Alignment of Short Fibres: An Overview

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Abstract

Fibre orientation is a major factor influencing composite performance; research, largely on synthetic fibre composites, supports that the best mechanical performances are achieved in composites when fibres are aligned in the loading direction. Generally, with short natural plant fibre (SNPF) composites, randomly oriented fibre mats are used as reinforcements due to the innate limits of fibre length and the difficulty of aligning short fibre. However, there are a number of methods that have been developed for aligning short fibre, again largely employed for synthetic fibres. The two main approaches employed to align short fibres relate to whether dry or wet processing is used available in literature; in wet processes, fibres are generally suspended in a liquid medium and alignment of fibre trails the fluid flow direction, whereas in dry processes, dry fibres are aligned in the direction of an induced or applied force such as pneumatic or electric. An overview of different alignment methods with their working principles is presented in this paper. This paper also describes an alignment technique currently under development to improve the alignment obtained for SNPFs.

1. Introduction

Polymer composites reinforced with oriented fibres have higher reinforcement efficiency. Generally, fibre reinforcements are either in continuous or discontinuous form. Continuous fibre reinforced composites perform better because of the continuous load path and fibre continuity also allows easy alignment in the preferred direction compared to short fibres [1]. However, discontinuous fibre reinforced polymer composites are becoming more attractive with major benefits including the ability to manufacture complex structural parts due to their higher ductility in all direction [1, 2].

There are different methods developed by researchers in order to manufacture aligned short fibre reinforced polymer composites (SFRPCs). These methods can be broadly classified as wet processes and dry processes [3]. Generally, in the former, fibres are suspended in a liquid medium and are forced through a converging nozzle for fibre alignment along the fluid flow direction [2, 4] while in the latter, generally, dry fibres along with polymer powder are aligned by electric or pneumatic means to form the aligned fibre preforms. Although dry alignment methods attain faster production rates and control over orientation of fibres, the degree of fibre alignment obtained has been higher with wet alignment methods [2, 3, 5].

Recently, growing environmental concerns have urged developments and usage of short natural plant fibre polymer composites (SNPFPCs) with good mechanical properties (specific strength and specific stiffness) [6]. Similar to synthetic short fibre polymer composites, the aligned SNPFPCs exhibit better mechanical properties when the fibre is aligned to the loading direction. However, obtaining alignment with short natural fibres is more complicated than with short synthetic fibres because of their variability in diameter along their length.

This paper provides an overview of the main alignment techniques for SFRPCs described in the literature and also describes a recently adopted alignment technique i.e. dynamic sheet forming which has been employed successfully to produce aligned natural fibre mat. These aligned mats can be incorporated with polymer matrices to manufacture aligned SNPFPCs.

2. Discontinuous Fibre Alignment Methods

2.1 Dry processes

The two main conventional short fibre alignment techniques used in the textile industry are carding, in which, generally rotating rollers as shown in Figure 1a, guide the fibres to produce a fibre web and combing, where the rows of pins in the comb as shown in Figure 1b, align the short fibres. These processes result in mats lack homogeneous packing and sufficient alignment [4, 7].

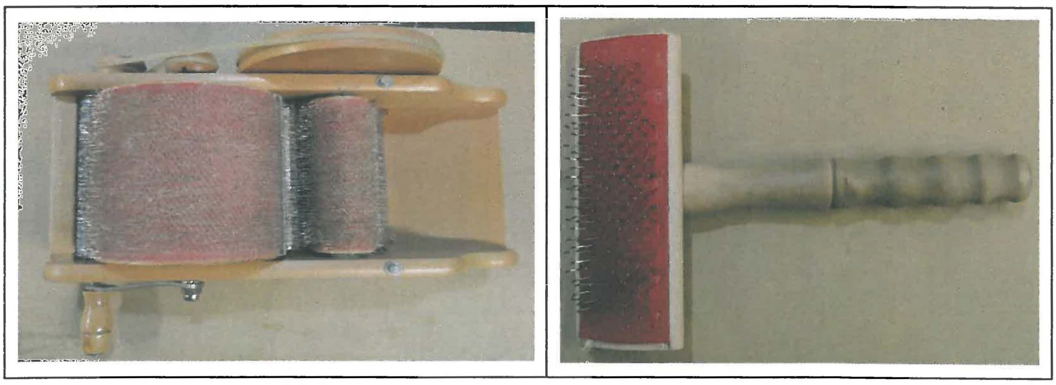

Figure 1: (a) Carding machine (b) comb

Alignment of short fibres by electrical and pneumatic means provides a higher production rate and a higher degree of alignment than carding and combing. Electric fields are used in the aligned discontinuous fibre composite process (ADF) [3]; have short fibres coated with polymer powder are fed into an orienting electric field chamber via a vibratory feeder. The alignment of conductive fibres occurs in the direction of the electric field generated by electrodes. The aligned fibres along with coated polymer powder are then deposited on a moving belt followed by exposure to heat which melts the polymer powder and joins the fibres together to form aligned ADF mats. Composites can be formed by compression moulding of ADF mats. The schematic diagram of ADF is shown in Figure 2. The ADF process depends on the conductivity of fibres and so are generally not relevant to SNPFPCs.

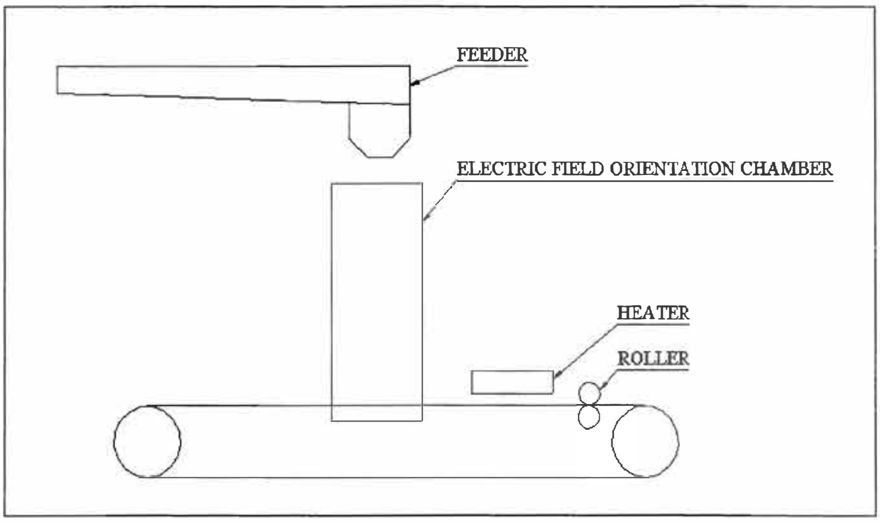

Figure 2: An overview of ADF process

The main pneumatic alignment method used is the glass-mat reinforced thermoplastic (GMT) technique. In this method, two orientation plates are used for the alignment of fibres as shown in Figure 3. Chopped glass fibres are mixed with thermoplastic power which are then sprayed into the orientation plates through tubes. The orientated mixtures are then drawn towards a perforated steel plate, followed by heating of the mixture and applying compression to form GMT preforms [8].

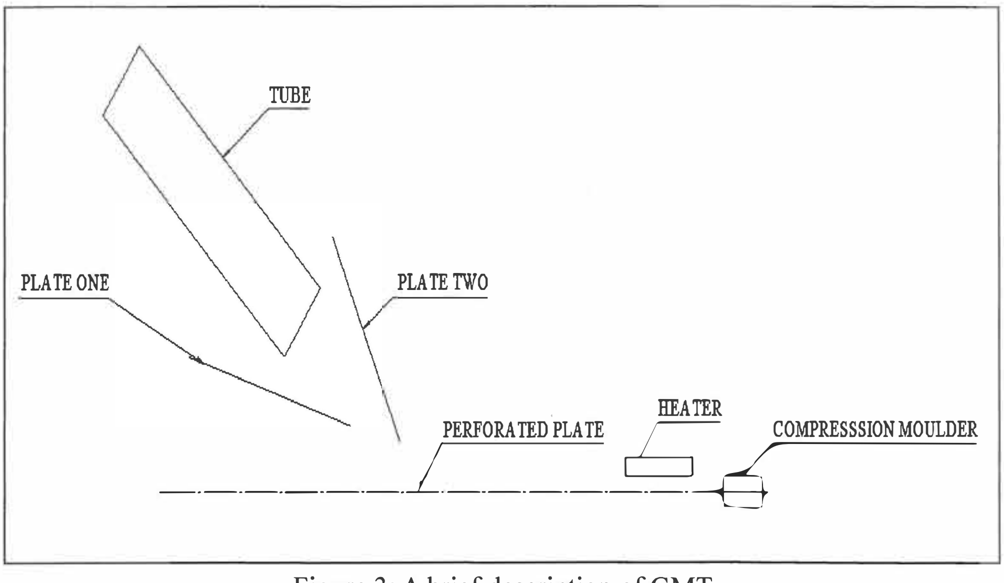

Figure 3: A brief description of GMT

Another pneumatic alignment process reported in the literature involves aligning fibres from a fibrous mass [9]. In this technique, a fibrous mass is laid on a screen and a pulsating compressed gas jet is discharged from the nozzle placed under the fibrous mass. A low pressure compressed gas is also directed towards the fibrous mass through an opening provided in the middle portion of the apparatus. The pressure difference causes fibre separation and fibres to flow upwards. A specially designed conical annular vertical passage as shown in Figure 4, of the apparatus with a width less than the longest fibre in the fibrous mass results in the alignment of fibres. The aligned fibres are collected at the top of passageway on a porous closure.

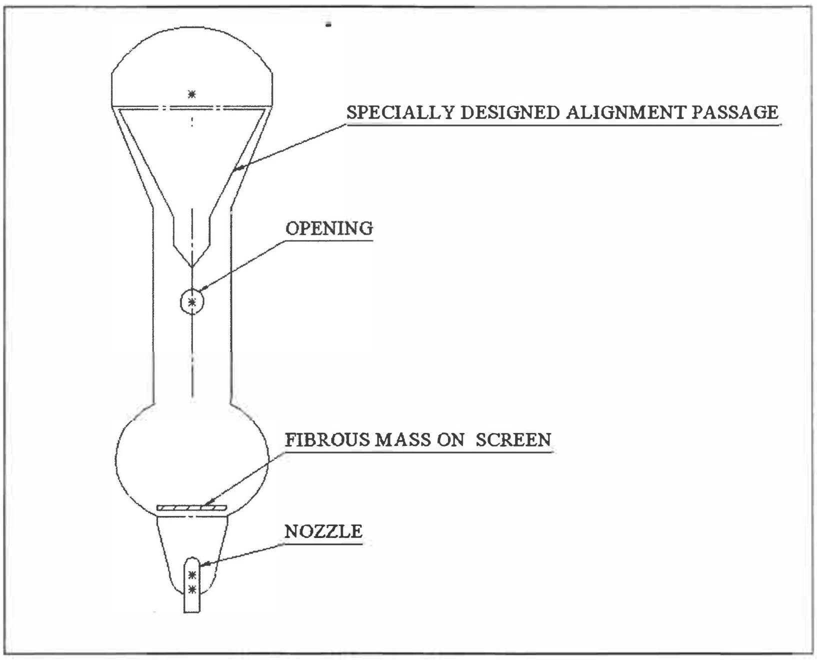

Figure 4: Apparatus for fibre alignment by pneumatic means

2.2 Wet processes

Wet processes generally involve dispersion of short fibres in a liquid medium. There are two main mediums used by researchers: ammonium alginate solution and glycerine [2, 7, 10, 11]. Processing with ammonium alginate solution involves suspension of whiskers or fibres in this medium. The highly resulting viscid mixture is then extruded through an orifice (where the alignment occurs) into a precipitate bath. The gel filaments so formed are wound onto a drum followed by cleaning and drying [4, 10].

Processing with glycerine involves dispersion of short fibres in this viscous medium which is made to flow through a reciprocating tapered nozzle (partial alignment of fibres) as shown in Figure 5, onto a flat gauze bed (wire mesh). The final alignment occurs as a result of fluid friction that occurs between the core layer and boundary layer thereby causing the fibre alignment towards the flow direction. Finally, the carrier fluid removal employing a vacuum was carried out with much care to prevent misalignment during removal [7, 12, 13]. Glycerine is used as a carrier fluid because of its low viscosity compared to alginate solution. The viscosity of the carrier medium affects the productivity by increasing the production time and the cost.

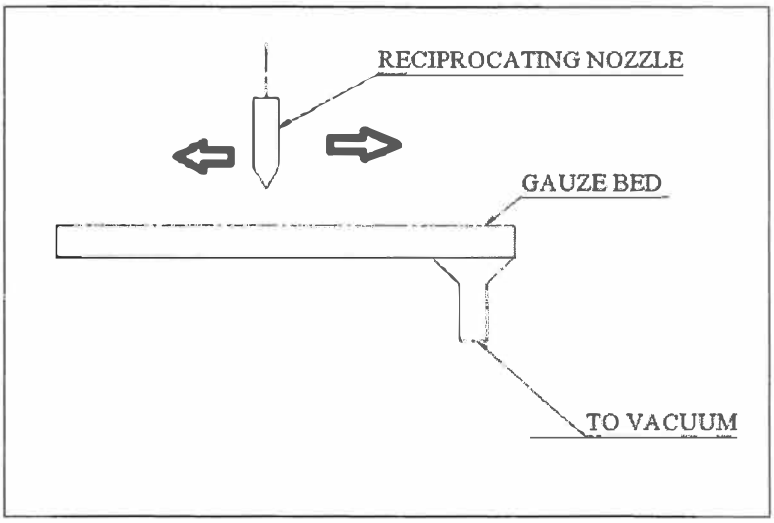

Figure 5: Viscous fluid technique

Centrifugal alignment methods reduce the difficulty of removal of carrier fluids. Generally, in these techniques, aligned fibre mats are produced by discharging the fibre suspension through an aligning nozzle onto the inner permeable surface of a rotating cylinder as schematically shown in Figure 6. This centrifugal rotation causes rapid removal of suspended fluid thereby retaining alignment [1, 11, 14]. Another related technique is the rotating vacuum drum method in which a rotating vacuum drum filter is employed to improve the fibre alignment [14]. The main drawback of the centrifugal technique is that it is a batch production method.

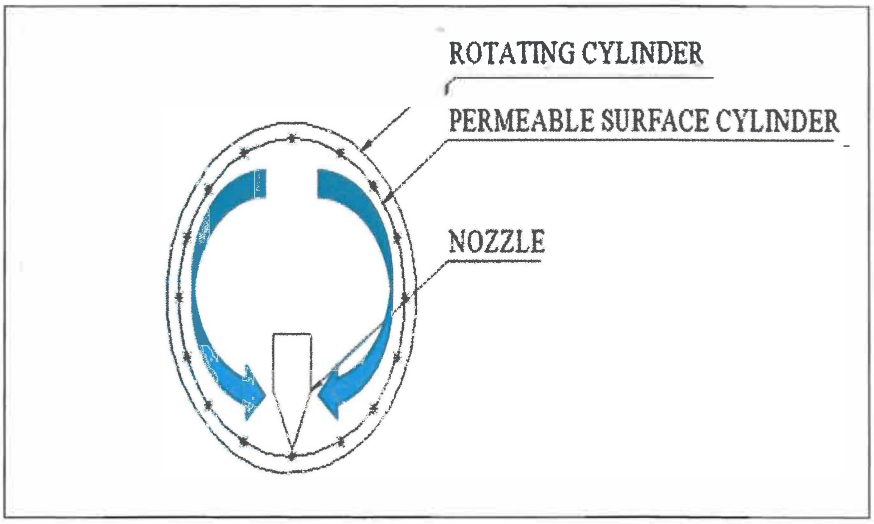

Figure 6: An indication of centrifugal process

A recent wet processing method to align short fibres to increase the production rate reported in the literature is the high performance discontinuous fibre method (HiPerDiF) [2] which produces a tape or tow type prepreg. In this method, the suspending fluid is water (less viscous compared to other conventional fluids). A nozzle, as shown in Figure 7, is used to discharge the fibre suspension to an orientation head. The orientation head has two parallel plates such that one of the plates along with moving belt orients the fibre perpendicular to the suspension jet and the other acts as a guiding plate to prevent overflow of the short fibres. Suction of the carrier fluid through a vacuum maintains the fibre alignment on the perforated moving belt. Finally the dried fibre is resin impregnated by the application of heat and pressure to form prepregs. The production rate can be increased with a multiple nozzle system (MNS). In MNS, the middle plate acts as an orientation plate for the first unit and guiding plate for the second unit.

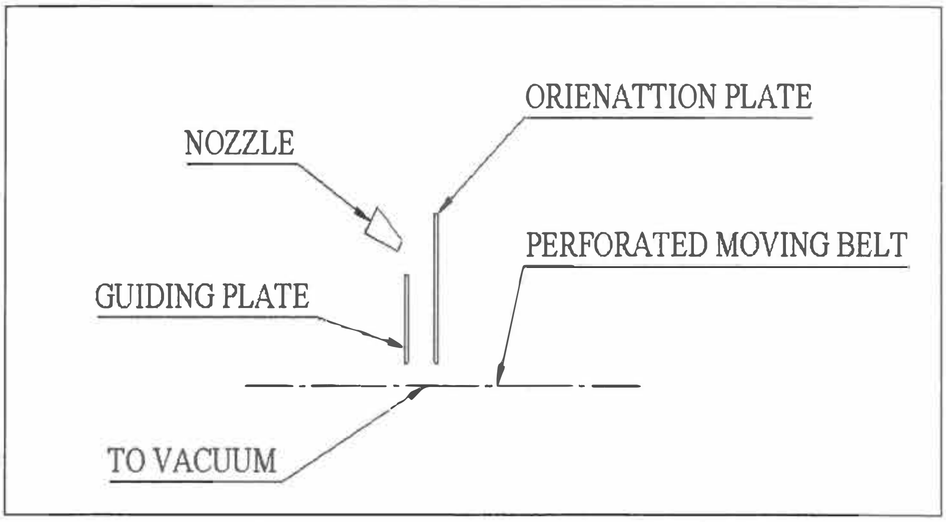

Figure 7: An overview of orientation head (HiPerDiF)

A method similar to the aforementioned centrifugal alignment methods is the dynamic sheet forming (DSF) method which has been successfully employed to align short natural plant fibre. Generally, this method is used in paper production to align fibres. The equipment consists of a rotating drum as indicated in Figure 8, with a wire (screening fabric) on the inside surface. Initially, in this technique, a water wall is built up on the wire (acts as a fibre cushion) with a reciprocating nozzle (up and down) during the entire production [15, 16]. Once the required water wall is obtained, similar to centrifugal methods, the aligned mats are produced by discharging the fibre suspension (water and short fibres) onto a rotating drum through an aligning nozzle. The rotating speed of the drum maintains the fibre alignment. Finally, the water is removed from the wet aligned fibre mat.

Figure 8: Dynamic sheet former

2.3 Other alignment methods

Alignment of short fibres using an ultrasonic device is also reported in the literature [17]. In the ultrasonic alignment (UA) technique, alignment of short fibres in different matrix media occurs in response to the standing waves produced by two piezoelectric transducers placed at either side of the UA device. The standing waves aligns the fibres in its nodal position. The main drawbacks are low fibre volume fraction.

Injection moulding is one of the main processes used to manufacture SFRPCs. Alignment of fibres generally occurs due to interactions between different layers in the mould. The alignment of fibres follows the flow direction in boundary regions of mould due to the friction exerted by the walls of the mould. The friction decreases towards the central region where the alignment of fibres is transverse to the flow direction. There is a chance of occurrence of a shearing flow between the boundary region and central region which may improve the fibre alignment in the central region [18]. Shear controlled orientation in injection moulding (SCORIM) is a modification mainly used for aligning short fibres along the flow direction during injection moulding [19]. In this macroscopic shears are generated with a device fitted between the mould cavity and nozzle of an injection moulding machine. This device consists of pistons which oscillate to produce macroscopic shear to solidifying melt inside the central region of the mould, thereby improving alignment of fibres in this region.

Combination of injection moulding and compression moulding have been used by researchers to produce aligned SNPFPCs. Injection moulding was initially used to produce cylindrical rods of the short fibres with polymer matrices. Finally, those rods were aligned in a leaky mould followed by compression moulding to produce the aligned short fibre composites [20].

Additive manufacturing or 3D printing of polymer composites have the potential to print or fused deposition modelling of aligned SFRPCs [6, 21]. Generally, in this method, extruded filaments of short fibres with polymer matrices are fed into a 3D printer to produce (or print) aligned SFRPCs [22].

Among all aforementioned methods, the highest degree of fibre alignment reported in the literature is +/- 3 ^{0} (measured within the prepregs or composites produced) [2]. The two methods that have exhibited this range of fibre alignment are the HiPerDiF (67% of the fibres with in this range) and rotating vacuum drum (60% of the fibres with in this range). The performance in terms of alignment reported by electric field and pneumatic methods are +/- 20 ^{0} (70% of the fibres with in this range) and +/- 52 ^{0} (majority of the fibres with in this range) respectively [23].

3. Potential Benefits Of Dynamic Sheet Forming Method

Various forms of short natural fibres are available including randomly oriented mats, long yarns, braiding and woven textiles [24], but literature reports that generally randomly oriented mats are used as reinforcement in SNPFPCs as they are cheap compared to other forms [25]. However, work carried out at the University of Waikato has proved that the dynamic sheet forming method is a potential technique to produce aligned short fibre mats [6]. The occurrence of fibre orientation in harakeke mats was assessed by determining the ratio of transverse tensile strength to longitudinal tensile strength indicate a good degree of orientation. The ratio obtained was 0.3; when the ratio closes to zero point to the higher degree of alignment. It was also observed from the optical images and scanning electron micrographs that the fibre mats had improved fibre dispersion. The composites produced with the harakeke and hemp fibre mats reinforced in epoxy resin (only harakeke) and polylactide polymers using compression moulding had exhibited higher tensile strengths and Young's modulus compared to random oriented short fibre mats [15, 16].

Currently, the nozzle used in the DSF is a slit type. For improvement in alignment, the potential of different tapered nozzles with a differently shaped is to be investigated along with analysis of fibre orientation in the fibre mats produced using optical methods such as micro-CT. Techniques for assessing orientation are also to be considered.

4. Conclusions

An overview of short fibre alignment processes with their working principles are described in this paper. The alignment of short fibres by some means are essential to achieve higher mechanical properties. Although pneumatic processes are productive, a higher degree of alignment has been found with wet processes. The possibilities of 3D printers to align short fibre have also to be further explored.

Composites, especially with short natural fibres, have a great future. Dynamic sheet forming (DSF) is a promising method to produce aligned fibre mat with natural fibres. However, more research needs to be carried out to optimise the production of DSF in order to improve the alignment of fibres in the fibre mat.

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