CHAPTER 6

EXPERIMENTS ON MILLED GRAPHITE SPECIMENS HAVING VARIOUS SURFACE ROUGHNESS

6.1 Introduction

Experiments were successfully carried out on OHNS steel to verify the accuracy and correctness of the method to quantify the surface finish with the non-contact optical technique, digital image processing.

Same experiments are to be carried out on graphite specimens representing the same class of material to which Carbon–Carbon Composites belongs.

6.2 Objective of the Experiment

To establish the datum for surface finish measurement of the carbon-carbon composites, graphite specimens which are of the same class is being used. Different textured machined surfaces are obtained by preparing the holes on graphite specimens by changing the speeds and feeds on vertical machining center (VMC-430). Complete analysis is carried out with the help of image processing tool of MATLAB.

6.3 Experimental Work

6.3.1 Materials

The material used for this work is graphite specimen. Graphite is a polymorph of the element carbon. Graphite is the stable form of carbon and has a sheet like structure. It exhibits the properties of a metal and a non-metal, which makes it suitable for many industrial applications. Graphite is a soft material even though the hardness within the atom layers approaches that of diamond. The metallic properties include thermal and electrical conductivity. The non-metallic properties include lubricity, inertness and high thermal shock resistance.
Products made from carbon fiber graphite composites include space age applications, fishing rods, golf clubs shafts, bicycle frames and pool sticks. Graphite foils use in valve packing and gaskets. Graphite is critical for many industrial applications, such as dies for continuous casting, rocket nozzles, and heat exchangers for the chemical industry. Graphite is consumed for refractory, steel making, brake linings, fuel cells, and brushes for electric motors. Other significant uses of graphite in carbon fiber reinforced plastics, in heat resistant composites such as reinforced carbon-carbon composites.

6.3.2 VMC – 430 Machine

The experiments are conducted on Vertical Machining Center machine - 430, Jyoti, Rajkot made. It is CNC SIEMENS SINUMERIK 802D solution line control system having AC spindle drive. Figure 6.1 shows the VMC - 430 machine used for the experiments. Figure 6.2 shows the graphite specimen machined (milled) on the VMC – 430 machine.

6.3.3 CCD Camera and Optical Microscope

High resolution color CCD camera, Samsung made (model: SAC -410PA) used which are having effective pixels are 768 (H) * 494 (V). Here Carlzeill optical microscope is used. With the help of above the images are grabbed.

6.3.4 Stylus Roughness Measuring Instrument

For these experiments, to measure the average surface roughness parameter, ‘Ra’, portable Surface Roughness Tester (figure 6.3), Model: Surftest SJ-201, Mitutoyo made is used. Measuring force is 4mN. Diamond material stylus having tip radius 5μm (200 μinch). Radius of skid curvature is 40 mm. Stylus roughness tester has resolution of 0.000125 μm / 0.00492 μin. Filter is 2RC type.
Figure 6.1 VMC 430 (Vertical Machining Center – 430)
Figure 6.2 Machined (milled) graphite specimen

Figure 6.3 Stylus roughness measuring tester
This work is carried out under the following conditions:

1. The machine used for machining purpose is Vertical Machining Center - 430 (VMC - 430).
2. Milled machined surface is obtained with help of 10 mm, two fluted end mill.
3. The material used for this work is graphite specimens.
4. Images of machined graphite specimens are grabbed with optical microscope with CCD camera.
5. Image analysis is carried out with software tool image processing of MATLAB.
6. Stylus roughness ‘Ra’ is measured for each specimen with stylus roughness tester.

6.4 Planning of Experiments

These experiments are carried out with 2 mm of depth of cut of machining. The process parameters chosen for machining of graphite specimens are speed (rpm) and feed (mm/min). Basic aim is to acquire the machined surface of graphite specimens having different roughness. To get this, machining is done on VMC – 430 with 10 mm, two fluted end mill.

According to the capability of VMC – 430 machine available and general recommendation of machining conditions for graphite specimens, the parameters selected are shown in table 6.1.

<table>
<thead>
<tr>
<th>Sr no</th>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2500</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>3000</td>
<td>10</td>
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<td>3</td>
<td>3500</td>
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<td>5</td>
<td>3500</td>
<td>16</td>
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<td>6</td>
<td>4000</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>4500</td>
<td>16</td>
</tr>
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</table>
6.5 Experimental Procedure

The experiments are carried out by preparing the holes in graphite specimens with use of 10mm, 2 fluted end mill on vertical machining centre (VMC-430). Surfaces with different textures are obtained by controlling the machine parameters, speeds and feeds. The depth of cut is 2mm. The images of these graphite specimens are grabbed by high resolution color CCD camera (Samsung SAC - 410PA having effective pixels 768 (H) × 494 (V)) with Carlzeill optical microscope.

Low pass filter is applied to all images. Histogram analysis and evaluation of optical surface roughness are carried out. Power spectrum is also obtained. These analyses are carried out with the help of image processing tool of Matlab. After completing the mentioned analysis, the arithmetic average roughness parameter is obtained for all specimens with the help of stylus roughness tester. Correlation is found out between measured stylus parameter and optical parameter.

6.6 Analysis of Result and Discussion

Analysis of each image is carried out. Here the images of graphite specimens having stylus roughness, ‘Ra’ of 0.64 µm and 0.8833 µm are shown in figures 6.4 and 6.5

6.6.1 Histogram Analysis

Gray scale analysis technique has used for surface characteristic which is known as histogram. Histogram drawn shows the variation of grey level intensity as per the surface roughness of the surface. It shows the occurrence (frequency) of grey level intensity over the surface. Figures 6.6 and 6.7 show histograms of images having different surface roughness.

As the surface becomes smoother, there is an increase in the frequency of larger value intensity. In histogram left side shows the smaller value of intensities and right side shows the larger value of intensities. As surface becomes smooth, reflectivity increases, resulting in higher value of frequencies in larger gray value intensities. In figure 6.7, rougher surface having surface roughness Ra = 0.8833 µm, there is a dominance of gray levels 100 - 150
Figure 6.4 Image of graphite having $Ra = 0.64 \mu m$

Figure 6.5 Image of graphite having $Ra = 0.8833 \mu m$

Figure 6.6 Histogram of graphite having $Ra = 0.64 \mu m$

Figure 6.7 Histogram of graphite having $Ra = 0.8833 \mu m$
approximately having frequency (number of times each gray value occurs in image) 2000. As well as rougher surface has non uniform histogram compared to smoother surface. However in the case of relatively smoother surface having surface roughness Ra = 0.64 μm, it is observed from figure 6.6 that 100 - 150 value of gray levels are having 5000 frequency.

So from histogram one can judge that whether the surface is relatively smooth or rough. Histograms have the limitation that they carry no information regarding the relative position of the pixel intensities with respect to each other.

6.6.2 Fourier Analysis (Power Spectrum)

The 3 - D perspective of the power spectrum of the surface image (after applying the filter) is to be shown in figures 6.8 and 6.9. It can be clearly seen from these figures that as surface roughness Ra decreases, amplitude of power spectra is also decreased.

Power spectrum is a magnitude of Fourier transform of an image. As the surface becomes smoother i.e. roughness value decreases, then the amplitude of power spectrum also decreases. Figure 6.9 shows that amplitude of power spectrum of graphite specimen having roughness Ra = 0.8833 μm is $2.3 \times 10^{10}$ while as shown in figure 6.8, the amplitude of power spectrum graphite specimen having roughness Ra = 0.64 μm is $1.9 \times 10^{10}$.

6.6.3 Evaluation of Optical Roughness Parameter

With the help of image processing tool of MATLAB software, the optical roughness arithmetic average of gray level, (Ga) is calculated using equations 5.4 and 5.5, for all the surfaces after capturing the images of surfaces. After applying the low pass Gaussian filter to all images, again ‘Gaf’ is calculated. Finally ‘Ga’ values before applying filter and ‘Gaf’ values after applying the filter are compared with the respective ‘Ra’ values measured using a stylus instrument. To obtain the stylus roughness, ‘Ra’, the diamond stylus tip is moved over the machined surface of each specimen. Cut – off length is taken as 0.25 mm and total traverse length is 1.25 mm. Result of all calculated values ‘Ga’, ‘Gaf’ and measured ‘Ra’ for graphite specimens is shown in table 6.2.
TABLE 6.2
MACHINING PARAMETERS USED AND THE CORRESPONDING OPTICAL AND STYLUS ROUGHNESS VALUES FOR MILLED GRAPHITE SPECIMENS HAVING DEPTH OF CUT 2 MM

<table>
<thead>
<tr>
<th>S no</th>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
<th>G_a (without filter)</th>
<th>G_a(f) (with filter)</th>
<th>R_a (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2500</td>
<td>10</td>
<td>36.9228</td>
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<td>10</td>
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<td>0.8833</td>
</tr>
<tr>
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<td>4500</td>
<td>16</td>
<td>23.08942</td>
<td>22.0362</td>
<td>0.64</td>
</tr>
</tbody>
</table>

6.6.4 Estimation of Correlation between Optical Roughness Parameters and Stylus Roughness Parameter

After calculating all the values of optical parameters ‘G_a’, before applying the filter to the images and ‘G_a(f)’, after applying the filter to the images, the correlation is found out with surface roughness, ‘R_a’, found out with stylus instrument. To achieve this purpose the graph is drawn between the optical surface roughnesses ‘G_a’ (before applying the filter to the images) and stylus surface roughness, ‘R_a’ for the graphite specimen which is shown in figure 6.10. Another graph is drawn between the optical surface roughnesses, ‘G_a(f)’ (after applying the filter to the images) and stylus surface roughness, ‘R_a’ for the graphite specimen which is shown in figure 6.11.

Figure 6.10 shows that there is a good cubic correlation established between optical roughness parameter ‘G_a’ (before applying filter) and stylus roughness ‘R_a’ for graphite specimen. The relationship between ‘G_a’ and ‘R_a’ for graphite specimen having depth of cut 2 mm is

\[
G_a = -128.7 \times R_a^3 + 338.9 \times R_a^2 - 276.4 \times R_a + 95.71
\]

(6.1)

Figure 6.11 shows that there is a better cubic correlation established between optical roughness parameter ‘G_a(f)’ (after applying filter) and stylus roughness ‘R_a’ for graphite specimen. Noise is reduced by applying filter to the images hence better correlation is
Figure 6.8 3D – Power Spectrum of graphite having Ra = 0.64 µm

Figure 6.9 3D – Power Spectrum of graphite having Ra = 0.8833 µm

Figure 6.10 Correlation between stylus Ra and optical roughness Ga (without filter) for graphite

Figure 6.11 Correlation between stylus Ra and optical roughness Gaf (with filter) for graphite
established. The relationship between ‘Gaf’ and ‘Ra’ for graphite specimen having depth of cut of machining 2mm is

\[ Gaf = -112.8 \times Ra^3 + 292.9 \times Ra^2 - 233.1 \times Ra + 81.55 \]  

(6.2)

6.7 Conclusions

The result obtained confirmed that the histogram and power spectrum can be successfully applied to decide whether the surface analyzed is coarse or smooth. Hence acceptance or rejection policy of the components can be generated by that. As the surface becomes smoother, reflectivity increases resulting into increase in the frequency of larger value intensity of histogram. There is a higher value of amplitude of power spectrum as surface having higher value of roughness i.e. rough surface.

It is established that there is a good cubic correlation between stylus parameter ‘Ra’ and optical parameter ‘Ga’. The correlation of ‘Gaf’, optical parameter after applying the Gaussian filter has a better cubic correlation with the average surface roughness ‘Ra’ measured using a conventional and widely accepted stylus type instrument for the milled graphite. After applying the filter, noise can be removed, which results in better cubic correlation between stylus roughness ‘Ra’ and optical roughness ‘Gaf’ for milled graphite specimens. The governing equations are

\[ Ga = -128.7 \times Ra^3 + 338.9 \times Ra^2 - 276.4 \times Ra + 95.71 \]  

(6.1)

\[ Gaf = -112.8 \times Ra^3 + 292.9 \times Ra^2 - 233.1 \times Ra + 81.55 \]  

(6.2)

It is established from this work that non-contact digital image processing can be successfully implemented on machined graphite in order to design quality control concept on the basis of acceptance and rejection policy of the graphite components according to the characteristics of the surface in question. Results obtained utilize to establish a datum to quantify the surface characteristics of machined graphites.