Carbonization Region Measurement in Vegetable Tanned Goat Leather using Machine Vision System for Evaluating Performance Measures of Leather Cut Contour Edges

by

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Abstract

Due to the widespread application and popularity of lasers in recent times, the usage of laser cutting for leather applications has increased as well. Laser technology is needed to provide more consistent and effective results while cutting leathers that include complicated geometries particularly in several sectors where leathers are often utilized such as footwear, apparel and fashion accessories. In this investigation, the diode laser was preferred for leather cutting due to its regulated power density, compact size and portability whereas the CO_2 lasers are uncontrollable. The benefit of employing a diode laser is that it can overcome some of the disadvantages associated with CO_2 lasers such as power consumption, carbonization layer and geometric inaccuracy. There is no technique available to measure the carbonization at the leather cut contour edges. Hence an attempt has been made to investigate the carbonization percentage with the help of a machine vision system to improve the machining process. The technique of measuring carbonization can be used effectively in the leather industry for the accurate measurement of carbonization. The lower duty cycle with moderate pulse width modulation (PWM) and amplitude could produce lower carbonization layer. PWM frequency has a high influential role on determining carbonization in leather cutting.

Introduction

The advancement in the leather cutting is necessary owing to the increased usage of such materials. For cutting intricate geometries, laser cutting process is preferable as it has maximum versatility, efficient setup and high adaptability to various material characteristics. For designers, these characteristics make laser an enticing tool.[1] Diode lasers have made enormous advances in applied physics that have proven new and ground-breaking techniques to researchers. Due to their efficiency and low operating cost, diode laser systems are especially important and have emerged as preferred equipment for tackling a broad variety of material processing applications.[2] The industrial application environment is now dominated by CO_2 and fiber laser sources. Diode laser technology has improved rapidly for material processing in cutting applications. They are typically inexpensive which may be utilized to provide much more laser power in combination. The direct use of a diode beam for material processing is a new accomplishment.[3] It is important to develop diode laser technology for cutting leathers with complex geometries under improved environmental measures such as carbonization, striations and dross formation in leather cutting. The carbonization in leather cutting is reduced by the lower focused energy from a laser power diode.[4] Laser assisted oxygen cutting (LASOX) is mostly favored due to its ability of easy adaptability for cutting thick mild carbon steel.[9] The conventional lasers have certain disadvantages in terms of cutting such as geometrical inaccuracies, carbonization, overcut etc. The usage of laser diodes may help to minimize this problem. The primary reason for utilizing a laser diode is to save energy.[5] In the laser power diode based leather cutting process, standoff distance has a significant impact on defining the lowest carbonization area and kerf width. If the diode laser module is not calibrated correctly, it may result in burns and undercuts while cutting leather. Changing the focal length of the laser module improves the cutting process.[6] Productivity measurement relies on the process parameters of input and output. In order to increase the effectiveness of the system, it is extremely important to evaluate the effects of the input process parameters on response parameter.[7] The manual inspection of leather is time consuming with high risks. The usage of a commercial digital camera resulted in poor enlarged pictures, which is one of the major disadvantages. Digital microscopic leather pictures are processed digitally to examine the darkening effects due to the thermal effect of the diode laser.[8,9] The laser cutting of leather was carried out using diode laser with the wavelength of 450nm. The diode based laser beam machining (LBM) process delivers superior results than CO_2 and other manual cutting procedures.

From the detailed literature, no suitable method to measure carbonization region on leather cutting has been found so far. Hence the present investigation has been made. In the present study, an attempt has been made to utilize the camera as sensing element to measure carbonization region. The novel measurement algorithm has been proposed and explained. Hence an attempt was undertaken
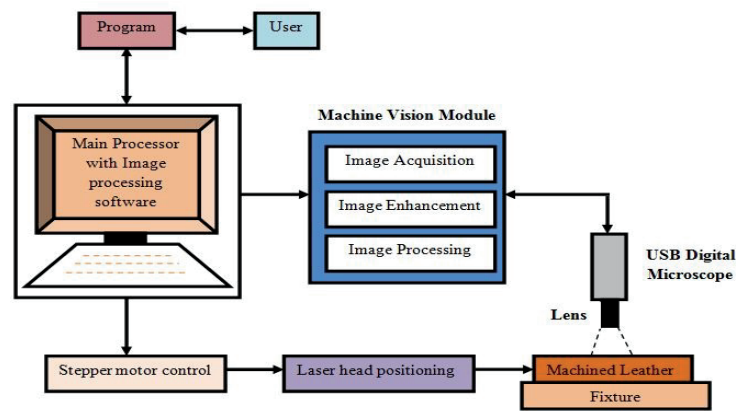
Figure 1. Machine vision based leather inspection

in this research to evaluate leather machinability and to measure carbonization region on leather cutting using a diode based laser beam machining process.

Experimental methodology

Natural vegetable tanned goat skin leather samples were utilized in the present study. The leather samples were purchased from M/s. Shafeeq Shameel & Co., Ambur, Tamilnadu, India. This leather is characterized by a particular grainy surface typical of the goat that together with a natural color and a soft temper make it the ideal material for leather goods making such as small bags, shoes, linings, wallets, crafts and bindings. Figure 1 shows human-machine interface carried out by means of the software Elekscam Evolution Desktop CAM v3.1 for laser control and MATLAB 2019a for the image analysis. The Firmwares can be readily available for converting G-codes to Embedded C and converting drawings to G-codes. The Elekscam firmware was used to control the movement of the system. The speed of the motor movement was controlled using G-codes. The input from the geometrical shape and leather cut dimension was done by means of G-codes uploading through Elekscam. Through the computer the instructions were provided for image acquisition,

processing and other activities. The user controls the laser action on the leather by interfacing with the computer and also the machine vision module. The computer controls the stepper motors complete operation including displacement in the X-Y direction.

Machine vision module arrangement

Image acquisition of leather specimens

Image acquisition is the process of obtaining the image. It is acquired via the use of Celestron Handheld USB digital microscope with the 5 MP CMOS imaging Sensor and 1600 x 1200 pixel array size. Image acquisition is a critical component of image processing because it should grasp the maximum information from the outside so that it can be used for processing. The microscope was utilized in the present study to take the magnified image.

Figure 2 shows the image captured using Celestron microscope The digital microscope comes with an inbedded digital camera and software for acquiring the image. When the microscope camera is connected to a computer, its field of view is shown on the computer through software. This assists the user in capturing the desired field of area.
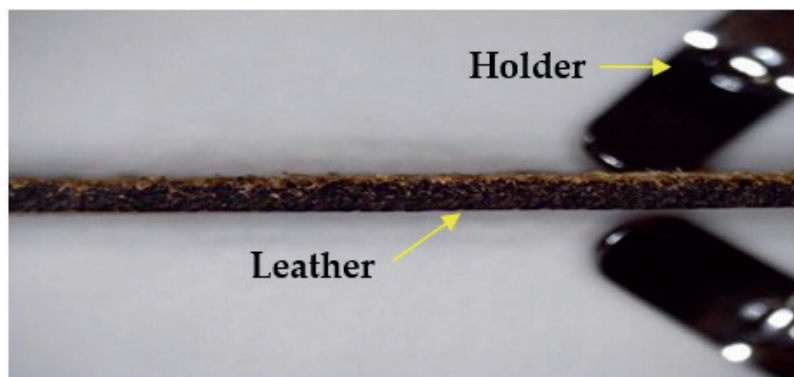

Figure 2. Leather cross section captured using Celestron digital microscope
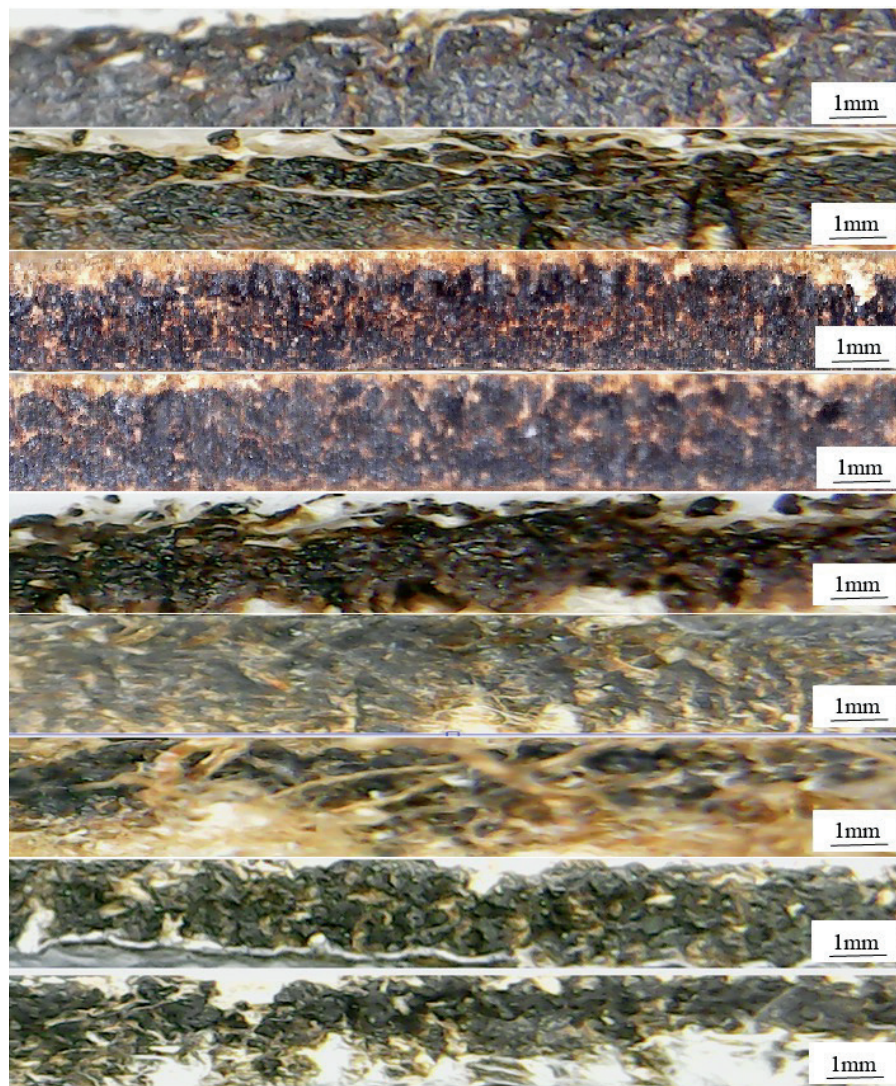
Figure 3. Examples of enhanced image of leather cross section

Enhancement of acquired images

The image enhancement is the next step after image acquisition. The acquired image is enhanced according to the requirements of the image processing software. This could assist in extracting maximum information from the captured image. Figure 3 shows the enhanced images with trimming using USB digital microscope. It is the process of enhancing the quality and information content of original data. The unwanted part in the image is taken off and only the area of interests are retained.

Conversion of color image to binary image

In the present study, MATLAB software package was used for image processing. It is a method of extracting particular characters or a number of specific details obtained from the acquired image. Figure 4 shows conversion methodology of captured image to binary image. The image processing begins with the conversion of an RGB image to a gray scale image, which is then transformed to a binary image.

The image was captured in real time using a digital microscope. Every image was captured in RGB. The conversion of RGB scale to a binary scale with a set threshold over trial and error method was implemented. Every leather sample of varying color has a different threshold. Based on this threshold the image is converted into the binary scale (i.e. 0 and 1) where 0 corresponds to the dark region and 1 corresponds to the light region.

Design layout in diode based LBM

The goat leather of 1mm thickness was used in this present study owing to its significance in the industrial production system. The input and output process parameters can influence the productivity measurement. Power (P), Frequency (F), Amplitude (A), Duty Factor (D), Cutting Speed (C) have been chosen as the input process parameters for the present investigation due to their importance in the LBM process.
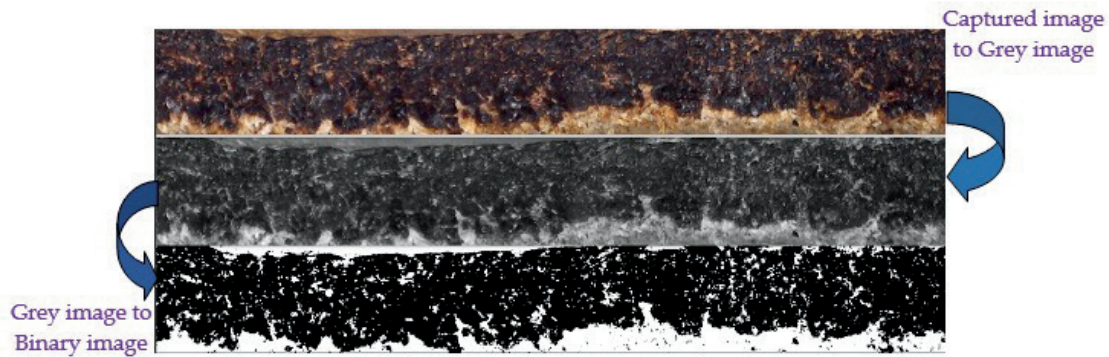
Figure 4. Conversion methodology of captured image to binary image

Table I

Input Process Variables

Process Parameter	Symbol	Unit	Values
Power	P	Watt	20
Frequency	F	Hertz	3000,6000,9000,12000,15000
Duty Factor	D	%	17,34,51,68,85
Amplitude	A	Voltage	3,3.5,4,4.5,5
Cutting Speed	C	mm/s	200,210,220,230,240

Table II

Design layout in Power diode based LBM

Trial no	Power (W)	Frequency (Hz)	Duty cycle (%)	Amplitude (V)	Cutting speed (mm/min)
1	20	3000	17	3	200
2	20	3000	34	3.5	210
3	20	3000	51	4	220
4	20	3000	68	4.5	230
5	20	3000	85	5	240
6	20	6000	17	3	200
7	20	6000	34	3.5	210
8	20	6000	51	4	220
9	20	6000	68	4.5	230
10	20	6000	85	5	240
11	20	9000	17	3	200
12	20	9000	34	3.5	210
13	20	9000	51	4	220
14	20	9000	68	4.5	230
15	20	9000	85	5	240
16	20	12000	17	3	200
17	20	12000	34	3.5	210
18	20	12000	51	4	220
19	20	12000	68	4.5	230
20	20	12000	85	5	240
21	20	15000	17	3	200
22	20	15000	34	3.5	210
23	20	15000	51	4	220
24	20	15000	68	4.5	230
25	20	15000	85	5	240

Diode based LBM method has been used to cut the leather material. The 20 Watt diode laser emits a beam of wavelength 450nm. The laser diode has the optical power of 5.5W and LD+C-lens light source. The laser diode can be triggered using pulse width modulation (PWM) approach. The power was maintained constant at 20W for all the trials. Table I shows a list of the input process parameters and their corresponding ranges. As shown in Table II, the cutting experiments were conducted using power diode based LBM. The controlling parameters are used to correct errors in the system and to provide the best possible outcomes by changing each parameter individually. The electrical parameters are power, frequency, duty factor and amplitude and the cutting speed belongs to the mechanical parameter. The duty cycle determines the pulse width of the signal. The duty cycle is usually stated in percentage terms. Since duty cycle is a critical control parameter that determines the quality and length of the cut, it is essential to accurately generate the necessary duty cycle in percentage. The frequency determines how often the signal is repeated over time. It is related to repetition of the signal. Amplitude is a power modulator measured in terms of peak to peak voltage. The cutting speed refers to the laser module movement in the appropriate direction to cut the leather. It is measured in mm/min.

Results and Discussion

The goat leather was machined into rectangular specimens using 20W power diode based Laser Beam Machining with the optical power of 5.5W and LD+C-lens light source as illustrated in Figure 5. The laser diode can be triggered using pulse width modulation (PWM) approach. The photo diode laser based LBM process has
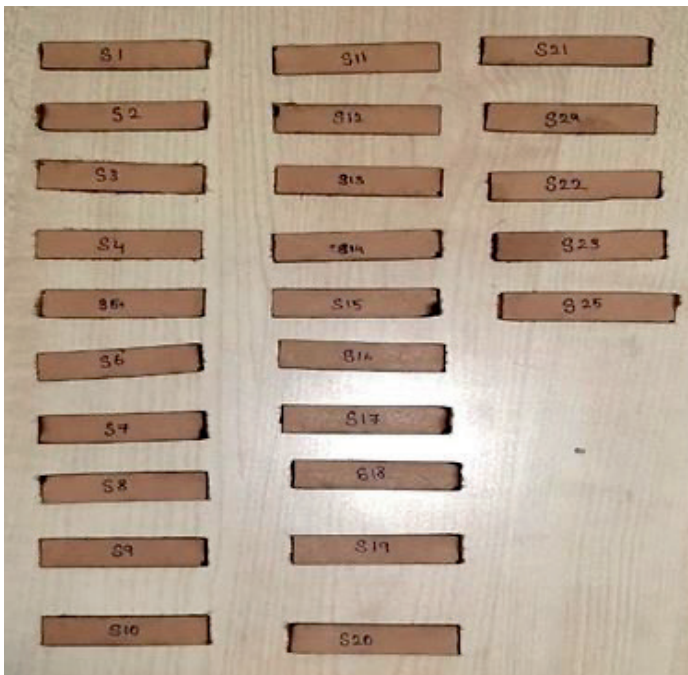
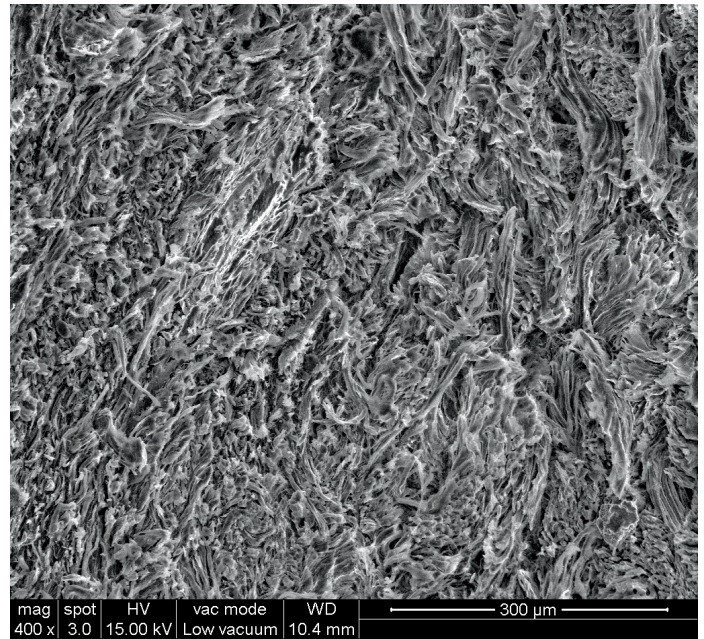**Figure 5.** Machined goat leather using power diode based LBM

Figure 6. Machined leather surface using scanning electron microscope

created lower region of heat affected zone as shown in the scanning electron microscope image in Figure 6. The surface morphology of machined leather was observed with dross and striations of natural skin layer. The working of the laser machining begins with the software which controls the X and Y axis movement of the laser head. The required geometry of the cut was fed into the software as an image or G-codes. The laser was mounted on the movable mount in the CNC. The power of the laser can be controlled with the help of the software whereas the other input parameters of the laser such as frequency, amplitude, duty factor and cutting speed are given with the help of the waveform generator. The waveform generator is used to give preset precise input to test the laser in different working conditions. The CNC setup can be fully operated and controlled using the software. The stepper motors move accordingly such that the laser head moves in a coordinated motion along X and Y direction.

Calibration of USB digital microscope
The USB-microscopic camera was primarily calibrated and fixed to the base for maintaining a stable position. This was suitable for capturing the image of laser cut leather edges. The digital camera acquired many images with internal software. This algorithm automatically adjusts the focal length and focal measures based on the optimal focus measures. Hence the acquired images were not in identical focus owing the external constraints with the same light source. The intensity was varied due to the different carbonization made by the process factors. Once the image acquisition was done by the camera, the acquired images were transferred to a computer using software called Celestron micro-capture pro. Then the images were uploaded into the MATLAB programming language

for the image processing. The acquired image was converted into a binary image to remove the RGB information in the image, since it is unnecessary with higher processing time. While converting to a binary image, the background of the image was also removed as it makes it difficult on determining the Heat Affected zone. The camera was calibrated to desirable level while capturing the image for attaining the maximum details via image, lighting, focus and height from the object. These are the parameters that can be varied in microscope camera to get the desired image. As lighting is one of the main aspects of image acquisition, it is very important to capture the image with adequate lighting for image processing. The lens was surrounded by an array of LEDs. These LED are adjustable which helps in varying the lighting intensity according to the needs. Focusing the camera is also important because it helps in attaining a clear image. The microscope camera is provided with a provision to adjust the focus to the desired level. As the camera is held in a stand, it allows the user to adjust the height from the material. There is a two way adjustable height which helps in maximum flexibility during image acquisition.

Image Processing of the specimens

The image of laser cut edge was taken for further processing. This was achieved with the help of the microscopic camera. The leather was placed in such a way that the camera captured the cross section portion cut edge of the leather. This was done with the help of clamps which were provided with the microscopic camera. The acquired image was trimmed such that the unwanted portions were cropped to do further processing. Once the image was inside the MATLAB program, the algorithm checks the grey scale value of each pixel. Then it was compared to the threshold value that had been set. If the value of a pixel fell below the set threshold value, then that pixel can be converted into white.

Table III

Measurement of carbonization percentage

| Trial No	Captured Image to binary image conversion	Carbonization (%)	Unaffected Zone (%)
1		74.401030	25.598970
2		73.636899	26.363101
3		72.850000	27.150000
4		80.973508	19.026492
5		72.969429	27.030571
6		80.351171	19.648829
7		79.097849	20.902151
8		78.048891	21.951109
9		80.522229	19.411111
10		73.294004	26.705996
11		74.549662	25.450338
12		71.539992	28.460008
13		77.778884	22.221116
14		75.086345	24.913655
15		80.222117	19.777883
16		85.438596	14.561404
17		81.736767	18.263233
18		77.899338	22.100662
19		80.608952	19.391048
20		80.547561	19.452439
21		78.274000	21.726000
22		80.370000	19.630000
23		80.434783	19.565217
24		80.057062	19.942938
25		76.387928	23.612072
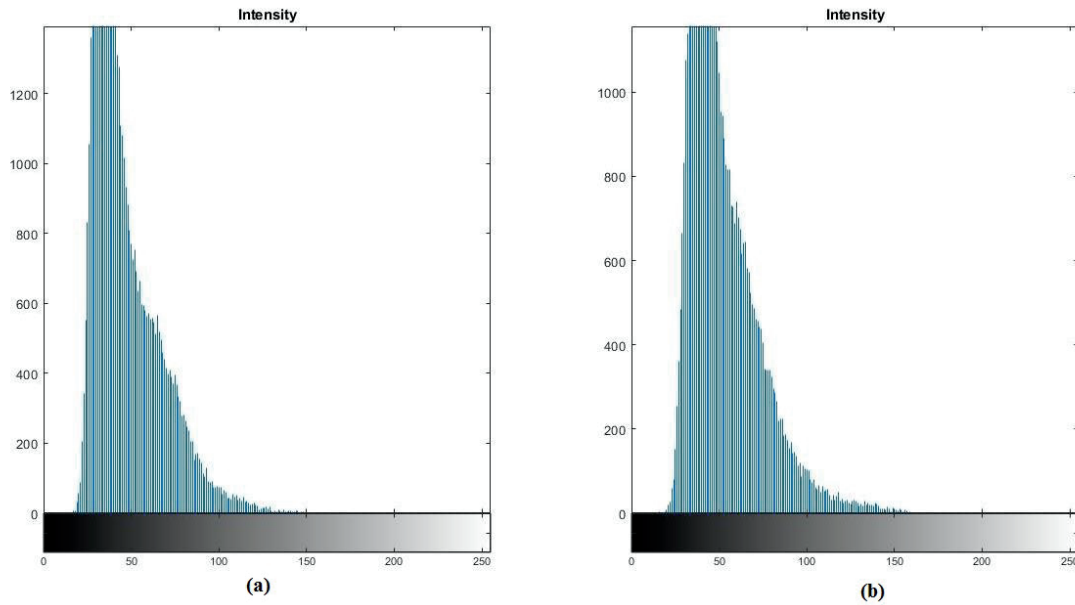
Figure 7. Histogram analysis for **(a)** Trial 1 **(b)** Trial 2

In the case of the value of a pixel being greater than the set threshold value, then that particular pixel was converted to black and accounts for the carbonization. The percentage of the carbonized and non-carbonized region was calculated by counting the number of white and black pixels and was displayed at the end of the algorithm.

Programming Techniques on the measurement

The leather samples were cut using a 20 W diode laser for the different input parameters. After the machining process, each and every sample's image was captured and processed to determine the percentage of carbonization. The images captured and processed for different samples are shown in Table III. In MATLAB, histograms are used to determine the range of gray level occurrences in a grayscale image as shown in Figure 7. It shows the distribution of

pixels in the grayscale image, since each pixel value varies from 0 to 255. The value of 0 being the darkest and 255 being the lightest. The histogram was used to illustrate distribution with a range of 0 to 255 in the graphical format. Since the carbonization is not uniformly distributed throughout the leather after the machining process, a histogram is used to plot the distribution in a graphical form. It can be observed that the machined leather has grey scale values lying slightly towards the dark-side, this account for the carbonization effect that takes place during the laser machining process. The output parameters such as carbonization and non carbonized zone in terms of percentage were calculated.

Effects of process parameters on carbonization

The effects of process parameters on carbonization can be analyzed using main effects plot analysis. In the present study, the main
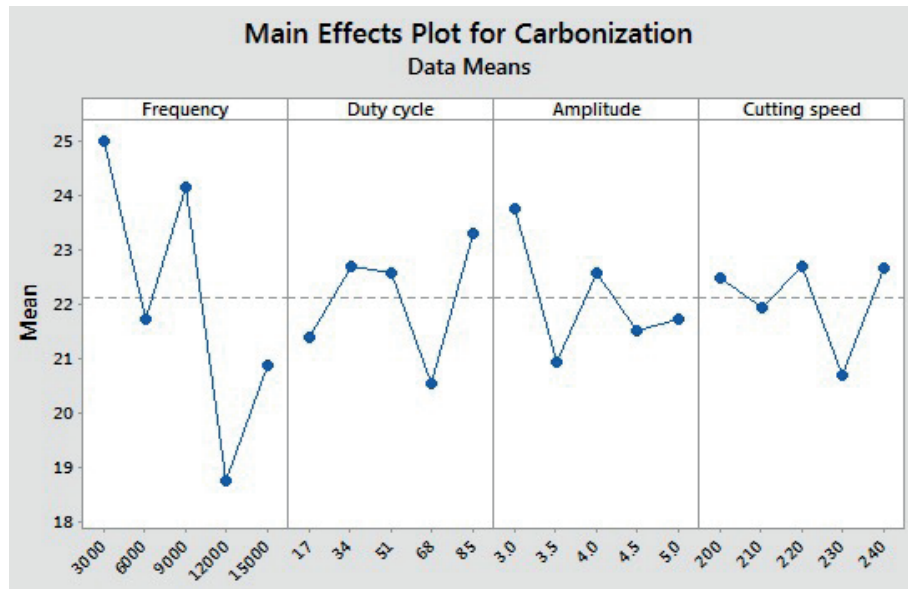

Figure 8. Main effects plot analysis on carbonization

effects plot analysis was performed with the help of Minitab 17 software package (State College, PA) as shown in Figure 8. The deviation of the mean response line with the horizontal line indicates the impact of the factors on the carbonization formed over the leather specimens. It was inferred that the PWM frequency has higher influential role on determining carbonization over the machined leather specimens. Since the PWM frequency determines the laser energy, it could determine the level of carbonization over the machined surface of leather specimens. Since the trial number 12 could produce lower carbonation region, it can be termed as optimal process factors combination. The lower duty cycle reduces the thermal energy. The lower duty cycle with moderate PWM and amplitude could produce lower carbonization layer. Hence trial 12 could produce better performance measures among the chosen process factors combination. The lower cutting speed and amplitude could produce higher carbonization owing to the higher thermal energy. Hence trial 16 could produce higher carbonization among the chosen process factors combination.

Conclusions

An experimental investigation was performed to analyze the effect of laser power diode on carbonization. From the experimental analysis, the conclusions made:

The technique of measuring carbonization can be used effectively in the leather industry for the accurate measurement of carbonization.

The lower duty cycle with moderate PWM and amplitude could produce lower carbonization layer. However, the lower cutting speed and amplitude could produce higher carbonization owing to the higher thermal energy.

PWM frequency has higher influential role on determining carbonization in leather cutting.

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