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Investigation of Fibre Orientation and Void Content in Bagasse Fibre Composites Using an Image Analysis Technique

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Abstract
In this research work, a nondestructive technique of image analysis was explored to determine the fibre orientation and void content in Bagasse fibre reinforced composites. Fibre length, alkali treatment and fibre loading were studied as variables. The fibre orientation was irrespective of the fibre length, fibre loading and alkali treatment variables. The void content and size decreased with increases in fibre length and alkali treatment. The alkali treatment resulted in the removal of lignin, making the surface of the fibres rough. It also led to making the fibre count fine i.e. reducing the diameter of the fibres and thus presenting more fibres for interaction with resin. Both these phenomena resulted in a slower flow of resin. The void content of bagasse fibre composites decreased with higher fibre loading because a higher number of fibres slows the resin flow. However, the size i.e. area of the voids increased with the fibre loading from 20 to 30%, probably due to increased wetting difficulty.

Key words: *bagasse fibre composites, fibre orientation, void content, weight percentage, alkali treatment.*

Introduction

Composite materials based on natural fibres are gaining a lot of interest because they are lighter in weight, produced from renewable resources and partially biodegradable as compared to their synthetic counterparts [1-3]. Composites manufactured from agricultural waste such as bagasse, coir banana and other fibres are giving us an opportunity to explore cheaper raw materials. These raw materials could be used as reinforcement to manufacture more value added products to help the agricultural economy [4-6].

Fibre orientation is one of the key parameters to determine the properties of a composite material. When a composite is manufactured as a laminate comprising some layers in a reinforcement, the concept of fibre orientation at 0°, 45° and 90° is considered to determine the effect of orientation on the tensile and flexural properties of such materials [7-9]. It is also important to determine the orientation of fibres in the length and widthwise directions in the case of textile material being used as reinforcement to manufacture a composite. The concept of anisotropy and random orientation are considered in [10-12]. The image analysis technique is a powerful tool to determine the orientation of fibres after the composites have been manufactured. A group of researchers determined the orientation of fibres in thermoplastic composites manufactured by injection moulding using a second order orientation tensor [13-16]. The technique of FFT is also used to determine the orientation of fibres in composite materials. Images of samples are taken in the cross section, where the fibres appear in the form of circular or elliptical shapes. The orientation of each fibre is determined and the results averaged [17, 18].

Void content is one of the important quality parameters to be considered for manufacturing composite materials. Voids are air bubbles entrapped within the reinforcement during the flow of resin. They are also caused by the reaction between the resin and the hardener. The voids are also caused because of the presence of moisture in the resin mixture [19-21]. It is important to investigate the phenomenon of voids in composite material because their presence results in a reduction in tensile, flexural and inter-laminar shear properties. The presence of voids also increases moisture absorption in composite material [22-25]. The common methods to determine the void content in composite material are based on removing the matrix material and determining the fibre, resin and void contents of the composite. However, these methods are destructive in nature and the resin is either burnt using a furnace or digested using the acid digestion method [26, 27]. Since we are dealing with bagasse fibre composites herein, we could not use methods such as ISO 1172 and ISO 11472 to determine the void content. However, some researchers have used the process of pyrolysis in a nitrogen environment to digest the resin and determined the fibre, resin and void contents [28]. The void content can also be determined by finding the ratio of theoretical density and measured density. But this method is partially destructive as it involves the interaction of water with the composite sample [24, 29, 30].

The non-destructive methods include image analysis, in which images of the cross section of the composite material are taken using microscopic techniques. Images can also be taken in the thickness direction [31-33]. Another non-destructive method is based on the use of the ultrasonic technique. In these methods the composite samples are scanned using ultrasonic rays; the presence of voids are detected with the help of these rays [25, 34].

In this research work, bagasse fibres were used as reinforcement to manufacture composite material using epoxy as the matrix. Alkali treatment, fibre loading and fibre length variables were considered to determine the void content and fibre orientation of those composite materials. Alkali treatment was used to remove lignin from the surface of bagasse fibre; it was believed that the alkali treatment would help to improve the interaction between the resin and fibres [35, 36]. The non-destructive method of image analysis was used to determine the void content and fibre orientation in bagasse composites. The orientation of fibres was determined using the Fast Fourier Transform (FFT) technique.

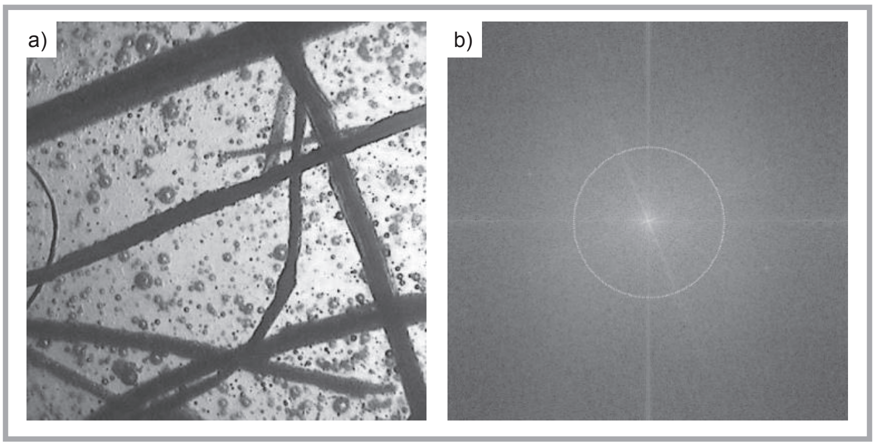

Figure 1. Procedure for determination of fibre orientation: a) grey scale image of 512 x 512 pixels and b) FFT of the image.

Materials and methods

Bagasse was obtained from a local sugarcane juice producer. It was dried in sunlight for 48 hours prior to the extraction of fibres manually using a knife and scrappers. The fibres were treated with alkali at 4, 6 and 8% for 24 hours, fibrewashed thoroughly and then dried at room temperature for 24 hours. Finally, they fibre were cut into lengths of 1, 2 and 3 inches.

Epoxy resins Araldite LY 5052 and Aradur Hardener HY 5052 were procured from Huntsman, Pakistan. These resins were used as matrix for manufacturing bagasse fibre composites using the hand lay-up technique. The following variables were considered in the experiments:

- Alkali treatment using different concentrations of alkali i.e. 4, 6 and 8%
- Fibre loading, i.e, 10 wt%, 20 wt% and 30 wt%
- Fibre length, i.e, 1 in, 2 in and 3 in.

During the process of manufacturing composites using hand the lay-up technique, it was observed that the fibres were strong enough to be handled. These fibres were cut into the desired length and spread manually as reinforcement to make bagasse composite material.

The above-mentioned factors and their different levels implied that 27 different composite samples were required to be prepared if the full factorial experimental design was to be employed. However, the technique of Response Surface Methodology (RSM) was used to reduce the number of samples to 15.

For each type of composite, five samples of 2 x 2 in^2 were used to determine the properties. To determine fibre orientation and void content, image analysis was carried out using a motic stereo microscope – Model DMW-143. Eight [8] images were acquired for each sample at 15X magnification in the transmittance mode.

Fibre orientation

In the field of composite manufacturing, fibre orientation is one of the more important properties. If a composite is anisotropic, its properties will vary in the length-wise and width-wise directions. The following method was used to determine the fibre orientation of bagasse fibre composites using 'Image J' software. The images of the composite samples acquired were reduced to the size of 512 x 512 pixels. Using the tools available in image J software, the RGB image was converted to a grey scale one. The contrast of the grey scale image was enhanced using the Enhance Contrast tool of the software to make the fibres more prominent. The output of this step is exemplarily shown in ***Figure 1.a***. The images were calibrated at 80 pixels per mm to obtain an image of 6.4 x 6.4 mm^2. The Fast Fourier Transform i.e. FFT of the image was obtained using the FFT tool available in the image J software. The FFT of the image represents a distribution of points i.e. the

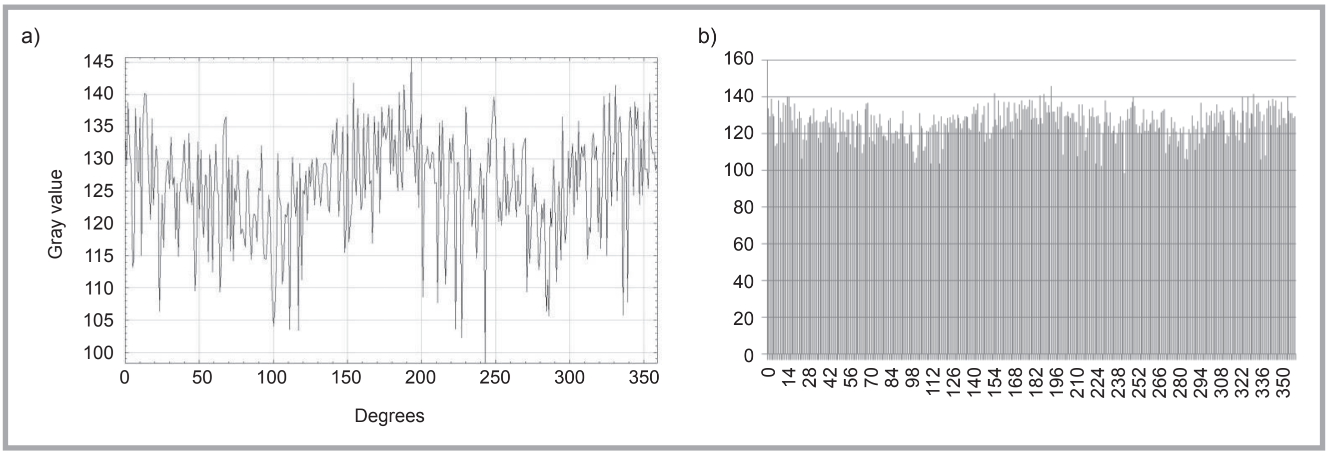

Figure 2. Data processed in Excel: a) fibre distribution from software and b) graphical representation of fibre distribution.

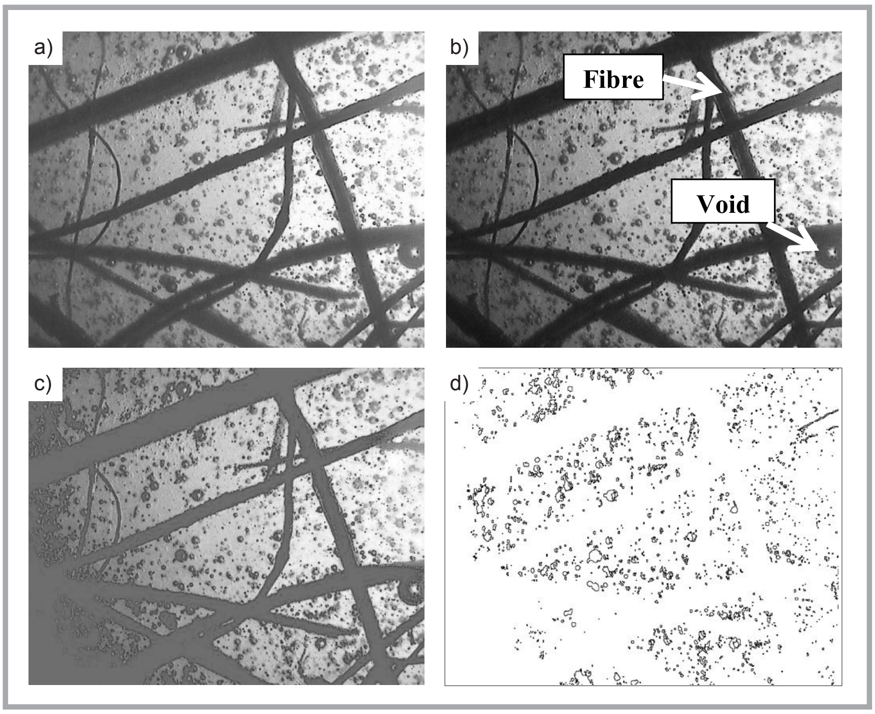

Figure 3. Procedure for determination of void content: a) original image, b) grey scale and enhanced contrast image, c) image after segmentation and d) image of the voids.

distribution of fibres in the composite sample. A circle of 7.54 mm circumference was drawn around the points of the FFT, shown in ***Figure 1.b***. Using the oval profile tool available in the software, the distribution of points along the circumference of the circle was plotted in terms of angle (0° to 360°) on the x-axis and the grey level (intensity) on the y-axis, shown in ***Figure 2.a***. The graph which is obtained from the software represents the distribution of fibres in the composite sample. These results were interpreted graphically using excel, as exemplified in ***Figure 2.b***.

Void content

Void content is also one of the important characteristics for a composite material because it has a direct impact on the mechanical properties of the final product. The following procedure was adopted to determine the void content of the composite samples. Using the image J software, the original RGB image (***Figure 3.a***) was converted to a grey scale image, as shown in ***Figure 3.b***. The contrast of the image was enhanced using the Enhance Contrast tool, which was also used to normalise and equalise the histogram to facilitate the separation of objects in the images. There are three distinctive features in the image i.e. fibres, voids, and spaces (pores) between the fibres in the composite samples. The contrast was enhanced to separate the pores (white area) and "fibres and voids", shown in ***Figure 3.b***. The image was calibrated at 80 pixels per mm

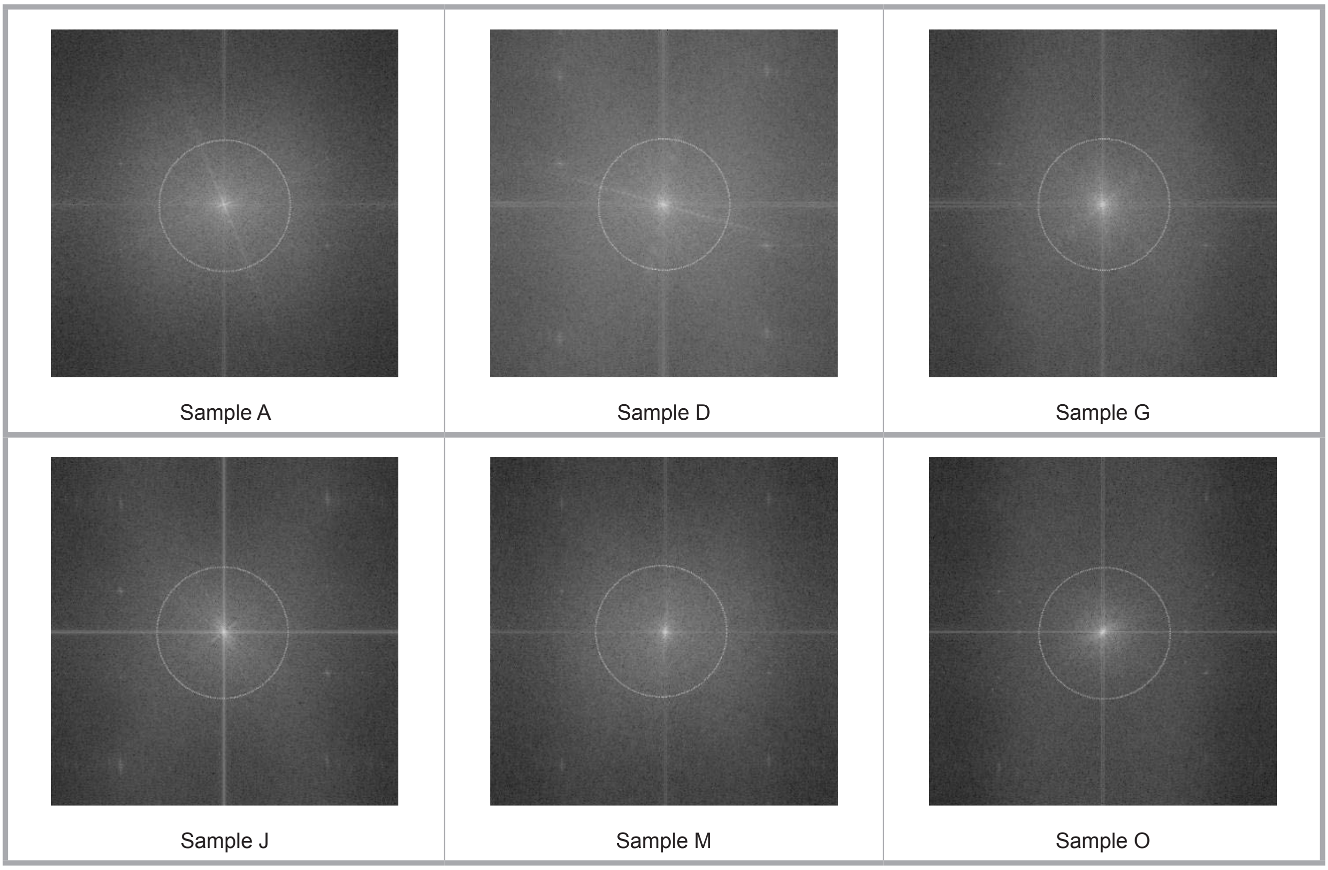

***Figure 4** FFT images for selected categories.*

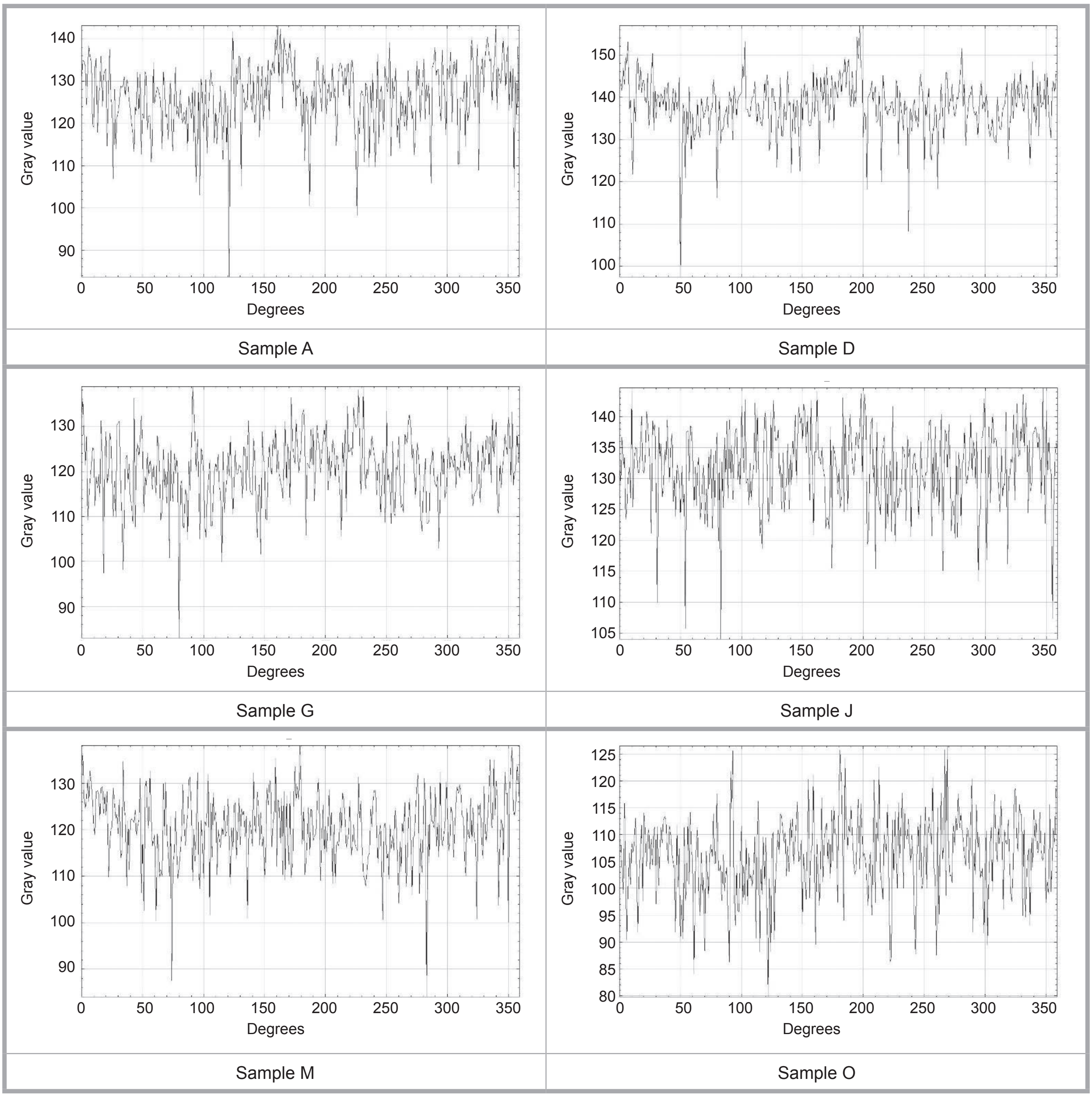

Figure 5. *Graphs of orientation angle and grey level obtained from software.*

and segmented to separate "fibres and voids" (black) from the pore area i.e. the spaces between fibres (white). An absolute threshold of 128 was chosen in this regard, shown in ***Figure 3.c***. Since we were interested in quantifying the voids, the fibres and voids were then separated on the basis of their area. Fibres longer in length as compared to the voids had a larger area, therefore the objects having an area ranging between 0 mm^2 and 2 mm^2 were considered as voids. These voids were counted and the number of voids, void content as a percentage, and the area of voids in a square micrometre were determined.

Results and discussion

Fibre orientation

The orientation of fibres in the composite samples was determined for all the 15 categories i.e. from Sample A to O, manufactured in such a way that all the factors and their levels, mentioned in the section 'Materials & Methods', were taken into account.

The Fast Fourier Transform FFT of some of the selected fibre networks is shown in ***Figure 4***, and graphs obtained from the software comparing the distribution of fibres along the circumference are shown in ***Figure 5***. The graphical representation obtained using Excel is shown in ***Figure 6***.

In order to find the fibre orientation i.e. the distribution of fibres, the Fast Fourier Transform (FFT) for the images of different composite samples was obtained using the FFT tool of the image J software. In ***Figure 4***, FFT images for the composite samples of some selected categories are shown. The FFT of the images gives a distribution of points. It was observed that the distribution of points did not show any specific pattern, therefore we can say that the fibres were randomly oriented.

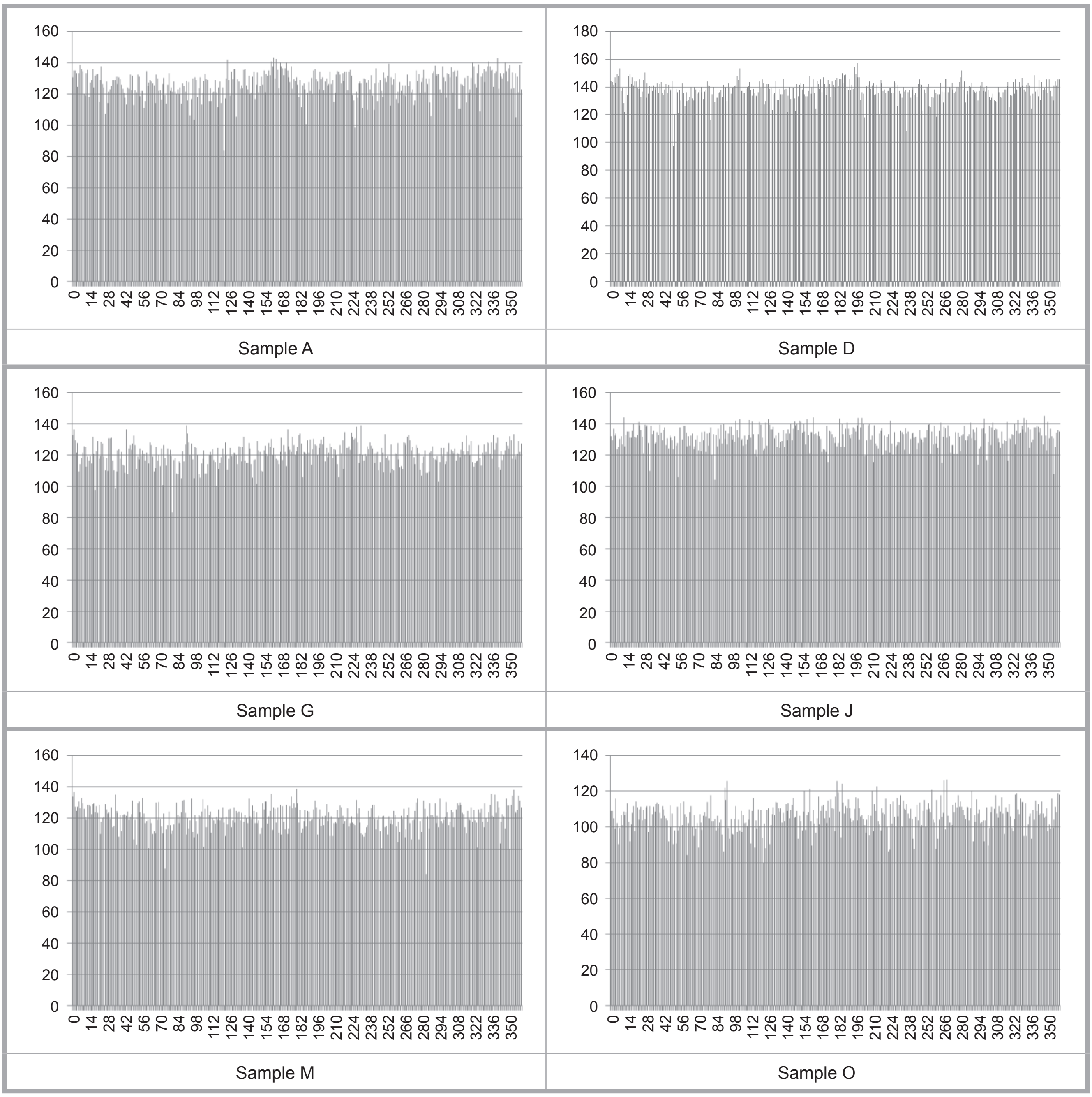

Figure 6. *Graphical representation of fibre orientation.*

From ***Figure 5*** and ***Figure 6***, it is evident that the orientation of fibres for all the samples did not show any particular trend. Therefore, it can be concluded that the orientation of fibres is random in the samples. The results also indicate that the orientation of fibres is independent of the variables i.e. alkali treatment, fibre length and fibre loading and that the hand lay-up technique resulted in a truly random distribution of fibres. This is in line with available literature, according to which in a nonwoven material the orientation of fibres is independent of treatment variables and is only dependent on the method of manufacturing [15].

Void content

The void content percentage and void area in square micrometres were determined using the method explained in the previous section. The effect of different variables, such as alkali treatment, fibre loading and fibre length on void content and void area was compared using the RSM technique. Results for the comparison are shown in ***Figure 7*** and ***Figure 8***.

The results presented in ***Figure 7*** show that with an increase in alkali treatment, the void content decreased. This could be attributed to the removal of lignin from the surface of the fibres, as a result of which the fibre diameter decreased and, consequently, more fibres were packed in a given volume of the composite. It is well-known that the presence of a greater number of fibres increases the resistance to the flow of resin, resulting in a decrease in void content.

Due to the increase in fibre length, the fibres offer more surface area for the resin to interact. This again is expected to slow down the flow of resin, hence there is a slight reduction in the void content. From the literature it is well-known that as a result of the multiple layering of fibres or with an increase

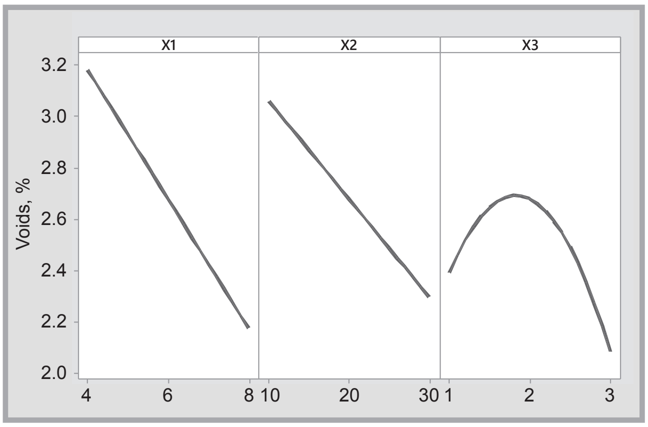

__Figure 7.__ Effect of different variables on void content in %.

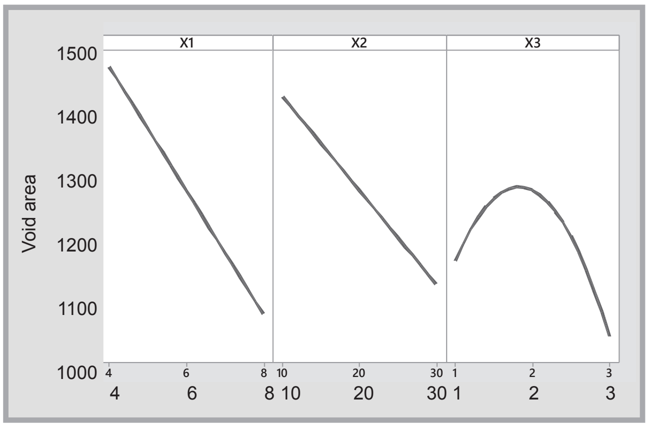

__Figure 8.__ Effect of different variables on the void area in square micrometres.

in the fibre volume fraction, the void content decreases. In conclusion, the reduced fibre diameter and increased fibre length are responsible for the decrease in void content [26].

Furthermore, the results presented in ***Figure 8*** clearly depict that with an increase in alkali treatment and fibre length, there is a decrease in the area of the voids. This may be due to the slow flow rate and resulting lower void content.

It can also be observed that with an increase in fibre loading from 10 to 20%, the area of the void decreases. This is perhaps due to the slowdown in the flow rate of the resin. However, from 20 to 30% the void area started to increase again. This may have been caused by the increased difficulty for the resin to wet a higher number of fibres. It was reported that the strength of bagasse fibre composites decreases with an increase in the fibre content due to the improper wetting of the fibres by the resin [37, 38].

Conclusions

From the results obtained in the present study, the following conclusions can be drawn.

The technique of image analysis can be successfully used to determine the fibre orientation and void content of bagasse fibre composites.

The orientation of fibres in most of the bagasse fibre composite samples made by hand lay-up is random.

The orientation of fibres is independent of variables such as alkali treatment, fibre length and fibre loading.

Alkali treatment decreases the void content and size i.e. the area of the void because the flow of resin slows down.

Increases in the fibre length also decrease the void content and size because longer fibres offer more area for the resin to interact, resulting in a slower flow of resin during composite manufacturing.

Increases in fibre loading decrease the void content because a higher number of fibres also slows down the flow of resin during composite manufacturing. However, very high fibre loading may increase the size (i.e. area) of voids because of increased wetting difficulty.

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