Thermo-Mechanical Stress Analysis of Engine Components Using FEA

Mantu Yadav, Bipin Kumar Mondal, Patit Pawan Gorai, Mukesh Piri, Chandan Kumar & Aziruddin Ansari
Department of Mechanical Engineering
K.K.Polytechnic, Govindpur,Dhanbad

ABSTRACT

This study proposes a thermo-mechanical finite element analysis model for engine piston stress and fatigue analyses. The piston, piston ring, pin, bushing, cylinder liner, and connecting rod constitute the model. All of the contact areas between piston and piston pin, piston pin and bush, piston skirt and cylinder liner are considered, as well as oil film and contact pressure. A self-assembled The initial oil film clearance between the piston pin and piston, the piston and bush, and piston skirt and cylinder liner is calculated using a code considering the ellipticity and piston skirt profile. To perform the stress and fatigue analyses, power train commercial software is used to calculate the dynamic loads of the connecting rod and the piston when subjected to the peak torque and peak power conditions. Unlike the ones in the literature, the present model can simulate the more accurately the piston's actual operating conditions. The piston skirt pressure, stress, and fatigue life of the corresponding piston sections can be analyzed and calculated using the model.

Keywords: oil film, piston, contact pressure, fatigue, thermal mechanical stress, and alphabetical order Space between lines; nanofluids

1. INTRODUCTION

The piston engine is frequently utilized by the automotive industry. The pistons form the core of the engine, and they consist of a moving metal cylinder with piston rings to provide a tight seal. once it has been installed in the cylinder of the engine. The piston pin is attached to the connecting rod, which has an attachment to the crankshaft. The crankshaft is rotated by the piston by passing on the power of combustion to the crankshaft. It also serves as a movable, gas-tight stopper to maintain combustion inside the cylinder. One part of automobile engines that experiences a lot of stress is the piston. Pistons are subjected to extreme mechanical, thermal, and chemical loadings during regular operation [1, 2]. Over the past 20 years, significant efforts have been undertaken to enhance piston performance and lower the associated emissions of pollutants. Some of the work involves the creation of analytical tools with the help of finite element analysis techniques [15, 16], the promotion of processing technologies [17, 18], the enhancement of wear and lubrication [9–14], the enhancement of piston geometry and combustion flow in diesel engines [3, 4], and the enhancement of materials for the purpose of enhancing the mechanical and thermal behaviors of pistons [5-8].

Among all the parts of a vehicle, the piston is one of the most complex mechanical components. Temperature stresses, wear mechanisms, and mechanical stresses can all damage pistons.degradation because of temperature, oxidation reactions, or both [2]. Fatigue is recognized as the most common reason for piston damage among them. Fatigue occurs when a structural element is subjected to cyclic loads and/or cyclic deformations. Cyclic stresses and/or cyclic deformations arise in pistons due to load and/or temperature variations. The performance of pistons in terms of strength and failure mechanism has been the focus of numerous studies carried out over the past decade [19–21].Lu et al. [20], for example, performed the thermally induced temperature field and thermal stress analysis for diesel engine pistons under steady temperature fields. Liu et al. [21] analyzed thermo-mechanical conditions in a piston of a diesel engine with finite elements. Zeng et al. [22] employed his CAE calculation method to analyze the cracking problem of the piston.Xu et al. [23] analyzed the thermal stress and fatigue life of a diesel engine piston based on the thermal-mechanical coupling method. Zu et al. [24] utilized a thermomechanical-fatigue coupled model to study the strength and deformations of a V-engine's piston. Zhang et al. [25] utilized the finite element method to model the temperature field of the piston numerically and analyzed the effectindicates the stress distribution of the piston resulting from the lateral thrust load. Buyukkaya and Cerit [26] subjected four different diesel engine pistons to a thermal analysis. It was found that the coating influenced the thermal behavior of the piston and that the piston's combustion bowl was the hottest. But most of these research studies did not consider the cylinder liner in the piston stress calculation, which was not realistic for the actual operating condition of the piston. Dry frictional contact between the liner and piston was incorporated in some of the numerical models [24], but in reality, there exists a contact interaction with the oil film. Cylinder liner and connecting rod. The center of the connecting rod, which is rather restricted, and big-end are where the distributing coupling element is utilized. A self-assembled The original clearance at the oil film surfaces between the piston, piston pin and bush, and between piston skirt and cylinder liner is calculated with a code that considers the piston skirt profile and ellipticity. The entire engine model is built utilizing a powertrain commercial program [28] in order to calculate the dynamic loads of the piston and connecting rod under the peak torque and peak power conditions. For stress calculations, the acceleration data at different crank angles is offered by the entire engine model. The present model can better describe the real running conditions of the piston than others reported in the literature. The model provides a practical approach for piston design orientation and optimization by quantifying the evaluation and inspection of the piston's skirt pressure, stress, and fatigue life of the concerned components.It remains difficult to quantify the piston skirt pressure in such evaluations, even though it is an important design target [27].

The loading features of a piston should be replicated as closely as possible in order to obtain a correct stress condition of the piston under its service conditions. The investigation formulates an analytical model of the thermal and mechanical link involving the piston, piston ring, piston pin, bushing.

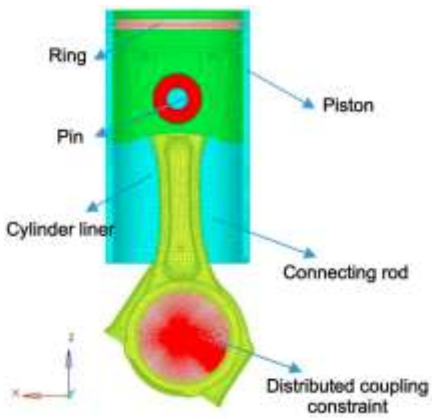

Fig. 1. Finite element analysis model of piston.

Table 1. The parameters of the engine

Category	Technical Parameter
Cylinder arrangements	I-engine,four strokes
Displaced volume	3.76(liters)
Number of cylinders	4
Cylinder diameter	102(mm)
Stroke	115(mm)
The maximum burst pressure	18.12(MPa)
The maximum torque speed	1300(rev/min)

The rated speed	2600(rev/min)

2. ENGINE PARAMETERS AND FINITE ELEMENT ANALYSIS MODEL OF PISTON

This model represents the aluminum piston found in a four-stroke engine. Table 1 lists the engine's specifications and related technical data. The piston assembly's finite element analysis (FEA) model for stress and fatigue assessments is displayed in Fig. 1. The model comes with a cylinder liner, connecting rod, bushing, piston, piston pin, and piston ring. In order to undertake the temperature, stress, and fatigue assessments, the three-dimensional geometry of the piston under analysis was constructed using 3D CAD drawings and imported into ABAQUS software. The second order tetrahedron solid element, with controlled element sizes ranging from 0.5 mm to 3.0 mm, is used to mesh all solid components.

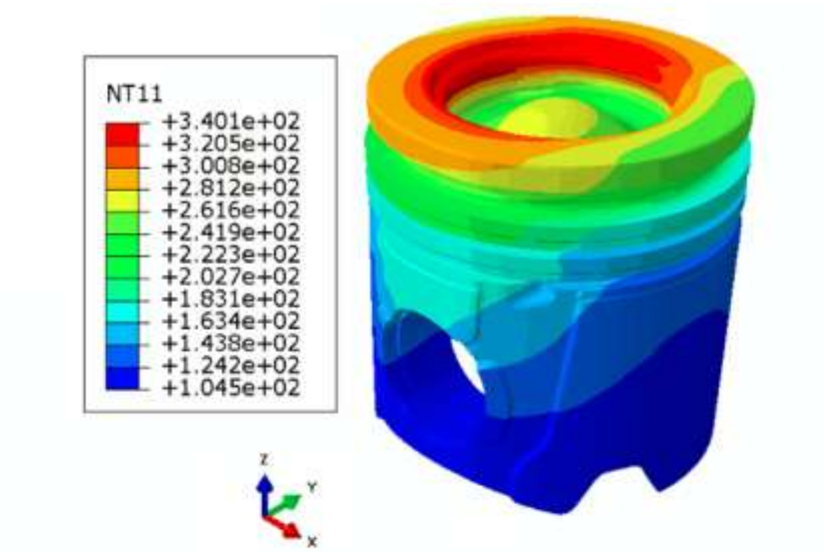

Fig. 2. Piston temperature contour plot.

There are two phases to the thermal analysis. One is the engine combustion chamber fluid flow analysis, which is often carried out with a CFD software program. The temperature field of the fluid surrounding the solid components is the analysis's outcome. The other uses the FEA model depicted in Figure 1 to analyze heat transfer for the solid components. The temperature field in the solid components is the analysis's outcome. The specifics of the fluid flow analysis for pistons are not covered here because they may be obtained elsewhere [29]. Rather, just its findings—which are displayed in Table 2—are given here since they are necessary to establish the heat flow boundary conditions for the heat evaluation of the solid components' transfer. Using FLUENT software, the heat transfer study is carried out for the piston assembly depicted in Figure 1. It is expected that the specific heat and conductivity coefficient depend on temperature; Table 3 displays their values. As a constant, the density is assumed to be 2700 kg/m3. It is assumed that the starting temperature for all solid components is 20 °C.The air temperature and heat transfer coefficient listed in Table 2 are used to apply the heat flow boundary condition to each individual component; the latter is computed based on databases and empirical formulas [27]. The experimentally determined temperatures for a piston with a comparable design under calibrated conditions are used to validate the thermal analysis model previously described. The hardness plug method was used in the experiment to measure the temperatures at several points on the piston. Fig. 2 displays the points of measurement. Figure 3 displays the piston's temperature distribution contour as determined by the current thermal analysis model. The figure shows that the piston's overall temperature distribution is reasonable.

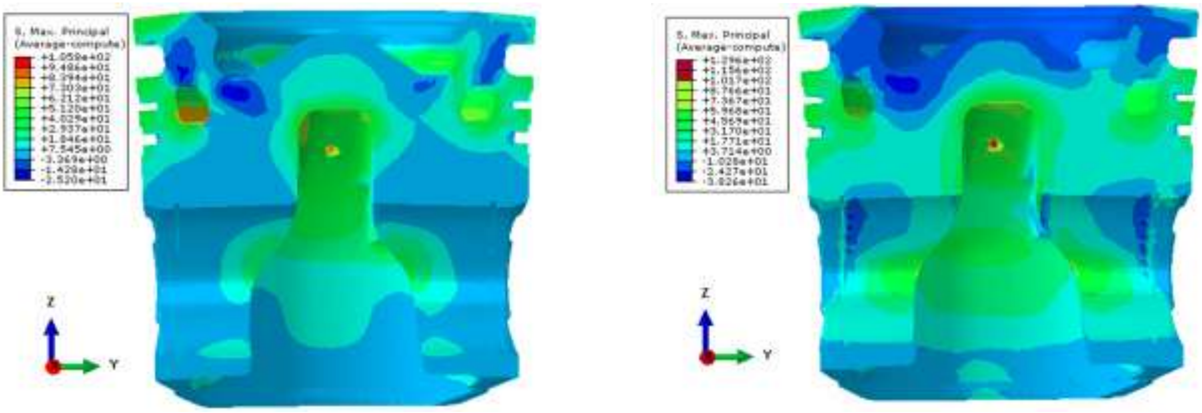

Fig. 3. (a) Stress distribution of piston under thermal load; (b) stress distribution of piston under thermal mechanical coupling.

3. ANALYSIS

Using the commercial software FEMFAT, the fatigue analysis uses the piston fatigue material properties in the form of a height diagram at 145 °C, 240 °C, and 340 °C. ForTo determine the high cycle fatigue safety factor of the piston at a specific temperature, five stress result files corresponding to the five loading and unloading scenarios mentioned above are input into the software for the peak torque (1330 rpm) example. The actual temperature of the node is then used to interpolate the fatigue factor result at a critical node. The research is predicated on the idea that the stress produced by the five loading and unloading scenarios mentioned above covers the piston's actual stress.

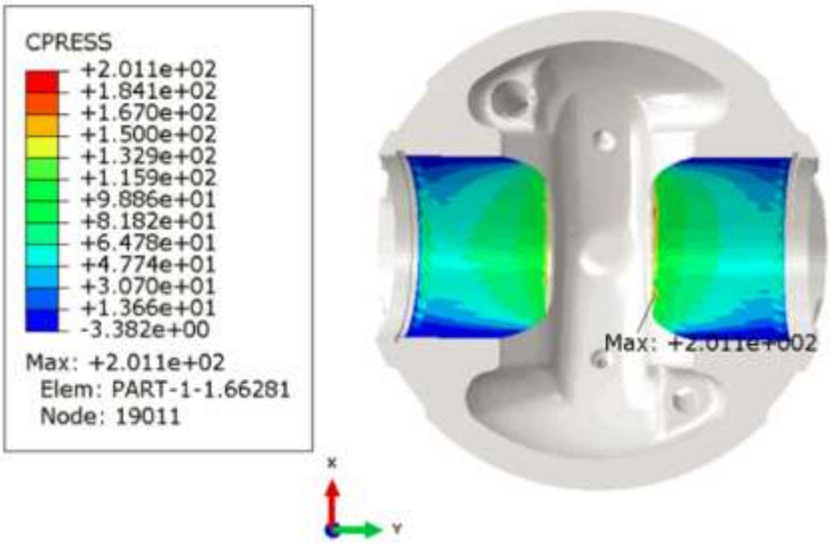

Fig. 4. Pressure at piston pin hole.

4. RESULT & DISCUSSION

The analyses' findings include the cases of peak torque (1330 rpm) and peak power (2550 rpm). When the two assessments above are compared, the peak torque of More important is the piston. The piston skirt pressure, pin hole contact pressure, piston stress, and high cycle fatigue factor must all be evaluated in accordance with the engineering failure modes of the piston design.

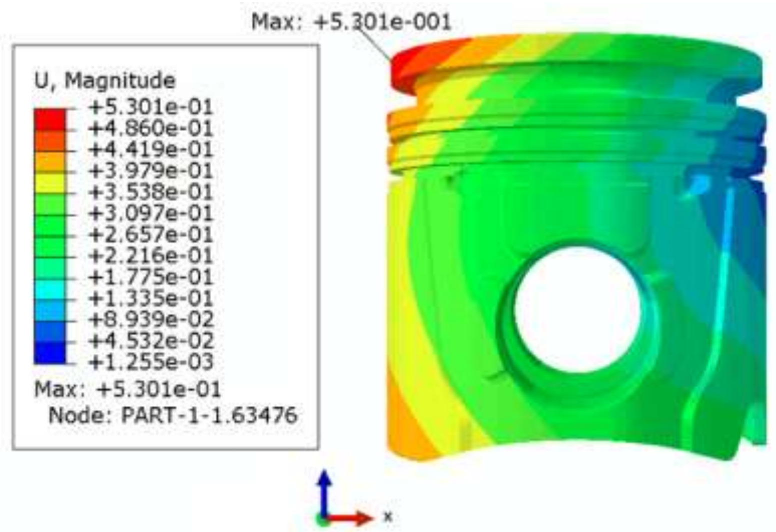

Fig. 5. Maximum deformation of piston under maximum compression load.

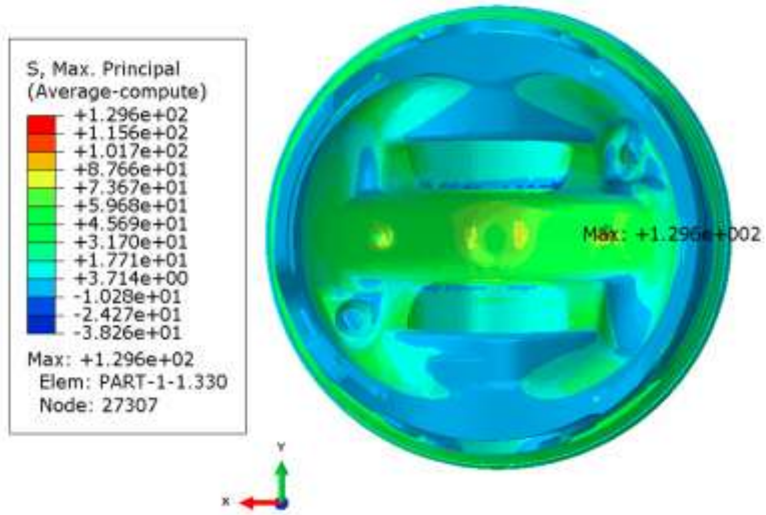

Fig. 6. Maximum principal stress of piston under maximum compression load.

5. CONCLUSION

This work develops a finite element analysis model for piston stress and fatigue. It mimics the piston's loading characteristics during real-world operation. The current model improves on previous research on problems including dry frictional contact between the piston and liner, irrational connecting rod constraints, and the stress analysis's failure to account for acceleration load. By comparing the expected minimum fatigue factor locations with the diesel engine's test cracking result, the viability of the current analysis procedure is confirmed. Initially, the piston's three-dimensional temperature field was examined, and the findings were contrasted with the temperature readings of a piston of a comparable design. in the calibrated state. Second, the movement characteristics of the connecting rod and piston under peak torque and peak power scenarios were computed using a comprehensive engine dynamic model. For the purpose of analyzing piston stress, it supplied the acceleration data at various crank angles. The piston, piston ring, piston pin, bushing, connecting rod, and cylinder liner were all included in the final piston model. In the middle of the connecting rod's big end, a distributing coupling constraint was imposed. In such oil film contact regions, oil film contact and the associated pressure formulation were carried out. A self-compiled code that takes piston factors into account The initial clearance at the oil film contact surfaces was determined using the skirt profile and ellipticity. The piston's stress and fatigue evaluations were carried out using the FEA model that was created. The results that were achieved and those that were published in the literature were contrasted. More accurate simulation of the piston's real operating circumstances is possible with the current model. It offers a solution for powertrain piston design direction and optimization.

6. REFERENCE

[1] F. Szmytka, M. Salem, F. Rézaï-Aria and A. Oudin, Thermal fatigue analysis of automotive diesel piston: Experimental procedure and numerical protocol, *International Journal of Fatigue*, 73 (2015) 48-57.

[2] F. S. Silva, Fatigue on engine pistons – A compendium of case studies, *Engineering Failure Analysis*, 13 (3) (2006) 480-492.

[3] H. Kajiwara, Y. Fujioka, T. Suzuki and H. Negishi, An analytical approach for prediction of piston temperature distribution in diesel engines, *JSAE Review*, 23 (4) (2002) 429- 434.

[4] F. Payri, J. Benajes, X. Margot and A. Gil, CFD modeling of the in-cylinder ow in direct-injection diesel engines, *Computers & Fluids*, 33 (8) (2004) 995-1021.

[5] R. Mogilewski, S. R. Brian, W. S. Wolbach, T. W. Krucek, R. D. Maier, G. L. Shoemaker, J. M. Chabala, K. K. Soni and R. Levi-Setti, Reactions at the matrix-reinforcement interface in aluminum alloy matrix composites, *Materials Science and Engineering: A*, 191 (1-2) (1995) 209-222.

[6] Y. D. Huang, N. Hort and K. U. Kainer, Thermal behavior of short ber reinforced AlSi12CuMgNi piston alloys, *Composites Part A: Applied Science and Manufacturing*, 35 (2) (2004) 249-263.

[7] W. J. Baxter, A. Alostaz and I. Jasiuk, The effect of shot particles on the fatigue of Kaowool bre-reinforced 339 Aluminum, *Metallurgical and Materials Transactions A*, 30 (1) (1999) 195-201.

[8] M. R. Joyce, C. M. Styles and P. A. S. Reed, Elevated temperature short crack fatigue behaviour in near eutectic Al–Si alloys, International Journal of Fatigue, 25 (9-11) (2003) 863-869.

[9] C. Friedrich, G. Berg, E. Broszeita, F. Rickb and J. Hollandb, PVD CrxN coatings for tribological application on piston rings, Surface and Coatings Technology, 97 (1-3) (1997)
661-668.

[10] C. E. Pinedo, The use of selective plasma nitriding on piston rings for performance improvement, Materials & Design, 24 (2) (2003) 131-135.

[11] T. Kikuchi, S. Ito and Y. Nakayama, Piston friction analysis using a direct-injection single-cylinder gasoline engine, JSAE Review, 24 (1) (2003) 53-58.

[12] T. A. Stolarski and Q. Zhou, Temperature–friction characteristics of used lubricant from two-stroke cross-head marine diesel engines, Wear, 252 (3-4) (2002) 300-305.

[13] M. Priest and C. M. Taylor, Automobile engine tribology – Approaching the surface, Wear, 241 (2) (2000) 193-203.

[14] M. Takiguchi, H. Ando, T. Takimoto and A. Uratsuka, Characteristics of friction and lubrication of two-ring piston, JSAE Review, 17 (1) (1996) 11-16.

[15] J. R. Cho, Y. S. Joo and H. S. Jeong, The Al-powder forging process: Its nite element analysis, Journal of Materials Processing Technology, 111 (1-3) (2001) 204-209.

[16] M. V. Babu, R. K. Kumar, O. Prabhakar and N. G. Shankar, Fracture mechanics approaches to coating strength evaluation, Engineering Fracture Mechanics, 55(2) (1996) 235-
248.

[17] K. Nakajima, H. Otaka, T. Kashimura, S. Sakuma and M. Tanaka, Newly developed hollow ring groove insert piston – Part 2: Producing technology of new piston, JSAE Review,
17 (4) (1996) 448.

[18] S. Sulaiman, A. M. S. Hamouda and D. T. Gethin, Experimental investigation for metal-□lling system of pressure diecasting process on a cold chamber machine, Journal of Materials Processing Technology, 119 (1-3) (2001) 268-272.

[19] G. G. Martin, Failure of a stationary pump engine piston, Journal of Failure Analysis and Prevention, 4 (1) (2004) 37-39.

[20] Y. H. Lu, X. Zhang, P. L. Xiang and D. W. Dong, Analysis of thermal temperature fields and thermal stress under steady temperature field of diesel engine piston, Applied Thermal
Engineering, 113 (2017) 796-812.

[21] X. F. Liu, Y. Wang and W. H. Liu, Finite element analysis of thermo-mechanical conditions inside the piston of a diesel engine, Applied Thermal Engineering, 119 (2017) 312-318.

[22] X. C. Zeng, X. W. Luo and J. K. Luo, Solving the piston crack problem by CAE analysis, South Agricultural Machinery, 3 (2014) 20-22.

[23] G. J. Xu, M. D. Li and Y. Zhao, Thermo-mechanical analysis of piston thermal stress and fatigue life for diesel engine, Chinese Internal Combustion Engine Engineering, 38 (2) (2017) 96-100.

[24] B. F. Zu, Q. Fang and J. Liu, Numerical analysis of pistonstrength and deformation based on thermo-mechanical coupling for China-V diesel engine, Chinese Internal Combustion Engine Engineering, 35 (1) (2014) 99-104.

[25] J. H. Zhang, Z. P. He and G. C. Zhang, Coupled thermal and mechanical load analysis in diesel engine piston, Transactions of CSICE, 29 (1) (2011) 78-83.

[26] E. Buyukkaya and M. Cerit, Thermal analysis of a ceramic coating diesel engine piston using 3-D finite element method, Surface & Coatings Technology, 202 (2) (2007) 398-402.

[27] C. Tian, Thermal-mechanical coupling analysis and fatigue simulation of YC6MK375N-30 CNG engine's piston, Dissertation for Master's Degree, Wuhan University of Technology,
Wuhan, China (2013).
[28] AVL Workspace, Excite-power-unit theory, AVL User Manuals (2014).
[29] H. Fridriksson, B. Sunden, S. Hajireza and M. Tunér, CFD investigation of heat transfer in a diesel engine with diesel and PPC combustion models, SAE Technical Paper, No. 01-
1838 (2011).
[30] L. M. Li, Y. P. Li and Y. Lin, Calculation table skirt profile combination horizontal line radius shrinkage, Locomotive Technology, 4 (2016) 34-36.
[31] Z. L. Chen, Engine bulkhead fatigue testing and correlation to FEA, Sany Technical Report, 6 (2012) 17-20.
[32] G. Floweday, S. Petrov, R. B. Tait and J. Press, Thermomechanical fatigue damage and failure of modern high performance diesel pistons, Engineering Failure Analysis, 18 (2011) 1664-1674.
[33] F. Szmytka and A. Oudin, A reliability analysis method in thermomechanical fatigue design, International Journal of Fatigue, 53 (2013) 82-91.