# ESTIMATION OF DELAMINATION FACTOR IN NATURAL COMPOSITES USING IMAGE PROCESSING

**T.D. SHASHIKALA[1], ROOPA.D[2], K.N. BHARAT[3], BASAVARAJAPPA. S[4]**

[1]Department of Electronics and Communication Engineering. University BDT College of Engineering. Davanagere, Karnataka, India
[2] Department of Mechanical Engineering, University BDT College of Engineering, Davanagere. Karnataka, India
[3]Department of Mechanical Engineering. GM Institute of Technology. Davanagere, Karnataka, India
[4]Department of Mechanical Engineering. University BDT College of Engineering, Davanagere, Karnataka, India

## Abstract

Image processing is an effective tool that can be used in manufacturing and material science areas. Delamination is one of the surface deformations observed in drilling. It is a limiting factor in the use of composite materials for structural applications. The images of the holes drilled in the coconut leaf sheath fiber-reinforced plastic composite are obtained using an image canner. These images are cropped and resized for each drill hole. The drilled hole in the image was detected by generating a mask. The delamination area is estimated using the distance transform and boundary tracing algorithm. It is evaluated by estimating the maximum damaged area to the actual drilled area.

*Key words:*

*Coconut leaf sheath composite, Delamination, Distance transform, Image processing, Delamination factor.*

## 1. INTRODUCTION

The actual scene of the world is represented by digital image. The visual characteristics in the scene are represented by equivalent average intensities in the image and are called pixels. These pixels are integers arranged in matrix form called the digital image. The characteristics of the 3D scene are processed, analyzed, and recognized by digital image processing (DIP). Dutta et al., [1] carried out a review on the application of image processing in tool condition monitoring. Advances in digital image processing techniques validated non-contact real-time tool condition monitoring. This will enhance the automation capability with fast and easier automatic detection of various types of tool wear. Image processing tool is used by Shoresh et al.,[2] for finding tillage moldboard blades and chisel tines. CCD camera images are binarized and region of white pixels are counted to find the wear area in percentage. Nanocomposites plays an important role in industries like Aerospace and automobile. Due to low weight and high aspect ratio, the glass fiber reinforced polymer (GFRPs) and carbon fiber reinforced plastics (CFRPs) composite materials are extensively utilized in aeronautical companies, sporting goods, domestic applications, railways, energy and in automobile sectors [3][4]. The most suitable and widely acceptable machining operation is traditional drilling. This operation is employed for creating holes in composite material. During drilling operation, some form of damage occurred such as cracking of the matrix, pull-out of fibers, breakage of fiber and drilling-induced damage i.e., delamination. It occurs due to the separation of layers of materials [5] [6].

One of the machining operations on a material is drilling. Drilling causes delamination. In composite material, it splits the layers within the laminated structure. This form of damage results in decreased precision during assembly weakens the structural integrity, and degrades the performance over time. Delamination damage is responsible for 60% of all component rejections during the aircraft's final assembly [3]. Delamination allows cracks in the material to connect and

helps to distribute the load without breaking the fibers themselves [7]. Gaitonde et al., [8] studied peel up delamination and presented the Taguchi technique of optimization for minimizing the delamination in high speed drilling of composites. The study results shows point angle is important parameter and increasing speed the point angle reduces the delamination. Pramod et al., [9] studied systematically the effect of delamination both feel up and push down in drilling of nano-fillers reinforced glass fiber reinforced composites. The have studied the potential effect of addition montmorillonite clay and graphene nano particle the material strength and it occurs at both the entry and hole exit planes. The have observed that the delamination reduced in the addition of nano particles.

The carbon/epoxy laminate composites are often drilled during manufacturing and assembly using common drill types like twist or Brad and spur drills. Drilling increases the chance of delamination in composite materials. Achieving better holes with minimal damage is a significant challenge. The radiography images of drilled holes are processed using image processing and analyzed to measure the delamination [10]. The damaged area is determined by digitally capturing and processing images to assess the extent of damage around a drilled hole. These images are processed using Image J 1.34 public domain software (National Institute of Health, USA). To obtain an image with acceptable quality, a series of parameters are appropriately selected, such as brightness intensity, noise suppression (de-speckle), image enhancement and edge detection. The binary image is obtained by selecting the threshold filter to separate grey and black pixels and after that, the damage area is finally measured [11].

Visual inspection cannot measure the delamination extent in carbon fiber/epoxy plates because they are not transparent. Therefore, for plate inspection, enhanced radiography is necessary. Radiography is effective in detecting delamination only when a contrasting fluid is used [12]. The theory of delamination as a cause of drill wear can clarify numerous wear patterns observed in experiments and offer insights into the underlying microscopic reasons for drill wear [13]. A new image processing method using digital scanning and tracing for characterizing delamination and fiber pull-out induced by drilling has been developed to address the limitations in the existing methods of quantifying drilled hole qualities. The capability of the proposed method as a delamination and fiber pull-out assessment tool was verified using simulated and real images of drilled holes [14]. The image processing can be an effective tool in automatic quality control systems for furniture manufacturing, where delamination is a key problem. Moreover, the research analyzed the quality effect of up or down milling of melamine faced MDF. The delamination factor increased significantly with increasing tool wear [15].

## 2. DELAMINATION MEASUREMENT

The usual non-destructive way to measure delamination involves calculation of the delamination factor. This factor is employed to describe delamination at both the hole's entrance and exit, and is given by $F_D = D_{max} / D_0$. The $D_{max}$ represents the largest diameter of the damaged area, and $D_0$ is the drilled hole diameter, as shown in Figure.1 [16] [12] [17]. In CFRP materials the delamination exhibits an irregular form while machining. Davim et al., [18] Suggested a modified delamination factor that considers the contribution of the delaminated area, defined as the adjusted delamination factor, $F_{DA} = F_D + (A_D/(A_{max} - A_0))(F_D^2 - F_D)$. Where $A_D$ is the damage area, $A_{max}$ represents the surface area corresponding to the largest diameter within the delamination zone ($D_{max}$), while $A_0$ denotes the area of the original, drilled hole [19] [20]. This is shown in Fig.1(b) [3].

Composites are extending the horizons of designers in almost all branches of engineering. Many new composites are being developed through research and innovations of recent years, which find applications in a wide range of fields. Glass fiber reinforced polymer or GFRP is such a composite used in structural applications. GFRP composites find applications as fairings, compartment panels and doors. However, composite laminates, by their very nature, are non-homogeneous, anisotropic, and highly abrasive with hard reinforcement fibers.
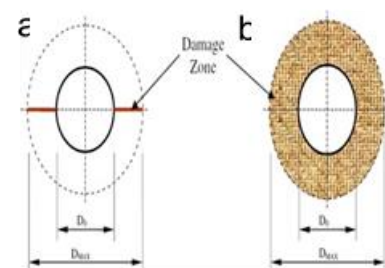


Fig. 1. Critical cases when drilling FRP laminate: (a) fine cracks and (b) uniform damage area [11].

There are multiple nondestructive testing methods to detect delamination in structures including visual inspection, tap testing (i.e., sounding), ultrasound, radiography, and infrared imaging. Visual inspection is useful for detecting delamination at the surface and edges of materials. The Albion DDT (Delamination Detection Tool) is a non-destructive rotary percussion testing tool used to detect delamination, voids and hollows quickly and easily beneath concrete, tile, and natural stones. X-ray radiography can reveal most of these properties and defects and has been used successfully by some researchers.

In estimation of the delamination factor, some of the apparatus like optical projectors and tool makers microscopes are used to quantitatively estimate the delamination factor on material surface. With optical projectors, the material surface images are projected onto a screen and the dimensions are calibrated with the actual dimensions onto the screen. The change in the diameter is observed from the projected image and is recorded for different material surface images. The significant limitation of this method is that, while observing the change in diameter after drilling, at some places, portions of the non-damaged region get included and, in some places, the damaged regions are excluded. This will result in improper quantification of delamination factor for the material. The drilled material is placed on the tool makers' microscope for observation, wherein, two circles are plotted, one for actual diameter and the other circle, plotted by approximately considering the damaged region. After plotting circles, the difference in diameters is calculated using the calibrated Verniers' scales on the microscope. The principal drawback associated with this method is that, like in optical projectors, the inclusion and exclusion of damaged regions at different places, results in improper quantification of delamination factor.

In view of the above, an attempt has been made in this study to find the delamination by using image processing technology. Research efforts in various studies revealed that imaging techniques satisfy non-contact measurements both offline and online. The literature review clearly illustrates that only a small amount of work has been carried out by using digital image processing to identify delamination. Hence an effort has been made to discover the same.

## 3. MATERIAL PREPARATION

The coconut leaf sheath, glass fiber, jute fiber, filler material and phenol formaldehyde are used for fabrication process by hand lay-up method. The mat fibers are cut first for a dimension of 200×200 mm. Pour the calculated amount of PF resin over the surface. Then place the reinforcement CLS and jute fabric in place with the proper orientation as per the fabrication procedure. Then a hot press system begins to press gently from the center of the mat making sure that the squeegee moves in the same directions as the fabrics of the mats. Keep the fabrics straight and press the fabric into the resin. Either brush or a roller can use to consolidate the composite prepared. The lay-up assembly was pressed using a hot press, so that the excess resin was allowed to come out. The laminate was cured in a room with ideal conditions for a period of 24 hours and the process is repeated for CLS and glass mat. Laminates are pressed using hot press and compressed for 24 hours at ambient conditions for a uniform wet ability of resin and constant pressure is also maintained. To get required dimension of 200×200×6 mm board, the laminate composites, made by coconut leaf sheath, glass and jute fiber and PF resin, were taken and placed in the mould uniformly. Finally, laminate was cut to the required size and shape.

Two composite materials are prepared with different stacking sequence with the same procedure for two kinds of fibers. Coconut leaf sheath fiber and the glass fiber are used for preparation of the composite materials. The material-1 is prepared with the stacking procedure of GGGGCGGGCGGGCGGG and the material-2 is prepared with the stacking procedure of GGGGGGGGCCCGGGGGGG; where G- Glass fiber and C- Coconut leaf sheath fiber.

## 4. EXPERIMENTATION

The prepared two composite materials are drilled using a vertical computer-controlled CNC machine. Two different drill tool materials viz., TI-NI coated HSS and Carbide drill bit with 5 mm diameter are used in this experiment are shown in Fig. 2 a) and b). These laminate materials are of dimensions 100mm $x$ 100mm $x$ 6mm.
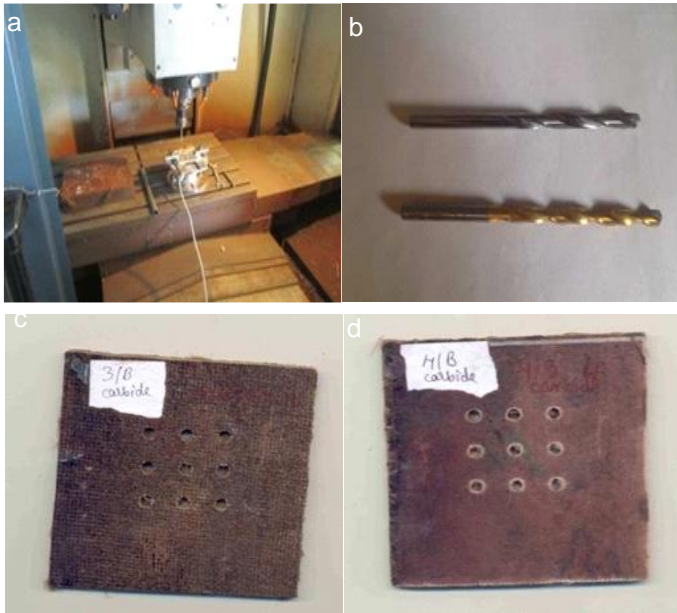
Fig. 2. a) Specimen set up on drilling TI- NI coated HSS drill bit. B) Carbide drill bit and c) Drilled specimen of material 1, d) Drilled specimen of material 2.

The drilling operation is designed by Taguchi technique at level 3. The parameters are speed at 400, 800, 1200 rpm, and feed rate at 0.1, 0.2 and 0.3 mm/revolution. The component covered with the aluminum foil to avoid the delamination at entrance and exit. The depth of cut is 6 mm. Delamination is measured using *Tool-Maker* microscope. The work piece is placed on mechanical sensing unit which is connected to digital indicator. Fig.2 c) and d) shows the specimens after drilling process is completed.

### 4.1 Delamination

Drilling of composites causes damage on the material in two distinct ways. One at drill entrance and other at drill exit. The damage at the entrance is called peel up delamination and the that at exit is called push down delamination. The delamination factor is found by measuring the maximum diameter of the damaged area around the hole periphery [13]. The images of the drilled specimen surfaces are generated by scanning in the image scanner with pixel depth of 600dpi. The material-1 drilled surface at the entrance of drill bit image is shown in Fig.3.
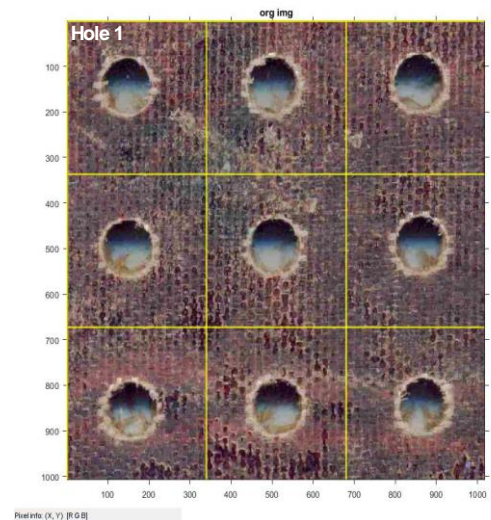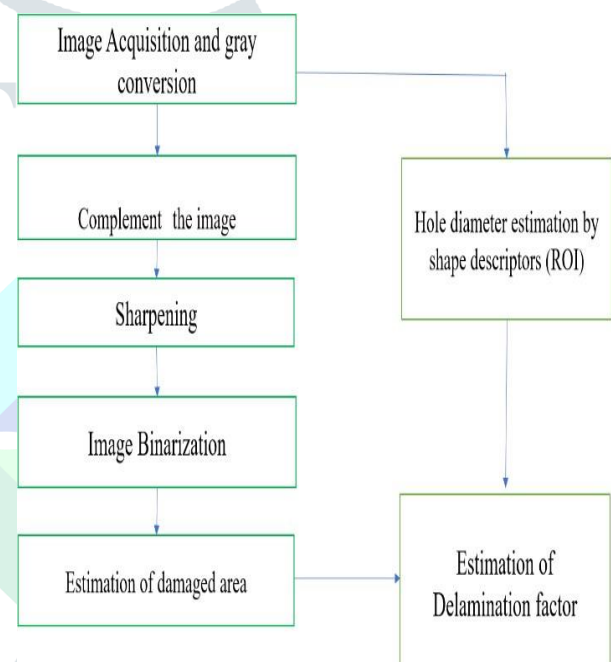


Fig. 3 Scanned color image of the holes drilled in the composite laminate (gfhss2a peel-up).



The digital image of the laminate surface with 9 holes is then cropped (340 x 340 x 3) to select all drilled holes with the specified drill geometries (Fig. 4(a)). The cropped images are then processed for identification of delamination. The cropped image of Hole-1 is considered here for all the processing stages in identifying delamination.

The results obtained for all other hole images of both material laminates are summarised in Table.2. The scanned colour image is first converted to gray image. The gray converted image is shown in Fig.4b. The gray image is then resized to 512x512 pixels. This image is then converted to binary image. The edges of the drilled hole in the image are then enhanced by sharpening the image using unsharp masking [21][22].. This preprocessed image is then processed further by high level image processing tools to estimate delamination.
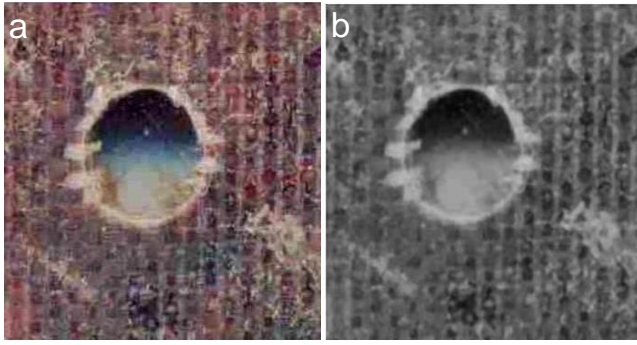
Fig. 4. a) Cropped drilled Hole-1 color image, and b) Gray image of Hole-1 in the composite (gfhss2a peel-up).
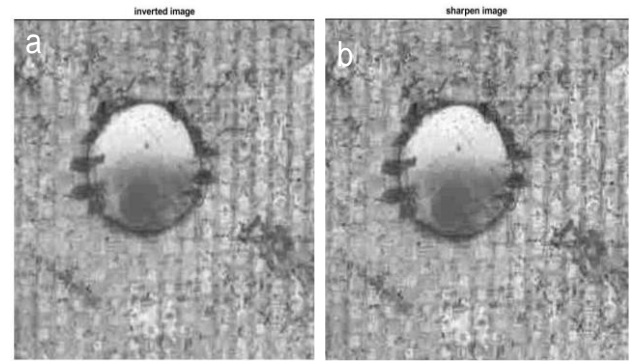


Fig. 6. a) Inverted image, and b) Sharpened Gray image.

In Fig.6 the delamination region is distinguished more clearly than in Fig.4(b). The segmentation algorithm then used to extract the delamination region.

# 5. IDENTIFICATION OF DELAMINATION

To find the delamination factor the drill hole area has to be extracted from the enhanced gray image of the worn surface cropped drill image. The proposed method for identifying the delamination factor using digital image processing is shown in the block diagram of Fig.5.

The delamination factor is calculated by estimating the maximum delamination area. The delamination area is determined by overlaying a mask. Masking is a region-growing image segmentation technique [23]. The mask generated by image growing technique exactly matches the actual drilled hole area. This mask is used to calculate maximum delamination and also delamination factor.

Fig. 5. Block diagram representation of delamination estimation by image processing.

The first stage of image processing is preprocessing and segmentation. The drilled hole gray image is first inverted to identify the pixels of the declamation region. The outline/edges of drilled hole pixels are then enhanced by sharpening. The blurred inverted image is enhanced by high pass filtering. Inverted image is blurred to remove the white regions in the original image (Fog.4a) which are of relatively same intensity as the delamination region as shown in Fig.4(b). Sharpening operation on inverted image enhance the darker region of the original image. This operation is performed to enhance delamination region from the background region. These images are shown in Fig.6.

## 5.1 Drill hole identification

Drill hole is identified by region extraction. The hole region is removed of material and hence this region's pixel intensities are the noise intensities. This noise region is removed by generating a circular mask of the same intensity values either black or white. This mask is generated by using the region-growing method recursively. It starts with a set of seed pixels and expands them into regions by adding neighboring pixels that satisfy a similarity measure. It uses many edge detection, motion detection, noise reduction, and logical operations.
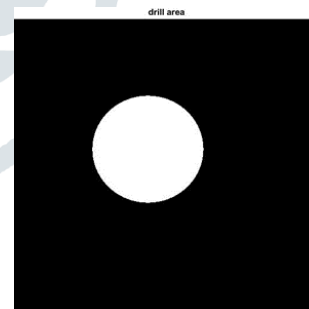


Fig. 7. Binary mask of radius of actual drill diameter.

In this work linspace function used to generate linearly spaced vectors between two diagonal points of the drill hole. And inpolygon(X(:),Y(:),xc',yc') function locates the hole and keeps the pixels inside and on the edge of hole region. The pixels outside the hole are filled with value 1(white). From this cropped hole, a binary mask image is generated by transforming pixels of mask intensity to 1(white) and the rest to 0(black) and is as shown in Fig.7. This mask represents the drilled hole detected on the delaminated worn surface image. The area of drilled hole is then measured by counting the number of white pixels in the mask region. This is the actual

area of drill, $A_O$. The same procedure is used to identify the drill hole area in all images obtained for different speed and feed rate conditions for the HSS drill bit experiments conducted on two composite materials.

### 5.2 Segmentation

The pre-processed image is binarized by selecting an appropriate threshold intensity of pixels based on the histogram of the enhanced image. The delamination is determined by extracting the drilled hole region by shape identification using image processing. It extracts the dominant hole region shape. This image is then processed by distance transform operation. An Euclidian distance transform converts a binary digital image consisting of feature and non-feature pixels, into an image where all non-feature pixels have a value corresponding to the distance to the nearest feature pixel. Edges and boundaries of these regions are then found by boundary tracing. This traces the exterior and interior boundaries of delaminated holes. It also descends into the outermost hole regions and traces inside hole boundaries completely enclosed by these larger outer regions. This is shown in Fig. 8 as white region and its area is estimated as 994 pixels. The morphological operators and boundary extraction tools are used to estimate this area and its distribution across the material surface. This is the wear caused by delamination.
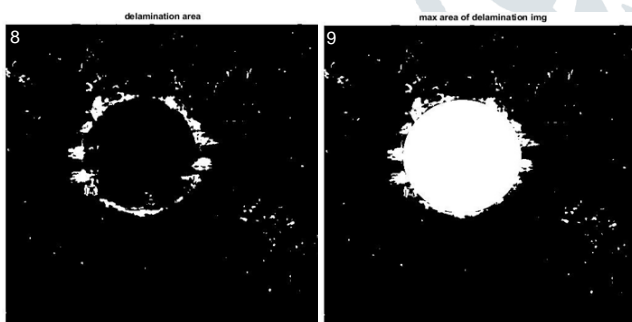


Fig. 8. Binary image showing the damaged area by delmination. Fig.9 Maximum area of delamination damaged zone.

Davim et al., [9] stated that the delamination factor gives better visualization of the variations in the damage area. The damage area obtained from image processing as shown in Fig.8 can be thus considered as the quantitative evaluation of wear by delamination.

### 5.3 Delamination Factor, Fd

The delamination is calculated by subtracting the hole area of the drill from the maximum delaminated hole area (Fig.1) as $F_D = D_{max} / D_0$. Where $D_{max}$ corresponds to the maximum diameter of the damage zone and $D_0$ is the drill bit diameter.

The drill bit diameter is calculated from the binary mask generated from the preprocessed image as shown in Fig.6. This mask equivalently represents the drill hole of diameter $D_0 = 5mm$. The maximum delamination area is estimated by overlaying the drill hole mask (Fig.7) on the damaged area of the segmented binary image of Fig.8 using image processing overlaying. The maximum delamination region is extracted by finding all the pixel intensities corresponding to the same brightness level on the worn surface. The total area of this maximum delamination is shown as the white region in Fig.9 and is calculated by counting white pixels in this region. This is the maximum area of delamination, $A_{max}$. The diameter of this maximum delamination area is $D_{max}$. The maximum delaminated area of diameter $D_{max}$ and drill bit area of diameter $D_0$ are illustrated in Fig.10(a) and (b). The delamination is then calculated quantitatively as the ratio of the maximum diameter of the damage around the hole periphery to the diameter of the drilled hole.
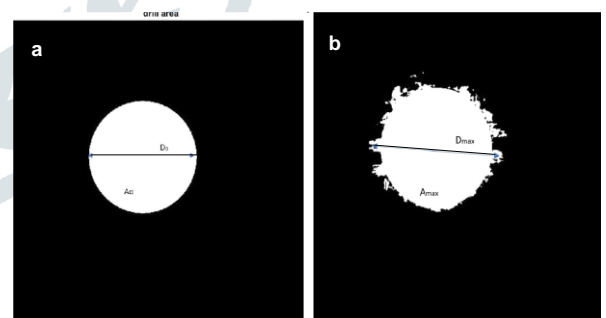


Fig. 10. Binary image of a) Actual drill area and b) Delaminated drill area.

The areas of all the connected components are calculated in terms of pixels in two images of Fig.10. The delamination area estimated from the image and that measured from the Tool-Maker Microscope are listed in first row of Table.1. The second row is indicated with the estimated drill area from the image equivalent to 5mm diameter drill bit. The damaged area estimated from the image is listed in pixels as 994 in third row.

The delamination factor determined from the segmented image by calculating the square root of the ratio of Maximum

delamination area to actual drill bit area. This is obtained as 1.0144 and indicated in $4^{th}$ row $2^{nd}$ column. The last column of the Table.1 indicates the measurements from Tool Maker Microscope. Delamination Factor is calculated by measuring the maximum delaminated area in the Microscope with the known drill area. It is calculated and recorded as 1.21.

Table.1 Delamination factor measurement by Digital Image Processing method.

| Parameters | Pixels | Proportional area from image | Actual Physical Measurement |
|---|---|---|---|
| Maximum worn area, Amax | 31735 | 20.19 mm$^2$ | 28.74 mm$^2$ |
| Actual drill area, A$_O$ ($\pi d_0^2$ /4) | 30843 | 19.63 mm$^2$ | 19.63 mm$^2$ |
| The Delaminated area from image | 994 | 0.63 mm$^2$ | 9.11 mm$^2$ |
| Delamination factor, $\mathbf{Fd} = \sqrt{\frac{Amax}{A0}}$ | **1.0144** | 1.014 | **1.21** |

The delamination factor is calculated for all other drilled holes in the two composite laminate materials using the above image processing methods and are listed in Table.2

## 6. PEELUP AND PULLDOWN DELAMINATION

The drilling of composites causes peel up and push down delamination at the entry and exit of the drill bit. These delamination factors evaluated using DIP techniques and from tool maker microscopic measurement are listed in Table.2. The DIP Column indicate the measurements from image processing method, Columns Material-1 and Material-2 indicate the measurements from tool makers' microscope for the two composite materials. A considerable difference in delamination factor between the two methods is observed. This is because, in image processing approach, only the delaminated region is exactly identified and considered. Whereas in the measurement using tool makers microscope, the maximum damage region at a particular point and the circle is drawn from the peak point and the area coming under the same is considered as delamination.

Table.2. List of Peel up and pulldown delamination factor measurement for the two composite testing materials with Titanium Nitrate coated HSS drill bit.

| Sl. No | Speed (rpm) | Feed Rate (mm/rev) | PEEL UP DELAMINATION | | | | PUSH DOWN DELAMINATION | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | DIP | Material 1 | DIP | Material 2 | DIP | Material 1 | DIP | Material 2 |
| 1 | 400 | 0.1 | 1.01 | 1.21 | 0.98 | 1.09 | 0.82 | 0.86 | 1.25 | 0.66 |
| 2 | 800 | 0.1 | 0.98 | 1.31 | 0.96 | 1.34 | 0.85 | 0.83 | 1.12 | 0.51 |
| 3 | 1200 | 0.1 | 1.04 | 1.39 | 1.07 | 1.42 | 0.79 | 1.85 | 1.14 | 1.38 |
| 4 | 400 | 0.2 | 0.99 | 1.07 | 1.21 | 1.03 | 0.93 | 1.47 | 1.02 | 1.28 |
| 5 | 800 | 0.2 | 1.02 | 1.24 | 1.23 | 1.32 | 0.79 | 1.42 | 1.04 | 1.10 |
| 6 | 1200 | 0.2 | 0.97 | 1.34 | 1.00 | 1.42 | 0.79 | 2.16 | 1.22 | 1.99 |
| 7 | 400 | 0.3 | 1.05 | 1.04 | 0.99 | 1.07 | 0.78 | 2.02 | 1.11 | 1.46 |
| 8 | 800 | 0.3 | 0.96 | 1.01 | 0.1 | 1.23 | 0.77 | 1.94 | 1.04 | 1.46 |
| 9 | 1200 | 0.3 | 1.02 | 1.32 | 1.08 | 1.21 | 0.88 | 0.86 | 0.98 | 0.66 |

## 7. CONCLUSIONS

Image processing tools can be used effectively in quantification of delamination factor for drilled holes particularly in natural fiber reinforced composites. The image processing techniques like region growing, image segmentation and distance transforms are used for modeling delamination factor. The optimized delamination factor can be evaluated by employing robust image processing algorithms like neural networks. The delamination factor due to various parameters like feed rate, thrust force, different drill bits and torque can be qualitatively analyzed. The actual area of the delamination can be identified by using this method.

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