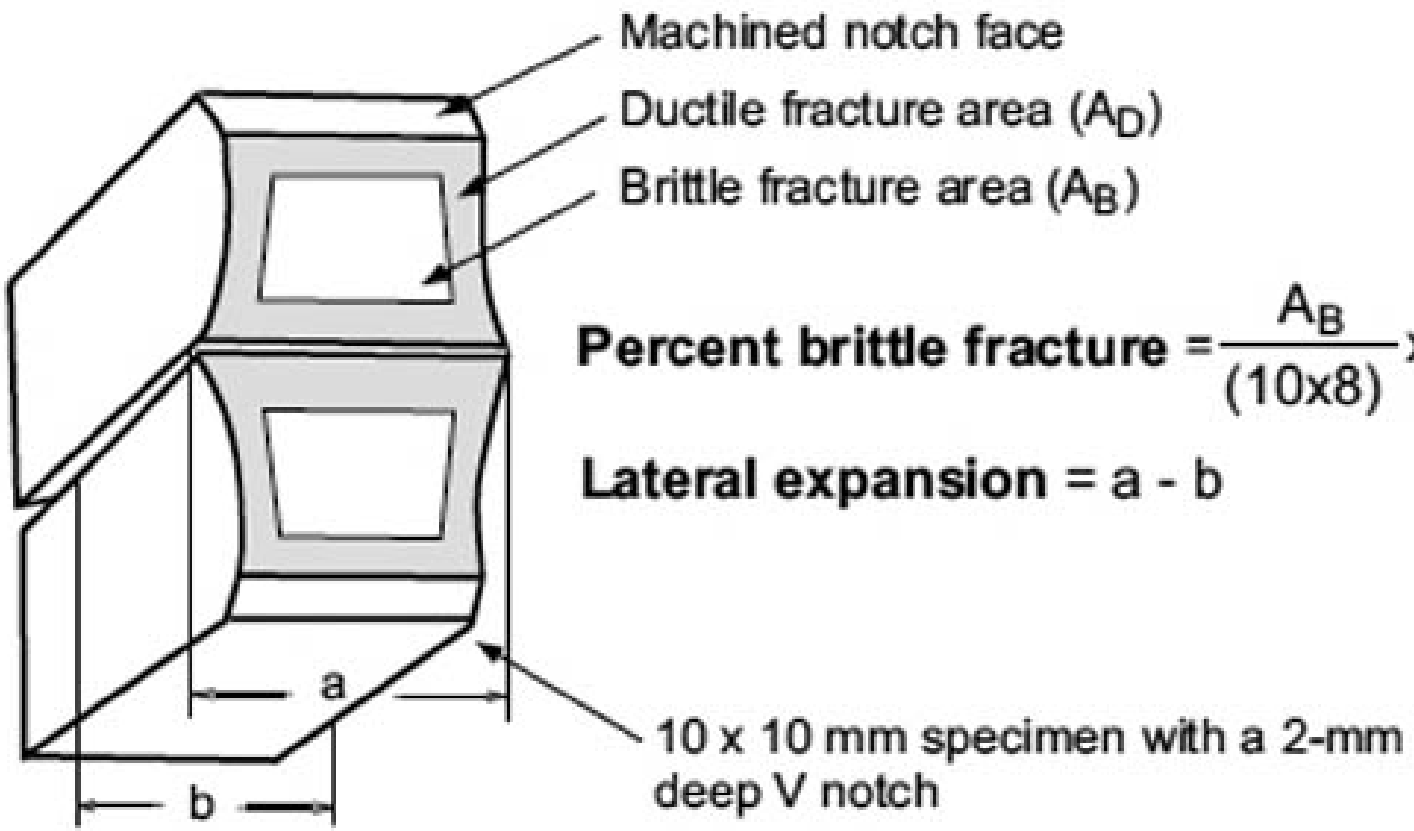


Near the ductile-to-brittle transition temperature, the fracture surface exhibits a mixed texture (dimples+cleavage)

after Kalpakjian & Schmid (2009)

Results from Charpy Impact Tests

- **ASTM E23:**
- **absorbed energy**
- **lateral expansion measurement**
- **percentage of shear fracture**

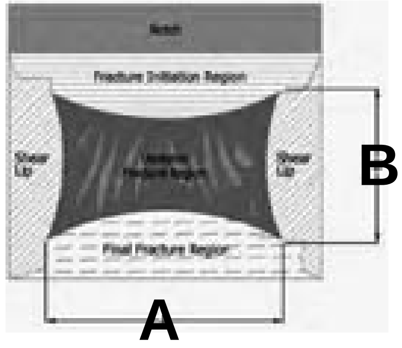


Percent brittle fracture $= \frac{A_B}{(10x8)} x\ 100$

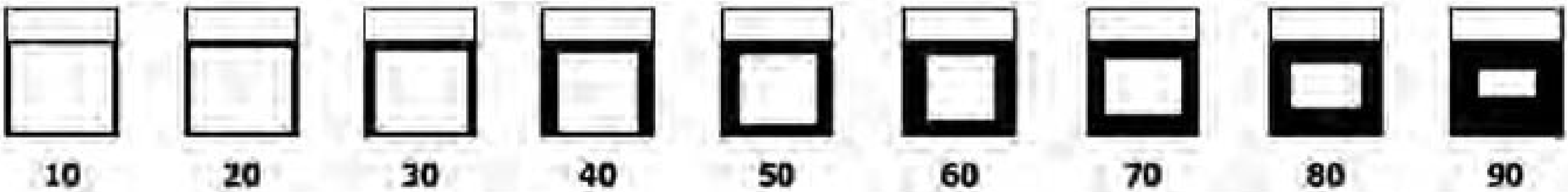
Lateral expansion = a - b

Results from Charpy Impact Tests

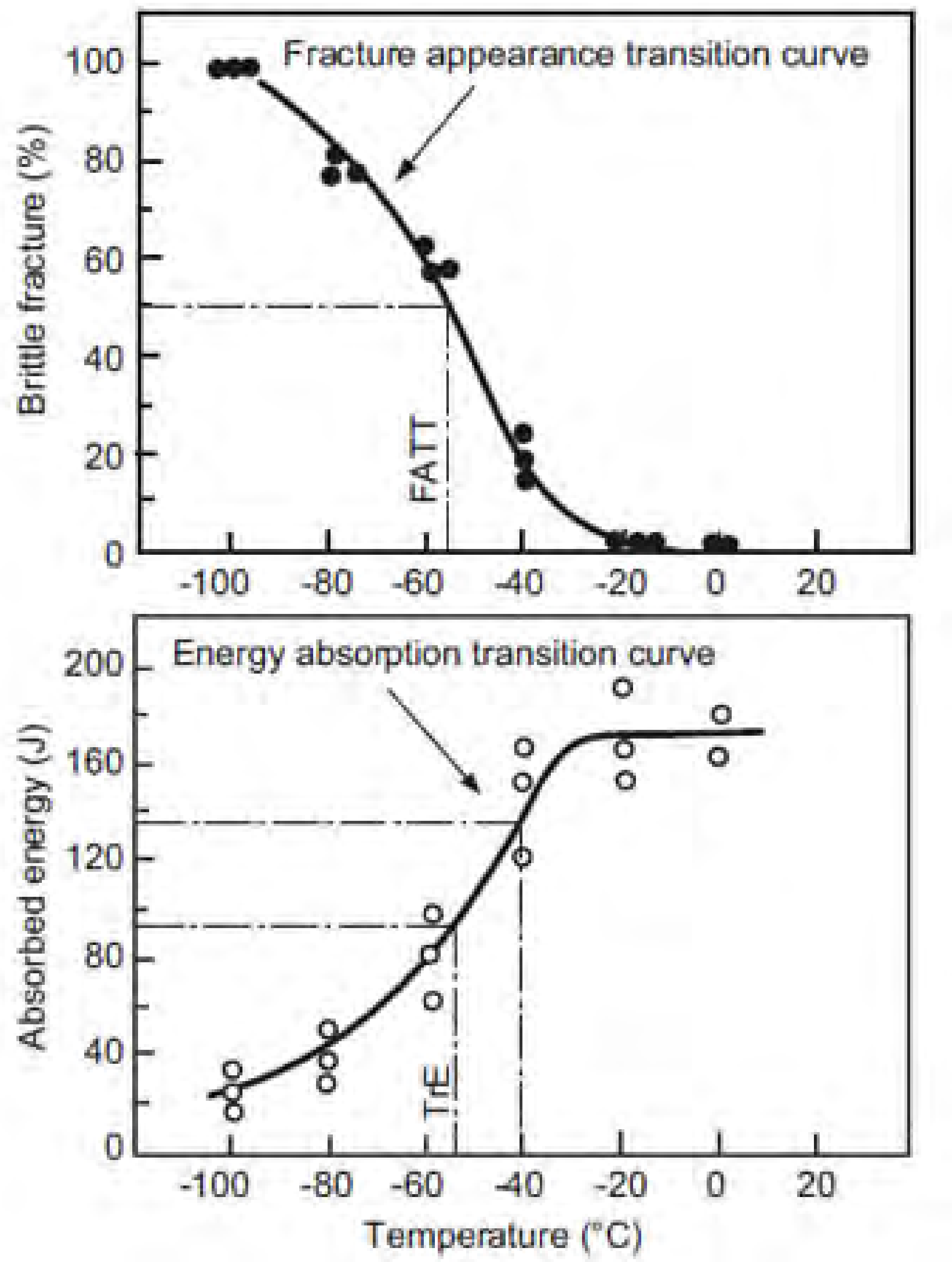
- **ASTM E23: percentage of shear fracture**



Dimension *B*, mm	Dimension *A*, mm																		
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10
1.0	99	98	98	97	96	96	95	94	94	93	92	92	91	91	90	89	89	88	88
1.5	98	97	96	95	94	93	92	92	91	90	89	88	87	86	85	84	83	82	81
2.0	98	96	95	94	92	91	90	89	88	86	85	84	82	81	80	79	77	76	75
2.5	97	95	94	92	91	89	88	86	84	83	81	80	78	77	75	73	72	70	69
3.0	96	94	92	91	89	87	85	83	81	79	77	76	74	72	70	68	66	64	62
3.5	96	93	91	89	87	85	82	80	78	76	74	72	69	67	65	63	61	58	56
4.0	95	92	90	88	85	82	80	77	75	72	70	67	65	62	60	57	55	52	50
4.5	94	92	89	86	83	80	77	75	72	69	66	63	61	58	55	52	49	46	44
5.0	94	91	88	85	81	78	75	72	69	66	62	59	56	53	50	47	44	41	37
5.5	93	90	86	83	79	76	72	69	66	62	59	55	52	48	45	42	38	35	31
6.0	92	89	85	81	77	74	70	66	62	59	55	51	47	44	40	36	33	29	25
6.5	92	88	84	80	76	72	67	63	59	55	51	47	43	39	35	31	27	23	19
7.0	91	87	82	78	74	69	65	61	56	52	47	43	39	34	30	26	21	17	12
7.5	91	86	81	77	72	67	62	58	53	48	44	39	34	30	25	20	16	11	6
8.0	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0



Results from Charpy Impact Tests



Energy absorption transition and fracture appearance transition curves of mild steel

Charpy Impact Test Video

https://www.youtube.com/watch?v=tpGhqQvftAo

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