Question 1:

Three long plates made of steel, aluminium and titanium respectively which are subjected to tensile loading of 500 kN (assume the cross sectional area of the plates are 0.0005 m^2)· In the technique used for the manufacturing of the plate, flaw size can only be limited to 700 micrometres. Select the suitable materials from the list and justify your answer.
Assume the parameter Y to be 1.
The data of the materials are provided below.

	Yield Strength		K_{Ic}	
Material	***MPa***	***ksi***	$MPa\sqrt{m}$	$ksi\sqrt{in.}$
Aluminum alloy[a] (2024-T3)	345	50	44	40
Titanium alloy[a] (Ti-6Al-4V)	910	132	55	50
Alloy steel[a] (4340 tempered @ 260°C)	1640	238	50.0	45.8

Solution:

The equation relating the Fracture toughness, flaw size and the stress is given below.

$$Kc = Y\,\sigma\,(\pi a)^{0.5} \qquad (1)$$

The tensile stress on the plate can be found by
$\sigma = F/A = 500*10^3/0.0005 = 1000$ MPa
Using the equation (1) the flaw size for the three specimen are obtained.

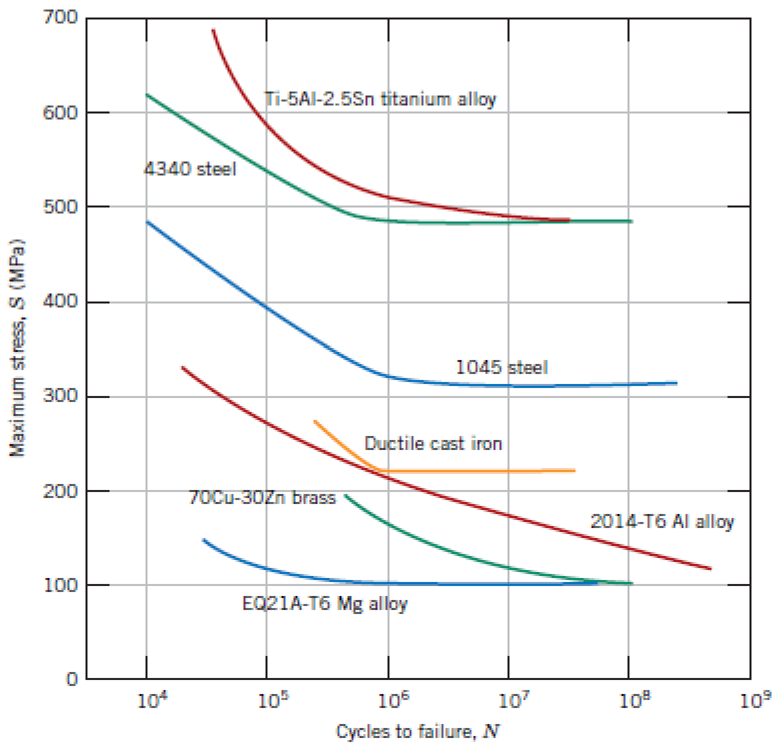
Material	Fracture toughness Kc	Flaw size a in micrometers
Aluminium	44	616
Steel	50	795
Titanium	55	962

It can be inferred that the maximum allowable flaw size of titanium and steel is above 700 micrometers whereas for aluminum it is less than 700 micrometers. So for this loading condition and manufacturing capability titanium and steel are the suitable materials.

Question 2:

A cylindrical bar of 20 mm diameter subjected to cyclic loading with the maximum load of 1200 N in the rotating-bending tests. Assume a factor of safety of 4.0 and that the distance between loadbearing points is 100 mm. (a) Suggest the suitable material from the list so that the cylindrical bar will not undergo fatigue failure in the given load and conditions.
The S-N curve data of the materials are shown in the figure below.
Consider a safety factor of 4 for all the beams.

(b) What is the percentage increase in the maximum load limit of the EQ21A- T6 Mg alloy cylindrical bar if the diameter is increased to 25 mm?
(c) Explain the difference between steel and aluminum in terms of fatigue behavior?



Solution:

(a)

For a cylindrical bar of diameter d_0 maximum stress for rotating–bending tests

may be determined using the following expression:

$\sigma = \quad 16*F*L / (\pi*d_0^3)$

Here, *L* is equal to the distance between the two loadbearing points

σ is the maximum stress (in our case the fatigue limit), and *F* is the maximum applied load.

$\sigma /S = \quad 16*F*L / (\pi*d_0^3)$

and solving for *F* leads to

$F = \quad \sigma*\pi* d_0^3 / 16SL$

For eg:

Material	Fatigue limit in MPa	Maximum Load in N
4340 steel	480	1884
1045 steel	310	1216.75
EQ21A- T6 Mg alloy	100	392.5

It is noted that the 4340 steel, 1045 steel have maximum load limit more than 1200 N , so they satisfy the requirements.

(b)

For the Mg alloy beam with a diameter of 25 mm the maximum load can be found as 766 N.

The percentage increase in the load limit is = (766 – 392.5)/392.5 *100 = 95.15%

(c)

It can be noted from the S-N curve data provided that the Aluminium have no endurance limit i.e. the Aluminum display a continuously decreasing S-N response without a saturation region, such material with no endurance limit are called non-ferrous materials whereas Steel have an endurance limit region, If the stress is below the endurance limit it will not fail with infinite number of cycles of operation, such materials are called ferrous materials

Question 3:

(a) Determine the longitudinal, transverse and shear modulus of elasticity and Poisson's ratio for graphite-epoxy lamina containing 50% volume of fibers. Consider the following mechanical properties of the composite.

E_f = 230 GPa E_m =3.5 GPa, ν_f = 0.2 ν_m = 0.3.

(b) Explain the role of fibre and matrix in a composite material.

Solution:

(a)

Vf = 0.50 (given)

E11 = Ef*Vf + Em*Vm = 230*0.5 + 3.5*(1 - 0.5)

= 116.75 GPa

E22 = Ef.*Em/(Ef.*Vm + Em*.Vf)

= (230*3.5)/(230*(1-0.5)+3.5*0.5) = 6.9 GPa

v12 = Vf*vf + Vm*vm = 0.2*0.5 + 0.3*(1-0.5) = 0.25

v21 = (E22/E11)*v12 = 0.015

Gf = Ef/2*(1+vf) = 230/2*(1+0.2) = 95.83 GPa

Gm = Em/2*(1+vm) = 3.5/2*(1+0.3) = 1.35 GPa

G12 = Gf*Gm/(Gf*Vm+Gm*Vf) = 2.66 GPa

(b) The primary function of the fibers is to carry the loads along their longitudinal directions. I.e. the fibres are the load carrying members in the composite material. The primary functions of the matrix are to transfer stresses between the reinforcing fibers (hold fibers together) and protect the fibers from mechanical and/or environmental damages. The fibre provides the reinforcement for the composite material whereas the matrix holds the fibre together thus protecting the alignment of the fibre in the composite.

Question 4:

a. What is shot peening? What is the purpose of using this process?

b. Briefly explain why BCC and HCP metal alloys may experience a ductile-to-brittle transition with decreasing temperature, whereas FCC alloys do not experience such a transition.

c. List four measures that may be taken to increase the resistance to fatigue of a metal alloy.

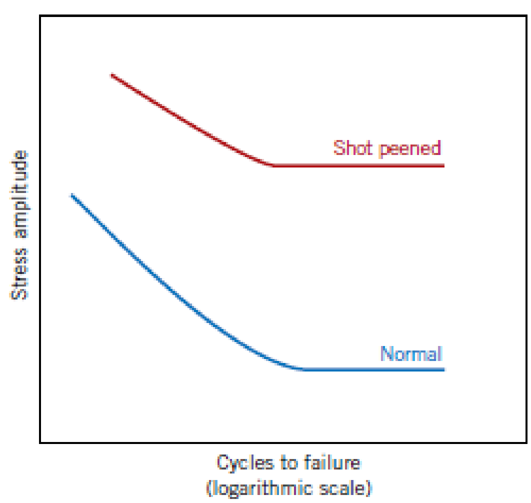
d. Explain the difference between fatigue striations and beachmarks also mention the similarities between the two.

Solution:

a.

Shot peening is a cold work process used to finish metal parts to prevent fatigue and stress corrosion failures and prolong product life for the part. Shot peening is a cold working process used to produce a compressive residual stress layer and modify mechanical properties of metals. In shot peening high speed steel balls are directed towards the surface of the metal on which compressive residual stress is to be developed. Impact of shots produces indentation through localized plastic deformation at the surface layers metal layers below the plastically deformed surface layers are subjected to elastic deformation. Material further deeper from the surface remains unaffected by shots and plastic deformation occurring at the surface.

Shot peening increases the fatigue life of the metal.



b. With decreasing temperature, FCC metals do not experience a ductile-to-brittle transition because a relatively large number of slip systems remain operable even to very low temperatures. On the other hand, BCC and HCP metals normally exhibit this transition because the number of operable slip systems decreases with decreasing temperature.

c. Four measures that may be taken to increase the fatigue resistance of a metal alloy are:

1) Polish the surface to remove stress amplification sites.
2) Reduce the number of internal defects (pores, etc.) by means of altering processing and fabrication techniques.
3) Modify the design to eliminate notches and sharp contour changes.
4) Harden the outer surface of the structure by case hardening (carburizing, nitriding) or shot peening.

d. The difference between striations and beachmarks is size: Striations are extremely small ridges, visible only with an electron microscope. Beachmarks are much larger than striations. If they are present, they are normally visible to the unaided eye.
The other difference between striations and beachmarks factor of origin. Striations represent the advance of the crack front by one load application in many ductile metals, whereas beachmarks locate the position of the crack front when repetitive, fluctuating loading was stopped for a period of time.

The similarities are:

Striations and beachmarks identify the position of the tip of the fatigue crack at a given point in time.

Striations and beachmarks expand from the fatigue origin or origins, often in a circular or semicircular fashion.

Striations and beachmarks are relatively parallel ridges which do not cross similar features from another origin.