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## STATIC AND DYNAMIC CRUSHING OF SANDWICH TUBES WITH A BIRCH CORE AND CARBON SKINS

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**Abstract:** This paper presents the results of static and dynamic crushing of wood sandwich tubes made with a birch core and carbon woven skins. 3 tubes (external diameter 64 mm, length 120 mm) were crushed in static and 3 others in dynamic under a drop tower. The results reveal very interesting energy absorption performance of such structures. The Specific Energy Absorption is 50.4 J/g in static and 66.6 J/g in dynamic, the energy absorbed is 5427 J in static and 7045 J in dynamic (170 kg launched at 4.2 m). These characteristics, which are quite comparable with those of tubes made of composite materials or aluminum alloys, show that these sandwiches with birch core are serious candidates for energy absorption with renewable materials.

**Keywords:** Wood; birch; sandwich tubes; crushing; energy absorption.

### 1. Introduction

Wood is a serious candidate for a sustainable transportation industry because of its light weight, its low embodied energy, its availability and its ability to store carbon. It was used extensively in the aeronautical industry during the Second World War with, in particular, the De Havilland Mosquito, one of the most famous planes of this war. Its fuselage and its wings were designed with a sandwich structure made with birch or Douglas fir skin and a Balsa core. It could reach 612 km/h and was manufactured in 7,781 units [1]. There is now renewed interest in these materials. Therefore, the authors have analysed statically many sandwich configurations whether with metallic or composite skins and a plywood core [2]. The behaviour of sandwiches with plywood core under low speed, low energy impact has also been the subject of recent studies [3]. It has been shown that wood-based sandwich structures also have very good residual compressive strength after impact [4], which prompted the authors to look more closely into the crash behaviour of these structures. Note that, despite the success of the WoodC.A.R program [5], the static and dynamic fracture modelling of wood structures remains an issue [6], therefore the studies on static and dynamic behavior of wood are mainly experimental.

The crushing response of wood was first studied by the authors on poplar tubes with different stackings [7]. The best configuration with horizontal layers on the inner and outer surfaces (belt effect) generates a SEA up to 30 J/g for a material 40 times less expensive than CFRP, and renewable. In addition, the authors also worked on sandwich tubes with a poplar core and skins either in carbon fabrics or in glass fabrics. Compression tests were performed statically [8] and dynamically [9] on a drop-weight crash test machine. It is remarkable that, in these two types of tests, the fact of passing from 2 to 6 internal poplar plies allowed the absorbed energy to be

doubled for a practically constant SEA. These results show the significant contribution of poplar in terms of energy absorption.

In this communication, the crushing tests of sandwich tubes with a core made with birch veneers and carbon skins will be presented.

## 2. Materials and Methods

The tubes were manufactured with carbon (M79 / 42% / 200 T2 / CHR-3 K, Hexcel) with an area weight of 345 g/m<sup>2</sup>. The orientation of the fabrics, balanced 2–2 twill, was always [0/90] to achieve a hoop effect due to the 90° fibers. The core was stacked with 12 plies of 0.5 mm thick birch veneers supplied by Garnica. Veneers density is 0,504 g/cm<sup>3</sup>, and veneers are bonded together between 8.8% and 9.8% HR. The tubes have an external diameter of 64 mm for a length of 120 mm. The manufacturing method will not be recalled here and readers can refer to previous papers of the authors [7, 8, 9]. After curing, a trigger is machined on the tubes. A picture of a typical tube is showed on Figure 1 (a). The static tests were carried out at a speed of 5 mm/min on an MTS system tension machine equipped with a 100 kN load cell and a displacement sensor. The tubes were crushed over  $\frac{3}{4}$  of their length, i.e. 90 mm, which was long enough for a stable crushing mechanism to be observed when it existed.

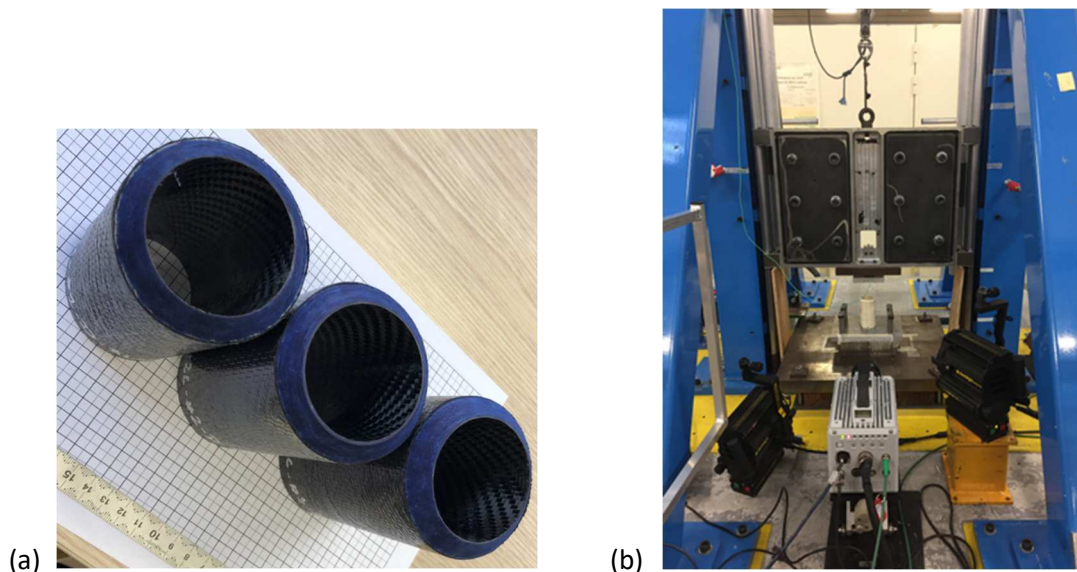


Figure 1. (a) Typical wood based carbon tubes (the trigger are paint in blue for post-mortem analysis), (b) Overview of the dynamic testing test rig with the high speed camera

The dynamic tests were carried out using a drop weight tower (Figure 1 (b)). These tests were interrupted after 80 mm of crushing for post-mortem observations on the samples. They were also filmed using a high-speed camera during the entire crash. A force sensor located between the mass and the upper crushing plate made it possible to obtain the crushing force with an acquisition frequency of 1 MHz. The displacement was calculated by double integration of the force from knowledge of the initial speed given by an optical sensor. No filtering was performed for data extraction. The high speed camera and the force signal were synchronized in order to

be able to link the images of the crushing front with the force-displacement curve. A redundant calculation of displacement was also carried out using the camera images for a few samples to verify the accuracy of the double integration method. More information on the tests and their analysis can also be found in [7, 8, 9]. Three tubes were crushed in static and three others in dynamics under a drop tower.

### 3. Static results

The force/displacement curves obtained experimentally for a static crushing length of 90 mm are shown Figure 2. The classical steps for crushing (initiation, transition and plateau) are found and the plateau is generally stable. The peak force ( $\approx 96,000$  N) is relatively close to the plateau force ( $\approx 65,000$  N) allowing a fairly good CFE (Crush Force Efficiency i.e ratio between the average effort and the maximum effort  $F_{\text{plateau}}/F_{\text{max}}$ ) of around 0.68 to be obtained. The plateau of tube #2 being slightly lower than the other two, the  $SEA_{\text{plateau}}$  (Specific Energy Absorption calculated in the plateau area, see [7, 8, 9]) of this tube is the lowest obtained (45.6 J/g). The  $SEA_{\text{plateau}}$  of the other two tubes is around 50 to 52 J/g. The total energy absorbed is in average 5427 J

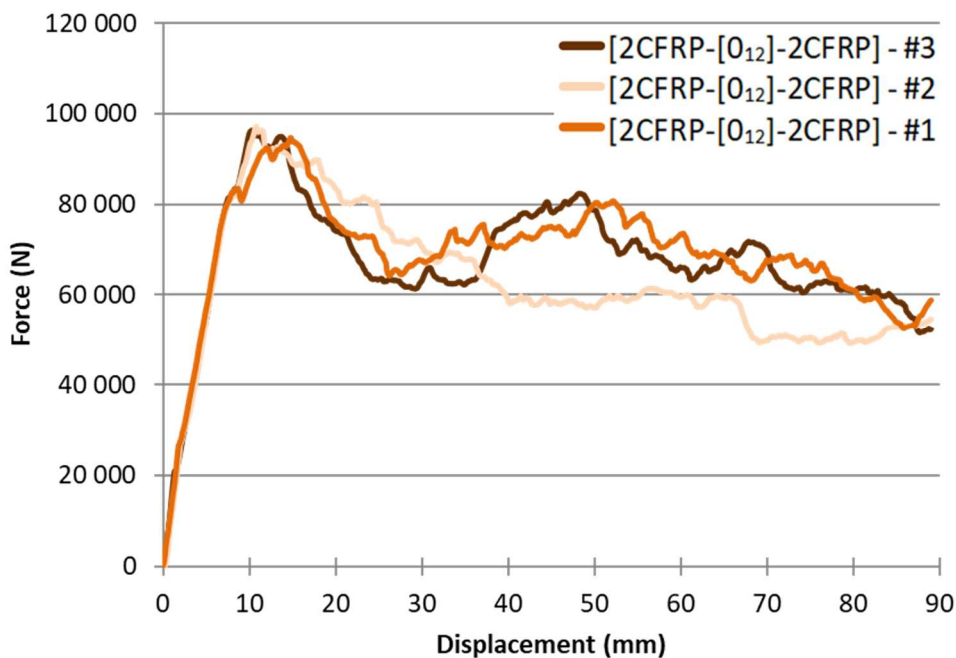


Figure 2. Force displacement curves for the 3 tubes under static crushing (the tubes are named from their stacking and their number).

The failure of these sandwich tubes is similar to that obtained with an I214 poplar core [8]. The initiation begins with the flattening of the chamfer that causes the fibers to break at 90°, dissociates the tube into a bundle allowing them to splay via bending (Figure 3). The main failure mode of this configuration seems to be splaying with the formation of petals.

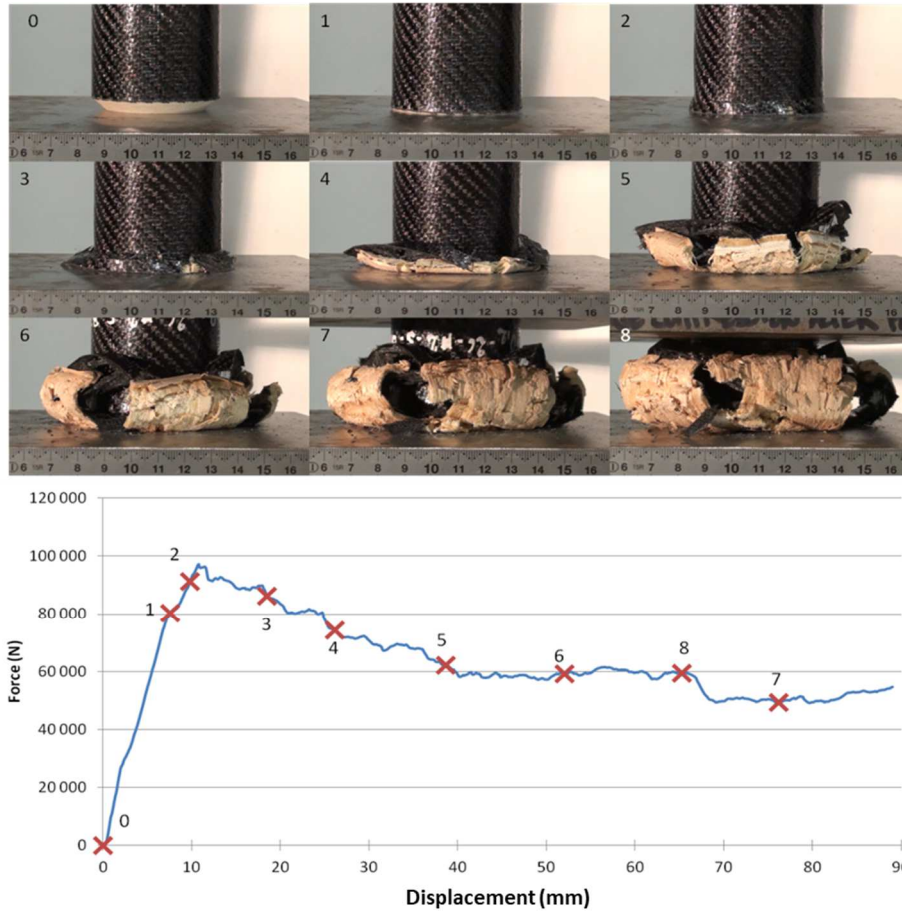


Figure 3. Static failure of specimen [2CFRP-[0<sub>12</sub>]-2CFRP] - #2, association image and point on the force-displacement curve.

#### 4. Dynamic results

The force/displacement curves obtained experimentally for a dynamic crushing length of 90 mm are shown Figure 4. A mass of 170 kg was launched at 4.2 m. The classical steps (initiation, transition and plateau) are found again but also much greater oscillations are observed on the plateau. This can be explained by the vibration of the experimental support due to the high energy absorbed. The averaged peak force is significantly higher than in static ( $\approx 121,590$  N) and the plateau force reach  $\approx 92300$  N for a CFE of around 0.76. The plateau seems to be constant firstly and then increases at the end of the crushing (around 60 – 70 mm). A SEA of the order of 66.6 to 69.5 kJ/kg is reached. The total energy absorbed is in average 7025 J. In the same way as observed under static loadings, the failure begins with the crushing of the chamfer, leading to the failure of the carbon fibers at 90°, allowing the tube to dissociate into bundles. The latter then bend and then splay, then creating petals.

Post-mortem observation by cutting the specimens in half tubes shows the presence of unbroken petals over the entire periphery of the tube (Figure 5). An interior containment of debris generated by the fairly large interior splaying is also present. The blue color present at the failure front where the walls divide is due to the coloring of the chamfer (see Figure 1). If at the end of the crushing, the blue color is still present, it suggests that the chamfer is responsible for it, otherwise the blue color would have disappeared (the chamfer and its debris would have



been "ejected" from the front of the ruin, and an absence of color blue would have been noted). The blue coloring of the chamfer thus indicates that it contributes since the start of the crushing and allow the establishment of the splaying.

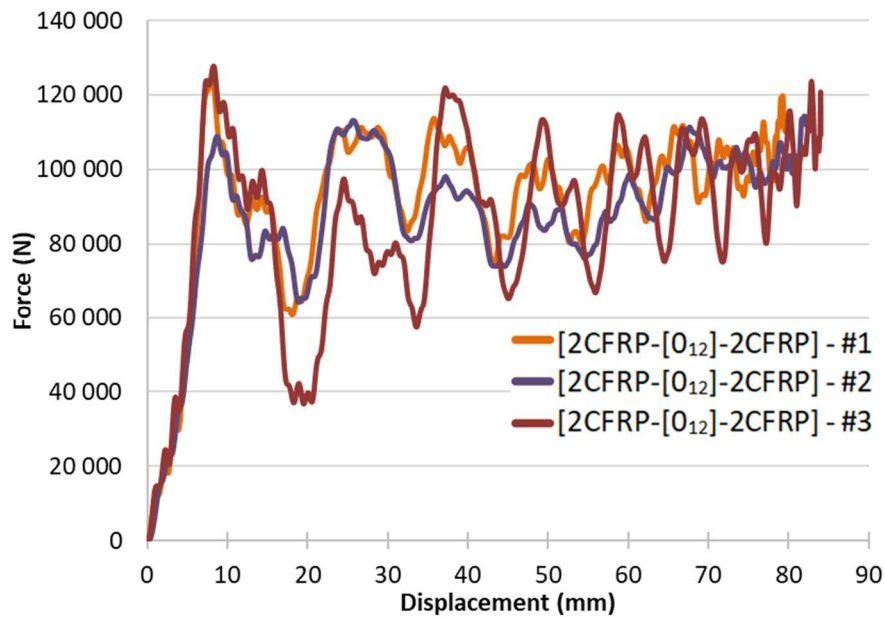


Figure 4. Force displacement curves for the 3 tubes under dynamic crushing (the tubes are named from their stacking and their number).



Figure 5. Post-mortem failure analysis of birch and carbon fiber sandwich tubes (a) overview (b) half-tubes.

## 5. Conclusions

The sandwich tubes with carbon skins and birch core have shown particularly interesting energy absorption performance. Whether static or dynamic, the overall failure mode of these tubes is splaying. However, in dynamics there is a compaction of internal debris absent in statics. The SEA is around 50 J/g in static and 65 – 70 J/g in dynamic. These values are of the same magnitude as for aluminum tubes or composite tubes. In comparison with a single carbon tubes made of four plies (See [8,9]), the coupling of birch to composite fibers is beneficial and allows additional energy absorption (7,300 J absorbed with the carbon fiber skins, 82% gain on absorbed energy) compared to the equivalence of independently crushed tubes. However, although the performances obtained with birch are superior to those obtained with poplar I214, CFRP tubes still work better on their own and have a higher SEA than sandwich tubes (81.3 J/g dynamic). A study in the process of being published shows that birch has very good characteristics in terms of energy absorption compared to oak and poplar. In general, this study shows that the composite skin/wood core coupling is a very good economic option for energy absorbers.

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