MSE C212/ME C225
Deformation and Fracture of Engineering Materials
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Due: April 11, 2007

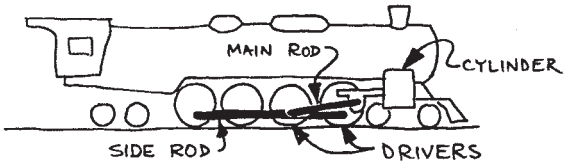
Homework No. 3

1. Illustrate, with sketches or diagrams of appropriate scale, the appearance of the fracture surface of specimens fractured under the following conditions, and explain each case.

   (a) Smooth bars, fractured in tension, of (i) high-purity aluminum at room temperature; (ii) the same aluminum at liquid helium temperature; and (iii) mild steel at room temperature.

   (b) Compact tension specimens, broken at room temperature, of (i) a temper-embrittled high-strength steel tested in plane strain; (ii) copper fatigued in the Paris law region of the da/dn—ΔK diagram; and (iii) an aluminum oxide composite strengthened with silicon carbide whiskers and tested under fatigue loading.

2. You have have been retained as a consultant on a project to restore a large steam locomotive to service for excursions. The locomotive has been on exhibit in a city park since 1957, and structural parts may have been degraded by rust, vandalism, etc. Of particular concern are high-strength parts, such as the main rods and side rods (see sketch), which experience high cyclic loads when the locomotive is operating near peak power (about 5000 horsepower). The steel used for them is a medium-carbon nickel steel similar to 4630, which was tempered to have 140 ksi yield strength, 190 ksi ultimate strength, reduction of area = 28%, and toughness of K_{Ic} = 100 ksi√in.



   (a) The rods are about 8 inches wide and 1.25 inches thick, and cracks which typically occur are edge cracks, for which you may assume $K_I = 1.12\,\sigma\sqrt{\pi a}$. What can you say about the state of stress in the rods?

   (b) The design stress of the rods is 0.5 of the yield strength. If dye penetrant inspection, recommended by another consultant, can readily detect cracks 0.30 inch long (or more), would you agree to a suggestion that the rods be removed from the engine and subjected to a proof test at 1.5 times the design stress? Why?

   (c) Assume the project engineer accepts a recommendation to use ultrasonic inspection instead of dye penetrant, and thereby detect cracks down to 0.15 inch. Would you agree to the proof test described in (b)? Explain.

   (d) The rods have now been inspected and have passed a subsequent proof test. You are asked to specify inspection intervals for the rods. At peak power, stresses range between 0.5 of the yield strength, and zero, on each revolution of the driving wheels. On a typical excursion, about 20,000 revolutions occur at peak power. At this R value, the material obeys the Paris relation with C = 4.1 x 10^{-11} inch/cycle and m = 2.25. What should be the crack growth rate when the engine is first put back into service? If the crack shape and growth behavior are such that ΔK remains nearly constant during crack growth, how many excursions can be made before fatigue failure of a rod? What do you think would be a prudent inspection interval? Discuss the reasoning behind your choice.