

Strength Analysis of a Cylinder Head Gasket Using Computer Simulation

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ABSTRACT

The properties sought in a multi-layer steel cylinder head gasket include cylinder pressure sealing and fatigue strength in order for there to be no damage while the engine is in operation. Diesel engines, in particular, have high cylinder pressure and a high axial tension by the cylinder head bolt demanding severe environment to the gaskets. As engine performance is enhanced, there are cases when cracks develop in the gasket plate, necessitating countermeasures. The cause of cracking in a flat center plate, in particular, has not yet been explained, and no method for evaluation had previously existed. Three-dimensional non-linear finite element calculation was therefore performed to verify the cause. First, a static pressurization rig test was used and the amount of strain was measured to confirm the validity of the calculations. Then the same method of calculation was used to verify the distribution of strain, with a focus on the plate position. This showed that strain occurred in the direction of cracking depending on the relative positions of the plates. Estimates were then calculated using a model equivalent to an actual engine endurance test. These yielded high strain, indicating that the cause of cracking was a gap of plate position. The method of calculation created here showed that when the center plate thickness was varied, increasing that thickness was effective in reducing strain. Optimization of the

center plate thickness made it possible to complete endurance testing of an actual engine without cracking.

INTRODUCTION

Recent years have brought increasing demands on environmental technology. In this context, the reduction in emissions of carbon dioxide (CO₂), considered a causal factor in global warming, is performed effectively in diesel engines, with their superior fuel economy performance, and there is growing need for them in Europe in particular. One characteristic of diesel engines is their high cylinder pressure, which means that high sealing performance in the combustion chamber is required.

The multi-layer steel cylinder head gasket (hereafter, head gasket) is used to seal in cylinder pressure, and it is tightened in place by the axial tension of the cylinder head bolt in between the cylinder head and cylinder block. The head gasket used here is made up of two bead plates and one center plate, and the gasket is structured to seal in the cylinder pressure by the reaction force of the bead. The center plate structure is made up of two thin plates of differing thickness joined together by laser welding, and this specification provide higher combustion chamber sealing performance.

In enhancing engine performance, there are cases when cracks occur in gasket plates, thereby necessitating countermeasures. The cracks occur almost entirely in the bead plate, and this is thought to be because of the repeated occurrence of stress from cylinder head lift due to cylinder pressure during engine operation, and because of micro cracks resulting from the processing stress applied to the thin sheet when it is stamped and formed. High-strength materials have therefore been developed for use in the bead plate, and methods have been devised to evaluate them using rig tests, so that the performance of the gaskets can be confirmed before endurance testing of the actual engine.

The present issue is cracking in the center plate that does not normally occur. In the case of the center plate, the structure is flat and there are no bent points. Consequently, no strain occurs in the plate by itself, and it was assumed that strain does occur from interconnection with bead plates above and below it. However, a strain gauge could not be attached to the center plate sandwiched between the bead plates above and below it, therefore it was difficult to measure the deformation and strain distribution of the center plate. Therefore, a three-dimensional non-linear finite element method of calculation was used to ascertain the deformation and strain distribution and to clarify the causal factors. The calculation technique established here was also used to optimize the countermeasures and determine head gasket specifications of the actual engine.

CALCULATION PROCEDURE AND VERIFICATION OF VALIDITY

CALCULATION PROCEDURE

Figure 1 shows the calculation model that simulated the static pressurization rig test. A symmetrical boundary condition was defined, and a portion of it was modeled. In order to attach a strain gauge in the measurement, guard plates were located above and below the center plate. The guard plates have slits in them and the strain gauge is situated so that it does not come into direct contact with the bead plates that are above and below. When the measurement and calculation were compared, guard plates were also added to the calculation model.

The detailed bead shapes were measured. The calculation model also represents a detailed shape that also takes into account warping during processing. The elements in the thickness direction of the thin sheet are divided into at least three, and parabolic elements about 0.1 mm length were used for the element size in the evaluation portion. Elements of various different sizes were used to test the influence this would have, but it was determined that the above size was necessary in

order to express the bending of the thin sheet and to evaluate the maximum value of localized strain.

A non-linear finite element method was used to define the contact between plates and between plate and jig, and friction was defined in the sliding direction. The definition of the material also takes plastic properties into consideration.

In the boundary condition, the bottom surface in the lower jig is entirely restrained. Load is applied in the upper jig by pressure.

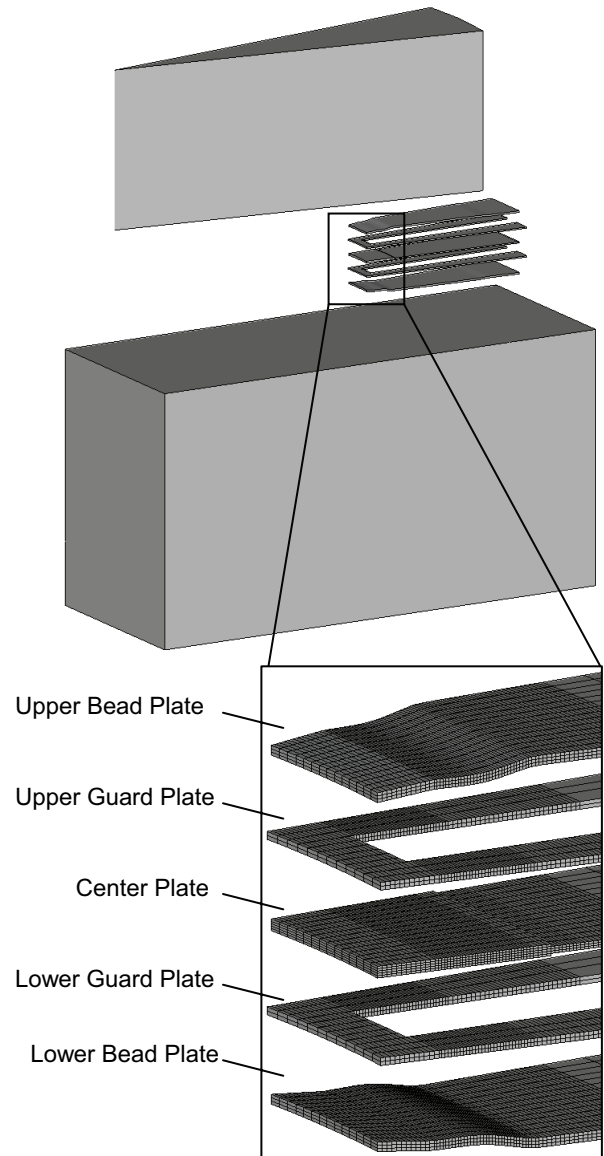


Fig.1 Calculation model

MEASUREMENT PROCEDURE

Strain was measured using a static pressure tester. The strain measurement position was chosen to be the

position where cracking occurs, and was situated 2 mm from the edge of the center plate. Figure 2 shows the state of a crack in an actual engine. In the actual engine, the crack is mainly generated in an about 2mm position from the center plate edge by the side of an air intake valve or an exhaust valve. The direction of a crack is the direction of a cylinder bore circumference, and the crack length of the direction of a circumference is about 7mm. Many cracks have penetrated the plate.

In order to obtain accurate measurements of local strain in a thin plate, a strain gauge with gauge length of 0.2 mm was used.

Measurement was performed by shifting the position of an upper plate. Taking the assembly tolerance of the each head gasket plate into account, a 0.3 mm gap was aimed for. Figure 3 shows the state of the model with the 0.3 mm gap by shifting upper plate.

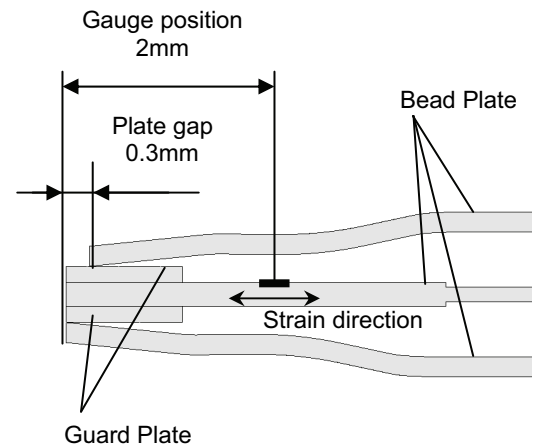


Fig.3 Gap model and strain gauge position

COMPARISON OF MEASUREMENT RESULTS AND CALCULATION RESULTS

Figure 4 shows the measurement and calculation results. Measurement was conducted twice, and the average values were taken as the results. The estimated strain at the center plate was measured from the left side of Fig. 3, and the direction of the strain is taken to be the direction of the gauge. The calculations show valid results for the absolute strain value and location. This demonstrates the accuracy of this calculation procedure.

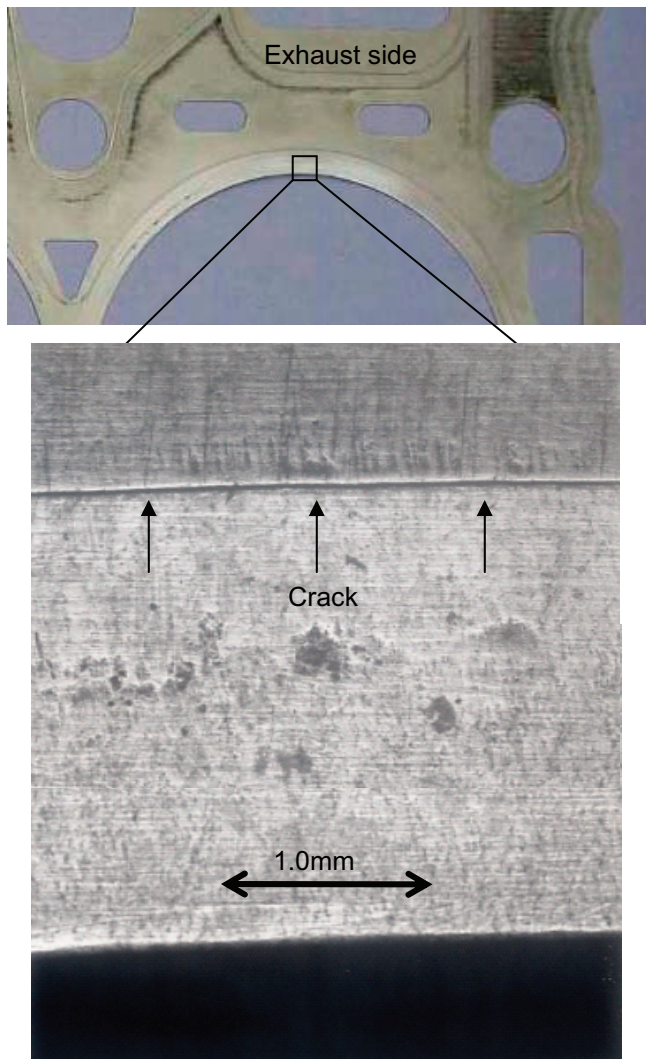


Fig.2 State of a crack

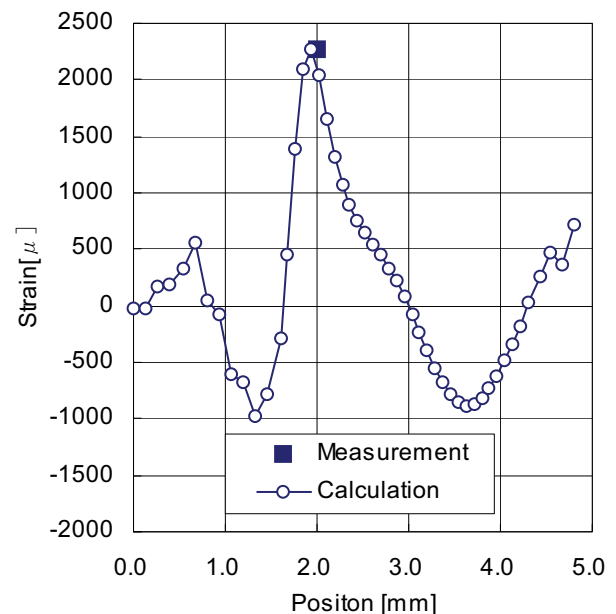


Fig.4 Measurement and calculation results