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Stress Intensity Factor Dependence of Hg-LME in Aluminum

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INTRODUCTION

The use of aluminum alloys is commonplace in all facets of engineering. When designs require a relatively inexpensive material that incorporates both high strength and low density, particular aluminum alloys can be chosen. In such applications, aluminum alloys are used to house liquid mercury; as is the case in chemical processing plants. The contact that results between the alloy and the mercury will have a negative effect on the load capability, possibly leading to premature failure [1]. At the root of the failure is a mechanism known as Liquid Metal Embrittlement (LME). In LME, a material that normally exhibits ductile behavior will display less plastic deformation before failure. Negative effects from the embrittlement of a material can lead to catastrophic failures, with the possibility of the loss of life.

Examination of LME can be conducted through a variety of tests. Mechanical tests include tension, bend, and classical fracture mechanics tests, where upon failure, the fractured surfaces can be analyzed. Small amounts of mercury are generally applied to the crack tip or by coating the entire specimen in a liquid metal [2,3]. The results from these tests indicate that there is a significant decrease in the fracture strain of the experimental aluminum alloy. Either through the observation of the fracture strain or the penetration speed of the liquid metal, the addition of the liquid metal plays a significant role in the embrittlement of the material.

These experiments applied a constant strain rate to the specimen until failure; however, they did not allow for the measurement of time-dependent diffusion of the liquid into the metal. Incubation time could play an important role in the fracture of the experiment, as it was shown by Ina and coworkers that it was not the metal liquid on the surface that caused LME, rather the amount of the liquid metal that had penetrated into the surface of the solid metal. With this knowledge, the effects of stress-dependence of diffusion and its effects on fracture toughness must be studied through incubation time in the manner as demonstrated by Gordon and An [4].

Recently, pre-cracked specimens have been used in the observation of LME [5]. Using pre-cracked specimens provides particular advantages over other methods, as most lifetime predictions assume that there are flaws and defects in the material. Employing Compact Tension (CT) fracture specimens in a fracture test, the effect of mercury on specific materials can be observed. Vital information, such as the plane strain fracture toughness, K_{IC}, can be calculated, allowing for the comparison of several failed specimens. By using a CT specimen, fatigue testing and incubation experiments can be conducted while immersed in a liquid bath.

Working with the aluminum alloy 7075-T651, CT specimens were machined with an S-L orientation. Several experiments have been conducted on this alloy with specimens in the T-L and L-T orientation [6,7]. As such, there is a considerable amount of information available regarding these orientations; however there is a lack in data available for S-L specimens. Interestingly enough, S-L orientated specimen provide a uniform microstructure ahead of the crack tip and is also the weakest orientation of the material in regards to fracture properties. These characteristics will help to ensure uniformity of results, while providing data on the fracture capabilities of designs incorporating components machined in this direction. Ultimately, it is the goal of this research to measure the K_{IC}, diffusion rate, and the change in surface energy in Al 7075-T651 through several mechanical tests with corroborating photographic/microscopic analysis.

To date, initial fracture experiments have been conducted in air, saltwater and liquid mercury. Specific routines have been employed in the testing, e.g. soaking the specimen in a solution prior to and following fatigue precracking and conducting the fracture test immersed in the fluid. The later example required the design of an environmental chamber capable of housing liquids while shielding the operator from any hazardous materials. This design has already been implemented in test routines and proven to be a successful design, Fig. 1.

With the environmental chamber, fatigue crack growth (FCG) and fracture experiments have conducted while immersed in a liquid. Initial results and preliminary analysis suggests that there is a strong correlation between the environment and fracture toughness in the aluminum, Fig 2. Load and displacement data is provided, along with the exposure routine that was utilized. From these plots, the SIF can be calculated and compared between specimens. Moreso, observation of the fracture surfaces has been made through optical microscopy.

Currently, modifications are being made to the chamber design, in which future designs will allow the use of a crack tip opening displacement (CTOD) gage to be used. Coupled with the load and displacement data, more accurate results can be obtained. With these modifications, the rate of diffusion of liquid metals and the change in surface energy for the material couples can also be calcuated with ease. Particularly, the affect the diffusion of mercury into the aluminum specimen and incubation period have on K_{IC} will be thoroughly investigated with these tools.

Through the development of more adaptable environmental chambers and new rigorous test routines, the LME of Al 7075-T651 in the S-L orientation can be further understood.

REFERENCES

[1] English, J. and Kobrin, G., *Liquid Mercury Embrittlement of Aluminum*, Materials Selection & Design, Volume 28 (2), pp. 62-63, 1989.
[2] Ina, K. and Koizumi, H., *Penetration of liquid metals into solid metals and liquid metal embrittlement*, Materials Science and Engineering, Volume 387 (1), pp. 390-394, 2004.
[3] Malu, M.K., and Preece, C.M., *The Role of Solute Additions to Aluminum on its Embrittlement by Mercury*, Materials Science and Engineering, Volume 11 (4), pp. 223-226, 1973.
[4]Gordon, P. and An, H., *The Mechanisms of Crack Initiation and Crack Propagation in Metal-Induced Embrittlement of Metals*, Metallurgical Transactions, A, Volume 13A (3), pp. 457-472, 1982.
[5] Epstein, J.S., *Crack Embrittlement Displacement Fields*, Optics and Lasers in Engineering, Volume 13 (1), pp. 3-16, 1990.
[6] Domack, M., *Critical Assesment of Precracked Specimen Configuration and Experimental Tests Variables for Stress Corrosion Testing of 7075-T6 Aluminum Alloy Plate*, International Conference and Exposition on Fatigue, Corrosion Cracking, Fracture Mechanics and Fail (ASM), pp. 191-198, 1986.
[7] Mächler, R. et al., *Structure, Mechanical Properties, and Stress Corrosion Behavior of High Strength Spray Deposited 7000 Series Aluminum Alloy*, Materials Science and Technology, Volume 7 (5), pp. 447-451, 1991.

Figure 1: Environmental chamber shown attached to the MTS Electromechanical Tensile Load Frame, along with cutaway view including specimen.

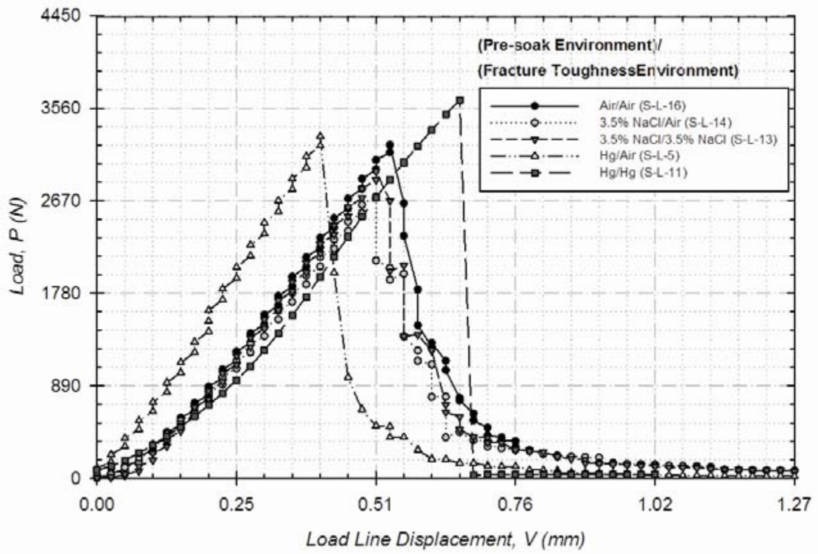

Figure 2: Load Line Displacement vs. Load for several CT S-L specimens in different environments.