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A repertoire of failures in connecting rods for internal combustion engines, and indications on traditional and advanced design methods

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ABSTRACT

Several typical and uncommon failure modes in con-rods for internal combustion engines are commented from the stress level viewpoint. The interpretation of the fractures is supported with traditional calculations, with more advanced analytical models, and with Finite Element (FE) predictions. The repertoire of failures in a con-rod is presented by separately addressing the parts composing the con-rod itself, namely the shank, and the small and big ends.

1. Introduction

The connecting rod is one of the most important components employed in internal combustion engines. Its extremities are shaped as eyes, named con-rod small end (upper) and con-rod big end (lower), connected by a beam-like shank. The small end of the connecting rod is joined to the piston by means of the gudgeon pin, whereas the big end is mounted on the crank-pin of the crankshaft. The function of the connecting rod is to translate the alternating transverse motion of the piston to the rotational motion of the crankshaft.

Making part of the engine, the connecting rod is subjected to high-cycle fatigue loading. Contributions due to both gas forces and inertial forces have to be considered. The connecting rod has to be strong enough to bear the external loading, rigid enough to allow a correct coupling with the gudgeon pin and the crank-pin and, at the same time, it has to be light enough to minimize the inertial forces derived from its motion. In particular, a certain portion of the connecting rod may be considered as an alternating mass, thus directly affecting the maximum value of the alternating forces. As a consequence, particular care has to be devoted to the connecting rod design process. Both analytical and numerical methods are usually employed for connecting rod optimization [1–4].

The collapse of a connecting rod is among the commonest causes of catastrophic engine failure. This paper presents several typical and uncommon failure modes of connecting rods employed in internal combustion engines, and it reports an explanation

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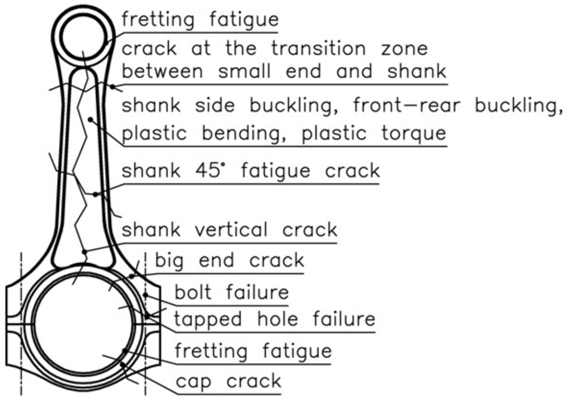

Fig. 1. The locations of the most critical con-rod sections.

of the various failures in terms of their stress field. The interpretation of the various collapses either rests on approximate formulae for the stress field, available in standard textbooks, see [5–10], or on more advanced theories, which will be recalled throughout the text where pertinent, or, finally, on FE forecasts.

To correctly interpret the con-rod fracture modes, it is necessary to understand the loads applied to this mechanical component. The following Sections separately address the various parts composing the con-rod, namely the shank and the small and big ends; their loading conditions and stress field are considered, and common and uncommon failure modes are discussed. The locations of the most critical con-rod sections examined throughout the paper are summarized in Fig. 1.

The collapsed con-rods illustrated in this paper form part of the collection of the Engineering Department Enzo Ferrari, Modena, Italy; the con-rods mainly originate from a long-lasting collaboration of the Engineering Department with several vehicle industries of the territory; the con-rods also constitute a teaching support to the courses offered on the structural design of internal combustion engine components.

2. Con-rod shank

The con-rod shank is subjected to compression, due to the combustion pressure, at top dead centre at the beginning of expansion, or when it is at bottom dead centre. Conversely, the shank undergoes tension, due to the inertial forces exerted by the mass of the piston and of the gudgeon pin, at top dead centre at the beginning of induction stroke. The fatigue stresses within the con-rod shank are therefore reversed.

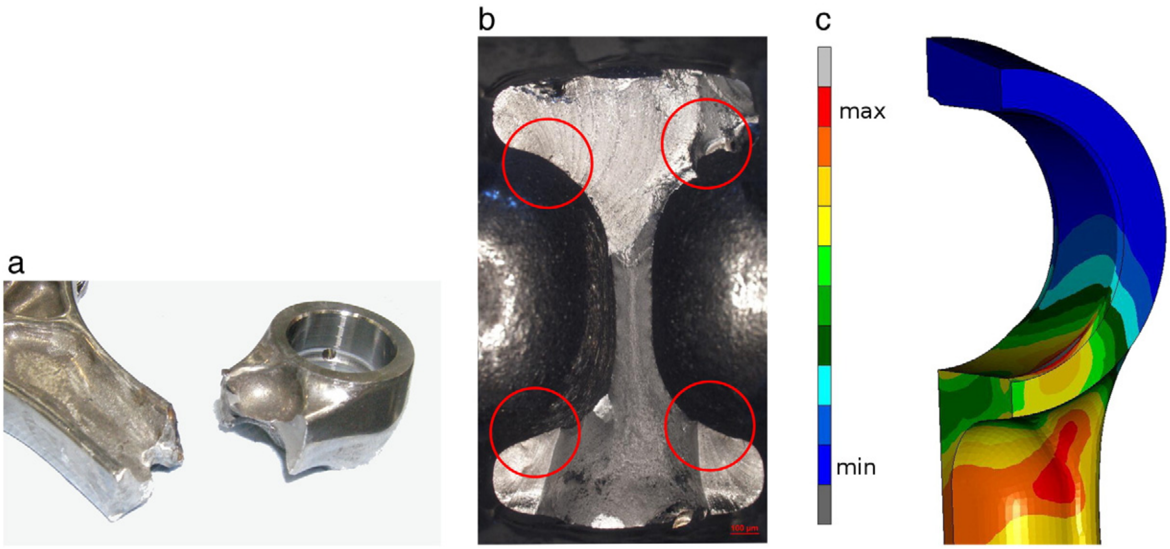

Fig. 2. Fatigue crack at the transition zone between the small end and the shank: (a) fatigue fracture; (b) crack initiation points; (c) FE forecasts: equivalent von Mises stress distribution.