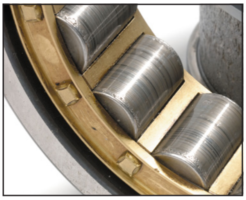
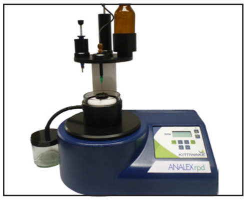
ANALEXrpd





Guide to Wear Particle Recognition

KITTIWAKE
monitoring innovation

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ANALEXrpd

Guide to Wear Particle Recognition

Contents

Introduction

When monitoring the health of plant machinery, the condition of critical components can be evaluated by the collection and analysis of wear debris being generated at interacting surfaces and transported by the fluid medium to a suitable sampling position. The analysis of the debris relates to various aspects such as quantity (concentration), size distribution, composition and morphology. Measurement of concentration and size distribution provides quantitative (objective) information on the progression of wear while the morphology and composition of the particles provide interpretive (subjective) information of the wear as a whole.

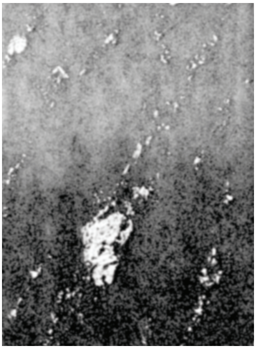
The Guide to Wear Particle Recognition has been developed to provide users of the Analex RPD with an indication of the type of wear taking place, and whether it is active or benign wear, by the observation of the distinctive features or compositional aspects of the particles being produced.

RPD Principle of Operation

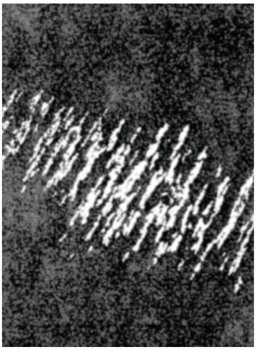
The RPD (Rotary Particle Depositor) extracts wear debris from a carrier fluid by the action of magnetic, centrifugal and gravitational forces on the debris. The debris is deposited onto a substrate in the form of three concentric rings termed the middle, inner and outer rings. During the deposition process the wear debris also undergoes a sizing operation in that the inner ring will contain a full particle size range, the middle ring intermediate to small sized particles and the outer ring just small sized particles. A typical deposition pattern is shown in figure 1.

Figure 1: Typical deposition pattern on RPD slide.

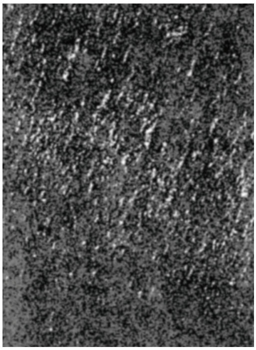
Three concentric rings
(Slide x2 magnification)



Inner Ring
Full particle size range
1 - 1000 + µm



Middle Ring
Normal size range
1 - 50 µm



Outer Ring
Normal size range
1 - 10 µm

Particle Examination

Both optical and scanning electron microscopy may be used for examining particles, each system having its own advantages.

Optical Microscopy

Optical Microscopy will give you information regarding the shape, size, concentration and type of particles present, together with some information on composition. A metallurgical microscope system is required to achieve this information and it should ideally have facilities for both reflected and transmitted light, filters, polarisers, magnifications of up to about x600 and a graticuled eyepiece.

When using reflected light the size, shape and colour of the wear particles are observed. Steel particles can vary in colour from white to blue depending on whether the particles have been produced by a mechanism which has caused significant heating, the blue colouration also indicating the severity of wear. The copper-based alloys have a reddish brown or yellow colour, while most remaining metals such as aluminium, chromium and nickel appear silver white. Iron oxides appear black or red/brown according to their chemical composition.

The use of transmitted light indicates whether a particle is transparent, translucent or opaque. Free metals are opaque and therefore appear black. Most other elements and all compounds are translucent or transparent and produce colours characteristic of the material.

The use of a red filter in the reflected light beam, together with a green filter in the transmitted light beam, produces a greater discrimination of the particles viewed. Free metal particles will reflect the red light, while blocking the green, and will therefore appear bright red. Compounds which transmit light will appear green, yellow or pink depending on their thickness. Opaque oxides have a dull red appearance.

Illumination with white transmitted light through crossed identical polarising prisms, the polariser and analyser, produces a dark field of view due to the absorption of the background light. Metal particles appear dark but the edges remain visible due to distortion of the polarised light field at the edges. Amorphous materials and single transparent of translucent crystals of the cubic system remain dark.All other crystal systems and extruded plastics, such as nylon fibres, appear bright except at specific orientations when the light may be extinguished. Polarised light has therefore been found useful in the rapid identification of particulate materials such as oxides, plastics and oil contaminants.

Scanning Electron Microscopy

Where more detailed observation and compositional analyses of individual particles are required a Scanning Electron Microscope (SEM) with an X-Ray energy dispersive spectrometer may be used. In order to provide sufficient electrical conductivity and prevent electrical charge build-up during an SEM study, the particulate deposit is usually overcoated with a thin layer of carbon which is of a sufficiently low atomic number that it will not interfere with any wear emission peaks and will allow a 'clean' compositional analysis.

The SEM is particularly useful in research-orientated investigations and where photographic records of particle assemblies requiring a large depth of field are required.

Particle Recognition

Wear particles have distinctive characteristics which correlate with the conditions under which they are formed and thereby give specific information concerning the condition of the moving surfaces from which they originated. The characteristics exhibited by metallic wear particles are their shape, size, colour, texture and type of material, that is, whether ferrous or non-ferrous. Non-metallic particles, such as silica, are often found deposited with the metallic wear debris and these can be characterised by their light attenuation properties.

The relationship between the wear particle properties and the conditions under which they are formed enable particle recognition to be readily classified into the following major groups:

Ferrous Rubbing Wear Particles

These are particles formed by the normal sliding of metal against metal. The particles are identified by their smooth flat platelet shape and their relatively high length to thickness ratio. The particle size is generally small, <15μm in the major dimension. The wear producing this particle type is of a benign nature and is frequently referred to as acceptable normal rubbing wear.

Contamination of a lubrication system can often occur and this can have a marked influence on the production of rubbing wear particles. The rate of particle generation and therefore the particle concentration increases rapidly and this is often accompanied by a corresponding increase in particle size, (sometimes greater than 100μm). Although catastrophic failure is unlikely under these conditions, the high wear rate will cause a rapid wear-out of the machinery and therefore care must be taken in assessment of the wear state.

Figures 2 - 5: Typical benign rubbing wear particles as viewed through the optical microscope. The average particle size is below 5 µm and the largest particles are about 10µm

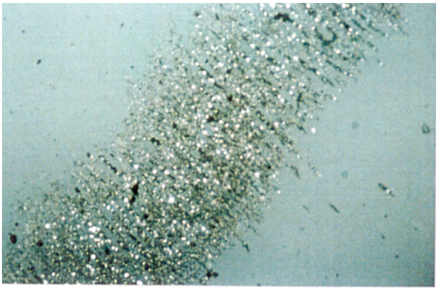


Figure 2 x 100 320µm

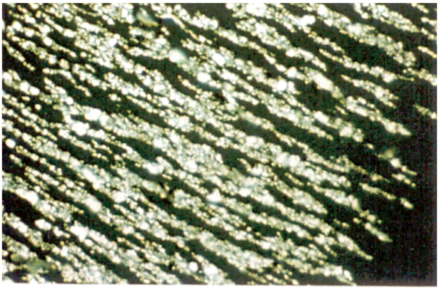


Figure 3 x 400 80µm

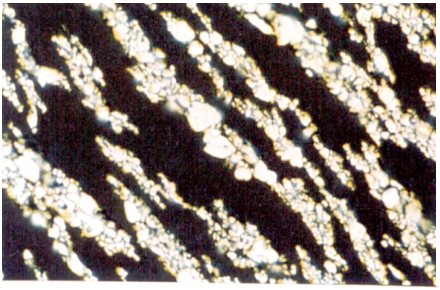


Figure 4 x 800 40µm

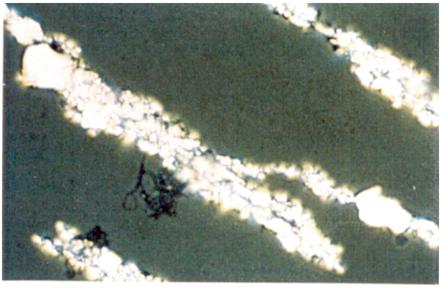


Figure 5 x 1600 20µm

Figures 6 - 7: SEM views of typical benign rubbing wear particles. The particles size is generally below 10 µm

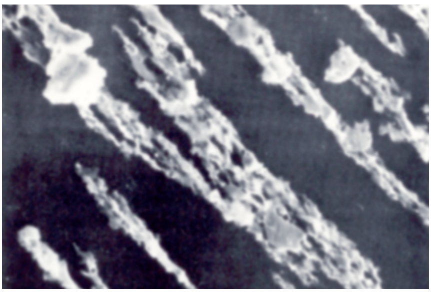


Figure 6

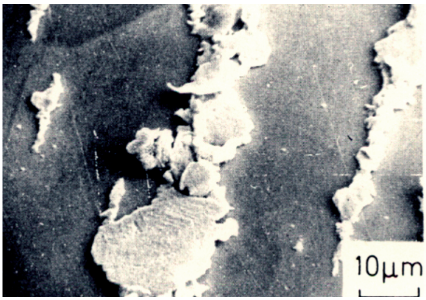


Figure 7

Figures 8 - 10: SEM views of typical benign rubbing wear particles. The particles size is generally below 10 µm

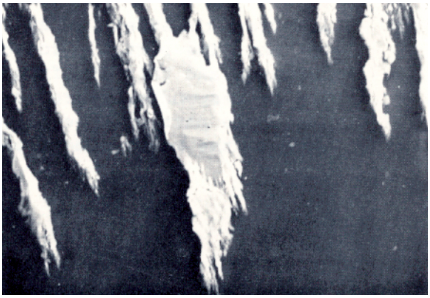


Figure 8

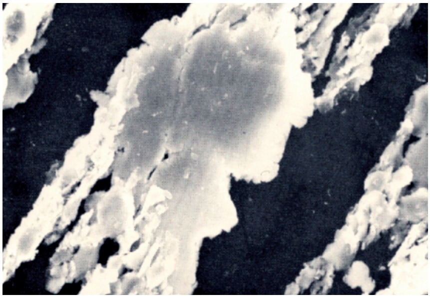


Figure 9

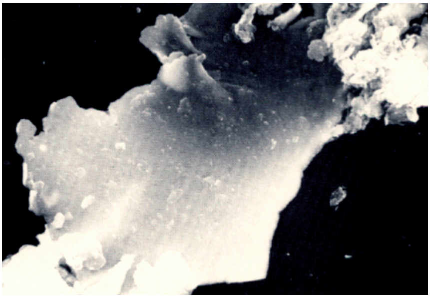


Figure 10

Figures 11 - 14: Illustrate the effect of system contamination. The particle concentration is increased and this is often by a corresponding increase in particle size, some particles being greater than 100µm in the major dimension. (SEM)

Figure 11

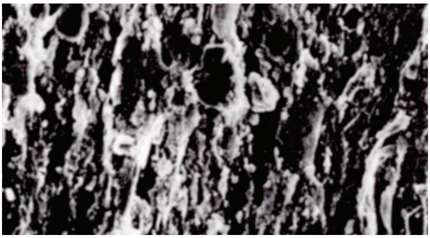


Figure 12

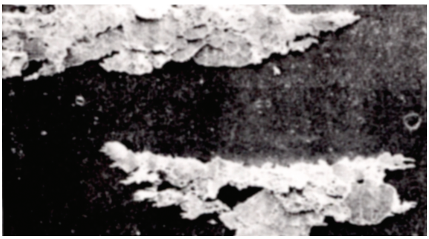


Figure 13

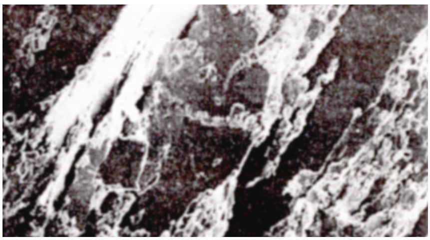


Figure 14

Ferrous Severe Sliding Wear Particles

Severe sliding wear particles can be formed under the conditions of excessive surface loading, increased running speed or poor lubrication. The particles are usually quite thin whereas their size in the major dimension is greater than that of normal rubbing wear, ranging from 20μm upwards. The particles are normally identified by the presence of surface striations, that is, parallel lines across the surface resulting from the sliding. The higher the excess stress the greater the number of particles present and the more prominent the surface striations.

Sever sliding of steel components frequently produces particles having a blue, brown or straw colour. The colours are the result of localised heating producing the temper colours associated with steel. The severity of the wear and hence the temperature attained is indicated by the colour of the particles, which changes from a straw colour to brown and then to blue with increase in temperature.

Figures 15 - 17: Typical severe sliding wear particles as viewed through the optical microscope. The particles exhibit surface striations, in the form of parallel lines, as a result of high stress sliding.

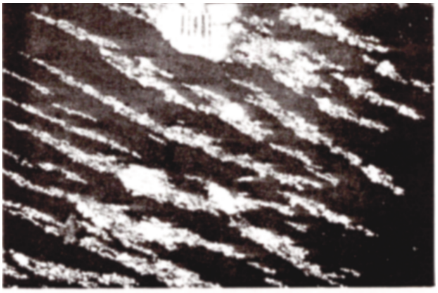


Figure 15 × 400 ⊢— 80μm —⊣

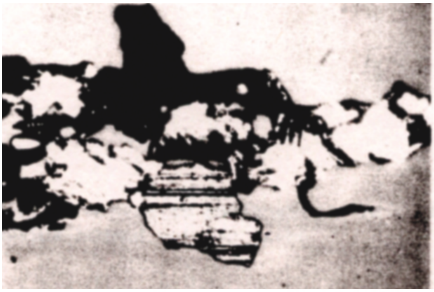


Figure 16 × 800 ⊢— 40μm —⊣

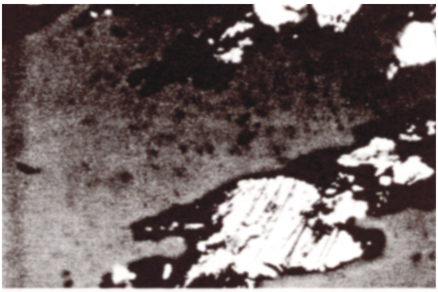


Figure 17 × 800 ⊢— 40μm —⊣

Figures 18 - 20: SEM views of severe sliding wear particles, again showing marked surface striations.

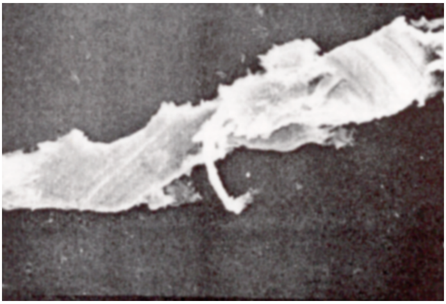


Figure 18

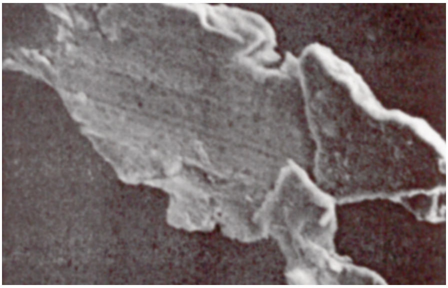


Figure 19

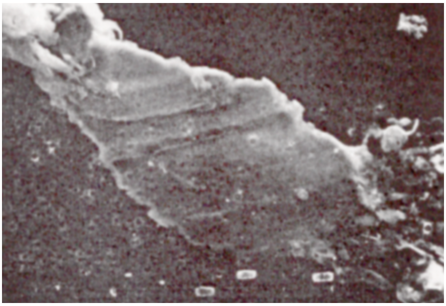


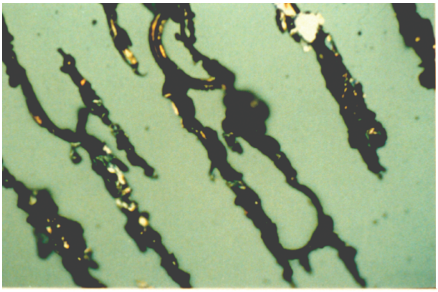
Figure 20

Ferrous Cutting Wear Particles

Cutting wear particles are indicative of an active wear state. The particles are produced by the penetration, ploughing or cutting of one surface by another. This is brought about by either the intrinsic differential in the hardness levels between the mating surfaces or by the embedding of a hard contaminant into the softer surface causing penetration of the opposing surface.

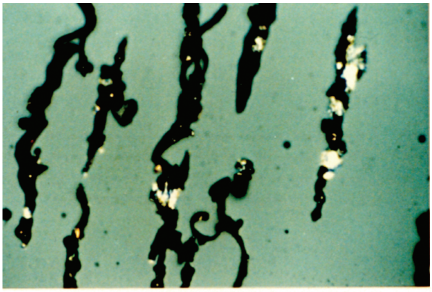
The particles produced by cutting wear are readily identifiable by their great similarity to machine chips or swarf, although they are much smaller. Cutting wear particles can range widely in length from as small as 5µm to greater than 100µm, with average widths of 2 - 15µm. Frequently the particles exhibit temper colouring resulting from heating during formation.

The presence of cutting wear particles is indicative of an abnormal wear situation and careful monitoring is required. Often some small individual cutting wear particles are found randomly dispersed within deposited debris and these in themselves do not indicate any adverse wear occurring.
If, however, the quantity and/or size of the particles increased with running time, the indications are that a failure of the machine component is imminent.



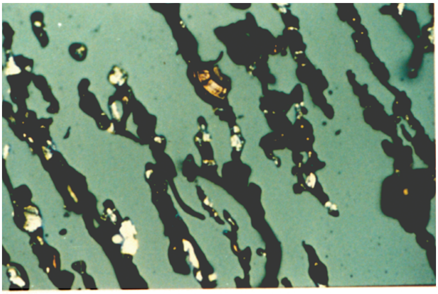
x 800 ⊢40µm⊣

Figure 21



x 800 ⊢40µm⊣

Figure 22



x 800 ⊢40µm⊣

Figure 23

Figures 21 - 23: Cutting wear particles as seen with the optical microscope. Some of the particles exhibit temper colours resulting from heating effects during formation. Complete focussing of cutting wear particles is often difficult due to their coil like shape. (Small, approximately 8 µm spherical particles can also be seen in Figure 23.

Figures 24 - 29: Cutting wear particles as viewed using the SEM. The large depth of filed associated with the SEM enables the particles to be fully focussed. (Spherical particles are again present in some views.)

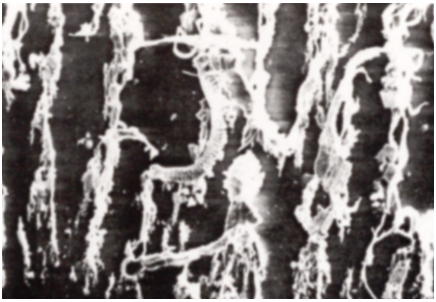
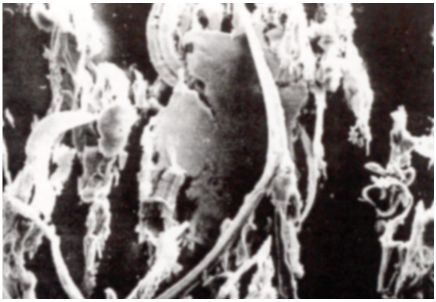


Figure 24



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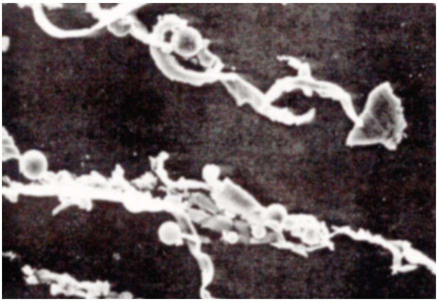

Figure 26

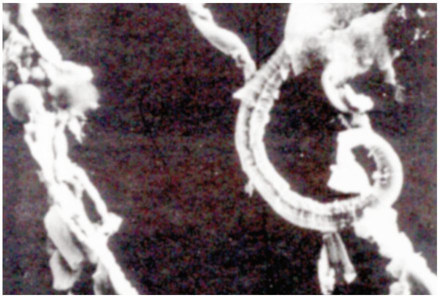

Figure 27

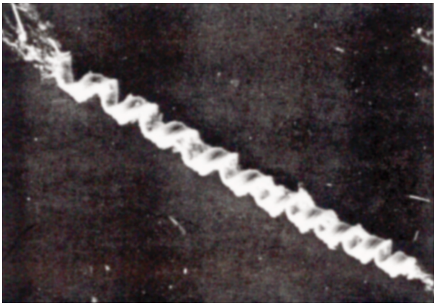

Figure 28

Figure 29

Ferrous Fatigue Particles

Fatigue particles are produced in both gears and rolling contact bearings.

Gear Fatigue Particles

Gear systems experience a combination of rolling and sliding and the fatigue particles originate at the pitch line of the gear teeth. On initiation of particle formation the fatigue particles generally have a smooth surface, irregular shaped edges and a major dimension to thickness ratio of about 10:1. With increased wear and higher surface stresses the major dimension to thickness ratio decreases markedly, producing chunky particles which are difficult to focus on fully when viewed by optical microscopy.

Rolling Fatigue Particles

The fatigue of rolling bearings produces three distinct types of particles, namely spherical particles, spall particles and laminar particles.

Rolling fatigue spherical particles are produced within bearing fatigue cracks and since they are formed prior too spall particles they give an early warning of probable failure. The spherical particles produced by rolling contact normally range in size from about 1μm to 10μm and the amount present is indicative of the severity of the wearing process. Often a few spherical articles will be found randomly dispersed within deposited debris and these are not normally indicative of an adverse wear situation. Should the quantity of spherical particles increase rapidly with running time, however, the presence of an active wear situation which could progress to a rapid failure is indicated.

Spherical particles can arise from sources other than rolling contact fatigue. They are produced by cavitation erosion, welding and grinding processes. The particles produced by these processes are generally much larger in size, ranging from 1μm - 100μm, and can therefore be distinguished from those produced in rolling contact fatigue. Unused oils as supplied by manufacturers often contain a few spherical particles resulting from the container manufacturing process.

Fatigue spall particles are particles of material, which are removed from the rolling contact surface when a pit or spall of the surface occurs. When initiated the particles can be quite large, up to 100μm in size, with a further increase in size often occurring as surface failure proceeds.

Laminar particles are thought to be the product of the passage of a wear particle through a rolling contact gap. This mechanism will produce an ironing out of the particle into a fairly large (up to 70μm in the major dimension), very thin particle with a major dimension to thickness ration of in the region of 40:1. A property frequently displayed by these particles is the presence of holes, rounded or elongated, which allow the passage of transmitted light when viewed by means of a microscope. Occasional laminar particles found in a debris deposit are not indicative of an adverse wear situation. However, if the quantity of laminar particles present increases rapidly, particularly in conjunction with an increase in the number of spherical particles present, the wear situation is deteriorating and indicative of impending failure.

Figures 30 - 32: Typical gear fatigue particles as seen through the optical microscope. The irregular edges to the particles clearly distinguish them from rubbing wear particles.

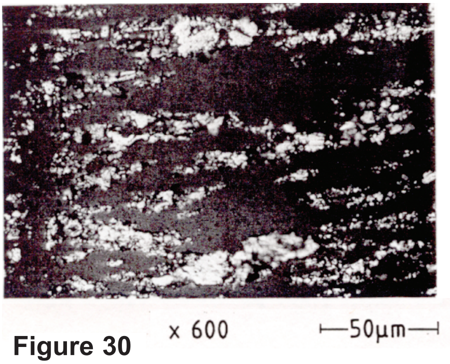

Figure 30

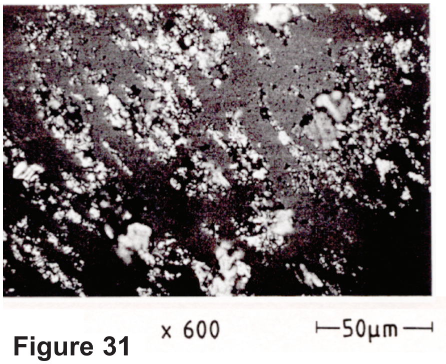

Figure 31

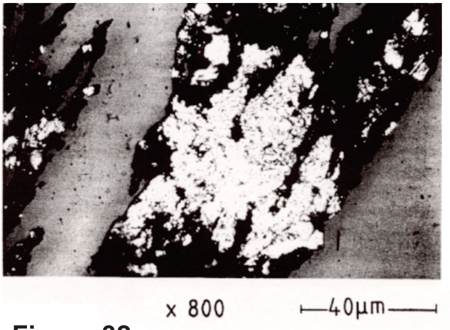

Figure 32

Figures 33 - 34: Fatigue chunks produced when the stresses on the gear surface cause deeper crack propagation resulting in the formation of particles with low major dimension to thickness ratios (SEM photographs).

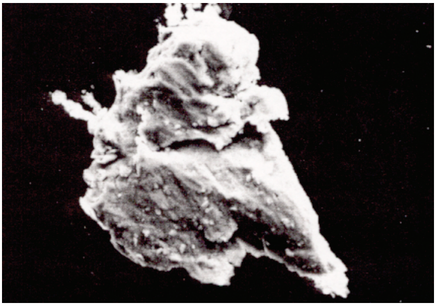

Figure 33

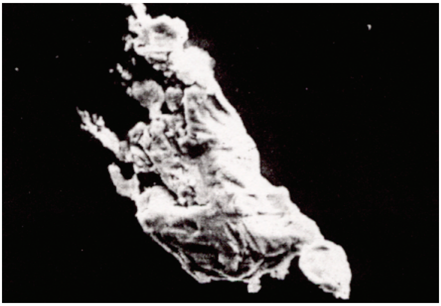

Figure 34

Figures 35 - 37: Rolling fatigue spherical particles as viewed using a SEM. These particles can also be seen using optical microscopy, but because of their shape, focussing is sometimes difficult.

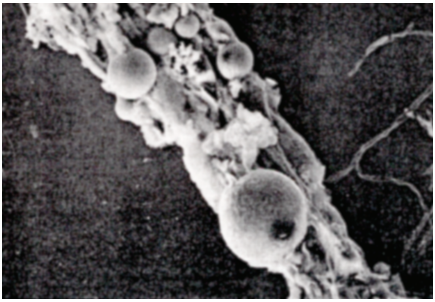

Figure 35

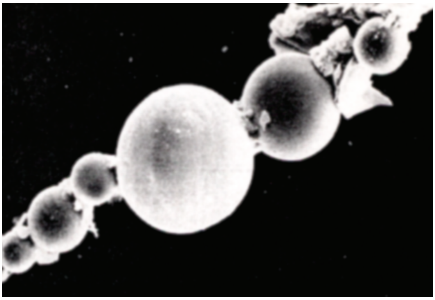

Figure 36

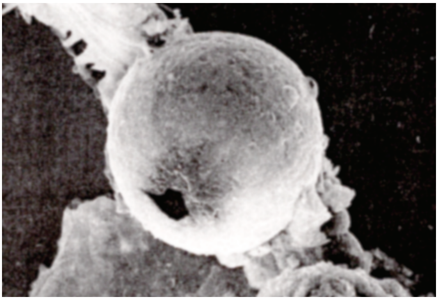

Figure 37

Figures 38: A fatigue spall particle seen with the optical microscope.

Figure 39: A laminar particle, approximately 60 μm in the major dimension, as seen through the optical microscope. The particle is very thin, about 2 μm thick and contains a number of holes.

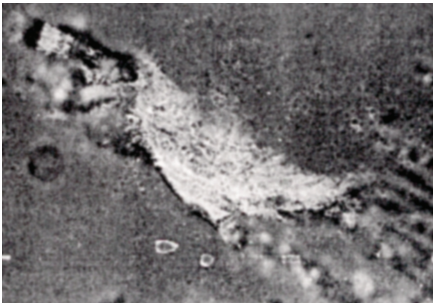

Figure 38

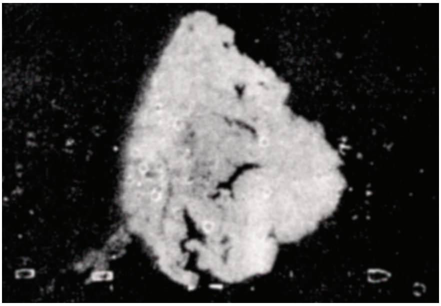

Figure 39

Non-Ferrous Metallic Particles

The RPD will deposit most types of non-ferrous metallic particles. The deposition of these particles is generally located in the outer rings because they are less magnetically susceptical when compared with ferrous materials (nickel being the exception). The particles produced by non-ferrous metallics often have similar characteristics to those exhibited by ferrous particles; for example the features observed in rubbing wear, cutting wear and high stress sliding are often present. The major distinguishing feature of non-ferrous metallics is, however, their colour.

Copper Particles
When viewed in reflected light copper particles appear salmon pink in colour. The size range can vary considerably, typically 2 - 100µm plus. The particle shape will depend upon the wear mode. Occasionally copper particles will be found welded to steel particles due to the intrinsic wear mechanism causing adhesion between the two materials.

Brass or Bronze Particles
When viewed in reflected light brass appears golden yellow in colour and bronze a darker yellow/pink. The topographical features displayed by the particles will again depend on the mode of wear.

Chromium Particles
When viewed in reflected light chromium particles appear bright silver in colour. Normally they have smooth surfaces which exhibit micro cracking and are generally below 50µm in size. A common source of such particles is from chromium-plated materials.

Nickel Particles
These are very similar to chromium particles in that they have a bright silvery colour with smooth surfaces when viewed in reflected light. The surfaces are, however, normally featureless. Usually they are the product of the break-up of nickel plating. Because of their strong magnetic properties they are normally found on the inner ring of the deposit, ranging in size from 5 - 50µm.

Aluminium Particles
These appear silvery grey when viewed in reflected light. Aluminium particles usually have an irregular surface topography giving a roughened appearance to the particles. The size of the particles can vary considerably but is usually quite large, 25 - 500µm.

Figure 40: Copper particles ranging in size up to 40 µm.
Figure 41: A large, 65µm severe sliding wear bronze particle.
Figure 42: A chromium particle, 40 µm in the major dimension.

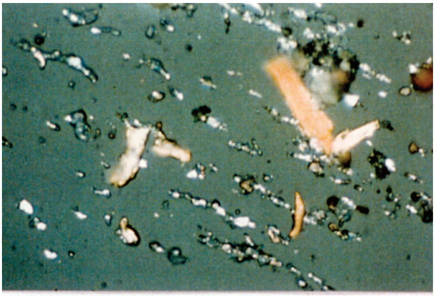

Figure 40 x 400

Figure 41 x 400

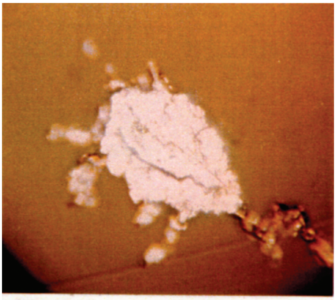

Figure 42 x 600

Figure 43: An example of a nickel particle, 22µm in length, found at the extremity of a deposition of small ferrous particles.

Figure 44: An aluminium particle, approximately 70µm in length, which appears to have been in the process of separating into smaller particles.

Figure 43 x 400

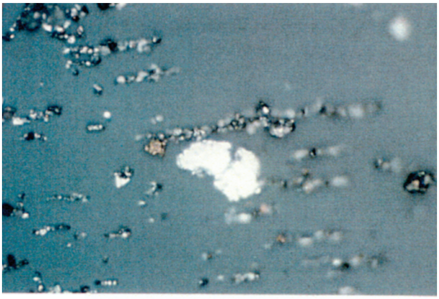

Figure 44 x 200

Miscellaneous Particles

Particles deposited other than free metal particles are oxides (including rust), non-metallic crystalline and non-metallic amorphous. The identification of these particles is best carried out using the polarizing facilities of the optical microscope.

The following table gives an indication how examples of these particles are identified.

Particle Type	Normal Reflected Light	Polarised Light	
		Transmitted	Reflected
Oxides (Ferrous)	Light brown in colour against a white background.	Bright to dark orange brown according to density - grey background.	Bright orange/ brown against black background.
Non-metallic crystalline (Silica)	Light grey transparent against a white background.	Bright silver white against a grey background.	Bright silver white against black background.
Polymeric Material	Dull cream/ brown with a cotton wool type of appearance against a white background.	Bright beige colour against a grey background.	Bright beige colour against black background.

Figure 45 (a): Ferrous oxide particles seen with the optical microscope using reflected light (x 400). For photographic purposes a brightness reducing neutral density filter has been used, giving a blue/grey background.

Figure 45 (b): The same field as in (a) as seen with the optical microscope using polarised reflected light, the oxide particles appearing in bright orange/brown against a black background (x 400).

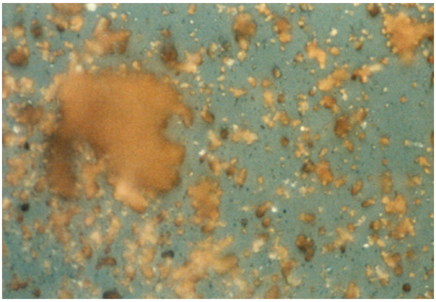

Figure 45 (a)

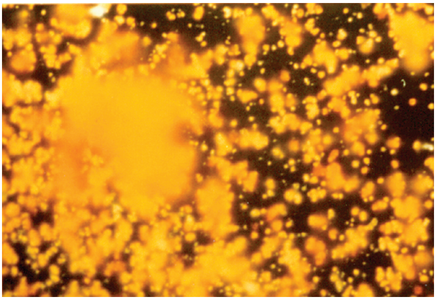

Figure 45 (b)

Figure 46 (a): A field of view containing small ferrous metal particles (bright), non-metallic crystalline particles of silica (light grey and transparent) and a polymeric particle (creamy-brown), x 400). The background appears blue/grey due to a neutral density filter in the reflected light beam.

Figure 46 (b): The same field seen with polarised light (x 400). The non-metallic crystalline silica particles appear bright silvery white and the polymer a bright beige against a black background.

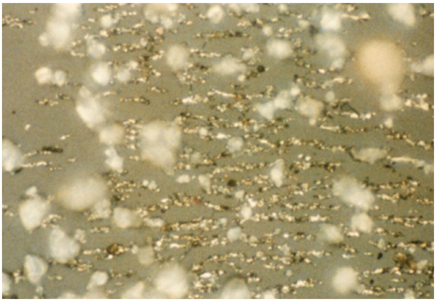

Figure 46 (a)

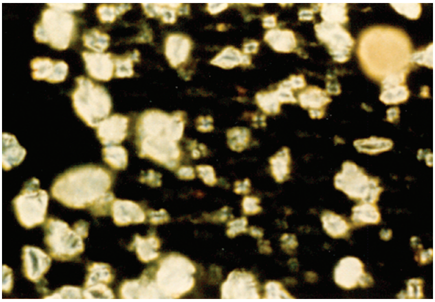

Figure 46 (b)

ANALEXrpd

Appendix

Appendix 1: RPD Analysis Reports

Slide No: 3
Organisation: UOA Labs Inc.
Equipment Type: Quench Oil Pump
Operating Time: 5000 hrs
Oil Type: Mineral Oil
Other Data: Drive End
Volume Processed: 2ml

Date: 17th July 2004
Sample No: 1
Serial Number: H-P-3C
Sample Date: 16/7/04
Time on Oil: 2000 hrs

PQ Index: 9

Types of Particles	None	Few	Moderate	Heavy
Normal rubbing wear / pitting		X		
Fatigue chunks (typical gear surface fatigue)	←	→		
Spheres (fatigue cracks in rolling bearings)	←	→		
Laminar Particles (gears or rolling bearings)	X			
Severe Wear Particles	←	→		
Cutting Wear Particles (high unit pressure)	←	→		
Corrosive Wear Particles	X			
Oxides Particles (includes rust)	X			
Dark Metallo-oxides (typical hard steels)	X			
Non-ferrous metallic	←	→		
Non-metallic, Crystalline	X			
Non-metallic, Amorphous (e.g. friction polymer)	←	→		

Comments

Low-density deposit.

The majority of the particles present were normal rubbing/pitting wear ranging in size up to 45μm but generally <15μm. Occasional small (<30μm) fatigue like chunk, sphere (<10μm), severe metallic wear (up to 25μm) and cutting wear (up to 50μm) also present. The non ferrous metallic were occasional copper containing particles ranging in size up to 65μm, but generally <20μm.

The wear rate is low and the wear situation appears normal.

Considered judgement of Wear Situation: Normal

RPD Analysis Report

Slide No: 230
Organisation: International Helicopters
Equipment Type: G-BEIC
Operating Time: 5000 hrs
Oil Type: Synthectic Diester
Other Data: MSG S/N A14-974
Volume Processed: 2ml

Date: 10th March 2004
Sample No: IC/48
Serial Number: JK-08-765
Sample Date: 02/03/04
Time on Oil: 8000 hrs

PQ Index: 14 (Pot Method)

Types of Particles	None	Few	Moderate	Heavy
Normal rubbing wear / pitting		←—	—→	
Fatigue chunks (typical gear surface fatigue)	←—	—→		
Spheres (fatigue cracks in rolling bearings)	←—	—→		
Laminar Particles (gears or rolling bearings)	X			
Severe Wear Particles	←—	—→		
Cutting Wear Particles (high unit pressure)	←—	—→		
Corrosive Wear Particles	X			
Oxides Particles (includes rust)	X			
Dark Metallo-oxides (typical hard steels)	X			
Non-ferrous metallic	←—	—→		
Non-metallic, Crystalline	X			
Non-metallic, Amorphous (e.g. friction polymer)	←—	—→		

Comments

Low / medium density deposit.

The majority of the particles present were normal rubbing / pitting wear ranging in size up to 40μm but generally <15μm. Some fatigue like chunks (up to 45μm), spheres (<10μm), severe wear (up to 35μm) and cutting wear (up to ~65μm) also present. The non ferrous metallic were pale yellow copper containing particles (bronze) ranging in size up to ~60μm, but generally <15μm.

Considered judgement of Wear Situation: Normal / Caution

RPD Analysis Report

Slide No: 1
Organisation: Medway Port Authority
Equipment Type: Crane (Port)
Operating Time: 18,000 hrs
Oil Type: Grease
Other Data: Slew Ring Bearing
Volume Processed: 1ml

Date: 31st May 2004
Sample No: 1
Serial Number: EJH1072
Sample Date: 31/05/04
Time on Oil: 10,000 hrs

PQ Index: 196 (slide)

Types of Particles	None	Few	Moderate	Heavy
Normal rubbing wear / pitting			X	
Fatigue chunks (typical gear surface fatigue)	←	→		
Spheres (fatigue cracks in rolling bearings)		X		
Laminar Particles (gears or rolling bearings)	←	→		
Severe Wear Particles	←	→		
Cutting Wear Particles (high unit pressure)	←	→		
Corrosive Wear Particles	X			
Oxides Particles (includes rust)		X		
Dark Metallo-oxides (typical hard steels)	X			
Non-ferrous metallic	X			
Non-metallic, Crystalline	←	→		
Non-metallic, Amorphous (e.g. friction polymer)	←	→		

Comments

Medium density deposit.

The majority of the particles present were normal rubbing / pitting wear ranging in size up to 104µm, but generally <20µm. Occasional fatigue chunk (up to 130µm), spheres (up to 71µm), laminar particles (up to 78µm), severe wear (up to 155µm) and cutting wear (up to 230µm) also present. Large oxidised particles also present ranging up to 1120µm together with some siliceaous material and polymer.

Considered judgement of Wear Situation: Caution

RPD Analysis Report

Slide No: 4
Organisation: Aexon Ltd
Equipment Type: Stenter
Operating Time: 400 hrs
Oil Type: Kluber PS
Other Data: Line 5 North Centre
Volume Processed: 1ml

Date: 3rd August 2004
Sample No: 1
Serial Number: CTIAT07
Sample Date: 03/08/04
Time on Oil: 389 hrs

PQ Index: 115

Types of Particles	None	Few	Moderate	Heavy
Normal rubbing wear / pitting			←——	——→
Fatigue chunks (typical gear surface fatigue)		X		
Spheres (fatigue cracks in rolling bearings)	X			
Laminar Particles (gears or rolling bearings)	X			
Severe Wear Particles	←——	——→		
Cutting Wear Particles (high unit pressure)		X		
Corrosive Wear Particles	X			
Oxides Particles (includes rust)	X			
Dark Metallo-oxides (typical hard steels)	X			
Non-ferrous metallic			←——	——→
Non-metallic, Crystalline	X			
Non-metallic, Amorphous (e.g. friction polymer)		X		

Comments

Heavy density deposit.

The particles present were a mixture of ferrous rubbing / pitting wear ranging in size up to about 65μm, but generally <15μm, and non-ferrous metallic copper containing particles which ranged in size up to about 145μm, but generally <20μm. Many particles exhibited evidence of heating (blue colour). Some fatigue-like chunks (up to 74μm) also severe wear (up to 48μm) and cutting wear (up to 52μm) also present together with some polymer.

Considered judgement of Wear Situation: Very high (Red Alert)

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