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MSE 175 — WINTER QUARTER, 2021

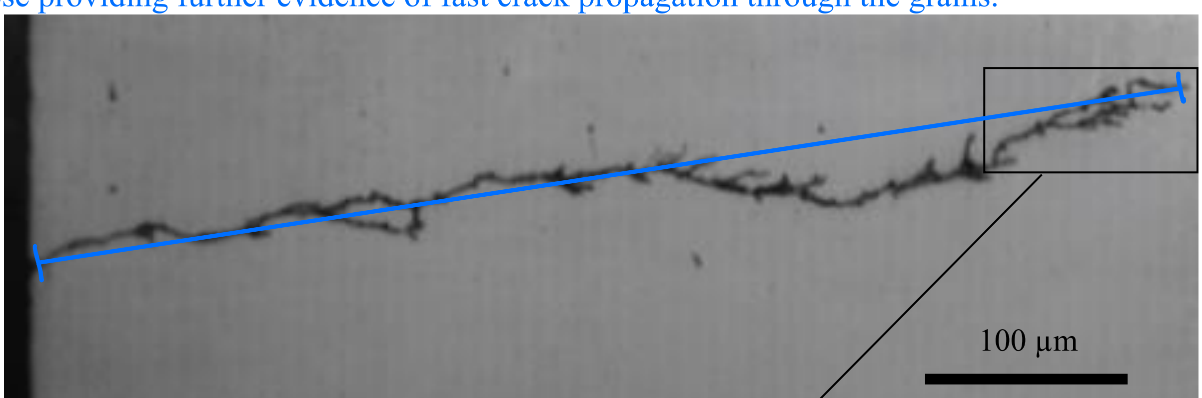
DESIGN FAILURE INVESTIGATION — Prof. J. C. Earthman

HOMEWORK ASSIGNMENT #4

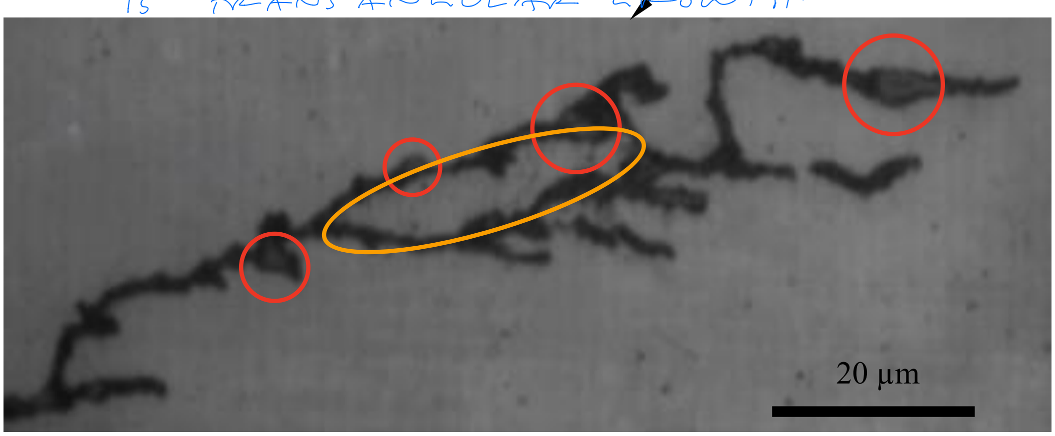
(Due: Wednesday, February 17)

1. What features present or absent on the cross-section of the high temperature component below indicate that the crack was probably produced by fatigue as opposed being produced by grain boundary cavitation? What other damage mechanism discussed in class is evident in this micrograph.

In the sample images, there is no presence of cavities along the crack which automatically prove that the crack was not formed through cavitation. The crack shows that it was formed by fatigue due to oxidation in the crack highlighted by the red circles. This happens when air gets into the surface of the crack from each loading cycle to then be oxidized and create added stress to the cracks propagation increasing the speed of formation. Furthermore, the growth of the crack in the image follows a straight line as indicated by the blue trend line showing the crack is a transgranular fracture (through the grains) in contrast to intergranular fractures (along the grain boundaries). The crack tip also splits in two then re-emerges together known as bifurcation shown by the orange ellipse providing further evidence of fast crack propagation through the grains.



m crack propagation follows a ~straight line proving it is not following grain boundaries & is transgranular growth



m oxide formation

m crack splitting then meeting back

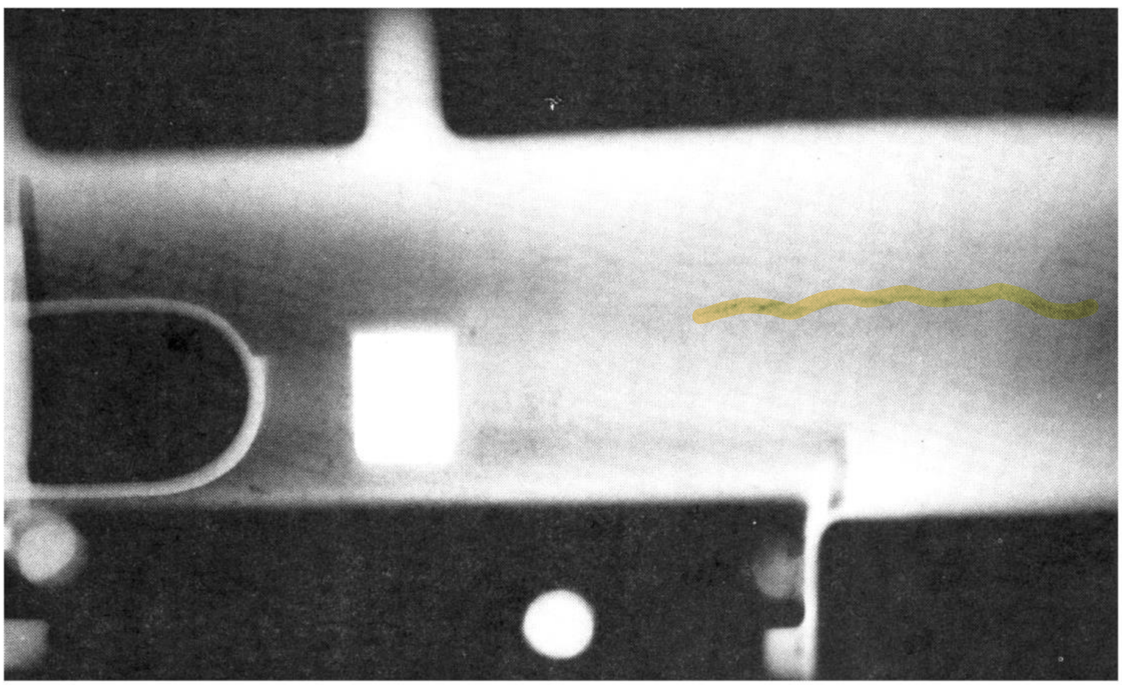
[@ T > $\frac{T_m}{2}$ IN AIR]

2. A stainless steel part is given to you that failed under static loads at elevated temperatures greater than half the melting temperature in air. A young engineer claims after examining the part using SEM that it did not fail by grain boundary cavitation because there were no dimples anywhere on the fracture surface. However, it is not clear how long the fracture surface oxidized at elevated temperatures after the failure occurred. How would you check the validity of the engineer's claim?

Knowing that the stainless steel part failed under static loads at elevated temperatures, T, greater that half the melting temperature, 0.5Tm, in air, the damage processes that occur predominantly are facilitated by diffusion. This means that diffusion is much faster at these temperatures along the grain boundaries. Also, because it was noted that the time for these parts in this condition was not clear, the overall effect high temperature dependent diffusion had could also be limited. Yet, since the the young engineer could not confirm dimpling on the surface signaling the failure type was not by grain boundary cavitation, this can be explained due to the unknown time these parts were left in the condition for. A possibility is that the time was short within the temperature condition which limited the production of cavities hence any indication of grain boundary cavitation. To test my hypothesis, I would first want to make sure to test other samples using SEM in case that if cavities did form on the surface, it wasn't overlooked from improper sample selection. However, I would also order a TEM test for the sample to review the grain boundary of the material to determine if there was an attempt of atomic diffusion eventually leading to cavity coalescence otherwise seen as dimples. If this was confirmed, then I could conclude that the sample did not undergo a large enough time period within the temperature condition to finish diffusing to present grain boundary cavitation. On the other hand, if the TEM images do not show any significant grain boundary plating out on the transverse boundary of the load, then it can be noted that high temperature rupture did not occur and would foe considered a brittle fracture instead.

3. A steel casting that has been in service for a year was inspected using X-ray system which produced the radiograph below. Your supervisor wants to know whether the defect in this radiograph was produce while the part was in service. What would your response be? What would you advise her to do in the future to avoid this defect?

After reviewing the part's radiograph, my response to if the defect seen was produced while in service would be no. The defect is highlighted in orange showing a faint wavy tear on the right side of the image. This had occurred when the part was solidifying in the mold and through this processing, hot tears are commonly formed as the hot liquid cools to a solid creating contraction stresses. These contraction stresses are surface level stresses because when a mold holds liquid metal, the center is the last to solidify so it keeps its initial liquid state and high temperature whereas the edges, or the surface, of the mold are the first to nucleate into solid phases cooling down the fastest. This contrast of phase and temperature is what starts the opposing stresses because the center wants to expand creating against the contracting surface which creates tensile stresses forming the surface cracks, or tears seen. Because the tear is only seen on the right side of the image, this means the majority of the heat was removed there and created a large thermal difference. My advice for my supervisor would be adjust the casting process to preheat the casting mold, especially on the right side, so the temperature from the liquid metal pouring into the mold is not as drastic preventing further hot tears.



X-RAY CONTRAST MEANING

DARK STRUCTURES CONTAINING AIR

↓

LIGHT DENSE STRUCTURES WILL BLOCK MOST OF THE X-RAY PARTICLES

~ TEAR FROM CASTING PART