Summary

The upcoming demanding targets in terms of CO_2 reduction and the increasingly stringent emission regulations are forcing the car manufacturers toward the adoption of innovative technologies left so far in the closet. In the future scenario, the diesel engine will still play a key role in the automotive market, especially for heavier applications, thanks to its higher efficiency respect to gasoline counterpart which can help to lower the average CO_2 emissions of the entire car fleet. Moreover, the estimated full electric cars penetration (only 21% in Europe by 2030) makes the diesel engine development fundamental for the remaining share of vehicles equipped by an internal combustion engine. Additionally, many cost-benefit analyses show that is more convenient to fully exploit the residual efficiency potential of combustion vehicles (including hybrid technologies) respect to transitioning immediately to fully electrified cars. Notwithstanding that, many obstacles (including NO_x and soot emissions, air quality regulations in metro-cities and diesel bans) are excluding diesel vehicles from the urban areas.

In this complex scenario, where CO_2 reduction technologies are becoming exponentially expensive, a high-priced solution, as engine thermal insulation, turns competitive, especially if combined with the exhaust aftertreatment systems on the new diesel engine generation. In particular, beyond the efficiency improvement, the thermal insulation technology can improve the aftertreatment system performance and accelerate the catalyst light-off, due to the produced higher exhaust gas temperature.

This *Thesis* investigates the potential of thermal insulation in reducing fuel consumption and CO_2 emissions of a 1.6 l automotive diesel engine.

The review on the state-of-the-art Thermal Barrier Coatings (TBCs), performed in collaboration with different Departments of Politecnico di Torino, has allowed identifying a large number of mechanical, chemical and thermo-dynamical issues deriving from the technology. In addition to the traditional TBCs (i.e., ceramics), a new kind of coating (anodized aluminium), exploiting the thermal swing concept, has been studied.

Successively, numerical analysis, by utilizing a one-dimensional Computational Fluid Dynamics (CFD) engine simulation code, was carried out to investigate the most promising thermal insulation technologies for engine efficiency enhancement and heat loss reduction. The investigation of the complete and ideal insulation of the engine components (piston, firedeck, liner, and valves) has pointed out that piston insulation is the most efficient technology for improving efficiency and reducing heat transfer. Then, the numerical analysis has been addressed to the evaluation of the most efficient piston TBC, using a lumped-mass thermal model directly coupled with the engine model. The simulations have shown on average 0.8% in Brake Specific Fuel

Consumption (BSFC) improvement and 5% in heat transfer reduction if a 100-μm-thick anodized aluminum TBC is used. The simulation outputs were successively used to set the guidelines for designing the theoretically most suitable piston coating, which was then tested on a real automotive application.

The last part of the *Thesis* focuses on the results of an experimental campaign carried out on a prototype automotive diesel engine, for evaluating the effects deriving from the use of full coated pistons, respect to the traditional ones (aluminum-made). Despite the promising potential for efficiency improvement highlighted by the numerical simulation, the experimental campaign has indicated a slight worsening of the engine efficiency (up to 2% at lower load and speed) adopting coated pistons. Moreover, the burn rate analysis has revealed that the coated configuration presents a slower mixing-controlled combustion phase, and a consequent combustion shift towards the late combustion, which are the leading causes of the indicated efficiency worsening. The higher surface roughness and porosity of the coating (R_a 8 μm of coating vs. R_a 3.2 μm of aluminium) are the critical factors for the combustion slowdown.

In conclusion, this research activity has led to the following outcomes:

- Piston results to be the component with the most significant potential in terms of heat transfer and BSFC reductions when it is thermally insulated. This result can be explained by the greater surface of the piston exposed to the in-cylinder gas during the combustion if compared with the other components. Furthermore, the combustion is intentionally directed towards the piston, causing higher turbulence and temperature near its surface and, consequently, a greater heat flux through this component.
- High coating surface roughness and porosity are detrimental for the engine efficiency and pollutant emissions (especially soot and unburned hydrocarbons). Surface roughness and porosity should therefore be reduced through an appropriate sealing of the coating pores.
- The use of TBC on the entire piston surface (including the bowl zone) can cause thermal efficiency worsening due to the interaction between the impinged fuel spray and the coating in case of increased surface roughness of the coating, therefore the use of TBC should be limited to the piston crown surface only.
- Thermal swing concept is fundamental for reducing the engine thermal losses without any penalties in term of volumetric efficiency and pollutant emissions. Thermal swing concept can be achieved with low-thermal-inertia and low-thermal-conductivity TBCs.