ASSESSMENT OF CYLINDER LINERS USING COMPUTER VISION AND NUMERICAL THERMAL ANALYSES

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Abstract:

Honing is required when the surface structure parameters of cylinder liners are varied critically. Wear and tear signs occur when cylinder liners of both 4-stroke, and 2-stroke engines are used extensively. Wear and tear is not evenly distributed. Most wears occur between the reversal points of the upper and lower piston rings. Scuffing marks are generally found where the upper piston ring changes its direction. When honing time approaches for most cylinder liners, oval shape of cylinder liners appears. In this study, images of cylinder liners with different surface topography were taken using 3D digital microscope with high resolution and different magnification factors. The sampled images were pre-processed using high pass filters in order to enhance images to catch high frequency components. Edges and patterns of enhanced images then were analyzed using X-Y Sobel algorithm. Then the results obtained from these image analyses studies were compared to have a better understanding about the relationship between temperature distribution contours and patterns on cylinder liners. The solid models of cylinder liners were drawn using Autodesk Inventor and imported to ANSYS Design modeler. The mesh model of the cylinder liner was achieved using CFX-meshing. With approximated boundary conditions, heat fluxes and temperature distribution were computed using numerical thermal analysis in ANSYS. The thermal analyses results indicated that the temperature of the inner surface of the cylinder liners increased about two times when the heat flux rates ranged from 100 to 500 kW/m². Edge and pattern determination results showed that scuffing marks and scratches and their morphological properties from the images of the cylinder liners could be identified using image processing and analyses techniques developed in this study.

Keywords: Computer vision, Manufacturing techniques, Roughness measurement, Wavelet transform

1. INTRODUCTION

In engineering applications, testing and measurement are used to characterize the surfaces of both the work piece and cutting tools. Measurement is therefore defined as the process of experimentally obtaining quantity values that can reasonably be attributed to a property of a body or substance. Metrology is the science of measurement. Testing is the technical application consisting of the determination of characteristics of a given object or process, in accordance with a specified method [1].

In this experimental work, the properties of the combustion engine cylinder liners were described using the different types of auto engines. The cylinder liner, serving as the inner wall of a cylinder, forms a sliding surface for the piston rings while retaining the lubricant within. The most important function of cylinder liners is the excellent characteristic as sliding surface and these four necessary points. These are; high anti-galling properties, less wear on the cylinder liner itself, less wear on the partner piston ring, less consumption of lubricant [2].

A cylinder wall in an engine is under high temperature and high pressure, with the piston and piston rings sliding at high speeds. Also, the cylinder liner receives combustion heat through the piston and piston rings and transmits the heat to the coolant [3].

Computational methods such as image and numerical thermal analyses are powerful tools to investigate, assess and characterize the surfaces of materials. Therefore, in this study the wear and tear signs of cylinder liners were analyzed using image and numerical thermal analyses methods in order to evaluate the surfaces of cylinder liners produced by different manufacturers.

2. SURFACE TOPOGRAPHY CHARACTERIZATION

2.1 Surface Profile Characterization

A cylinder liner is a cylindrical part to be fitted into an engine block to form a cylinder. It is one of the most important functional parts to make up the interior of an engine. In the course of this experiment two essential terms will be used to describe the different scales of the cylinder liner surface, ótextureô and óroughnessö. Texture is described as the larger scale cross-hatch as a shape left behind by the first stage of the honing process. Roughness is described as the smaller scale, smaller amplitude of the surface between the cross-hatching, the diamond like plateau.

2.2 Surface Measurement Procedure

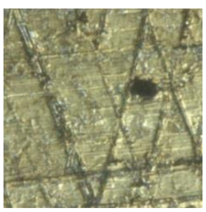
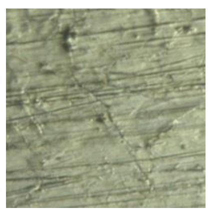
The surface roughness and wear behaviors of various types of cylinder liners were investigated by using a stylus profilometre (Form Talysurf Intra50) [4] and 3D Digital Microscope (Keyence VHX-2000) [5]. In the roughness measurements, the cut-off values were chosen as 0.25 mm and the evaluation length was as 1.25 mm.

3. PRECISE MEASUREMENT AND EVALUATION

The wear problem of the internal combustion engines through numerical and visual ways was evaluated in order to understand two different types of cylinder liners during the lifetime and to compare with each other. Additionally, in order to create a reference point for used cylinder liners, three different types of cylinder liner (Table 1) were analyzed with the same method.

The results from the used cylinder liners were given. These samples were investigated in 3 different regions and 4 different areas. These measurement areas are under the bottom dead center, direction of operating piston and perpendicular to the direction of operating piston as last two areas. This region is exposed to wear due to friction, because piston-cylinder-ring trio are in contact with each other in this region.

Table 1: Type of Cylinder Liners.

Type of Cylinder Liners	Cylinder Liner for X Engine (Diesel)	Cylinder Liner for Y Engine (Gasoline)
Original Images		

The surfaces of the first sample taken from cylinder liner of X engine have Ra values in 10 profiles between 0.061 εm and 0.11 εm, Rz values in 10 profiles between 0.46 εm and 0.84 εm. This area taken by 200x lens is under bottom dead center. The lines on the surface of cylinder liner for X Engine (Diesel) caused by friction between cylinder liner-piston ring were observed within honing lines.

The cylinder liner of Y Engine (Gasoline) was used as another sample in this experimental work. Ra values were found between 0.037 εm and 0.054 εm; Rz values were found between 0.21 εm and 0.39 εm.

4. COMPUTATIONAL ANALYSES

4.1 Machine Vision

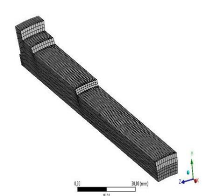
High resolution images were captured using 3D digital microscope. The capturing resolution of the camera for images was set to 1000×1000 pixels. The captured images were processed to enhance and analyze the images in order to draw conclusions using Matlab Image processing Toolbox and programs. Firstly, captured images were filtered using high pass filter. To sharpen a color image, the luma intensity transitions were made while preserving the color information of the image. To do this, an R'G'B' image is converted into the Y'CbCr color space and a highpass filter to the luma portion of the image only is applied. Then, the image is transformed back to the R'G'B' color space. Enhanced images then were used in edge detection phase. In edge detection phase custom made matrix were used.

4.2 Thermal Modeling

The purpose of the thermal analysis is to provide an insight into surface temperature and surface characteristics of the cylinder liner. Solid modeling of a typical cylinder liner is shown in Fig. 1. Since it was a symmetrical geometry, only a 10º slice of the geometry was modeled to reduce memory requirements and solution time, and symmetry boundary conditions were applied to represent the remaining geometry. The solid model in which each element is hexagonal with 8 nodes was then meshed. The entire model has 35784 elements and 42809 nodes. Due to the use of hexagonal elements, the maximum value of skewness, a measure of element quality, was less than 0.51 which was interpreted as very good.

(a)

(b)



(c)

Fig. 1: a) solid geometry, b) 10º slice geometry, c) meshed geometry.

During a typical engine operation, it is well-known that heat is transferred from hot combustion gases to engine coolant through cylinder liner and engine block. The heat transferred from the hot combustion gases to the inner surface of the cylinder liner was considered to be as heat flux to the surface, and the remaining other surface which is the outer surface of the liner was assumed to be as in the real situation. That is, the other surface experiences the convection. In fact there is an engine block surrounding the outer surface of the liner, but the effect of the block to the heat conduction was neglected. The heat transfer is assumed to be steady state, the governing heat conduction equation can be written in the Cartesian coordinates as

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}=0 \qquad (1)$$

where T is the temperature, and x, y, and z are the space variables. To solve Equation (1), certain boundary conditions must be described at the surface of the numerical model of the cylinder liner. As mentioned in the beginning of this analysis, the heat flux rate at the inner surface of the liner can be expressed as

$$q_0 = k\frac{\partial T}{\partial x}+k\frac{\partial T}{\partial y}+k\frac{\partial T}{\partial z} \qquad (2)$$

where q_0 is the heat flux rate at the inner surface, and k is the thermal conductivity of the liner material. For the other surface, a convection boundary is defined as

$$k\frac{\partial T}{\partial x}+k\frac{\partial T}{\partial y}+k\frac{\partial T}{\partial z}=h(T_s-T_\infty) \quad (3)$$

where h is the convection heat transfer coefficient, T_s is the surface temperature which is the variable depending mostly on the heat flux rate, and T_∞ is the average engine coolant temperature. Some relevant parameters related with the thermal analysis are given in Table 2.

Table 2: Relevant input parameters for thermal analysis.

Thermal conductivity of the tool k (W/m ºC)	48
Convection heat transfer coefficient h (W/m²ºC)	12000
Engine coolant temperature T_∞ (ºC)	90
Heat flux rates q_0 (kW/m²)	100, 200, 300, 400, and 500

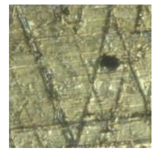
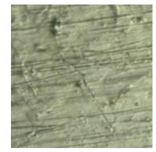
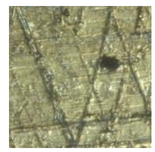
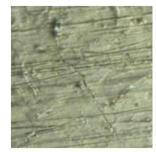
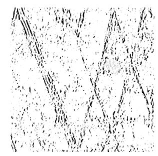
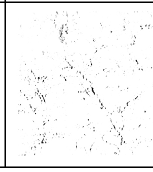
Note that there is a heat flux rate ranging from 100 to 500 kW/m² with an increment of 100 and numerical calculations are repeated for each heat flux value while the remaining parameters are kept constant. These heat flux rates were obtained from the literature [9,10,11], and they were happened to be typical values. The meshing of the model geometry and the finite element solution of Eqs. (1), (2) and (3) were solved using ANSYS CFX software package.

5. RESULTS

5.1 Image Analysis

Previous studies [6,7,8] showed a significant relationship between image processing and surface roughness. Table 3 indicated that filtering original images of cylinder liners belonging different auto engines such as X and Y enhanced and emerged high frequency components of the images. Scratched, defected, and worn surfaces of the cylinder liners could be identified from Table 3.

Table 3: Image Analyses results.

	X	**Y**
Original Images		
Enhanced Images		
Edge Detected Images		

5.2 Thermal Analysis

The results obtained from the analysis are shown in Table 4. The results show that the liner inner surface temperature increases with increasing the heat flux rate. It can be said that the surface temperature increases about two fold when the heat flux increases 5 times of the first value.

Table 4: Average inner surface temperature of the cylinder liner.

Heat flux rates q_0 (kW/m²)	Average inner surface temperature of cylinder liner (ºC)
100	112.3
200	134.5
300	156.8
400	179.0
500	201.3

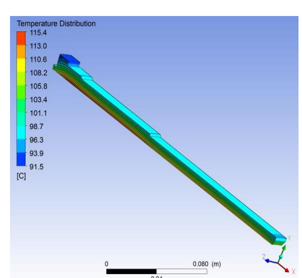


Fig. 2: A typical temperature distribution

A typical temperature distribution of a 10º slice of the geometry of the cylinder liner is shown in Fig. 2. In Table 5, surface roughness values and the amount of reduction of Ra value per km of cylinder liner, which have reached to end of physical life, are shown.

Table 5: Comparison of Engine performance

	Ra (µm)	Rz (µm)	Mileage of vehicle (km)	Reduction of Ra per km (nm/km)
X	0.088	0.582	300,000	0.00187
Y	0.046	0.298	300,000	0.00201

Table 5 indicates the case of a comparison between same mileage vehicles which use different fuels, the amount of reduction of Ra parameter per km in diesel engine is less than in gasoline engine. Due to friction between cylinder-ring and piston, wear occurs on the surfaces of cylinder liner. As a result of wear, the gap between piston and cylinder liner increase, the leakage of gases increase. Due to this leakage, reduction of pressure force on pistons occurs and efficiency of the engine decrease.

6. CONCLUSION

For the surface roughness parameter of cylinder liner (Ra), the values between 0.1 εm and 1.0 εm are optimum. Generally, the optimum value of parameter Ra for cylinder liner manufacturer, which is obtained from engine maintenance companies and experimental application, was found approximately as 0.65 εm. The reference value, which is used to calculate the wear of cylinder liner, consists of that parameter.

Based upon the results of this experimental research, the performance of diesel engine vehicle (X) is higher than gasoline engine vehicle (Y) in comparison to operation efficiency of cylinder liner-ring and piston according to the reduction of Ra per km.

According to a study [9], characterizing of wear on cylinder liner and analyzing the affecting factors are beneficial to keep the wear in minimum level. The amount of wear occurred on the cylinder liners in engines depends on not only material type, surface texture, friction condition and chemical impacts but also macro form deviation of cylinder liners. The results from the thermal analyses inferred that the temperature of the inner surface of the cylinder liners increased from 112.3 to 201.3 ºC when the heat flux rates are changed from 100 to 500 kW/m². Scuffing marks, scratches, torn and worn surfaces and their morphological properties from the images of the cylinder liners were identified using X-Y Sobel filters and pattern recognition algorithms.

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