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Energy absorption capacity of braided frames under bending loads

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ABSTRACT

The energy absorption capacity of braided composite frames under bending loads was studied by conducting quasi-static four-point-bending tests. As specimen geometry C-shaped frame segments where chosen which show the typical failure behaviour of frames with open cross section, such as local buckling and crippling. The braiding manufacturing process offers the possibility to influence the fracture mechanics by a local hybridization of the braider yarns. Different hybridization concepts were investigated to identify design principles for braided frame structures with enhanced energy absorption capacity. The test results show that the post-failure energy absorption of braided frame segments can be significantly increased by a local modification of the braid architecture.

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1. Introduction

Whilst braided composites are already used in many applications such as fan blade containment or as energy-absorbing crash structures in racing cars there is interest to increase the usage of braided composites for further structural components in the aerospace and automotive fields. The main reason for the growing interest is the requirement of the industries for cost-efficient highly automated manufacturing of high performance composite structures. Braids are often manufactured using rotary braiding machines which can be tailored to provide a wide variety of complex preform shapes. In comparison to non-crimped fabrics, 2D-braids feature a high impact resistance and crash energy absorption potential, while still remaining competitive regarding stiffness and strength properties. In the braiding process closed, tubular shaped structures can be produced, which are particularly suitable for manufacturing of frames, crash elements and other structural beam components. The tow waviness of braids acts as reinforcement through thickness which provides an improved damage tolerance for braided structures.

The understanding of the mechanical properties and the failure mechanisms of braids is important for the design process of braided structures. In the literature studies can be found which investigate the mechanical performance of 2-D braided carbon/epoxy composites in comparison to laminates made of unidirectional tape. Due to twisting and fibre misalignment of fibre tows braided composites show a 10% reduced stiffness in tension and compression [1]. Due to the fibre damage during the braiding process and due to the undulation of the braid fibre path the failure strength values are 20–30% lower compared to unidirectional tape specimens [1,2]. Swanson and Smith investigated the strength properties of triaxial braided composites under biaxial loading conditions. The experimental study showed similar shaped failure envelopes for triaxial braid and laminates under biaxial loading. The biaxial failure properties of triaxial braid can be obtained by using critical strain values in the axial and braid direction, but with degraded strength properties due to the undulating nature of the fibre path [2,3]. Potluri et al. [4] investigated the flexural and torsional behaviour of biaxial and triaxial braided composite structures. For the assessment of the flexural behaviour, 3-point bending test on turbular specimens were conducted to investigate the influence of the braiding angle on bending stiffness. Experimental studies investigating the strain rate dependency of 2D biaxially and triaxially reinforced braided composites found strain rate dependent behaviour for stiffness, strength and onset of damage [5]. In the literature numerous publications can be found investigating the numerical assessment of the material characteristics of braided composites on mesoscale level [6–9]. Due to the necessary detailed discretisation of fibre tows and resin, this approach is not applicable on the structural level. Limited studies can be found in the literature addressing modelling strategies for components made out of braided composite material [10].

The specific energy absorption of composite structures which are designed to absorb kinetic energy by crushing is significantly higher compared to those which are designed to absorb kinetic energy by bending. This is a significant disadvantage for the

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application of composite materials for crash related structural components since metals can absorb energy by plastification independent of the failure mode. In the field of aerospace the importance of frames with increased energy absorption capacity after bending failure was identified for composite fuselage sections, if the vertical acceleration loads of the passengers should not exceed values typical for a metallic fuselage design [11,12]. Limited experimental studies are published, investigating the energy absorption characteristics of composite frame structures under bending loads. In [13] damage initiation and energy absorption of twin-walled fuselage panels with foldcore were investigated. The study showed that position and failure load can be adapted according to the defined kinematic hinge requirements by adjusting locally the through-thickness compression strength of the core. Bending failure of CFRP frame segments with epoxy resin were studied by Pérez [14] and Heimbs [15]. The improvement of the energy absorption capacity of CFRP frames was investigated for frame segments made out of AS4/PEEK [11,16]. In this study ductile titanium sheets were embedded in the flange laminate of C-shaped frame segments. In the experiments the hybridisation did not provide significant improvement in the energy absorption capacity after bending failure compared to frame segments purely made out of CFRP.

Since braided composites are commonly recognised as a promising concept for future frame design, the presented study contributes to the development of design principles for fibre architecture and hybridisation of braided frames with enhanced energy absorption capacity under bending loads.

2. Specimen definition and manufacturing

The energy absorption capacity of braided composites was studied by conducting quasi-static four-point-bending tests. Generic C-shaped frame segments were chosen as specimen geometry, since this geometry shows the typical bending failure characteristics of open frame profiles. Frames with an open cross section typically fail due to instability failure of the compressed frame flange (crippling). Fig. 1 shows the test setup and the specimen definitions. The specimen was encased in aluminium fittings in the region of load introduction to avoid failure initiation in the area of stamp and support. Additionally the solid fittings stabilize the test specimen against lateral displacement due to bending–torsion coupling effects. In the final test setup the distance between the two supports was L_{su} = 640 mm, the distance between the stamps had a distance of $L_{\Delta s}$ = 300 mm and the free length of the test specimen was L_C = 260 mm.

Fig. 1 depicts additionally the dimensions of the C-shaped test specimen. The cross-sectional dimensions of the test specimens were H = 80 mm for the web height and B = 38 mm for flange width. The radius between flange and web was R = 4 mm. The test specimens had a length of 600 mm. For the applied modification of the fibre architecture the flange was defined to include the complete radius area between web and flange.

For compensation of the variable laminate thicknesses the test specimens were embedded into the aluminium fittings using epoxy resin as filling material between test specimen and fixture. The aluminium fittings were treated with release agent to allow the dis-assembly of the aluminium fittings and the test specimen. Therefore, the boundary conditions of the load introduction correspond to a loose clamping of the test specimen within the casing. Three strain gauges were used to measure local strains in the centre section of the test specimen.

For manufacturing of the braided test specimens a quadrangular shaped mandrel made out of aluminium was used. The mandrel design enabled a direct infiltration after the braiding process using the Vacuum Assisted Resin Injection (VARI) process. The advantage of this manufacturing strategy was that two C-shaped test specimens could be obtained per braiding and infiltration process by splitting the quadrangular braid. The laminate was therefore cut into two separate specimens with a wet saw after the infusion. In Fig. 2 the braiding process and the fixed test specimens within the aluminium fittings are shown. The braiding of a quadrangular shaped form leads to considerable changes of the braiding tow angles. This relation could also be observed in the manufactured test specimens.

The specimens were braided on a radial braiding machine with 176 bobbins and 88 feedings for zero degree in a 2×2 pattern. Toho Tenax® E HTS40 12K F13 carbon fibres, Teijin Twaron® D2200 Aramid fibres and Owens Corning FliteStrand® S ZT glass roving were used as braider yarns. The aerospace qualified resin RTM6 was infused in a VARI process obtaining an averaged fibre volume ratio of 58.1%. All specimens consisted of 4 braided layers.

The main focus of the study conducted was the identification of design strategies for braided frames with improved energy absorptions capacity under bending. Different strategies were investigated for the improvement of the energy absorption. These design strategies were

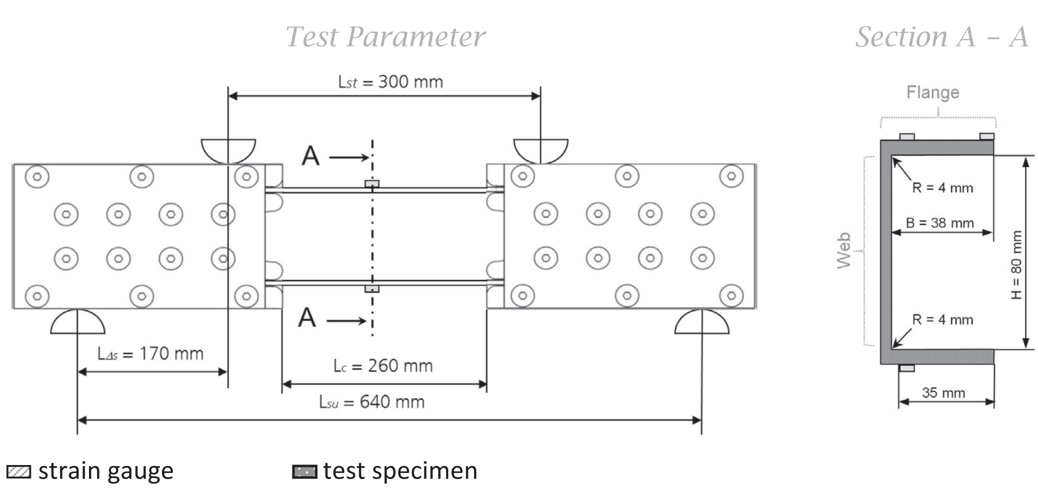

Fig. 1. Schematic drawing of the four-point-bending test and parameters of the test specimen.

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