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► **To cite this version:**

C. Vangsøe, N. Nørskov, M. Devaux, Estelle Bonnin, K. Bach Knudsen. Oriented granulometry to quantify fibre orientation distributions in synthetic and plant fibre composite preforms. *Industrial Crops and Products*, 2020, 152 (37), pp.1-7. 10.1016/j.indcrop.2020.112548 . hal-03162857

HAL Id: hal-03162857

<https://hal.inrae.fr/hal-03162857>

Submitted on 22 Aug 2022

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1 **Oriented granulometry to quantify fibre orientation distributions in synthetic and**
2 **plant fibre composite preforms**

3

4 Victor Gager ^{1,2}, David Legland ³, Alain Bourmaud ¹, Antoine Le Duigou ¹, Floran Pierre
5 ², Karim Behlouli ², Christophe Baley ¹

6

7 ⁽¹⁾ Univ. Bretagne Sud, UMR CNRS 6027, IRDL, F-56100 Lorient, France

8 ⁽²⁾ Eco-technilin SAS, ZA Caux Multipôles, 76190 Valliquerville, France

9 ⁽³⁾ UR1268 Biopolymères Interactions Assemblages, INRA, F-44316 Nantes, France

10 **Corresponding author: alain.bourmaud@univ-ubs.fr**

11

12 **Abstract**

13 Fibre orientation is an essential factor governing the mechanical properties of composite
14 materials. This study proposes **an original** method based on gray-level granulometry to
15 analyse the fibre orientation distribution (FOD) of synthetic and natural fibre
16 reinforcements aiming composite applications. An orientation maps is computed from
17 SEM images and frequency of fibre orientation is graphically illustrated for each
18 angular direction. First, glass fibre nonwoven and unidirectional preforms were
19 analysed as a model to validate the method before testing their flax fibre counterparts.
20 Differences in structural organisations were found between flax and glass fibre
21 reinforcement FOD due to the specific structure and mechanical behaviour of plant
22 fibres but also to the preform manufacturing process. Promising results were obtained
23 confirming the reliability of this novel numerical method for fibre orientation
24 determination.

25

26 Keywords: Biocomposites; Preforms; Fibre Orientation Distribution; Flax fibre,
27 Microstructure analysis; Nonwovens;

28

29 **1. Introduction**

30 Flax fibres are now widely used as reinforcements for semi-structural and structural
31 composite applications (Shah et al., 2013). Their specificities (low density, good
32 mechanical properties, particular structure, low environmental impact, etc.) make them
33 a very attractive alternative to synthetic fibres (Bourmaud et al., 2018). Flax fibres are
34 commercially available for extrusion, injection moulding or as structured preforms for
35 infusion and compression moulding such as unidirectional, multi-directional woven
36 fabrics and also nonwoven mats. Selection of preforms can be managed depending on
37 the properties and expected end applications. Nonwoven composites are mainly used in
38 the automotive industry as interior parts because they combine good mechanical and
39 acoustic properties (Merotte et al., 2016) but also thanks to their low manufacturing cost
40 compared to fabrics. Composites performances are usually defined by the
41 reinforcement, matrix and fibre/matrix interface properties (Jones, 1999). In terms of
42 mechanical properties, additional parameters such as fibre volume ratio, fibre
43 architecture and individualisation, porosity content as well as fibre orientation are of
44 great importance. For this later, it is even more true when dealing with nonwoven
45 biocomposites where the fibre orientation distribution can be considered as quasi
46 isotropic (Gnaba et al., 2018). Still, depending on the manufacturing method and
47 especially with carding process, they can highlight preferred orientations (Miao and
48 Shan, 2011; Russell, 2007). Also, during a mechanical loading, fibres will be loaded
49 differently depending on the orientation distribution. Due to their structure, flax fibres
50 highlight high anisotropic properties and longitudinal, transverse and shearing
51 properties of flax elementary and technical fibres (bundles) (Baley et al., 2006;

52 Thomason et al., 2017) that could greatly influence the overall composite's behaviour
53 and properties (Gager et al., 2019; Merotte et al., 2018).

54 Through research work around the world, there is now a good knowledge based on
55 nonwoven composites, particularly in terms of the influence of the type of
56 reinforcement, their microstructure and their various properties (Martin et al., 2016;
57 Merotte et al., 2016; Mieck et al., 1996). However, to allow optimised structural and
58 semi-structural applications, modelling and designing tools of these materials are
59 required. In terms of modelling mechanical properties, one of the major challenges to be
60 addressed is the implementation of fibre orientation and curvature. To do this, it is
61 necessary to rely on trusted data that can only be determined experimentally from
62 existing preforms.

63 Several studies have focused on the determination of the fibre orientation distribution
64 for various materials including fabrics, paper or fibre reinforced polymers. Acquisition
65 of images with digital cameras, optical, electronic or confocal microscopes are the most
66 commonly used (Enomae et al., 2006; Erdman et al., 2016; Koh and Madsen, 2018).
67 Miao and Shan (Miao and Shan, 2011) have studied the relationship between fibre
68 orientation and mechanical properties of flax nonwoven composites thanks to optical
69 microscopy imaging and then analysis Fiji[®] image processing software. Other methods
70 such as ultrasound scanning and X-ray Computed tomography were used by Smith et al.
71 to create 3D representations of carbon fibre composite plates (Smith et al., 2015). From
72 **synchrotron radiation-based micro-computer tomography, Graupner et al. (Graupner et**
73 **al., 2016, 2014) characterised the fibre orientation of cellulose fibre-reinforced**
74 **polylactide composites by analysing the in-plane fibre orientations of several slices**
75 **through the thickness of the composite.** All acquisition techniques can be justified
76 depending on the aim of the observation afterward. Indeed, different methods will allow
77 to get 2D or 3D images, characterise diverse surface areas from micro to macro scale,

78 with more or less precision and contrasts. Some techniques are also more suitable for
79 the analysis methods through which they will then be computed to determine the
80 orientation of the fibres (i.e. gray level or colour images) (Syerko et al., 2019).

81 Methods applicability must also be evaluated depending on the morphology of the
82 reinforcing fibres. Depending on the required performances and on their final use
83 application, composites can be reinforced with short or continuous fibres. For the first
84 category, the fibre orientation will mainly be a result of the flow of the suspension
85 within the polymer during the process. For long, continuous fibre composites, the
86 orientation will be given by the structure of the preform (i.e. woven fabrics, nonwoven
87 preforms etc..) as well as the structure of the long fibres which will govern their
88 straightness. Plant fibre reinforcement potentially being made of both bundles or
89 individual fibres (Baley et al., 2019); diameters are also of great importance. Thus, to be
90 consistent, fibre orientations quantification methods must correctly identify the
91 reinforcing elements (individual fibres, bundles) as well as their curvature and take the
92 fibre morphological characteristics (diameter and length) into account.

93 The main method used to determine the fibre orientation distribution in long fibre
94 reinforced composites is the Fast Fourier Transform (FFT) whose efficiency is
95 discussed in the literature (Ghassemieh et al., 2002; Pourdeyhimi and Kim, 2002). Due
96 to the periodic character of the Fourier transformation, this method is useful to describe
97 regular patterns in woven fabric where information is concentrated in the Fourier
98 spectrum in the vertical or horizontal direction, respectively. In contrast, purely random
99 orientation of fibres causes the frequency components in the power spectrum to be
100 approximately isotropic and possess a nearly circular shape (Yousfani et al., 2012).
101 Tunák et al. (Tunák et al., 2014; Tunák and Antoch, 2018) highlighted that the "global"
102 approach commonly used was not suitable enough to analyse nonwoven textiles or
103 nanofibrous layers, which often present non-homogeneity as well as anisotropy, and that

104 further detailed analysis were more convenient. By automatically splitting the image
105 into several small sub-images and analysing them, they increased the efficiency of the
106 determination of the (fibre orientation distribution) FOD for textiles with several peaks
107 of orientations. However, results obtained with FFT based methods are very dependent
108 of the applied algorithms and smoothing filters (Kratmann et al., 2009). Furthermore,
109 this method needs a strong contrast between the background and the fibres which works
110 relatively well with fibres such as polymeric or metallic and synthetic fibres. In the case
111 of natural fibres, contrast can vary significantly, even one a singular fibre, because of its
112 structure and biochemical composition which may bias the results. Other methods such
113 as the stereological method can be used; the composite is observed in its crossed
114 direction and the orientation of a circular fibre is determined from the ratio of the
115 ellipse formed by the orientation of a fibre (Eberhardt and Clarke, 2001; Jeon et al.,
116 2014; Yurgartis, 1987). This method does work for circular diameter fibre such as a
117 glass fibre but it cannot be applied to plant fibres which present complex heterogeneous
118 structures. Furthermore, as it is only at one location in the in-plane direction, curvature
119 of the fibre cannot be determined. Local gradient orientation method can also be used
120 but this way is questionable as only fibre edges are detected by filtering operators which
121 means fibre widths are not taken into account and this is a predominant information
122 when dealing with plant fibres. Other methods such as structure tensor (Krause et al.,
123 2010; Van Kempen et al., 1999) or mean intercept length (Luo et al., 1991; Sander and
124 Barocas, 2009) methods were also applied on composite materials and each of them has
125 its own benefits and drawback from the complexity to the accuracy of the method
126 (Syerko et al., 2019).

127 Despite their applicability to analyse composite materials, the methods previously
128 enounced are usually programmed in operating systems/software for which it is not
129 possible to manage settings such as the time of calculation and the accuracy of the
130 results. Also, depending on the applications, there is a need of a method where such

131 parameters can be managed. For scientific matters, the accuracy of the results is
132 prevalent. From an industrial point of view, a method quantifying the fibre orientation
133 in a preform directly after the production in order to control its conformity might be of
134 great interest. For this purpose, even if accuracy is important, the time of calculation is a
135 predominant factor if there is a large area to analyse. Moreover, by developing a method
136 for which there is a full understanding of the protocol, it is easier for the developers to
137 modify calculation algorithms to make them more efficient according to the material
138 characteristics.

139 This paper presents **an original method** based on gray-level granulometry to analyse the
140 fibre orientation distribution of both synthetic and flax preforms for composite
141 reinforcement. After a validation of the method developed on glass fibres unidirectional
142 (UD) and nonwoven preforms, results obtained with similar flax fibre preforms are
143 shown and discussed.

144 **2. Materials and methods**

145 2.1 Materials

146 Flax (*Linum usitatissimum*) tows and scutched fibres grown in Normandy (France) were
147 used to produce the nonwoven and the unidirectional tape (Martin et al., 2014). **Natural**
148 **fibre nonwovens were manufactured according to the carding/over-lapping/needle**
149 **punching technology (Russell, 2007) whereas the unidirectional tape is produced by a**
150 **specific process well described by Khalfallah et al. (Khalfallah et al., 2014). The**
151 **materials (i.e. nonwoven and UD tape), coming from Eco-Technilin SAS[®], have an**
152 **areal weight of respectively 70 g.m⁻² and 110 g.m⁻², respectively.** E-Glass fibre mat and
153 unidirectional fabric made respectively following air blowing (Russell, 2007) and
154 weaving technologies were also studied to validate the method. They were supplied by
155 Composite Distribution and have both an areal weight of 200 g.m⁻². The unidirectional

156 fabric is not a pure UD fabric as it presents a few fibres in the weft direction (weight
 157 fraction around 0.4%). Names and properties related to the different preforms are given
 158 in table 1.

159 **Table 1. Characteristics of the various preforms analysed.**

Name	Type	Fibre type	Areal weight (g/m ²)	Preform thickness (μm)	Fibres/bundles length (mm)	Preferred orientation (°)
Flax UD	Unidirectional	Flax	70	150 ± 20	Bundles assembly	Longitudinal
Flax NW	Nonwoven	Flax	110	200 ± 10	50-200	Cross direction (CD)
Glass UD	Unidirectional	Glass	200	190 ± 20	continuous	Longitudinal
Glass mat	Nonwoven	Glass	200	460 ± 40	40-70	None

160

161 2.2 Scanning Electronic Microscope Imaging

162 SEM observations were performed on glass and flax preforms. Rectangular samples
 163 (60x40 mm) were sputter-coated with a thin layer of gold in an Edwards Sputter Coater
 164 and analysed with a Jeol JSM 6460LV SEM at 20 kV.

165 2.3 Images Analysis Methodology

166 Images were analysed by computing the histogram of the preferred orientation of pixels.
 167 The preferred orientation is computed by applying gray-level granulometry curves with
 168 various orientations, computing a typical size in each direction, and estimating the
 169 preferred orientation from typical sizes.

170 **Figure 1.**

171 Gray-level granulometry is an approach for image texture analysis based on the
 172 application of morphological filters (typically opening or closing) of increasing size
 173 (Devaux et al., 2008; Soille, 2003). Gray-level morphological opening is an operation
 174 that removes bright structures that are smaller than the structuring element. Let us denote
 175 by $\gamma_B(I)$ the result of morphological opening with structuring element B_λ of size λ on the
 176 image I . The computation of granulometry involves a family of structuring elements

177 $\{B_{\lambda_i}\}_{i=1,\dots,n}$ of increasing sizes λ_i . The result obtained with each size λ_i is summarised by
178 the image volume curve V_i , that corresponds to the sum of the gray level values in the
179 corresponding result of opening. The derivative of the image volume curve results in
180 granulometric curves that can be interpreted in terms of size distribution:

181
$$G_i = \frac{V_{i+1} - V_i}{V_\infty - V_0}$$

182 Figure 1 presents an example of granulometric curve computed on a sample image of a
183 flax fibres nonwoven. A peak can be noticed around 5 pixels, that corresponds to the
184 thickness of the majority of fibres visible in image. Another peak can be noticed around
185 15 pixels, corresponding to thicker fibres. The corresponding fibres are visible on the top
186 images.

187 A granulometric curve can be summarised by a gray-level mean size that depicts the
188 typical size of the structures within the image. The geometrical mean $m_G =$
189 $\exp[\sum_i \log \lambda_i G_i]$ was considered, which resulted in values closer to the centre of the peak
190 than the mean or the median (Devaux et al., 2008).

191 Gray-level granulometry is typically computed using structuring elements with square or
192 disk shapes. In order to assess the preferred orientation of texture, linear structuring
193 elements with various orientations may be used (Devaux et al., 2008; Legland et al.,
194 2012; Soille, 2003). Families of linear structuring elements were considered; they are
195 obtained by identifying the pixels around the line with orientation θ containing the origin,
196 and keeping the number of pixels that best approximates the expected length. The
197 computation of granulometric curves on the whole image using linear structuring
198 elements with various orientations results in a granulometric curve for each orientation.
199 The computation of geometric means results in a function $m_G(\theta)$ that depicts the typical
200 size depending on the orientation.

201 **Figure 2.**

202 In order to compute preferred orientation for a given pixel, it is necessary to compute
203 locally (i.e. for each pixel) the functions $m_G(\theta)$. In practice, this requires to replace the
204 computation of global image volumes V_i by their local counterparts $V_i(x, \theta)$, where x
205 corresponds to the pixel position and θ corresponds to the orientation. Resulting
206 granulometric curves $G_i(x, \theta)$ can be summarised by computing for each pixel and for
207 each orientation the local oriented gray-level mean size $m_G(x, \theta)$. Fig. 2.B and Fig. 3.C
208 show examples of local gray-level mean size maps for orientations corresponding to 0,
209 45, 90, and 135 degrees computed on a synthetic image (Fig. 2.A) and on a cropped
210 image of flax fibres (Fig. 3.A). The elongated regions result in a large mean size value
211 when the orientation corresponds to the orientation of elongation.
212 For each pixel, the function $m_G(x, \theta)$ exhibits one or several maxima for orientations
213 corresponding to the presence of fibre. Fig. 2.C represents this function for point located
214 in a vertically oriented region, shown as a red cross in Fig. 2.A. The best orientation
215 $\theta^*(x)$, corresponding to the most prominent fibre direction for the pixel x , is computed
216 by integrating the function $m_G(x, \theta)$ over the circular domain $[0; 2\pi[$. The resulting map
217 of orientation is represented using a colour map depending on the orientation: the red
218 colour corresponds to a horizontal orientation, and the light blue colour corresponds to a
219 vertical orientation (Fig. 2.D).
220 The estimate of local orientation is computed for all pixels. However, as the dark pixels
221 correspond to background, it is relevant to consider only the orientation of the bright
222 pixels. Therefore, parametric maps of local orientation are represented using a colour
223 coding that takes into account both the orientation and the local intensity of the pixel
224 (Fig. 3.C). For the same reason, the histogram of preferred orientations is obtained by
225 computing the histogram of the values $\theta^*(x)$ weighted by $I(x)$, the intensity of x in the
226 original image (Fig. 3.D).

227

Figure 3.

228

229 3. Results and discussion

230 3.1 Validation of the method

231 This method was originally developed to estimate the fibre orientation distribution (FOD)
232 of flax fibre nonwovens. These materials can be considered as complex materials. Indeed,
233 in the stem, flax fibres are arranged in bundles and are then more or less individualised
234 during the processes they undergo (retting, scutching, carding, etc.) resulting in individual
235 fibres and bundles with heterogeneous diameters and lengths. Also, flax fibres and
236 bundles are flexible enough to bend and therefore, the analysis is more complicated than
237 if the fibres remained straight as it is the case for glass fibre.

238

Figure 4.

239 For all these reasons, the method is validated with more conventional materials before
240 testing flax fibre webs. Figure 4 A, B and C show SEM images of three reference
241 materials: Glass fibre mat, glass fibre UD fabric and UD flax tape, respectively. The
242 computed preferred orientation maps are also represented in Figure 4 D, E and F where a
243 colour represents an orientation; thus, a random orientation is presumed to give a large
244 range of colours whereas a reduced colour shade is expected when a unidirectional
245 preform is analysed. The trends shown in Figures 4 D, E and F are clearly in this
246 direction and are confirmed with the results shown in Fig.4 G). Indeed, the glass fibre
247 mat FOD exhibits a quasi-monotonous line fluctuating between 0.4 and 1% highlighting
248 the random in-plane orientation of fibres. On the contrary, glass fibre unidirectional
249 fabric FOD shows a thin peak between orientations ranging from 80 to 100° and displays
250 a maximum value at 89° (longitudinal axis). If the curve is compared with the one of flax
251 fibre unidirectional tape, the peak is higher and thinner. Indeed, for flax, a peak is also
252 present with a maximum at 90° but it only represents 5% of the fibres (13% for glass) and
253 it is also more scattered with orientations ranging from 75° to 105°. As glass

254 reinforcement is made of continuous individual fibres assembled in 2 mm wide bundles,
255 it is less likely to bend due to its higher moment of inertia compared to flax individual
256 fibres and bundles (Tanguy et al., 2018), with diameters varying from 15 to 100 μm
257 (Charlet et al., 2010; Haag and Müssig, 2016). Also, bundles may have been damaged
258 during the mechanical scutching process and the manufacturing process of unidirectional
259 flax tapes (Khalfallah et al., 2014), where some individual fibres can break up from the
260 bundle and become disoriented, this is visible on Fig. 4.C and 4.F) with some small
261 diameter **bent** fibres. On this point it should be kept in mind that the production of flax
262 fibre reinforcements is a much more complex process than for glass fibres; the glass
263 fibres are extruded and calibrated in an industrial way then directly assembled into roving
264 and preforms. In the case of flax, they are mechanically extracted from a plant, then
265 aligned and ribboned with all the risks involved in these successive operations, with new
266 possibilities for creating defects at each stage.

267 From figure 4. F. it can be observed that on large flax fibre bundles, there is a variation in
268 colour for the same element that can be explained by the fact that the method detects
269 elements crossing each other and for the area where fibres are overlapping, it gives a
270 mean orientation of these later. Also, if the fibres are too wide, the method can hardly
271 recognize them as a single element and thus it gives two symmetric orientations for this
272 element. This later can be resolved by adjusting the image analysis settings with the
273 increase of the morphological filter size which will give a more accurate result but needs
274 a longer time to process.

275 3.2 Application to flax fibre nonwoven preforms

276 **Figure 5.**

277 Similar analyses were performed on flax nonwoven (Figure 5). Referring to the fibre
278 orientation distribution curves, there is a preferred orientation around 90° . This was not
279 reported for glass fibre mats (Fig. 4.G) and this phenomenon can be explained by the

280 manufacturing process of nonwovens which are different for the two materials. Indeed,
281 the glass fibre mat studied here is made by air blowing where fibres are randomly
282 dispersed in the plane whereas flax fibre nonwovens were produced by carding
283 technology with a roller card; fibres are conveyed by several rolls to be disentangled and
284 mixed in order to form homogeneous web of uniform weight per unit area. **Fibres are thus**
285 **more oriented in the machine direction (Van De Velde and Kiekens, 2003). During the**
286 **overlapping step, the web is reoriented almost perpendicularly to the machine direction**
287 **allowing a preferred orientation in the cross direction (CD) (90° in figure 5 and 6). Same**
288 **observations as for unidirectional flaxtape with the fibres overlapping each other can be**
289 **reported for nonwovens.**

290

Figure 6.

291 Fig. 6 represents an analysis of the fibre orientation distribution for four different
292 locations on the nonwoven. Trends are found to be quite similar for areas 1, 2 and 3 with
293 a preferred orientation at 90° whereas for the fourth location, the peak is wider and
294 shifted to 70° values and this is likely due to the size of the analysed area. The
295 observation scale is a key point for the accurate analysis of the fibre orientation
296 distribution because if the latter is too small then there are not enough fibres analysed and
297 the distribution thus obtained will not be representative of that of the whole material. On
298 the contrary, if it is too large, the smallest elements may not be detected due to a lack of
299 image quality, leading to an error in determining the orientation of the fibres. With the
300 magnification used here, smaller diameter fibres are detected and by analysing over
301 several areas, it is possible to obtain a precise and representative fibres orientation
302 distribution within the nonwoven. By automating the image analysis, it would then be
303 possible to analyse a very large surface of a sample that can then be mechanically tested
304 and thus verify the actual orientation distribution of the fibres and the impact this will
305 have on the mechanical properties; on the other hand, these data could make it possible to

306 implement a mathematical model to predict the properties of nonwoven composites
307 reinforced by plant fibres. Particular attention should be paid to the fact that with this
308 method, only a surface analysis is performed. This corresponds well for so-called
309 lightweight preforms since the majority of the fibres are analysed here. That said, the
310 increase in weight will affect the thickness of the preform with more fibres in the
311 background that may not have the same orientation as those analysed. **Additionally, in the**
312 **special case of needle-punched nonwovens with higher thickness, the needle punching**
313 **step drives few fibres through the thickness of the material resulting in a three-**
314 **dimensional orientation of the fibres. From these points, a three-dimensional image**
315 **acquisition method and analysis may be required to ensure a reliable fibre orientation**
316 **characterisation on the entire material.**

317

318 **4. Conclusion**

319 This paper presents a new method to analyse the fibre orientation distribution (FOD) of
320 both synthetic and flax preforms for composite reinforcement. Preforms images were
321 obtained by scanning electronic microscopy (SEM) and analysed by computing the
322 histogram of pixels preferred orientations by using gray-level granulometry. Gray-level
323 granulometry is an approach for image texture analysis based on the application of
324 morphological filters (typically opening or closing) of increasing size which results in
325 granulometric curves that can be interpreted in terms of size distribution. The method
326 computes a parametric map of local orientation using a colour coding taking into account
327 both the orientation and the local intensity of the pixel. It also gives a histogram
328 representing the preferred orientations of the analysed elements.

329 Originally developed for flax fibre nonwovens, the method is first validated with more
330 conventional materials such as unidirectional glass fabric, UD flax tapes as well as glass

331 fibre mat. The results obtained are in accordance with those expected with significant
332 differences between the FOD of the different preforms highlighting the influence of
333 parameters such as the intrinsic characteristics of the materials and their production
334 methods. Similar analyses were performed on different locations of a flax nonwoven
335 which highlighted a preferred orientation around 90°. Due to the reduced size of the
336 analysed area, it is necessary to process to image analysis on different location and
337 arithmetically average the values to assure reliable material fibre orientation distribution.

338 This method could be combined with several image acquisition techniques (SEM,
339 tomography) both at the preform and composite level offering a large range of
340 applications including composite materials. Potential improvements of the method can be
341 imagined with the quantification fibres and bundles diameters or determination of the
342 orientation in the three dimensions. Finally, it provides interesting perspectives for
343 numerical modelling of biocomposite mechanical properties.

344

345 **Acknowledgments**

346 The authors would like to thank the French National Association of Research and
347 Technology for funding this work.

348

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- 493

494 **Figure captions**

495 **Figure 1.** Computation of granulometric curves using morphological opening. Top row:
496 sample results of morphological opening using square structuring elements of increasing
497 sizes. Bottom: resulting granulometric curve. The dots on the curve correspond to the
498 stages shown on the first row.

499 **Figure 2.** Computation of preferred orientation map on a synthetic image. A) Original
500 image. B) Results of local mean size for different families of linear structuring element
501 oriented with 0, 45, 90 and 135 degrees. C) Mean size function for a single pixel and the
502 whole range of orientations. D) Synthetic map of preferred orientation represented using
503 colour.

504 **Figure 3.** Computation of local orientation map from granulometry curves obtained by
505 analysis on a flax nonwoven. A) Original image (inverted) B) Granulometric size
506 obtained with various orientations of structuring elements C) Colour representation of
507 preferred orientation map. D) Histogram of preferred orientations.

508 **Figure 4.** Original SEM images of A) glass fibre mat, B) glass fibre unidirectional
509 preform and C) flax fibre unidirectional tape. D), E) and F) are the computed preferred
510 orientation maps of glass fibre mat, glass UD and flax UD, respectively. G) is the
511 comparison of the fibre orientation distribution (FOD) of the preforms.

512 **Figure 5.** Original SEM image of flax fibres nonwoven A). B) is the computed preferred
513 orientation maps of A) and C) shows the histogram representing the fibre orientation
514 distribution.

515 **Figure 6.** Original SEM image of a larger area of flax fibres nonwoven divided in four
516 areas A). The histogram represents the fibre orientation distribution of each area analysed
517 B).

518

Figure 1.

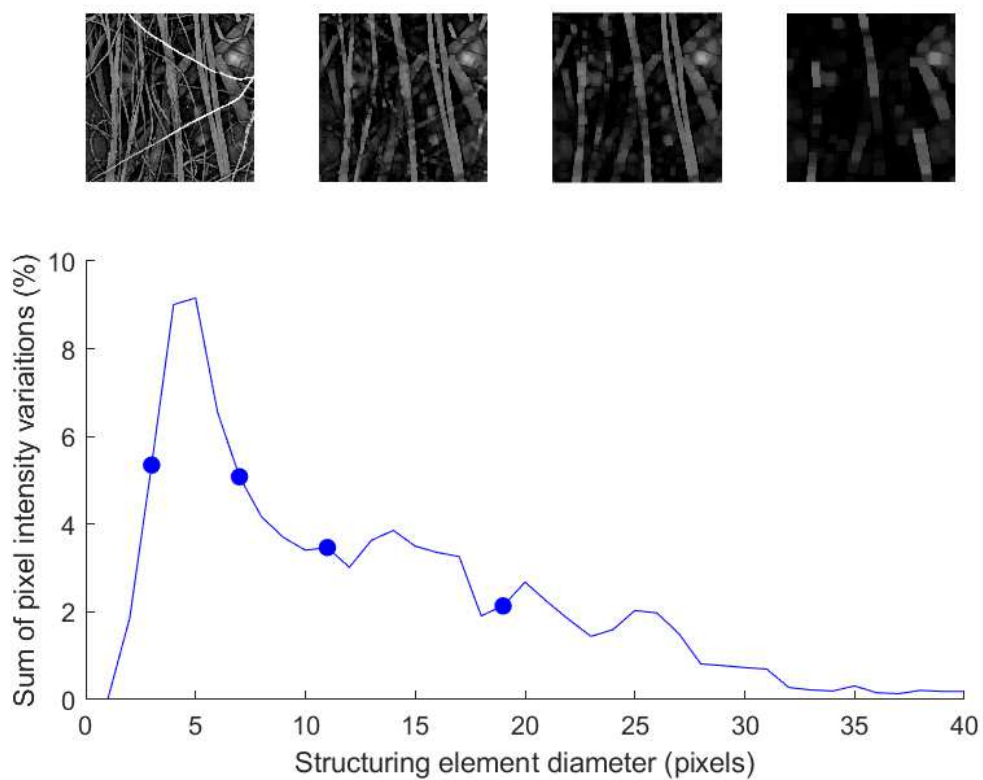


Figure 2.

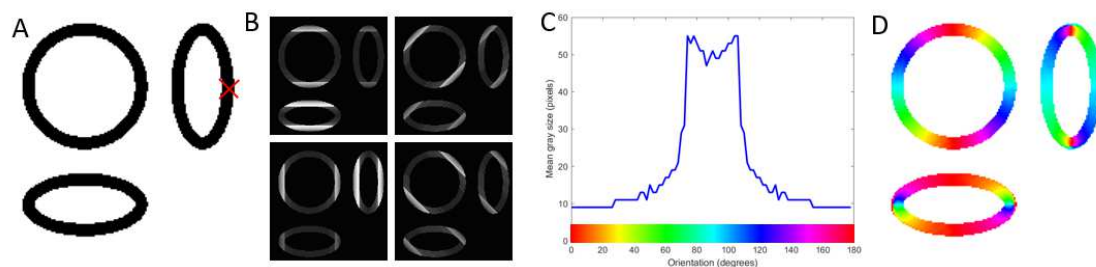


Figure 3.

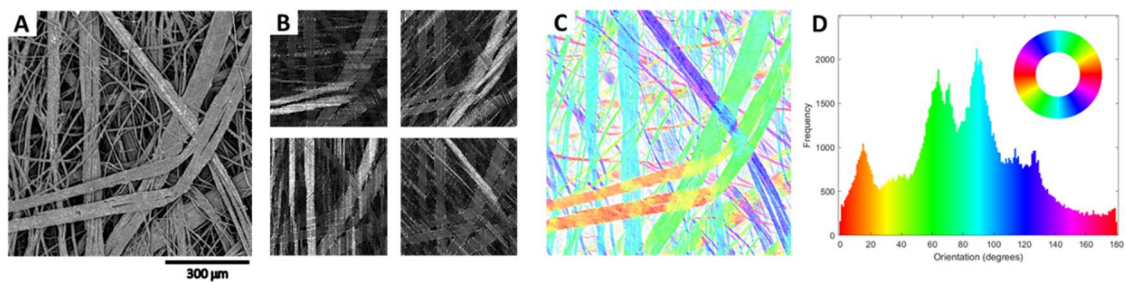


Figure 4.

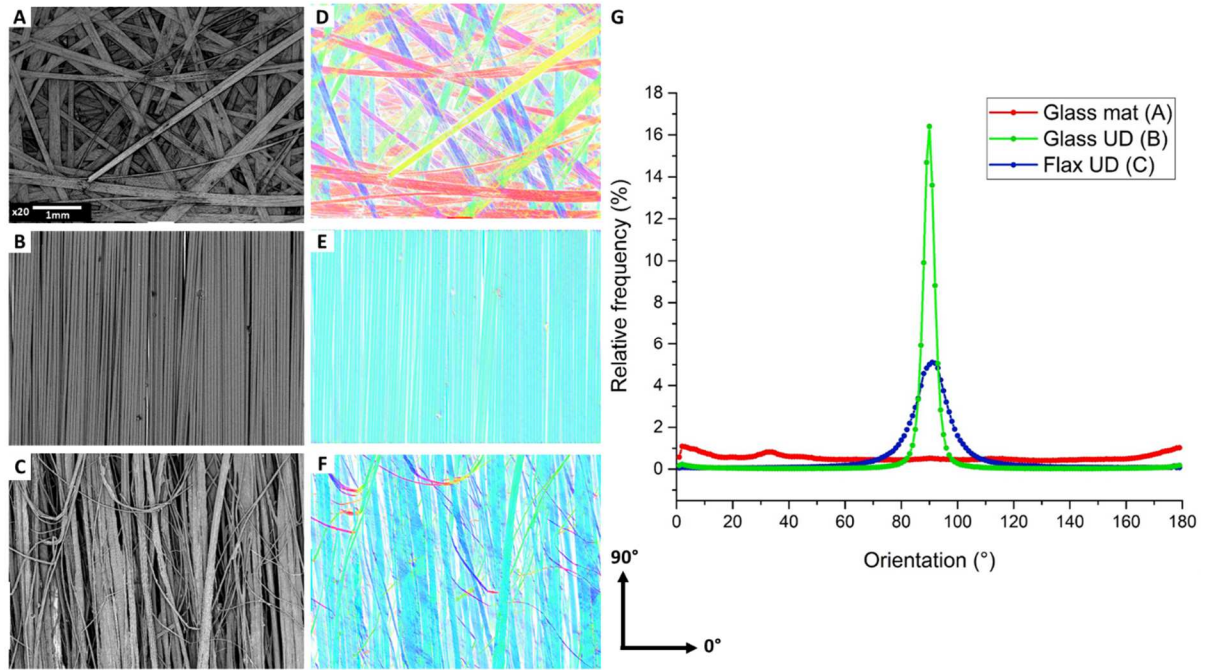


Figure 5.

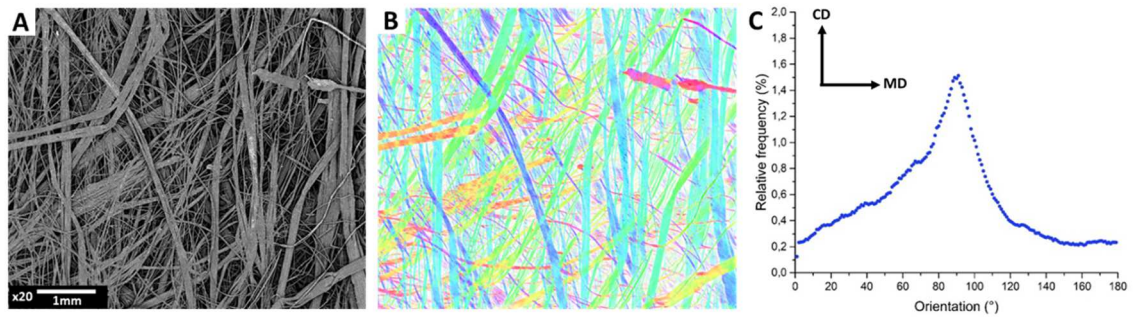


Figure 6.

