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MSE 175
DESIGN FAILURE INVESTIGATION

WINTER QUARTER, 2021
Prof. J. C. Earthman

HOMEWORK ASSIGNMENT #3

(Due: Wednesday, February 3)

1. You are inspecting a corroded valve at a water-treatment plant. You find out that the construction project was behind schedule and short of parts at the time the valve was installed. Apparently two valves were needed for immediate installation: one for a location in the system where the water is rich in oxygen, and another for a location where the oxygen content is practically zero percent (anaerobic). You come to learn that only two valves were readily available: one made of a steel containing 18% Cr and another made of a steel containing 5% Cr. Which valve should have been installed at the oxygen-rich location? Explain your answer. If the wrong valve was chosen, which valve most likely failed by corrosion?

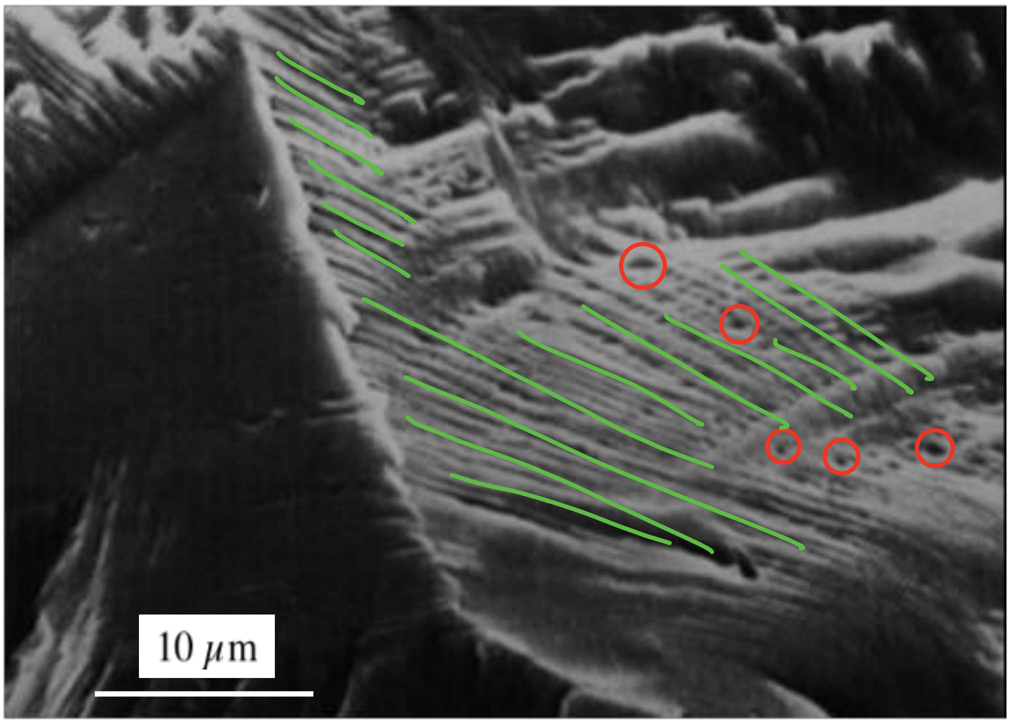
Out of the two locations stated, the first being a system where the water is rich in oxygen, requires a valve that is not affected by corrosion failure from chemical attacks. This means that steel pipes without any additives, just iron and carbon, would undergo an oxidation-reduction (redox) reaction from the high concentration of oxygen bonding with iron, forming iron oxide, or rust. From the two alloys given, chromium is added to the steel because it is more reactive than iron blocking the electrons from moving through and out into the electrolyte. Therefore, this bonds with the oxygen from the system to produce a continuous chromium oxide layer protecting the steel from corrosion, specifically rust. From the two pipes, the first location would heavily benefit from having more chromium added into the pipe so that the iron in the steel does not bond with the rich amounts of oxygen to produce any rust and cause failure.

If valve with only 5% Cr is installed in the first location instead of the 18% Cr, the limited amount of chromium would not be as effective against the extreme concentration of oxygen and would fail by corrosion. This is form the excess of oxygen not being bonded with chromium and forming openings to instead iron producing iron oxide. This lowers the resistance barrier to prevent corrosion and will develop localized corrosion in the vessel from the formation of a concentration gradient, more specifically low concentrations of chromium and high concentration of oxygen.

2. What failure mechanisms are evident in the fracture surface on a brass condenser tube shown below? On what feature(s) on this micrograph do you base this assessment? About how long did it take the crack to grow from the bottom of figure to the top if the loading frequency was 0.001 Hz?

↳ # OF CYCLES OF FAILURE DEPENDS ON f OF LOADING ($Hz = \frac{1}{s}$; $Hz^{-1} = s$)

[CORROSION FATIGUE ; SOLN OF PH 2 → ACID CORROSION]



PITS FROM CORROSION

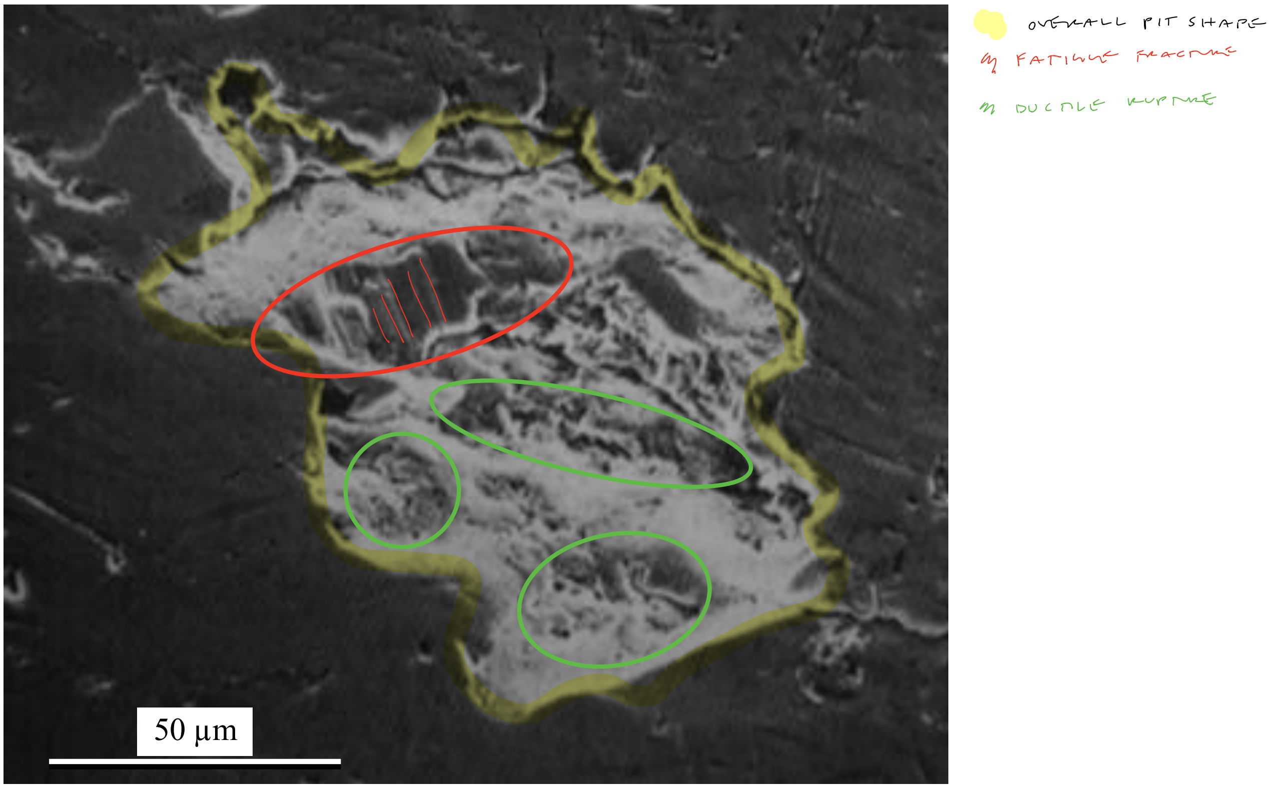
STRIATIONS FROM FATIGUE

The failure mechanisms evident on this fractured surface is fatigue and corrosion also referred to as corrosion failure.

I can tell that fatigue failure occurred based on the striations seen indicated above. This feature is a result of stage 2 fatigue failure crack grown by an alternating slip that produced these striations. However, a closer look between these striations I can see small holes called pits shown above by the circles. These pits are formed by localized corrosion that broke through a passive film and helped the crack grow faster. (Not given but referencing the lecture slide, this austenitic steel was bleached in a solution with a pH of 2 which result in acid corrosion affecting any passive layer through gradual degradation)

Knowing that the loading frequency is 0.001 Hz and that the inverse of Hz is equal to seconds, the crack grew in 1000 seconds from the bottom to the top.

3. What features in the micrograph below indicate that the pit was caused by wear as opposed being produced by corrosion? What other damage mechanisms discussed in class are also evident in this micrograph.



Pits caused by corrosion are very unique in their geometric structure meaning they are symmetrical depend on symmetry. Even at earlier stages, pitting can form into square or triangle holes then as they develop further by increasing the crack growth, they can turn into circles. The overall shape of indicated above in the fractograph does not follow this symmetry seen by corrosion based pits, instead the outline shown is quite rough and irregular due to the presence of fins. This indicates that corrosion was not present and that this was formed due to wear of the material from fluctuated loading.

Drawn above, I indicated that both fatigue failure and ductile rupture are seen. This is proven by the crater detailing striations following the vertical orientation of the image for fatigue failure and dimples on the surface from ductile cup and cone fracture.

4. You are an engineer for a large steel company that makes pipe. Some pipe that was sent to an oil company failed at a field in Canada in February injuring some of the workers. The rest of the pipe in that production run was sent to another oil company at about the same time in Saudi Arabia. None of this pipe failed yet. You have just looked at the fracture surface of the pipe that failed and you see indications of quasi-cleavage in the SEM. What would you suspect regarding the steel used to make the pipe that failed? What test would you perform to check your suspicion? What test result would prompt you recommend recalling the pipe in Saudi Arabia? How might your assessment affect (1) public health, safety, and welfare, as well as (2) global, (3) cultural/social, (4) environmental, and (5) economic factors.

Because the fracture surface of the failed pipe indicated quasi-cleavage failure in the SEM, I know that there are some brittle cleavage fractures and ductile tearing in the material. Both of these create pockets of brittle and plastic deformation throughout the material and depending on how the loads are applied, can begin forming cleavage micro cracks that then have plastic deformation between them revealing tear ridges. Because the material experiences both plastic and brittle deformation, there will be a transition temperature relating each deformation property to a range of plotted temperatures on a Brittle/Ductile Transition Curve Graph. This means the pipe that failed in February in the Canadian winter is assumed to have failed under brittle fracture because of the cold temperature experienced since the pipe in Saudi Arabia has not yet failed.

In order to prove my assumption about the Canadian pipe failing under brittle cleavage failure, I would go ahead and run a tensile test a sample of the pipe. This test would run at temperatures experienced in both Canada and Saudi Arabia to find the plausible range experienced in industry while also seeing if there is a transition temperature among this plotted data. If there is a curve regarding the transition temperature from brittle to ductile, then I would have to look at what temperature this transition starts and ends at. This would signify when the pipe would fail as a brittle material or as a ductile material. It is preferred that materials fail from ductile fractures because they are less catastrophic like brittle fractures. However, if the graph on the brittle failure side is at higher temperatures that are experienced in Saudi Arabia and does not transition into ductile fractures until even high temperatures this would be a cause for concern. Because the pipe would still have an opportunity to fail by brittle fracture in Saudi Arabia it would be required for a recall.

If my assessment is deemed correct, the public health, safety and welfare would benefit from this decision and reduce any preventable accidents. On a global level, initially recalling a product is never a good look because in the public's eye, they question why the product was allowed in the market in the first place. This could cause some short backlash since it would occur on opposite sides of the world putting more countries at risk. Yet, the overall goal of preventing anymore injuries to workers would be achieved, so in the long run, the global impact would be positive. Similarly, looking at the cultural and societal impact, I think it would follow the same trend of the global impact. There would be a short period of backlash towards the company for letting innocent workers be injured on behalf of a faulty pipe. I believe, that over time, this would be acknowledged as a smart decision to prevent further accidents and eventually be supported. For the environmental factors, oil company's are looked down upon due to their contribution to greenhouse gases increasing climate change. Although, I believe recalling a pipe that burst and had possibly leaked oil into the environment it is located in is beneficial for this factor. I believe a factor of the economy from this would follow the global, cultural and societal factors, of negative press first then eventually disappears. However the total profit of the steel company would decrease for a longer amount than the previous factors because it is their responsibility to produce high quality products and making a mistake that causes harm to workers is not easy to move past. Through attempts of redemption, such as recalling the pipe, would be the easiest way to profit again.