Sheraz Hussain Siddique Yousfani,
***Rong Hugh Gong,**
***Isaac Porat**

Department of Textile Engineering
N.E.D University of Engineering & Technology
Karachi, Pakistan
E-mail: siddique@neduet.edu.pk

***Department of Textile & Paper**
School of Materials
The University of Manchester
Manchester, United Kingdom
E-mail: hugh.gong@manchester.ac.uk
E-mail: Isaac.Porat@manchester.ac.uk

Manufacturing of Fibreglass Nonwoven Webs Using a Paper Making Method and Study of Fibre Orientation in These Webs

Abstract
Nonwovens are manufactured by different methods such as dry laying, wet laying, spunbonding and melt blowing. This paper discusses the processing of chopped fibreglass strands to form nonwoven webs using the wet laying process. Chopped fibreglass strands are used to manufacture fibreglass mats and also mixed with resins to form composites. In this project these strands were used to manufacture nonwoven webs by the wet laid method. Modification of the paper hand sheet making method was necessary at the stage of web formation and bonding in order to overcome problems caused by the stiffness and inert nature of glass fibres, as compared to pulp. The fibre orientation of the fibreglass webs was analysed using the Fast Fourier Transform, in which it was found that in most of the fibreglass webs, the fibres were oriented randomly.

Key words: *composites, fibre orientation, area density, nonwoven webs, fibreglass strands.*

Introduction

Different methods of processing chopped fibreglass strands exist in the industry, such as the laying of these strands on a conveyor belt and binding them mechanically, chemically and thermally to form mats. Some researchers have tried to manufacture fibreglass nonwoven webs by using dry laid or wet laid methods. The main advantage of a nonwoven web compared with laid chopped strands is that the nonwovens contain fibres which are much more uniformly distributed.

Due to higher inter-fibre friction and stiffness it is difficult to manufacture nonwovens by using carding or air-laid methods [1]. Some researchers have tried to manufacture nonwoven webs by mixing some carrier fibres or some chemicals [2].

In 1997 Kemey [3] developed a special type of fibre known as Miraflex fibres, which can be processed with the help of carding due to crimps introduced in the structure.

Air laid nonwovens are more isotropic in their properties and have a greater volume than comparable carded nonwovens' but there is a proneness to fibre entanglement during the fibre transfer by air, and variation in airflow can also cause non-uniform fibre distribution in the web. Both carding and airlaying require the opening of fibres in a dry state, and neither carding nor airlaying has been found appropriate for forming glass fibre nonwovens [1]. Wet laying provides a better option as the fibre dispersion can be aided by a solution which has a greater viscosity than air. Wet laid webs can be isotropic and are more compact than air laid or carded webs.

Paper hand sheets are manufactured by using pulp as raw material on a laboratory scale, which involves the following steps: dispersion, dilution, de-flocculation and hand sheet formation. These hand sheets are pressed and dried and are used for testing purposes [4].

In order to observe the effect of different variables on the quality of fibreglass webs, it was decided to use the hand sheet method to manufacture a fibreglass nonwoven web from chopped fibreglass strand as raw material.

Raw material

Chopped fibreglass strands were used as the raw material, obtained from the PPG fibreglass Company [5].

The fibre strands were dressed with a special sizing agent to make them water dispersible. During the manufacturing of the fibreglass strands, the sizing agents were applied to the strands with the help of the impregnation process. The properties of these fibreglass strands are shown in ***Table 1***.

Equipment used for experimentation

The steps of dispersion, de-flocculation, web formation and bonding were involved in the manufacture of fibreglass nonwoven webs, in which the following equipment was used.
1 Disintegrator
2 De-flocculator
3 Hand sheet former

Disintegrator

A standard disintegrator, shown in ***Figure 1*** (see page 62), was used to disperse the fibres in water; it is usually used to disperse paper pulp on a laboratory scale in order to make hand sheets for testing purposes.

The driving head drove the propeller at 3000 r.p.m. The speed of the propel-

Table 1. *Properties of fibreglass strands [5].*

Sample No	Fibre length, mm	Fiber diameter, μm	Moisture content, %	Silane sizing content, %
1	6	10	8	0.40
2	9	10	8	0.15

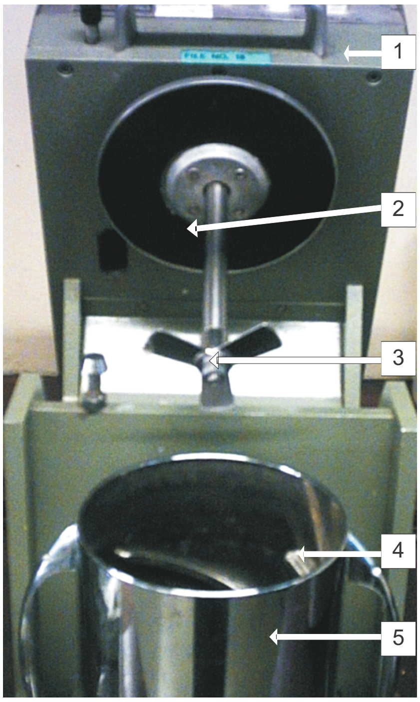

Figure 1. *Standard laboratory disintegrator; 1 - driving head, 2 - driving shaft, 3 - propeller, 4 - groove, 5 - trough.*

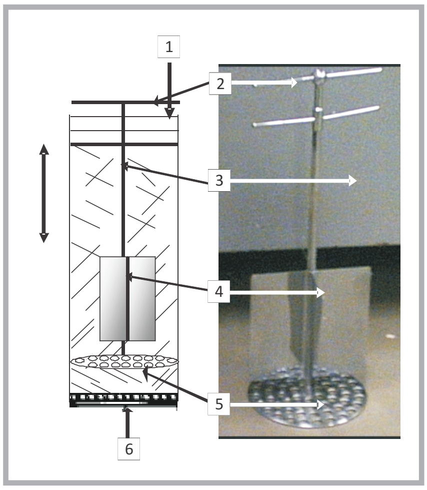

Figure 2. *De-flocculator; 1 - de-flocculator moving up and down, 2 - handle, 3 - metal bar, 4 - metal plates or fins, 5 - metal plate with holes, 6 - sheet former.*

ler was fixed. A detachable trough with grooves was used to maintain the shear force of water. The capacity of the trough was 2 litres.

The term slurry in this case means a mixture of fibreglass strands and water. In order to disperse the fibre strands, the amount of slurry required was poured into the trough, and the driving head was moved downwards to close the trough. The propeller was started to create vigorous agitation in the slurry, leading to fibre dispersion.

De-flocculator

After the fibres were dispersed, the next step was to de-flocculate them i.e. to keep them away from each other in order to form an even web. The dispersed fibres were diluted to the consistencies desired, and the slurry was poured into the cylinder of the hand sheet formation machine.

The fibres tended to collide with each other and flocculate if the slurry was stagnant. In order to de-flocculate the fibres in the water, mechanical agitation was created by using a de-flocculator, immersed in the slurry and moved up and down manually. The de-flocculator is shown in ***Figure 2***.

The de-flocculator comprised of a handle at the top and a circular metal plate with holes at the bottom. They were connected with a metal bar long enough to reach the bottom of the cylinder.

When the de-flocculator is in use i.e. when it is moved up and down in the slurry, mechanical agitation is created by the circular metal plate with holes. Four metal fins are fixed near the circular metal plate to prevent the swirling of water. The holes in the circular metal plate help the fibres to pass through with water when the de-flocculator is taken out.

Hand sheet former

Fibreglass nonwoven webs or hand sheets were formed by draining most of the water from the slurry. It is believed that the combined principles of filtration and thickening are applied to form these hand sheets [6]. The hand sheet former is shown in ***Figure 3***.

The machine base is a fixed mesh on top of a basin which is connected to a draining valve. A finer mesh is placed on top of the machine mesh, and a cylinder is placed on top, filled with slurry which drains through the mesh, leaving behind a fibreglass web. The metallic cylinder covers the sheet former from the top.

When the hand sheet former is in use, water is introduced into the machine from the bottom by using an inlet pipe as the handle for the water inlet is moved up. When the machine is in the open state, as shown in ***Figure 3***, water coming from the water inlet flows over the sheet former and cleans it. When the machine is in the closed state, water coming from the inlet is mixed with the slurry,

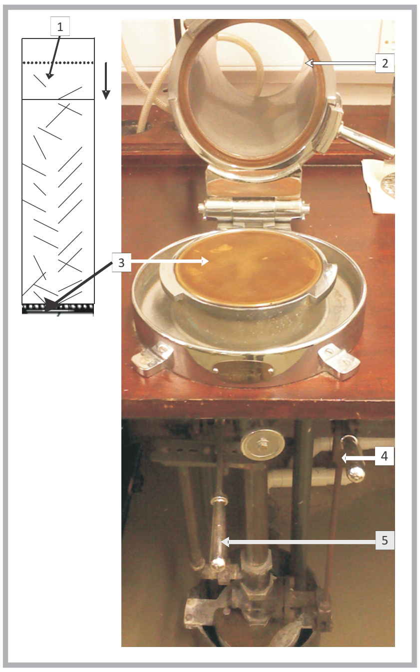

Figure 3. *Hand sheet former; 1 - slurry draining downwards, 2 - cylinder, 3 - sheet former, 4 - handle for water drainage, 5 - handle for water inlet.*

which is poured from the top to attain the consistency required.

The slurry is then deflocculated, and the water is drained from the outlet pipe when the handle for water drainage is moved down. Finally a hand sheet or nonwoven web is formed on the surface of the sheet former.

Modification in the standard process

Fibreglass nonwoven webs were manufactured using the processing steps of dispersion, dilution, de-flocculation, web formation and bonding. The standard hand sheet making method [4] was utilised up to the de-flocculation step.

The standard procedure with paper slurry suggests that the hand sheets are removed from the sheet former by pressing them against blotting paper so that they stick to it, and these sheets are then transferred to drying plates using a pressing machine. Finally these sheets are dried at room temperature and get self-bonded when water is evaporated from them.

However, with the fibreglass webs, when they were pressed against the blotting paper, some of the fibres stuck to it and some fibres were lost when the webs were transferred to the drying plates.

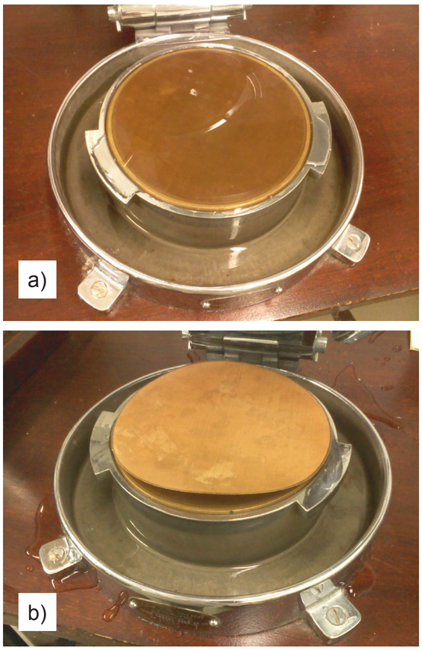

Figure 4. *Sheet former - a), wire mesh placed on the sheet former - b).*

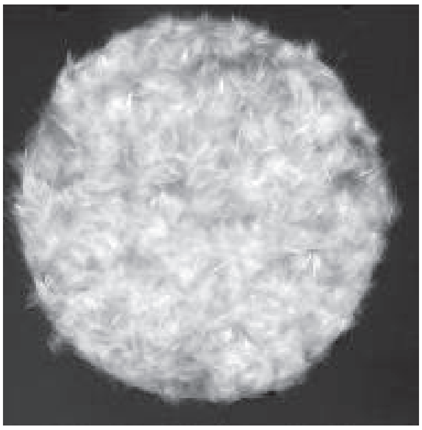

Figure 5. *Nonwoven web with uneven surface.*

Some of the fibres also stuck to the drying plate when the webs were dried in an oven to evaporate the water and consolidate them.

A circular wire mesh (60 ends by 60 picks) was placed on the sheet former in order to form a web on its surface. The web was then transferred manually from the wire mesh to a metal plate; this plate, known as a couch plate, is normally used for couching i.e. to press the blotting paper so that the hand sheet is transferred to it. However, it was used only to transport the fibreglass webs to the oven for drying. It was observed that the fibres did not stick on the surface of the wire mesh. It was also noted that after drying in the oven, the fibres did not stick to the couch plate.

The fibreglass webs were manufactured by using a consistency ranging from 0.01 to 0.15%. Glass fibres are inert by nature, therefore, in order to provide some strength to the glass fibre sheet, some polyvinyl alcohol (PVA) was added to the slurry as a bonding agent, depending on the weight of the dry fibres. A ratio of 0.5 g of PVA for 1 g of fibre was found to be appropriate for web weights ranging from 1 to 3 g (50 to 150 g/m^2) or (1.2 to 3.6 lb/ft^2), and it was reduced from 0.2 g to 1 g of fibre for heavier webs, such as 10 g (500 g/m^2) or (12 lb/ft^2).

The wet webs placed on the couch plates were put in a drying oven and dried at 110 °C for 40 minutes. The webs were easily peeled from the surface of the couch plates for further processing. The modified procedure is shown in ***Figure 4***.

Some initial experiments were performed, and it was found that the fibreglass webs manufactured by the method explained above were uneven in nature, as shown in ***Figure 5***. The problem of unevenness was related to the flow rate of water in the web formation region.

The problem of unevenness was addressed by introducing filter paper between the wire mesh and sheet former, as shown in ***Figure 6***.

By introducing filter paper as described above, the drainage rate of water was reduced from 1400 - 1750 ml/second to 80 - 200 ml/second. The reduction in the drainage rate helped the fibres to redistribute during the web formation process and form an even web. An example of a fibreglass web having a more even surface formed as a result of this modification is shown in ***Figure 7***.

Determination of fibre orientation

Fiber orientation is an important property of nonwovens because it affects the property distribution of nonwoven webs. For example, if there are more fibres orientated in a particular direction, the nonwoven is stronger in that direction. The following methods have been used to determine whether a nonwoven web is isotropic or anisotropic.

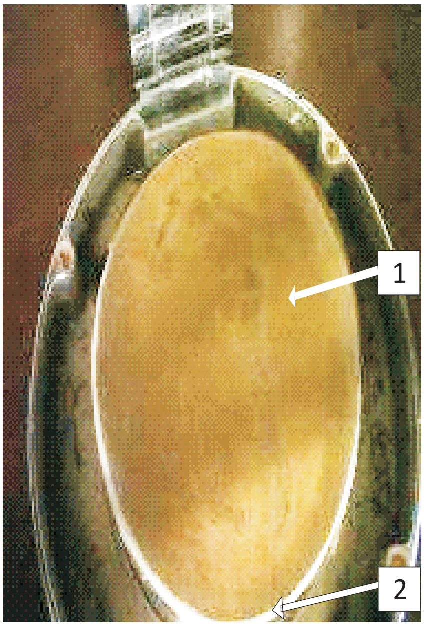

Figure 6. *Filter paper (80 g/m^2) between wire mesh and sheet former; 1 - wire mesh, 2 - filter paper.*

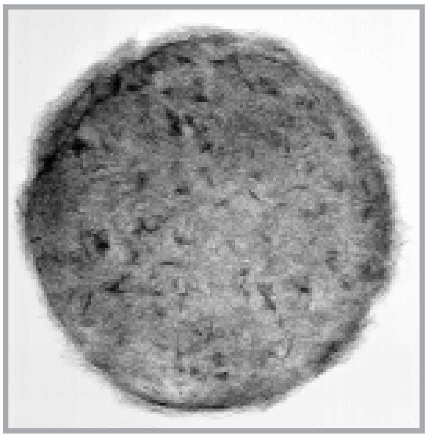

Figure 7. *Fibreglass web with improved evenness.*

1. Calculating the anisotropy by using the ratio of strength in the machine and cross machine directions.
2. Using liquid distribution, where the distribution of the flow of a drop of water on the web surface is observed and fibre orientation distribution estimated [7]
3. Using image processing, where grey scale images of the nonwoven web are analysed through Fast Fourier Transform (FFT) to obtain the fibre orientation distribution.
4. Using the image tracing process [8].

The Fast Fourier Transform method is perhaps the most widely used [1, 9, 10] and [11] and was chosen in this research as well.

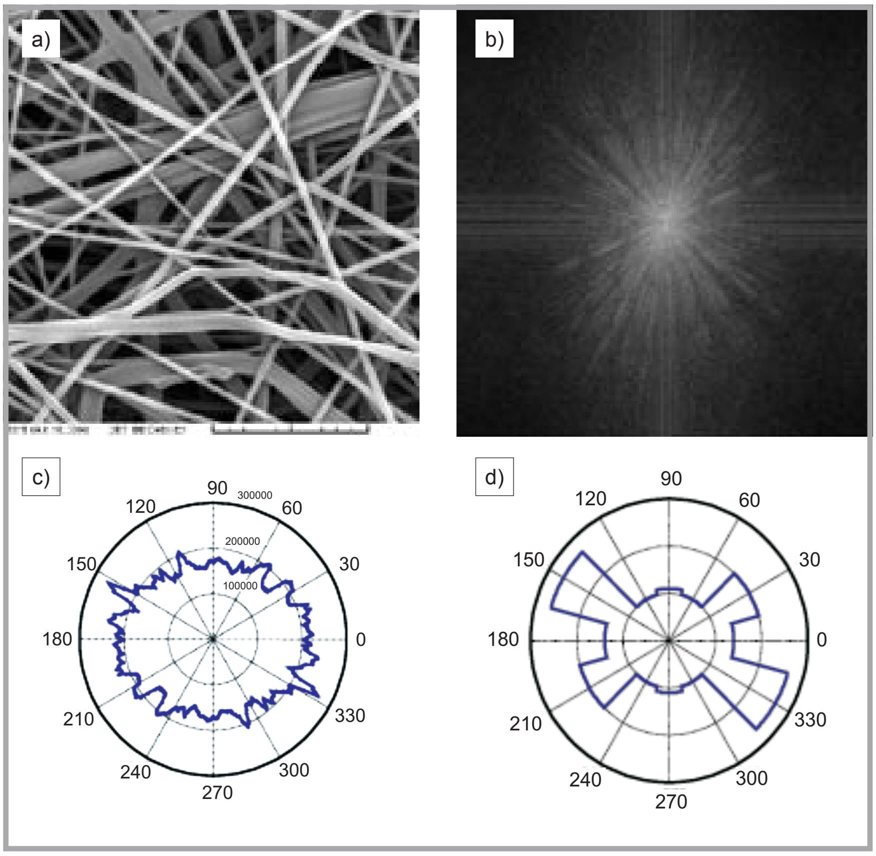

Figure 8. *Grey scale image - a), FFT of the image - b), polar plot generated by the software - c) and estimation of the fibre orientation - d) [12].*

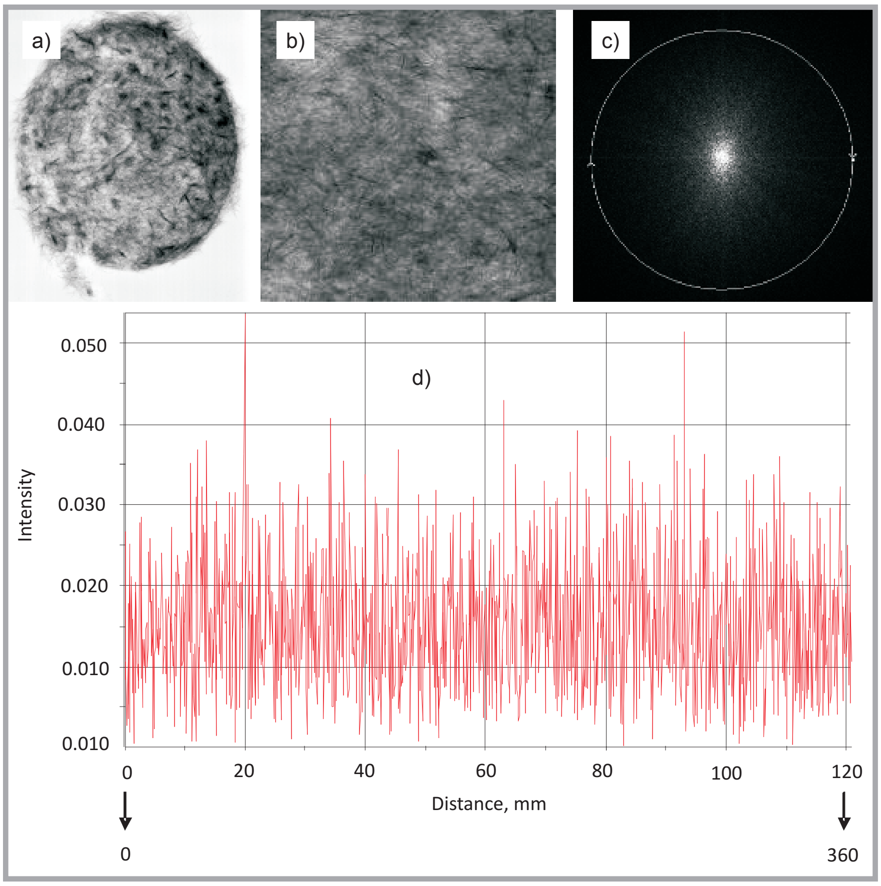

Figure 9. *Original image - a), square image of 1024 by 1024 pixels - b), FFT of the square image - c), and graph distance vs. intensity - d).*

FFT for the nonwoven webs

Maroš [12] developed software in Matlab to generate a polar plot from the FFT, the of which is shown in ***Figure 8***.

Methodology for determining fibre orientation

The hand sheets obtained in this work were circular, hence the concept of machine and cross machine direction was not relevant. The following procedure was adopted to determine the orientation of fibres and their distribution.

1. Grey scale images of the circular webs were taken under transmitted light using a scanner. The scanner used for this purpose was a desktop scanner - UMAX Power Look 1000 fitted with a transparency adaptor.
2. The areal density of the fibreglass webs ranged from 85 to 110 g/m^2 (2 to 2.64 lb/ft^2).
3. The resolution of the images was fixed at 300 dots per inch, which was sufficient to see clearly fibres in the image of the fibreglass web.
4. If the image is 2^n pixels in size, then the best results are obtained from the Fourier Transformation. Therefore, a square image of 1024 by 1024 pixels was cut from the circular image.
5. Image analysis software - 'Image-pro' [13] was used to obtain the FFT of the images. The distribution of points was shown in the FFT images so that the orientation of the fibres could be estimated.
6. The FFT of the image was calibrated at 12 pixels per mm by using the software in order to convert the units from pixels to mm.
7. In order to generate a polar plot from the Fourier Transform of an image, a circle was drawn manually around the distributed points using the software.
8. The circumference of the circle was fixed at 120 mm so that most of the visible points were covered by it.
9. A graph was produced plotting the distance along the circle`s circumference with the intensity.
10. The distance along the circle`s circumference was in mm. In order to convert it into polar co-ordinates, the starting point along the circumference of the circle was considered as 0 degrees and the finishing point as 360 degrees.
11. Graphs for different types of samples were generated, the results of which are shown in Section '**Results**'.

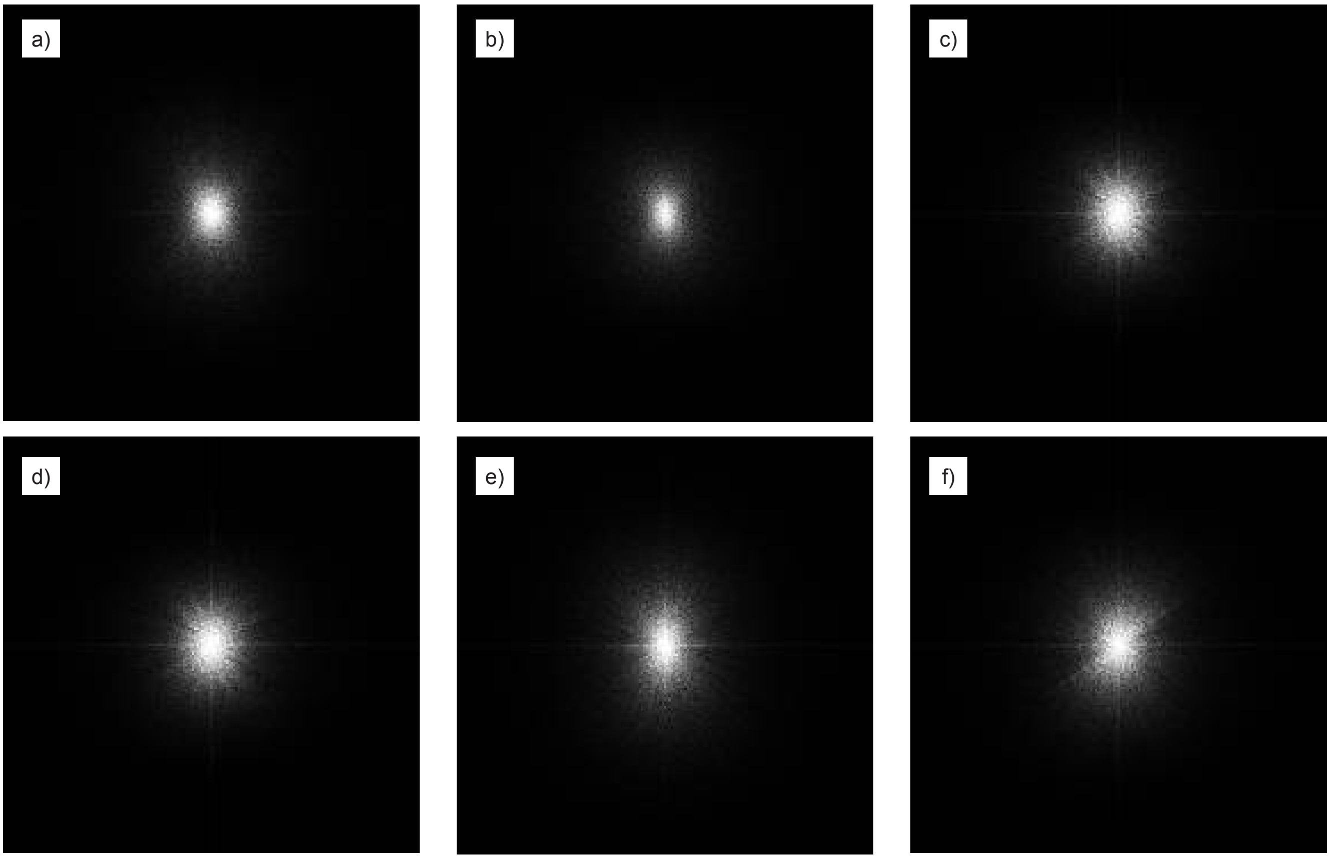

Figure 10. *FFT images: W6 ndnd - a), W6 ndbd - b), W6 10-0 - c), W9 ndnd - d), W9 ndbd - e) and W9 10-10 - f).*

12 The whole process is represented diagrammatically in ***Figure 9***.

Variables for determining fibre orientation

In order to determine the fibre orientation of different types of fibreglass webs, the following variables were considered:
1. Fiber length
2. De-flocculation and dispersion

Fibre length

Fibreglass strands of two different lengths, 6 and 9 mm, were used as shown in ***Table 1***.

De-flocculation and dispersion

Fiberglass webs were manufactured using the following conditions.
1. Fibreglass strands were not dispersed and de-flocculated.
2. Fibreglass webs were not dispersed but de-flocculated
3. Fibreglass strands were dispersed and de-flocculated (the conditions for dispersion i.e. consistency and time, will be discussed in the next paper)

Results

In order to determine the fibre orientation of the fibreglass webs, the following types of samples were considered:
1. 6 mm-NDND and 9 mm-NDND (Neither dispersion nor deflocculation), coded as W6 ndnd and W9 ndnd.
2. 6 mm-NDBD and 9 mm-NDBD (No dispersion but with deflocculation), coded as W6 ndbd and W9 ndbd.
3. 6 mm-DIS and 9 mm-DIS (Dispersion and de-flocculation) coded as W6 dis and W9 dis.

Five fibreglass webs were used for each category to determine the fibre orientation. FFT was performed following steps 1 to 5 in the methodology section. Some FFT images are shown as examples in ***Figure 10***.

As shown in some examples above, a nearly random distribution of points was observed in most of the FFT images for different types of samples. The distribution of points in the FFT images was represented in the form of graphs. Following steps 6 to 11 in the methodology section, the results are shown in ***Figures 11***.

Discussion

For ***Figures 11*** it was observed that most of the graphs obtained were symmetrical in nature. It was also observed that the distribution of intensity from 0 to 360 degree did not show any particular trend. Therefore it was concluded that the distribution of fibres was nearly random in the fibreglass webs produced using laboratory paper making equipment.

Effect of fibre length

Fibres of 6 and 9 mm were used for this project. Since there is not much difference in the fibre length, the scattering of fibres in the slurry could be considered as similar.

The laying of fibres on the surface of wire mesh in order to form a web is dependent on the drainage of water from the slurry. Since the drainage was random, the fibres were orientated randomly in the fibreglass webs.

Effect of de-flocculation

The fibres in the slurry have the tendency to entangle together and form flocks. As discussed earlier in Section '**De-flocculator**', a de-flocculator was introduced in the slurry and moved up and down to create mechanical agitation in order to disentangle the flocks and form a uniform web.

After the de-flocculation, the water was drained from the slurry. The drainage of

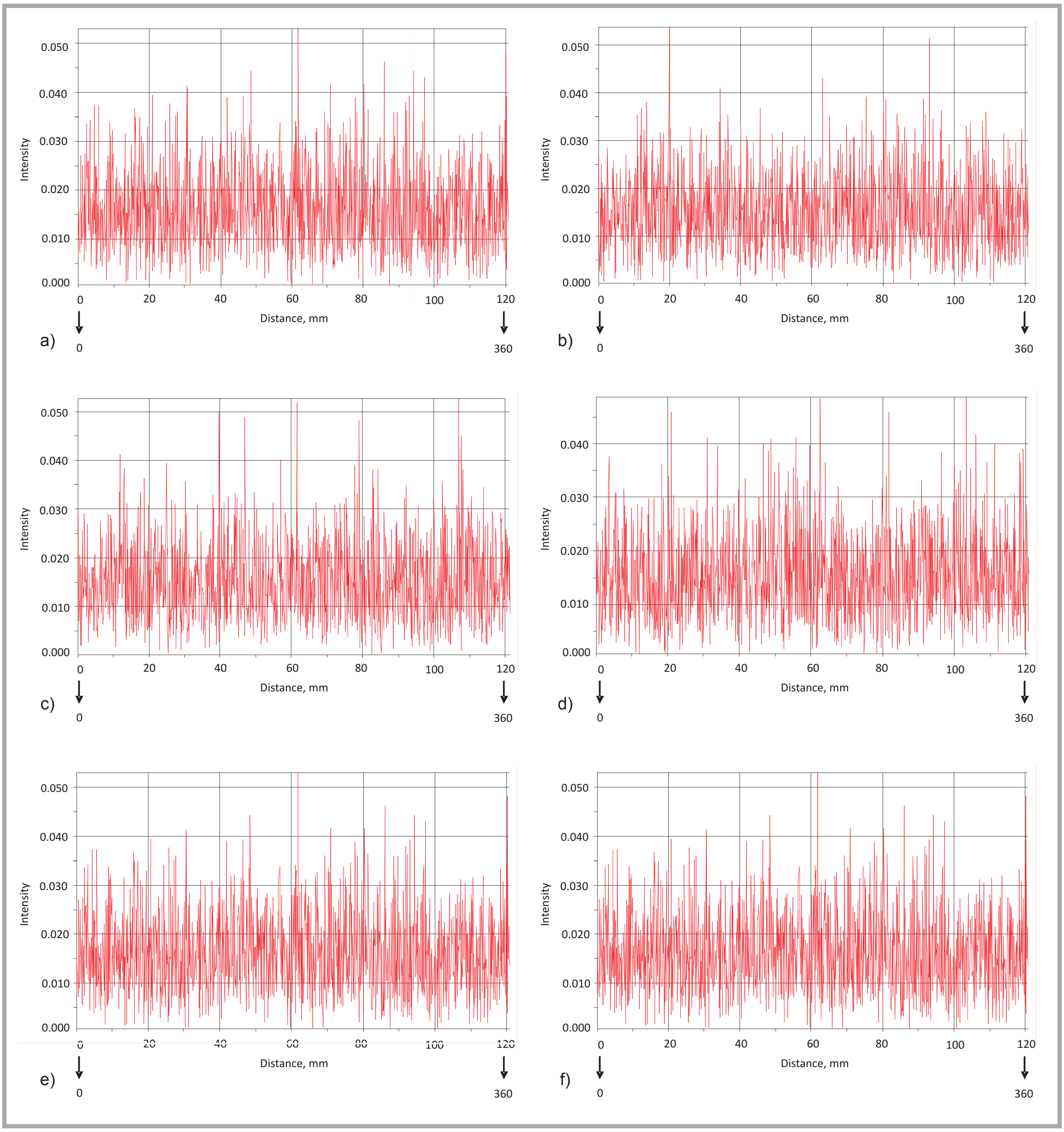

Figure 11. Comparison of the distance travelled along the circumference of the circle with intensity for: W6 ndnd - a), W6 ndbd - b), W6 dis - c), W9 ndnd - d), W9 ndbd - e), and W9 dis - f).

water through the wire mesh was random, therefore the orientation of fibres in the fibreglass webs was also random.

Effect of dispersion and de-flocculation

The process of dispersion was performed with the help of a disintegrator, as explained earlier in Section '**Disintegrator**'. The fibre strands were dispersed so that they opened up to an individual fibre stage and scattered in the slurry uniformly.

After the dispersion they were de-flocculated to induce disentanglement. When the water was drained from the slurry, the drainage was random; therefore the orientation of fibres in the web was also random.

Generally for the paper making and wet laid nonwoven processes, the orientation of fibres is considered to be either in the machine or cross machine direction, depending on how the water is drained out of the slurry. However, this concept was not relevant for this study because the webs formed were circular, and the drainage of water through the mesh was not direction dependent, hence it could give fibres a particular orientation. These webs can be considered isotropic.

Conclusions

The following conclusions are drawn:

1. In order to manufacture even fibreglass webs, it was necessary to modify the standard paper hand sheet man-

ufacturing method; it was especially necessary to reduce the drainage rate.
2. The orientation of fibres was nearly random in almost all the fibreglass webs analysed because the drainage of water during the web formation process was random and not direction dependent.
3. The orientation of fibres was independent of the web area density and variables used i.e. dispersion and fibre length. However, the orientation of fibres is dependent on how the fibres are laid down in the web formation region and how the water is drained from the slurry.

References

1. Vaidya, N. The Manufacturing of wet-laid hydro-entangled glass fibre composites for industrial application, *Textiles,* North Carolina, North Carolina State University. Masters, 2002.
2. Frank, K. K.; Williams, M. P.; Pastore, C.; Carey, J. Structure and properties of carded glass composites, INDA TEC, 1987, 333-346.
3. Kenney, M. C.; Barlow, S. K.; Eikleberry, S.L. New glass fibre geometry - a study of nonwoven processability, *TAPPI journal*, 1997.
4. Tappi Standard T 205, Forming hand sheets for physical tests of pulp, 2002, T 205 sp-95. Tappi.
5. PPG Fiberglass Europe, Data sheet of chopped strands 3075, 8031 and 8069, 2001, from http://www.ppg.com/glass/fibreglass/products/Pages/wet_chop.aspx.
6. Rojas, O. J.; Hubbe, M. A. The dispersion science of papermaking, *Journal of Dispersion Science and Technology,* 2004, 25(6), 713-732.
7. Konopka, A.; Pourdeyhimi, B.; Kim, H.S. In-plane liquid distribution of nonwoven fabrics: part 1 — Experimental Observations, *International Nonwovens Journal*, 2003.
8. Gong, R. H. Digital image processing techniques for the investigation of nonwoven structures, Textiles. Manchester, UMIST. Ph.D, 1989, 136 -145.
9. Jeddei, A. A. A.; Kim, H. S.; Pourdeyhimi, B. Measurement of fibre orientation: Optical Fourier Transform, *International Nonwoven Journal*, 2001.
10. Pourdeyhimi, B. Optical method for evaluating surface and physical properties of structures made wholly or partially from fibres films polymers and combinations thereof U. S. Patent. U.S.A., 2005.
11. Toshiharu, E.; Yoon-H, H.; Akira (Nondestructive determination of fibre orientation distribution of paper surface by image analysis,*Nordic Pulp and Paper Research Journal,* 2006, 21(2), 253-259.
12. Maroš, T.; Aleš, L. Analysis of planar anisotropy of fibre system by using 2D Fourier Transform, *Fibers & Textiles in Eastern Europe,* 2007, 15(5), 64-65.
13. Media Cybermetics Incorporate, Image pro plus software for image analysis, 2004.

Received 21.06.2011 Reviewed 25.11.2011