IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

Simulation of heat transfer processes in a diesel engine equipped with pistons coated by using Galvanic-plasma Method

To cite this article: M S Al-Bdeiri *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1014** 012001

Simulation of heat transfer processes in a diesel engine equipped with pistons coated by using Galvanic-plasma Method

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Abstract. The methodology for analyzing the thermodynamics and heat transfer of the combustion chambers of a diesel engine is presented. The work is devoted to the modified quasi-steady method (MQM) for the analysis of a diesel engine piston coated with an aluminum alloy. The oxide-coated piston using a galvanic-plasma modification (GPM) depending on the thickness of the coating, including comparison with the results for uncoated piston temperature, to achieve higher characteristics of the Cummins KTA-50 diesel engine. In thermodynamic modeling of a diesel engine, instantaneous gas temperatures and convective heat exchanges are first predicted. The time-dependent boundary conditions are then applied to the gas-blown surfaces of two-dimensional, transitional finite element models of the components of the combustion chamber. Further, the predictions on the finite elements of the instantaneous heat flux passing through each surface of the component are used to determine when the engine goes into quasi-stationary operation. The results show that our path in methodology can identify the complex transition paths of the heat process in the engine combustion chamber and significantly improve heat conduction and convection heat models when modeling a diesel engine.
Keywords: modified quasi-steady method (MQM), thermodynamics, a galvanic-plasma modification (GPM), heat transfer, diesel engine piston, aluminium alloy coating.

1. Introduction
Heat transfer from gas to the wall of a diesel engine critically affects engine performance, fuel economy, and exhaust emissions [1]. In addition, it affects the design of the elements of the combustion chamber, their cooling system, and lubrication. The heat transfer in cylinders, affecting the expected increase in average effective pressure and exhaust energy, led researchers to develop many thermodynamic simulations of the engine to determine the decrease in cooling or insulation of the components of the combustion chamber using ceramics and other materials with low thermal conductivity[2, 3]. The accuracy of engine performance and heat removal predictions is critically dependent on the modeling the heat transfer mechanisms in the piston and their relationship with components structural for the combustion chamber. Multidimensional, transitional models of wall thermal conductivity in complex geometries were developed on the basis of the finite element method (FEM) and were used together with the found cycle time and boundary conditions for gases to study the cyclic thermal behavior of individual components. This approach significantly contributed to our understanding of the problems associated with engine design, such as thermal failure of ceramic coatings caused by stress near sharp angles, heat transfer from

the exhaust gas to the cooling oil, and thermal breakdown of the lubricant [4, 5]. However, from the point of view of computational efficiency, FEM simulations of the cyclic heat equation were highly discretized.

2. Engine configuration and boundary condition

The engine is a 16-cylinder, two-stage turbocharged engine with direct injection and high pressure. Figure 1 shows the geometry (to scale) and material composition of a cylinder-piston group system (CPG).

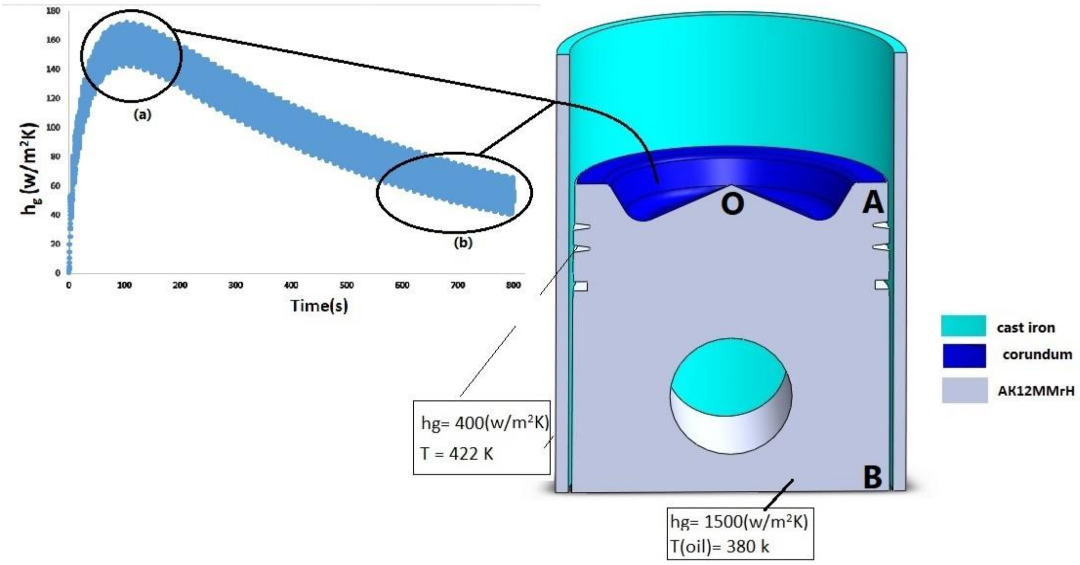
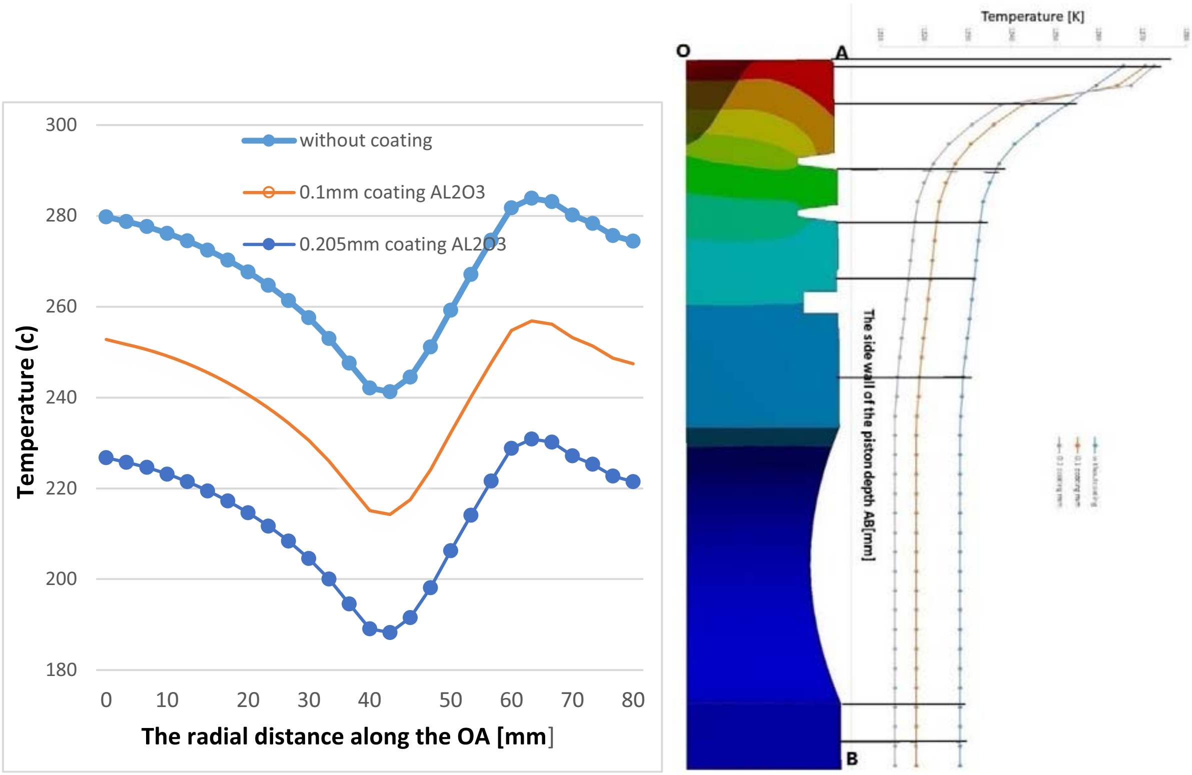


Figure 1. Determination of the geometry and materials of (CPG), as well as their thermal environment. Boundary conditions (including MQM profiles of average gas temperature and convective heat transfer coefficient) are used for FEM analysis

Figure 1 defines the boundary conditions used to perform transient thermal analysis of the components of the combustion chamber. The instantaneous convective heat transfer coefficient of the gas is obtained by the MQM analysis. The instantaneous extended convective coefficient is calculated in the FEM based on the radiation temperature of the gas and the local component of the surface temperature We can see in Figure 1 zone (a) the maximum change in temperature at the start of the engine and this continues till 100 seconds, Hence the transient temperature turns gradually going to be stable as shown in the zone (b). A reduced cyclic convective coefficient (without radiation) is applied to the surfaces of the gap between the piston and the sleeve above the main ring. Corundum (Al_2O_3) [6]with a thermal conductivity of k = 35 W / (m * K) is applied to the upper insert of an aluminum piston with a thickness of 0.1 mm and 0.2 mm, respectively[7]. Our study focuses on cyclic thermal transients when the engine reaches a quasi-stationary mode of operation at a constant speed of 1,500 rpm [8].

3. Results and discussion

Figure 2 shows the predicted instantaneous temperatures at the outer edge of the ceramic-coated piston through many thermodynamic cycles of the engine as shown in Figure 1. The effect of realistic piston geometry on the heat flux can be seen in Figure 2a. The increasing surface temperature near the center of the piston (r = 0) is observed. When you move away from the center of the piston (r ~ 30 mm) the temperature drops as the cooling effects of the piston interface increase the radial heat transfer. The surface temperature rises sharply near the outer edge of the bowl (r ≅ 55 mm). As expected, the surface temperature of the aluminum substrate is significantly lower than that of the uncoated piston surface due to the low thermal conductivity of the coating. The temperature curves obtained for different bottom thicknesses are similar to each other and approximately equidistant. Lowering the temperature on the metal surface makes a positive contribution to the strength of the piston material. Changes in maximum temperatures with coating thickness for substrate coating surfaces are shown.



a) b)

Figure 2. It is shown the distribution of the temperature of the piston surface. **a)** The radial distance represents a radius of piston OA and **b)** Distribution of transient temperatures along the sidewall of the piston AB

Figure 2b) shows the distribution of the transient temperature along the sidewall of the ceramic-coated piston. As expected, because of the heat transfer process in coated piston through a three-layer wall. The first layer is an oxidized layer, the second is the base material of the piston, and the third is the layer of cooling engine oil, this would lead the transient temperatures gradually decreases towards the skirt of the piston.

In the process of thermodynamic modeling of a diesel engine, the instantaneous gas temperatures and convective heat transfers are determined, and the predictions on the finite elements of the instantaneous heat flow are used to determine the moment when the engine goes into quasi-stationary operation. This technique allows us to identify complex trajectories of heat flow transition in the combustion chamber and significantly improve the thermal conductivity of diesel engine heat flow models. This makes it possible to plan thermal areas in components, providing designers with tools to track the heat flow path.

4. Conclusion

The methodology of conjugate thermodynamic and heat transfer analyzes of a diesel engine is presented. The methodology is based on the modified quasi-steady method (MQM) and finite element methods (FEM). It was shown that this methodology can reveal the complex transitional paths of the heat flux in the combustion chamber of the engine and reveal the details of the distribution of heat losses in various cooling media. Using two-dimensional resistor networks, it is possible to more accurately analyze the heat generation and the predictions of engine performance with geometrically similar components. Despite the fact that the methodology of coupled thermodynamics and heat transfer presented here was demonstrated using the MQM and FEM programs developed by our group, it is certainly general and can be adapted to any programs that have capabilities similar to those used in this analysis . In addition, the methodology can be easily expanded to determine the values of resistors associated with heat flow paths obtained from the analysis of three-dimensional FEM. However, it is believed that such additional complexity is not justified, unless the boundary conditions for gas used in the FEM analysis are not for space, but for time are formulated. The latter approach will require the use of a program based on fluid mechanics (in contrast to the MQM analysis in combination with three-dimensional models of thermostructural components).

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