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THE FORMATION OF SPHERICAL PARTICLES UNDER ABRASIVE CONDITIONS

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Abstract

The formation of spherical wear debris was investigated by an analytical ferrograph in different machines. It was stated that the abrasive contamination in gear boxes, I.C. engines and hydraulic systems is a contributor to the generation of spherical particles. According to examinations carried out so far the spherical third body formation can be created through joint plastic deformation of delaminated particles or as a result of forming to supercooled liquid due to the collective effects of state variables.

Keywords: wear particles, abrasion, spherical wear particles, condition monitoring, ferrograph.

1. Introduction

It is well known that the wear mechanisms operating in a certain sliding system under given conditions can be determined to a large extent by studying the shape, size and distribution of loose wear particles generated in the process. In particular, the size and number of spherical wear particles (observed in a variety of friction couples) seem to be valuable indicators of the degree of tribological distress in those systems. For example, spherical debris has been observed on fracture surfaces produced by rolling contact fatigue [1], [2], [3], [4], [5], during sliding wear [6], fretting wear [7], and as a result of cavitation erosion. The detailed mechanism of the formation of these particles is unclear. SCOTT and MILLS [8] found that spherical debris is a characteristic feature associated with rolling contact fatigue. They suggested spherical particles to be formed by deformation processes; pieces of metal can be severely worked and rounded by the pressure build-up in the lubricant entrapped in the propagating surface fatigue crack. The possible formation of spherical particles in deformed subsurface material by subsurface crack propagation was also suggested.

SMITH and SMITH [9] found that the spherical particles were formed in unlubricated fatigue cracks subjected to mode II displacement (in-plane sliding displacement). They concluded that spherical particles in their experiments were generated by plastic deformation heavy wear of non-spherical primary wear particles. A model using crack surfaces constructed from plasticine seems to substantiate their conclusions.

Spherical wear debris was also observed by CONOR and MCROBIE [10] in partially lubricated high velocity sliding contacts between hard steel surfaces. They provided evidence that the mechanism responsible for the formation of such particles is the melting of surface asperities.

Through investigating the loose wear particles of locomotive diesel engines YUASHENG and QIMING [11] found that the occurrence of spherical particles on ferrograms is associated with the running-in of the engine.

In the present paper the condition monitoring measurements in our laboratory on many tribological systems (I.C. engines, gear boxes, hydraulic systems) under real working conditions were carried out to reveal the connection between abrasive processes in the system and the occurrence of spherical particles. The results of this investigation are described.

2. Experimental Details

The loose wear particles originated from oil samples of different machines were investigated.

Two groups of measurements were carried out:

- The characteristics of wear particles were analysed from machines working under real conditions. The data of some of the investigated machines can be found in *Table 1*. At each of these machines a malfunction was observed by the operator and this was the reason of the wear diagnostic measurement.

Table 1. The main groups of tested machines

No.	Machine type/unit	Lubricant	Characteristic friction mode for the formation of wear particles	Maximum oil temperature, °C	Malfunction
1	Komatsu/gearbox	EP 90	rolling-sliding	60	ext. contamination
11	diesel engine Rába 2156	API CC	sliding	90	air filter
34	diesel engine Rába D10	API CD	sliding	95	air filter
77	diesel engine Perkins	API CD	sliding	90	air filter
95	industrial hydraulic syst.	HLP	rolling-sliding	60	contamin./oil filter

- Wear particles originated from an I.C engine operating under controlled bench test conditions. The oil samples were taken at regular intervals along the test period. The test conditions can be seen in *Table 2*.

The sample was taken from the oil systems with hand-operated vacuum pump bottle sampler which avoids external contaminants during sampling. One ml of this sample was diluted with 1 ml tetrachloroethylene and the Ferrogram was made on

Table 2. Data of the tested I.C. engine

Machine type	Power, KW	Duration of the test, hours	Sampling period, hours	Lubricant	Characteristic friction mode for the formation of wear particles	Maximum temperature of the oil, °C
Diesel engine Rába D10 TLL-235 E1	235	500	50	API CC 15W-40	sliding	85

an analytical Ferrograph (made by Foxboro Analytical, USA). *Fig. 1* shows the working principle of the Ferrograph. The particles deposited on the Ferrogram were observed with the aid of a bichromatic microscope (Olympos BHC). Specific characteristic details of some wear particles were examined and photographed by scanning electron microscopy and their composition was determined by means of XES (Philips XL 40 EDAX XES).

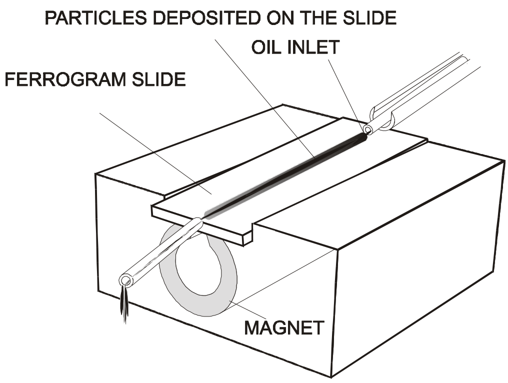

Fig. 1. Working principle of the Ferrograph

3. Results of Observation of Wear Particles and Discussion

The scatter of the type of characteristic wear particles taken from machines can be seen in *Fig. 2*. According to this result the presence of abrasive particles coincides with the formation of spherical wear particles.

The characteristics of the spheres deposited on the ferrogram slides originated from the bench test were examined.

- The particles proved to be ferromagnetic, they were collected in groups or

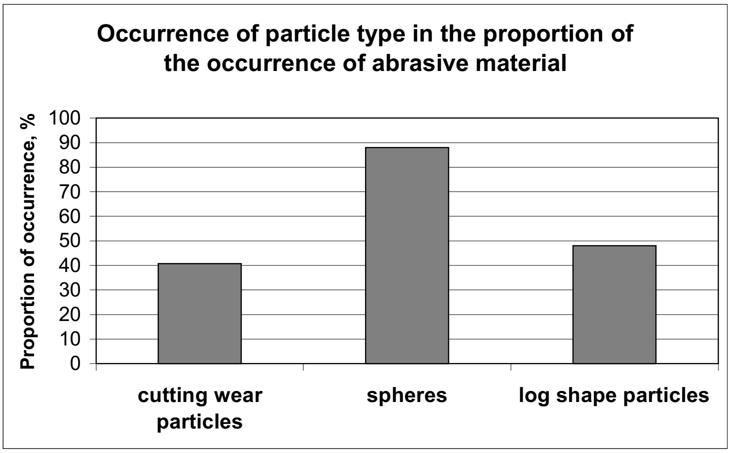

Fig. 2. Occurrence of various particles under abrasive condition at machines working under real working conditions (see *Table 1*)

lines parallel to the direction of the magnetic field (see *Fig.3*).

- After heating the ferrograms to 330 °C a light, blue temper colour can be observed, indicating that they are low carbon steel.
- Slight etching of the slides with 3% HNO_3- Ethanol (Nital) reagent showed no significant change on the surface of the spheres under microscope.

In *Fig. 4* the abrasive particles found on the ferrogram slide in '300 hour sample' of I.C. engine under bench test can be seen.

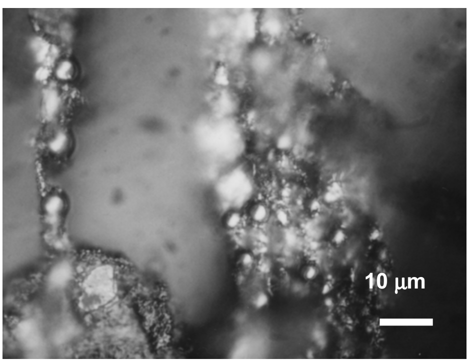

Fig. 3. Spherical particles of I.C. engine during bench test on a ferrogram

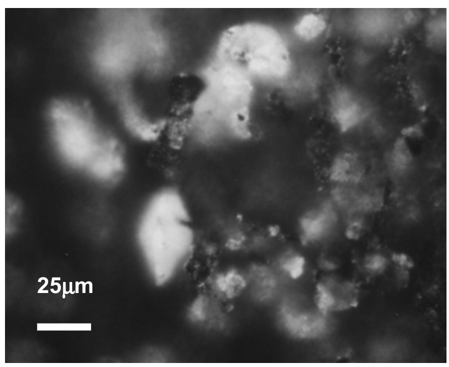

Fig. 4. Abrasive particles among metallic ones illuminated with polarised light

The photomicrographs of ferrograms inspected by scanning electron microscope can be seen in *Figs.* 5 and 6. In *Fig.* 5 spheres can be seen with a smooth surface, and in *Fig.* 6 particles with a surface which looks like cabbage-leaves rounded together. In this Figure also a chip-like particle can be observed which may be the "raw material" for the formation of spheres.

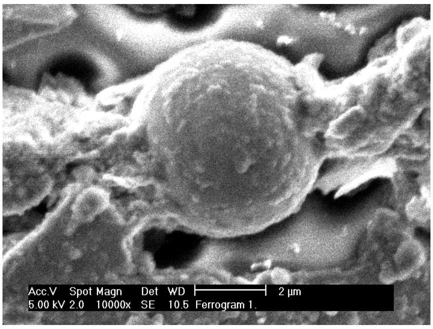

Fig. 5. Spherical particle with a smooth surface

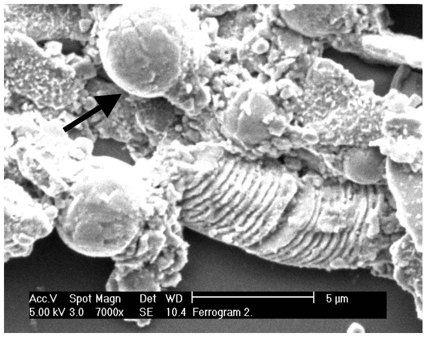

Fig. 6. Spherical particle with a cabbage-leaf-like surface

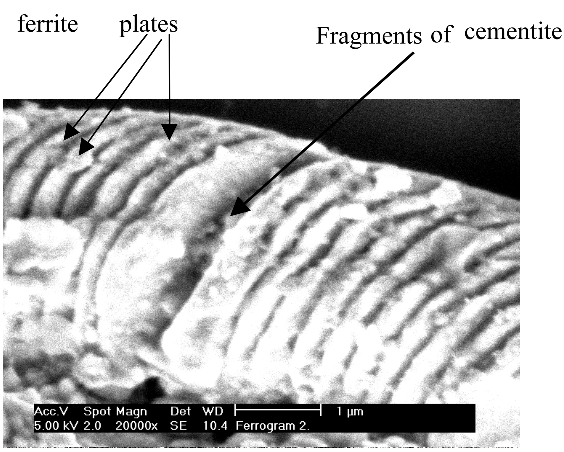

Fig. 7. Chip-like particle of pearlite

The result of XES analysis of the spheres gives ~ 1.5% wt of Zn, which shows the third-body formation characteristic of the particles. It contains elements of the reaction film of oil antiwear additive ZDDP (zinc dialkyl dithiophosphates).

The formation of spherical wear particles can be summarised as follows:

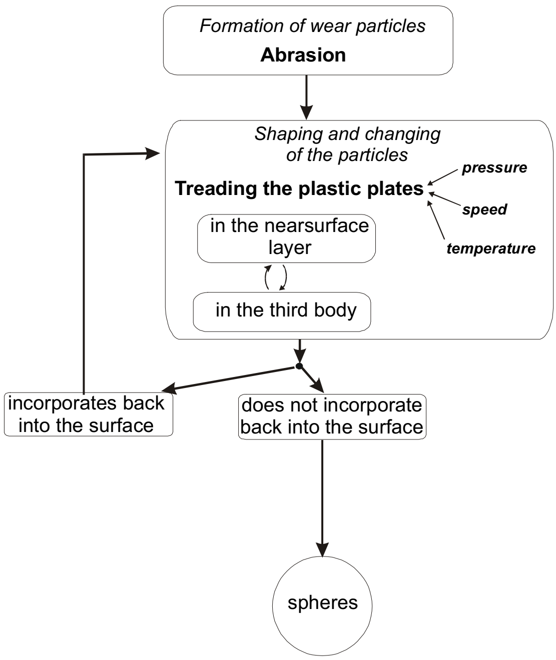

Fig. 8. The mechanism of spherical particles formation under abrasive action

- The abrasive action provides raw materials for the spheres formation (see *Fig. 7*), like chips of pearlite.
- During plastic deformation of these chips the brittle cementite breaks onto small pieces and the remaining ferrite plates can be deformed as third-body between the sliding surfaces (between the first-bodies). During this process the surface reaction films can be mixed into the particles. This process can be seen in *Fig. 8*.

4. Conclusions

It seems that under different working conditions the spherical third-body formations are developed from the primary wear particles. The sphere characterises only one period of the frictional process and its appearance refers to the presence of hard abrasive particles. According to examinations carried out so far spherical third-body formation can be created through joint plastic deformation of delaminated particles or as a result of forming to supercooled liquid due to the collective effects of state variables.

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