CHAPTER 8

EXPERIMENTS ON GRAPHITE SPECIMENS OF DIFFERENT DENSITIES
HAVING VARIOUS SURFACE ROUGHNESS WITH THE TRINOCULAR ZOOM
STEREO MICROSCOPE

8.1 Introduction

Experiments were carried out on graphite specimens of different densities having various roughnesses with the binocular stereo microscope. It is to be well known that according to the surface finish i.e. value of surface roughness, the intensity gray values are to be varied. One of the observations from experiments is that the gray intensity values are changed as the angle of illumination is to be changed. So there will be a necessity for the experiments that the angle of illumination must be remained constant. In binocular stereo microscope, the inclined light is attached with objective column of microscope. So during focusing (to obtain the better images) the light illumination angle is also to be varied with the movement of objective column of microscope. This is to be affected the gray intensity values. To overcome the above problem Radical made, the trinocular zoom stereo microscope is used. In this microscope the intensity values are not to be changed with movement of objective column of microscope, as the light is not inclined but straight rays of light illuminates the specimens.

8.2 Objective of the Experiments

To establish the methodology for surface finish measurement of carbon – carbon composite class of materials, experiments are carried out on machined surface of high density graphite specimens. Machined surfaces of graphite specimens are obtained by controlling the cutting parameters (speed and feed) on vertical machining (VMC-850). Images of machined graphite specimens are captured with trinocular zoom stereo microscope. Estimation of optical roughness parameters is carried out. Governing equation developed between optical roughness parameter ‘Gaf’ and stylus roughness ‘Ra’ is used to assess ‘Ra’ value of EDM machined C – C composite without moving stylus on surface. Complete analysis is carried out with the help of image processing tool of MATLAB.
8.3 Experimental Work

8.3.1 Materials

The material used for this investigation is graphite specimens having different densities. Graphite, layered compound, is one of allotropes of carbon crystalline exhibits the properties of a metal and a non-metal, which makes it suitable for many industrial applications. Graphite holds the distinction of being the most stable form of carbon under standard conditions. 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 inertness, high thermal shock resistance and lubricity.

Graphite is mostly 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. 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.

8.3.2 VMC - 850 Machine

The experiments are conducted on Vertical Machining Center machine - 850, Jyoti, Rajkot made. It is CNC SIEMENS SINUMERIK 810 D solution line having AC spindle drive. Figure 8.1 shows the VMC - 850 machine used for the experiments

8.3.3 DIGIEYE 210 Color Camera

The Radical Instruments Ltd.(Delhi) made DGI 210 is equipped with high quality 1/2 inch (MICROS USA) “CLEAR VID” sensor. DGI 210 is 2 megapixel, USB 2.0 interface camera. The embedded driver of DGI 210 has CAPTURE PRO. The CAPTURE PRO opens camera in software with a simple click of Camera Icon. The software’s advance controls
Figure 8.1 VMC-850 (Vertical Machining Center – 850)
white balancing, frame rate, brightness, contrast, hue, saturation, etc. This camera has high resolution of 1280 × 1024.

8.3.4 Trinocular Zoom Stereo Microscope

To obtain the quality images, Trinoocular zoomstereo microscope, Model: RSM – 9F, Radical Instruments, Ambala, made is used. This microscope feature a zoom magnification from 7X to 45X, zoom ratio 6.4:1 with standard Eyepieces WF 10X / 20X. Here 10W halogen ring light is clamped with objective housing for illumination. Due to this surface of the specimens are illuminated in straight ways. Figure 8.2 shows the Trinoocular Zoom Stereo microscope (model RSM – 9F) with DIGI 210 color camera. Figure 8.3 shows the DIGIEYE 210 color camera.

8.3.5 Stylus Roughness Measuring Instrument

For these experiments, to measure the average surface roughness parameter, ‘Ra’, portable Surface Roughness Tester (figure 8.4), Model: Surftest SJ-201, Mitutoyo made is used. Measuring force is 4mN. Diamond material stylus having tip radius 5μm (200 μinch). Radius cf skid curvature is 40 mm. Stylus roughness tester has resolution of 0.000125 μm / 0.00492 μin. Filter is 2RC type.

This investigation is carried out under the following conditions:

1. The machine used for machining purpose is Vertical Machining Center - 850 (VMC – 850).
2. Machined surface is obtained with help of 12 mm, four fluted end mill.
3. The material used for this work is graphite specimens having different densities.
4. Images of machined surface graphite specimens are grabbed with trinocular zoom stereo microscope with DIGIEYE color camera.
5. Image analysis is done with software tool image processing of MATLAB.
6. Stylus roughness ‘Ra’ is measured for each specimen with stylus roughness tester after grabbing the images of machined specimens.
Figure 8.2 Trinocular Zoom Stereo Microscope
Figure 8.3 DIGI 210 High Resolution Color Camera

Figure 8.4 Stylus Roughness Measuring Tester
8.4 Planning of Experiments

These experiments are carried out with 2mm of depth of cut of machining. The process parameters chosen for machining of each graphite specimen having different density are the combination of different speed (rpm) and feed (mm/min). Basic aim is to acquire the machined surface of graphite specimen having different roughness. To get this, machining is done on VMC – 850 with 12 mm, four fluted end mill.

According to the capability of VMC – 850 machine available and general recommendation of machining conditions for graphite specimens, the different parameters selected are shown in respective tables.

Experiments are carried out on graphite specimens of different densities: 1.541, 1.8478, 1.45 and 1.7082 g / cc.

For each image of above mentioned specimens following analysis are carried out using MATLAB.

1. Preprocessing (Filtering)
2. Histogram Analysis
3. Fourier Analysis (Power Spectrum)
4. Estimation of Optical Parameters, Arithmetic Average of Gray Level Ga (before applying filter) and Gaf (after applying filter).
6. Estimation of Governing Equation which Shows the Relationship between ‘Ga’ and ‘Ra’.
7. Estimation of Governing Equation which Shows the Relationship between ‘Gaf’ and ‘Ra’.
8.5 Experiments Carried out on Graphite Specimen having Density 1.541 g/cc

8.5.1 Experimental Procedure

Graphite specimen having density 1.541 g/cc is machined on vertical machining center (VMC-850) with 12mm, four fluted end mill. Various surface roughnesses are obtained by controlling the machining parameters i.e. different speeds and feeds on VMC machine.

According to the capability of VMC – 850 machine available and general recommendation of machining condition for graphite, the following parameters shown in table 8.1 are selected.

<table>
<thead>
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<th>S no</th>
<th>Speed (rpm)</th>
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</tr>
</thead>
<tbody>
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<td>5</td>
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</tbody>
</table>

The depth of cut of machining is set at 2 mm. The images of these machined specimens are grabbed by high resolution DIGI 210 color camera having effective pixels 1280 x 1024 with trinocular zoom stereo microscope (RSM -9F).

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 done 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.
8.5.2 Analysis of Result and Discussion

Analysis of each image is carried out. Here the images of graphite specimen (density 1.541 g / cc) having stylus roughness, 'Ra' of 2.035 μm and 3.8166 μm are shown in figures 8.5 and 8.6.

8.5.2.1 Histogram Analysis

Gray scale analysis technique has been 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 8.7 and 8.8 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 for larger gray value intensities. In figure 8.8, rougher surface having surface roughness Ra = 3.8166 μm, there is a dominance of gray level 150 approximately having frequency (number of times each gray value occurs in image) 25,000. However in the case of relatively smoother surface having surface roughness Ra = 2.035 μm, it is observed from figure 8.7 that 150 value of gray level is having 30,000 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.
Figure 8.5 Image of graphite (density = 1.541 g/cc) having Ra = 2.035 μm

Figure 8.6 Image of graphite (density = 1.541 g/cc) having Ra = 3.8166 μm

Figure 8.7 Histogram of graphite (density = 1.541 g/cc) having Ra = 2.035 μm

Figure 8.8 Histogram of graphite (density = 1.541 g/cc) having Ra = 3.8166 μm
8.5.2.2 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 8.9 and 8.10. 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 8.10 shows that amplitude of power spectrum of graphite specimen having roughness Ra = 3.8166 μm is $3 \times 10^{11}$ while as shown in figure 8.9, the amplitude of power spectrum of graphite specimen having roughness Ra = 2.035 μm is $2.7 \times 10^{11}$.

8.5.2.3 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.

Arithmetic average of the gray level Ga (optical roughness) can be expressed as

$$ Ga = \frac{\sum (g_1 - g_m + g_2 - g_m + g_3 - g_m + \ldots + g_n - g_m)}{n} \quad (5.4) $$

Where $g_1, g_2, g_3, \ldots, g_n$ are the gray level values of a surface of image along one line and $g_m$ is the mean of the gray values and this can be determined as

$$ g_m = \frac{\sum (g_1 + g_2 + g_3 + \ldots + g_n)}{n} \quad (5.5) $$

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 8.2.
TABLE 8.2
MACHINING PARAMETERS USED AND THE CORRESPONDING OPTICAL AND STYLUS ROUGHNESS VALUES FOR GRAPHITE SPECIMEN HAVING DENSITY 1.541 g / cc

<table>
<thead>
<tr>
<th>S no</th>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
<th>(G_a) (without filter)</th>
<th>(G_{af}) (with filter)</th>
<th>(R_a) (μm)</th>
</tr>
</thead>
<tbody>
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<td>20.614815</td>
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8.5.2.4 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 ‘\(G_{af}\)’, after applying the filter to the images, the correlation is found out with surface roughness, ‘\(R_a\)’, measured with stylus instrument. To achieve this purpose the graph is drawn between the optical surface roughness \(G_a\) (before applying the filter to the images) and stylus surface roughness, ‘\(R_a\)’ for the graphite specimen (density 1.541 g / cc) which is shown in figure 8.11. Another graph is drawn between the optical surface roughness, \(G_{af}\) (after applying the filter to the images) and stylus surface roughness, ‘\(R_a\)’ for the same graphite specimen which is shown in figure 8.12.

Figure 8.11 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 having density 1.541 g / cc. The relationship between ‘\(G_a\)’ and ‘\(R_a\)’ for graphite specimen having density 1.541 g / cc is

\[
G_a = -4.606 \times R_a^3 + 40.13 \times R_a^2 - 110.8 \times R_a + 118.3
\]

(8.1)

Figure 8.12 shows that there is a better cubic correlation established between optical roughness parameter \(G_{af}\) (after applying filter) and stylus roughness ‘\(R_a\)’ for graphite specimen having density 1.541 g / cc. Noise is reduced by applying filter to the images hence
Figure 8.9 3D Power spectrum of graphite (density = 1.541 g/cc) having Ra = 3.8166 μm

Figure 8.10 3D Power spectrum of graphite (density = 1.541 g/cc) having Ra = 2.035 μm

Figure 8.11 Correlation between stylus Ra and optical roughness Ga for graphite (density = 1.541 g/cc)

Figure 8.12 Correlation between stylus Ra and optical roughness Gaf for graphite (density = 1.541 g/cc)
better correlation is established. The relationship between ‘Gaf’ and ‘Ra’ for graphite specimen having density 1.541 g / cc is

$$Gaf = -4.582 \times Ra^3 + 39.9 \times Ra^2 - 110 \times Ra + 116.4$$  \hspace{1cm} (8.2)

8.5.3 Conclusions

The result obtained confirmed that the histogram and power spectrum can be successfully applied to decide whether the analyzed surface 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. As surface becomes smooth, the amplitude of power spectrum decreases.

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 graphite specimen having density 1.541 g / cc. After applying the filter, noise can be removed, which results in better cubic correlation between stylus roughness ‘Ra’ and optical roughness ‘Gaf’ for the graphite specimen having density 1.541 g / cc. The governing equations are

$$Ga = -4.606 \times Ra^3 + 40.13 \times Ra^2 - 110.8 \times Ra + 118.3$$  \hspace{1cm} (8.1)

$$Gaf = -4.582 \times Ra^3 + 39.9 \times Ra^2 - 110 \times Ra + 116.4$$  \hspace{1cm} (8.2)
8.6 Experiments Carried out on Graphite Specimen having Density 1.8478 g / cc

8.6.1 Experimental Procedure

Graphite specimen having density 1.8478 g / cc is machined on vertical machining center (VMC-850) with 12mm, four fluted end mill. Various surface roughnesses are obtained by controlling the machining parameters i.e. different speeds and feeds on VMC machine.

According to the capability of VMC – 850 machine available and general recommendation of machining condition for graphite, the following parameters shown in table 8.3 are selected

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<td>4500</td>
<td>300</td>
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<tr>
<td>4</td>
<td>2000</td>
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<tr>
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<td>100</td>
</tr>
<tr>
<td>6</td>
<td>2000</td>
<td>300</td>
</tr>
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</table>

The depth of cut of machining is set at 2 mm. The images of these machined specimens are grabbed by high resolution DIGI 210 color camera having effective pixels 1280 x 1024 with trinocular zoom stereo microscope (RSM -9F).

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 done 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.
8.6.2 Analysis of Result and Discussion

Analysis of each image is carried out. Here the images of graphite specimen (density 1.8478 g/ cc) having stylus roughness, ‘Ra’ of 2.34 µm and 3.25 µm are shown in figures 8.13 and 8.14.

8.6.2.1 Histogram Analysis

Gray scale analysis technique has been 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 8.15 and 8.16 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 for larger gray value intensities. In figure 8.16, rougher surface having surface roughness Ra = 3.25 µm, there is a dominance of gray level 150 approximately having frequency (number of times each gray value occurs in image) 16000. However in the case of relatively smoother surface having surface roughness Ra = 2.34 µm, it is observed from figure 8.15 that 150 value of gray level is having 25000 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.
Figure 8.13 Image of graphite (density = 1.8478 g/cc) having Ra = 2.34 µm

Figure 8.14 Image of graphite (density = 1.8478 g/cc) having Ra = 3.25 µm

Figure 8.15 Histogram of graphite (density = 1.8478 g/cc) having Ra = 2.34 µm

Figure 8.16 Histogram of graphite (density = 1.8478 g/cc) having Ra = 3.25 µm
8.6.2.2 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 8.17 and 8.18. 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 8.18 shows that amplitude of power spectrum of graphite specimen having roughness Ra = 3.25 μm is $3 \times 10^{11}$ while as shown in figure 8.17, the amplitude of power spectrum of graphite specimen having roughness Ra = 2.34 μm is $2.5 \times 10^{11}$.

8.6.2.3 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.

Arithmetic average of the gray level Ga (optical roughness) can be expressed as

$$Ga = \left( \frac{\sum (g_1 - g_m + g_2 - g_m + g_3 - g_m + \ldots + g_n - g_m)}{n} \right)$$  \hspace{1cm} (5.4)

Where $g_1, g_2, g_3, \ldots, g_n$ are the gray level values of a surface of image along one line and $g_m$ is the mean of the gray values and this can be determined as

$$g_m = \left( \frac{\sum (g_1 + g_2 + g_3 + \ldots + g_n)}{n} \right)$$  \hspace{1cm} (5.5)

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 8.4.
TABLE 8.4
MACHINING PARAMETERS USED AND THE CORRESPONDING OPTICAL AND STYLUS ROUGHNESS VALUES FOR GRAPHITE SPECIMEN HAVING DENSITY 1.8478 g / cc

<table>
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<th>S no</th>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
<th>$G_a$ (without Filter)</th>
<th>$G_{af}$ (with filter)</th>
<th>$R_a$ (µm)</th>
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8.6.2.4 Estimation of Correlation between Optical Roughness Parameters and Stylus Roughness Parameter

After calculating all the values of optical parameters ‘Ga’, before applying the filter to the images and ‘Gaf’, after applying the filter to the images, the correlation is found out with surface roughness, ‘Ra’, measured 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, ‘Ra’ for the graphite specimen (density 1.8478g / cc) which is shown in figure 8.19. Another graph is drawn between the optical surface roughnesses, $G_{af}$ (after applying the filter to the images) and stylus surface roughness, ‘Ra’ for the same graphite specimen which is shown in figure 8.20.

Figure 8.19 shows that there is a good quadratic correlation established between optical roughness parameter $G_a$ (before applying filter) and stylus roughness ‘Ra’ for graphite specimen having density 1.8478 g / cc. The relationship between ‘Ga’ and ‘Ra’ for graphite specimen having density 1.8478 g / cc is

$$Ga = - 3.36 \times Ra^2 + 23.72 \times Ra - 17.01 \quad (8.3)$$

Figure 8.20 shows that there is a better quadratic correlation established between optical roughness parameter $G_{af}$ (after applying filter) and stylus roughness ‘Ra’ for
Figure 8.17 3D Power spectrum of graphite (density = 1.8478 g/cc) having Ra = 2.34 µm

Figure 8.18 3D Power spectrum of graphite (density = 1.8478 g/cc) having Ra = 3.25 µm

Figure 8.19 Correlation between stylus Ra and optical roughness Ga for graphite (density = 1.8478 g/cc)

y = - 3.36x^2 + 23.72x - 17.0

Figure 8.20 Correlation between stylus Ra and optical roughness Gaf for graphite (density = 1.8478 g/cc)

y = - 3.252x^2 + 22.97x - 16.69
graphite specimen having density 1.8478 g / cc. Noise is reduced by applying filter to the images hence better correlation is established. The relationship between ‘Gaf’ and ‘Ra’ for graphite specimen having density 1.8478 g / cc is

\[ \text{Gaf} = -3.252 \times \text{Ra}^2 + 22.97 \times \text{Ra} - 16.69 \] (8.4)

8.6.3 Conclusions

The result obtained confirmed that the histogram and power spectrum can be successfully applied to decide whether the analyzed surface 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. As surface becomes smooth, the amplitude of power spectrum decreases.

It is established that there is a good quadratic correlation between stylus parameter ‘Ra’ and optical parameter ‘Ga’. The correlation of ‘Gaf’, optical parameter after applying the Gaussian filter has a better quadratic correlation with the average surface roughness ‘Ra’ measured using a conventional and widely accepted stylus type instrument for the graphite specimen having density 1.8478 g / cc. After applying the filter, noise can be removed, which results in better quadratic correlation between stylus roughness ‘Ra’ and optical roughness ‘Gaf’ for the graphite specimen having density 1.8478 g / cc. The governing equations are

\[ \text{Ga} = -3.36 \times \text{Ra}^2 + 23.72 \times \text{Ra} - 17.01 \] (8.3)

\[ \text{Gaf} = -3.252 \times \text{Ra}^2 + 22.97 \times \text{Ra} - 16.69 \] (8.4)
8.7 Experiments Carried out on Graphite Specimen having Density 1.45 g / cc

8.7.1 Experimental Procedure

Graphite specimen having density 1.45 g / cc is machined on vertical machining center (VMC-850) with 12mm, four fluted end mill. Various surface roughnesses are obtained by controlling the machining parameters i.e. different speeds and feeds on VMC machine.

According to the capability of VMC – 850 machine available and general recommendation of machining condition for graphite, the following parameters shown in table 8.5 are selected.

| TABLE 8.5 |
| MACHINING PARAMETERS USED FOR GRAPHITE SPECIMEN HAVING DENSITY 1.45 g / cc ON VMC – 850 |

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</table>

The depth of cut of machining is set at 2 mm. The images of these machined specimens are grabbed by high resolution DIGI 210 color camera having effective pixels 1280 x 1024 with trinocular zoomstereo microscope (RSM -9F).

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 done 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.
8.7.2 Analysis of Result and Discussion

Analysis of each image is carried out. Here the images of graphite specimen (density 1.45 g / cc) having stylus roughness, ‘Ra’ of 2.905 µm and 3.4 µm are shown in figure 8.21 and 8.22.

8.7.2.1 Histogram Analysis

Gray scale analysis technique has been 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 8.23 and 8.24 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 for larger gray value intensities. In figure 8.24, rougher surface having surface roughness Ra = 3.4 µm, there is a dominance of gray level 150 approximately having frequency (number of times each gray value occurs in image) 18000. However in the case of relatively smoother surface having surface roughness Ra = 2.905 µm, it is observed from figure 8.23 that 150 value of gray level is having 27000 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.
Figure 8.21 Image of graphite (density = 1.45 g/cc) having Ra = 2.905 µm

Figure 8.22 Image of graphite (density = 1.45 g/cc) having Ra = 3.4 µm

Figure 8.23 Histogram of graphite (density = 1.45 g/cc) having Ra = 2.905 µm

Figure 8.24 Histogram of graphite (density = 1.45 g/cc) having Ra = 3.4 µm
8.7.2.2 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 8.25 and 8.26. 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 8.26 shows that amplitude of power spectrum of graphite specimen having roughness \( Ra = 3.4 \, \mu m \) is \( 3.2 \times 10^{11} \) while as shown in figure 8.25, the amplitude of power spectrum of graphite specimen having roughness \( Ra = 2.905 \, \mu m \) is \( 3 \times 10^{11} \).

8.7.2.3 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.

Arithmetic average of the gray level \(Ga\) (optical roughness) can be expressed as

\[
Ga = \frac{\sum (|g_1 - g_m| + |g_2 - g_m| + |g_3 - g_m| + \ldots + |g_n - g_m|)}{n} \quad (5.4)
\]

Where \( g_1, g_2, g_3, \ldots, g_n \) are the gray level values of a surface of image along one line and \( g_m \) is the mean of the gray values and this can be determined as

\[
g_m = \frac{\sum (g_1 + g_2 + g_3 + \ldots + g_n)}{n} \quad (5.5)
\]

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 8.6.
8.7.2.4 Estimation of Correlation between Optical Roughness Parameters and Stylus Roughness Parameter

After calculating all the values of optical parameters ‘Ga’, before applying the filter to the images and ‘Gaf’, after applying the filter to the images, the correlation is found out with surface roughness, ‘Ra’, measured with stylus instrument. To achieve this purpose the graph is drawn between the optical surface roughness Ga (before applying the filter to the images) and stylus surface roughness, ‘Ra’ for the graphite specimen (density 1.45 g / cc) which is shown in figure 8.27. Another graph is drawn between the optical surface roughness, Gaf (after applying the filter to the images) and stylus surface roughness, ‘Ra’ for the same graphite specimen which is shown in figure 8.28.

Figure 8.27 shows that there is a good quadratic correlation established between optical roughness parameter Ga (before applying filter) and stylus roughness ‘Ra’ for graphite specimen having density 1.45 g / cc. The relationship between ‘Ga’ and ‘Ra’ for graphite specimen having density 1.45 g / cc is

\[ Ga = 8.281 \times Ra^2 - 40.89 \times Ra + 68.28 \] (8.5)

Figure 8.28 shows that there is a better quadratic correlation established between optical roughness parameter Gaf (after applying filter) and stylus roughness ‘Ra’ for graphite specimen having density 1.45 g / cc. Noise is reduced by applying filter to the
Figure 8.25 3D Power spectrum of graphite (density = 1.45 g/cc) having Ra = 2.905 µm

Figure 8.26 3D Power spectrum of graphite (density = 1.45 g/cc) having Ra = 3.4 µm

Figure 8.27 Correlation between stylus Ra and optical roughness Ga for graphite (density = 1.45 g/cc)

Figure 8.28 Correlation between stylus Ra and optical roughness Gaf for graphite (density = 1.45 g/cc)
images hence better correlation is established. The relationship between ‘Gaf’ and ‘Ra’ for graphite specimen having density 1.45 g / cc is

\[
Gaf = 7.066 \times Ra^2 - 33.18 \times Ra + 55.24
\]  

(8.6)

### 8.7.3 Conclusions

The result obtained confirmed that the histogram and power spectrum can be successfully applied to decide whether the analyzed surface 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. As surface becomes smooth, the amplitude of power spectrum decreases.

It is established that there is a good quadratic correlation between stylus parameter ‘Ra’ and optical parameter ‘Ga’. The correlation of ‘Gaf’, optical parameter after applying the Gaussian filter has a better quadratic correlation with the average surface roughness ‘Ra’ measured using a conventional and widely accepted stylus type instrument for the graphite specimen having density 1.45 g / cc. After applying the filter, noise can be removed, which results in better quadratic correlation between stylus roughness ‘Ra’ and optical roughness ‘Gaf’ for the graphite specimen having density 1.45 g / cc. The governing equations are

\[
Ga = 8.281 \times Ra^2 - 40.89 \times Ra + 68.28
\]  

(8.5)

\[
Gaf = 7.066 \times Ra^2 - 33.18 \times Ra + 55.24
\]  

(8.6)
8.8 Experiments Carried out on Graphite Specimen having Density 1.7082 g / cc

8.8.1 Experimental Procedure

Graphite specimen having density 1.7082 g / cc is machined on vertical machining center (VMC-850) with 12mm, four fluted end mill. Various surface roughnesses are obtained by controlling the machining parameters i.e. different speeds and feeds on VMC machine.

According to the capability of VMC – 850 machine available and general recommendation of machining condition for graphite, the following parameters shown in table 8.7 are selected.

<table>
<thead>
<tr>
<th>S no</th>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3000</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>3000</td>
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<tr>
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<td>200</td>
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<tr>
<td>4</td>
<td>3000</td>
<td>300</td>
</tr>
<tr>
<td>5</td>
<td>1000</td>
<td>50</td>
</tr>
</tbody>
</table>

The depth of cut of machining is set at 2 mm. The images of these machined specimens are grabbed by high resolution DIGI 210 color camera having effective pixels 1280 x 1024 with trinocular zoom stereo microscope (RSM -9F).

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 done 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.
8.8.2 Analysis of Result and Discussion

Analysis of each image is carried out. Here the images of graphite specimen (density 1.7082 g / cc) having stylus roughness, ‘Ra’ of 3.48 μm and 4.355 μm are shown in figure 8.29 and 8.30.

8.8.2.1 Histogram Analysis

Gray scale analysis technique has been 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 8.31 and 8.32 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 for larger gray value intensities. In figure 8.32, rougher surface having surface roughness Ra = 4.355 μm, there is a dominance of gray level 150 approximately having frequency (number of times each gray value occurs in image) 18000. However in the case of relatively smoother surface having surface roughness Ra = 3.48 μm, it is observed from figure 8.31 that 150 value of gray level is having 25000 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.
Figure 8.29 Image of graphite (density = 1.7082 g/cc) having Ra = 3.48 µm

Figure 8.30 Image of graphite (density = 1.7082 g/cc) having Ra = 4.355 µm

Figure 8.31 Histogram of graphite (density = 1.7082 g/cc) having Ra = 3.48 µm

Figure 8.32 Histogram of graphite (density = 1.7082 g/cc) having Ra = 4.355 µm
8.8.2.2 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 8.33 and 8.34. 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 8.34 shows that amplitude of power spectrum of graphite specimen having roughness Ra = 4.355 µm is $3 \times 10^{11}$ while as shown in figure 8.33, the amplitude of power spectrum of graphite specimen having roughness Ra = 3.48 µm is $2.5 \times 10^{11}$.

8.8.2.3 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.

Arithmetic average of the gray level Ga (optical roughness) can be expressed as

$$Ga = \left( \frac{1}{n} \left( g_1 - g_m + g_2 - g_m + g_3 - g_m + \ldots + g_n - g_m \right) \right)$$  \hspace{1cm} (5.4)

Where $g_1, g_2, g_3, \ldots, g_n$ are the gray level values of a surface of image along one line and $g_m$ is the mean of the gray values and this can be determined as

$$g_m = \left( \frac{1}{n} \left( g_1 + g_2 + g_3 + \ldots + g_n \right) \right)$$  \hspace{1cm} (5.5)

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 8.8.

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TABLE 8.8
MACHINING PARAMETERS USED AND THE CORRESPONDING OPTICAL AND STYLUS ROUGHNESS VALUES FOR GRAPHITE SPECIMEN HAVING DENSITY 1.7082 g/cc

<table>
<thead>
<tr>
<th>S no</th>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
<th>( G_a ) (without Filter)</th>
<th>( G_{af} ) (with filter)</th>
<th>( R_a ) (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3000</td>
<td>50</td>
<td>30.642</td>
<td>29.4886</td>
<td>3.64</td>
</tr>
<tr>
<td>2</td>
<td>3000</td>
<td>100</td>
<td>25.0991</td>
<td>23.97233</td>
<td>3.925</td>
</tr>
<tr>
<td>3</td>
<td>3000</td>
<td>200</td>
<td>27.75083</td>
<td>26.643266</td>
<td>3.885</td>
</tr>
<tr>
<td>4</td>
<td>3000</td>
<td>300</td>
<td>24.8853</td>
<td>23.8728</td>
<td>3.48</td>
</tr>
<tr>
<td>5</td>
<td>1000</td>
<td>50</td>
<td>24.58576</td>
<td>23.56836</td>
<td>4.355</td>
</tr>
</tbody>
</table>

8.8.2.4 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 \( G_{af} \), after applying the filter to the images, the correlation is found out with surface roughness, \( R_a \), measured with stylus instrument. To achieve this purpose the graph is drawn between the optical surface roughness \( G_a \) (before applying the filter to the images) and stylus surface roughness, \( R_a \) for the graphite specimen (density 1.7082 g/cc) which is shown in figure 8.35. Another graph is drawn between the optical surface roughness, \( G_{af} \) (after applying the filter to the images) and stylus surface roughness, \( R_a \) for the same graphite specimen which is shown in figure 8.36.

Figure 8.35 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 having density 1.7082 g/cc. The relationship between \( G_a \) and \( R_a \) for graphite specimen having density 1.7082 g/cc is

\[
G_a = 166 \times R_a^3 - 1958 \times R_a^2 + 7664 \times R_a - 9932 \tag{8.7}
\]

Figure 8.36 shows that there is a better cubic correlation established between optical roughness parameter \( G_{af} \) (after applying filter) and stylus roughness \( R_a \) for graphite specimen having density 1.7082 g/cc. Noise is reduced by applying filter to the images.
Figure 8.33 3D Power spectrum of graphite (density = 1.7082 g/cc) having Ra = 3.48 μm

Figure 8.34 3D Power spectrum of graphite (density = 1.7082 g/cc) having Ra = 4.355 μm

Figure 8.35 Correlation between stylus Ra and optical roughness Ga for graphite (density = 1.7082 g/cc)

Figure 8.36 Correlation between stylus Ra and optical roughness Ga for graphite (density = 1.7082 g/cc)
hence better correlation is established. The relationship between ‘Gaf’ and ‘Ra’ for graphite specimen having density 1.7082 g / cc is

\[ Gaf = 163.6 \times Ra^3 - 1929 \times Ra^2 + 7551 \times Ra - 9784 \] (8.8)

8.8.3 Conclusions

The result obtained confirmed that the histogram and power spectrum can be successfully applied to decide whether the analyzed surface 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. As surface becomes smooth, the amplitude of power spectrum decreases.

It is established that there is a good cubic correlation between stylus parameter ‘Ra’ and optical parameter ‘Gaf’. 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 graphite specimen having density 1.7082 g / cc. After applying the filter, noise can be removed, which results in better cubic correlation between stylus roughness ‘Ra’ and optical roughness ‘Gaf’ for the graphite specimen having density 1.7082 g / cc. The governing equations are

\[ Ga = 166 \times Ra^3 - 1958 \times Ra^2 + 7664 \times Ra - 9932 \] (8.7)

\[ Gaf = 163.6 \times Ra^3 - 1929 \times Ra^2 + 7551 \times Ra - 9784 \] (8.8)

This analysis shows that there is a higher value of optical roughness parameters, Ga (with filter) and Gaf (without filter) when images of graphite specimens are captured with trinocular zoom stereo microscope. This behavior can be attributed to the constant angle of illumination of light of trinocular zoom stereo microscope. Constant angle of light illumination provided by trinocular zoom stereo microscope gives higher value of optical roughness parameters of graphite specimens compared to optical roughness parameters of same graphite specimens whose images are captured with binocular stereo microscope. This
result can be confirmed by histograms of same graphite specimens whose images are captured with trinocular zoom stereo microscope. Histograms of images captured with trinocular zoom stereo microscope are having more dynamic range. Moreover, this investigation states that optical roughness parameters $G_a$ (without filter) and $G_a f$ (with filter) have a lower value for denser graphite specimens machined under same machining conditions i.e. smoother surface is obtained.