EMA 4324 Problem Set 1

1-1. [Jones II, 1-1 (modified)] Radial steel belted automobile tires are commonly constructed of rubber reinforced with braided steel wire, each strand coated with copper. The copper is included to enhance adhesion of the rubber tire casing to the wire.

[a] What are ways in which the tire can fail [a preview of what to expect in EMA 4714].

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Tire is basically a donut shaped pressure vessel. When the material from which the pressure vessel fails due to exceeding its failure strength, the tire fails. Thus [1] deterioration of the polymer, [2] failure of that component which sustains the majority of the applied stress are factors .

[b] How might corrosion contribute to tire failure?

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[1] Reduction in cross-sectional area of the wire making up the steel "belts" will increase the stress applied to the remaining cross-section, eventually leading to mechanical failure. [2] Some heavy metal cations lead to deterioration of polymeric materials.

[c] Which forms of corrosion might be involved?

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General and galvanic corrosion are the most obvious answers; if steel were to separate [disbond] from the rubber, crevices might form.

[d] How does copper enhance adhesion of the rubber to the steel?

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Copper forms strong bonds with sulfur - copper sulfide is an extremely stable compound [Cu_2S = chalcopyrite, a common constituent of copper ore]. Sulfur in rubber [vulcanizing agent] allows rubber to bond to copper which, in turn, is strongly bonded to steel.

1-2. [Jones II, 1-5] The corrosion rate of titanium was measured at a rate of 100 mpy in dilute sulfuric acid which was free of dissolved oxygen and other oxidizers. Iron was found to corrode in the same environment at a rate of 250 mpy. Contamination of the environment by Fe^{+3} ion [an oxidizer] produced a decrease in the corrosion rate for titanium to 1.5 mpy but an increase in the corrosion rate of iron to 3500 mpy [mpy = mils per year, where a mil is 1/1000 of an inch - 0.001]. Explain how this might be possible.

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Corrosion in a non-oxidizing mineral acid should involve oxidation of metal to positively charged cations [Fe^{+x}, Ti^{+y}], with the only supporting reduction [cathodic] reaction being the reduction of hydrogen ion [H^+] to hydrogen gas [H_2]. Assuming that the overall corrosion rate [proportional to j_A, A/cm^2] is limited by the cathodic reduction reaction rate

[proportional to j_C, A/cm^2], any increase in concentration of reducible species [oxidizers like Fe^{+3}] would increase j_C, allowing j_A [which is limited by j_C] to increase. The behavior if iron is then to be expected - adding Fe^{+3} increases the corrosion rate of iron from 250 to 3500 mpy. This behavior is illustrated by Figure 1.2 which shows increased anodic polarization - an increase in corrosion rate [corrosion current] with an increase in potential [proportional to oxidizer concentration]. The only way an increase in oxidizer concentration can result in a *decrease* in corrosion rate is if the increased corrosion current allows formation of an insoluble corrosion product [passivity]. This increased resistance to current flow leads to a decrease in anodic current for titanium - see Figure 1.3.

Note that 1-1[a] requires some thought, 1-1[d] some research. All other questions can be answered by reading [and understanding] the text.