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The Effects of the Specific Material Selection on the Structural Behaviour of the Piston-Liner Coupling of a High Performance Engine

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ABSTRACT

The materials commonly employed in the automotive industry are various and depend on the specific application field. For what concern the internal combustion engines the choice is guided by the thermomechanical performance required, technological constraints and production costs. Actually, for high-performance engines, steel and aluminium are the most common materials selected for the piston and the cylinder liner manufacturing.This study analyses the effect of possible material choice on the interaction between piston and cylinder liner, via Finite Element analyses. A motorcycle engine is investigated considering two possible pistons: one (standard) made of aluminium and one made of steel. Similarly, two possible cylinder liners are considered, the original one made of aluminium and a different version made of steel obtained by simply thinning the aluminium component in order to obtain two structurally equivalent components.In particular, four possible combinations of coupling between piston and cylinder liner are identified, derived from the two variants of applied materials. The components theoretically necessary for the Finite Element model are the engine head, the engine block, the bolts, the gasket, the upper part of the crank mechanism and the cylinder liner. Nevertheless, a simplified methodology is employed to reduce the computational effort.This analysis makes it possible to evaluate gap and interference with respect to the material choice. A first proposal of the barrel shape and ovality of the steel piston is obtained starting from the original aluminium piston and the thermal field involved in the analysis. Besides, the presented methodology consists of a useful tool to estimate the stress field and the fatigue safety factor of the components involved.The results obtained with this methodology can guide the definition of the correct piston profile, temperature field and stress distribution estimation, as a function of the specific materials employed for piston-liner coupling.

Introduction

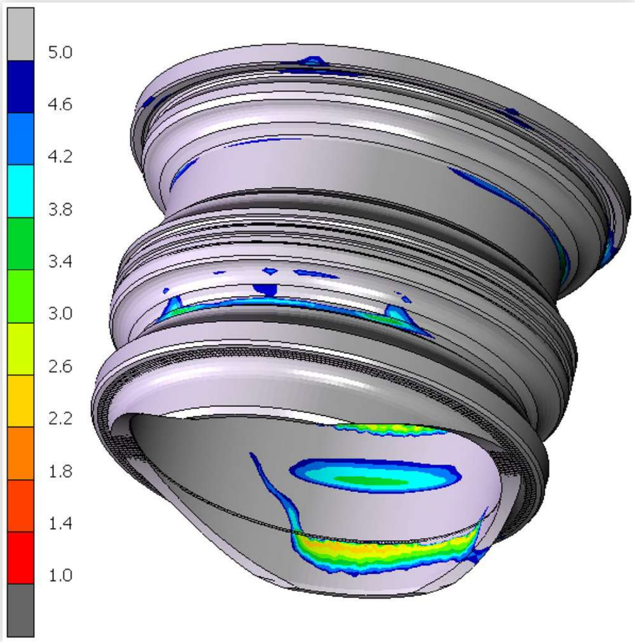
The piston is a crucial element in the transmission of power [1]. In the combustion chamber of an engine, the chemical energy contained in the fuel is rapidly converted into heat and pressure during the combustion phase. The piston, which is the moving part of the combustion chamber, has to convert this energy into mechanical work. The most important tasks that the piston must fulfil are: to transmit force from the working gas (power stroke) and to the working gas (compression stroke), to be the variable lower bounding for the combustion chamber and to seal it, to guide the connecting rod, to dissipate heat, to support (in four-stroke engines) or to control (in two-stroke engines) the charge exchange, to support the mixture formation and to house the ring pack. Therefore, the most common requirements are high structural strength, adaptability to operating conditions, low friction, low wear, low oil consumption and low pollutant emissions. It is obvious that a proper material choice for this component is fundamental to meet these tasks [2, 3, 4].

Nevertheless, almost the whole road vehicles circulating nowadays adopt pistons made of aluminium. The only exceptions are present in fields far from series applications: in slow Diesel engines, cast iron is used, while, in competitions, magnesium alloys are employed, which have less density, but also less resistance and a high friction coefficient combined to the other engine components.

On one hand, aluminium exhibits low density, low friction coefficient with the cylinder liner and a good heat dispersion thanks to its high value of thermal conductivity. On the other hand, the high value of its thermal expansion coefficient might cause blow-by during the cold start phase, thus resulting in not being able to fulfil the recent pressing emission norms. Moreover, the mechanical properties of aluminium collapse above 300°C and its high value of thermal conductivity negatively affects the adiabatic efficiency of the combustion chamber, even if a high value of thermal conductivity might help the temperature of the piston to be controlled.

Steel could be a much more suitable material for any kind of piston regardless of its specific usage. In particular, steel presents a low thermal expansion coefficient, thus resulting in a cold shape of the piston more similar to the one reached during the operating conditions, if compared to an aluminium piston [5]. In addition, steel exhibits a low thermal conductivity, which can positively affect the adiabatic efficiency of

FIGURE 32 Dang Van fatigue safety factor contour plot, steel piston and steel liner.



to obtain the same thermally deformed shape of the skirt when compared to the aluminium piston. Afterwards, the geometry of the steel liner was defined; in particular, the internal bore was calculated to exhibit the same diameter if compared to the aluminium one during the operating condition.

These components were analysed using numerical tools; in particular, four different configurations were investigated: piston and liner made of aluminium, aluminium piston and steel liner, steel piston and aluminium liner and, finally, both piston and liner made of steel. The main aspects analysed in the results have been the presence of gap or overlap, the distribution of the contact pressure, the extent and position of the contact area and the fatigue life safety factor of the liner. Obviously, the original configuration of the aluminium piston and liner did not exhibit any critical issue. The second configuration, aluminium piston and steel liner, showed a wide gap when the cold engine condition was taken into account. Therefore, the lubricant oil distribution could not be optimal during the first engine cycles. The fatigue analysis of the stell liner did not show any issue, thus suggesting the possibility to further thin this component. The third configuration, steel piston and aluminium liner, showed a strong overlap between these two components during the cold start. Preheating the liner and the block before starting the engine appeared to be mandatory, thus limiting this application to the racing cars field. This third configuration displayed also the necessity to correct the oval shape of the piston, which could not be simply retrieved from the original aluminium piston. Iterative cycles of geometry modifications and Finite Element verifications should be performed. Also the last fourth configuration, steel piston and steel liner, displayed that the steel piston ovality should be increased. In addition, a small overlap was present at room temperature, thus suggesting to correct the external shape of the steel liner and the water jacket to be modified in order to properly cool down the lower part of the liner thus allowing a larger cold bore to be designed.

Future works should include an experimental validation of the results obtained. First, the static and fatigue strength of the designed steel piston must be checked. It could be possible to insert the new piston directly into the engine with the original aluminium cylinder liner, but there would be an unnecessary risk of seriously damaging the entire engine. Instead, an ad hoc test rig could be built, in which the crank mechanism moves inside a simplified cylinder liner and the pressure exerted by combustion is simulated by a compressible body placed on the top of the piston. Secondly, it would be necessary to test in detail the contact interaction between piston and cylinder liner in the four configurations according to the different materials used. Finally, it is necessary to test the four possible configurations in the actual engine and investigate in detail the cylinders and pistons looking for breakages, damages or polishings of the components that could be the consequence of too high contact pressures and therefore a probable symptom of not sufficiently suitable piston profiles.

Further analysis could be performed to consider also the different dynamic effects based on the different configuration adopted. In fact, the gap strongly affects the secondary motions of the piston. In particular, the simplified methodology exposed in [24] would speed up also this possible last phase.

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Definitions/Abbreviations

ps - profile of the steel piston

hs - hot profile of the steel piston

ha - hot profile of the aluminium piston

s - steel

a - aluminium

HTC - heat transfer coefficient