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A Review of Considerations in Material Selection for the Design of a Push Chair

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ABSTRACT

This work discusses the criteria for materials selection for a push-chair design in terms of performance indices. Due to variety and complexity of the factors involved in materials selection, a systematic approach is essential if the best decision is to taken in terms of requirement. Comparison was made between steel and aluminum in terms of strength in engineering design.

Keywords – Material selection, push chair design, performance indices, steel or aluminium, which to select

1.0 INTRODUCTION

The performance of an engineering component is limited by:

- the properties of the material of which it is made; and
- formability

Satisfactory performance of the member depends on a combination of properties. And, the selection could be based on specifying ranges for individual properties. Final decision is then made by maximising one or more 'performance indices', Ashby [1]. The decisions on what to settle for in terms of performances is rooted in the initial design requirements, engineering member shape, ease of production, and cost.

More often, however, performance depends on a combination of properties, and then the best material is selected by maximising one or more 'performance indices'. An example is the specific stiffness E/ρ (E is Young's modulus and ρ is the density). Performance indices are governed by the design objectives. Component shape is also an important consideration. Hollow tubular beams are lighter than solid ones for the same bending. Information about section shape can be included in the performance index to enable simultaneous selection of material and shape.

2.0 MATERIALS SELECTION CRITERIA

2.1 PERFORMANCE INDICES

Ashby [1] defines performance indices as a group of material properties derived from simple models of the function of the component, which governs some aspect of the performance of the component. Examples of performance indices are: specific stiffness, E/ρ – also called the stiffness to weight ratio, (E is Young's modulus and ρ is the density), Stiffness constant, (EI), where, I is the second moment of area.

As an illustration, [1], gives the following example:
A material is required for a light, stiff beam. The aim is to achieve a specified bending stiffness at minimum weight. The beam has a length, L, and a square, solid, cross–section as shown in fig. (1)
The mass of the beam is given as

$$m = AL\rho \quad (1)$$

Where,
A = area of the cross-section
ρ = density of the material of which the beam is made
The stiffness, k, of a simply–supported beam with modulus, E, second moment of area, I, central load, F, and central deflection, δ, ($\delta = FL^3/48EI$ from Singh [2]) is

$$k = \frac{F}{\delta} = \frac{48EI}{L^3} \quad (2)$$

Where,

L = length of beam

For a square section beam of side length, b, the second moment of area is:

$$I = \frac{b^4}{12} = \frac{A^2}{12} \quad (3)$$

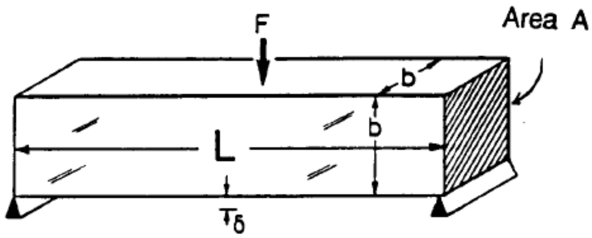

Fig. (1): A square–section beam loaded in bending – Source: (Ashby [1])

The edge-supports put a restraint on the member, thus, the stiffness, k, and the length, L, are constrained by the design. Optimum selection can be achieved by treating the area, A, as a 'free' variable to minimise the mass, and thus, cost in line with the constraints.

Substituting for, I, in equation (2) and eliminating, A, between this and equation (1) gives,

$$m = \frac{1}{2}(k)^{0.5}(L)^{2.5}\left(\frac{\rho}{E^{0.5}}\right) \quad (4)$$

Ashby, [1] deduces that, using this basic model, the mass of the member can then be minimised (and hence, the performance maximised) by seeking the material with the largest value of the performance index defined by equation (5).

$$m = C\left(\frac{E^{0.5}}{\rho}\right)^{-1} \quad (5)$$

Other materials selection criteria include, Elastic modulus, Density, Strain rate sensitivity, Formability, Hardness, Damping, and Magnetic properties amongst others.

How these properties affect the performance of an engineering member will depend on the purpose of the design [3].

In the design of the push-chair, hollow cylindrical tubular sections are selected. And, in terms of bending stiffness, hollow tubes are lighter than solid circular ones. The USS, [4] guide is adopted in considerations for using either, steel or aluminium. When strength is the basis for consideration, the following obtains:

2.2 ELASTIC MODULUS

Selection **advantage for this property leans towards steel.** USS [4], observes that since, the elastic modulus of steel (210 GPa) is three times the elastic modulus of aluminum (70 GPa)**,** in shaping and forming, aluminum possesses higher spring back than mild steels as for example in stamping operations. Same applies when high strength steel is compared to aluminium on a strength-to-strength level.

2.3 DENSITY

Aluminum =2.72 Mg/m^3

Steel = 7.85 Mg/m^3.

Density of Aluminium is, approximately one-third that of steel.

The Criterion for selection is the bending specific stiffness of hollow-sections.

2.4 APPLIED SPECIFIC STIFFNESS RELATION

The applied stiffness relation is: E/ρ. Calculations reveal that, steel, again, has **slight advantage** with a specific stiffness value of 26.75 versus aluminum at 25.74, and thus, suitable for the selected hollow structural sections. Same will apply to other structural sections of other forms.

2.5 STRAIN RATE SENSITIVITY

USS, [4] notes that steel is strain rate sensitive, while many aluminum structural grades are not. From a safety point of view, in the push-chair design, this is an important design consideration, since the positive strain rate performance displayed by steel, associated with high strain rates are factors in crashworthiness tests. Steel thus, has higher energy absorption at a given part weight. In analyzing the crashworthiness records of both materials [4] concludes that, steel offers the best solution for:

- Maximum energy absorption at mixed failure modes

- Energy absorption in bending and axial collapse
- Positive strain rate sensitivity

The advantages of steel over aluminium are many, and can be seen in the fig. (2), abstracted from [4] of the result of a study conducted at the University of Michigan and the Ford Scientific Research Lab on the effects of high speeds on aluminum 5754-O, and DQSK (Mild Steel) materials.

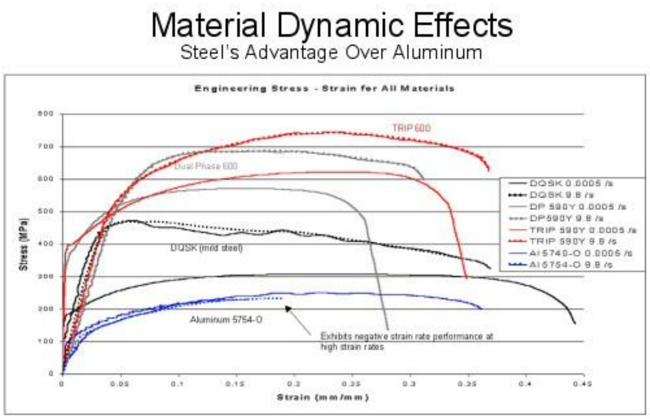

Fig. (2): Effects of high speeds on aluminum 5754-O, DQSK (Mild Steel) materials. Source: USS, [4]

2.6 DURABILITY AND FATIGUE

It is not unusual for families to keep in store, one push chair used by one child to be passed on to another child's use. Steel has advantage over aluminum in terms of durability and fatigue since the endurance limit of aluminium (about, 120 MPa is less than half that of steel (about, 300 MPa).

2.7 FORMABILITY

USS, [4] observes in terms of styling and manufacturing robustness, that aluminum's formability is approximately two-thirds that of steel (less forming range).

2.8 DAMPING

Noise, Vibration, and Harshness, (NVH). Steel clearly has an advantage in damping since, the ability of any material to attenuate noise and vibration is directly proportional to its mass.

2.9 MAGNETIC

This closely relates to environment friendly design considerations. And, the magnetic properties of steel, makes it a very important recyclable product, since it can easily and efficiency be separated from other unwanted residual materials like plastics, glass, ceramics to mention a few. Aluminum, like other non-ferrous materials such as lead, copper, zinc is non-magnetic, and while it can be 100 percent recycled, it does not separate easily from other material types.

2.0 CONCLUSION

The primary focus of the design objective is the use of light weight materials for push chair design. While aluminium will meet the requirements of the design requirement, the comparison leans in favour of steel for the same geometric property class.

ACKNOWLEDGING NOTE

As part of introducing engineering students to the art of technical writing, final year engineering students in the engineering faculty of the University of Port-Harcourt are encouraged to produce articles (alongside their project supervisors acting also as mentors) based on their final year research project. The students take a course in technical writing in the third year. This work is based on the work of the push-chair design and fabrication team.

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