**1.3.**  Prepare a graph using specific strength and specific modulus as coordinate axes, and using data in [Table 1.1](https://jigsaw.vitalsource.com/books/9781119389972/epub/OPS/c01.xhtml#c01-tbl-0001), plot the points for various metals, fibers, and bidirectional composites. Also show points for unidirectional composites using data from [Table 1.1](https://jigsaw.vitalsource.com/books/9781119389972/epub/OPS/c01.xhtml#c01-tbl-0001). Add any other materials you feel are relevant.

A white sheet with black text and numbers

Description automatically generated

Ans:

A screenshot of a computer program

Description automatically generated

A chart with different colored dots

Description automatically generated

**1.4.**  a. A rectangular cross-sectional beam subjected to a bending moment is made of steel and is 10 cm in width and 6 mm in thickness. If the width of the beam is held constant, calculate the beam thickness if designed from 2024-T4 aluminum and the various composites shown in [Table 1.2](https://jigsaw.vitalsource.com/books/9781119389972/epub/OPS/c01.xhtml#c01-tbl-0002) to provide the equivalent stiffness C in one case and in another the equivalent strength.

b. Calculate the beam weight differences (per unit of beam length) for the preceding cases.

c. For all materials considered in part (a), if the beams are to be of identical weight, calculate the stiffnesses and bending strengths relative to those of the steel beam.

A white sheet with black text

Description automatically generated

Ans:

To calculate the equivalent strength and equivalent stiffness for a rectangular cross-sectional beam made of steel and then redesigned using 2024-T4 aluminum and other materials, we will follow these steps.

# Given Data:

Steel:  
- Tensile Strength (σ\_steel) = 0.83 GPa  
- Modulus of Elasticity (E\_steel) = 210 GPa  
- Width (b) = 10 cm = 100 mm  
- Thickness (t\_steel) = 6 mm

We will calculate the new thickness for the beam designed from:  
- 2024-T4 Aluminum  
- E-glass–epoxy composite  
- Kevlar 49–epoxy composite  
- Carbon fiber–epoxy composite  
- Boron–epoxy composite

# a. Equivalent Strength Calculation:

The equivalent thickness of the beam for different materials must have the same strength as steel.  
The formula for equivalent thickness based on strength is:  
t\_material = t\_steel \* (σ\_steel / σ\_material)^(1/3)  
  
Where:  
- σ\_steel is the tensile strength of steel.  
- σ\_material is the tensile strength of the material (from the table).

## Equivalent Strength Calculations:

2024-T4 Aluminum:  
- Tensile Strength (σ\_2024-T4) = 0.41 GPa  
- Thickness t\_2024-T4:  
 t\_2024-T4 = 6 \* (0.83 / 0.41 GPa)^(1/3)

E-glass–epoxy composite:  
- Tensile Strength (σ\_E-glass–epoxy) = 0.57 GPa  
- Thickness t\_E-glass–epoxy:  
 t\_E-glass–epoxy = 6 \* (0.83 / 0.57 GPa)^(1/3)

Kevlar 49–epoxy composite:  
- Tensile Strength (σ\_Kevlar) = 0.65 GPa  
- Thickness t\_Kevlar:  
 t\_Kevlar = 6 \* (0.83 / 0.65 GPa)^(1/3)

Carbon fiber–epoxy composite:  
- Tensile Strength (σ\_Carbon) = 0.38 GPa  
- Thickness t\_Carbon:  
 t\_Carbon = 6 \* (0.83 / 0.38 GPa)^(1/3)

Boron–epoxy composite:  
- Tensile Strength (σ\_Boron–epoxy) = 0.38 GPa  
- Thickness t\_Boron–epoxy:  
 t\_Boron–epoxy = 6 \* (0.83 / 0.38 GPa)^(1/3)

# 2. Equivalent Stiffness Calculation:

The equivalent thickness of the beam for different materials must have the same stiffness as steel.  
The formula for equivalent thickness based on stiffness is:  
t\_material = t\_steel \* (E\_steel / E\_material)^(1/3)  
  
Where:  
- E\_steel is the Young’s modulus (stiffness) of steel.  
- E\_material is the Young’s modulus of the material (from the table).

## Equivalent Stiffness Calculations:

2024-T4 Aluminum:  
- Young's Modulus (E\_2024-T4) = 73 GPa  
- Thickness t\_2024-T4:  
 t\_2024-T4 = 6 \* (210 / 73 GPa)^(1/3)

E-glass–epoxy composite:  
- Young's Modulus (E\_E-glass–epoxy) = 21.5 GPa  
- Thickness t\_E-glass–epoxy:  
 t\_E-glass–epoxy = 6 \* (210 / 21.5 GPa)^(1/3)

Kevlar 49–epoxy composite:  
- Young's Modulus (E\_Kevlar) = 40 GPa  
- Thickness t\_Kevlar:  
 t\_Kevlar = 6 \* (210 / 40 GPa)^(1/3)

Carbon fiber–epoxy composite:  
- Young's Modulus (E\_Carbon) = 83 GPa  
- Thickness t\_Carbon:  
 t\_Carbon = 6 \* (210 / 83 GPa)^(1/3)

Boron–epoxy composite:  
- Young's Modulus (E\_Boron–epoxy) = 106 GPa  
- Thickness t\_Boron–epoxy:  
 t\_Boron–epoxy = 6 \* (210 / 106 GPa)^(1/3)

# b. Beam Weight Differences (Per Unit Length):

To calculate the weight difference per unit length, we use the formula for beam weight (per unit length):  
Weight = ρ \* b \* t  
  
Where:  
- ρ is the density of the material (from the table).  
- b is the width of the beam (constant at 100 mm).  
- t is the thickness (calculated in the previous steps).

The weight difference for each material compared to steel will be calculated using the densities provided in the table.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Material** | **Density (g/cm^3)** | **Thickness (mm)** | **Thickness (m)** | **Beam Weight per Unit Length (kg/m)** |
| Steel | 7.8 | 6 | 0.006 | 4.68 |
| 2024-T4 Aluminum | 2.7 | 7.590132003 | 0.007590132 | 2.049335641 |
| E-glass–epoxy | 1.97 | 6.800679832 | 0.00680068 | 1.339733927 |
| Kevlar 49–epoxy | 1.4 | 6.509378058 | 0.006509378 | 0.911312928 |
| Carbon fiber–epoxy | 1.54 | 7.784835063 | 0.007784835 | 1.1988646 |
| Boron–epoxy | 2 | 7.784835063 | 0.007784835 | 1.556967013 |

# c. Stiffness and Strength for Identical Weight Beams:

For beams with identical weight, the thickness for each material can be found using the formula:  
t\_material = t\_steel \* sqrt(ρ\_steel / ρ\_material)  


Where ρ\_steel and ρ\_material are the densities of steel and the material, respectively.

Once the new thickness is calculated, we can compute the relative stiffness (modulus of elasticity) and bending strength (tensile strength) compared to the steel beam. These values will be expressed as ratios of the respective properties of the new material to those of steel.