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Three dimensional analysis of low cycle fatigue failure in engine part subjected to multi-axial variable amplitude thermo-mechanical load

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ABSTRACT

During the E5 engine durability test, the failure happens in cast iron cylinder head. This is characterized as low cycle fatigue. The macro-scale cracks initiate and propagate in valve bridge region. The present investigation focuses on simulating durability test and evaluating low cycle fatigue life of the failed part. The simulation includes one pre-step as a determination of material grid and three steps as fluid, structural and fatigue analyses. In order to cover the durability test, the analysis steps are repeated at five crack speeds, 750, 1650, 2075, 2350, and 2600 rpm. The cylinder head is subjected to cyclic multi-axial variable amplitude loads. In fatigue analysis, critical plane and cumulative damage theories are utilized in order to predict fatigue life. A general script is developed and validated so as to calculate fatigue life in the whole model. The numerical results also show that the failure of critical cylinder head can be characterized as low cycle fatigue. The valve bridge region, in which high temperature exists during engine operation, is the critical area in fatigue analysis approach. The simulation results are in a good agreement with the durability test observations.

1. Introduction

The increasing demands for higher specific engine powers lead to the need of focusing on some engine components so as to be designed more efficiently and hold a better and safer performance. Cylinder heads are such components which undergo repeated multi-axial thermo-mechanical loadings resulting in fatigue phenomena. Accordingly, the thermo-mechanical fatigue life prediction of cylinder heads is one of the most important issues for designers to enhance the quality, durability, and safety of the engines. This leads to many investigations about cylinder head structural and failure analyses via different approaches.

The microstructure studies of the fatigue failure of the cylinder heads were accomplished by some researchers. However, most of the studies done in this field would be accounted as an individual case study [1]. Beck et al. [2], for instance, investigated the micro structural thermo-mechanical fatigue behavior of cast aluminum alloys in cylinder heads. Xu and Yu [3] conducted a metallurgical examination in the crack origin zone in a diesel engine cylinder head made of gray cast iron. Mottas et al. [4] considered the fatigue properties and micro-mechanism fracture of a cast alloy used in diesel engine cylinder head. Tsuyoshi-Takahashi and

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Fig. 1. Engine durability test setup.

Sasaki [5] focused on the effects of the microstructure on the low cycle thermal fatigue of aluminum alloy cylinder head. Their investigation revealed how precipitates interact with dislocation, and the great effects of aging on microstructure in terms of strength and fatigue life.

The evaluations of fatigue criteria in order to gain more accurate predictions of failure were accomplished for different cylinder heads. Rahman et al. [6] assessed multi-axial fatigue criteria for the cylinder head of new two-stroke free piston linear engine using the finite element method. In order to determine the best model for the prediction of the fatigue failure of engine components made of aluminum alloy, Minichmayr et al. [7] conducted a comparative studies between different damage parameters, energy criteria and the complex damage rate model of Neu/Sehitoglu. Trampert et al. [8] evaluated the thermo-mechanical failure of the cast iron cylinder head using the principal strain and energy based fatigue criteria. Grieb et al. [9], employing a simple geometry, studied the thermo-mechanical fatigue failure of several cast aluminum alloys with respect to their thermal and mechanical properties using a continuous damage mechanics model. Augustins [10], based on the modification of one parameter of the Dang Van fatigue criterion, developed an empirical criterion with respect to the biaxiality rate and load ratio. Mendes and Cardoso [11], utilizing the high cycle fatigue criteria, presented a methodology for structural analysis and of a high-speed Diesel engine aluminum cylinder head. Shalev et al. [12] carried out an experimental and theoretical macrostructure study to consider the mechanism of crack development in cylinder heads of two stroke diesel engines. Their results revealed that the dominant process of cracking is low cycle thermal fatigue and residual tensile stresses which appear after engine shut off.

A survey through the works previously published in the field of cylinder head failure analysis shows that the thermo-mechanical fatigue behavior of aluminum cylinder heads has been considered much more than the response of cast iron ones in literatures.

In this paper, the low cycle failure of a cast iron cylinder head during the E5 standard durability test is studied. The low cycle fatigue life evaluation of the aforementioned cracked part and the durability test simulation are set to be the goals. Due to the complex multi-axial variable amplitude thermo-mechanical load subjected to the cylinder head, a general script is developed to

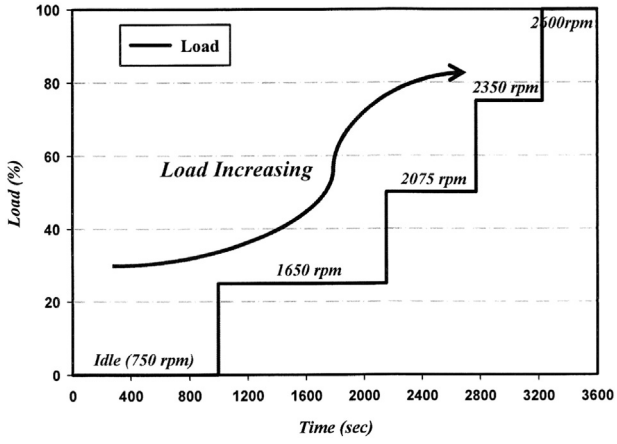

Fig. 2. E5 engine durability test cycle program.