Strain Localization During Slow Strain Rate Testing of Sensitized Al-Mg Alloys

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Abstract:
Aluminum is a desired commodity for building vehicles, electronics, or other miscellaneous things. However, pure aluminum is soft and not as durable as needed for certain objects such as ships. Therefore, Aluminum-Magnesium alloys were introduced as a solution. These alloys help keep the lightweight features of aluminum while increasing strength, formability, and weldability. Yet, the magnesium segregation can lead to localized corrosion and stress corrosion cracking. This research is primarily focused on applications of Al-Mg alloys in saltwater environments, such as Navy ships, which are built using Al 5xxx alloys. This project investigated 20 samples of Aluminum 5456 that were broken into five subgroups which underwent different conditions to simulate the everyday stress and strain of a ship. The different conditions tested include sensitization, longer sensitization, salt corrosion, and sensitization-salt corrosion. After enduring these conditions, the samples underwent a slow strain tensile test to further simulate the rough life of a ship. These tensile tests used a slow strain rate to ensure the observance of hydrogen embrittlement and stress corrosion cracking during the failure of the alloy. After failure, the samples' fracture surface was observed under the scanning electron microscope (SEM) to examine the strain effects on the metal. Aluminum alloys seem to experience brittle failure more often than ductile failure after exposure to nautical conditions, which is more catastrophic. Understanding the different fractures and cracks of the grain boundaries can help lead to the design of better materials that are more resistant to brittle failure and reduce the precipitation of magnesium.

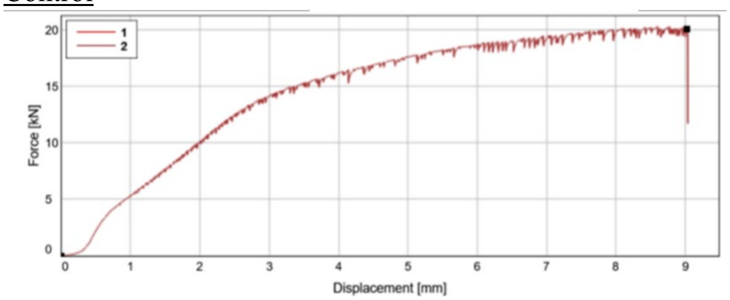
Introduction:
Aluminum is a desired metal for many purposes, especially for building large quantities because of its lightweight features, low cost, and the fact that it is infinitely recyclable. However, aluminum is too soft for structural purposes, so it is often mixed with other metals to increase its strength. Particularly, the Al 5xxx alloy was the focus for this project since it is used to build ships for the military. Aluminum (Al) 5xxx is an Al alloy with 3% weight Magnesium. In this project, the metal underwent various conditions like that of a ship, while simultaneously being observed to understand how it reacted. Understanding the makeup of the alloy is important in understanding how it is affected in certain environments. Aluminum is made up of grains separated by grain boundaries and magnesium is spread out within the grains in the alloy. However, when the metal is sensitized, exposed to heat from machinery or the sun, the magnesium transverses across the grains and precipitates in the grain boundaries, causing corrosion inside the metal. Another nautical process that the metal experiences that can cause corrosion is when Al 5xxx is exposed to saltwater; the magnesium molecules can react negatively with the salt and corrode the surface. When the metal corrodes, it becomes more brittle. In this project, 20 samples were tested in different conditions such as sensitization, longer sensitization, salt corrosion, and a mixture of sensitization and salt corrosion.

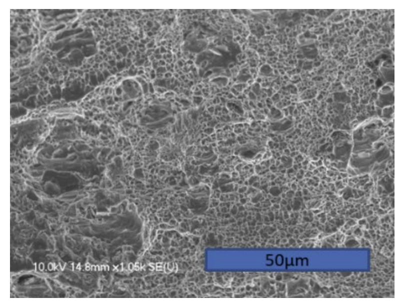
Experimental Procedure:
To prepare the samples for the slow strain rate test, ten samples were put in a furnace at 175°C for 48 hours for the sensitization process. After it was complete, five samples from the furnace and five unsensitized samples, were put in a saltwater solution with 3.5% wt NaCl in H2O for 10 days. Two more samples were put in the furnace at 100°C for 10 days for the longer sensitization process. The remaining 3 out of the 20 samples remained untouched to simulate a brand-new boat without any wear and tear. There are a couple ways to understand how the metal reacted to certain conditions. One way is to perform a

slow strain rate tensile test to simulate the everyday stress and strain of a ship. The slow strain rate helps ensure the effects of hydrogen embrittlement and to decrease the metal's elasticity. This test was run on an Instron by putting the sample into metal clasps that pulled on the alloy until it broke. A single test took approximately eleven hours and provided a stress strain curve that gave insight to the strength of the metal. After the sample failed, it was examined in a Scanning Electron Microscope (SEM) to observe the fracture surface. The differences in the way the surface is composed reveals which of the two types of failure occurred in the sample. Ductile failure is a slow fracture, where the metal is reluctant to break. This failure is identified as a more porous surface. The other type of failure is brittle failure. Brittle failure is a catastrophic break, and the metal is more likely to rip apart. The surface with this type of fracture will appear smoother with flat ridges. When building a boat, it is much better to use a ductile metal than a brittle metal. These failures can also be identified by the type of graph given by the stress strain curves from the tensile tests on the Instron. A brittle graph is steeper and has more dislocation diffusion ridges than a ductile graph.

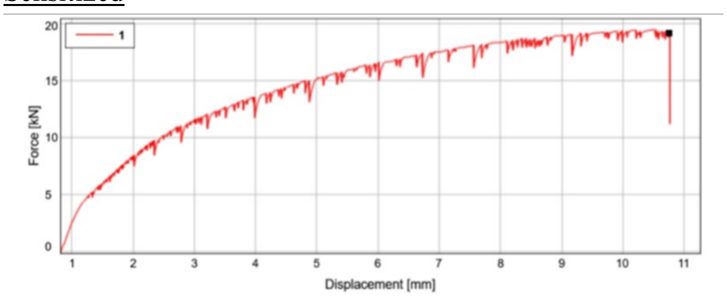
Results and Conclusions:
Understanding how the metal fails under strain helps determine how the alloy reacts to certain conditions. The harshness of the environment seems to be directly proportional to increased brittle failure.

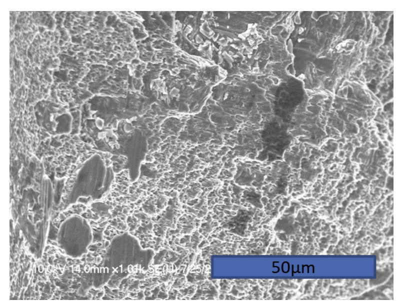
<u>Control</u>



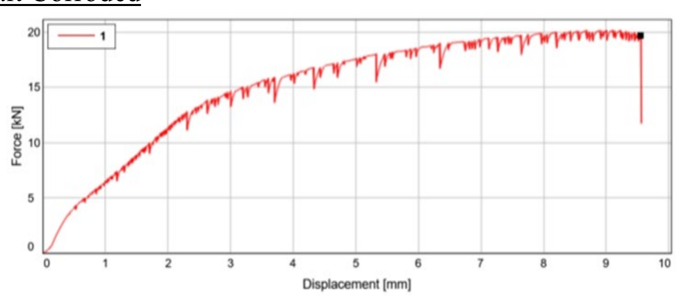


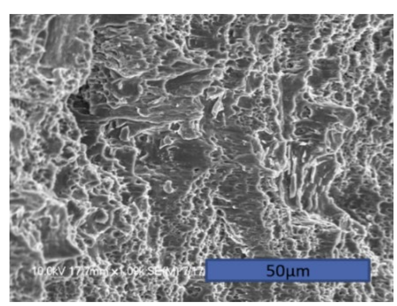
<u>Sensitized</u>



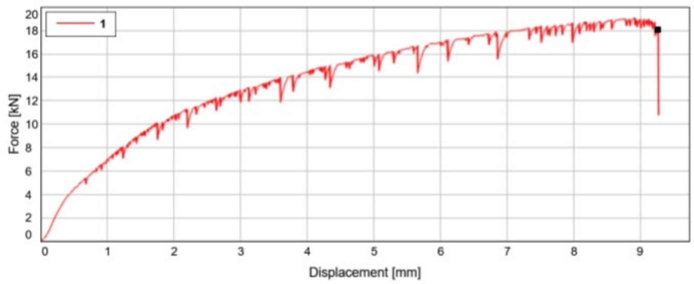


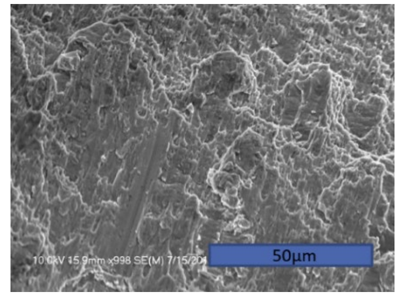
<u>Salt Corroded</u>



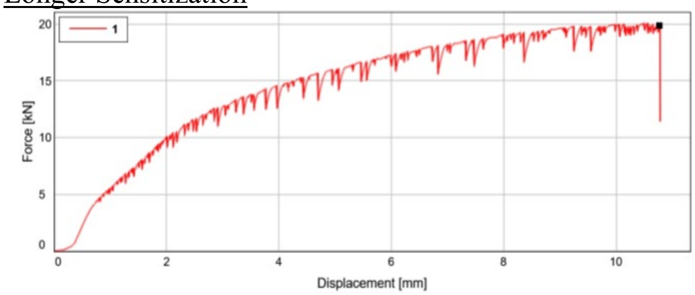


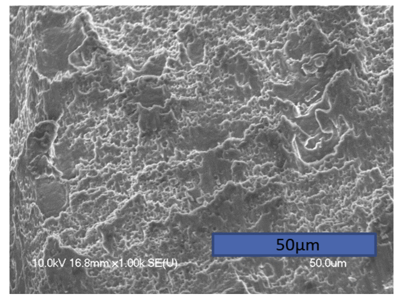
<u>Salt Corroded and Sensitized</u>





Longer Sensitization





When observing the graphs, there is an increase in the amount of spikes on the graphs based off the order given above. These spikes account for dislocation diffusion. During the tensile test, the dislocations get stuck on the magnesium molecules, so it requires more force until it breaks free. The SEM Images also tend to show that the metal increasingly becomes more brittle after it is exposed to heat and salt water.

Future Work:
To continue this project, the group will perform EBSD (Electron Back-Scattering Diffraction) on samples to understand what boundaries are cracking and why they are being affected. After that, they plan to work with a computer modeling group to understand the physics of hydrogen embrittlement. That information will be used to build a computer model to help design materials to be more resistant to brittle fracture and decrease the precipitation of magnesium.

Acknowledgements:

- SUIN REU for providing this opportunity.
- NSF for providing funds through the grant NSF EEC-1757579.
- Dr. Kacher and his graduate students, Jordan and Jahnavi.
- Leslie O'Neill and Dr. Quinn Spadola
- Dr. Chris Yang, Todd Walters, and the MILL Fellows

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