MSE C212/ME C225
Deformation and Fracture of Engineering Materials
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Homework No. 4

1. You have been asked to serve as an expert witness for the court in a case involving cracking of a recently installed Interstate highway bridge. The cracking occurred in the webs of the main structural I-beams of the bridge.

The following facts are agreed to by both parties in the court action (the bridge contractor and the state Department of Transportation). Examination of the cracks showed that they had originated at weld-related flaws. The following property data are available: yield strength of the steel used, 90 ksi; ultimate strength of steel, 140 ksi. Design stress for the bridge, 0.6 of yield strength. Toughness K_{Ic} of steel (base metal, as-rolled beam): 60 ksi√in; estimated J_{Ic} of weld metal: 75 in-lb/in^2; length of crack in weld, 0.10 inch.

The I-beams are 6 feet deep (width of web) and the web material is 1.25 inch thick. The controversy is between the contractor's claim that the bridge design is incorrect, and the state DOT's claim that the welds were inadequate (brittle). An important aspect here is the disagreement as to whether the crack grew an additional 0.2 inch into the base (unwelded) metal before the crack propagated across the entire web. Winter salting of the bridge deck prior to discovery of the cracked beams has damaged the fracture surfaces and makes fractographic characterization difficult.

a) The plaintiff (the state) claims that fast fracture occurred as soon as the crack extended across the weld zone (0.10 inch), while the defendant (the contractor) alleges that slow crack growth continued into the base metal until the total crack length was 0.30 inch. What is your conclusion on this point, in light of the evidence available?

b) Why is the crack length important in establishing fault in this case? There is evidence that overweight trucks were being operated over this bridge in the winter, when state patrol weighing stations tend to be closed. Should this be factored into consideration? Why?

c) What post-failure investigations of the fracture or of the material itself would you wish to conduct that could help to differentiate between the two sides in this case? Do the tests you selected reflect your view of the weakest links in the analysis? If you include fracture surface examination, what types of features would you look for?

d) What precautions could be taken to avoid a recurrence?

2. A large hydraulic cylinder has been designed for use on a crane which will load and unload containers at a seaport. Typically the crane moves containers between seagoing ships and stacks of containers on the dock. The maximum design stress of the cylinder is 0.6 of the yield strength; during operation of the crane, lifting loads will result in stresses which vary between 0.3 and 0.5 of the yield strength. The crane will be in use 7 days a week, for two shifts (16 hours) a day. It is anticipated that in the average shift, 55 loads will be moved.

The material selected is a high-strength, low-alloy steel which exhibits a yield strength of 180 ksi, ultimate strength of 220 ksi, Paris law constants (for stress in ksi) of $C = 7 \times 10^{-12}$ inches/cycle and $m = 4.2$, and a K_{Ic} of 60 ksi√in. Assume that cracks in the cylinder wall will obey $K_I = \sigma \sqrt{\pi a}$. The cylinder will be proof tested at 1.5 times the design stress prior to being placed in service.

You have been asked to specify inspection intervals for this cylinder. Your guideline is that the largest crack in the cylinder should not be permitted to exceed 75 percent of the critical crack length at the design stress (this is a factor of safety).

a) How long can the cylinder be in service before the first inspection? Which of the provided data would you most like to confirm before making a final recommendation?

b) If the cylinder were ultrasonically inspected at the time you specify, and no cracks larger than 0.050 inch were detected, how long could the cylinder remain in service before the second inspection? What uncertainties would you have about this recommendation?

The hydraulic fluid is known to contain chloride compounds and will gradually accumulate condensation water in service. The stress corrosion cracking threshold for this steel has only been determined for sea water, and in that case the value was about 40 ksi.

c) Do you think stress corrosion cracking in service is possible for this part? What tests would you conduct to be sure?

Additional sea water tests on this steel showed that the maximum sustained-load crack growth rate was about 1×10^{-8} cm/s.

d) What inspection interval would be needed to fulfill the crack length guideline for this cracking rate? Is the use of seawater data reasonable here? Why?

e) In the seawater test program, crack growth rate data were also obtained in distilled water, and the maximum measured rate was 9.5×10^{-10} cm/s. If a chloride-free hydraulic fluid could be used, what would be the inspection interval? How much confidence do you have in this answer? What test data would increase your confidence? Can you make a recommendation on the composition of the hydraulic fluid?