—Technical Note—

FLEXURAL STRENGTH AND FATIGUE CHARACTERIZATION OF EXOTENSIONED COMPOSITE BEAMS

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ABSTRACT

An exotensioned composite structure is developed as a light-weight and low-cost load carrying members for structural applications. The beam body, consisting of carbon-fiber composite skeletons with insertions of high-tension fiber strands, is externally weaved to provide extra structural integrity. Monotonic and cyclic flexural loading experiments are performed in this study to quantify the basic mechanical response of the structure. The bending strength, ductility, and fatigue resistance are specifically assessed.

Keywords: Carbon fiber composite, Flexural strength, Fatigue, Brockwell structure.

1. INTRODUCTION

Fiber reinforced polymers (FRP) have found increasingly wider applications, due partly to their light weight and high specific stiffness and strength [1-4]. However, their structural integrity may be hindered by the brittle failure characteristics, with the material displaying little ductility and energy dissipation upon fracture. The Brockwell Structure Technology [5] has been developed to alleviate this problem for targeted aerospace, automotive and infrastructure applications. This engineered composite structure consists of high-tensile strength embedded insertions (such as Zylon), a structural skeleton made from a carbon FRP composite, and tensioned external weaves (such as Kevlar strands). An example of the structure is shown in Fig. 1. The carbon fiber pre-preg, forming a skeleton with "*x*" shaped cross section, is strengthened, along the longitudinal direction of the beam, with internal Zylon strands at the core (center of cross section) and Kevlar strands at the four edges. In addition, pre-tensioned Kevlar strands were externally fixated at the edges via small guiding notches, giving the netted appearance. Note that the various elements can be tailored for specific applications, which provides great flexibility in designing and manufacturing structural components.

This technical note reports experimental characterization of some of the key mechanical properties, namely the strength under monotonic and cyclic flexural loading conditions. The specific objectives are:

- To quantify the bending resistance of a representative beam structure, and study the effect of external weaves on the bending response.
- To assess the fatigue performance of the structure by monitoring its load carrying capability under cyclic deformation.

The specimens used in the tests are shown in Fig. 1. The beam length is 305 mm, and the two panels forming the x-shaped cross section both have a lateral span (*d*) of 25.4mm and thickness (*t*) of 1.59mm. The specimens were subject to three-point bending using an Instron load frame as shown in Fig. 1(b). Smooth aluminum blocks were used as the loading contact and supports, with the two supports being 254mm apart. The prescribed loading rate is 4.45N/s.

Figure 2 shows the measured load-displacement curves during monotonic loading. For comparison purpose the result from a specimen without the external weave is also included. The beams show a significant linear response at the initial stage; non-linearity appears when buckling of the composite panel near the contact point starts. The regular (weaved) specimen displayed a maximum load of about 854N. At the displacement of about 11mm, a sudden load drop occurred due apparently to local crushing at the buckled region. Upon the load drop a load bearing capacity of about 580N was still maintained (in fact moderately enhanced) over a further displacement range of 2.5mm, after which a second reduction of load occurred. Cracking on the tensile side occurred at a very late stage, showing its remarkable energy absorbing capability. For the unweaved specimen, the maximum load attains only about 64% of that of the weaved structure. The overall ductility is also significantly smaller.

The results in Fig. 2 illustrated the advantages of applying the external weaves. The pre-tensioned Kevlar strands helped delay local buckling. They also serve

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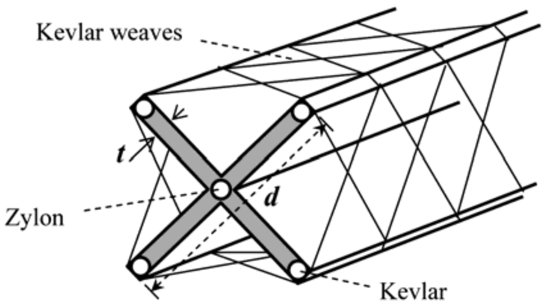
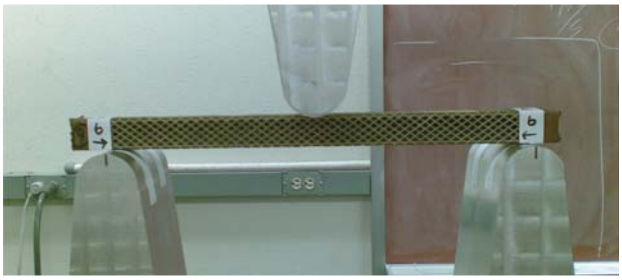


1(a)



1(b)

Fig. 1 (a) Schematic of the composite beam specimen. (b) An actual specimen and the three-point bending experimental setup

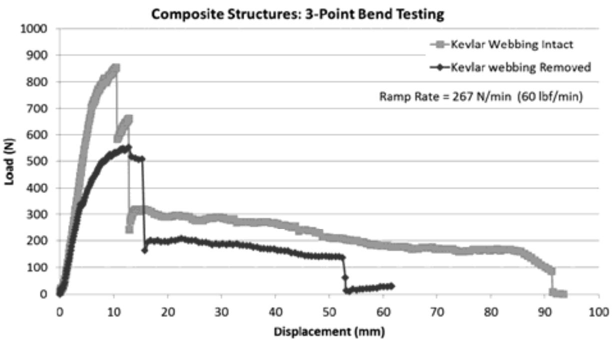


Fig. 2 Load-displacement response of the specimens with and without the external Kevlar weaves, during monotonic three-point bending

to constrict the inner mass so any local damage would not propagate out in a catastrophic manner. It is noted that the internal Zylon/Kevlar insertions, which were introduced during the molding process, also contributed to toughening the skeletal composite structure.

Attention is now turned to fatigue response of the beam structure (with external weaves). The cyclic tests were under displacement control, which allows for the degradation of peak load to be monitored over the cycles. Three maximum bending displacements were selected for the tests: 5.72mm, 4.57mm and 3.43mm. The greatest of these maximum displacements corresponds to the initial peak load of about 730N, which is at the end of the linear portion of the load-displacement curve, Fig. 2. This is to avoid any structural damage induced during the initial loading phase. The minimum bending displacement was set at 1.27mm in all cases, for ensuring that a firm contact is always maintained. The displacement rate of 0.212mm/s is prescribed.

Figure 3 shows the measured variation of peak load (corresponding to the maximum bending displacement) as a function of number of cycles, up to about 2500-3000 cycles tested. Because the testing was conducted in an interrupted manner for each specimen, at each resumption of loading there is a certain degree of recovery of initial load. This transient period, however, is brief and the load soon follows the previous trend, and an overall smooth variation of the peak load is observed. In general the peak load shows a decreasing trend as the cycling continues. This implies the accumulation of cyclic damage, although in general the specimens can still maintain better than 70% of their original strength after 3000 cycles. In the case of the prescribed maximum displacement of 3.43mm, the peak load remains essentially unchanged at a level of about 365N. This load may thus be considered as the "fatigue strength," in that any applied maximum load below this value is not expected to cause fatigue failure.

The present characterization of cyclic deformation does not yield the traditional format of S-N curves in fatigue testing. Therefore, a direct comparison of fatigue life with other materials is not feasible. Nevertheless, the fatigue strength defined above may be used as an indicator when it is normalized with the monotonic ultimate strength [1]. The composite beams we tested showed a normalized bending fatigue strength of about 0.42, which is in the general range displayed by FRPs [6-8] and better than many light-weight engineering alloys such as aluminum [9-12]. The result presented in Fig. 3 also lends itself to quantification of damage using another parameter — the reduction of stiffness (manifested by the reduction of peak load over cycles with a constant displacement amplitude), which is directly related to the accumulated fatigue damage [1]. Taking the case of maximum bending displacement of 4.57mm in Fig. 3 as an example, one observes that, at about 1000 cycles, the reduction of stiffness is smaller than 15%. This is a better performance than that reported for glass fiber reinforced polymer composites [13].

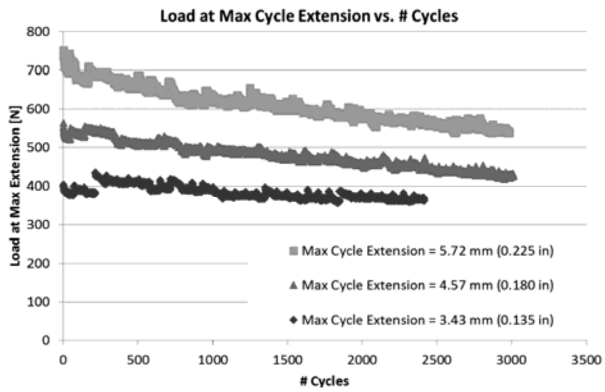


Fig. 3 Variation of the peak load with number of cycles during the cyclic three-point bend test. Three maximum bending displacements are prescribed: 5.72mm, 4.57mm and 3.43mm

In summary, we have characterized the monotonic and cyclic flexural response of the light-weight Brockwell composite beam structure. Its unique energy absorbing capability and failure resistance, along with the advantages of the external weaves, were experimentally demonstrated. The extent of the load reduction during cycling as well as the normalized fatigue strength suggested that its fatigue performance is comparable to or better than common fiber-reinforced polymers and light-weight engineering alloys.

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