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# Current challenges in material choice for high-performance engine crankshaft

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**Abstract**

The segment of high-performance cars will progressively deal with the trade-off among cost saving, high performances and quality due to customers' higher expectations and the regulations requests for higher-power, safer, more intelligent and environmentally-friend cars. Dealing with these complicated systems requires additional designing phases and optimization of all components in terms of performances, reliability and costs. Among such mechanical parts assembled in an Internal Combustion Engine (ICE), the crankshaft is one that still requires extra attention regarding materials choice, thermal treatments, producing processes and costs. The aim of this work is to analyze the actual and future scenarios about the material choice for the crankshaft of high-performance engines. In particular, what is considered here is the actual development and improved quality reached by base materials and manufacturing technologies for this critical component of the engine. In this context, different materials are analyzed, together with surface hardening techniques, thermal treatments and their technical and cost saving potentials.


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## 1. Introduction

The need to deepen the aspect of costs savings while designing and manufacturing mechanical components is becoming a feature of hard management by automotive manufacturers. In fact, they must offer products that not only

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should guarantee high performances and elevated standards of quality, but also be attractive for a demanding clientele asking for safer, more powerful and intelligent cars. Moreover, all these aspects must be compliant with the more and more stringent regulations for vehicles imposed by governments and with the new procedures for the control of emissions, such as the adoption of new Real Driving Emission (RDE test) and Worldwide Harmonized Light Vehicle Test Procedure (WLTP test) (as Commission Regulation 2016/427suggests). Internal Combustion Engines (ICE) solution is still the main power technology adopted for urban vehicles, and plays a critical role on the matters presented above; therefore, when it comes to ICE development, OEMs need to carefully consider their design and construction. On one hand engines should develop high powers and torques, while on the other hand they have to keep low levels of fuel consumption and emissions (95 g/Km $CO_2$ emission by 2021, which means fuel consumption equal to 4.1 l/100km of gasoline and $NO_x$), as well as being cost-effective for OEMs. Therefore, the way that is currently going to be followed by automotive companies is to produce engines with higher specific powers, low weight and optimized thermal performances. Nowadays, hybrid supercharged/turbocharged ICE coupled with electric machines are more and more compulsory options among OEMs because they allow the use of compact and downsized thermal units, thus lighter (although electric machine systems are considerably heavy), or in any case better weight-balanced.

This is true also for high-performance car makers, which are heading towards the production of sophisticated hybrid vehicles with electromechanical systems that affect both the powertrain behavior and the vehicle dynamics. Moreover, time schedule issues sum up to these technical complications, causing to rush not only the design phase of components themselves, but also the production processes as well as the overall quality (Arcidiacono (2004)).

Considering all the above, the crankshaft is one of the most complex and functional component when dealing with ICE, and requires strategic investments in its production. This is a critical component for the ICE due to the high loads coming from the mixture combustion, the inertia of pistons and connecting rods and from the transmission assembly. In order to safely avoid the shaft to catastrophic failures caused by stresses, a very robust and proper design project has to be done.

Crankshafts for road vehicles are generally made by casting irons or forged steels. Considering high performance engines, the choice often falls on forged steels because they guarantee high mechanical properties, as studies have shown (Williams and Fatemi (2007), Zoroufi and Fatemi (2005), Nallicheri et al. (1991)). However, Menk et al. (2007) and Druschitz et al. (2006) revalued the cast irons due to improved casting processes and developed new type of austempered iron (MADI machinable austempered ductile iron) respectively – the article will take into consideration the steel forged crankshaft only. More specifically, the aim of this article is to highlight the current design and implementation scenario of a component such as the crankshaft, considering the entire production process from the design phase to the realization one, giving prominence to the technical aspects, volume of production and costs.

The design phase of the components is guided by several constraints. Basically, the first steps of the project are related to the definitions of the crankshaft configuration, starting from the engine layout – that means linear or V shape, the stroke length value and the maximal length of the crankshaft. The values of the combustion pressures, thus the value of the generated forces, must be well defined in the early stages, as well as the inertia forces of the piston, those of the connecting rods and the maximum revs. At this stage, the values of the mechanical characteristics needed for the project are at least identified. Moreover, other several critical points shall be considered for the best design of the crank; the vibration modes generation is relatively important, but this aspect will be no further investigated. Anyhow, it is interesting to concentrate on the possible solutions related to the development of a crankshaft with high mechanical properties. The simplest way to counteract high loads would be working on the geometry of the crankshaft and increase its dimensions. This is a hazard because in such way the moment of inertia and the mass become higher, and so are the friction losses and the power required for the acceleration of moving components, as reported by Cevik et al. (2009). A second option is related to the possibility of shaft elongation to increase the resistant section, avoiding the modification of the journals in terms of diameter size. This is a risk because of the decrease in rigidity of the shaft and the extension of the length of the engine affecting the room available. In literature many scientific papers developed some design approaches using methodologies such as TRIZ (Arcidiacono et al. (2016)) and Axiomatic Design (Arcidiacono et al. (2017)) to guarantee the reliability and robustness of the system during design phase. Through these approaches it could be possible to develop an optimized design solution for the chranshaft. Otherwise, the designers can concentrate their efforts on multi-objective optimization in materials selection (Cavallini et al. (2013), Giorgetti et al. (2017)) or deal with material, choosing for better and stronger materials while keeping and optimizing the geometry of the components with very few modifications.