

A Development of the Fretting Fatigue Analysis Techniques for Engine Aluminum Block

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ABSTRACT

Periodically, engine block-bearing cap structure is subject to the mixed bearing load from combustion and inertia mass of crank. Recently, due to the trend of lightness, cast steel is replaced with aluminum in the material of gasoline engine block. And, the load acting on the main bearing cap is rapidly rising due to the increase of engine power. Therefore, in the development stage, fretting fatigue failures frequently occurred on the block face contacted with the bearing cap. Fretting is a kind of wear which is occurred by micro relative movement. Even though various researches have been made to investigate fretting fatigue failure with FEA approaches, they are not enough to evaluate the phenomenon. In this study, the new CAE method simulating the fretting fatigue failure on the engine block face is developed and the mechanism of the fretting fatigue on the engine block is investigated. As the results, the FS parameter showed a good correlation with the fretting fatigue crack position and a good agreement between numerical and experimental results.

INTRODUCTION

Engine block-bearing cap structure is subject to the mixed bearing load from combustion stroke and inertia mass of crank. Recently, due to the trend of engine lightness, cast steel is replaced with aluminum for the material of gasoline engine block. And, the bearing load acting on the main bearing cap is rapidly rising due to the increase of engine power. Therefore, in the development stage, fretting fatigue failures are frequently occurred on the block face contacted with the bearing cap.

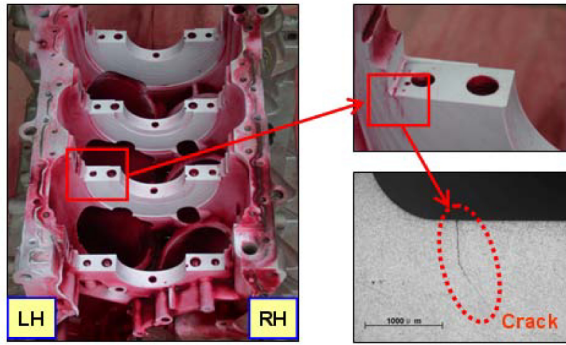
Fretting wear and fretting fatigue occur at the contact interface between two bodies when there is small amplitude oscillatory relative movement. An unfavorable combination of high clamping forces from bolt assembly and oscillating dynamic forces from bearing load may lead to a severe shear traction development in the contact interface between block and bearing cap, which increases the fretting fatigue risk.

A lot of work and interest has been devoted to the development of multi-axial fatigue parameters for fretting fatigue prediction.^{(1),(2),(3),(4)} Many of these parameters have been reviewed in the literature for simple geometries like a cylinder-on-flat contact configuration. While these simplified geometries provide a platform for investigating the effectiveness and accuracy of various fatigue parameters, there is scarcely any study on the application of the parameters to the mechanical assembly components. One such study is by Das and Sivakumar for notched shaft specimens under plain fatigue conditions.⁽⁵⁾ Even so, application to more complex components under contact conditions has yet to be done. Predicting the fretting fatigue crack of aluminum engine block is difficult due to the cyclic multi-axial stress states they experience, the geometrical complexity and the frictional contact between engine block and bearing cap.

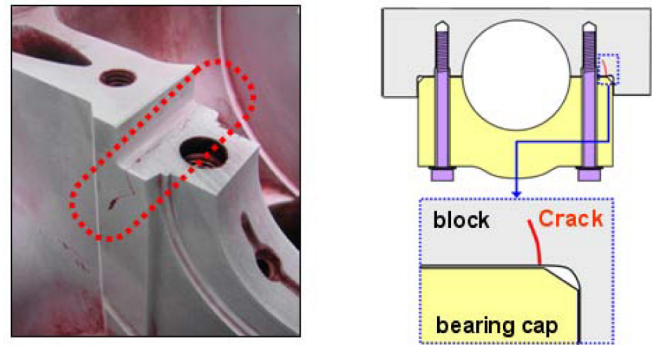
The present work therefore addresses the development of a validated fretting fatigue prediction approach for engine block using CAE. In this study, through the applications of the new CAE method for simulating the dynamic behavior of the engine block system and the multi-axial fatigue parameter, the evaluation method for the fretting fatigue in the contact interface between block and bearing cap is

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(a) V6 type engine



(b) Inline 4 engine

Figure 1. Fatigue failures of the gasoline engine block

developed. The analysis results using the Smith-Watson-Topper(SWT) and the Fatemi-Socie(FS) multi-axial fatigue parameter are compared. The FS parameter showed a good correlation with the fretting fatigue crack position for engine block fretting phenomenon and a good agreement between numerical and experimental results. Using the FS parameter, the main mechanism of the fretting fatigue failure on the engine block is investigated. And, varying the engine run condition and design parameters, the effectiveness of fretting fatigue durability is revealed.

FRETTING FATIGUE

FATIGUE FAILURE ON THE BLOCK

Fig.1 shows the failure phenomenon of V6 and Inline 4 type gasoline engine block. As the result of the cause analysis of V6 engine block damage, the micro crack is occurred on the block face contacted with the bearing cap end edge at the #2 bulkhead. The material imperfection is not detected, but the trace of the fatigue failure is discovered. And, as the result of the analysis of Inline 4 engine, the crack is occurred at the #3 bulkhead and the crack position is coincided with V6 engine, on the block face contacted with the bearing cap end edge.

These failures are occurred at the aluminum block of the gasoline engine and frequently occurred at the engine demanding the higher performance. Also, as depicted in Fig. 1, the failures are characterized by occurring on the block face contacted with the bearing cap.

FRETTING FATIGUE PARAMETER

Fretting is a kind of wear which is occurred by micro relative movement. Fretting fatigue has some features. Among these, the first is that the contact face is under clamping or compressive force. The second is that there is micro relative slip movement between the two components. Finally, there is a distinction of material strength. Fretting fatigue crack is occurred at the weak material. These features are coincided with the features of engine block. The bearing cap is

assembled with the block by the bearing cap bolt. Namely, by the clamping force, block face is under the compressive force. Next, the bearing load occurring from the rotating inertia of crankshaft and firing pressure generates the relative slip movement between the block and bearing cap. Finally, the material of the bearing cap is steel and that of the block is aluminum. There is a distinction of material strength. From these common features, the fatigue failures of the engine block face are confirmed as the fretting fatigue crack.

Fig.2 shows safety factor(S.F) distribution calculated from the existing FE evaluation method for the fretting damaged engine block. Safety factor based on Von-Mises effective stress is the ratio of stress amplitude and material endurance strength. This result shows that the weakest point(B) is on the corner of the block and the real fretting fatigue crack position(A) is safe. In conclusion, the existing CAE method for engine block incorrectly specifies the crack position so a new analysis method is needed.

In the fretting-related studies and literatures, Fatemi and Socie(F.S) have proposed the use of one of two multi-axial fatigue damage criteria, one for shear cracking failure modes and one for tensile cracking failure modes. For shear cracking failures modes, the parameter should include shear strain amplitude for crack initiation, and maximum normal stress on the plane of maximum shear strain amplitude for crack propagation. For tensile cracking, the parameter should include maximum principal strain amplitude for initiation, and maximum normal stress on the plane of maximum principal strain amplitude for propagation. The SWT parameter has been shown to give good correlation with multi-axial in phase and out of phase fatigue lives for combined cyclic axial and torsional loading displaying tensile cracking. These two parameters have already been used by a number of authors in conjunction with the critical plane method to predict fretting fatigue life. FS and SWT equation for fretting fatigue evaluation are follows.

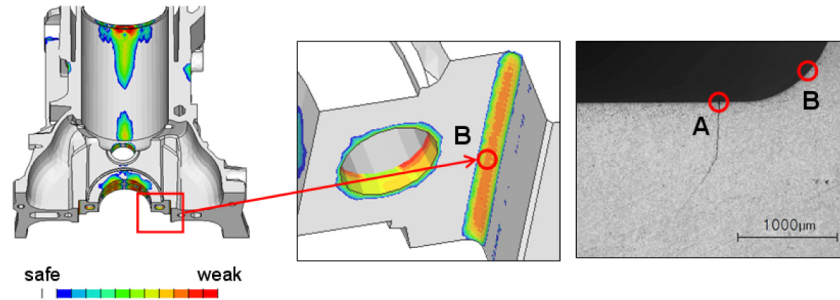


Figure 2. Safety Factor(S.F) distribution for fretting damaged engine block

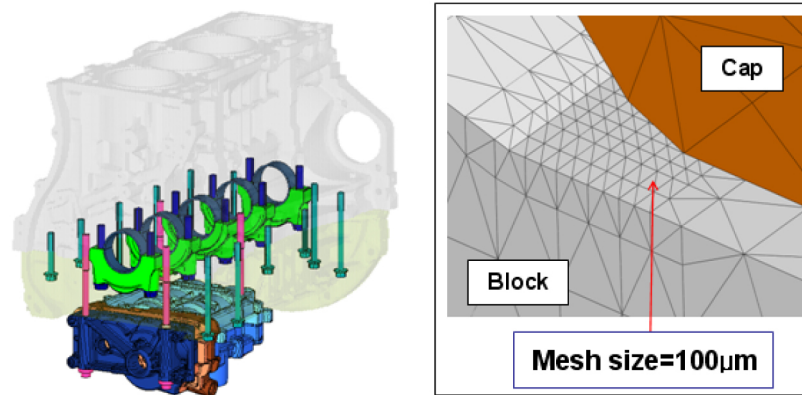


Figure 3. FE model and detailed element on the crack position

$$SWT = \sigma_{n,max} \varepsilon_a \quad (1)$$

$$FS = \gamma_a \left(1 + k \frac{\sigma_{n,max}}{S_y} \right) \quad (2)$$

Where $\sigma_{n,max}$ are the maximum normal stress on the maximum critical plane and ε_a and γ_a are normal strain amplitude and shear strain amplitude on the maximum critical plane, S_y and k are the yield strength and material coefficient. The k value is specified as 1.

By the fatigue crack mechanism of engine block failure mode, the analysis results of the two parameters will be different. And, by comparing between numerical and experimental results, a suitable parameter for engine block fretting evaluation will be adopted.

FE MODEL CONSTRUCTION AND ANALYSIS PROCEDURE

Fig.3 shows a finite element full model and a detailed element on the block face contacted with bearing cap end edge for the fretting evaluation of the damaged engine, Fig.

1(b). The model is composed of a full model of the engine block system, including cap bolt, bearing cap, balance shaft module(BSM), ladder frame. The 10 node tetrahedron elements were used to mesh the full model. The total number of elements of full model is 403,452. Contact conditions were adopted between block and bearing cap, block and ladder frame, ladder frame and BSM, bolt and block with interface elements. For exactly simulating contact pressure on the block face and slip movement between block and bearing cap, element size on the block face is about 100um. The friction coefficient is 0.2. Table.1 shows the material properties and material strength of the aluminum alloy for the engine block. Through the cranktrain dynamic analysis, bearing load and BSM bearing load are calculated. These cyclic loads are applied to the engine block durability analysis for fretting evaluation.

Table 1. Material properties and strength for the engine block

Block (aluminum alloy)	Material property	Young's modulus	Poisson's ratio	Thermal expansion coeff.
	Material strength	70GPa	0.32	20.5e-6
		Tensile strength	Yield strength	Endurance(fatigue) strength
		320MPa	160MPa	140MPa

Table.2 shows the procedure of the cyclic engine durability analysis. At the first step, bearing shell's crushing and side-fitting between block and bearing cap must be simulated. At the second step, the block system model is assembled by bolt