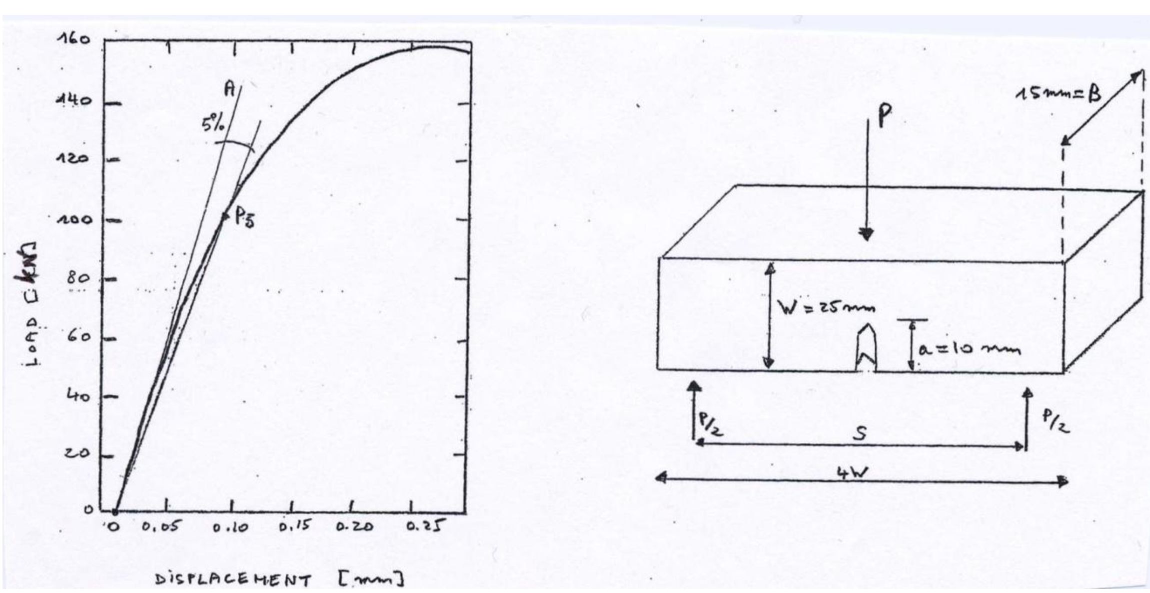
9.4 If, instead of Charpy specimens with standard thickness equal to 10 mm, you would test specimens with reduced thickness (e.g., 5 mm) and increased thickness (e.g., 30 mm) what changes would you expect in the Charpy energy value, normalized to the thickness of the specimen.

Specimens with reduced thickness (e.g., 5 mm) would show higher ductility, i.e., the DBTT will be reduced. This is because there will be more plane stress condition than in 10 mm specimen. Specimens with increased thickness will have more incidence of plane strain fracture, i.e., the ductility will be reduced or the DBTT will be increased.

9.5 The load--displacement curve, obtained from a fracture toughness test on metal sample is shown in Figure Ex9.5. The dimensions are as follows:

Crack length a = 10 mm,
Specimen thickness B = 15 mm,
Specimen width W = 25 mm,
Span S = 50 mm,
Yield stress, σ_y = 300 MPa.

Use the recommended procedure to determine the K_{Ic} from this curve. Check whether this is a valid K_{Ic} test.



Let OA be the linear-slope. The angle between OA and the displacement axis = 74°. Now, we draw a second line, OP_5, at a slope 5% less than that of line OA, = 74° - 5% = 70.3°. The point of intersection of this secant line with the load-displacement curve is called P_5. Since the load on every point of the curve, before P_5 is less than P_5, we have $P_Q = P_5$

Now that P_Q is known, we can calculate K_Q, as shown below.

$$K_Q = f(a/W)\frac{P}{B\sqrt{W}}$$

where the function f(a/W)is given by (see eqn. 9.6 in the t ext)

$$f\left(\frac{a}{W}\right) = \frac{3\frac{S}{W}\sqrt{\frac{a}{W}}}{2\left(1+2\frac{a}{W}\right)\left(1-\frac{a}{W}\right)^{3/2}}\left[1.99 - \frac{a}{W}\left(1-\frac{a}{W}\right) \times\left\{2.15 - 3.93\left(\frac{a}{W}\right) + 2.7\left(\frac{a}{W}\right)^2\right\}\right].$$

Plugging in he values of a and W in this expression, we get

f(a/W) = 3.9636

This will give us K_Q = 167.12 MPa $m^{0.5}$.

Now one needs to check whether K_Q is really $K_{Ic.}$ We calculate the yield strength, σ_y, which turns out to be 300 MPa. Next we check the dimensions of the test piece.

i. Thickness: $B \geq 2.5 (K_{Ic}/\sigma_y)^2$

   Is15 mm $\geq 2.5 (K_{Ic}/167.12/\sigma_y)^2$ = 0.776 mm? No.

ii. Crack length: $a \geq 2.5 (K_{Ic}/167.12/\sigma_y)^2$

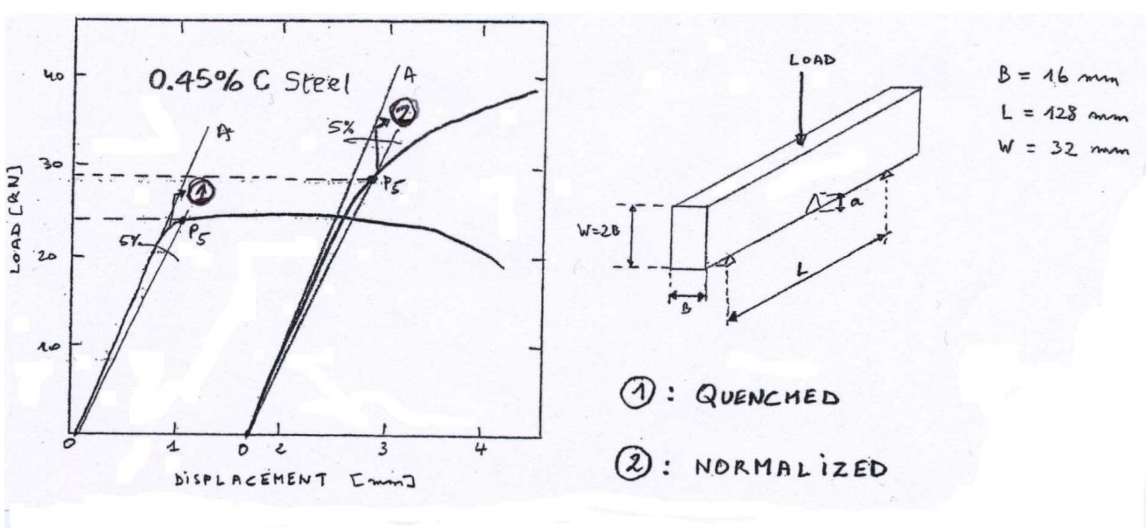
   Is10 mm $\geq 2.5 (K_{Ic}/167.12/\sigma_y)^2$ = 0.776 mm? No.

We therefore conclude that this is not a valid test.

9.7 Two samples of 0.45% C steel, one quenched and the other normalized, were tested for fracture toughness in a three-point bend test. The dimensions of the sample and the load--deflection curves for the two are shown in Figure Ex9.7 Determine K_{Ic} for the two samples, and establish whether the tests are valid. Verify whether the plane-strain conditions are met. Which steel would you expect to show a higher toughness? Does the result match your expectation?

Given:

	QUENCHED	NORMALIZED
	$\sigma_y = 1{,}050\ \text{MN/m}^2$	$\sigma_y = 620\ \text{MN/m}^2$
	$a_1 = 13.7$ mm	$a_1 = 9.3$ mm
Precrack	$a_2 = 11.6$ mm	$a_2 = 8.9$ mm
lengths:	$a_3 = 9.6$ mm	$a_3 = 9.4$ mm



Let us designate the linear slope part as OA. The angle between OA and the displacement axis is:

a) for curve 1: 67°
b) for curve 2: 67.5°

Now we draw a secant line, OP_5, at a slope 5% less than that of line OA. The new angles are:

a) for curve 1: 67° - 5% = 63.65°
b) for curve 2: 67.5° - 5% = 64.1°

Normalized steel

One can see that since the condition $B \geq 2.5\ (K_{Ic}/\sigma_y)^2$ is not met, the test is not valid for the normalized steel.

Quenched steel

In this case, the condition $B \geq 2.5\ (K_{Ic}/\sigma_y)^2$ is satisfied, so the test is valid for the quenched steel.

However, all the plain stress conditions are not met, because K_{Ic} is dependent on the crack size, i.e., we're still in the plane stress region of the curve shown in Fig. 9/13 (p. 536 in the text).

Expectation

We expect the normalized steel to have higher toughness than the quenched steel.

Remark: Strictly, the crack depth a, should be between 0.45W and 0.55W, which means between 4.4 and 17.6 mm. Taking this into account, the test is not valid!

Specimen	B[mm]	S[mm]	W[mm]	a[mm]	f(a/W)	P_Q[N]	K_Q[MPam$^{0.5}$]	σ_y[MPa]	$2.5(K_{Ic}/\sigma_y)^2$
Quenched	16	128	32	13.7	8.579714	24000	71.94308722	1050	0.011736526
Quenched	16	128	32	11.6	7.16044	24000	60.04211537	1050	0.008174729
Quenched	16	128	32	9.6	6.084982	24000	51.02412933	1050	0.005903541
Normalized	16	128	32	9.3	5.940928	29000	60.19457324	620	0.02356521
Normalized	16	128	32	8.9	5.754575	29000	58.30641192	620	0.022110026
Normalized	16	128	32	9.4	5.988521	29000	60.6767956	620	0.023944287

9.8 A notched polymer specimen was tested for fracture toughness in a three-point bend test. The relevant dimensions of the specimen are:

Thickness $B = 5$ mm,
Width $W = 15$ mm,
Crack length $a = 1$ mm,
$S = 3.5W$

The load–deflection curve was linear until fracture occurred at 150 N. Compute K_{Ic} for this material.

$$B = 5mm$$

$$W = 15mm$$

$$a = 1mm$$

$$S = 3.5mm$$

$$P = 150N$$

$$K_{IC} = f(\frac{a}{W})\frac{P}{B\sqrt{W}}$$

$$f(\frac{a}{W}) = \frac{3\frac{S}{W}\sqrt{\frac{a}{W}}}{2(1+2\frac{a}{W})(1-\frac{a}{W})^{3/2}}[1.99-\frac{a}{W}(1-\frac{a}{W})*\{2.15-3.93(\frac{a}{W})+2.7(\frac{a}{W})^2\}$$

$$f(\frac{a}{W}) = 1.32*1.87 = 2.48$$

$$K_{IC} = 2.48*\frac{150N}{5*10^{-3}\sqrt{15*10^{-3}}} = 6.07*10^5 Pa*m^{1/2}$$

9.19 After Charpy testing, what is the correlation between the energy absorbed and the appearance of the fracture surface? How does this relate to ductile and brittle materials?

The higher the shear lip portion of fracture surface after the Charpy test, the higher the energy absorbed or more ductile the material. Conversely, the higher the percentage of the flat portion, the more brittle will be the material. This transition in fracture appearance can be used as equivalent to DBTT, and is referred to as FATT (fracture appearance transition temperature).

9.21 Estimate the minimum specimen thickness for a valid plane-strain fracture toughness test for a material having the following properties: yield stress, σ_y = 600 MPa; fracture toughness, K_{Ic} = 150 MPa $m^{1/2}$.

The plain strain validity criteria require that specimen thickness and crack length be $\geq 2.5\ (K_{Ic}/\sigma_y)^2$.

For our problem, we have

$2.5\ (K_{Ic}/\sigma_y)^2 = 2.5\ (150/600)^2 = 0.15625$ m

Thus, the minimum specimen thickness for the specimen should be greater $\geq$ 0.156 m.

9.22 A structural aluminum plate (7075-T561, K_{Ic} = 29 MPa $m^{1/2}$), part of an engineering design, has to support 200 MPa under tension. Determine the largest crack size that this plate can sustain.

$$K_{IC} = 29 MPa * m^{1/2}$$

$$a \geq 2.5\left(\frac{K_{IC}}{\sigma_y}\right)^2$$

$$a \geq 2.5\left(\frac{29 MPa * m^{1/2}}{200 MPa}\right)^2$$

$$a \geq 0.053 m$$

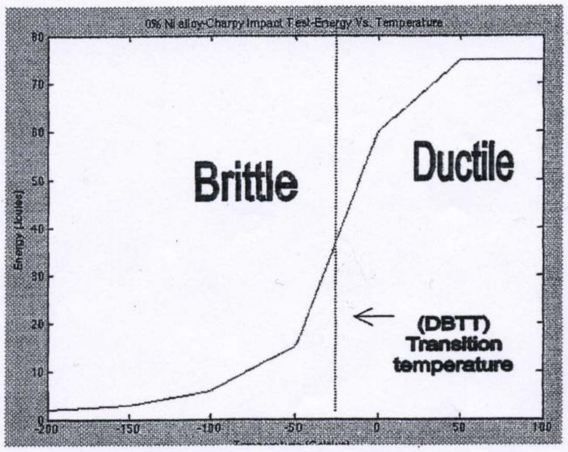
9.25 A number of Charpy impact tests were conducted on steels containing different levels of Ni. The energy levels (in J/m^2) are given in the table below:

Test Temp.(°C)	0%Ni	2%Ni	5%Ni	8%Ni
−200	2	2	5	28
−150	3	5	30	35
−100	6	15	55	37
−50	15	55	70	47
0	60	80	75	60
50	75	85	80	65
100	75	85	85	67

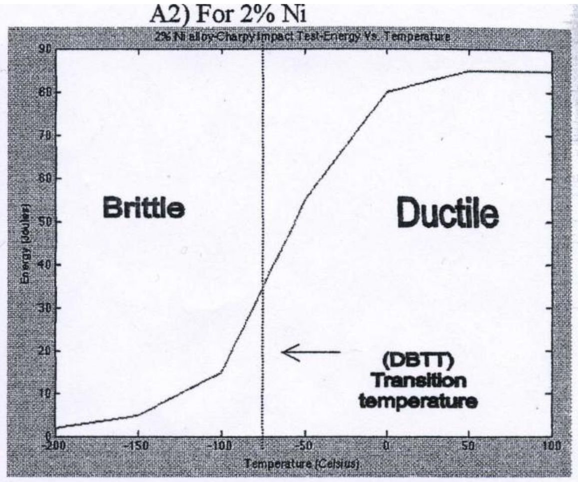
(**a)** Plot the curves for the different alloys.
(**b)** Find the DBTT for each alloy.
(**c)** What can you conclude from your analysis?

Plots of Charpy energy vs. temperature are shown below.

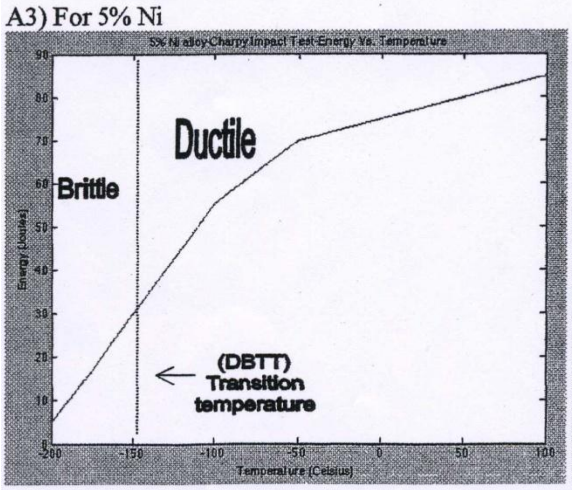
A1) For 0% Ni



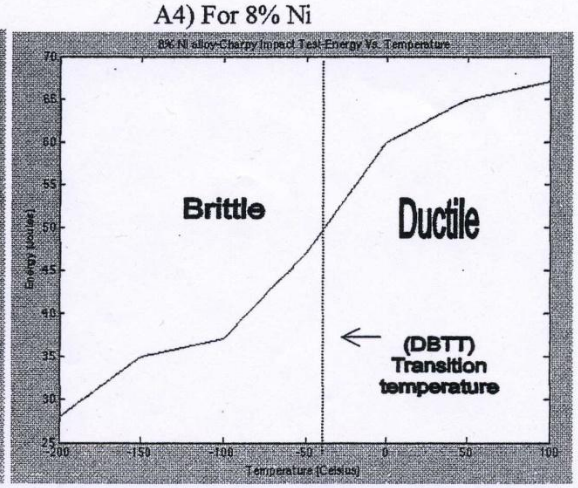
A2) For 2% Ni



A3) For 5% Ni



A4) For 8% Ni



(b) DBTT for each alloy

In the plots above, the ductile-brittle transition temperature (DBTT) for each alloy is indicated by the vertical line. DBTT is the temperature at which the Charpy impact energy changes from a low value or lower shelf (brittle) to high value or upper shelf (ductile). However, in practice there may not be a sharp transition, i.e., there is some arbitrariness in the determination of DBTT.

(c) What can you conclude from your analysis?

1. It would be desirable to retest the sample A3 (5%Ni), this sample showed a very different trend from the other samples.
2. A material subjected to an impact during service should have a DBTT below the service temperature.
3. As the amount of nickel is increased in the steel, the Charpy curve shows a higher absorbed energy, i.e., the ductility increases. This is understandable because Ni (FCC) is more ductile than steel (BCC).