In-plane bending of carbon fiber yarns

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Introduction

A unique manufacturing process of carbon fibre preforms has been developed at the University of Ottawa for improving the manufacturing efficiency of aerospace carbon fibre components. This process involves creating two dimensional preforms that can be draped onto relatively complex three dimensional moulds. In-plane bending of carbon fibre yarns is critical to this manufacturing process to avoid in-plane shearing of the carbon fiber yarns when draped (figure 2). Such bending is currently limited to large radii due to the difference in turning radius of the inner and outer fibres of the yarn. To compensate for this difference, the fibres accumulate towards the outer radius, creating a void on the inside of the bend (figure 3). This is a practical limitation to the manufacturing process' potential. The purpose of this project is to determine the effects of various methods of manipulating the carbon fibre yarns to improve their bending behavior. The results will contribute to understanding and potentially lessening the geometric limitations of the University of Ottawa's preform manufacturing process.

Figure 1 – Textile preform and final product

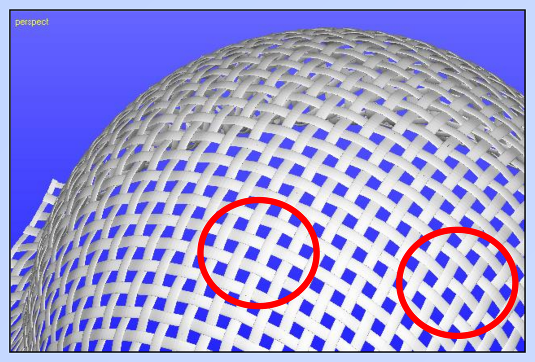

Figure 2 - In-plane shear/deformation

Figure 3 – Curved yarn behavior

Methods

There are two main approaches for improving the in-plane bending behavior of carbon fiber yarns. The first is to manipulate the yarn before the process of laying it down. The second is to manipulate it afterwards (i.e. when the yarn is curved).

Three methods of manipulating the yarn before laying it down were developed.

① The first method is to apply mechanical pressure to the yarn by using rollers with various geometries. The device that will be used to test this method has been designed and is in the process of being made (figure 4).

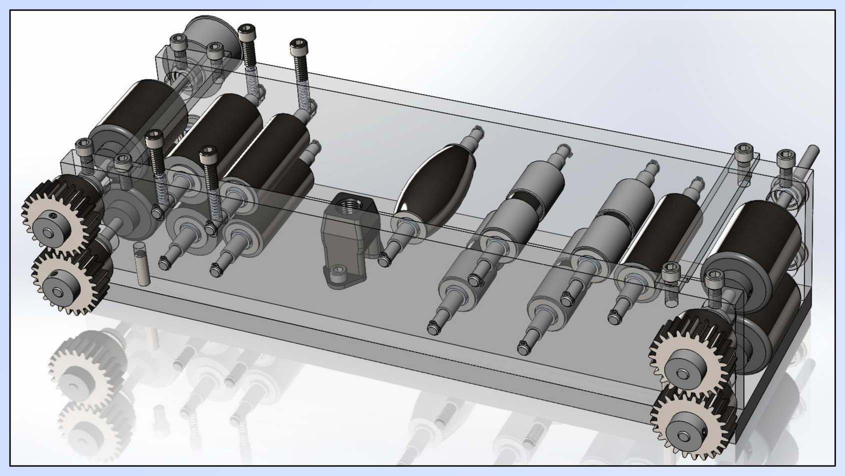

Figure 4 - Design of yarn manipulation device

② The second method consists of feeding the yarn through two identical tapered rollers (figure 5). In theory, if there is no slippage between the rollers and the fibers, the yarn will be forced to bend with a radius determined by the geometry of the rollers. Two 3D printed tapered rollers wrapped in a thin layer of polyethylene (to avoid slippage) were used to test this concept. Each roller was supported by two bearings on a plastic axle (figure 5).

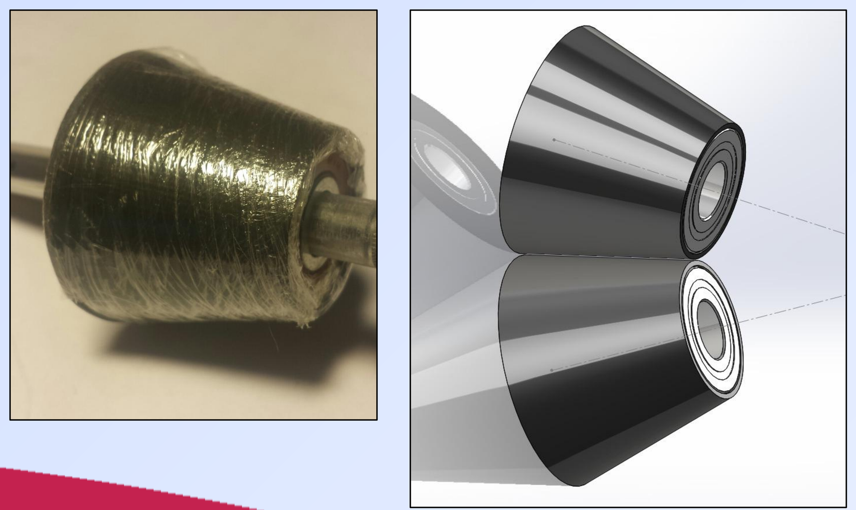

Figure 5 – Plastic tapered roller (left) and the design (right)

Methods (Continued)

③ The third method of manipulating the carbon fiber yarn is to force pressurized air through the fibers. This is done by sliding the yarn over the air current of a specially designed nozzle (figure 6). Several variations of the nozzle were made using a 3D printer to test different spreading widths, air flow-rates and air pressures.

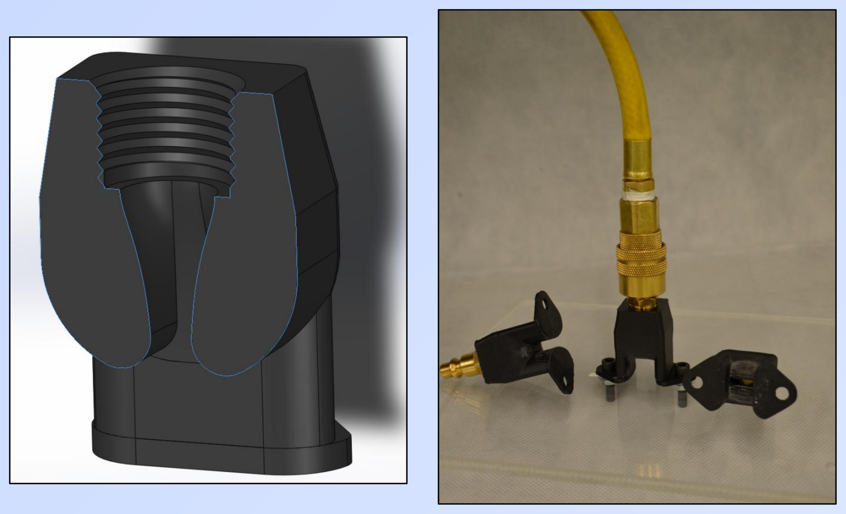

Figure 6 - Air nozzles (right) and cross section of air nozzle (left)

Manipulating the carbon fiber yarn after the process of laying it down involves certain restrictions since it cannot be displaced relative to the preform.

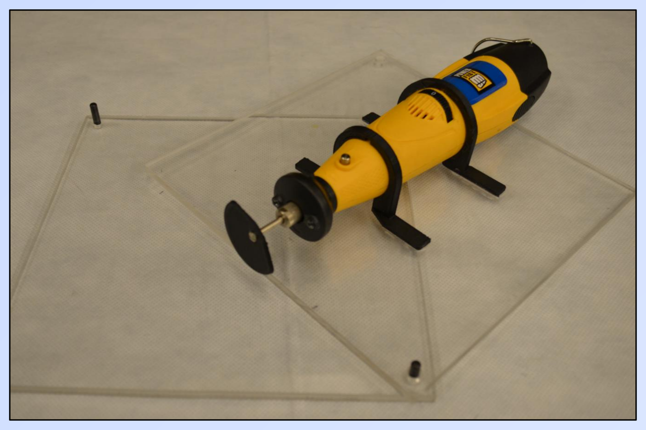

Figure 7 - Vibration device

④ The method that is tested consists of pressurizing the curved yarn between two flat surfaces and inducing vibrations on one of the surfaces. Testing was done with a bending radius of 100 mm and a vibration frequency of approximately 200 Hz. The pressure and vibration amplitude were arbitrary values. Though vibration-assisted compaction has been proven to be successful under certain conditions[1], no documentation was found of its application to curved fibers.

Results

① Applying pressure to the yarn with rollers is expected to spread it along its width and to discourage clumping of the fibers due to the fiber sizing. There is a risk that this form of manipulation could damage/break some fibers. In future work, the mechanical properties of the manipulated yarn will be compared to that of the un-manipulated yarn.

② Figure 8 illustrates a yarn that has been curved with tapered rollers up to the point where it bends back to its original direction. There are several problems with the application of this process. Firstly, as the yarn is curved, its unbending accumulates and impedes the ability to curve it any further. Therefore, this process is only applicable for large radius curves with short arc lengths. Secondly, the taper angle of the rollers would have to be continuously adjustable to create a curve with a varying radius. Lastly, changing the direction of the curve can only be achieved by inversing the tapered rollers. Integrating the necessary mechanisms to the University of Ottawa's preform manufacturing process would add significant complexity and cost with very limited functionality; therefore it was deemed an inadequate solution.

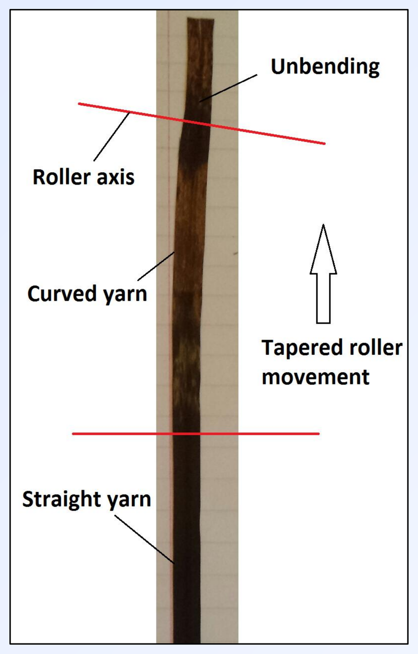

Figure 8 – Effects of tapered rollers

③ Figure 9 and 10 illustrate the effect of compressed air on carbon fiber yarn. This method increases its malleability by separating the individual fibers from each other and improves the yarn's bending behavior. Due to the nature of the fibers and the fiber sizing that holds them together, they have a tendency to clump together to reduce the resistance on the air flow. However, this behavior occurs less when pressurized air flow is combined with mechanical pressure (i.e. rollers) to create equal spreading. The device shown in figure 4 will be used to test different combinations of rollers and air nozzles to produce the desired effect on the yarn.

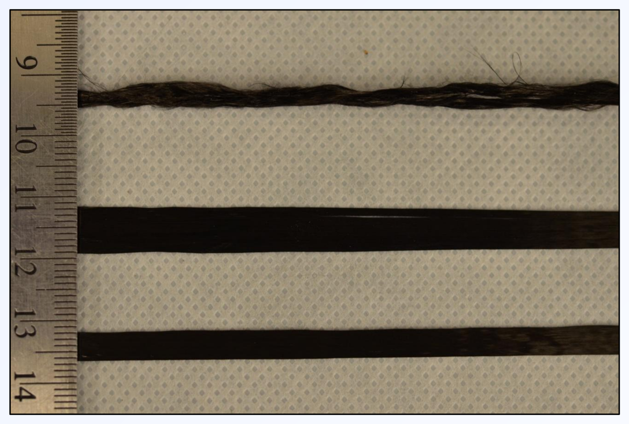

Figure 9 – Narrowed yarn (top), spread yarn (middle) and un-manipulated yarn (bottom)

Results (Continued)

Although increasing the width of the yarn with compressed air produced positive results, returning the yarn to its original width with a narrow nozzle produced very poor results. One possible explanation for this is the thinning process's inability to recreate a layer of fibers that are stuck together by the fiber sizing. The yarn must be manipulated with rollers to return it to its previous state.

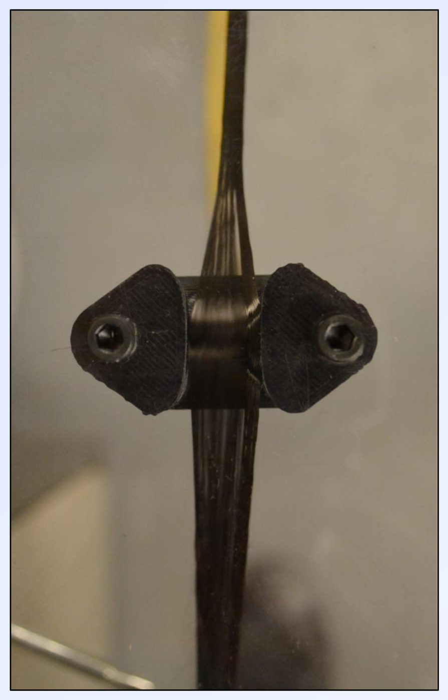

Figure 10 - Spreading the carbon fiber yarn

④ Figure 11 and 12 illustrate the effects of vibrations-assisted compaction on a curved carbon fiber yarn. The forces from the vibrations overcome the friction forces between the fibers, making them reposition to increase the fiber density across the width of the yarn. This is a desired effect since a higher fiber density results in improved mechanical properties of the final part. Obtaining consistently reproducible results would require specialized equipment to accurately control the pressure, vibration frequency and vibration amplitude. Also, vibration-assisted compaction could be tested on multiple layers of yarns and different preform structures to quantify the inter and intra layer behavior of the fibers (e.g. nesting between layers).

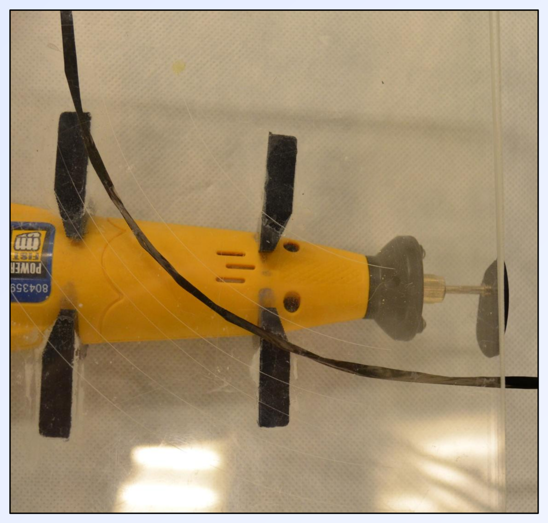

Figure 11 - Before vibrations

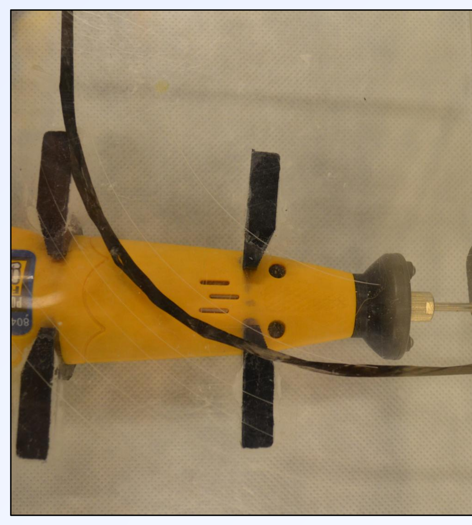

Figure 12 - After vibrations

Conclusion

• Tapered rollers were used to successfully curve a carbon fiber yarn. This method of yarn manipulation is limited to a very short arc length and a large turning radius, therefore it is not a viable solution for the University of Ottawa's manufacturing process.

• Spreading the yarn by directing a pressurized air flow though it decreased the friction between individual fibers. This resulted in improved in-plane bending behavior. However, returning the yarn to its previous state requires the use of rollers combined with pressurized air.

• Under certain conditions, high frequency vibration-assisted compaction increases the fiber density across the width of a curved carbon fiber yarn.

Future work

• Assessing the effects of various rollers on the in-plane bending behavior of carbon fiber yarns and quantifying the changes in their mechanical properties.

• Testing various combinations of rollers and air nozzles. Understanding the mechanical properties of carbon fibers that have been manipulated with air.

• Further investigating the effects of varying the parameters of vibration-assisted compaction for curved yarns. Testing this method with multiple layers of yarn and various preform structures.

Acknowledgements

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