SCUFFING INITIATION, SCUFFING PROPAGATION AND PITTING OF A FOUR-BALL TRIBOSYSTEM LUBRICATED WITH MINERAL AND SYNTHETIC OILS

Waldemar Tuszyński, Witold Piekoszewski, Marian Szczerek

Tribology Department
Institute for Terotechnology (ITeE)
Radom, Poland

ABSTRACT
The research aimed at finding an effect of various base oils on the scuffing initiation, scuffing propagation and pitting.

The following base oils were tested: mineral oil, synthetic hydrocarbon oil (polynomialfins), synthetic non–hydrocarbon oils (polyol ester, polyglycol) and highly refined mineral one known as a white oil.

The tests were performed in two different four-ball testers. One was used to investigate scuffing at pure sliding friction. The second instrument was employed to test pitting at rolling movement.

To avoid an effect of the oil viscosity, base oils having similar viscosities $\nu_{100}$ ($3,8 - 5,5$ mm² s⁻¹) were compared. In this group the highest load causing the scuffing initiation is given by the polyglycol, and the lowest one - by polynaphalphaolefins and white oil. The scuffing propagation is similar for all the oils. The best resistance to pitting is given by the mineral oil, and the worst - by the white oil.

INTRODUCTION
In heavy-loaded, non-conformal (concentrated) contacts of lubricated machine components the dominating forms of wear are scuffing and pitting (surface fatigue). Scuffing is a form of damage typical of components sliding at high velocities and high loads, e.g. toothed gears. Pitting occurs on components working in a rolling contact, e.g. rolling bearings.

Scuffing and pitting depend on many various factors. They are: material properties, surface machining, geometry of the tribosystem, working conditions and physico-chemical properties of lubricating oils. Among these factors an influence of oils, e.g. synthetic ones, needs more investigation.

In the last few years many works have been published on lubricating oils with synthetic bases. The researchers look for oils with better rheological characteristics and meeting more restrictive ecological requirements. These cannot be fulfilled by popular mineral oils, so synthetic ones are developed.

From among many types of synthetic oils for lubrication of machine components working in a concentrated contact, e.g. gears and rolling bearings, one uses oils based on polynaphalphaolefins, polyol esters and polyglycols [1]. Their share in the global synthetic oil sale is now up to 80%, polynaphalphaolefins being the most popular (45% of the sale).

Another group of base oils are the so-called white oils used for lubrication of machine components in the food, pharmaceutical and cosmetic industry. They are highly refined mineral oils. Although white oils are non-toxic and can potentially find many other applications, in the literature there are still insufficient data on their tribological behavior.

This paper compares the resistance to scuffing and pitting given by various base oils.

MATERIALS
The following base oils were tested: mineral oil (denoted as SN 100), polynaphalphaolefins (PAO 4) polyol ester (PE 4), polyglycol (PAG-5) and white oil (WO-5). To avoid an effect of the oil viscosity, only base oils having similar viscosities $\nu_{100}$ ($3,8 - 5,5$ mm² s⁻¹) were selected for testing. In this group the white oil is the only non-toxic lubricant. The polyol ester is the most biodegradable and has the highest viscosity index.

RESEARCH EQUIPMENT
The tribological experiments were performed in two different four-ball testers. One was used to investigate scuffing at pure sliding friction. The second instrument was used to test pitting at rolling movement.

In the both rigs test balls were chrome alloy bearing steel, with diameter of 12.7 mm. Surface roughness was $R_s = 0.032$ µm and hardness 60 to 65 HRC.
After tribological experiments the worn surface was analyzed using a scanning electron microscope (SEM) and energy dispersive spectrometer (EDS).

**TEST METHODS**

Scuffing was investigated according to a test method developed in the Tribology Dept. of ITeE, presented in detail in the literature [2]. A four-ball sliding tribosystem was used, immersed in the tested lubricant. The load during the run increased continuously and the friction torque was analysed. When the friction torque abruptly rose, it meant that the lubricating film had collapsed and the scuffing initiation occurred. It takes place at the so-called **scuffing load** \( P_t \). The run continued until seizure occurred, i.e. maximum limiting friction torque was reached and the tribosystem stopped. The load applied at this moment is called the **seizure load** \( P_{oz} \). Then, basing on the seizure load and wear on the bottom balls the so-called **limiting pressure of seizure** \( p_{oz} \) was calculated [2]. This measure reflects the scuffing propagation - the higher is \( P_{oz} \), the less intensive is the scuffing propagation, hence better properties of the lubricant under extreme-pressure conditions.

The resistance to pitting was measured by the 10% fatigue life \( L_{10} \) determined according to IP 300. \( L_{10} \) represents the life at which 10% of a large number of test balls, lubricated with the tested lubricant, would be expected to have failed.

**RESULTS AND DISCUSSION**

Figure 1 presents an effect of the tested oils on the scuffing initiation characterized by the scuffing load \( P_t \).

![Figure 1. Scuffing load \( P_t \) for the tested oils.](image)

The highest load causing the scuffing initiation is given by the polyglycol (PAG-5), and the smallest one - by polyalphaolefins (PAO 4) and white oil (WO-5). The best properties of the polyglycol in postponing the scuffing initiation result from its great ability to create a strong boundary layer owing to very active alcohol (OH) groups in the polyglycol molecules.

Figure 2 presents an effect of the tested oils on the scuffing propagation reflected by the limiting pressure of seizure \( p_{oz} \).

![Figure 2. Limiting pressure of seizure \( p_{oz} \) for the tested oils.](image)

The results for all the oils do not differ significantly. This means that the scuffing propagation is practically independent of the type of the base oil - under scuffing conditions chemical activity of the base oils themselves (without lubricating additives) seems not to play any role.

Figure 3 shows an effect of the tested oils on the resistance to pitting measured by 10% fatigue life \( L_{10} \).

![Figure 3. Fatigue lives \( L_{10} \) for the tested oils.](image)

The best resistance to pitting is given by the mineral oil (SN 100), and the worst - by the white oil (WO-5). The calculated minimum thickness of EHL film for all the oils was similar and very small (about 0.01 µm). So, rheological properties of the oils cannot be attributed to different fatigue lives. Surface analyses (SEM/EDS) show that the worn surface was modified by carbon - the highest its content was noted for SN 100 oil, and the smallest for WO-5. This may come from deposition of organic compounds and/or tribodiffusion. So, it is surface phenomena that affect pitting for the base oils tested.

**CONCLUSIONS**

From among the tested oils the polyglycol is the most “universal” as it best prevents from scuffing and quite good from pitting. So, although polyglycols are aggressive to sealing materials, their wider application in lubrication of machines should be promoted. This will require the use of sealings more resistant to dissolution, which are now widely available.

**REFERENCES**
