CHARACTERIZATION OF A SLIT EDGE USING IMAGE ANALYSIS

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ABSTRACT

The paper deals with the characterization of edge quality of a slit web. The conventional way of determining the edge quality of a slit web is usually through visual inspection, sometimes under an optical microscope. In this paper, an algorithm was developed and implemented in a code to analyze digital image of a slit edge to characterize and quantify the edge quality of a slit web. The Root Mean Square (RMS) value of the edge profile after image analysis has been used to characterize the quality of the slit web. The image analysis involves grayscale thresholding to convert a digital image of 8 bits or higher into a binary image, component labeling to determine the connectivity of different domains generated through thresholding and the computation of the RMS. The proposed method is capable of quantifying the edge straightness and cleanness through the acquired micrograph image of a slit edge, and the approach works equally well for aluminum, paper, plastic and non-woven webs.

NOMENCLATURE

Y	Distance from the top of the image to the nearest white pixel (edge).
Y_M	Average distance from the top of the image to the nearest white pixel.
N	Number of points that are white obtained from the current selection.

INTRODUCTION

Slitting is the process of converting a web into two or more narrower webs. This can be done in several ways, such as razor slitting, shear slitting, score slitting, water-jet slitting and laser slitting. For many applications, the condition of the slit edge resulting from the slitting operation can have a primary influence on the utility and value of the narrower webs. The quality of edges formed during slitting of thin webs is important for many industrial applications. Slit-edge quality varies and depends on the slitting conditions and the material being slit.

An ideal slitting process will form a smooth, clean slit edge that is perpendicular to the web, leaving no debris from the cut. It has to be formed at high speeds and should have no deformation in the cut edge. It should not generate any secondary fractures and be both stable and straight. For example, in case of non-woven webs, a good slit edge can be described as one that does not have too many extended or loose fibers. Characterization of slit edge enables us to describe the slit edge quality in a quantitative term and thus enable comparison between various edge qualities. Conventional way has been to use a profilo-meter to scan through the edge and measure the variation along the edge. However for non-woven webs, it is an extremely difficult proposition. There have been efforts to characterize the slit edge quality using image analysis. Wise [1] developed an optical method to analyze the edge quality of a paper using image analysis. In this method the edges of the paper was scanned and evaluation of cut edge quality was done by the standard deviation of the roughness profile from a pre-determined ideal cut line. Welp et al. [2] developed a method for objective evaluation of the cut quality of thin, plane materials. They separated a cut edge into a roughness profile and then converted this weighted roughness profile into a quality grade.

Once the web is slit, the slit edge is examined under an optical microscope and an image is captured by a digital image acquisition system. Image analysis provides information about web structure or slit edge quality. Image based techniques have the advantage of being highly automated to avoid fatigue and errors associated with tedious and repetitious manual measurements. Image is normally stored as an 8-bit or higher resolution digital format file giving 256 (0-255) or higher possible different shades of gray scale from black to white. The image obtained from the microscope is then converted into a binary image i.e., with just black and white colors. Then the image is processed pixel by pixel to determine the RMS of the slit edge to justify whether the edge is good or bad. Binary images allow easy visualization of the image. Identifying the edge is the most important part in image analysis techniques.

Colored images can also be converted to a binary image and image analysis can be performed on the same. Threshold values for performing image analysis on a color image may vary and may be entirely different than a gray scale image. Gray scale images have equal shades of Red, Green and Blue for a particular shade of gray. Threshold value may vary according to the distribution of intensity values in the image, but it is usually taken to be 128 in order to get a binary image descriptive of the original gray scale image without losing much of the information. Threshold just adjusts the gray values around the edges thus creating a sharp contrast between the web and the surrounding. This enables the image analysis algorithm to exactly identify the edge of the slit web.

EXPERIMENTAL ASPECTS

Figure 1 shows a schematic diagram of the shear slitting setup for the slitting of non-woven web. With the help of the two blades, a pair of shear force is applied on the top and bottom surfaces of the non-woven web to facilitate controlled crack propagation in the web to separate the web into two parts.

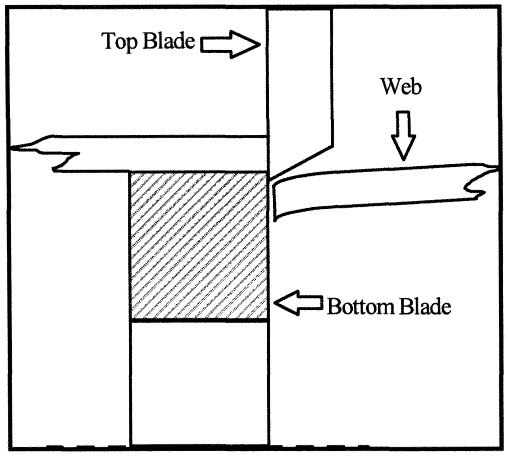

Figure 1: Shear slitting process

The experimental slitting was carried out using a laboratory slitter, which has a class II 'C' series knife holder (Tidland) that holds a blade with a diameter of 150 *mm*. Figure 2 shows the schematic of web path in the slitter. The slitter allows shear slitting at a constant speed under controlled tension. The slitter can reach a speed of up to 450 *m/min*. A web guide (Fife, model CSP-01-06) is used to control the lateral movement so that the web is centered all the time. A pair of Tidland rotary slitter of 150 *mm* diameter is used to shear slit the web. A bowed roller is placed before the winding roller to separate the two webs after slitting.

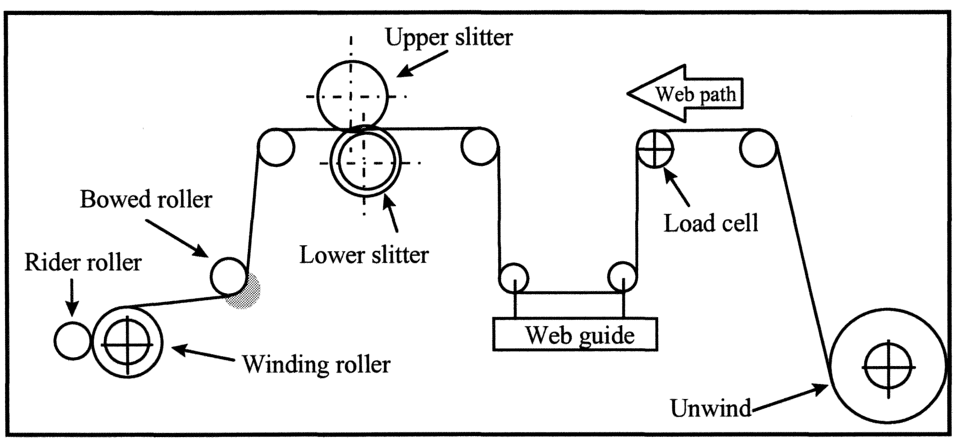

Figure 2: Schematic of web path

Image acquisition setup

The slit edge sample was placed under the optical microscope with a magnification of 40 times and it was illuminated using an optical fiber light (FOSTEC fiber optic light). A Kodak Mega plus ES 1.0 camera that has a spatial resolution of 1000 × 1000 pixels with a recording software Omni Speed and a Pentium 200MHz IBM compatible PC was used to capture the image. Figure 3 shows the schematic diagram of image acquisition setup.

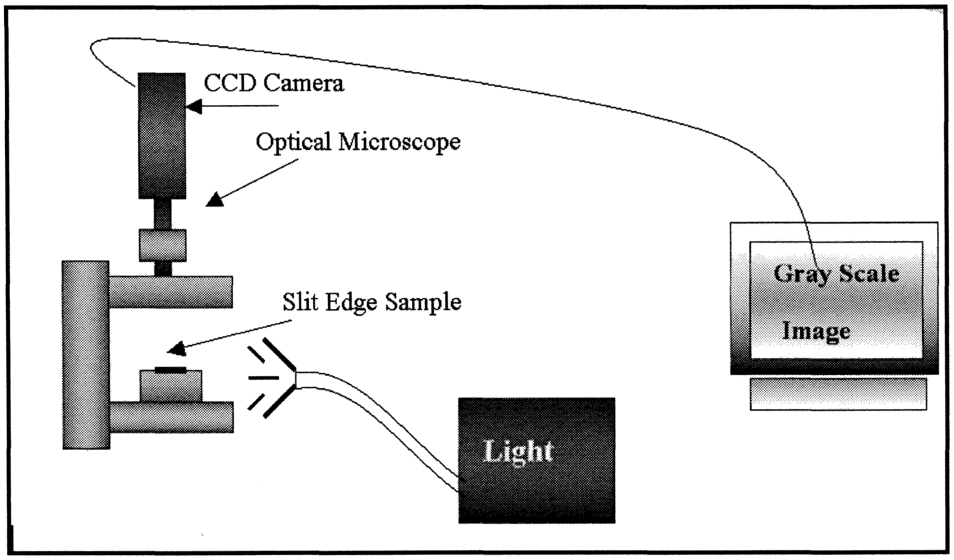

Figure 3: Schematic of the image acquisition setup

IMAGE ANALYSIS

The web is first slit under various slitting conditions that include web speed, web tension, blade overlap, offset, etc. After slitting, the slit web is analyzed under an optical microscope.

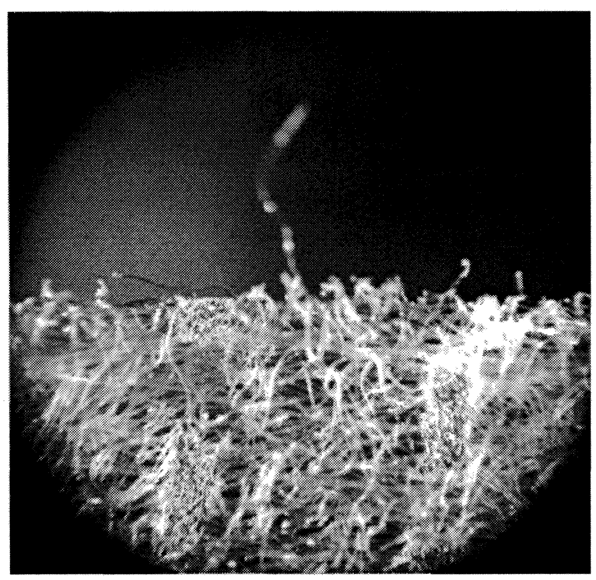

Figure 4: Gray scale image

An 8-bit gray scale image, shown in Figure 4, of the edge of the slit web material is captured which is then used for image analysis. The gray scale intensity is stored as an 8-bit integer giving 256 possible different shades of gray from black to white. This gray scale image is converted into a binary image, shown in Figure 5. Binary images are images whose pixels have only two possible intensity values. They are normally displayed as black and white. Numerically, the two values are often 0 for black, and either 1 or 255 for white. Figure 4 shows an image in gray scale and Figure 5 shows its corresponding binary image. The threshold value used in converting Figure 4 into Figure 5 is 128. Figure 6 shows the gray scale image of a slit plastic web. As the intensity in the plastic web is less, threshold value used for a plastic web may slightly differ from the threshold value used for the non-woven web.

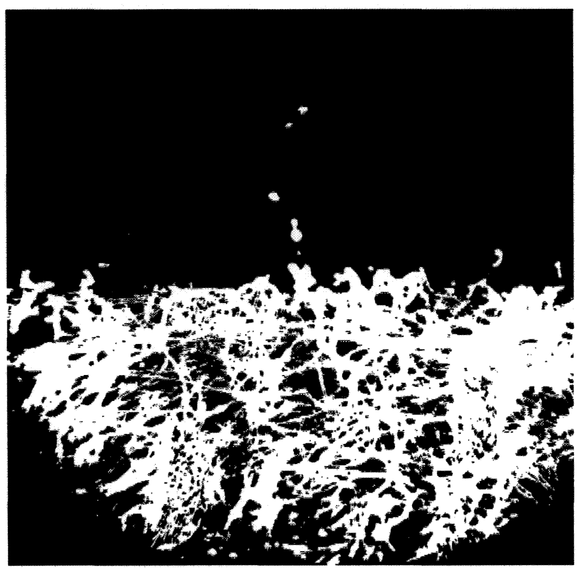

Figure 5: Binary image

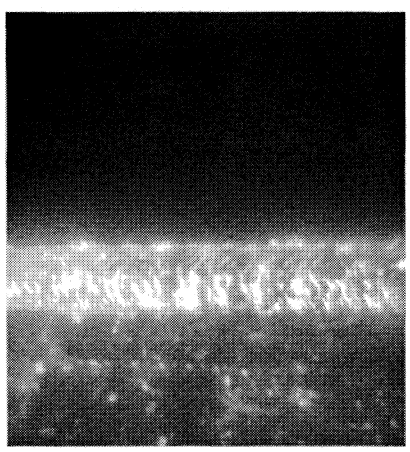

Figure 6: Slit plastic web

Though value of the threshold plays an important role, identifying the edge is more important. Thresholidng is just a tool to achieve this. Binary image obtained thus will have areas that are connected or independent. The white areas describe the web material and small areas that are independent describe the extended fibers in a non-woven web. It can be observed from the binary image of a plastic web that such small areas do not exist. The binary image is now analyzed for detection of the edge and the quality of the slit edge. The process of converting gray scale image to a binary image is an intermediate operation in the algorithm. Figure 7 shows gray scale image of a plastic web and the corresponding binary image in Figure 8.

Figure 7: Grayscale image of a slit plastic web

Figure 8: Binary image for slit plastic web

Edges are places in the image with strong intensity contrast. Image analysis is done on this binary image, in order to separate an object in the image from the background. The color of the object (usually white) is referred to as the foreground color. The rest (usually black) is referred to as the background color. However, depending on the image that is to be analyzed, this polarity can be inverted, in which case the object is displayed with zero and the background is with a non-zero value.

This binary image is processed pixel by pixel in a selected area. For a particular y-axis value the lowest x-axis value is taken as the edge since this is the point where the binary value is changing and indicating that there is a edge here. This reasoning is based upon the fact that there is a color change between the empty area and the edge. Empty area is black or below the threshold value and the material is white or above the threshold value. The formula for calculating RMS is described below:

$Y_{ave} = \Sigma(Y-Y_M)^2.$

$RMS = (Y_{ave} / N)^{1/2}.$

The above formula is a coarse method of obtaining the data points. In some cases, in non-woven material, some fibers may extend out after slitting and this code does not differentiate between extended fibers and continuous material. As soon as it sees a white pixel, which may be an extended fiber, it stops processing that particular column of pixels. To overcome this the code was refined to take into account extended fibers and other small pores that may cause troubles of the sort explained above.

Removing protrusions

The technique for finding the edge profile assumes a dark background, where bright areas highlight the edges. When there are fibers protruding from the edges, these fibers, which are brightly lit, may be mistaken as edges, thereby leading to a wrong edge profile. These fibers should be removed to produce an accurate edge profile.

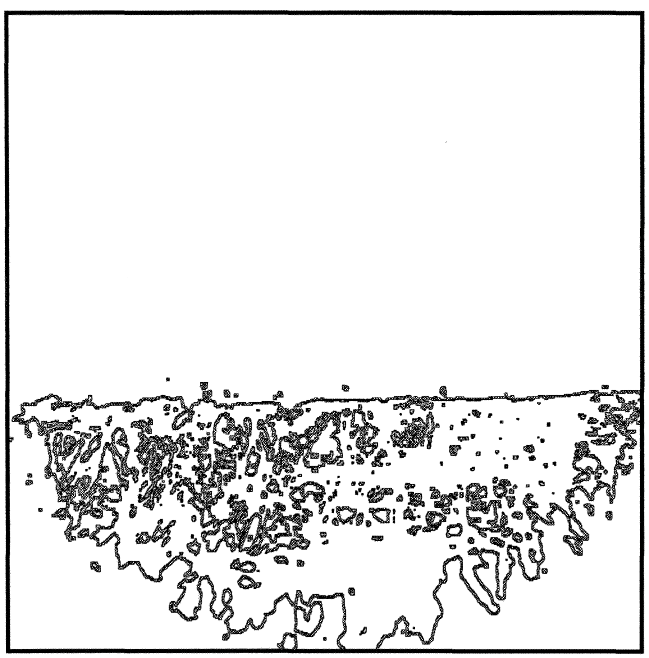

Figure 9: Inverted binary image of a non-woven web

The technique used for removing protruding fibers relies on the fact that the protrusions appear as regions disconnected from the actual edge, as shown in the binary image in Figure 5. These protrusions are normally small in area compared to the actual edge. If these disconnected regions are identified and their areas are measured, they can be removed. To accomplish this, the binary image is first inverted, so that the background is white and the fibers appear as dark regions disconnected from the edge in Figure 9.

Figure 10 shows the inverted binary image for the plastic web. This inverted image is subjected to a process called connected component labeling.

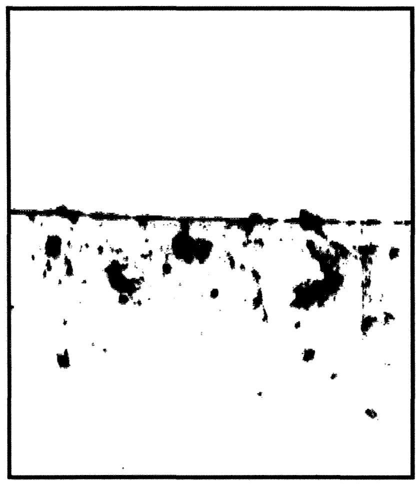

Figure 10: Inverted binary image of a plastic web

Connected component labeling

The aim of this process is to identify and mark independent connected regions. A connected region is made of adjacent pixels that share the same intensity value. In this process, each pixel of the picture is assigned a number, also called a label. All pixels in a connected region are assigned the same label. The process works by scanning the image pixel by pixel, left to right, top to bottom. When a dark pixel *p* is encountered, two of its neighbors, one to the left of *p* and the one above *p* are examined. If both neighbors are white, a new label is assigned to *p*. If only one neighbor is dark, its label is assigned to *p*, else, if one or more of the neighbors are dark, one of the labels of the two neighbors is assigned to *p* and a note is made of the equivalence of the two labels of the neighbors. After completing the scan, the equivalent label pairs are processed and a unique label is assigned to each connected region. Then, the area of each independent connected region is determined by counting the number of pixels with the same label. With this count of area for each label, all the pixels in the image whose label has an area less than a particular threshold area value are identified and removed. This removes the extended fibers from the image. Now the image is ready for recording the profile. The stored points are then plotted in a graph with the length across x-axis and profile of the edge along y-axis. This graph represents the profile of the edge after processing.

RESULTS

All the above methods were implemented in an Image analysis software algorithm and tested. The results obtained were in accordance with visual inspection.

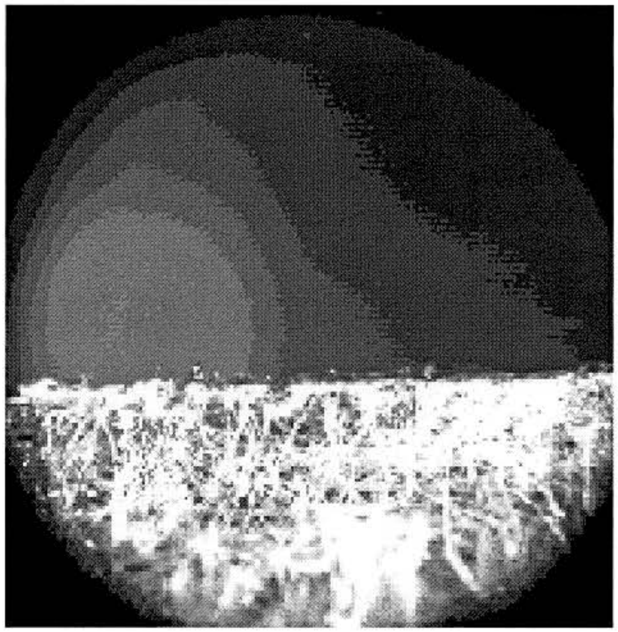

Figure 11: Good edge (gray)

The algorithm was able to differentiate between a good edge and a bad edge and the RMS value obtained was indicative of the edge. A lower value of RMS indicated a better quality edge. The threshold value used for processing was 128 in all the cases for gray scale images of non-woven web and plastic web.

Image analysis was also performed on the polypropylene web. The web was not straight but given a slight slant. The image of the slit polypropylene web was a colored image with a slightly greater blue component. Consequently, the threshold value to convert this image also changed.

Figure 11 and Figure 14 show the image in gray scale and Figure 12 and Figure 15 show the image in binary. Figure 13 and Figure 16 show the profile of the edge after the image analysis, for two different images. The profile has been plotted on top of the binary image to compare the actual slit edge and the slit edge identified by the image analysis algorithm. It can be observed that the edge identified by the algorithm exactly follows the profile of the actual edge in cases when the edge quality is good.

After the analysis the RMS values of the edge of Figure 11 was 2.10 pixels, whereas the RMS value of Figure 14 was 3.82 pixels. For clear comparison, the profile of the edge after image analysis has been plotted over the contour of the image. Figure 13 and Figure 16 are the contour of the images in Figure 11 and Figure 14. Figure 13 shows the profile of the slit edge obtained after the analysis overlapping the contour of the image. It is seen that the overlapping is good and the straightness of the profile suggests a good edge.

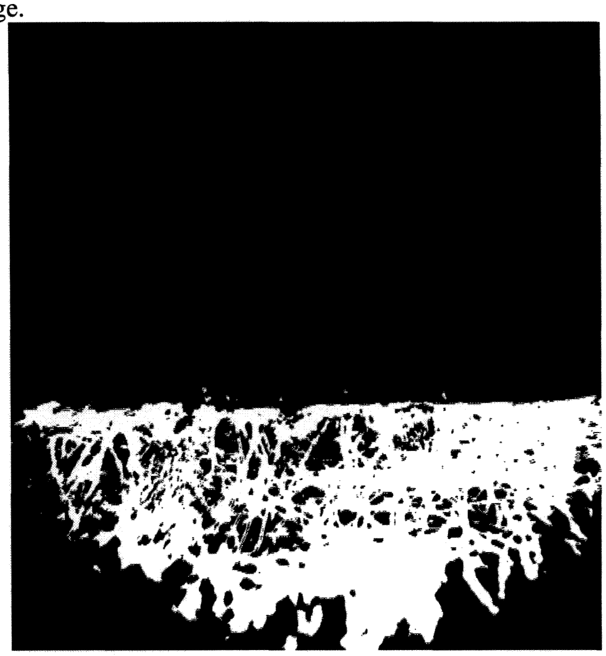

Figure 12: Binary image of a slit non-woven web (Good edge)

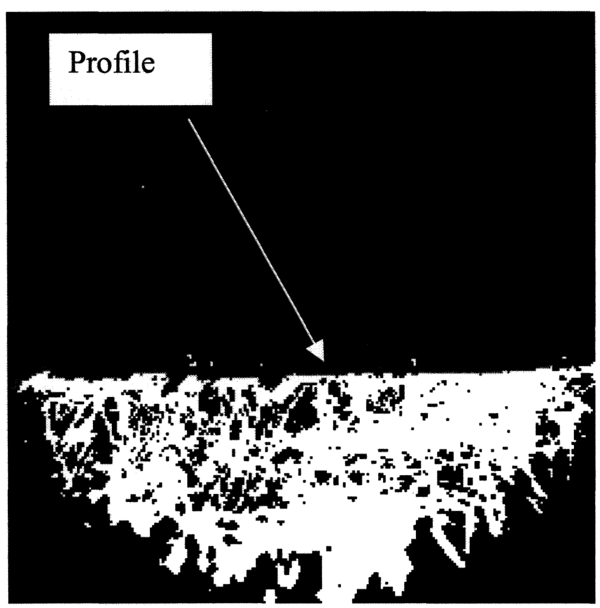

Figure 13: Profile of the edge after image analysis (good edge)

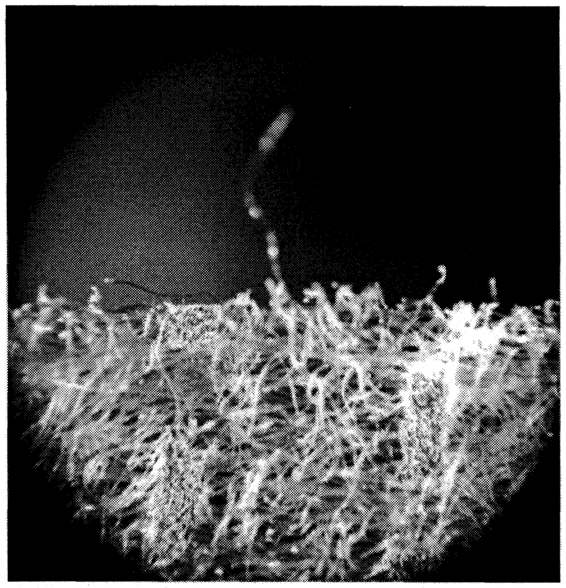

Figure 14: Bad edge (gray)

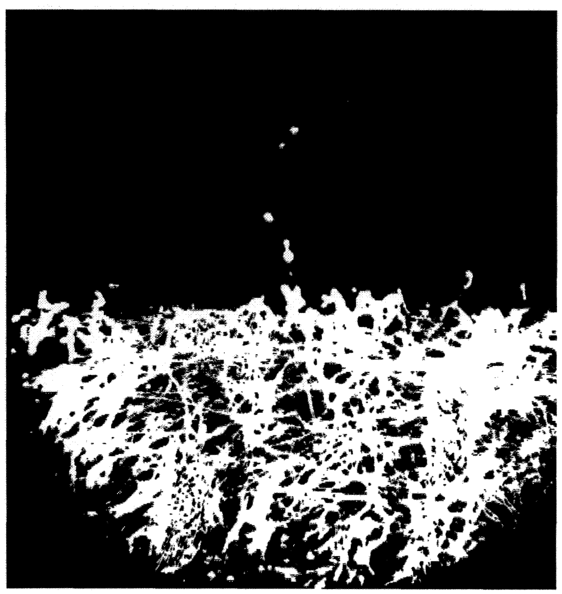

Figure 15: Bad edge (binary)

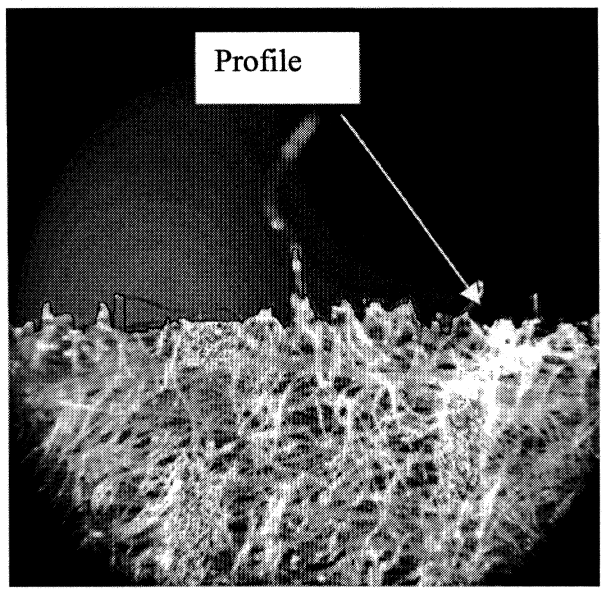

Figure 16: Profile of the edge after image analysis (bad edge)

Figure 16 shows the profile of the slit edge obtained after the analysis overlapping the contour of the image in an enlarged scale. Here the overlapping is not so good, this is because the image had lot of discontinuous fibers that were removed during the analysis. The image had extended discontinuous fibers because the quality of the slit edge was not good which can also be inferred from the profile of the slit edge.

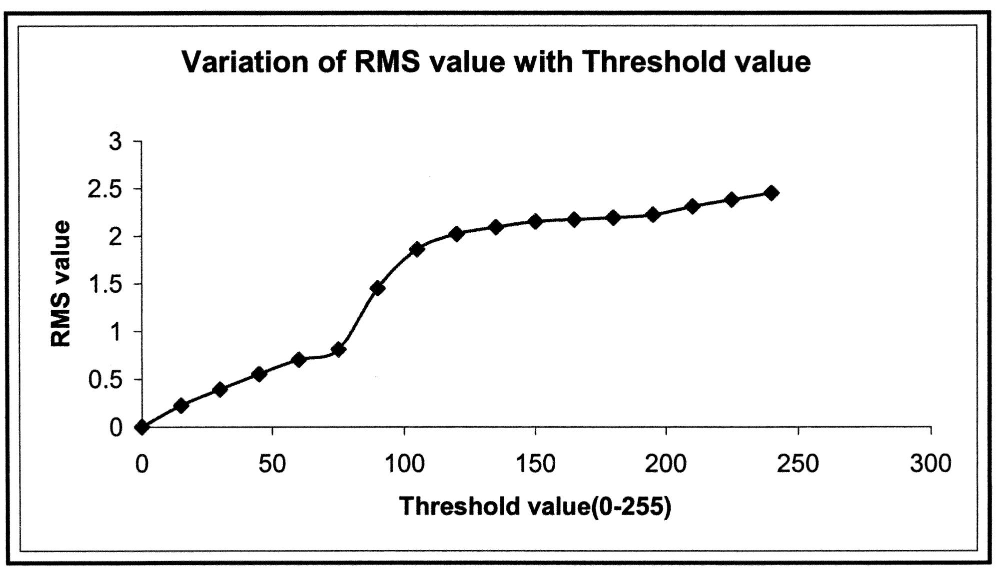

Figure 17: Variation of RMS with threshold value

In addition, the effect of threshold value on the value of RMS has been noted. For a profile whose RMS value is 2.02 at a threshold value of 128, the graph between the threshold value and RMS is plotted for various values of threshold in Figure 17.

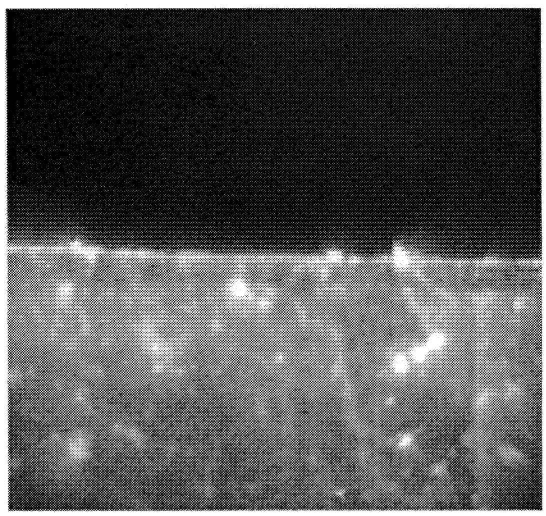

Figure 18: Slit plastic before image analysis (Good edge)

It can be observed that the effect of threshold is to just increase or decrease the RMS value and if the threshold values for two images to compared are the same then the relative quantitative differentiation can still be achieved. For a gray scale image areas, which are on the border, often cause the sudden increase in the RMS value. If the areas are small such as those of extending fibers, then increasing threshold could be used to remove the effect of such fibers in calculation of RMS. However, if the area of such protrusions is very high indicating a very bad edge then increasing threshold will result in loss of information.

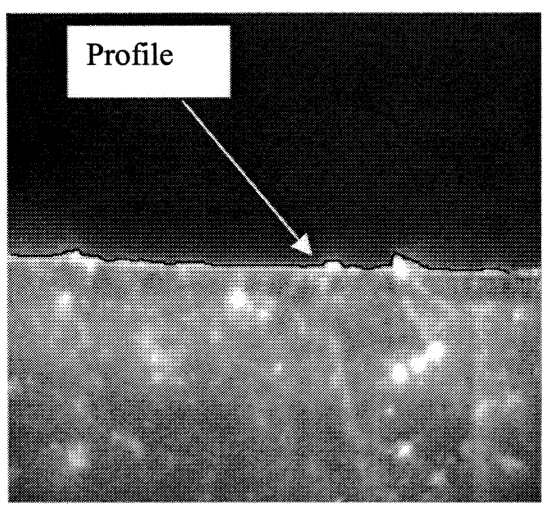

Figure 19: Profile of the slit edge for a plastic web (Good edge)

Figure 18 shows a slit plastic web. Since plastic webs do not have extended fibers as in the case of non-woven web, identifying the edge is made simpler. Figure 19 shows the profile of the slit edge for the plastic web. RMS value for the edge shown in Figure 18 was found to be 1.19.

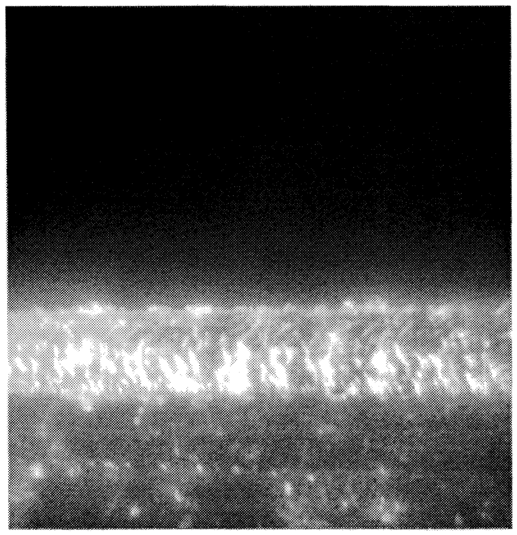

Figure 20: Slit plastic web before analysis (Bad edge)

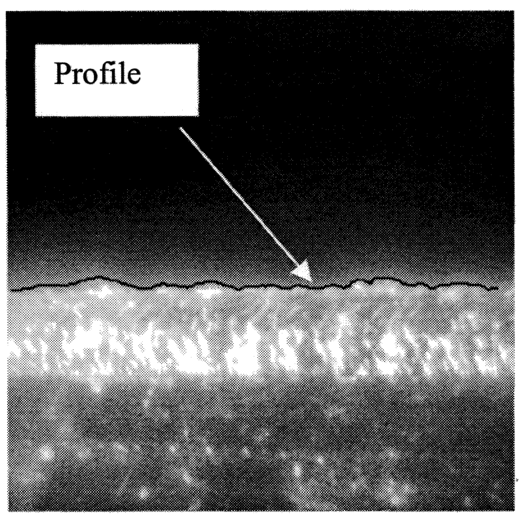

Figure 21: Profile of the slit edge for a plastic web (Bad edge)

Figure 20 and 21 show gray scale image and profile of the slit edge of a slit plastic web. RMS value calculated from Figure 21 was 1.59, which suggests that slit edge quality was better in Figure 19.

CONCLUSIONS

An algorithm and the associated software code were developed to analyze the edge quality and characterize the slit web. Image analysis for quantification of the slit edges is seen to be in accordance with visual inspection and can be very useful in cases where it is impossible to determine visually the quality of the slit edge. The profile of the slit edge obtained after image analysis closely follows the edge of the binary image where the color changes from black to white and hence can be assumed descriptive of the edge. It is observed that if the slit edge is not good then the image after processing tends to have lot of discontinuous fiber which are removed during the image analysis and consequently the profile of the slit edge does not exactly overlap the contour of the image.

The Root Mean Square value i.e., RMS of the profile of the edge can be considered as a value which quantifies the slit edge quality and the lower the value of this parameter the better is the slit edge. Threshold value has great effect on the value of RMS. The higher the threshold, the higher is the value of RMS for the same profile. For a color image threshold value can have great effect depending on the color components in the image. As any image before analysis is converted to binary, the threshold value just affects the numerical value of the RMS but the relative difference in RMS between the edges being compared remains unaffected. Therefore, it is prudent to have the same value of threshold when comparing the quality of slit edge of two or more images.

Image analysis technique described above has been successfully implemented on different kinds of webs such as non-woven, plastic etc., and also on different kind of images such as gray scale and color. It was also noted that alignment is not a factor while determining the slit edge quality. The algorithm was successful in identifying the edge in all such cases.

Threshold value for converting the image is useful in separating the web from the surrounding and thus enable edge detection. Component labeling is useful in identifying independent regions and area threshold will remove regions that are descriptive of extended fibers or thin pieces of metals or plastics etc.

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1. Wise J.D., "An automated method for evaluating the edge quality of cut-sheet papers", TAPPI Finishing and Converting Conference Proceedings, 1998, pp.153-158
2. Welp E.G., Wolf E., Heindl J., "A new objective method for quantitative assessment of cut edge quality for paper and board", Sixth International Conference on Web Handling, 2001