الجامعة التكنولوجية
قسم هندسة المواد
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Selection of Engineering Materials (CousreII)
Lec-3
Digital Logic Method (DL)

By

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Digital Logic Approach

The digital logic (DL) method can be employed for the material selection with ranking. When numerous materials properties are specified and relative importance of each property is not clear determination of weighting factors can largely be sensitive which in turn will reduce the reliability of selection. DL approach can solve this problem to find the weighting factors. Only two properties are considered at a time. As a first step, the property requirements are determined based on the material selection chart. The total number of possible decisions is expressed as $N = n\ (n - 1)/2$, where n is the number of properties under consideration. The properties and the total number of decisions are shown in Table 5.3. The *weighting factor* for each property, which is indicative of the importance of one property as compared to others are obtained by dividing the numbers of positive decisions given to each property by the total number of decisions as shown in Table 5.4. After that calculate the scale value of each property followed by the materials performance index as explained in Sect. 5.5.2.

Table 5.3 Functional properties of candidate material and total number of positive decisions created by DL approach

Decision numbers										
Properties	1	2	3	4	5	6	7	8	9	10
Tensile strength	0	0	0	1						
Yield strength	1				1	0	1			
Young's modulus		1			0			0	1	
Toughness			1			1		1		0
Density				0			0		0	1

Table 5.4 Weighting factor of the functional properties based on positive decision numbers

Properties of material	Positive decisions	Weighting factor (α)
Tensile strength	1	0.1
Yield strength	3	0.3
Young's modulus	2	0.2
Toughness	3	0.3
Density	1	0.1
Total	10	1.0

value will have more influence than is warranted by its weighting factor. This drawback is overcome by introducing scaling factors. When evaluating a list of candidate materials, one property are scaled proportionally. Introducing a scaling factor facilitates the conversion of normal material property value to scaled dimensionless value. For a given property, the scaled value, B, for a given candidate material is equal to:

$$\text{Scaled property} = \frac{\text{Numerical value of property} \times 100}{\text{Maximum value in the list}} \tag{5.3}$$

For properties like cost, corrosion or wear loss, weight gain in oxidation, etc., a lower value is more desirable. In such cases, the lowest value is rated as 100 it is calculated as:

$$\text{Scaled property} = \frac{\text{Minimum value in the list} \times 100}{\text{Numerical value of property}}.$$

Material performance index can be calculated using the following equation:

$$\text{Material performance index, } \gamma = \sum_{i=1}^{n} \beta i \alpha i \tag{5.4}$$

where, β is the scaled property, α is the weighting factor and i is summed over all the n relevant properties. Though numerous material properties are considered but relative importance of each property is not defined clearly. Therefore, the weighting factors are become sensitive and as a result reduce the reliability of the material selection.

The cost of material should be emphasized when there are a large number of properties in the selection process which will lead to the further modification of the performance index of the material. Therefore, a figure of merit (FOM) for the material can then be calculated using the following formula:

$$M = \gamma/(C)(\rho) \tag{5.5}$$

where C = total cost of material per unit mass; ρ = density of material.

Alternatively, figure of merit can be calculated based on cost of unit strength (CUS) as we discussed under Sect. 5.5.1. The FOM then become:

$$M = \gamma/\acute{c} \tag{5.6}$$

where, ć is the relative cost of the material and it is defined as the ratio of the price per unit mass of the material and low carbon steel.

Application of Digital Logic Method

Material Selection for Automotive Brake Disc

Disc brake

Material used for brake systems should have stable and reliable frictional and wear properties under varying conditions of load, velocity, temperature, environmental factors and high durability. There are several factors to be considered when

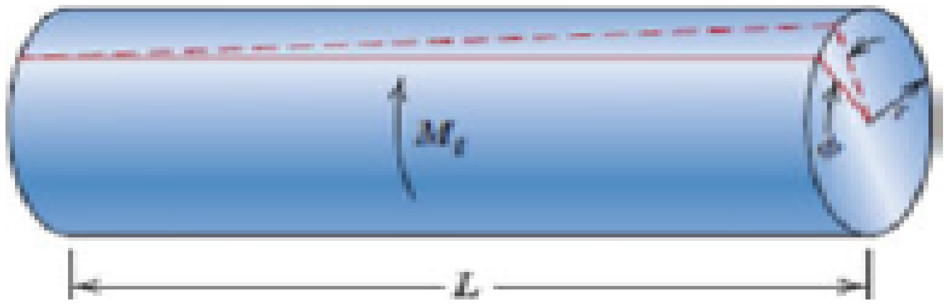

Fig. 5.5 A solid cylindrical shaft that experiences an angle of twist in response to the application of a twisting moment M_t

selecting a brake disc material. The most important consideration is the ability of the brake disc material to withstand high friction and less abrasive wear. Another requirement is to withstand the high temperature that evolved due to friction. Weight, manufacturing process ability and cost are also important factors those are need to be considered during the design phase. Figure 5.5 shows the advantage and disadvantage of the digital logic method with comparing with the weight properties methods (Table 5.5).

Initial screening can be performed using Ashby's material selection chart (as calculated in Fig. 5.4) and based on the properties, potential candidate materials for automotive brake disc are selected as:

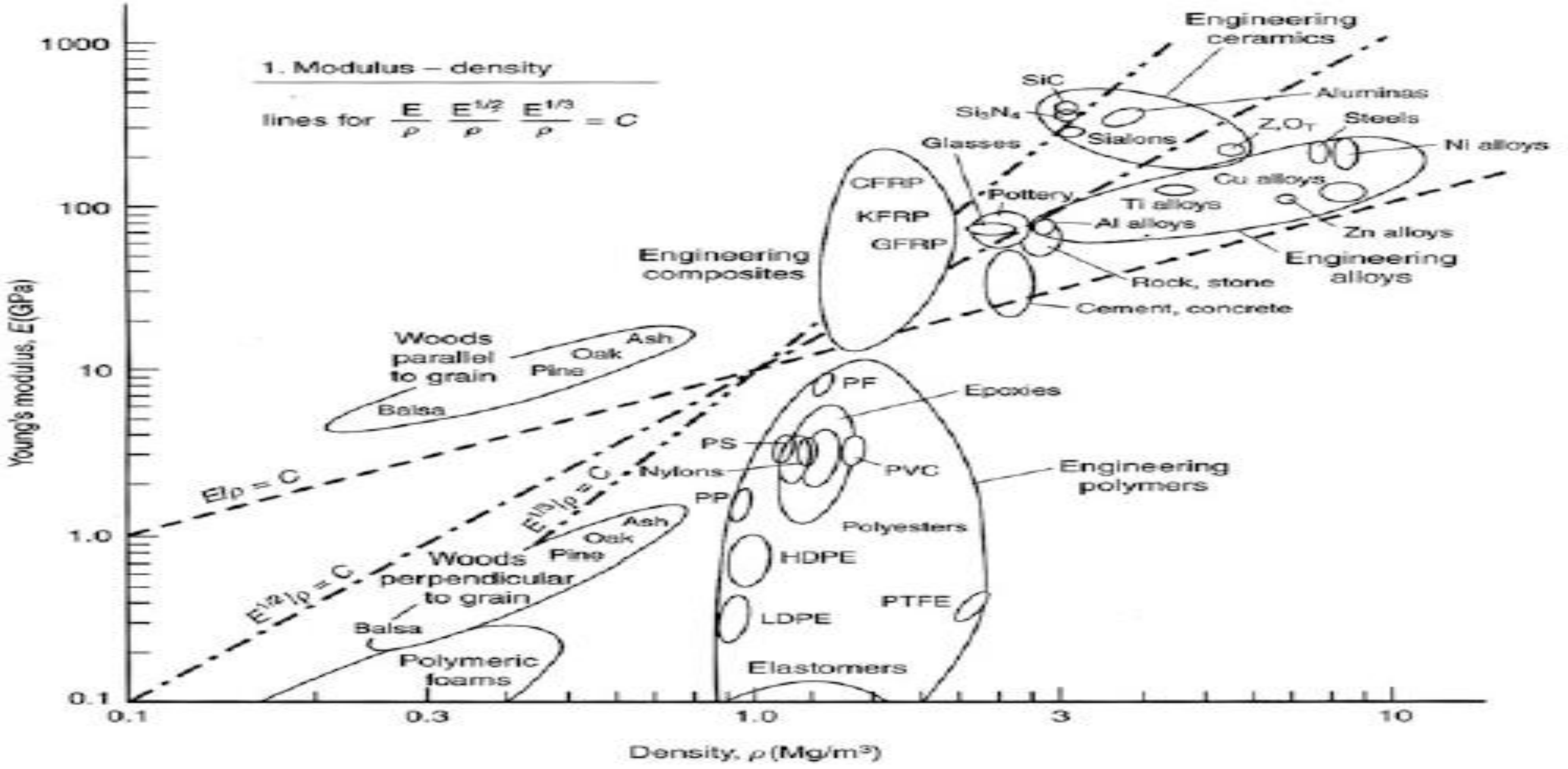

Fig. 5.4 Ashby materials selection chart: young's modulus versus density (From materials science and technology, vol. 5, 1989, pp. 517–525) (This material is reproduced with permission of Elsevier)

- Gray cast iron (GCI)
- Ti-alloy (Ti-6Al-4V)
- 7.5 wt% WC and 7.5 wt% TiC reinforced Ti-composite (TMC)
- 20 % SiC reinforced Al-composite (AMC 1)
- 20 % SiC reinforced Al–Cu alloy (AMC 2).

The properties and decision numbers are shown in Table 5.6 and corresponding weighting factors for each property is shown in Table 5.7.

The numerical value of the each property of each candidate material is shown in Table 5.8 whereas the calculated value of the scale properties of each material

Table 5.6 Functional properties of candidate material and total number of positive decisions created by DL approach for brake disc material selection

Decision numbers, N										
Material property	1	2	3	4	5	6	7	8	9	10
Compressive strength	0	0	0	1						
Friction coefficient	1				1	0	1			
Wear resistance		1			0			1	1	
Thermal capacity			1			1		0		0
Specific gravity				0			0		0	1

Table 5.7 Weighting factors based on positive decision numbers for brake disc

Property of material	Positive decisions	Weighting factor (α)
Compressive strength	1	0.1
Friction coefficient	3	0.3
Wear resistance	3	0.3
Thermal capacity	2	0.2
Specific gravity	1	0.1
Total	10	1.0

Table 5.8 Numerical value of the each property of brake disc materials

Material	Properties				
	1	2	3	4	5
	Compressive strength (MPa)	Friction coefficient (μ)	Wear rate ($\times 10^{-6}$ $mm^3/N/m$)	Specific heat, Cp (KJ/Kg. K)	Specific gravity (Mg/m^3)
GCI	1,293	0.41	2.36	0.46	7.2
Ti-6Al-4V	1,070	0.34	246.3	0.58	4.42
TMC	1,300	0.31	8.19	0.51	4.68
AMC 1	406	0.35	3.25	0.98	2.7
AMC 2	761	0.44	2.91	0.92	2.8

along with corresponding performance index (PI) is shown in Table 5.9. Finally, figure of merit (FOM) and ranking of the candidate materials for the application of automotive brake rotor system is shown in Table 5.10. From the Table, it can be seen that AMC 2 material showed highest PI followed by GCI. Finally, selection of optimum materials must be done. After narrowing down the field of possible candidate materials to those that do not violate any of the rigid requirements, one should start searching the material that best meet the soft requirements for optimum selection.

Table 5.9 Scaled value (SV) of properties of each material and corresponding performance index (PI)

	Scaled value of each property and PI					
	1	2	3	4	5	Performance index (γ)
GCI	99	93	100	47	38	81.0
Ti-6Al-4V	82	77	0.96	59	61	49.5
TMC	100	70	29	52	58	56.0
AMC 1	31	80	73	100	100	79.0
AMC 2	59	100	81	94	96	88.6

Material	*Density (ρ) (g/cc)*
GCI	7.2
Ti-Alloy	4.42
Ni-Alloy	8.4
Al-Alloy	2.73
AMC1	2.7
AMC2	2.8
TMC	4.68

Ti-6Al-4V = 4.41 g/cm3

Table 5.10 Cost and figure of merit of candidate materials

Material	Relative cost	Performance index (γ)	Figure of merit	Rank
GCI	1	81.0	11.25	2
Ti-6Al-4V	20	49.5	0.56	5
TMC	20.5	56.0	0.58	4
AMC 1	2.7	79.0	10.84	3
AMC 2	2.6	88.6	12.17	1