International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-5, June 2019

Evaluation of Effective Area of Wear Particles Using Image

Puja P. More, M.D. Jaybhaye

***Abstract:** The aim of this study is to calculate effective area of wear particles collected from oil sample through ferrographic analysis. Area was calculated using ImageJ software, which is image processing software used for analyzing, editing and processing image. The experimental result collected from direct reading ferrography indicated increase in concentration of large and small size wear particles. As large size particle count was above 90, ferrogram slide was prepared to study the morphology of wear particles and observed under bi-chromatic microscope. The morphology of wear particle in terms of their size, shape and color reflects the complex nature of wear progression involved in the formation of particle. This methodology helps to improve the performance of ferrographic analysis by calculating area of wear particle which helps to detect the type and nature of wear particles. Suggested methodology can help researchers to obtain effective area of wear particle and its morphology.*

***Index Terms:** Wear Particle, Ferrography, Area, ImageJ*

I. INTRODUCTION

Wear particles carries noteworthy information, which helps to determine severity of wear and wear mechanism. Wear particles are produced due to frictional interaction between mechanical parts and insufficient lubrication. Wear Debris Analysis plays an important role to get information related to health of machine condition. Ferrography is a technique for measuring wear rate through analysis of lubricating oil, to prevent catastrophic failure of machine component. Few literatures are discussed in this paper related to ferrography and image processing:

D. Scott and V. C. Westcott [1] developed the methodology of ferrography and performed oil analysis using it for predictive maintenance. Ferrography was used for machine condition monitoring to avoid expensive periodic dismantling of machines, and to prevent failure. It has been observed by researchers that there is a presence of cutting wear particle, normal rubbing wear particle, fatigue chunk and spherical metallic particle in the oil.

G.J Wright and M.J. Neale [2] explained different condition monitoring techniques to study health of machine condition. They have explained the principle of wear debris monitoring which tells that wear debris found in lubricating oil carries lot of information related to wear rate, wear mechanism, wear particle morphology.

O. Levi and N. Eliaz [3] applied ferrography for open loop system for wankel engine. Ferrographic analysis showed the presence of rubbing and spalling particles. Visual inspection showed pits on rotor bushing, radial cracks on circumference of bushing, excessive wear on rotor face, removal of material from eccentric element due to excessive temperature.

R.K Biswas, M.C. Majumdar *et al.* [4] performed oil analysis using ferrography for turbine. Vibration analysis was carried out to support ferrographic results, the amplitude of vibration was within range of 7mm/sec. Image processing was performed on ferrographic images to calculate percentage area fraction of wear particles, which showed that as time passes percentage area fraction increases due to increase in wear rate.

M.C. Isa, N.H.N. Yusoff, *et al.* [5] carried ferrographic analysis for engine, generator and gearbox of commercial marine ship. EDX analysis showed the presence of Cu was observed in generator 2 (71ppm), concentrations of Fe were observed in generator 2 (38ppm), generator 3 (107ppm) and gearbox 2 (26.1ppm). Ferrographic analysis showed the presence of normal rubbing wear, fatigue wear and severe sliding wear. Jiayoyi Wu, Junhong mao, *et al.* [6] used Image Projection Transformation to extract overall characteristics of wear debris collected through on line visual ferrography.

Xingjian Dai, Yong Wang, *el al.* [7] performed ferrographic analysis on used oil collected from pivot jewel bearing. Large sized particles were collected at entry point of ferrogram slide, small size particles were collected at exit point. Particle sizes ranging from 0.5 to 30 microns were observed under ferrogram slide.

S. Ghose, B. Sarkar, *et al.* [8] implemented fractal analysis for wear particle characterization through image vision system. They concluded that larger sized wea particles indicated lower fractal dimensional value and vice-versa.

Shuo Wang, Tonghai Wu, *et al.* [9] used photometric stereo technology to calculate surface normal for captured 2D images to reconstruct 3D surface of wear particle. 8 cameras were used to capture 2D images of wear particle from different angle. Reconstruction accuracy was verified by analyzing same wear particle under Laser Scanning Confocal Microscopy. Wei Yuan, K.S. Chin, *et al.* [10] developed a new method as Classification and Regression Tree Method used particle boundary to analyze wear particle features.

A.B Gholap, M. D. Jaybhaye [11,12] used ferrography for condition based maintenance of gearbox setup and ImageJ software to classify wear particles.

G. W. Stachowiak, T.B Kirk *et al.* [13] carried ferrographic and fractal analysis to distinguish contaminants from ununsed lubricating oil samples.

Manuscript published on 30 June 2019.
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T.B. Kirk, G.W. Stachowiak *et al.* [14,15] used fractal analysis to describe surface and texture complexity of wear particles collected from ferrographic analysis.

Jian Li, Qian Du *et al.* [16] used box counting algorithm to calculate fractal dimension of different images and compared those values with kell and pent method.

H Shah and H Hirani [17] performed online condition monitoring of gearbox using ferrography and vibration analysis.

Manoj Kumar [18] reviewed different techniques for wear analysis to monitor condition of machine.

Prabir K. Bandyopadhyay, Ram Balak Choudhary *et. al.* [19] used ferrographic analysis to study oil condition from equipment in steel plant.

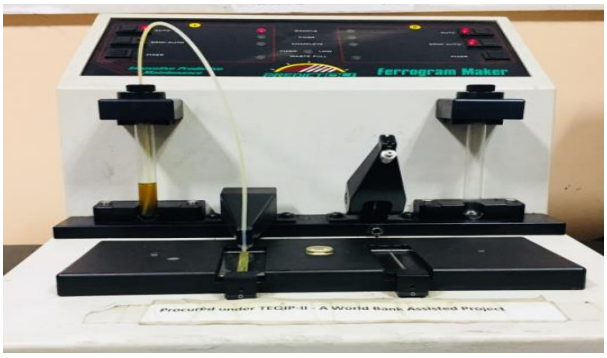
Now a days, efforts are being made to develop an automatic system which is reliable for wear particle analysis. This will reduce inspection time and dependency on expertise.

II. FERROGRAPHY

Ferrography is a condition monitoring technique used for oil analysis to get information related to machine deterioration. Effect of Lubricant additives, contaminants, lubricating oil, wear debris and their influence on condition of machine is examined by Ferrography. Ferrography is divided into two sections that is qualitative analysis and quantitative analysis [20]. Quantitative analysis is carried out by Direct Reading ferrography which gives the concentration of large and small size wear particles which are magnetic in nature, so that we can detect change in particle concentration and wear severity index through lubricating oil. Qualitative analysis is carried out using Analytical Ferrography and bi-chromatic microscope which gives the information related to shape, morphology, and color of wear particle [21]. Qualitative analysis is performed if the concentration of large size particles crosses the limit of 90.

III. WEAR PARTICLE DETECTION

Wear particles found in lubricating oil provides the information related to degradation of machine components like which type of wear mechanism is happening during machine running, whether we need to replace any machine component or need to change lubricating oil. Oil samples (HP EP 90 Gear Oil) were collected from gear box system after 800hrs of running machine. Qualitative analysis of oil sample showed the increase in concentration of large and small size particles. Concentration of Large size particle is 188.3 and concentration of small size particles is 177.6.



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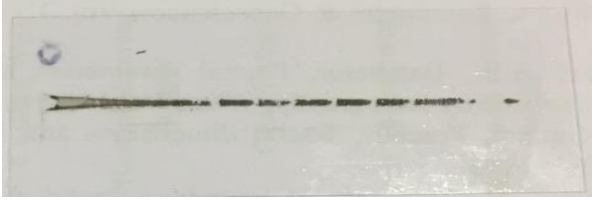
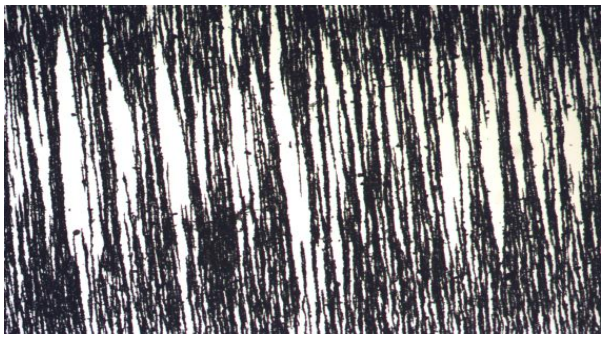


(b)

Fig 1. Preparation of Ferrogram Slide (a)Dual Slide Ferrogram Maker, (b) Ferrogram Slide 60x25 mm^2

Ferrogram slide was prepared by using Analytical ferrography as shown in Fig 1. Slide was examined under bi-chromatic microscope (Olympus BX 51) which showed the presence of rubbing wear particles, cutting particles, red oxide, sliding wear particles (Fig 2). All images which are to be analyzed are taken at 10x magnification factor.



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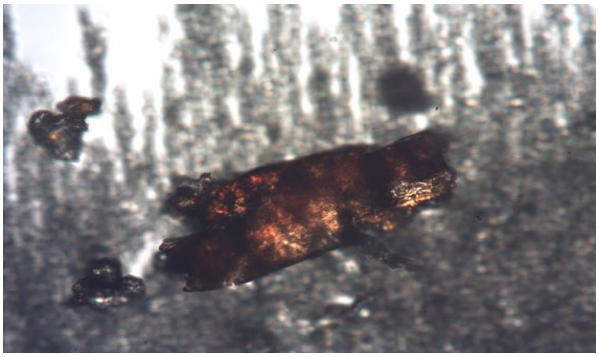

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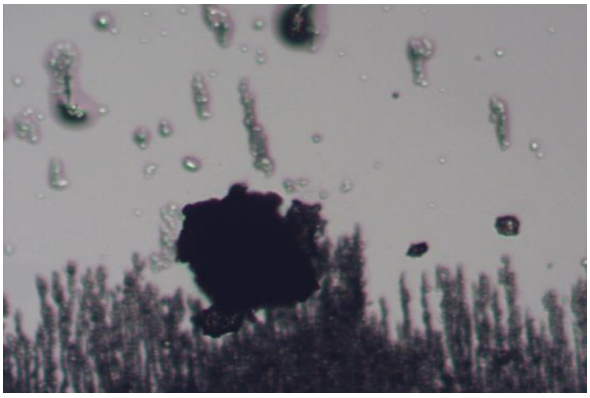


(d)

Fig 2. Microscopic Images (a) Normal Rubbing Wear (b) Cutting Wear (c) Red Oxide (d) Sliding Wear

Wear particles can be distinguished by area, perimeter, standard deviation, size, fractal dimension which helps to get the present situation of machine under consideration.

IV. AREA CALCULATION USING IMAGEJ

ImageJ is a Java based image processing software used to display, edit, process, analyze and save 8-bit, 16-bit, 32-bits images. It is also used to calculate area, pixel value, angle. It can perform standard image processing functions like smoothing, sharpening, contrast manipulation, edge detection and filtering. Few case studies are explained further to calculate different parameters of the wear particle images taken from bi-chromatic microscope. While using ImageJ, the image which is to be analyzed is to be calibrated to required scale. After calibration is done we will get the ratio of pixel/scale for all images. Before calculating area of particle, the image should be converted to 8-bit binary image and then smoothing operation is performed to smoothen boundaries of wear particle. Thresholding tool is used to separate required wear particle from background so that we get the required area of selected particle. ROI (Region of Interest) Tool Manager is used to calculate area, perimeter, standard deviation, circularity of wear particle. To calculate area using ImageJ following steps to be followed mentioned in Fig 3.

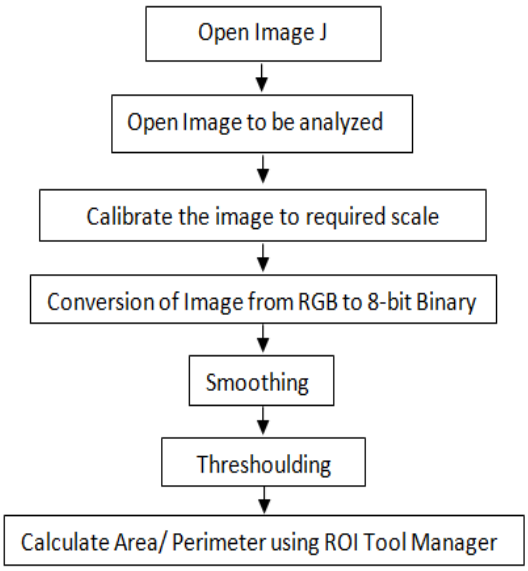
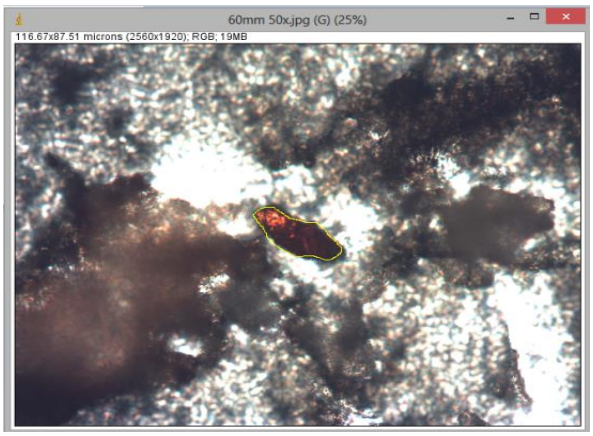
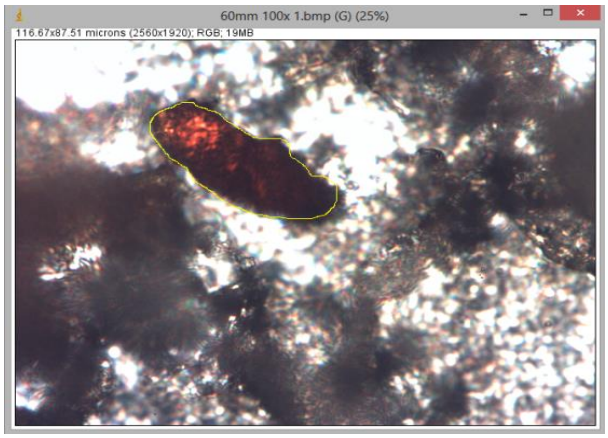


Fig 3. ImageJ Steps to Calculate Area

To compare areas of different types of wear particles magnification factor for all the images should be same. If we take two images of same wear particle at 50x and 100x, area will differ for both the images. Area of red oxide shown in Fig 4(a) is 113.44 micron^2 and area of same red oxide (image taken at 100x) shown in Fig 4(b) is 539.14 micron^2.



(a)



(b)

Fig 4 (a) Red Oxide at 50x Magnification Factor, (b) Red Oxide at 100x Magnification Factor

CASE 1: Area and Perimeter Calculation of Cutting Particle

Cutting Particles are formed due to abrasive wear. These particles appear as long and curled shape. Increased amount of cutting particle indicates that severe wear has been occurred in system under consideration. Fig 5 shows the cutting wear particle captured under bi-chromatic microscope.

Fig 6 shows the thresholded image of cutting wear particle, thresholding operation is performed to separate wear particle from background. Right side of fig 6 shows the threshold value for required image and set scale option gives the calibration scale, which is 21.9419 pixel/ microns. Selecting 'Global' option in set scale window indicates that the calibration scale is applied to all the images which is to be analyzed before we close the ImageJ window.

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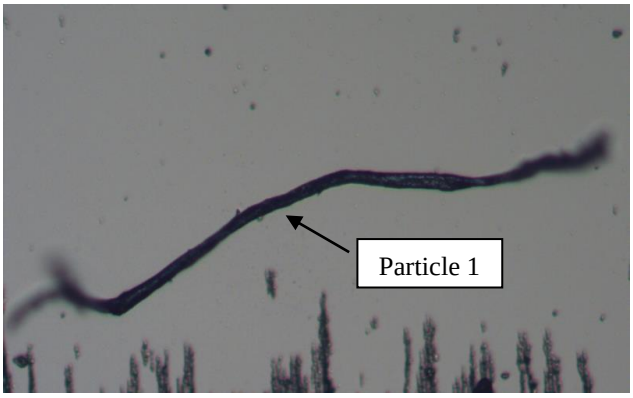

Fig 5. Cutting Wear Particle

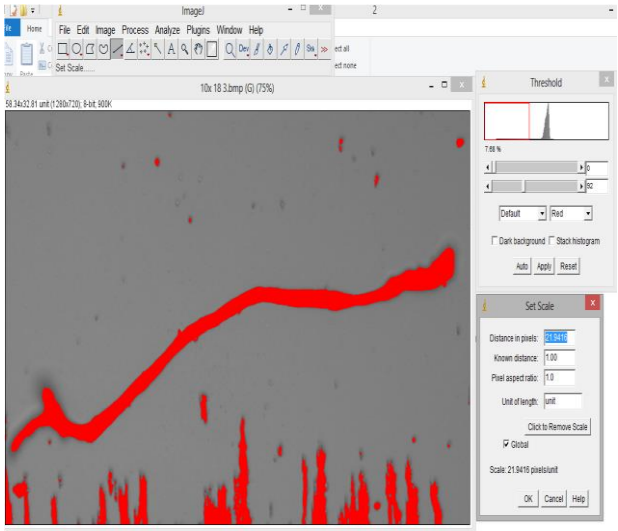

Fig 6. Thresholded Image for Cutting Particle

Table 1. Area of Cutting Particle

Label	**Area (micron^2)**	**Perimeter (micron)**	Major	Minor	Angle	Circul.
Particle 1	**80.788**	**133.763**	33.877	3.036	14.583	0.057

Table 1 shows the output result of ROI tool which gives the required area and perimeter of selected wear particle. Column Major indicates the maximum distance covered by the particle and column minor indicates the minimum distance covered by the particle. Angle indicates the inclination of wear particle with x-axis and circularity indicates how close the object is to be a true circle. Area of Particle 1 is 80.788 micron^2 and its perimeter is 133.763.

CASE 2: Area and Perimeter Calculation of Sliding Wear Particle

Sliding wear particles are generated due to adhesive wear mode and brittle fracture [22]. Sliding wear particles are irregular in shape having random boundary. Practically it is difficult to calculate the area of irregular shape as it does not come under standard shapes like triangle or rectangle. An attempt is made to calculate area of irregular shaped wear particle using ImageJ. Fig 7 shows the sliding wear particle collected from given oil sample. Fig 8 indicates thresholded image of sliding wear particle along with thresholded value and scaling option.

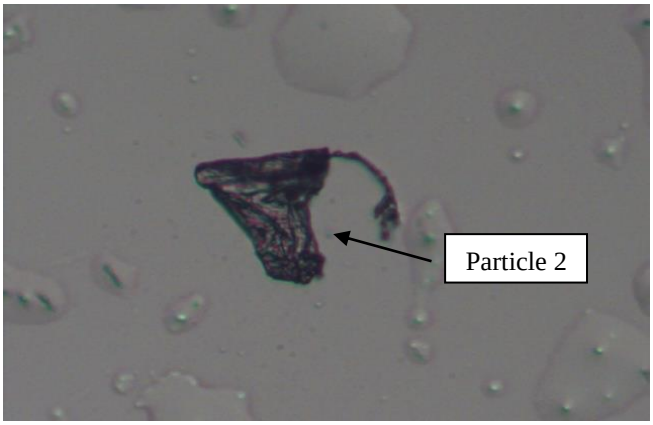

Fig 7. Sliding Wear

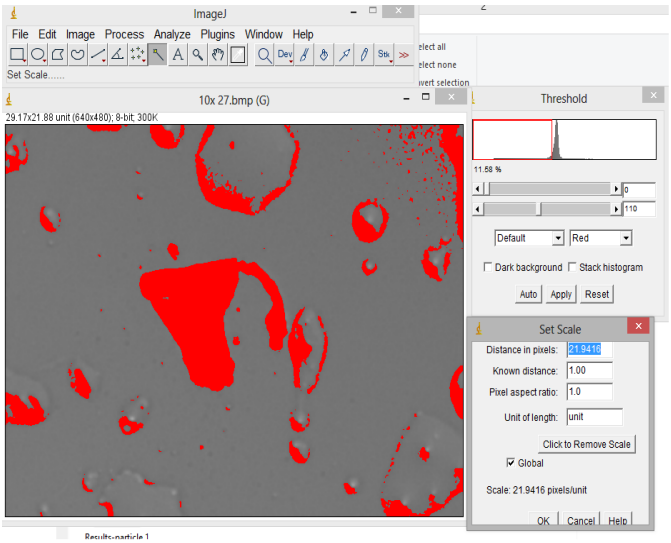

Fig 8. Image Thresholding for Cutting Particle

Table 2. Area of Sliding Particle

Label	**Area (micron^2)**	**Perimeter (micron)**	Major	Minor	Angle	Circul.
Particle 2	**33.81**	**38.402**	7.084	6.077	161.86	0.288

Table 2 gives the output result of ROI tool manager used for area calculation for Fig 8. Area of sliding wear particle shown in Fig 8 is 33.81 micron^2 and perimeter is 38.402 micron.

V. CONCLUSIONS

Quantitative and qualitative study was performed for HP EP 900 gear oil after 800hrs of running a machine. Quantitative analysis showed the increase in large and small size wear particles. Concentration of large and small size particle in given oil sample was 188.3 and 177.6 respectively. Qualitative analysis showed the presence of cutting particles, red oxide, sliding particles and normal rubbing wear particles. It has been observed from analytical ferrography that adhesive and abrasive wear mechanism has occurred in gear pair. Area and perimeter of specific ferrographic images of cutting and sliding wear particles were calculated using ImageJ software. While calculating area of any particle, magnification factor for all the images should be kept same for comparison.

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By calculating area, perimeter, aspect ratio and standard deviation, wear particles can be distinguished by image processing tool, which helps to monitor current condition of machine or component. From the obtained results and observations of area occupied by the wear particles, which shows particle coverage. Also it helps in suggesting oil replacement policy and keeps the health of machine intact with change in time. It can be used as predictive maintenance tool for oil replacement.

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