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HEAT TREATMENT OF WEAR PARTICLES OF AUTOMOTIVE ENGINES TO DETERMINE THEIR MATERIALS FROM TEMPER COLOURS

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ABSTRACT

This work aims to evaluate wear severity of the internal combustion engines installed in the cars and buses running in Saudi Arabia by examining wear particles retained by their oil filters. The photomicrographs of wear particles, illustrated in this work, provide specific information about the severity of wear. The visual inspection of those particles by microscope reveals their wear mechanisms, detects the transfer from one wear mechanism to another and identifies the abnormality of wear.

Through following the temper colours of the tested wear particles the temperatures of the moving surfaces reached a value of 540 °C, during the generation of those particles, which indicate the wear severity and confirm the critical influence of both the lubricant and surface materials. Besides, some of the collected wear particles were heated up to 540 °C to identify their materials and have specific information about their sources. This operation can detect the moving surfaces which suffered from excessive wear and facilitate the maintenance procedure.

Observation of wear particles indicated that most of the engines inspected were suffering from fatigue wear. This conclusion can confirm the importance of developing the lubrication properties of the engine oils as well as the anti-wear additives. Besides the oil filters should be developed to withstand the relatively high sand concentration which has accelerating wear rate of the engine surfaces.

KEYWORDS: Temper Colours, Wear Particles, Surface Temperature

INTRODUCTION

Inspection of solid contaminants in lubricating oil guided the study of tribological problems such as friction, wear and lubrication as well as developing filtration technology, oil additives and testing both bearing and mating surface materials. Specific information to identify the wear and solid particles contaminating lubricating oils used in different applications was provided, [1]. This information can help in identifying images during the visual inspection of those particles by microscope and the description of wear mechanism which generates those particles. Furthermore, the transfer from one wear mechanism to the other and the abnormality of wear can be identified. It offers a guide to interpret the data obtained during the study of tribological problems such as friction, wear and lubrication as well as developing filtration technology. Furthermore, it helped in considerations for exercising predictive maintenance and condition monitoring of the mechanical equipment.

It was found that oil filters contain the most significant wear particles and solid contaminants which characterize the mode of engine wear. Besides, they remove and store metallic, non metallic and polymeric particles generated from the rubbing surfaces. The size and morphology of wear particles obtained from oil filters that are much bigger than those deposited by Ferrography, described the past history of wear and signaled the early failure of the sliding surfaces through following the striation marks caused by abrasion, [2 - 8]. The temper colours of wear particle surface, which can give specific information about the temperature of the sliding surface from which wear particle was removed, were much pronounced for oil filter.

It was found that wear particles retained by oil filter of an internal combustion engine working in El-Minia Governorate, Egypt, were examined by optical microscope to reveal details of size, shape and quantity of particles, [9]. It was detected the generation of large severe wear particles that signal the imminent failure of wearing surface. Particles in the form of loops, spirals, and bent wires were generated, where increase in the number and size of these particles showed that an abrasive wear mechanism is progressing rapidly. Sand particles of different size in relatively high concentration were detected. Based on this observation, it can be concluded that the prevailing mode of wear was abrasion.

Solid particles contaminated in lubricating oil have detailed information about wear mode, [10, 11]. Examining the form of particle shape, composition, size and quantity indicates excellent failure analysis. Ferrography is one of the methods used to examine wear particles. It is based on the magnetic precipitation of ferromagnetic and paramagnetic wear particles from the oil onto a thin glass slide called a Ferrogram substrate for examination by bichromatic light microscope or scanning electron microscope (SEM), [12 - 14].

The wear of internal combustion engines has been studied by Ferrography, [15 - 17], in which engine tests were developed for the determination of the wear particle generation rate and oil filter efficiency. Examples of particle generating surfaces include the cylinder liner, piston rings, main bearings, crankshaft, camshaft and valve guides. The carbon soot contained in the exhaust products can be absorbed into the oil film on the cylinder wall, [18 - 21]. Sand particles can enter into the system through intake air, fresh oil and fuel.

Heat treating ferrograms and observing the change in appearance of the particles may help in determining the composition of wear particles of ferrous alloys. The effect of heating wear particles for periods of 90 s at increments of temperature was investigated using a standard laboratory hotplate. The temper colours of wear particles the were observed to separate metals and alloys into four groups characterized by 52100 steel, cast iron, nickel and austenitic stainless steel, respectively, [22].

Silver, cadmium, chromium, aluminum, magnesium, titanium and zinc did not respond to heating to any significant extent. Copper-based alloys which may show temper colors are readily identified by their characteristic yellow or bronze color prior to any heat treatment.

Because of the electronic mechanism of oxidation, the oxide film formed is remarkably uniform in thickness and in optical properties so that optical interference can give rise to the appearance of colors depending on the thickness of the film. The rate of oxidation and therefore the thickness of an oxide film is determined by the crystallographic orientation of the substrate metal.

It had been established that heating the Ferrogram for 90 s at 330 °C turns low carbon and/or alloy steels blue, cast iron brown but does not affect lead, [23]. Heating of the Ferrogram to 370 °C for a further 90 s changes low carbon and/or alloy steels to a lighter or silver blue, cast iron to dark brown with slight dark blue areas. Lead remains unaffected by heating.

In the present work, the temper colours of wear particles, retained by the oil filter, were considered to determine the working surface temperature before failure in order to control the performance of the lubricant and surface materials.

EXPERIMENTAL

Wear particles were collected from the full flow oil filters removed from the tested engines, Fig.ure 1. The oil filter housing was opened. A square piece, 20 × 20 mm, Figures. 2 & 3, of the pleated papers was cut and ultrasonically scrubbed in 50 ml of normal heptanes to re-disperse the particles for 30 minutes. Then the wash was filtered by 0.4 μm membrane. The material deposited on the membrane is considered to be the wear and solid contaminant as well as oxidation products. The membrane was washed by 50 ml of benzol to dissolve the oxidation products. Wear particles were inspected by optical microscope using the white light.

Figure 1: Tested Oil Filter

Figure 2: Removing the Filtering Paper

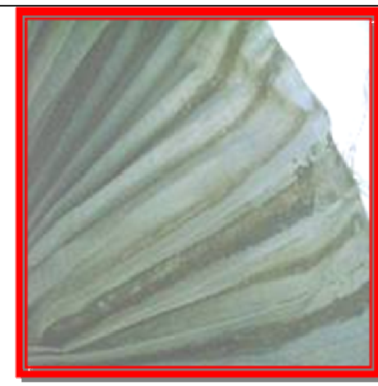

Figure 3: Tested Filtering Paper

RESULTS AND DISCUSSIONS

Inspection of wear particles retained by the oil filter showed complete surface failure detected by very big wear particles. Wear particles were of surface striation indicating severe sliding. This would be occurred due to the lack of lubrication. Examples of the different types of wear particles collected from the oil filters of the tested internal combustion engine are illustrated in Figures. 4 - 7. Those types are cast iron wear resulted from excessive piston ring/cylinder wall wear as well as steel wear from crank shaft and cam shaft surface failure.

The examination of the oil filter disassembled from the tested engine revealed the presence of very large flaky wear particles removed from the surfaces of pistons, piston rings, cylinder liners, sliding bearings and crankshaft. The formation of those particles could be resulted from the severe wear of machine elements at starved lubricated sliding. The mechanism of the generation of such particles is explained on the basis of material transfer onto the counterface forming a well adherent layer of the transferred material, which is probably the softer.

The accumulation of the layers of the transferred material may produce the relatively large wear particles which were adhered to the counterface by the action of the contacting asperities then removed from the surface when the shear stress exceeds the adherence between the transferred layers and the counterface.

Severe wear particle of alloyed steel is shown in Figure 4. Although those particles were not exposed to heat treatment their colours showed some red striations on their surfaces. The presence of the red colour indicated that surface temperature exceeded up to 450 °C. There are some dark metallic oxides, on the edges of the particles, are shown as a result of the excessive heat and/or lubricant starvation during particle generation. The shape and size of the particles confirm the complete failure of the sliding surface, where the wear particles are considered as fatigue wear.

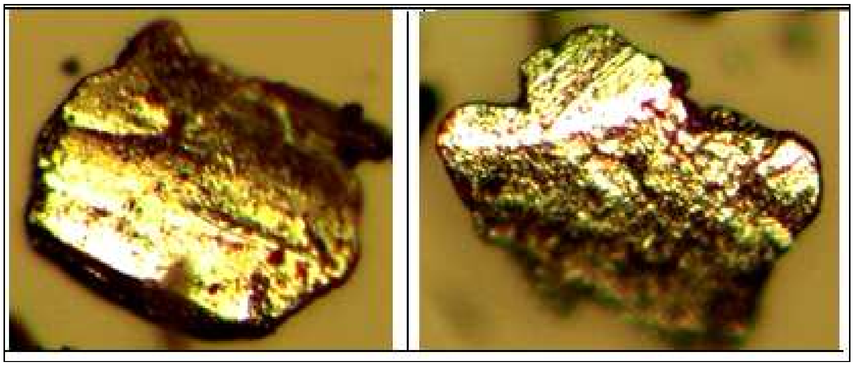

Figure 4: Fatigue Wear Particles Retained by the Oil Filter that Disassembled from the Tested Combustion Engine

Alloyed steel particles of faint yellow colour and red striations is shown in Figure 5. The change in colour may be from the local variations in composition or crystal orientation. The shape of the particle of the straight edges indicates that this particle was removed from the worn surface under fatigue wear mechanism.

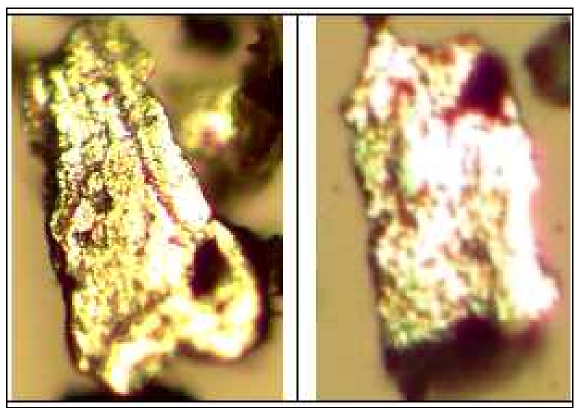

Figure 5: Fatigue Wear Particles of Straight Edges

Figure 6: Fatigue Wear Particles

Low alloy steel particle has striation marks on the surface indicating severe sliding wear is shown in Fig.ure 6. Due the size and shape it can be considered as an abnormal wear particle. The particle has smooth surface and irregularly shaped circumferences typical of fatigue spall particles. Relatively large free metal particle resulted from complete surface breakdown is shown in Figure 7. It consists of cast iron of deep bronze and some reddish appearance which confirmed that the temperature of the worn surface reached 450 °C. The source of those particles is the cylinder liner and piston ring surfaces.

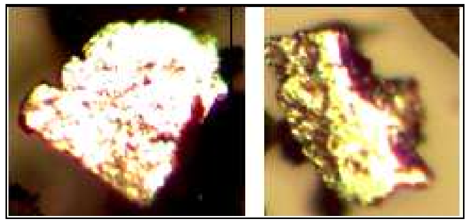

Figure 7: Cast Iron Wear Particles

After heating the wear particles up to 450 °C the colour of the alloyed steel turned to red, Figure 8. The size and shape indicated the severity of sliding condition. This is catastrophic sliding wear mode, which is indicative of failure of the surfaces. Excessive surface shear stresses caused complete breakdown of one or both surfaces and generation of free metal wear particles having dimensions up to 1 mm. Figure 9 shows a large high alloy steel wear particle. A distinctive red colour (450 °C) with a subsequent fading to black was evident. The size and form of the particle revealed that the surface from which was removed suffered from complete failure. The source of the particles might be from crank shaft or cam shaft or cam seat. It is recommended in this condition to use lubricating oil of higher quality. Anti-wear additives are recommended to withstand the severity of wear.

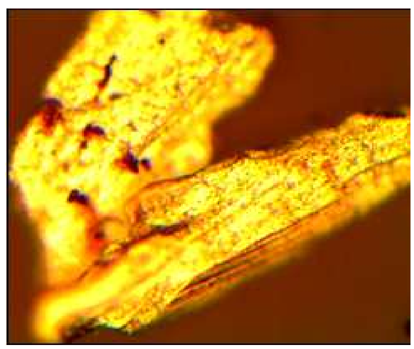

Figure 8: High Alloy Steel Particles after Heating to 450 °C

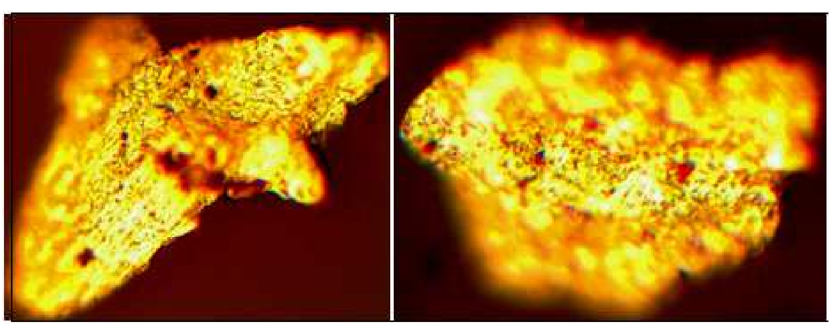

Figure 9: High Alloy Steel Particles

Figure 10 shows fatigue wear particles that were heated up to 475 °C. The reddish colour began to turn to yellow. Heating wear particles of ferrous alloys and observing the change in appearance of the particles helped in determining their composition. The oxide film formed during heating is remarkably uniform in thickness so that optical interference is responsible to the appearance of red and yellow colors depending on the thickness of the film. The rate of oxidation and therefore the thickness of an oxide film are determined by the crystallographic orientation of the substrate metal. Increasing the temperature of heating of the wear particles up to 540°C increased the intensity of red colour, Figure 11. The majority of the wear particles were generated from fatigue wear mechanism. They were probably of cast iron and alloyed steel.

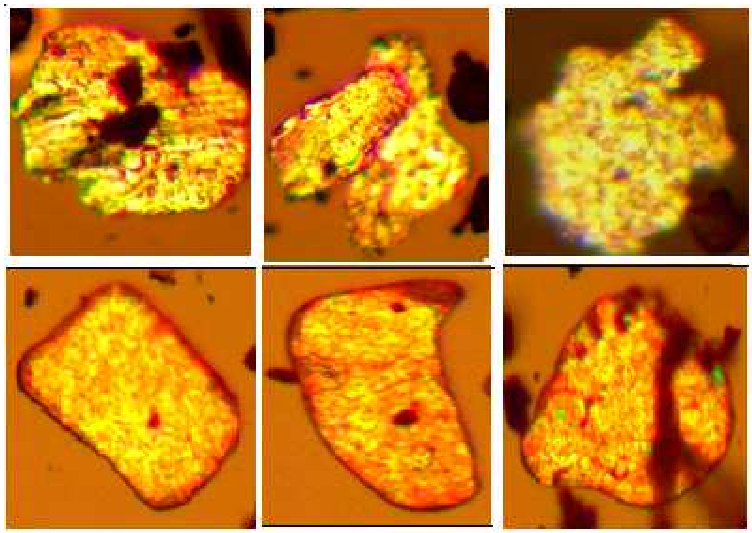

Figure 10: High Alloy Steel Particles Heated Up to 475 °C

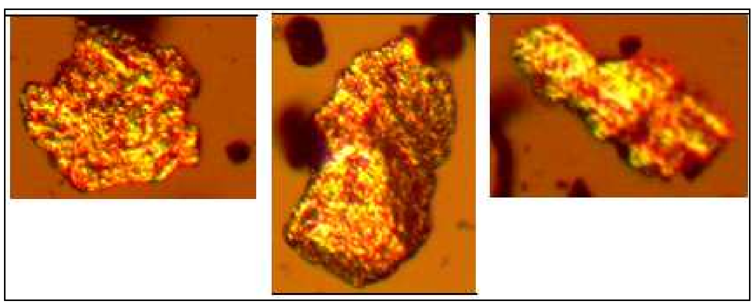

Figure 11: High Alloy Steel Particles Heated Up to 540 °C

The scanning electron microscope of wear particles is shown in Figure 12. Thin flakes of aluminum alloy of 100 μm size generated from the wear of piston are illustrated in the figure. The quantitative analysis of those flakes is shown in Figure 13, where the aluminum content reached 95 wt. % while the iron content was 1.37 wt. %. The size of aluminum wear particles confirms the severity of wear. The X-ray diffraction pattern, Figure 10, of wear particles retained by the oil filters revealed the presence of copper of 3.97 wt. % content.

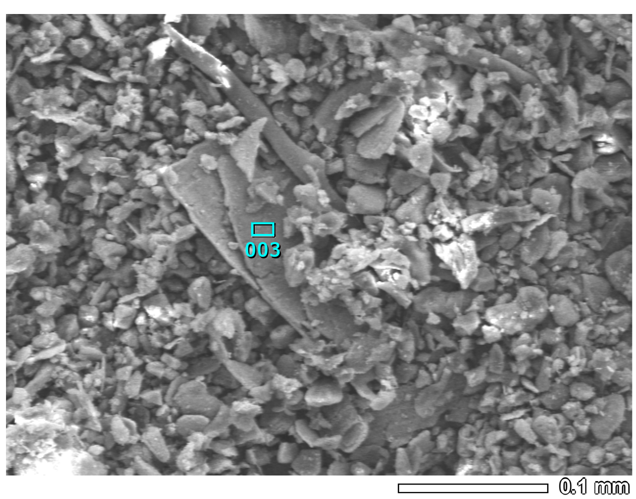

Figure 12: Scanning Electron Microscope of Wear Particle

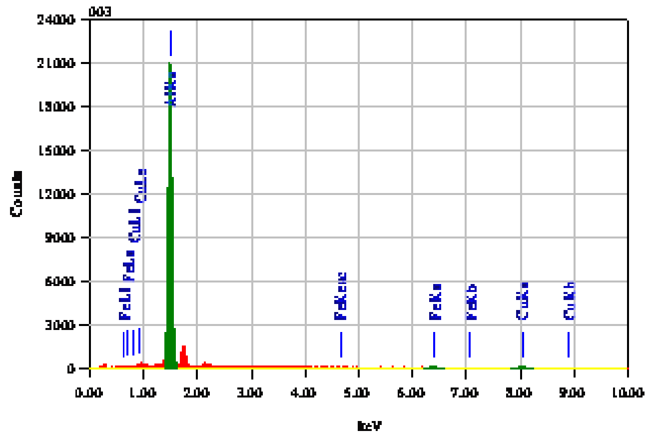

Figure 13: Quantitative Analysis of the Wear Particles and Solid Contaminants

Figure 14 shows the solid contaminants retained by the oil filter, where the iron content was 4.14 wt. % accompanied by some traces of copper, magnesium and aluminium, Figure 15. The majority of the particles were carbon soot. The energy-dispersive analysis of X-rays (EDS) showed peaks of carbon and oxygen from the combustion products of the fuel inside the engine.

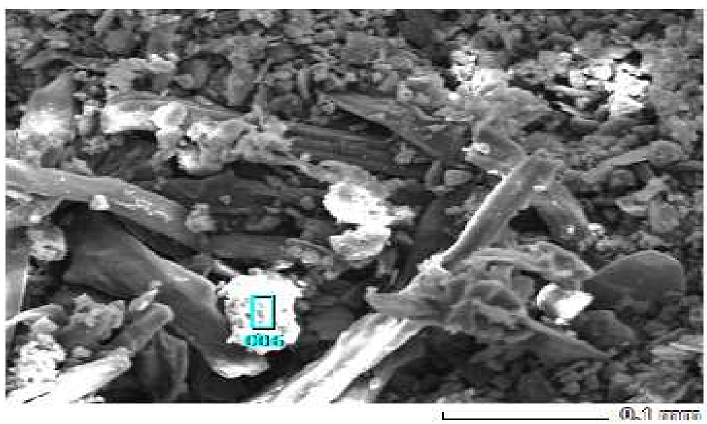

Figure 14: Scanning Electron Microscope of Wear Particle

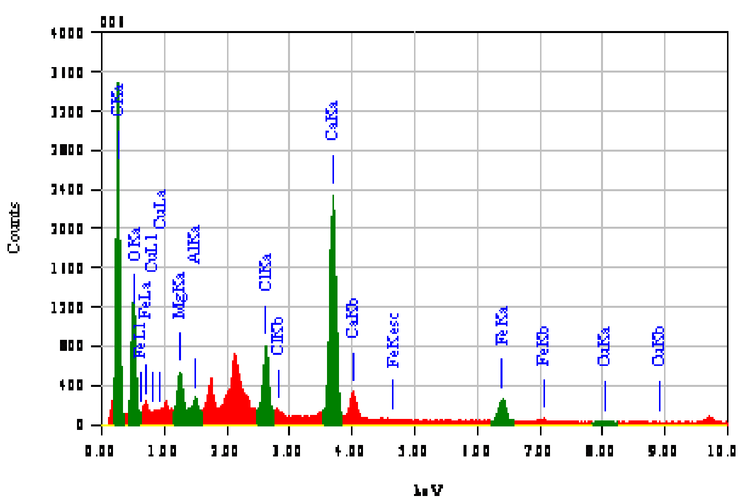

Figure 15: Quantitative Analysis of the Wear Particles and Solid Contaminants

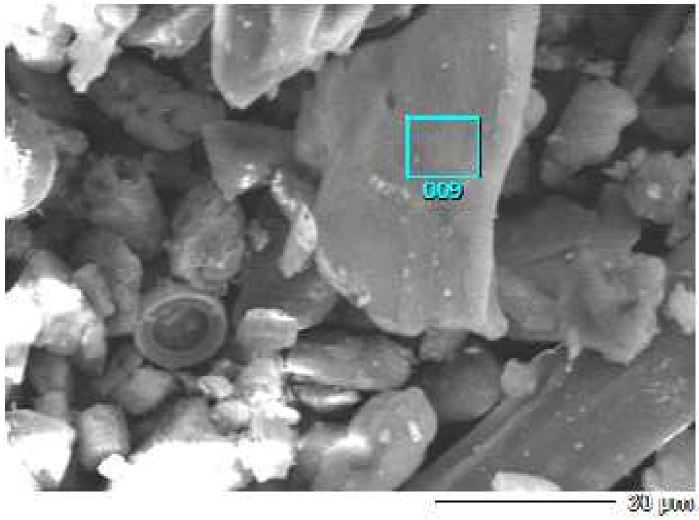

Figure 16: Scanning Electron Microscope of Wear Particle

Chunky type wear particle generated from the fatigue wear of the sliding surfaces is shown in Figure 16. Presence of such particle reflected the severity of wear condition inside the engine.

EDS spectrum of wear particles is shown in Figure 17. The peaks of carbon and oxygen come from combustion products. The peaks of iron and aluminum result from the wear of the piston and cylinder liners.

Relatively small steel wear particles generated from the wear of the cylinder liner surfaces are shown in Figure 18. The intensity of such particles reveals the accelerated wear rate inside the engine.

EDS spectrum of wear particles is shown in Figure 19. The peaks of carbon and oxygen come from the combustion products. The peaks of iron (16.6 wt. %) and aluminum (4.59 wt. %) were displayed by wear of the piston, piston rings and cylinder liners.

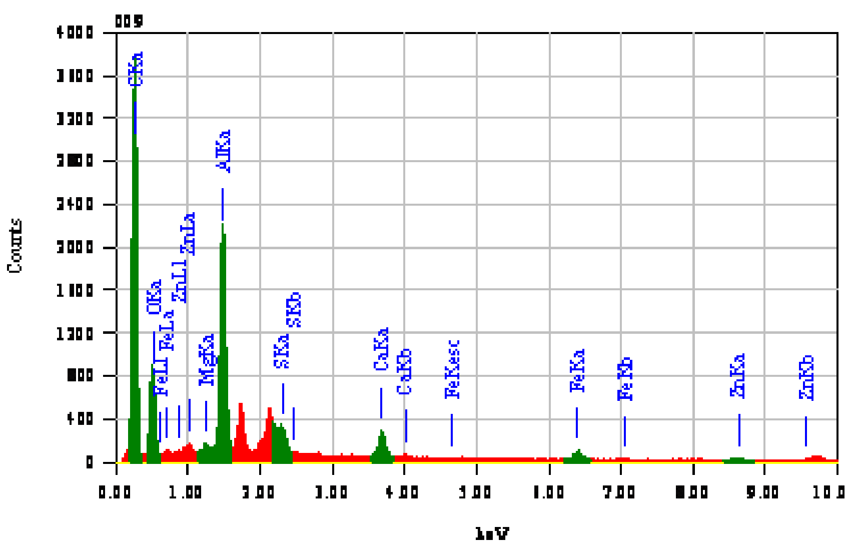

Figure 17: Quantitative Analysis of the Wear Particles and Solid Contaminants

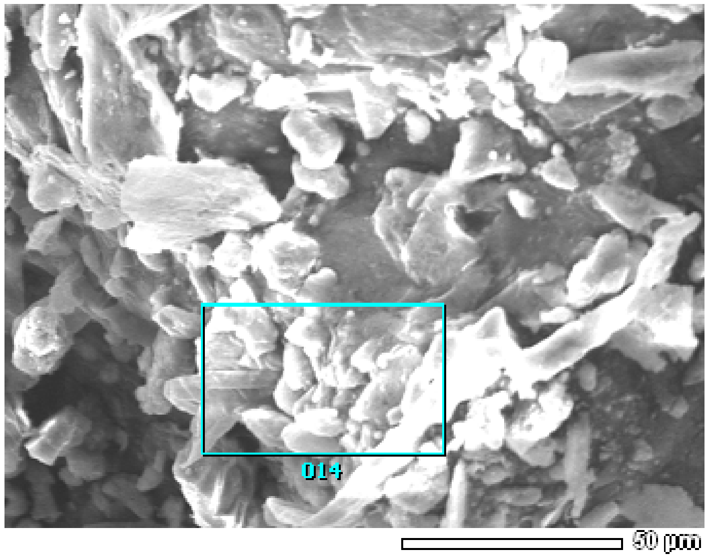

Figure 18: Scanning Electron Microscope of Wear Particle

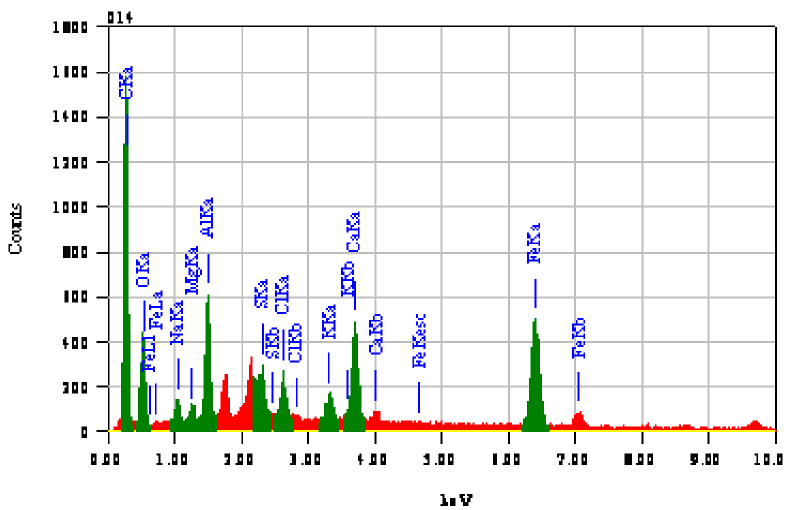

Figure 19: Quantitative Analysis of the Wear Particles and Solid Contaminants

CONCLUSIONS

The present work can be applied to monitor the condition and performance of internal combustion engines by determining the working temperature of the moving surfaces. Inspection of the temper colours of wear particles enabled the detection of a critical operation of the engine through knowing the maximum surface temperatures during the generation of the wear particles. With the knowledge of the materials of the wear particles the source of excessive wear could be identified. Besides, application of heating wear particles could provide an insight into the wear mechanism responsible for the abnormality of the wear particles. Inspection of the wear particles retained by oil filters of the tested engines showed excessive amount of wear generated from piston, piston rings and cylinder liners surfaces. It is recommended to develop the oil filters as well as the oil additives to withstand the severe working condition.

ACKNOWLEDGEMENTS

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