FATIGUE IN LUBRICANTS ENVIRONMENT

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The lubricant as environment modifies the fatigue behaviour, particularly in fatigue contact. The lubricant influence is studied :
- on fatigue crack propagation which shows a strong influence of lubricant and temperature effect.
- on crack initiation on which lubricant has a beneficial effect.

Fractography and surface analysis with LAMMA micro-probe analysis indicate that water contained in oil has an effect of stress corrosion on fatigue crack propagation.

INTRODUCTION

Rolling contact fatigue appears on the surface of components such as cams and toppets, gears with cyclic loading. The first step is the formation of little pits and flakes which can develop and finally cause the failure of the machine. Generally, this phenomenon is studied by rolling contact tests conducted on four-ball fatigue machine, full scale ball bearings and thrust bearing rigs, gear rigs, discs machines, cams and toppets rigs, etc ...

The interpretation of these results is difficult due to the interaction of several parameters, but these tests are convenient to rank lubricants and additives quickly and easily.

The lubricant has two major influences :

- Influence on rheological and tribological properties.
- Influence on fatigue mechanism.

The lubricant controls the operating conditions of lubricated contacts such as oil-film thickness, friction coefficient, boundary film adherence and surface wear. These lubricant parameters are known to have a strong influence on fatigue pitting by disturbing stress condition and temperature contact. Lubricant influence on fatigue mechanism are not well-known. Some authors : Galvin and Maylor (1) , Kennel (2) and Armstrong et al (3) have studied the influence of the lubricant on the total life of steel specimen in rotating beam fatigue. Polk, Murphy and Rowe (4) are the unique authors studying the lubricant effect on the propagating phase with notched rotating specimens.

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Considering that friction leads to introduce tensile stress in the contact stress distribution and the maximum value of these stresses are proportional to the friction coefficient μ ($\sigma_{max} = 2\mu \cdot P_{max}$) with P_{max} = maximum hertzian pressure test, and considering that tensile stresses have the major effect on crack propagation, we have studied lubricant influence in fatigue crack process in opening mode.

A particular attention was payed to initiation stage and to propagation stage by using specific fatigue tests.

Influence of lubricant on fatigue crack propagation

Crack propagation tests were led in lubricant environment on 35NCD16 steel.

The chemical composition is the following (in percentage) :

C	Mn	Ni	Si	Cr	Mo	P-S
0.3-0.37	0.3-0.6	3.7-4.2	0.1-0.4	1.6-2	0.3-0.5	0.035 %

Tests were performed on CTW 80 B 20 samples (20 mm thick) put into an immersion cell filled with a lubricant which is circulating around the specimen. The crack is first initiated in the air, then the lubricant is introduced into the cell and the propagation starts under load frequency of 5 Hz and a load ratio R = 0.1. Crack growth measurement was achieved with an optical method. Results are plotted in a bilogarithmic diagram for the variation of the crack growth rate da/dN versus stress intensity factor range ΔK.

The following parameters were studied (basic oil, additives, temperature, viscosity) :

- The effect of basic oil on crack propagation rate as reference ; tests were also led in the air and the crack growth rate curve was linear according to Paris law. In presence of 200 NS basic oil, at 80°C, the crack growth curve deviates from linear shape (Fig. 1). The maximum deviation is in intermediate stress intensity factor range. At low and high ΔK values, the two curves are quite the same. This generally indicates an environment influence. Residence time of lubricant is reduced at low and high crack growth rates.

- The effect of additives : we have also added three additives in the basic oil :

  . ditertiododecyl-polysulphyde (S.A.) (3 % by weight)
  . triaryl-phosphate (S.A.) (2 % by weight)
  . chlorine additive (CA) (3 % by weight)

Tests were conducted at 80°C. The results are reported in terms of relative speed versus logarithm of the stress intensity factor. The relative speed is defined as the ratio of the speed measured in a given environment to the speed measured in the air. The results show that the behaviour of lubricant containing these three additives are quite similar ; they present a maximum effect in intermediate stress intensity factor range. Ditertiododecyl-polysulfide has a lower influence.

- The effect of temperature on crack growth rate in lubricant environment. The 40°C - 100°C range was investigated with the basic oil. Results are presented in the same manner : relative crack growth rate versus logarithm of of stress intensity factor range.

- The effect of viscosity. Tests were conducted with straight mineral oils of different viscosities at 80°C (100 NS, 200 NS, 350 NS, 600 NY). Their viscosities are given in the following table :

OIL	100 NS	200 NS	350 NS	600 NS
VISCOSITY at 80°C (cst)	6.0	9.8	15.6	21.7

It seems that viscosity is not a governing parameter (Fig. 4).

Crack initiation

Tests for studying crack initiation are conducted on the same CT specimens. Mechanical slots have different acuteness and are more blunted than for crack propagation tests (ρ = 2.5 mm and ρ = 1 mm). The same immersion cell is used. The loading frequency is 10 Hz. The behaviour of the materials towards initiation is expressed by the number of cycles required to initiate fatigue crack. We use for this determination a crack opening displacement gauge which is fixed in the front of the notch. Before any crack develop in the specimen, the signal delivered by the gauge is constant. When fatigue cracks start to develop in the specimen, the signal increases. We determine the number of initiation cycles by the signal changement. A series of tests conducted in ambient air are used as reference. Test have been led in 200 NS and 200 NS oils plus 3 % of a chlorinated wax.

The results (Fig. 5) are reported in terms of the number of cycles for fatigue crack initiation Ni, versus the $\Delta K/\sqrt{\rho}$ parameter used by many workers (5). We find a beneficial effect of lubricant environment slightly higher than the scattering band which we can expect in this kind of tests.

DISCUSSION

The influence of lubricant on crack propagation gives an acceleration of crack propagation with temperature. The maximum effect is for 60°C. An observation of the fracture surface shows a corrosion effect at 40, 60°C. On the contrary, at 80°-100°C, the fracture aspect is similar to that one obtained after testing in the ambient air. The SEM fractographs show intergranular failure areas for the tests conducted at 40°C and 60°C, whereas at 80° and 100°C we found the same pattern as that one obtained with the tests conducted in the air (ductile tearing fracture mode - Fig. 6).

Surface analysis with LAMMA microprobe analysis (Laser Microprobe Mass Analysis) indicates the presence of iron oxide. We assume that the acceleration of crack propagation is due to a fatigue corrosion mechanism induced by water in oil.

For verification, we make a fatigue crack propagation test in deshydrated oil with molecular screen (20 p.p.m. of water). Crack propagation decreases in comparison with the oil containing 80 p.p.m. of water but it seems that very few quantities of water in oil are enough to induce stress corrosion fatigue.

The effect of temperature can be explained by a decreasing os viscosity of 200 NS oil (39 cst at 40°C; 6.1 cst at 100°C) and the decreasing of water contents with temperature.

The relative beneficial effect of lubricant on crack initiation can be explained by exclusion of humidity pitting and environment protection. This result is an experimental controversy to literature assumption generally presented. Lubricant influence has not been found on crack initiation but on crack propagation. All tests are conducted in mode I loading, assuming that lubricant influence, as environment agent, is the same in any kind of loading. Lubricant has also a strong influence on mechanical loading in contact fatigue. Stress distribution is influenced by friction coefficient, tensile stress, and important shearing stress are present in pressure contact. Stress intensity and distribution are modified by the friction coefficient and crack propagated in mixed mode condition (I + II).

In this condition, verification of the lubricant influences on crack propagation through rupture criteria is required. The modification of crack propagation allowed spalling phenomena on surface.

CONCLUSIONS

To explains lubricant influence as environment on fatigue, conventional tests are led.

We notice a small beneficial effect on crack initiation.

Fatigue crack propagation is very sensitive to lubricant.

The increasing of crack speed is depending upon the temperature and stress intensity factor range.

It seems that water contents have a stress corrosive effect during each propagation under lubricant environment.

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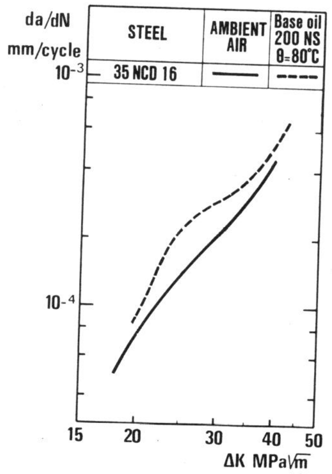

Figure 1 Effect of the lubricant on the crack propagation rate

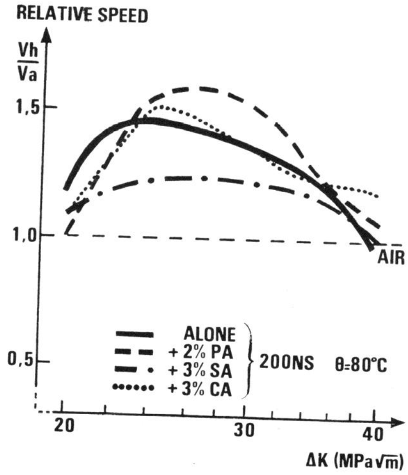

Figure 2 Effect of additives on the crack propagation rate

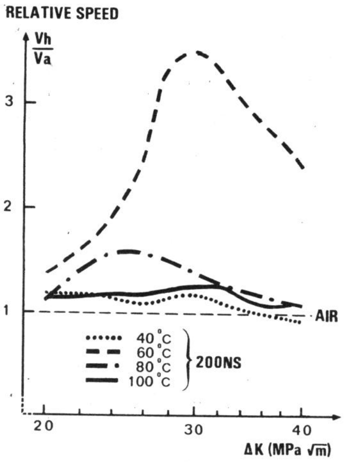

Figure 3 Effect of temperature on crack propagation rate

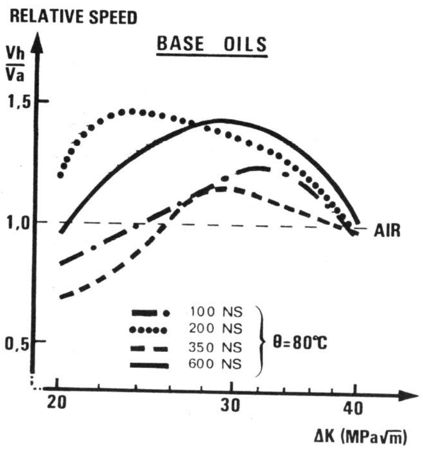

Figure 4 Effect of lubricant viscosity on crack propagation rate

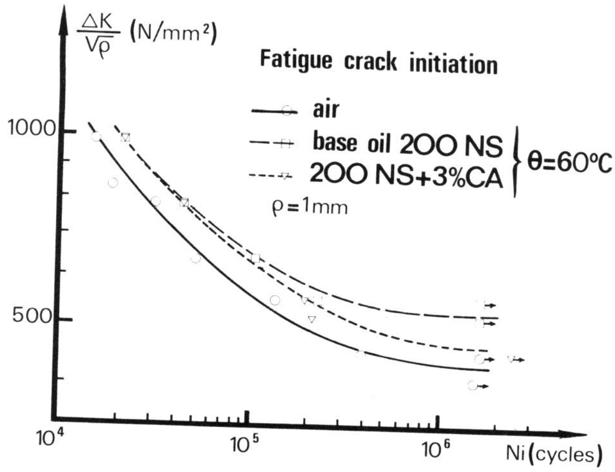

Figure 5 Effects of lubricant on the fatigue crack initiation

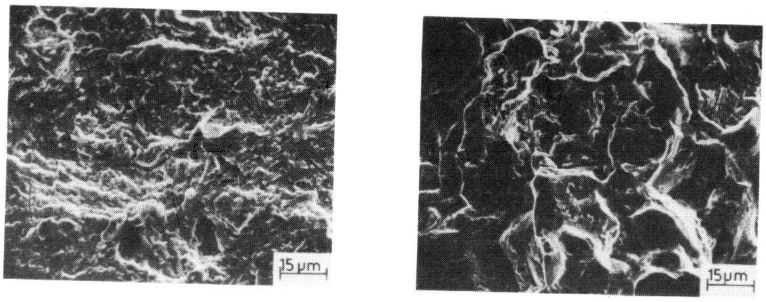

Figure 6 SEM micrographs of the fracture surfaces
a) Test run in ambiant air - b) Test run in 200 NS oil at 60°C

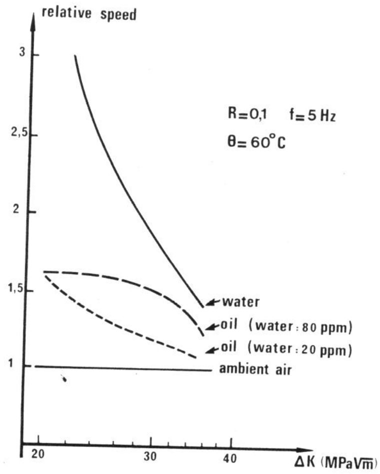

Figure 7 Comparison of fatigue crack propagation with water contents