<u>Engineering Ethics Cases with Numerical Problems</u>

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Mechanical Engineering Case 7

Hyperbaric & Hypobaric Windows

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<u>Suggested Courses</u>:

Strength of Materials, Materials Properties, Mechanical Design

<u>Level</u>:

Sophomore, Junior & Senior

I. Narrative

Windows used in hyperbaric chambers and submersible vehicles, are required to meet standards developed years ago by a Navy Engineering Officer. This standard has been adopted by all federal agencies.

Jim Anderson, a materials engineer specializing in polymeric materials, has been asked to evaluate the cost associated with the replacement of hyperbaric and hypobaric windows. Current regulations require that the windows be replaced every 2 years, no exceptions. The cost of these windows is $1000 per window. In addition, the cost to replace these windows on an annual basis far exceeds the cost for operating the chamber. It is hoped that Jim will be able to produce a replacement for the windows that is more cost effective.

To begin his investigation, Jim decided to study the origins of the code. Jim learned that the following procedure was used to develop the standard.

A Navy engineer, not trained in polymer engineering, produced different cantilever beams from five polymeric materials; polycarbonate, polystyrene, polyacrylate, polyethylene, and polyvinylchloride. The engineer placed each of the beams in his backyard (in Arizona) and suspended a X pound weight on the free end of the beam. After, two years the polyacrylate was selected for the standard since it had the lowest deflection. Thermal and oxidative aging were not considered.

As a professional engineer, Jim is aware of his obligations to honestly represented his area of expertise and realizes that the engineer who set this standard has not met this obligation. Jim therefore decides to calculate the deflection associated with each of these materials.

II. Problems

1. Assume that the temperature profile over a given year can be approximated as 3 months at 70°F (period 1), 5 months at 85°F (period 2), 2 months at 30°F (period 3) and 2 months at 50°F (period 4). Calculate the beam deflection as a function of time for a two year period.

Since the specimens were placed in the Navy Engineer's back yard, the possibility of dramatic temperature change exists. As an engineer, he has an obligation to anticipate, where possible, unexpected events. This concept of "Good Works"* applies to experimentation for design as well as to general professional practice.

2. What would be the effect of a two day drop in temperature to -40°F and a two week increase in temperature to 95°F, in the third and first time periods respectively, on the final displacement of the beam. Were the tests adequate to meet the engineer's obligations for a "Good Works" concept? What temperatures should be in the design criteria?

3. Having completed his analysis, Jim is concerned that deflection of a polymer cantilever beam is not related to the failure of hyperbaric or hypobaric chamber circular windows. Describe the possible modes of failure for typical hyperbaric windows. See Figure 1 for a schematic of a typical chamber window.

4. Using your result from Problem 3, you may reach the conclusion that beam deflection is related to the potential failure of hyperbaric windows or you may conclude that beam failure is not related to deflection. If the latter is concluded, what are your professional obligations and how would you attempt to resolve this obligation? b.) If you conclude the former, you are faced with the fact that the two year replacement window is a result of the Navy Engineer ending his test after two years. As a professional engineer, you have an obligation to *perform as a faithful agent or trustee*, that is to say you must serve the best interest of your company. Is this two year replacement period in the best interest of your company considering the cost? How would you address this issue? Are there safety trade-offs that conflict with your responsibility to protect the public?

III. Solutions

To complete this problem it is assumed that students are familiar with statics & dynamics, and are enrolled in a course that exposes students to linear viscoelasticity. They must be familiar with the concepts of time-temperature superposition, Boltzman superposition principle and polymer creep.

The creep functions needed for each polymer are presented in Table 1 below.

<Table 1 to be provided by instructor from relevant textbook>

The following shift factors will be needed as well.

Table 2 <details to be provided by instructor from relevant textbook>

Temperature	Shift Factors, a_T				
	Polycarbonate	*Polyethylene*	*Polyacrylate*	*Polystyrene*	*PVC*
-40°F					

30°F

50°F

70°F

85°F

95°F

Problem 1 Solution:

For a circular rod, the displacement at the end of the rod is calculated as

$$f = -\frac{Pl^3 D(t)}{3I}$$

where "f" is the displacement, "P" is the load, "l" is the length of the rod, "I" is the moment and D(t) is the creep compliance as a function of time, where "t" is the time. From linear viscoelasticity, the creep compliance is defined as,

$$D(t) = \frac{\varepsilon(t)}{\sigma_o}$$

where e(t) is the time dependent strain and s_o is the fixed stress.

Assuming Boltzman superposition applies, the displacement may be represented in the following fashion.

$$f(t) = f_1(t) + f_2(t) + f_3(t) + \ldots + f_n(t)$$

For the first period, correcting for the temperature,

$$f_1 = \frac{-Pl^3 D\left(\frac{t_2 - t_1}{a_{85°F}}\right)}{3I} \qquad I = \frac{\pi r^4}{4}$$

where t_2 is the end of the first time period, t_1 is the beginning of the first time period, $a_{85°F}$ is the sift factor, I is the moment and f_1 is the displacement after the end of the first period. A general solution can be derived,

$$f_{total} = \sum_i -Pl^3 \frac{D\left(\frac{t_{i+1} - t_i}{a_{i+1}}\right)}{3I}$$

where I is the number of periods, all other terms have their usual meanings. The times for this problem are reproduced in Table 3 below.

Table 3

Times for Problem 1

t_1	3 months
t_2	8 months (5 months + 3 months)
t_3	10 months (2 months + 5 + 3)
t_4	12 months
t_5	15 months
t_6	20 months
t_7	22 months
t_8	24 months

For problem 2, the solution is of identical form but with 12 time periods (2 more for each year). See Table 4 below for times and appropriate shift factors.

Table 4

Data for Problem 2 Solutions

t_{i+1}	Total Time	a_{Ti+1}	$t_{i+1} - t_i$
t_1	0.5 months(2 weeks)	a_{95}	0.5 months
t_2	3 months	a_{70}	2.5 months
t_3	8 months	a_{85}	5 months
t_4	8 months, 2 days	a_{-40}	1/15 months
t_5	10 months	a_{30}	29/15 months
t_6	12 months	a_{50}	2 months
t_7	12.5 months	a_{95}	0.5 months
t_8	15 months	a_{70}	2.5 months
t_9	20 months	a_{85}	5 months
t_{10}	20months, 2 days	a_{-40}	1/15 months
t_{11}	22 months	a_{30}	29/15 months
t_{12}	24	a_{50}	2 months

Problem 3

For the typical window application, there exists a large differential pressure (1000's of PSI) between the two sides of the window. The constant change from atmospheric conditions to hyper or hypobaric conditions suggest a fatigue crack growth problem or a fracture problem. This is the mode students are to reason as the most likely failure mode. Creep is not related to the most likely failure mechanism.

Problem 4

This problem should be discussed in a group/interactive environment. An ethical analysis that looks at conflicting obligations would be the direction the discussion should take. Students may list obligations suggested in the question and attempt to find a course of action that meets as many obligations as is possible. If the student concludes that creep is the dominate mode of failure, she should address part b of the question through group discussion, they should be directed to understand how this conclusion is technically unlikely (have her calculate the time for a typical window to creep to failure, develop a mechanism for a window to creep to failure).