NUMERICAL STUDY ON REDUCING METHODS OF STATIC STRAIN ALONG THE FILLET ON UPPER DECK OF DIESEL ENGINE CYLINDER BLOCK

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ABSTRACT

Large static strain appears on the fillet on upper deck of diesel engine cylinder block by tightening force of cylinder head bolts. Reducing static strain is necessary to avoid the crack initiation on the fillet. The static strain along the fillet can be reduced, for example, by modifying the depth of thread engagement, and modifying the bead shape and position into the bore grommet of cylinder head gasket. In the present study, the depth of thread engagement was optimized considering four conditions, the overall magnitude of strain, the circumferential fluctuation of strain, the change rate of strain against the depth of thread engagement, and the length of cylinder head bolt. The bead shape or position was optimized considering two conditions, the overall magnitude of strain, and the distribution of contact pressure on the contact area with the cylinder block and the cylinder liner. The analysis results of the circumferential distribution of static strain were agreed with the measurement results. The optimum depth of thread engagement of cylinder head bolt and the optimum type of the cylinder head gasket were evaluated using FEM.

KEYWORDS
Stress Concentration, Diesel Engine, Finite Element Method, Optimum Design, Cylinder Block, Fixing.

1. INTRODUCTION

In recent years, diesel engines which have features such as high thermal efficiency and low emission are attracting much attention against global warming[1]. Whereas, the high performance, high power, low power weight ratio and long-term durability have been requested to diesel engines.

One of effective ways to obtain the high power for diesel engines is to increase the combustion pressure in the cylinder. With the increase of the combustion pressure, higher tightening force of the cylinder head bolts is necessary to prevent the leakage of combustion gas from the cylinder. However, the high tightening force of the cylinder head bolts causes the cracking on the fillet of an upper deck of the cylinder block[2].

In order to secure the reliability of the cylinder block of diesel engines, several analytical studies have been performed on the deformation of whole cylinder block and the stress around the main bearing casings of the cylinder block[3]~[5]. However, the evaluation of the stress and strain around the fillet on upper deck of the cylinder block has scarcely been reported.

Based on this background, the authors have been studying the method for prediction of the critical position of crack initiation to optimize the main parts of internal combustion engine. In the present study, the effect of depth of the thread engagement and the effect of the bead position of the cylinder head gasket for reducing the static strain of the fillet on the upper deck of the cylinder block were examined for the water-cooled diesel engines.

2. CRACKING ON THE FILLET OF THE UPPER DECK OF THE CYLINDER BLOCK

The cylinder block is one of main bodies of the diesel engine. The fillet is machined to the upper deck of the cylinder block to prevent interference between the cylinder block and the cylinder liner. The tightening force of the cylinder head bolts is transmitted to the cylinder block through the cylinder head, the cylinder head gasket, and the upper part of the cylinder liner. Therefore, the stress concentrates especially on the fillet of upper deck of the cylinder block.

An example of the crack on the fillet on upper deck of the cylinder block is shown in Fig.1. Early crack initiation is expected in higher performance engine with higher tightening force.

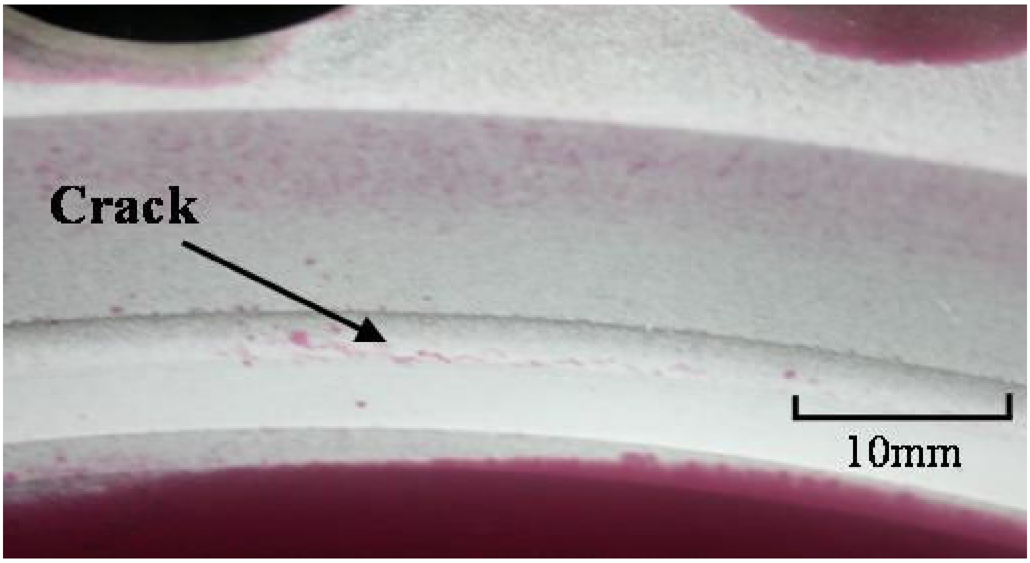


Fig.1 An example of crack on the fillet of the cylinder block.

3. ANALYSIS METHODS

3.1 STATIC BALANCE OF FORCES ACTING ON THE CYLINDER BLOCK

The static balance of the force acting on the cylinder block by the tightening cylinder head bolts is shown in Fig.2. Upward force F_{HB} (HB means the cylinder head bolt) acting on thread engagement position of the cylinder head bolts is transmitted to the cylinder block through the cylinder head, the cylinder head gasket, and the cylinder liner. This force is equal to the force F_F (F means the fillet on upper deck of the cylinder block) to push the upper deck of the cylinder block downward, thus;

$$F_{HB} = F_F \quad (1).$$

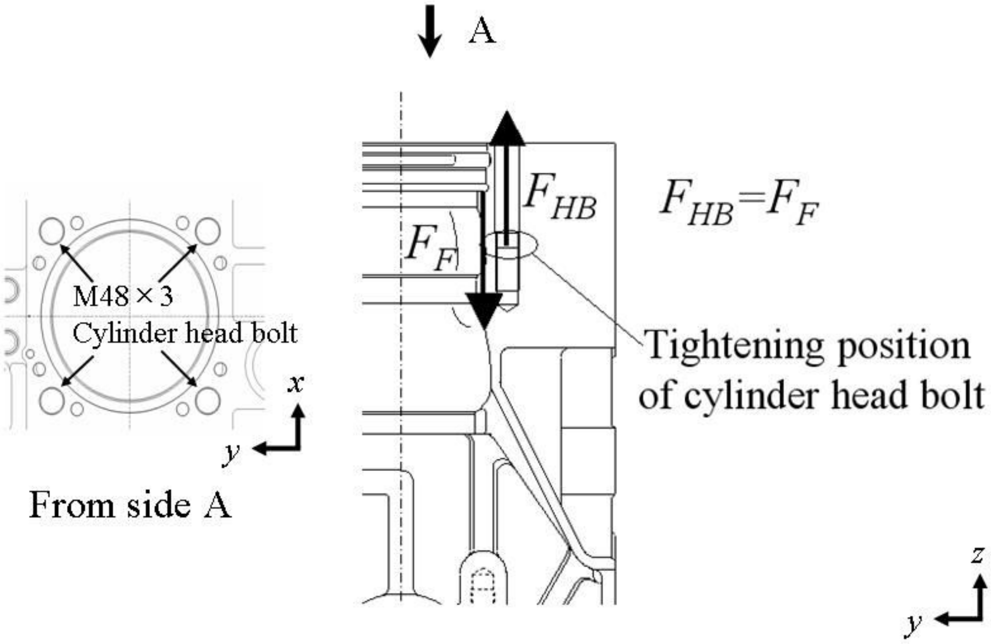


Fig.2 Balance of static force in the cylinder block.

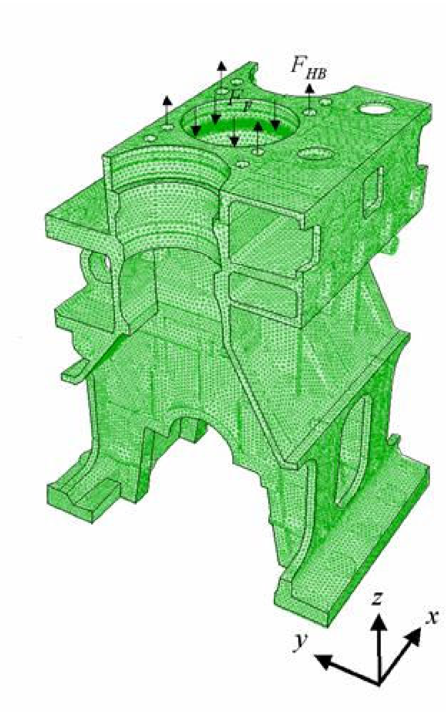
3.2 ANALYSIS MODEL

Table 1 shows the specification of the diesel engines employed for the analyses in the present study. Because the model 6EY26 was designed to be able to change the depth of thread engagement, it was used for evaluating the optimum depth of thread engagement. And, because the cylinder head gasket was adopted in the model 6CX, it was used for investigating the effect of the bead position of cylinder head gasket on the static strain along the fillet of the cylinder block and surface pressure on the contact area of the upper part of the cylinder block and the cylinder liner.

Table 1 Specification of diesel engine analyzed.

Engine model	6EY26	6CX
Bore diameter (mm)	260	110
Stroke (mm)	385	130
Radius of fillet (mm)	8.0	0.2
Type of cylinder liner	Wet	Dry
Type of seal for combustion	Cylinder head packing	Cylinder head gasket
Method of tightening by cylinder head bolts	Hydraulic	Torque
Type of analysis model	3D-Solid	Axisymmetric

Fig.3 show the analysis models. A 3D solid model was used for the analysis of 6EY26 which is a wet-liner structure. Meanwhile, an axisymmetric model was used for the analysis of 6CX. Because 6CX is a dry-liner structure with the sleeve-guide that was the axisymmetric structure.



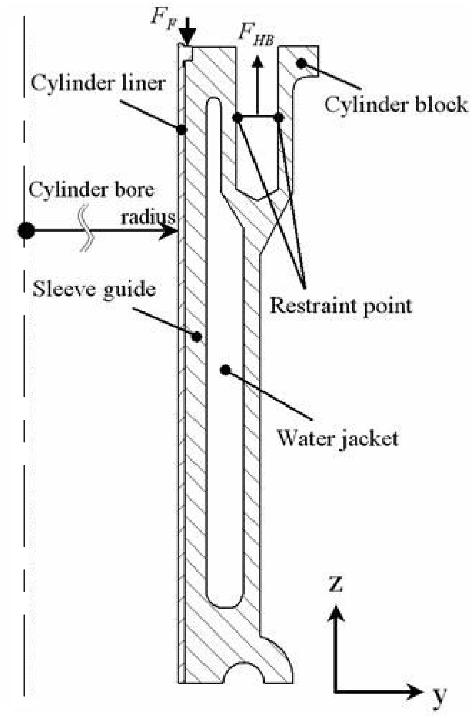


Fig.3 Analysis models.

The cylinder block was made of gray cast iron FC300 (JIS G5501). The stress-strain relation for analyses is shown in Fig. 4. The Young's modulus was E=98.1GPa and the Poisson's ratio was ν=0.26.

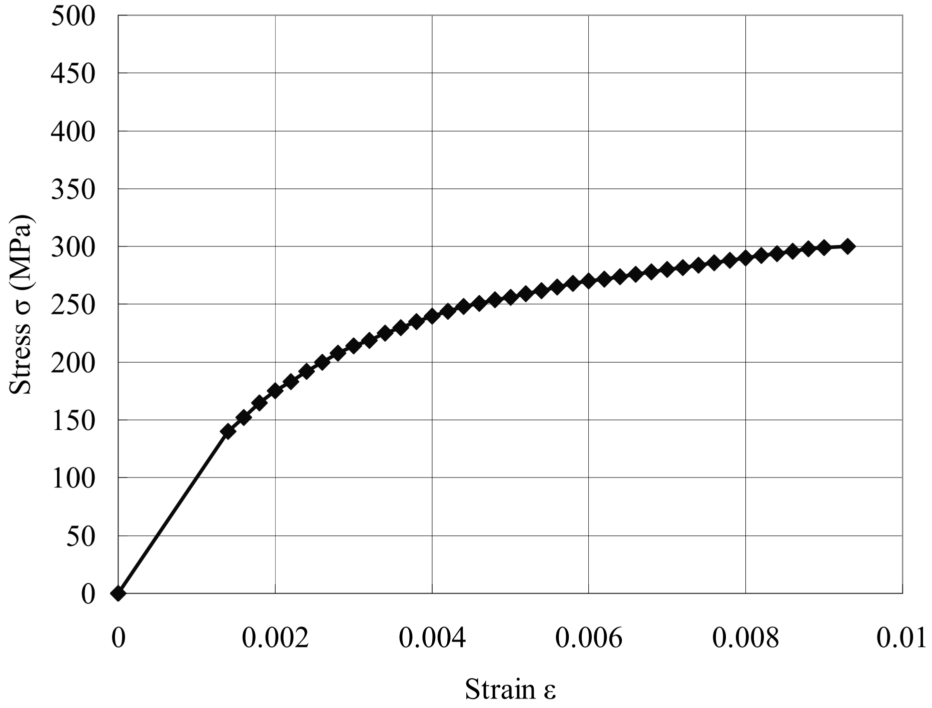


Fig.4 Stress-strain relation of cast iron for elastic-plastic finite element analyses.

In the 3D-Solid model, the average surface pressure calculated by the tightening force of the cylinder head bolts was applied to the contact area of the upper deck of the cylinder block. In the axisymmetric model, the average surface pressure was applied to the contact area of the cylinder liner and the cylinder head gasket. The contact condition with no friction was applied to the contact area of the upper part of the cylinder block and the upper part of the cylinder liner. The thread engagement positions were restrained in all direction in both models.

3.3 STRUCTURE OF THE CYLINDER HEAD GASKET

Structures of the cylinder head gaskets are shown in Fig.5. The structure shown in Fig.5(b) is called plate type cylinder head gasket and that shown in Fig.5(c) is called bead type cylinder head gasket.

The plate type cylinder head gasket can apply the uniform surface pressure on the whole area of the upper part of the cylinder liner. Meanwhile, the bead type cylinder head gasket can apply the uniform surface pressure only on the limited area of the upper part of the cylinder liner of the bead position of the gasket. The number of elements, the restraint and contact conditions are constant in all analyses of model 6CX.

Plate type is low cost, but severe flatness tolerance is necessary. Bead type is expensive, but the position where tightening force of cylinder head bolts is transmitted can be changed by changing the position of the bead. Fig.6 shows various loading patterns for different bead types analyzed.

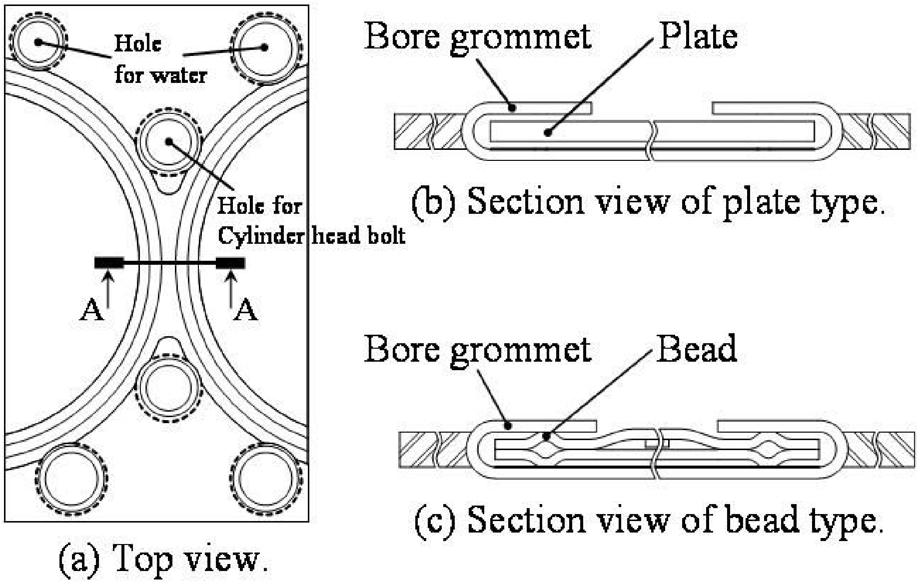


Fig.5 Structure of the cylinder head gaskets.

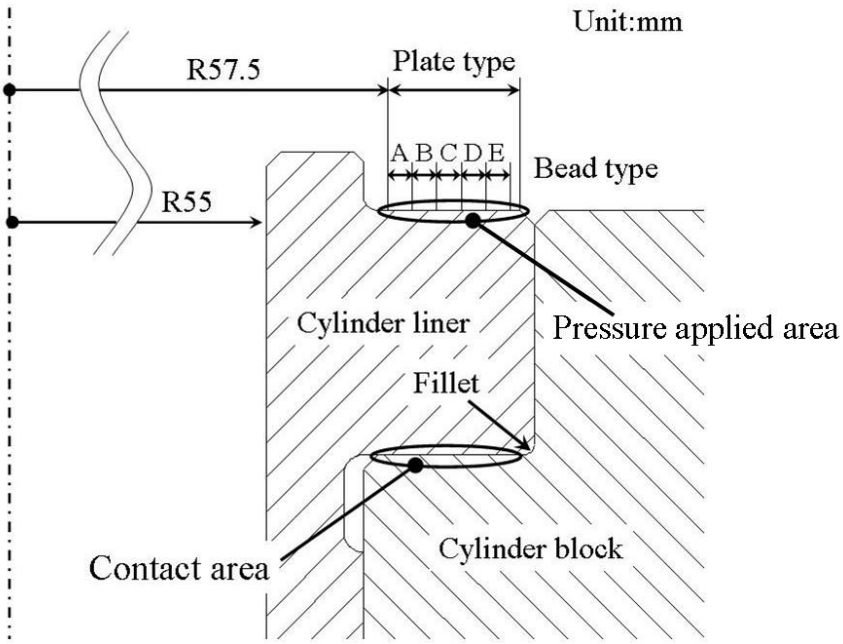


Fig.6 Various loading patterns by using cylinder head gaskets with different bead types.

4. RESULTS AND DISCUSSIONS

4.1 STRAIN DISTRIBUTION ALONG THE FILLET ON UPPER DECK OF THE CYLINDER BLOCK

The maximum principal strain distribution along a circumferential direction of model 6EY26 is shown in Fig.7. The experimental results were measured by strain gage. The model 6EY26 was analyzed with the condition of the optimum depth of thread engagement. An average error of 4.9% was found by the comparison with experimental results.

The variation of the maximum principal strain for the angle on the fillet of all analyses models of 6CX is shown in Fig.8. The analysis results show that the angle of maximum value of maximum principal strain depends on each bead type. It was found that the strain variation for the plate type cylinder head gasket shows similar tendency with that for the bead type-C cylinder head gasket.

4.2 OPTIMUM DESIGN OF THE DEPTH OF THREAD ENGAGEMENT AND BEAD

The relationships between depths of thread engagement for cylinder head bolt and analyses results of static strain of the fillet on upper deck of the cylinder block are shown in Fig.9 for the model of 6EY26. If the tightening forces by cylinder head bolts were the same, the static strain value and unevenness of the fillet on upper deck of the cylinder block can be reduced by changing the depth of thread engagement. Based on this result, the optimum depth of thread engagement was determined to be about 100mm from the viewpoints of the overall magnitude of strain, the circumferential fluctuation of strain, the change rate of strain against the distribution of the static strain, and the length of cylinder head bolt.

Decreasing the maximum principal strain is an effective way to take precautions against cracking on the fillet on upper deck of the cylinder block. It is also necessary to keep the positive surface pressure on the contact area. Analysis results of surface pressures on the contact area of the upper part of the cylinder block and the cylinder liner are shown in Fig.10 for the model of 6CX. The place where a surface pressure on the contact area was found to close to zero in bead type-D and bead type-E. This result implies that both types of the cylinder head gaskets may cause serious damage on the cylinder block by repeated contact with intermittent combustion. The plate type and the bead type-C cylinder head gaskets were optimum structure when considering maximum strain on the fillet shown in Fig.8 and surface pressure on the contact area shown in Fig.10.

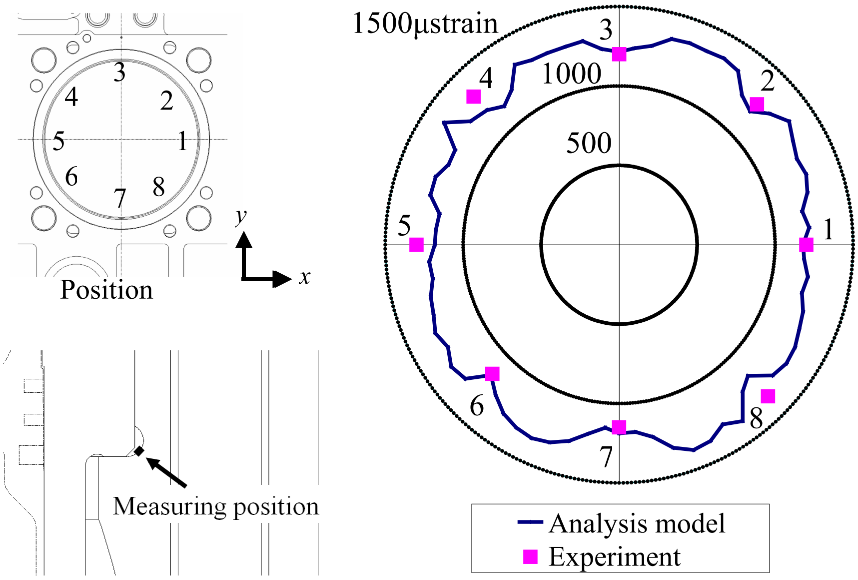


Fig.7 Comparison of experimental and calculated strain of model 6EY26.

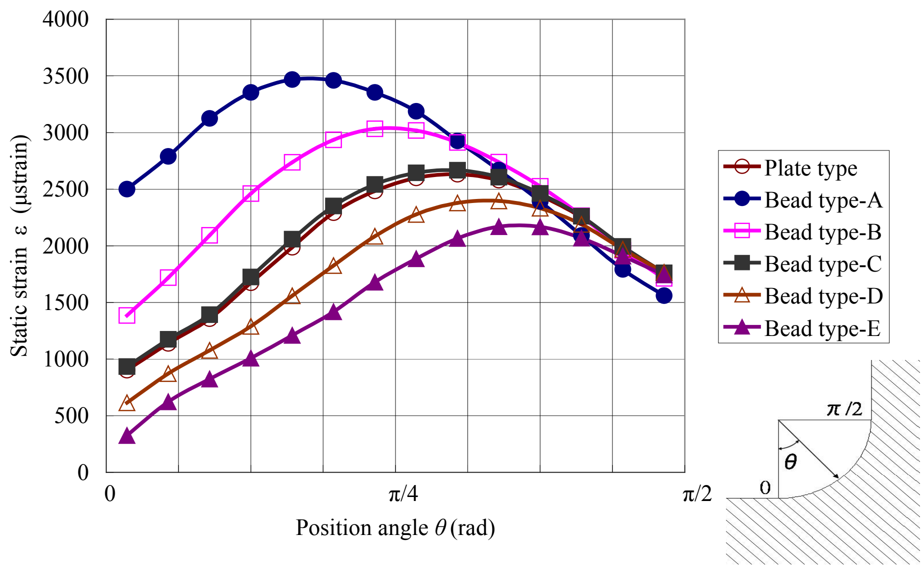


Fig.8 Maximum principal strain on the fillet of the cylinder block by elastic-plastic analysis of model 6CX.

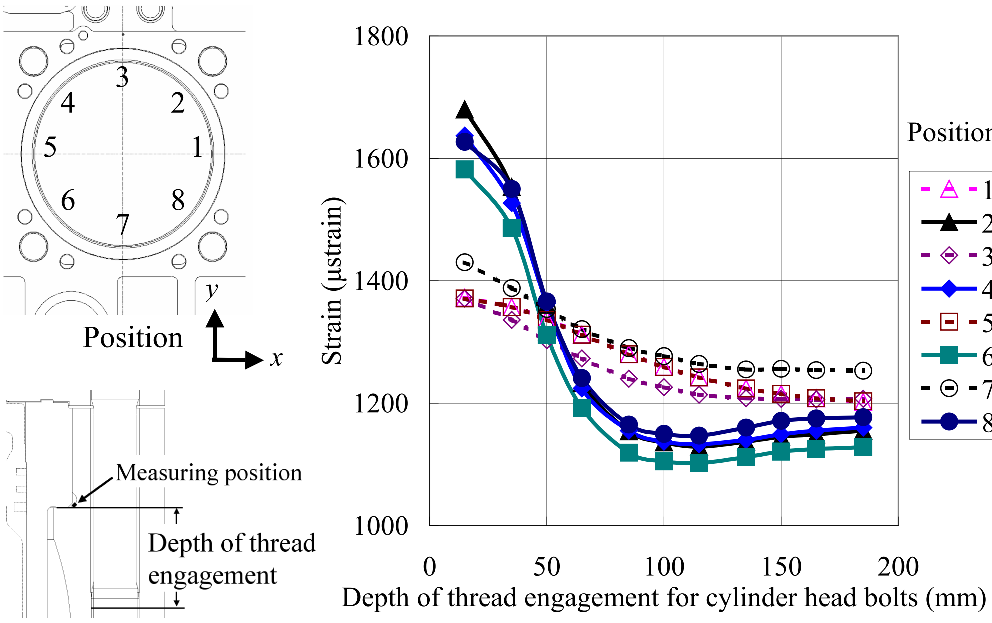


Fig.9 Change in the maximum principal strain at the fillet with the depth of thread engagement for cylinder head bolts of model 6EY26.

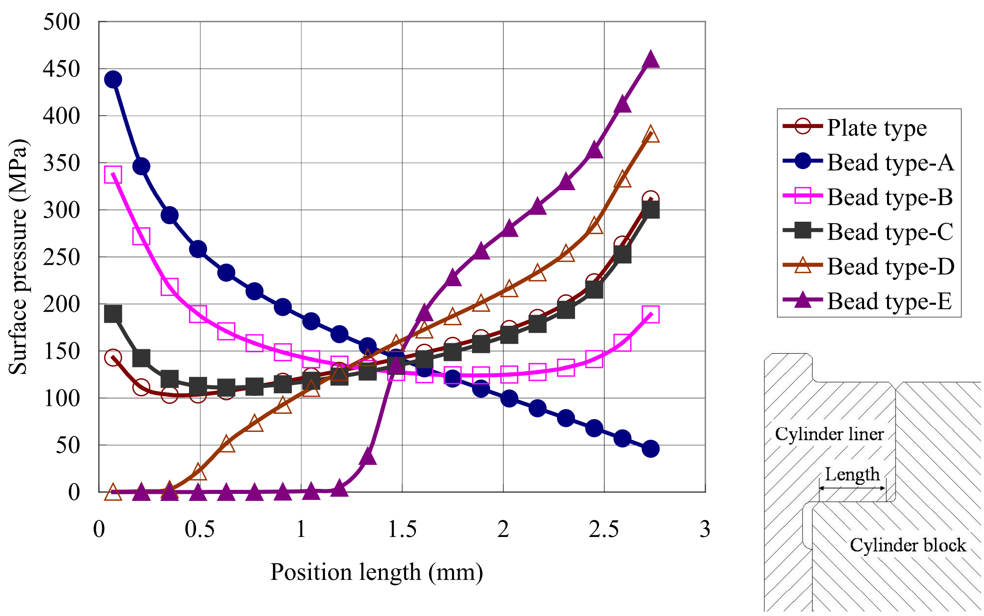


Fig.10 Surface pressure distribution on the contact area of the upper part of the cylinder block and the cylinder liner of model 6CX.

5 CONCLUSIONS

In the present study, we focused on the static strain along the fillet on upper deck of the cylinder block caused by tightening cylinder head bolts of the water-cooled diesel engine. Its dependency on the thread engagement for cylinder head bolt and the effect of the bead position of the cylinder head gasket were evaluated using two difficult models with wet-liner and dry-liner structures. The main results are summarized as follows:

(1) The analysis results of the static strain were agreed with the measurement results in the condition of the optimum depth of thread engagement.

(2) Based on the results for the model 6EY26 with wet-liner structure, the static strain was depended on the depth of thread engagement of cylinder head bolt. The optimum depth of thread engagement was determined to be about 100mm from the viewpoints of the overall magnitude of strain, the circumferential fluctuation of strain, the change rate of strain against the depth of thread engagement, and the length of cylinder head bolt.

(3) As for the model 6CX with dry-liner structure, the following result was obtained. From the viewpoints of the magnitude of strain along the fillet on upper deck of the cylinder block and the surface pressure on the contact area of the upper part of the cylinder block and the cylinder liner, the plate type cylinder head gasket to apply pressure to whole area or the bead type-C cylinder head gasket to apply pressure to center area were optimum.

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