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# Rolling Contact Fatigue: experimental study of the influence of sliding, load and material properties on the resistance to micro-pitting of steel discs.

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## 1. Introduction

Rolling Contact Fatigue (RCF) is a major issue in the transport industry, as the formation of pits and/or spalls on contacting surfaces may cause the failure of vital components. A twin-disc machine was used to reproduce the contact conditions met in gears [1, 2], and a preliminary study was carried out to determine the effects of sliding and load on the formation of micro-pits, in the range found in common gearboxes. As sliding is known to modify the sub-surface stress fields, bringing the crack initiation sites closer to the surface [3], the range of slide-to-roll ratios found on gear teeth may lead to different fatigue mechanisms. Metallographic studies were used to study the crack initiation sites for a low amount of sliding, and they also pointed out the effects of heat treatments on the material structure and their influence on crack propagation. Finally the impact of surface roughness on the resistance to fatigue was considered, by comparing different surface machining techniques and surface treatments such as shot peening.

## 2. Influence of operating conditions on the resistance to RCF

This initial study was carried out on 27CrMo4 steel with a carbonitride heat treatment under atmospheric pressure. The first tests were carried out in the same conditions but for four different slide-to-roll ratios (SRR): 6%, 20%, 40% and 80%. The influence of the SRR on RCF is shown on Figure 1. The damage on these surfaces was quantified in terms of surface and depth of the micropits formed during the test. It appears that the higher the SRR, the greater the damage. For 80% SRR however, the absence of micropits is due to an important abrasive wear, which seems to remove the pits as they appear. An increase in SRR consequently seems to decrease the resistance to RCF until wear becomes predominant over fatigue [4]. In the current test conditions, this threshold is reached between 40% and 80% SRR. Typical crack profiles found on the samples are shown on Figure 2: a main crack first appears near the surface, propagating through the material in the sliding direction. Secondary cracks then originate from or near this main crack, extending back to the surface. The pit is then formed, and the debris ejected from the surface.

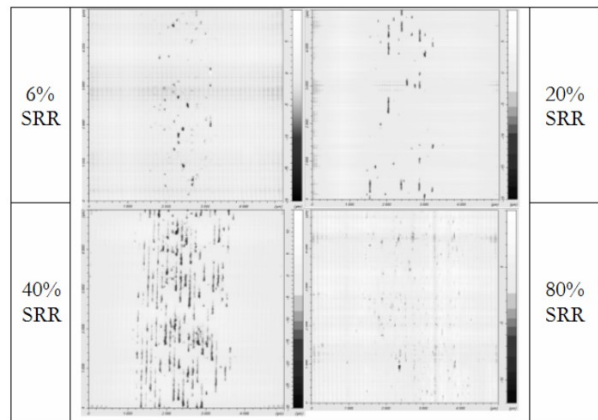


Fig. 1. Influence of the SRR on pitting

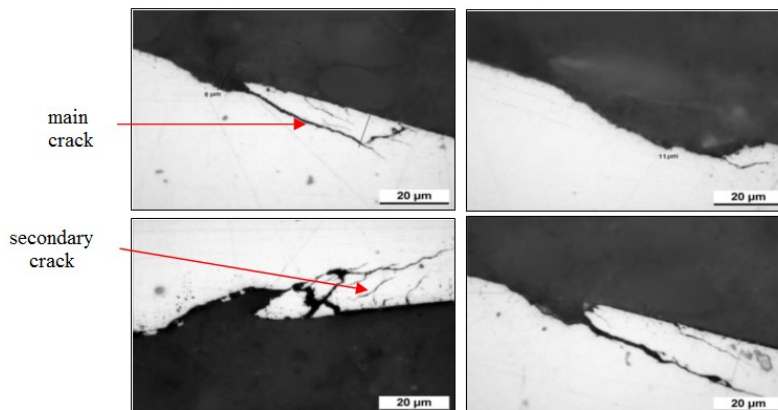


Fig. 2. Metallographic observations of the cracking phenomenon at 6% SRR

The load influence was also studied, for the following contact pressures: 1.5, 2 and 2.5 GPa (Fig. 2). The tests were carried out under the same conditions as previously, with a 20% SRR. The amount of damage was similar for all the discs. These results show the absence of any influence of the contact pressure on RCF in the range studied.

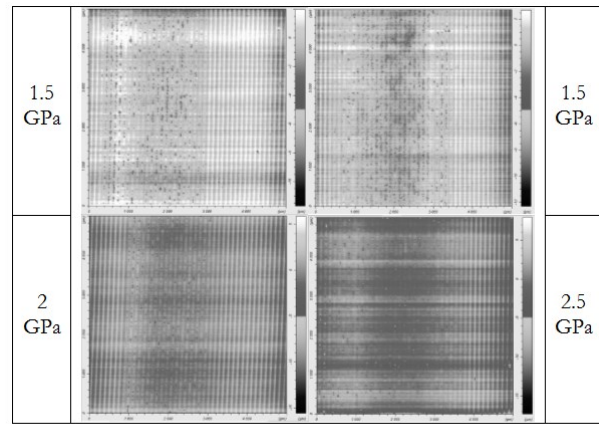


Fig. 3. Influence of the contact pressure on pitting

### 3. Influence of material properties on the resistance to RCF

The crack profiles observed in Figure 2, and more particularly the numerous secondary cracks, seem to betray the existence of discontinuities in the material. When heat treatments are carried out under atmospheric pressure, the presence of oxygen in the oven causes oxide formation which may act as discontinuities, facilitating crack propagation [5]. To verify this, tests were carried out for both low-pressure and atmospheric pressure carbonitride heat treatments applied to 29MnCr5 steel. Less surface damage was inflicted to the surface in the first case, and the samples exhibited much shorter primary cracks (Fig. 4). This confirms the negative effect of atmospheric-pressure heat treatments on the resistance to RCF, due to the formation of oxides under the material surface.

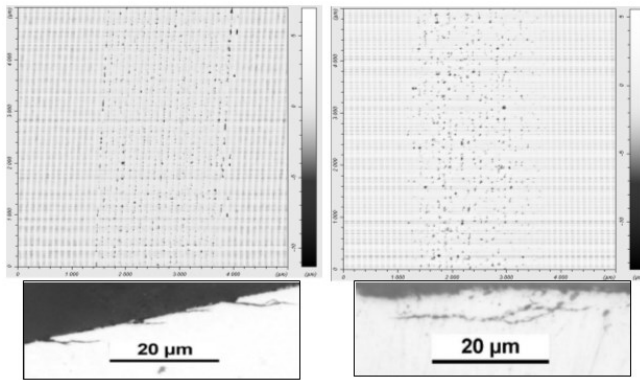


Fig. 4. Crack profiles for 29MnCr5 steel under different heat treatments

metallographic observations show a clear difference in crack profiles: for 29MnCr5 the cracks seem to propagate to a certain depth (approx. 7-8 µm) and then become parallel to the surface, whereas for 27CrMo4 the cracks extend to a greater depth. The mechanical and structural properties being similar for both steels, their oxide layers were observed using 3% Nital etching (Fig. 5). They are approximately twice as deep for the 27CrMo4 steel than for the 29MnCr5 steel, although they were heat treated under the same conditions. It shows a better oxygen diffusion for the first alloy, which was more damaged during testing. The depths to which the cracks extend for each steel can furthermore be related to the thicknesses of the oxide layers.

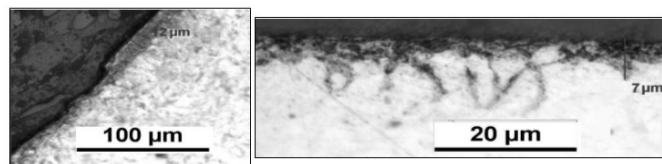


Fig. 5. Oxide layers for 27CrMo4 (on the left) and 29MnCr5 (on the right) steels for heat treatments carried out under atmospheric pressure

The influences of shot-peening and of the machining techniques used on the surfaces were furthermore considered. Two types of shot peening were used: class A shot peening (CASP) and the more severe class B shot peening (CBSP). Under the operating conditions used and for discs obtained by turning, shot peening improved the resistance to pitting of both the low-pressure treated and the atmospheric-pressure treated discs. For CBSP, the improvement was such that the resistance to RCF was found to be the same for both heat treatments.

Surface roughness plays a predominant role on the component's resistance to fatigue wear, as it affects directly the surface and sub-surface stress distribution. The final objective of this experimental study was to test the influence of surface machining on the resistance to RCF. Two processes were considered: grinding and turning. Whereas the disc with the turned surface showed many pits with depths reaching 20µm, the ground disc did not exhibit any pits at all (Fig. 6). An additional test was carried out with a

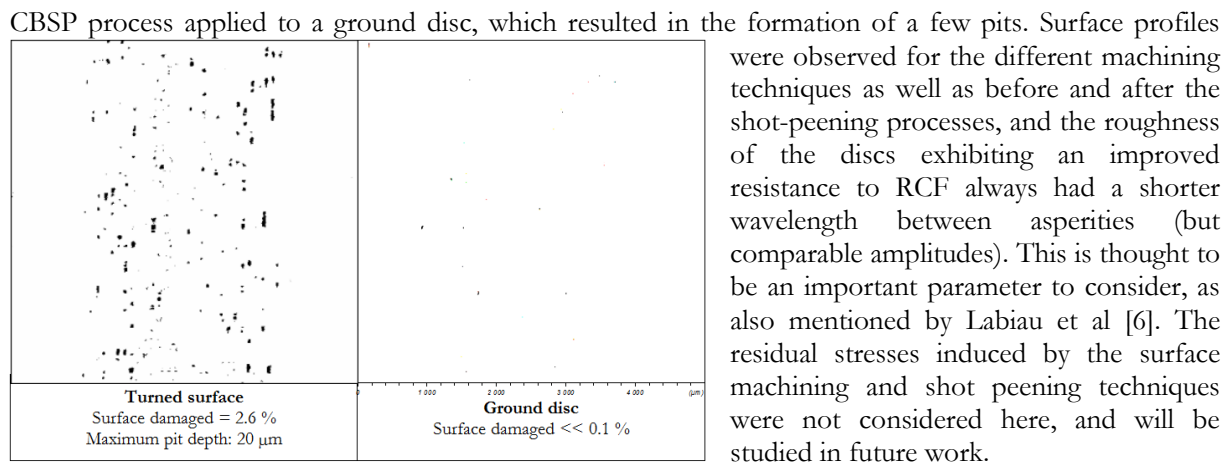


Fig. 6. Benefits of resurfacing for atmospheric-pressure heat treated steel discs

#### 4. Conclusion

To summarise, this study gives rise to several conclusions for the tested operating conditions, which are comparable to those found in automotive gearboxes:

- an increasing SRR will tend to reduce the material's resistance to RCF, until a threshold SRR is reached when wear becomes predominant;
- the contact pressure did not affect the material's resistance to RCF in the range considered (1,5 - 2,5GPa);
- the diffusion of oxygen in the material during heat treatments carried out under atmospheric pressure will weaken the component's resistance to pitting considerably, by forming oxides in the material structure. The benefit of using low-pressure heat treatment to avoid this oxide formation was shown. For steels treated under atmospheric pressure, a greater resistance to pitting was directly linked to the poor diffusion capacity of oxygen in the material, forming thinner oxide layers at the surface.
- shot peening improves the material's resistance to RCF. A greater improvement was observed for the most severe process. This may be due to some or all of the following: surface hardening, smoothening of the surface roughness and addition of compressive residual stresses in the material surface.
- the surface machining technique used may greatly affect the material's resistance to RCF: in this study, grinding instead of turning the discs greatly improved their resistance to pitting. This may be related to the average wavelength between asperities of the resulting surfaces.

#### 5. References

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#### 6. Keywords

Rolling Contact Fatigue (RCF), micro-pitting, heat treatments, surface treatments, shot peening, material properties, twin-disc machine.