COMPARATIVE EVALUATION OF BRAIDING AND 3D COMPLEX WINDING FOR AUTOMOTIVE CHASSIS FRAMES

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Key words: Carbon fibre, Composites, 3D winding, Braiding, Bending

Abstract
This paper compares and contrasts two potential preforming technologies for automotive chassis frame structures. Composite beams have been produced using the patented Axontex™ beam technology (braided material around low density square foam cores) and the novel 3D winding technology at Cygnet. 3D complex winding machine (shortened to 3D winding) produces quasi-interlaced architectures with significantly lower crimp in comparison to conventional braiding. Representative commercial carbon fibres were placed at the angle of around 27° on the beam in both the winding and braiding process. The beams were manufactured by RTM under identical conditions. This paper presents results from three point bending tests.

1. Introduction

The 3D Winder (Figure 1) is a robotic 3D winding machine capable of making complex composite parts with three dimensional non-linear axes and varying cross-sections. The technology was originated from the concept of 9-axis filament winding machine developed by the robotics and textile composites group in the University of Manchester [1-2]. It then has been developed as part of a Knowledge Transfer Partnership project by Cygnet Texkimp in cooperation with the University of Manchester. It then won the "Composites UK" Industry Award; Innovation in Manufacturing in 2017.

Figure 1. 3D winding machine

By mounting the winding mechanism onto a rotating ring (Figure 2) rather than feeding fibres onto a rotary mandrel, the 3D winder can quickly and precisely lay down multiple carbon fibre tows with the same or varying tow sizes. The ring is then mounted at the end of a robot head, which enables the ring to follow a defined path under robotic control. In this set up, the winding ring is free to follow any complex curves or cross sections of the mandrel. The strength of the mandrel only needs to withstand the tension difference between tows, as the winding tension is uniformly distributed around the mandrel. In this way, the strength requirements and cost of the mandrel material can also be greatly reduced.

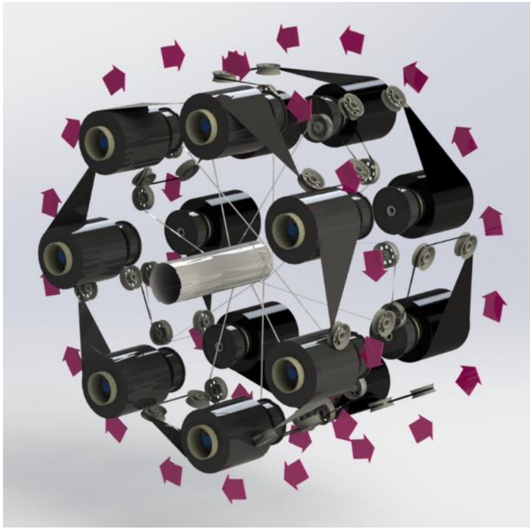


Figure 2. Ring winding mechanism

The technology has clear added value for the high-volume mainstream automotive and aerospace industries to manufacture components such as fuel pipes, cant rails, impact beams and wing spars. The 3D winding machine is designed to deposits fibres in more than one direction and at predefined angles with a high deposition rate. Through accurate control over the amount of fibre that goes into each component and the winding angle, the composites part can be created with high strength at high speed with minimal waste.

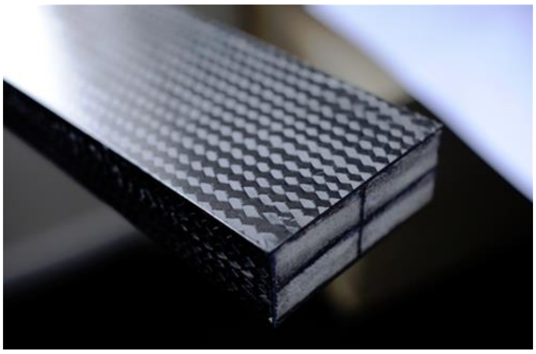


Figure 3. Axontex™ beam structure [3]

An Axontex™ beam, as shown in Figure 3, is developed by Axon Automotive, which has many years' experience in high performance composites for lightweight solutions and the breadth of experience to provide components. Axontex™ beam technology is currently being used to produce up to 200,000 vehicle structures each year including cant rails and chassis (Figure 4). The process involves applying braided carbon fibre sleeves around a foam mandrel to create components that are highly resistant to impact. In pursuit of a long-term solution to increase throughput and reduce costs while maintaining production quality, and therefore make its parts accessible to the wider market, an opportunity has been identified to potentially substitute the products manufactured by conventional braiding to by the 3D winding technology. Thus, a series of studies including but not limited to the comparison of the composite beam manufacturing process, various mechanical properties and FEA modelling are necessary. This paper focuses on the flexural properties of the beams manufactured by the two type of technologies.

Figure 4. Axon 60 2010 made of Axontex^{TM} beam [4]

2. Manufacturing Process

2.1. Beam Materials

In order to keep the wound beam and the braided beam as similar as possible, the following parameters were controlled. Toray T700 12k carbon fibre was wound and braided around the same low density square foam core with a square cross section at the size of 30 mm* 30 mm. Both the winding and braiding angle are closed to ± 30 º. Only one layer of winding and one layer of braiding were applied. Same foam low density cores with 30 mm* 30 mm square cross section were used in both the braided and wound beams.

2.2. 3D Winding

The 3D winding machine used in this study is a research and development prototype machine located in Cygnet Texkimp. It has double rings with a 650 mm diameter and 8 fibre package holders on each ring. Both of the rings can rotate clockwise or anti clockwise as needed. This means that the machine can wind maximum 16 tows at the same time. However, a ring adaptor, as shown in Figure 5, has to be used to accurately control the winding angle due to the small size of the foam core. In the case of winding around a lightweight core, only one ring is rotated functioning as a winding ring while the other side of the ring acts as a beam support to prevent the beam from twisting and bending during the winding process. In this study, a total of 8 carbon fibre packages were used at the same time to wind the beam. The foam core was also held under tension along the longest axis to stop bending caused by gravity. In order to reduce the edge crushing effect to the foam core, the winding tension was reduced to around 100 grams. The winding angle was determined through calculations based on the available braiding angle and then achieved by matching the robot speed and the ring speed. The actual winding angle achieved in this trial is near ± 33º.

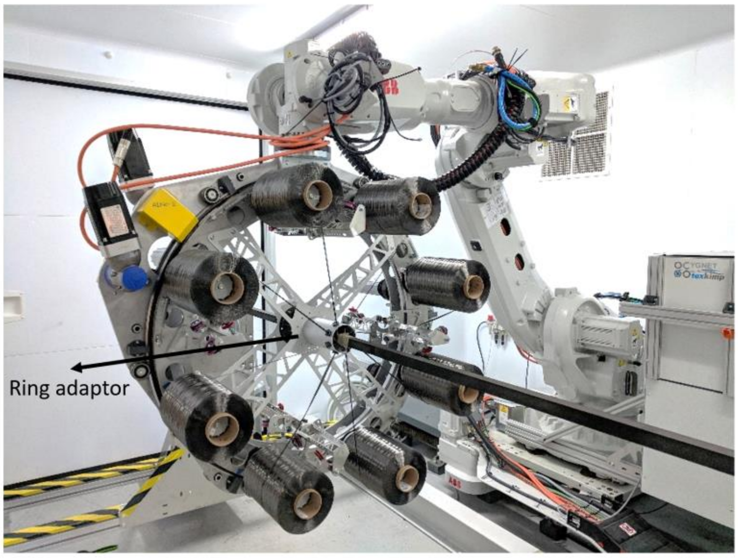


Figure 5. Winding process of Axontex^{TM} beam using 3D complex winding machine in Cygnet Texkimp

2.3. Braiding and Beam Manufacturing Process

The braiding process of Axontex™ is shown from step 1 to step 4 in Figure 6. High grade carbon fibre was first braided into sleeves, then the low density closed cell foam was pulled through the sleeves to form the braided preform. Thus, the final fibre alignment in the braided beams was defined also by the shape of the foam. The braiding angle used in this study is around ± 28 º. Both the wound beam and the braided beam were manufactured in Axon using the same vacuum resin transfer moulding (V-RTM) process [3], as shown in the step 5 to step 7 in Figure 6. And described in paper "Opportunities for the use on composite materials in rail applications – a case study", previously presented at the international Conference on Composite Materials, Xi'an 2107 [5]

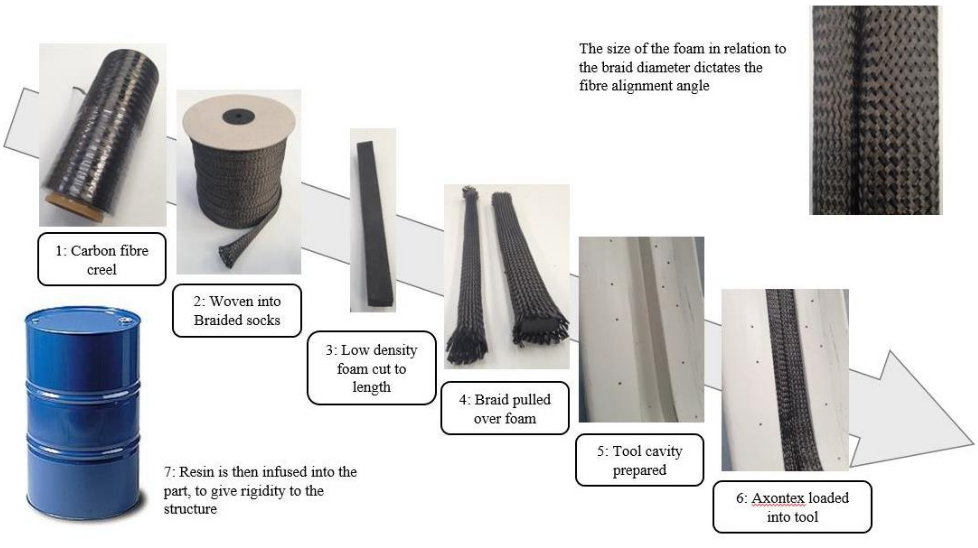


Figure 6. Braiding and beam manufacturing process of Axontex™ beam [5].

3. Results and Discussion

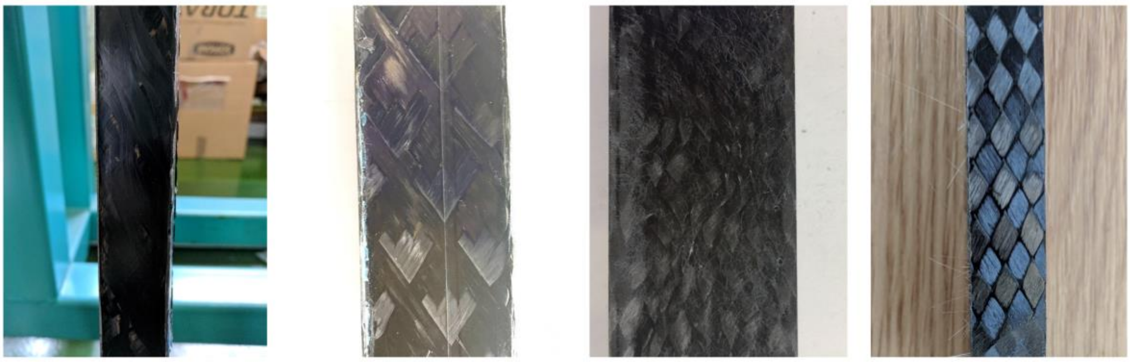
3.1 Comparison of Manufacturing Process

The wound and braided preforms are shown in Figure 7. The fibre in the braided beam is securely interlocked through interlacing during braiding, while in the wound beam the fibre is aligned and located only by the winding tension. In terms of yarn damage, winding applies yarns to the target core directly from the original fibre package, while braiding involves a series of fibre re-spooling and a complex guiding system with many more guiding elements before fibre is placed on the core, which can cause more serious yarn damage [6] than the 3D winding process. Another key difference is that winding eliminates crimping in the braided material which can cause weakness in the finished product. While on the other hand, the interlacing present in braiding can improve the through thickness properties of the composite parts.

a. Braided beam, b. Winding beam

Figure 7. Braided Axontex™ beam and wound beam

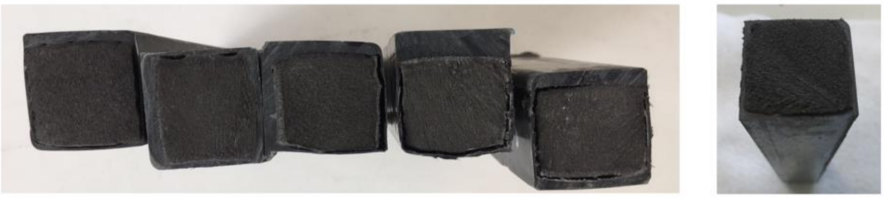
Comparing the current winding and braiding speed, the 3D winder at, 0.3 m/min, is significantly lower than that of braiding speed, 2.5 m/min. However, there is clear scope for increasing the speed of the 3D winding technology. A few limiting factors in the current machine are as follows: The ring speed is limited on this development machine and the mandrel support limits the number of fibre packages that may be used. However, when running at the same line speed, the running time of the 3D winder is significantly longer than that of the braiding as a full carbon package rather than respooled one is used during the winding process.



a. Fibre distortion in winding beam b. Winding beam c. Fibre distortion Braided beam d. Braided beam

Figure 8. Defects in wound beam and braided beams

Different type of defects were shown after the V-RTM process. Fibre flushing and distorsion (Figure 8.a and c) was found in both wound beams and braided beams, but more seriously in the wound beams, while the uneven thickness (Figure 9.a) around the foam core mainly exists in the wound beams. The fibre flushing is caused by the strong resin flow during the V-RTM process. The reason for uneven thickness and more obvious in the wound beams are summarised as follows. 1. The fibre was directly placed on the foam core in the wound beams, while the braided sleeves were pulled over the foam leaving no tension on the core. Thus, the braided beams were easy to accommodate in the mould comparing to the wound beams. 2. Glass veils which can help improve the resin flow were missing during the wound beam manufacturing process. 3. The braided fibre interlace structure may interlock the fibre together more securely while in winding this is realised only through the light winding tension. During braiding, glue was also applied to hold the fibre together which is not applied in the wound beams leading to a more serious fibre flush. A V-RTM process optimised for the braided Axontex™ beam was used to process the wound beams without change.



a. Thickness variation in winding beams b. Braided beams

Figure 9. Thickness variation in wound beams and braided beam

3.2 Comparison of Flexural Properties

The 3 point bending tests was performed on an Instron 5969 with 10 kN load cell. Three repeats of each beam in each test were carried out. The 3 point bending test, as shown in Figure 10, has a span of 600 mm and a total length of 800 mm referencing ASTM D790 [7].

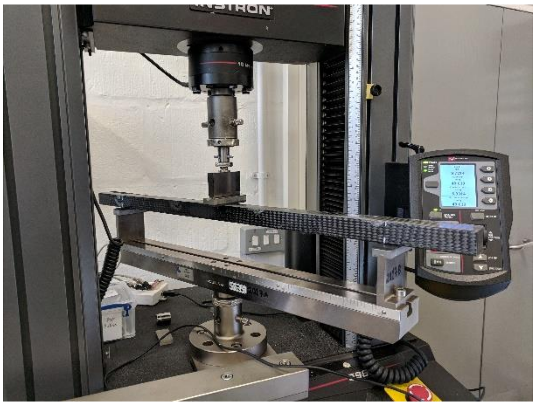


Figure 10. Three point bending test setup

The three bending results are shown in Figure 11. Both of the flexural strength (FS) and the flexural modulus (FM) of the braided beams (FS_{braid} = 38.3 ± 3.7 MPa, FM_{braid} = 10.2 ± 0.5 GPa) are significantly higher than that of the wound beams ($FS_{winding}$ = 25.2 ± 2.8 MPa, $FM_{winding}$ = 4.0 ± 0.8 GPa). It is worth noticing that the wall thickness of the wound beam (Wall thickness winding = 0.7 ± 0.1 mm) is near half of that of the braided beam (Wall thickness braiding = 1.3 ± 0.2 mm). Based on the flexural strength calculation (Eq.1) provided in the ASTM D790 [7],

$$\sigma_f = 3PL/2bd^2 \qquad (1)$$

where σ is the flexural strength, P is the load, L is the support span, b is the width of the beam tested and d is the depth of the beam. The data given in Figure 11 is treating the beam as a whole structure, thus the flexural strength calculation is based on the thickness of 30mm, rather than the real wall thickness. Taking the wall thickness into consideration, it is possible that the flexural strength of the wound beam could be equivalent to, or even higher than that of the braided beam. However, due to the existence of the side wall and various changing factors introduced during the composite manufacturing process, further work will need to be done to verify this point.

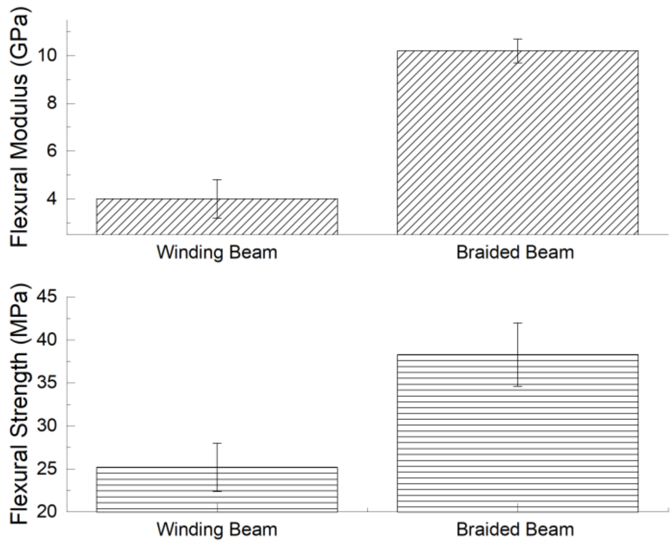
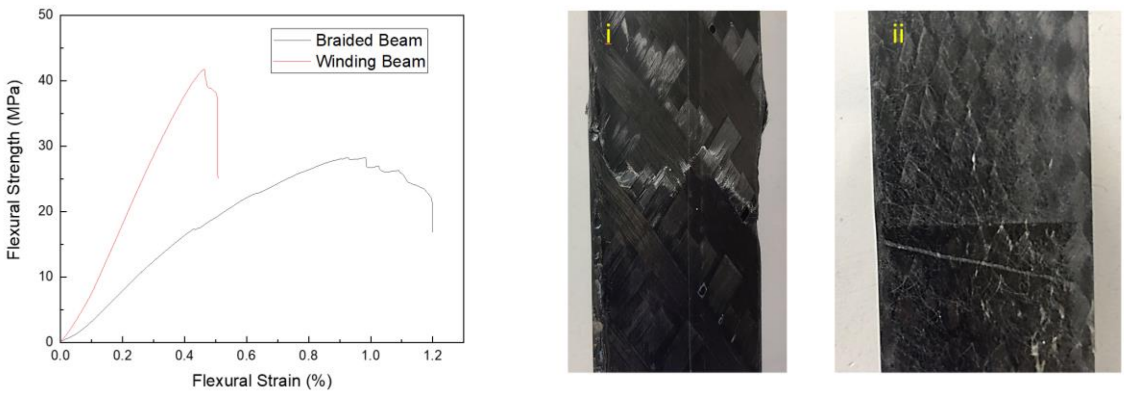


Figure 11. Flexural strength and flexural modulus of wound and braided beams

During the three point bending test, different failure behaviours were also observed for the two types of beams. When looking at the flexural strength and flexural strain curve, as shown in Figure 12.a, the wound beam shows progressive crack development, while the braided beam failed immediately after reaching its peak value. This can also be reflected through the crack development shown in Figure 12.b. The wound beam failed across the loading point and the crack travelled from one end to another. In comparison, there was barely observable small cracks developed around the loading point in the braided beam, which leads to less energy absorption compared to the wound beam.



a. Flexural strength– flexural strain curve b. Crack development (i--winding beam, ii—braided beam)

Figure 12. Typical flexural strength vs flexural strain curves of wound and braided beams and their crack development

4. Conclusions and Future Work

The 3D winding process was applied to manufacture low density foam core filled composite beams to create a like-for-like study of Axontex^{TM} beams. Due to the different fibre structure of wound beams, new challenges were also raised during the V-RTM process such as mould accommodation, resin impregnation and fibre flushing. Three point bending tests were carried out to test the flexural properties of both beams. The flexural strength and flexural modulus of the wound beams are significantly lower than that of the braided beams. However, more research is needed to verify this result as various changing factors were involved in the manufacturing process.

Acknowledgements

The project was supported by Innovate UK's Knowledge Transfer Partnership funding. Thanks also goes to the technical support from Cygnet Texkimp and Axon Automotive.

References

[1] S.S. Roy. P. Potluri. C.Soutis. A study of quadriaxial and triaxial composite tubes developed by braid-winding. The 19th International Conference on Composite Materials. 2017.
[2] S.S. Roy. P. Potluri. Tensile response of hoop reinforced multiaxially braided thin wall composite tubes. Applied Composite Materials. 24:397-416. 2017.
[3] Picture from http://www.axonautomotive.com/axontex/hollow-structures
[4] Scott Bader, Far-UK. Press release: Far-UK Wins Composites UK Engineering 2015 Innovation in Design Award. 2015.
[5] Keating E.M., Raath N, Winnett J, Hughes D. Opportunities for the Use of Composite Materials in Rail Applications – A Case Study. In 21st International Conference on Composite Materials. 2017.
[6] C. Ebel, A. Mierzwa, K. Kind. Yarn damage during braiding of reinforcement fibers for composites. Advances in Braiding Technology. P319-354. 2016.
[7] ASTM D790-10 Standard Test Methods For Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. ASTM U.S. 2010