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Crashworthiness of hybrid carbon and flax tubes for aerospace applications

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Abstract

The potential of hybrid natural and carbon fiber reinforced plastics (NFRP and CFRP) as structural composite materials used in helicopter and other aerospace applications should be investigated.

Flax is a natural fiber which has comparable mechanical properties to glass fibers. The main motivational aspect is the improved ecological footprint, which is due to the lower energy input in the production process, compared to carbon. Another promising factor is the lightweight potential, as flax fibers have a lower density than the conventional fibers, carbon and glass. The energy dissipating properties are emphasized in different sources, including very good vibrational damping, crash absorbing and impact resistance properties, which should all be analyzed in comparison to the contemporary used carbon reinforced structures.

The energy absorbing capabilities of hybrid layered tubes with woven flax and carbon layers should be evaluated within this project. Therefore specimen will be crashed under a static pressure test and afterwards dynamically with a dropping weight. In both tests force and displacement sensors as well as type of damage will give guidance to the analysis

Crashworthy Helicopter Structures

The aim of crashworthiness in helicopter applications is to reduce the peak loads that strain the occupants, keep the integrity of the cabin to protect the occupants, reduce the hardware damage and to minimize the risk of post-crash risks, such as fire. [1]

Representative crash scenarios of helicopters are in civil helicopters velocities of up to 16 m/s. For crash landing conditions according to CS 27 the inertial load factors are between 1,5 g and 20 g, in which cases the survivability of the occupants should be verified. Tube-like structures are commonly used in seat crashworthy structures.

The crashworthy requirements in test pulses vary between commuter, pilot and passenger seats.

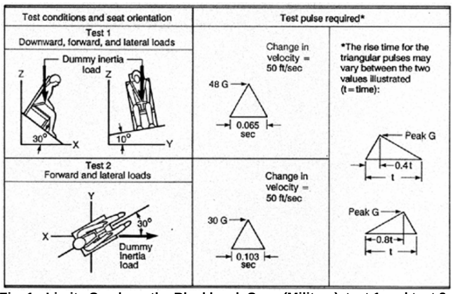

Fig. 1.: Limits Crashworthy Blackhawk Crew (Military), test 1 and test 2 conditions [1]

Goal

The goal of this research project is to find out about the potential of flax and carbon woven hybrid laminates in crashworthiness structures. Beneficial would be an linear force-displacement curve with an almost steady state force while dynamic energy is absorbed.

Additionally a high specific energy absorption, a high Crush Force Efficiency and a high Stroke Efficiency are beneficial. These parameters are described by the following formula and shown in Fig. 3, below.

$$\mathit{Specific\ Energy} \qquad E_S = \frac{E_{abs}}{m_{destroyed}} \left[\frac{kJ}{kg}\right]$$

$$\mathit{Mean\ crushing\ stress} \qquad \sigma_{Cr} = \frac{F_{avg}}{A_0} [\mathrm{MPa}]$$

$$\mathit{Crush\ Force\ Efficiency} \qquad A.E. = \frac{F_{avg}}{F_{peak}}$$

$$\mathit{Stroke\ Efficiency} \qquad S.E. = \frac{l_s}{l_0}$$

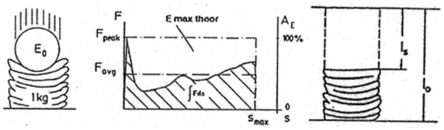

Fig. 3: Energy Absorbing Parameters [1]

Materials

The materials used are flax and carbon prepregs. The flax prepreg is LINEO FLAXPREG BL150, the Carbon is specified as SIGAPREG C W200-TW2/2-E503/45% In the following table the characteristics of each material is summarized.

Table 1: Summary of Carbon and Flax Prepreg Material

	Carbon	Flax
Areal weight of fiber weave [2], [3]	200 g/m²	140.6 g/m²
Thickness	0.225	0.225
Weave style	Twill 2/2	Twill 2/2
Fiber density [2], [3]	1,8 g/cm³	1,45 g/cm³
Epoxy Resin [2], [4]	SIGAPREG E501	HUNTSMAN Araldite LY 5150
Matrix density [2], [4]	1,2 g/cm³	1,2 g/cm³
Tensile strength 0° [2], [5]	1000 MPa	161 MPa
Tensile Modulus 0° [2], [5]	72 GPa	12.2 GPa

The combination of 200 g/m² carbon and 150 g/m² flax was chosen due to their same thickness and mesh size. Additionally preliminary studies proved 150 g/m² flax is mechanically better than 200 g/m² flax.

Specimen Tubes

The specimen were made with the use of flax and carbon prepreg material. The mold-cylinders were made out of aluminum, due to deforming reasons with the high thermal expansion coefficient.

The prepregs were cut in bands and winded around the molds. Each Tube is made of 8 layers which order in the following stackings:

Table 2: Specimen Stacking, Weigth and Fiber Volume Fraction

Type	Layer number (inside to outside)								Amount	Mean Weight	Fiber fraction
-	1	2	3	4	5	6	7	8	-	g	Vol.-%
FFF	F	F	F	F	F	F	F	F	3	20,1	48
FCF	F	F	C	C	C	C	F	F	4	21,2	53
CFC	C	C	F	F	F	F	C	C	4	21,3	53
CCC	C	C	C	C	C	C	C	C	3	25,8	48

The curing cycle was 90 min at 140°C with a 95% vacuum and additional pressure of 5 bar. Heating and Cooling rates were about 2°C per minute.

Remarkable are the higher fiber volume fractions within the hybrid specimen. This phenomenon might be due to a better compaction during consolidation as the mesh and filament sizes vary. This makes the beneficial weight of the hybrid specimen, which is closer to Flax than to Carbon.

Fig. 4: Specimen Tubes made of Flax Prepreg Material

Fig. 2: Cabin Crash Test [1]

Sources:
(1) Untersuchungen zur Crashsicherheit von Hubschraubern, C. Kindervater, CCG-Seminar TV 3.12, Oberpfaffenhofen, 10/2006
(2) Technical Datasheet, FLAXPREG BL150, SAS LINEO, 08/2016
(3) Technical Datasheet, SIGAPREG C W200-TW2/2-E503/45%, SGL Group, 07/2016
(4) Technical Datasheet, Araldite LY 5150 Aradur 1571 Accelerator 1573 Hardener XB 3471, Huntsman, 06/2009
(5) Laminate Datasheet, SIGAPREG C W200-TW2/2-E501/48%, SGL Group, 11/2016
(6) Crashworthiness of carbon fiber hybrid composite tubes molded by filament winding, Xu J. et al, Composite Structures Vol. 139, 04/2016
(7) A study on the energy absorption properties of carbon/ aramid fiber filament winding composite tube, Yan Ma et al, Composite Structures Vol. 123, 05/2015

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