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Finite Element and Experimental Analysis in Material Characterization of A356 in Low Cycle Fatigue Loading

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ABSTRACT

This study deals with simulation of low-cycle fatigue (LCF), followed by evaluation of fatigue parameters, which would be suitable for estimating fatigue lives under uniaxial loading. Cyclic elastic–plastic stress–strain responses were analyzed by using the incremental plasticity procedures. Finite element (FE) simulation inelastic–plastic regime was carried out in FE package ABAQUS. Emphasis has been laid on calibration of A356 Aluminum Alloy for LCF behavior. For experimental verifications, a series of low-cycle fatigue tests were conducted under strain-controlled, fully reversed condition in MTS 810 with MTS Flex Test GT controller at temperatures of 120 and 280 °C. The comparisons between numerical simulations and experimental observations reveal the matching to be satisfactory in engineering sense. Based on the cyclic elastic–plastic stress–strain response, both from experiments and simulation, loop areas, computed for various strain amplitude, have been identified as fatigue damage parameter. The surface microstructure of the specimens were examined and images showing the microstructure of certain dendritic structure with secondary dendrite arms (SDAS) of approximately 25 micrometers. The results of isothermal experiments at temperatures 280 and 120 °C and the fixed cycle reveal alloy hardening behavior of those cycles of 120 °C and cyclic softening behavior in 280 °C.

KEYWORDS:

Low Cycle Fatigue, A356 Aluminum Alloy, FE Analysis

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1- Introduction

Nowadays, aluminum alloys are significantly used in the automotive industry due to weight reduction and fuel saving. Microscopic structure of A356 aluminum alloy depends on α-phase primary and eutectic matrix of aluminum, magnesium and iron. One of the challenges observed in an aluminum cylinder head is fatigue. Takahashi et al. [1] investigated thermo-mechanical fatigue (TMF) in A356 alloy. Matos et al. [2] studied the properties of fatigue and micro-mechanism failure in AlSiMg0.6.

2- Methodology

In this study, behavior of aluminum alloy - silica (A356) that is used in cylinder head production, has been discussed. Specimens were produced using the casting method. In this method of casting according to ASTM B108-08 (2008), cylindrical shaped specimens were made with a diameter of 12.5 mm. In this study, to obtain the elastic modulus at different temperatures, the tensile test is implemented. MTS 810 servo-hydraulic machine connected to a micro-computer was used for LCF testing. The specimens temperatures were measured by an infrared pyrometer and fatigue tests were done under strain control, using an extensometer for high temperatures. Strain control fatigue testing according to ASTM E 606-04 at a temperature of 120 °C and strain amplitude of 0.3% and 0.5% and at a temperature of 280 °C and 0.3% total strain is done.

3- Simulation Results

Isothermal fatigue tests were simulated by finite element software ABAQUS with nonlinear kinematic- isotropic hardening model [2-4]. For this simulation, hardening and viscous parameters were applied at different temperatures [5]. After twenty cycles, the cycles get stable. In the following figures simulation and experimental results are shown.

Alloy shows cyclic hardening behavior at a temperature of 120 °C and cyclic softening behavior at 280 °C.

In following figures, stable hysteresis loops for different for different strain obtained from experiments and simulations in 120 °C and 280 °C have been compared.

In the first cycle in accordance with the hysteresis loop simulation and experimental results, it is seen that the initial simulation cycle is more accurate.

By comparing the stable cycle simulation and testing, it can be concluded that differences are acceptable in engineering.

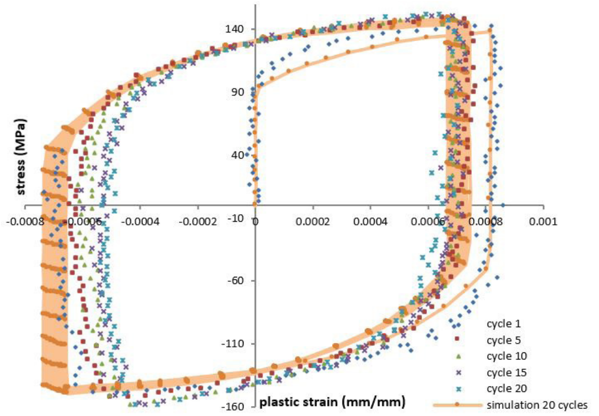

Figure 1. Comparison of twenty first cycle of isothermal experimental results with crosponding simulation result for a temperature of 120 °C and the amplitude strain 0.3%

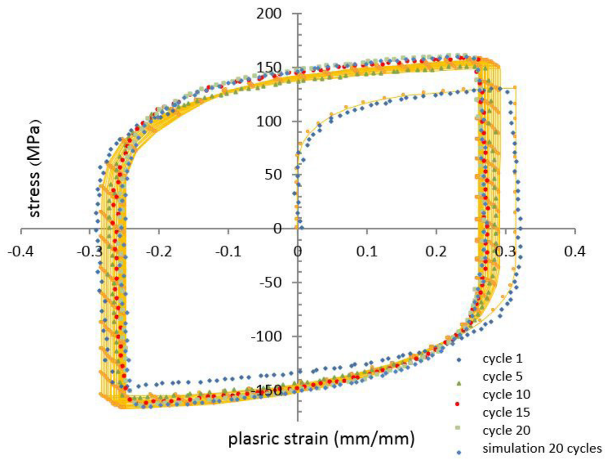

Figure 2. Comparison of twenty first cycle of isothermal experimental results with crosponding simulation result for a temperature of 120 °C and the amplitude strain 0.5%

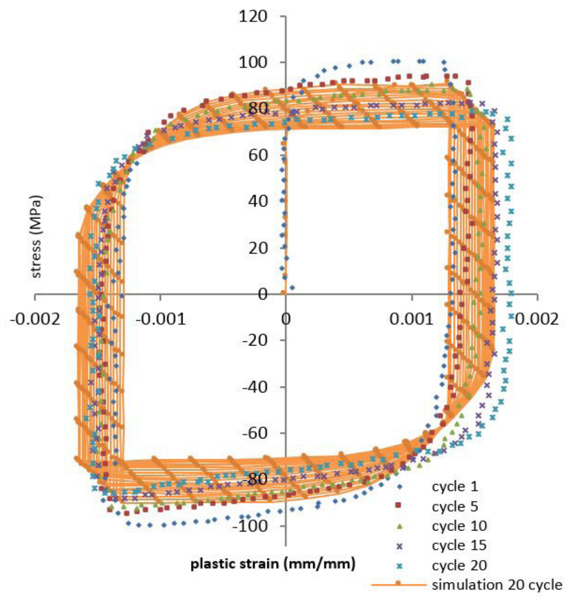

Figure 3. Comparison of twenty first cycle of isothermal experimental results with crosponding simulation result for a temperature of 280 °C and the amplitude strain 0.3%

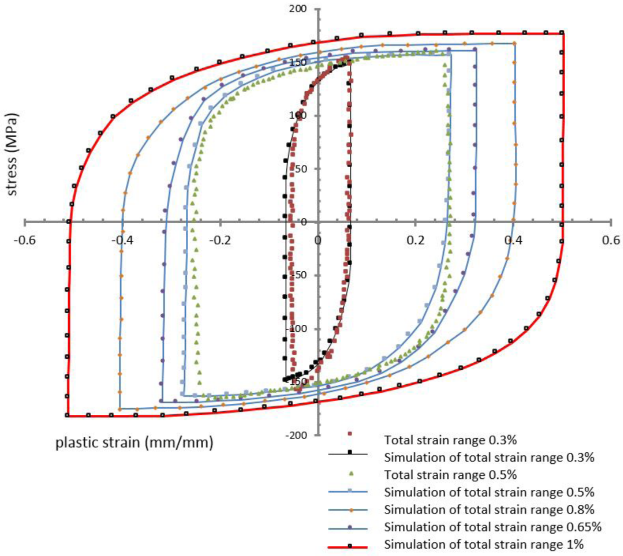

Figure 4. Comparison of stable hysteresis loop for a range of different strains obtained from experiments and simulations in a temperature of 120 °C

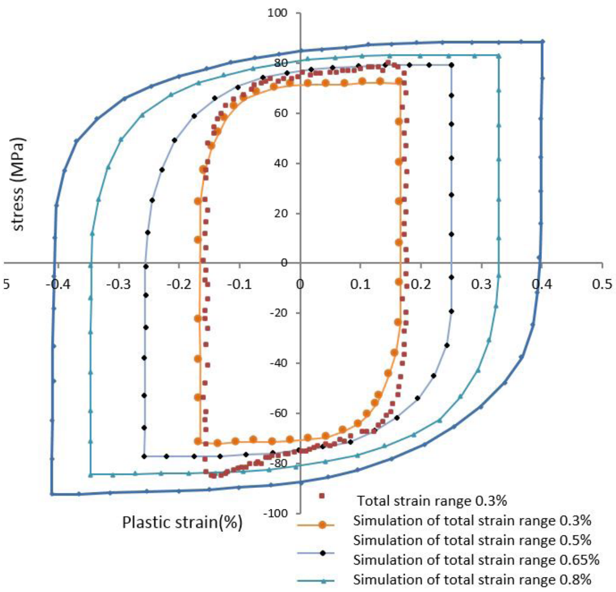

Figure 5. Comparison of stable hysteresis loop for a range of different strains obtained from experiments and simulations in a temperature of 280 °C

4- Conclusion

In this research, the cyclic behavior of A356 alloy used in an automobile cylinder head was determined based on isothermal fatigue test method. The results are as follows:

- Microstructural studies show dendritic structure with secondary dendritic arms, which are about 25 micrometers. In addition, a high degree of porosity (about 9.49 percent of area) can be observed.
- Results obtained from tensile tests show that the elastic modulus at 25°C is approximately 1.5 times of elastic modulus at 280°C. The ultimate stress at a 25°C is about 3.5 times of ultimate stress at 280 °C.
- The results obtained from isothermal fatigue tests show that samples life at 120° C (with constant strain amplitude) is almost ten times longer than its life at 280 °C. Life of specimens with 0.3 strain amplitude at 120°C is almost 2.5 times of the one at 0.5 strain amplitude.
- The results of isothermal fatigue test in a fixed cycle at 120°C and 280°C show that the alloy has cyclic hardening behavior at 120°C and cyclic softening behavior at 280°C.

5- Main References

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