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TITLE: LIGHTWEIGHT POTENTIAL OF CARBON/FLAX HYBRID LAMINATES

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1. INTRODUCTION

Carbon fiber reinforced polymers (CFRPs) are the material of choice for highly stressed components due to their strength and stiffness properties and the resulting lightweight design potential. Classical fiber reinforced polymers (FRPs) for lightweight structures consist of synthetic fibers such as carbon fibers (CF), glass fibers or aramid fibers combined with a polymer matrix. Since the production of carbon fibers is very energy-, greenhouse gas- and cost intensive, the question arises about possibilities for the realization of more ecological and cost-efficient lightweight FRP structures. Engineers and designers need to find a trade-off between structural integrity, environmental compatibility, costs and manufacturing feasibility. One approach to make CFRP structures more energy- and cost-efficient is to reduce the carbon volume fraction and use carbon fibers partially only exactly where they are really needed and where they are structural efficient. In the remaining areas, the carbon fibers are substituted by cheaper and more environmentally friendly fibers, which reduce the overall environmental impact and the costs of the FRP structure. The combination of different fiber types in a composite is called fiber hybridization. The present assessment [1] aims to hybridize carbon and flax fibers (FF) in an interlayer configuration without reducing the mechanical FRP performance (stiffness, strength and weight) significantly. As illustrated in Figure 1, the processing and manufacturability of CF/FF hybrid laminates is investigated and the mechanical properties of pure CF-, FF- and CF/FF- hybrid laminates are characterized. Based on the results, the analytical lightweight potential of various CF/FF laminate configurations and their preferred load cases are calculated, in order to quantify the structural lightweight potential of CF/FF hybrid laminates compared to pure CF laminates and to define general design guidelines for CF/FF hybrid laminates.

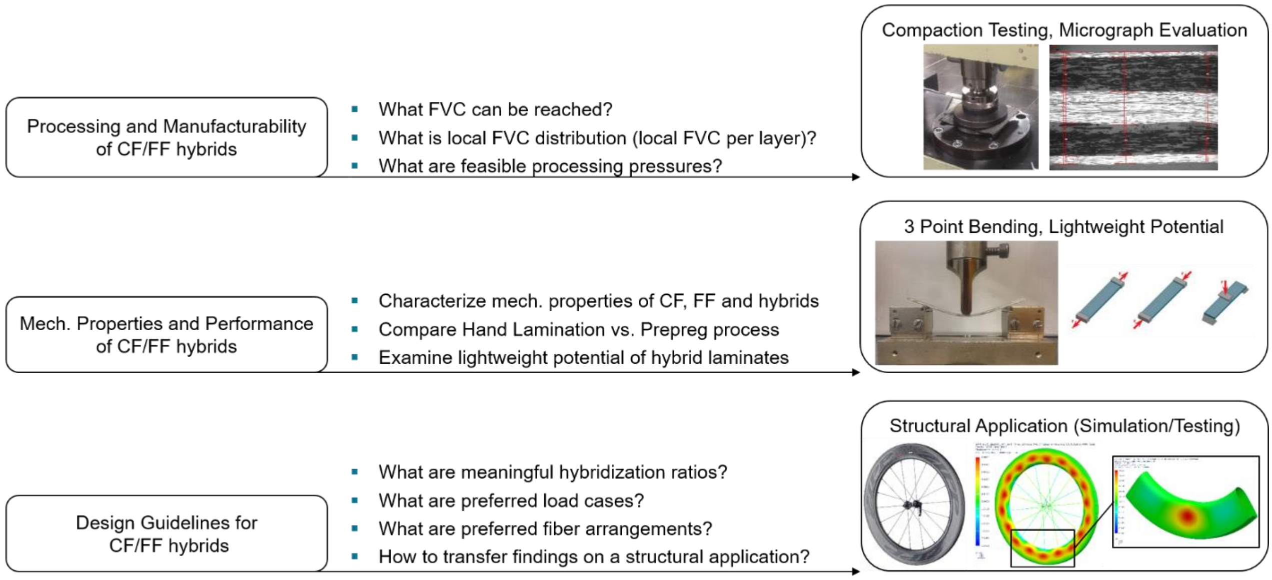

Fig. 1: Research questions and assessment methods.

2. PROCESSING AND MANUFACTURABILITY

Method

By means of compaction response testing pure CF and FF (saturated and unsaturated) are exposed to different compaction pressures. For each single fiber type, it is measured what fiber volume content (FVC) can be reached at which specific pressure. In addition, cross sections of different cured CF/FF hybrid samples are evaluated by micrograph analysis. With this technique, the local layer thicknesses and thus the local fiber volume contents in the individual CF and FF layers can be determined. By combining the results of both assessments, a statement about the manufacturability and definition of preferable processing pressures for the combined processing of CF and FF can be made.

Results

From the compaction response it can be seen, that flax FVC is up to 30% lower than carbon FVC at low compaction pressures (0.5-1bar). As shown in Figure 2, a strong dependency of flax fiber compaction capability and the applied pressure is observed, resulting in a low FVC deviation of 10% between carbon and flax for high pressures (10-20bar).

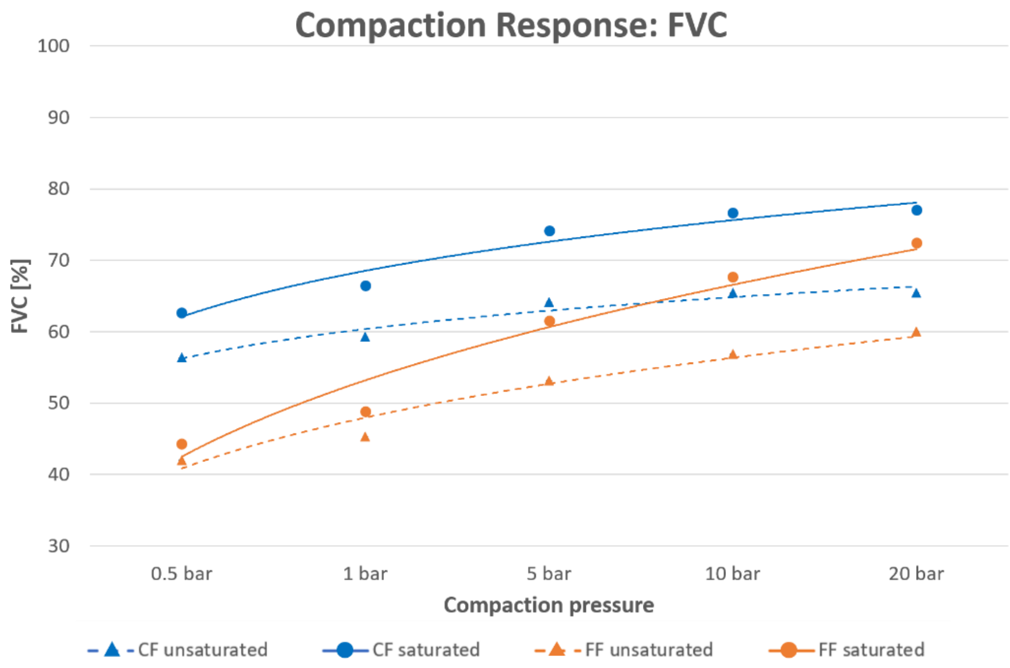

Fig. 2: FVC response of saturated and unsaturated CF and FF fibers .

3. LIGHTWEIGHT POTENTIAL

Method

The mechanical properties of pure CF, FF and CF/FF hybrid laminates are characterized by standardized three-point-bending tests. Each of the analyzed samples is produced by two different manufacturing processes, the hand lamination and the autoclave prepreg technique. Based on the mechanical properties, the so-called lightweight potential of different materials and material combinations can be calculated in a further step. This calculation is a methodological approach to find replacement laminates with same tensile-, compression-, bending- strength and stiffness in order to substitute a pure CF laminate. The calculation method computes the alternative material thickness in order to reach the structural constraints. This allows to evaluate which replacement configurations are lighter or heavier compared to the reference CF laminate at the same load case. From this analysis, it can be deduced for which load cases hybridization makes structurally sense and what are the benefits or drawbacks in terms of weight.

Results

Although there is a difference in the local fiber volume contents between carbon and flax, hybrid laminates with only 16% less flexural modulus and 17% less flexural strength compared to the pure CF reference laminate could be produced. Comparing the mechanical properties of the samples manufactured by hand lamination and autoclav process, it is noticeable that the hand laminated ones perform significant poorly.

As illustrated in Figure 3, from the calculation of the lightweight potential emerges that CF/FF hybrid structures can be built up to 8% lighter than a pure 0° CF structure, having the same compression- and bending strength as well as the same bending stiffness. This effect can be seen as well in a 0° UD arrangement with the flax (in the middle of the specimen) and the carbon in 0° direction as when they are arranged in a cross ply configuration where the 0° fibers are from carbon and the 90° fibers (in the middle of the specimen) are from flax. The biggest benefit appears at a hybridization ratio of 60/40 vol.% (CF/FF). From the preferred load cases, such as compression strength, bending strength (limited by buckling) and bending stiffness, it can be said that buckling critical structures hold a great lightweight potential for incorporating CF/FF hybrid laminates.

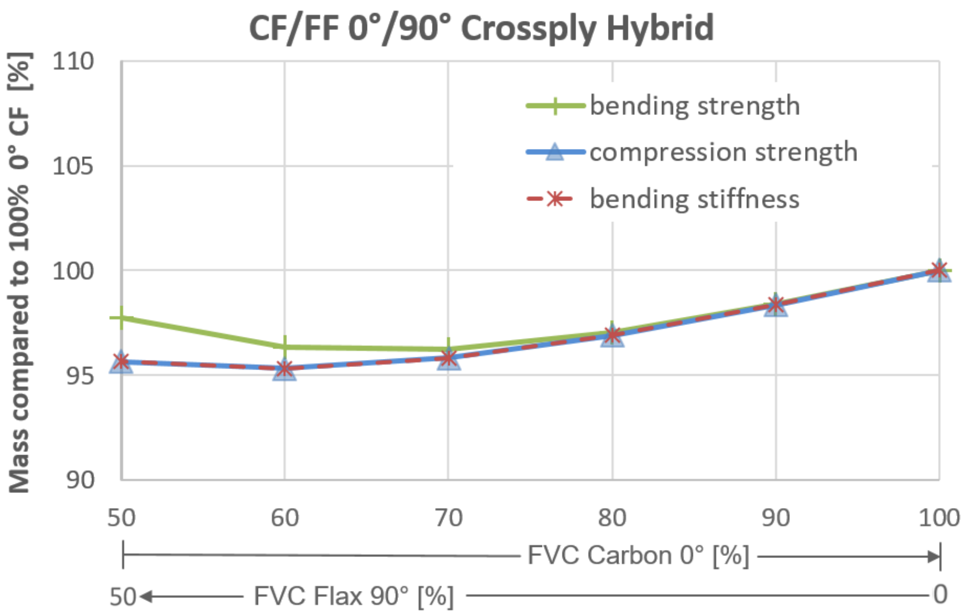

Fig. 3: Mass comparison of CF/FF cross ply hybrid, referenced to 0° CF for the preferred load cases.

4. CONCLUSION

It could be shown that flax fibers have lower fiber volume contents at the same compression pressures compared to carbon fibers. The deviation is strongly pressure depended and can be reduced by increased compaction pressures from a maximum of 30% to a minimum of 10%. Means higher processing pressures will result in lower local FVC deviation between the CF and FF layers within a hybrid laminate and therefore increased mechanical properties. Combined with the good resulting mechanical properties it can be concluded that carbon and flax can be very well processed together to hybrid laminates using the conventional composite manufacturing processes.

Resulting from the lightweight potential calculation, hybridization makes no sense in the case of tensile loading and compression stiffness since in this cases the carbon fibers are dominating with their high tensile stiffness and strength properties. By contrast, the properties of flax have a much greater impact on the load cases bending strength/stiffness and compression strength (limited by buckling), thus enabling to even reduce the weight under these loads. It can be said that hybridization in a pure structural sense only makes sense for these three load cases. The flax fibers unfold their full potential when combined as a kind of sandwich laminate with the carbon fibers. The maximum lightweight construction potential is achieved by sheathing the flax fibers (low density) as core material with carbon fibers (high stiffness & strength) as facings. A maximal weight reduction of up to 8% could be achieved by a CF/FF, 0° UD laminate and by a CF/FF, Cross ply laminate with 90° flax fibers arranged as core sheets. In both cases meaningful hybridization ratios are between 50-60/50-40 vol.\% (CF/FF). This insight quantifies that hybridization not only helps to improve the eco- and cost structure of laminates, but additionally offers a potential for lightweight design exceeding the one of pure carbon laminates within the preferred load cases.

REFERENCES

[1] Schmid, Jonas: Assessment of the lightweight and cost potential of carbon/flax hybrid laminates, Mater Thesis at CMAS Lab, ETH Zürich; 2018