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CONTRACTOR: UNIVERSITY OF CALIFORNIA, LOS ANGELES

CONTRACT TITLE: DEVELOPMENT OF THE MICROSTRUCTURE BASED STOCHASTIC LIFE PREDICTION MODELS

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TECHNICAL OBJECTIVES:

- Ascertain microstructural features relevant to fatigue in aluminum 7050 alloys and develop quantitative techniques for their characterization.

- Characterize initial microstructures and fatigue damage accumulation in aluminum 7050-T7451 plate alloys.

- Formulate and test scaling relationships and models relating relevant microstructural features and accumulation of fatigue damage in aluminum 7050 alloys.

TECHNICAL APPROACH:

This study explores the methods of incorporating material microstructural characteristics into the fatigue life prediction models based on the results of the microstructural characterizations and fatigue testing of aluminum 7050-T7451 plate alloys. The emphases in the microstructural characterization part of the program are on the identification of the fatigue-relevant microstructural features and on the characterizations of the microstructural gradients. The characterizations are carried out using both the standard and novel techniques such as tessellation, fractal and modified linear intercept methods. The key measurement is determination of the size distributions of the fatigue crack initiating flaws -- they are assumed equal to the extreme value distributions of the micropore and/or constituent particle size distributions measured on the metallographic sections. The predicted distributions are verified by comparing them with the actual crack initiating flaw size distributions obtained from the fractographic examinations. Results of the microstructural characterizations, supplemented with the results of the fatigue testing acquired from Alcoa group, are used to develop Paris/Erdogan type microstructure based fatigue life prediction models. It is anticipated that different specialized microstructural models may be needed to describe behavior during different stages of fatigue life. They will be integrated using the Markov chain approach.

TECHNICAL ACCOMPLISHMENTS:

Main focus during the reporting period was (1) on the completion of the metallographic and fractographic characterizations of the high and low porosity 7050-T7451 commercial 6" plate alloys, (2) refinement of the methodology for predicting size distributions of the fatigue crack initiating flaws and (3) on the development of the microstructure based life prediction models. The microstructural characterizations of the high and low porosity plates have been now completed. Collected information include description of the through thickness grain structure gradients and quantification of the fluctuations in the volume fractions and size distributions of the constituent particles, pores and precipitates. Results indicate that the new pedigree alloy contains 24% fewer pores and 13% less constituent particles then the old one. The size distributions of pores and constituent particles are lognormal and their spatial distributions are random with clusters. Characterizations of the fracture surfaces and microstructures of fatigued samples are in progress. Up to date results include data on the change of surface roughness and fractal dimension with fatigue crack length and information about microstructural features and dislocation structures along the crack path. Modeling has been focused on the prediction of the size distributions of the fatigue crack initiating pores and on the incorporation of the microstructural variables into existing fatigue life prediction models. In the microstructural part of the modeling effort it was possible to show that the crack initiating pore sizes were extreme values of the parent pore size distributions obtained from metallographic characterizations. The best predictions of the crack initiating pore sizes distributions have been obtained by approximating pore parent distribution with the Gumbel model and by using sample size equal to the number of pores in the specimen surface layer. In addition, the predictive capabilities of two types of the life prediction models have been studied. The first model was of the Paris/Erdogen type with initial crack sizes, texture and crack deflections as stochastic variables. The model allowed for the prediction of the distributions of fatigue lives and for the study of the effects of different stochastic variable, and their combinations, on the predictions. The model has very good predictive capabilities, particularly for the new pedigree alloy. The second tested model was of the Markov chain type. Interrogation showed that it was capable of correctly predict change in fatigue lives due to the fluctuations in the initial crack sizes and in the nucleation and growth rates. This model is intended for use in linking together several specialized microstructural models describing different stages of fatigue life.

SIGNIFICANCE OF THE ACCOMPLISHMENTS:

- The first ever comprehensive set of the microstructural, fractographic and fatigue damage accumulation characteristics of two different variants of the aluminum 7050-T7451 plate alloys have been measured. These data are going to provide designers with the information about expected microstructural gradients, flaw size distributions and fatigue crack nucleation sites in the aluminum 7050 plate alloys.

- The previously proposed method for predicting size distributions of the fatigue crack initiating pores has been refined. The method should be instrumental for obtaining preliminary estimates of the material fatigue quality without the need for fatigue testing and/or in estimating flaw size distributions in large components.

- A Paris/Erdogan type life prediction model with three microstructural stochastic variables has been proposed. The model can be used for estimating the sensitivity of the material fatigue resistance to the microstructural fluctuations.

FUTURE EFFORT:

Characterize microstructures of the low porosity and thin plate variants of the 7050 alloys. Complete fractographic characterization of the 7050-T7451 plate alloys. Refine extreme value methodology for predicting size distributions of the fatigue crack initiating microstructural features. Incorporate results of the microstructural characterizations into the next versions of the proposed life prediction models and scaling relationships.

PUBLICATIONS:

1. J. Zhang, A. J. Luévano and M. A. Przystupa, " Theoretical Models for Quantitative Analysis of Grain and Particle Shapes", submitted to Materials Characterization.

2. A. J. Luévano, M. A. Przystupa and J. Zhang, "Accumulation of Microstructural Damage Due to Fatigue of High Strength Al Alloys", submitted to Journal of Materials Engineering and Performance.

REPORTS:

1. M. A. Przystupa, J. Zhang and A. J. Luévano, "Development of the Microstructure Based Stochastic Life Prediction Models", Progress Report, August 1993.

2. M. A. Przystupa, J. Zhang and A. J. Luévano, "Development of the Microstructure Based Stochastic Life Prediction Models", Quarterly Report, September 1993.

PRESENTATIONS:

1. M. A. Przystupa, J. Zhang and A. J. Luévano, "Distribution of Microstructural Features on the Fatigue Crack Path in Aluminum 7050 Alloy", TMS Fall Meeting in Chicago, November 2-5, 1992.

2. A. J. Luévano, J. Zhang and M. A. Przystupa, "Characterization of Grain Boundary Precipitates in the Aluminum 7050-T7451 Alloy", TMS Fall Meeting in Chicago, November 2-5, 1992.

3. J. Zhang, A. J. Luévano and M. A. Przystupa, "Quantitative Characterizations of Pores and Constitutive Particles in the Aluminum 7050 Alloy", TMS Fall Meeting in Chicago, November 2-5, 1992.

4. J. Zhang, A. J. Luévano and M. A. Przystupa, "Quantitative Analysis of Fatigue Fracture Surfaces of the Aluminum 7050 Alloy", TMS Annual Meeting, Denver, February 21-25, 1993.

5. M. A. Przystupa, J. Zhang and A. J. Luévano, "Predictions of the Size Distributions of the Fatigue Crack Initiating Flaws", TMS Annual Meeting, Denver, February 21-25, 1993.

6. M. A. Przystupa, "Estimation of the Size Distributions of the Fatigue Crack Initiating Pores in Aluminum Alloys", invited presentation, Conference on Extreme Value Theory and its Application, Gaithersburgh, Md., May 2-7, 1993.

7. A. J. Luévano, J. Zhang and M. A. Przystupa, "Accumulation of Microstructural Damage During Fatigue of High Strength Al Alloys", AeroMat'93, Anaheim, Ca., June 7-10, 1993.

PATENTS: None.

PARTICIPANTS:

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