EVERYDAY EXAMPLES OF ENGINEERING CONCEPTS

S5: Torsion stress & strain

This is an extract from 'Real Life Examples in Mechanics of Solids: Lesson plans and solutions' edited by Eann A. Patterson, first published in 2006 (ISBN:978-0-615-20394-2) which can be obtained on-line at www.engineeringexamples.org and contains suggested exemplars within lesson plans for Sophomore Solids Courses. Prepared as part of the NSF-supported project (#0431756) entitled: "Enhancing Diversity in the Undergraduate Mechanical Engineering Population through Curriculum Change".

INTRODUCTION

(from *'Real Life Examples in Mechanics of Solids: Lesson plans and solutions'*)

These notes are designed to enhance the teaching of a sophomore course in mechanics of solids, increase the accessibility of the principles and raise the appeal of the subject to students from a diverse background[1]. The notes have been prepared as skeletal lesson plans using the principle of the 5Es: Engage, Explore, Explain, Elaborate and Evaluate. These are not original and were developed by the Biological Sciences Curriculum Study[2] in the 1980s from work by Atkin and Karplus[3] in 1962. Today they are considered to form part of the constructivist learning theory and a number of websites provide easy to follow explanations of them[4].

These notes are intended to be used by instructors and are written in a style that addresses the instructor, however this is not intended to exclude students who should find the notes and examples interesting, stimulating and hopefully illuminating, particularly when their instructor is not utilizing them. In the interest of brevity and clarity of presentation, standard derivations and definitions are not included since these are readily available in textbooks which these notes are not intended to replace but rather to supplement. Similarly, it is anticipated that these lessons plans can be used to generate lectures/lessons that supplement those covering the fundamentals of each topic.

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[1] Patterson, E.A., Campbell, P.B., Busch-Vishniac, I., Guillaume, D.W., 2011, The effect of context on student engagement in engineering, *European J. Engng Education*, 36(3):211-224.
[2] http://www.bscs.org/library/BSCS_5E_Instructional_Approach_July_06.pdf
[3] Atkin, J. M. and Karplus, R. (1962). Discovery of invention? *Science Teacher* 29(5): 45.
[4] e.g. http://www.science.org.au/primaryconnections/constructivist.htm

TORSION

5. Principle: **Torsional stress and strain**

Engage:

Enjoy a drink the evening before class, providing it has a screw top (similar to those on individual bottles airlines give you on international flights) and take the empty bottle and its top into class. Some non-alcoholic drinks have the Stelvin closure (opposite) and would allow you to offer drinks to the whole class! Other screw tops would work but the aluminum top is the simplest for analysis. Discuss the stress and strain system produced just before you break the seal when opening the bottle.

Explore:

Discuss the forces induced when opening a bottle and how the torque is transmitted from one hand to the other along the bottle as shear stress. Discuss the mode of failure in the closure. Noting that aluminum is a ductile material and thus weaker in shear than tension, thus ensuring closure remains sealed until twisted.

Explain:

Work through the example below:

Ultimate strength in shear for aluminum alloy is 240MN/m^2. So, to release the cap we need to achieve this stress level in the closure.

Shear stress due to torsion, $\tau = \frac{Tr}{J}$

where T is applied torque, r is the radius at which the shear stress occurs and J is the second polar moment of area, "$J = \pi R^4/2$" and for a thin-walled tube is approximated by $J = 2\pi R^3 t$, where R is wall radius and t the wall thickness. Thus the torque required to open the bottle when R =1.2cm and t =0.1mm:

$$T = 2\pi R^2 t\tau = 2\pi \times 0.012^2 \times 0.0001 \times \left(240 \times 10^6\right) = 22\,\text{Nm}$$

This is about three times the average hand-grip torque strength of an adult[5]. Perforations imply that the load bearing area is reduced by about a quarter thus reducing the torque required to =22/4=5.5Nm.

[5] Imrhan, S.N., Farahmand, K., 'Male torque strength in simulated oil rig tasks: the effects of grease-smeared gloves and handle length, diameter and orientation, Applied Ergonomics, 30(1999)455-462.

Elaborate:

Consider the effect of the torque on the glass neck of the bottle, if the thickness of the glass is 3mm:

$$\tau = \frac{Tr}{J} = \frac{5.5 \times 0.012}{\pi\left(0.024^4 - 0.018^4\right)/32} = 3.0\,\text{MPa}$$

Since the mean strength of soda glass is about 65MPa there is no danger of failure even allowing for a stress concentration of three in the threads of the bottle, i.e. $\tau_{\max} = \tau \times SCF = 9\,\text{MPa}$. Now if the cap is damaged by a dent then it may jam and a strong person could exert three times the typical torque for an adult, i.e. about 22N then $\tau = 36\,\text{MPa}$ (including the stress concentration) – still no problem.

However, if the thread on the bottle is mis-formed so that the wall thickness is reduced by 1mm <u>and</u> the cap is damaged <u>and</u> a strong adult attempts to open the bottle, then

$$\tau_{\max} = \frac{Tr}{J} \times SCF = \frac{22 \times 0.012}{\pi\left(0.022^4 - 0.018^4\right)/32} \times 3 = 62.4\,\text{MPa}$$

Failure is likely! This simplistic analysis ignores the presence of cracks etc. and instead focuses on using the torsion stress-strain relationships.

Evaluate

<u>Example 5.1</u>

Ask students to repeat the analysis for a half size bottle of wine.

<u>Example 5.2</u>

Ask students to look for two other examples in their everyday life and explain how the above principles apply to each example.

<u>Example 4.2</u>

Ask students to look for two other examples in their everyday life and explain how the above principles apply to each example.