

Development of Fatigue Durability Analysis Techniques for Engine Piston using CAE

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ABSTRACT

A piston in a diesel engine is subject to the high pressure and the high thermal load. The high structural reliability is required to the piston in the automotive diesel engine and it is important to confirm the design parameters of piston in initial design stage. There are lots of research works proposing new geometries, materials and manufacturing techniques for engine pistons. But, the failures of piston occur frequently in development stage. Failure mechanisms are mainly fatigue related. This paper presents failure mechanisms of the high cycle fatigue and low cycle thermal fatigue cracks which occur on the piston during durability test using engine dynamometer. In this study, FE analysis was carried out to investigate the root cause of piston failure. The analysis includes the FE model of the piston moving system, temperature dependent material properties, mechanical and thermal loadings. The results show that the crack on the flame position is caused by the stress amplitude during the full-load test. The crack at the rim on the thrust axes is due to the large compressive plastic strain amplitude generated in the thermal shock test. It shows a good agreement between numerical and experimental results.

INTRODUCTION

The piston is one of the most stressed components of an entire engine. Maximized pressures due to the diesel engine combustion may reach about 180~200bar and temperatures at the piston crown may reach about 400 °C. As one of the major moving parts in the power transmitting assembly, the piston must be so designed that it can withstand the extreme heat and pressure of combustion. Pistons must also be light enough to keep

inertial loads on related parts to a minimum. The piston also aids in sealing the cylinder to prevent the escape of combustion gases. It also transmits heat to the cooling oil and some of the heat through the piston rings to the cylinder wall [1].

As one of the main components in an engine, pistons technology evolution is expected to continue and they are expected to be stronger, lighter, thinner and durable. There are lots of research works proposing new geometries, materials and manufacturing techniques and these trends have undergone with a continuous improvement over the last decades [2].

Notwithstanding all these studies, the failures of piston occur frequently. Damages may have different origins: mechanical and thermal stresses, wear mechanisms, oxidation mechanisms, etc. Among these origins, fatigue is responsible for a significant number of piston failures. Fatigue exists when cyclic stresses and deformations occur in an area on a component. The cyclic stresses and deformations have mainly two origins: load and temperature. Among the fatigue failures, thermal fatigue by the temperature change and mechanical fatigue by firing pressure play a prominent role [3].

In this study, the root cause of piston cracking in diesel engine on development is investigated by FEM analysis. The early full load durability test showed that piston had cracks at the flame position in the rim of the piston crown, as depicted in Fig.1. And, the thermal-shock test showed that piston had cracks at the rim of the piston crown on the thrust axes, as depicted in Fig.2. In these endurance tests, piston damages are attributed to the high cycle and low cycle thermal fatigue. Simulations analogous to thermal-shock and full load test mode were

performed. Through these simulations, the critical area of the piston was revealed and the cracking mechanisms were analyzed.

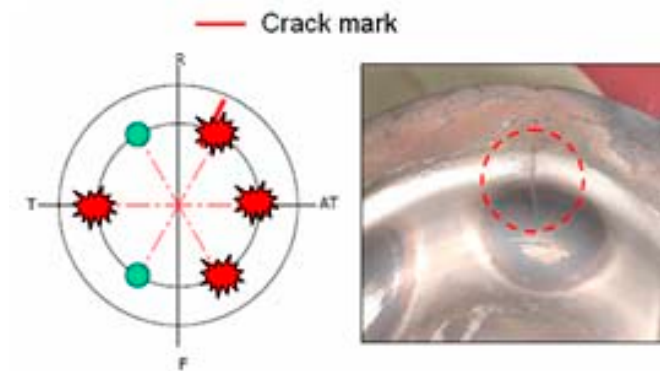


Figure 1. Crack position after full load durability test

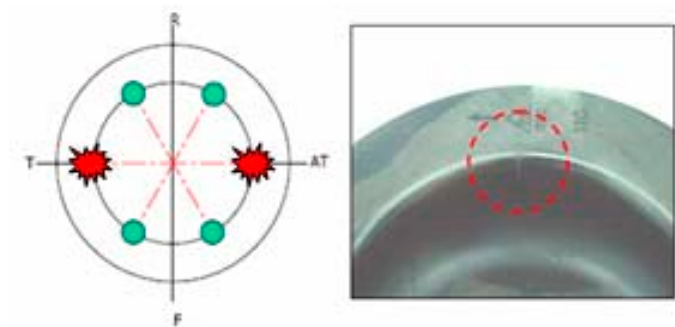


Figure 2. Crack position after thermal-shock test

FULL LOAD DURABILITY TEST SIMULATION

Full load durability test is objected to the durability evaluation for moving system under the engine high run condition. The procedure of the full load test is carried out in the high uniform temperature field at the rated rpm. High cycle fatigue analysis was performed because the full load test includes high cycle loading by the combustion pressure.

ANALYSIS PROCEDURE

The procedure of the cycle fatigue analysis is schematically shown in Fig.3. First of all, the temperature field must be calculated in a steady state condition at rated rpm. The resulting temperature distributions are used to simulate the nonlinear thermal-mechanical stress analysis, which considers temperature dependent material properties, firing pressure and inertia effects. The stress analysis is coupled between thermal and mechanical loadings. For the evaluation of the high cycle fatigue behavior, safety factors by modified Goodman Theory are calculated by the use of thermal-mechanical stress analysis results and temperature dependent fatigue strength. The commercial software ABAQUS is used for nonlinear thermal-mechanical stress analysis [4]. Safety factors are calculated by use of the commercial software FEMFAT [5].

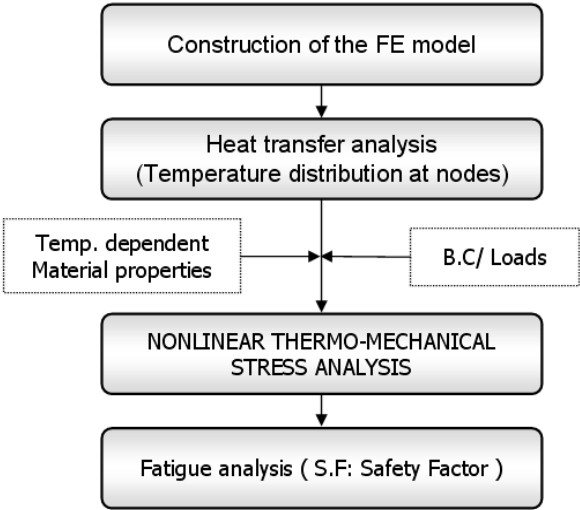


Figure 3. Procedure for the high cycle fatigue analysis

FINITE ELEMENT MODEL

Fig.4 shows a finite element model for the high cycle and low cycle fatigue analysis. The model is composed of a half model of the piston component, including the piston, piston pin and connecting rod. The 10 node tetrahedron elements were used to mesh the piston and other components. Contact conditions were adopted between the piston and bush, bush and connecting rod with interface elements. Table.1 shows the elastic material properties of the aluminum alloy for the piston.

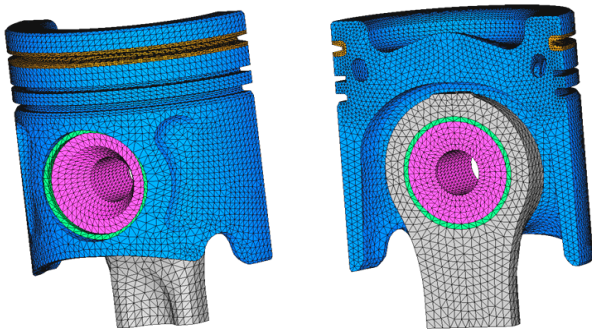


Figure 4. Finite element model of the piston assembly

Table 1. Properties of aluminum alloy

Temperature (°C)	20	150	250	350
Elastic modulus (GPa)	84	79	75	70
Poisson's ratio	0.32	0.32	0.32	0.32
Thermal expansion coefficient (e-6)	19.2	20.5	21.1	21.8