

Fretting Analysis of an Engine Bearing Cap Using Computer Simulation

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ABSTRACT

The independent bearing cap is a cylinder block bearing structure that has high mass reduction effects. In general, this structure has low fastening stiffness compared to the rudder block structure. Furthermore, when using combination of different materials small sliding occurs at the mating surface, and fretting fatigue sometimes occurs at lower area than the material strength limit. Fretting fatigue was previously predicted using CAE, but there were issues with establishing a correlation with the actual engine under complex conditions, and the judgment criteria were not clear, so accurate prediction was a challenge. This paper reports on a new CAE-based prediction method to predict the fretting damage occurring on the bearing cap mating surface in an aluminum material cylinder block. First of all, condition a fretting fatigue test was performed with test pieces, and identification of CAE was performed for the strain and sliding amount. In addition, the fatigue life results obtained by the test-piece test were used to construct a fretting fatigue limit line for the strain and sliding amount of the CAE results. Next, identification was performed with an excitation rig test that simulates an actual engine operating condition, and the CAE boundary conditions were determined. The strength predicted by CAE and the fretting result by the excitation rig test were correlated well. It showed the validity of the newly constructed CAE method. Finally, fretting damage under the actual engine durability test was also predicted, and the results were confirmed to also exhibit good correlation.

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INTRODUCTION

Demand for lightweight vehicle components to enhance fuel efficiency is growing due to increased environmental awareness worldwide. One of the candidate portions of engine weight reduction is crankshaft support structure of cylinder block. As a lightweight and simple structure, there is bearing cap structure which supports each bearing independently. [1,2] However, the fastening stiffness of this structure is low compared to the rudder block structure and subject to small sliding movement at the mating surface, causing fractures due to fretting fatigue during engine development processes.

Fretting fatigue fracture occur when residual wear particles causes a fatigue crack that extends inward on the mating surface between components. Such fractures are frequently generated when materials of different rigidities such as aluminum cylinder blocks and cast-iron bearing caps are used. [3]

It has been challenging and taken a long time to address the fretting fatigue fracture issue during the engine development processes. This is partly because fretting fatigue fractures have only been evaluated through durability tests using actual engines. Therefore, the present

study performed excitation rig test and computer aided engineering (CAE) simulation instead of actual durability tests. [4] CAE predictions are important when studying component shapes in early stages of design. This paper introduces a prediction method for fretting fatigue fractures using CAE.

Factor analysis results have shown that stress (strain) and slip amplitude are two main factors of fretting fatigue fractures. Considering these two factors, material strength was measured in a material excitation test using test pieces, and the validity of the prediction method was verified using an excitation rig test capable of reproducing engine operating conditions.

In addition, the effects of mating surface properties were investigated using a calculation model.

MATERIAL STRENGTH

Test Method of Material Strength

A material fatigue test was conducted according to the fretting fatigue test method of the standards formulated by the Japan Society for

Mechanical Engineers (JSME) [3] (Figure 1). Fretting conditions were reproduced by pushing the contact pad (FC250) to the fretting fatigue test piece (ADC12). Note that the fretting fatigue test piece was cut from actual cylinder block bearing and then machined. The slip amplitude between the fretting fatigue test piece and the contact pad was directly measured using a high temperature clip gauge. Table 1 lists the test conditions. The number of excitation cycles until the test piece broke was used for evaluation. The highest excitation cycles were set to be 10^7 .

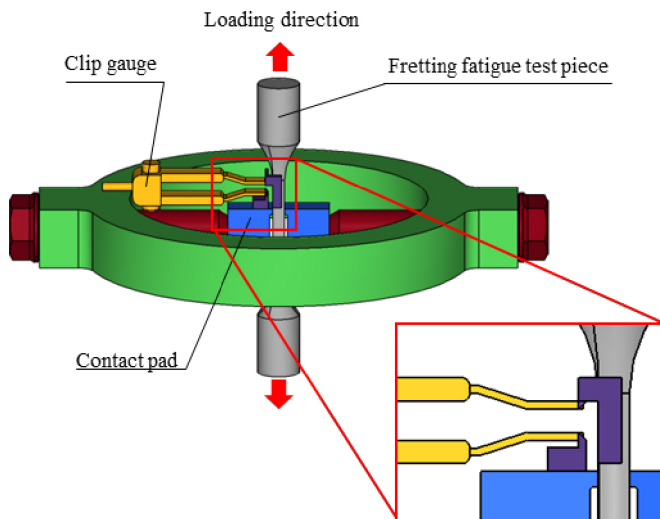


Figure 1. Fretting fatigue test schematic diagram

Table 1. Material strength test condition

Testing machine	SERVO PALSER
Testing temperature, atmosphere	150 degC, Air
Testing speed	15 Hz
Excitation Load	1, 1.5, 2.0 kN
Pushing pressure	50, 100, 150 MPa
Number of cycles	$\sim 10^7$

Calculation Method of Material Strength

Calculation Model of Material Strength Test

A calculation model for simulating the material fatigue test was created. The fretting fatigue test piece and contact pad were modeled using the finite element method (FEM), and pushing pressure were added to the contact pad as in the fatigue test before static loads were applied to the modeled fretting fatigue test piece. Abaqus [5], commercial software, was used for calculations. The calculation model shown in Figure 2 is a 1/4 section model, and symmetric constraints were added to each section. The friction coefficient of each contact surface was 0.19. This value was determined considering the correlation with this material fretting fatigue test and the excitation rig test which is discussed later. The element size of the evaluation portion was 0.1 mm.

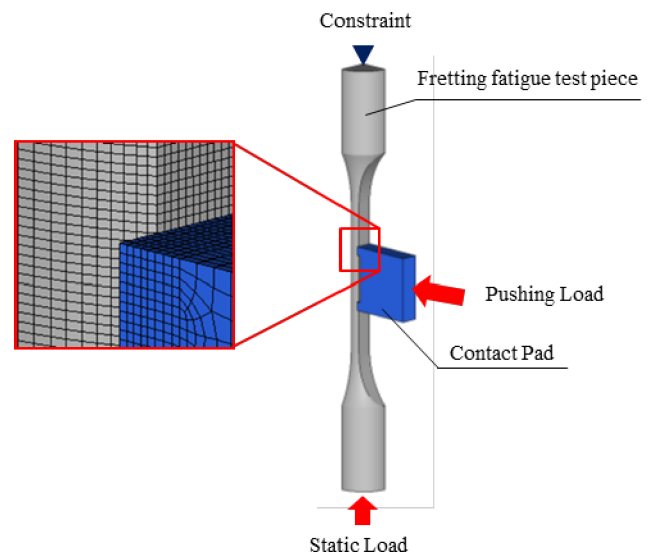


Figure 2. Calculation model of material fatigue test

Comparison of Measurement and Calculation Results in Material Strength Test

The strain amplitude was measured by a strain gauge attached near the fracture portion, whereas the slip amplitude was compared with the amount of slip obtained by a clip gauge. Figure 3 shows the positions of strain measurement. The measurement direction for the strain was parallel to the mating surface. Figures 4 and 5 show comparison results for strain amplitude and slip amplitude, respectively, with different pushing pressure and excitation loads. A good correlation in terms of absolute values can be observed in the comparison of strain between the test and calculation values for the same evaluation position. On the other hand, a near two-fold difference in terms of absolute values is generated when comparing slip amplitude. This is a result of the difference in positions: the values for the test were obtained through measurements using a clip gauge, while the calculation values were based on the slippage on the contact surface. The test values are greater because they include the elastic deformation of the fretting fatigue test piece, contact pad, and measurement devices. The two kinds of values showed good tendency correlation and the calculation model was judged to be valid.

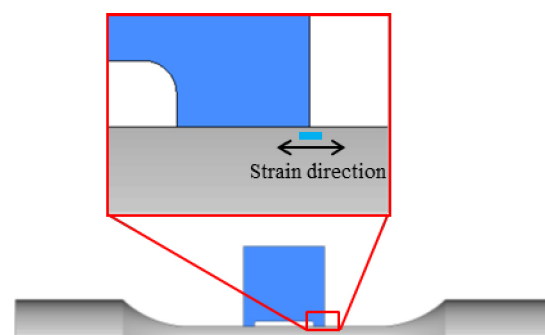


Figure 3. position of strain measurement

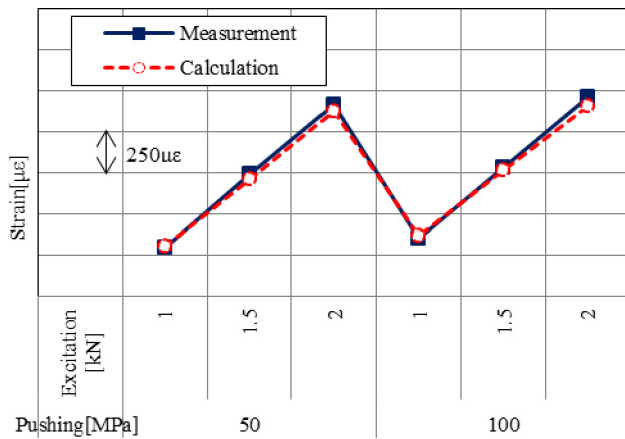


Figure 4. Measurement and calculation result of strain amplitude

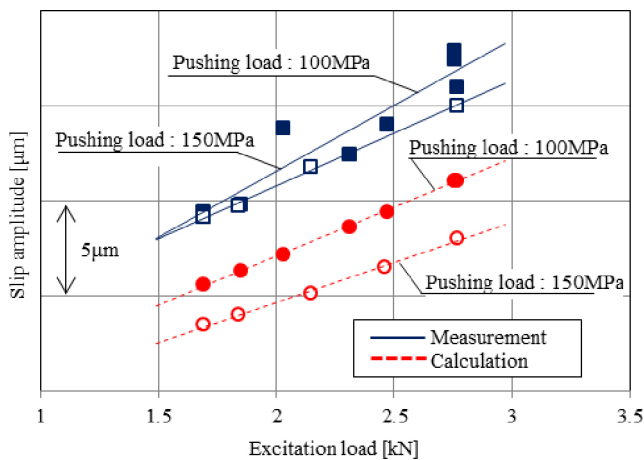


Figure 5. Measurement and calculation result of slip amplitude

Fretting Fracture in Material Strength Test

Figure 6 presents a photograph of fracture in the material fretting fatigue test. Fretting damage was generated on the mating surface with the contact pad and the fretting fatigue test piece broken at the outer mating surface. Figure 7 shows contour charts for stress amplitude and slip amplitude obtained by calculation under loading conditions for the fracture in the test. The maximum stress amplitude position coincides with the maximum slip amplitude position and with the fracture position in the test.

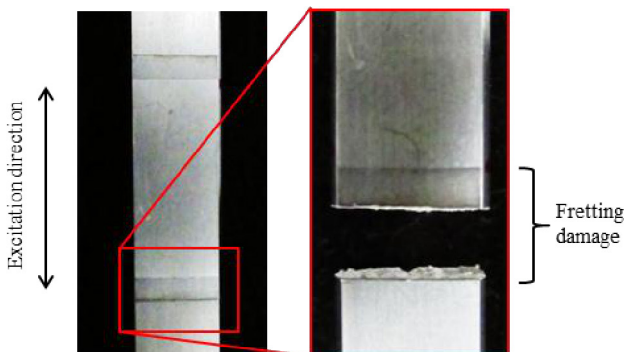


Figure 6. Fretting fatigue by material strength test

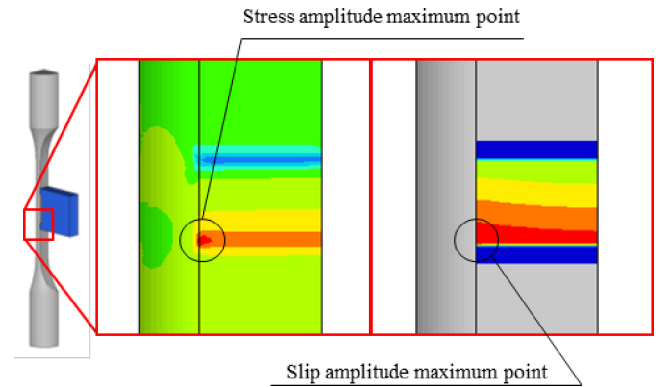


Figure 7. Calculation result of stress amplitude and slip amplitude

Fretting Fatigue Limit Line

A fretting fatigue limit line for calculations was drawn using the valid calculation model. The creation method of the limit line was the same as those in the material fatigue test, while stress amplitude and slip amplitude on the mating surface was directly evaluated in the CAE calculations for the limit line. Note that, the stress amplitude near the mating surface and the slip amplitude by clip gauge are used for the limit line of testing.

A test was carried out by applying different pushing pressure and excitation loads using some contact pads of different widths to obtain different slip amplitudes. Calculations were performed under the same conditions, and then stress amplitude and slip amplitude determined in the calculations as well as cycles up to the fracture in the test were used to draw the limit line. Figure 8 shows the limit line at 1×10^7 with a fracture probability of 10%. The graph shows fatigue strength decreases with increasing slip amplitude, indicating a correlation between stress amplitude and slip amplitude. It should be noted that the limit line obtained by calculation has higher values than those of the limit line determined by the test because the former used the maximum value of the contact surface. By using this limit line for calculation, the values of the mating surfaces can directly be evaluated in calculation.

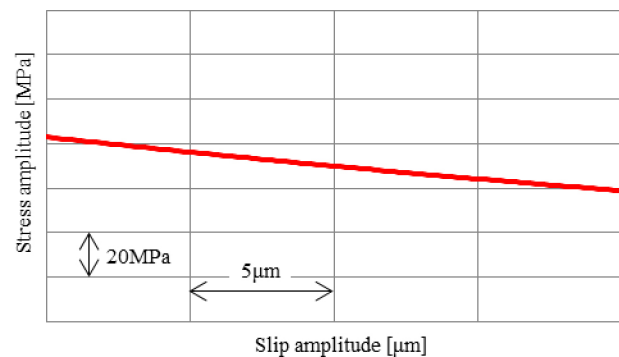


Figure 8. Fretting limit line for calculation