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FDMDII conference (Extended Abstract)

Characterising the impact of surface integrity on the fatigue behaviour of forged components

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Abstract

The present study focusses on analysing and modelling the influence on fatigue behaviour of the surface of a hot-forged C70 connecting rod which undergoes a shot-blasting treatment. The shot-blasting heavily affects the surface and thus the fatigue properties. In addition, the forging process introduces large defects which also have an effect on the fatigue strength. So as to be able to determine which aspects of the surface integrity are the most influential in fatigue, various surface states were thoroughly characterised and then tested in high cycle fatigue in bending. The various aspects studied are the surface roughness and large defects, residual stresses, microstructure and hardness.

This study is part of a French national research project involving nine partners from the metal supplier to the final user (French car maker). Its object is to study the influence of surface integrity on the fatigue behaviour of forged components. This paper will focus on a hot-forged connecting rod for automobile engines. The component has various surface states which, in addition to fatigue tests, have been thoroughly characterised. The combination of fatigue tests and surface characterisation allow us to determine and to model the aspects of the surface integrity with the most influence on the fatigue behaviour. The goal of the study is to develop a fatigue criterion which takes into account the surface integrity to predict the fatigue strength of a forged component and ultimately, to improve the fatigue behaviour of said components.

1) Characterising the surface state of the connecting rod

The studied component is a C70 pearlitic steel hot-forged connecting rod which is then shot-blasted to clean off the scale. This shot-blasting process has a very large influence on the fatigue strength of the component.

In order to study a sample relevant of the forging process, 500 consecutive shot-blasted connecting rods (without the usual shot-blasting process) were sampled from the production line. This large sample allows for a statistical study of the surface integrity and the extrapolation as-forged to the entire production.

Shot-blasting affects many properties of the treated surface in addition to modifying its topography. It affects the microstructure of the component's surface, its hardness and roughness and introduces residual stresses. In addition to the homogenous roughness, the components feature large defects before and after shot-blasting, which also have a noticeable effect on fatigue, as shown by Murakami [1].

The surface integrity is characterised through hardness tests, X-ray diffraction, EBSD and surface topography scans. Shot-blasting has a small effect on roughness (Ra ~8 µm) but modifies heavily the aspect of the surface. This roughness could have a negative effect in fatigue (Suraratchai et al [2]). In addition, it introduces 500 MPa of compressive residual stresses in the surface. The residual stresses are at their maximum value on the surface and reach zero at a depth of around 500 µm.

To distinguish the influence of the various effects of shot-blasting, fatigue tests and characterisations were done on two additional surface states: the as-forged surface (before shot-blasting), and a machined and polished surface. An additional 500 consecutive as-forged connecting rods were sampled. The as-forged surface has negligible residual stresses (< 50 MPa) and no hardening or microstructure gradient. It does however have the large defects from the forging process. The polished specimens have no surface effects and serve as the fatigue reference for the study.

2) Fatigue tests

Fatigue tests on specimens with various surface conditions are performed in addition to the surface analysis. The fatigue specimens are machined out of connecting rods prior in order to characterise the fatigue behaviour of the surface. Fatigue tests are performed in plane bending with min/max stress ratio of R = -1 and serve to quantify the effect of surface integrity on the fatigue strength at 2.10^6 cycles (frequency: 70 Hz). Table 1) gives an overview of the various surface states with their provisional fatigue limits.

Surface State	**Machined & Polished**	**As forged**	**Shot-blasting**
Ra (µm)	~0	6	8
Surface Residual Stresses (MPa)	~0	-40	-500
Surface Hardness (HV)	300	300	350
Provisional Fatigue Limit (MPa)	425	330	> 500

Table 1) Summary of surface states with corresponding roughness, surface residual stresses and provisional fatigue limit

Comparing the polished surface with the as-forged surface shows that the surface topography has a large negative effect in fatigue (-22%). Observation of the fracture surfaces show that the fatigue behaviour is dictated by the large defects. Additional tests performed on 20 specimens following the “step” technique as proposed by Maxwell and Nicholas [3] show a correlation between defect size and associated fatigue strength.

Concerning the shot-blasted connecting rods, the hardening and residual stresses introduced by the shot-blasting increase the fatigue strength (+50% fatigue strength compared to as-forged). In this case, because of the competing effects of the defects versus the residual stresses combined with hardening, it is more difficult to determine the most influential factor in fatigue.

The first step in creating a model for these two competing effects is to characterise the influence of the surface topography. The fatigue tests combined with the surface scans allow for the easy detection of the critical defects and their associated fatigue strength. Combined with finite element simulations of the defects, this will lead to a fatigue criterion based on the defect shape and size (see fig (1) for a diagram detailing this approach).

The next step will then be to introduce in the model the hardening and residual stresses present in the shot-blasted surface. The goal of this approach is to be able to predict the critical defect and the fatigue strength of a specimen without resorting to a fatigue test, simply by analysing the surface of said specimen.

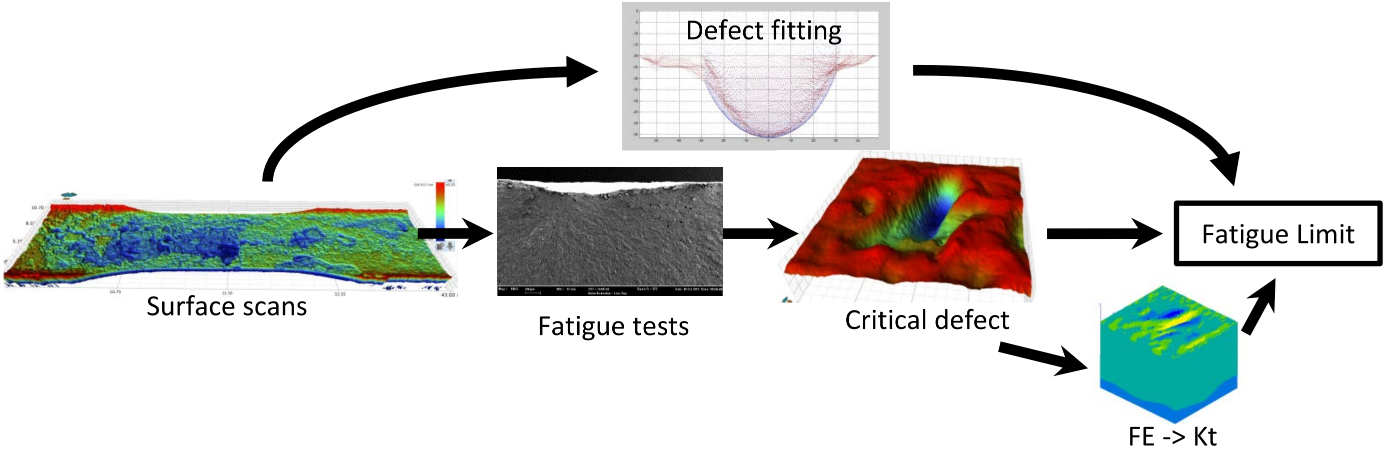

Fig 1) Approach for modelling the influence of defects in fatigue: fatigue limit prediction based on defect shape fitting.

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