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# TOWARDS FIBER BUNDLE MODELS FOR COMPOSITE PRESSURE VESSELS

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Finite element models for composite pressure vessels (CPV) are usually based on the classical laminate theory (CLT). In the CLT the composite laminate is represented by a stack of homogeneous plies. Each ply is described by thickness, orientation angle and orthotropic mechanical properties [1]. For filament wound CPV each wound layer is modeled by two unidirectional plies with opposite fiber angles ($\pm\alpha$). Ply thickness and fiber angle vary throughout the laminate depending on vessel geometry and fiber path. The thickness build-up due to overlap is described by analytical or semi-empirical formulas [2].

Close observation of the actual fiber geometry of filament wound CPV reveals that this model is only a simplification of reality. Because of the finite band width and band overlap more than two plies may be present at any point of the wound layer (Fig. 1). The fiber angle at a given point is not unique in the actual ply stack. These effects can be modeled by an enhanced filament winding simulation which tracks the deposition of a finite-width band on the winding surface [3].

However, the transformation of this detailed laminate information into a suitable finite element model based on CLT is not well-defined. The classical approach uses layered shell or solid elements to model the laminate [4]. This requires the use of a certain number of plies, each with unique angle and thickness within each finite element. A mesh layout which respects the detailed description of the fiber geometry within the framework of CLT is hard to envision because this geometry is not strictly a laminate.

In the present research the filament wound band is modeled as a group of fiber bundles following the real fiber path on the winding surface. The fiber bundles are embedded in a structured mesh representing the matrix material. In the simplest case this can be achieved with reinforcing elements [5]. An alternative is the use of embedded truss elements [6]. In a more evolved approach the fiber bundles may be described by embedded beam or solid elements.

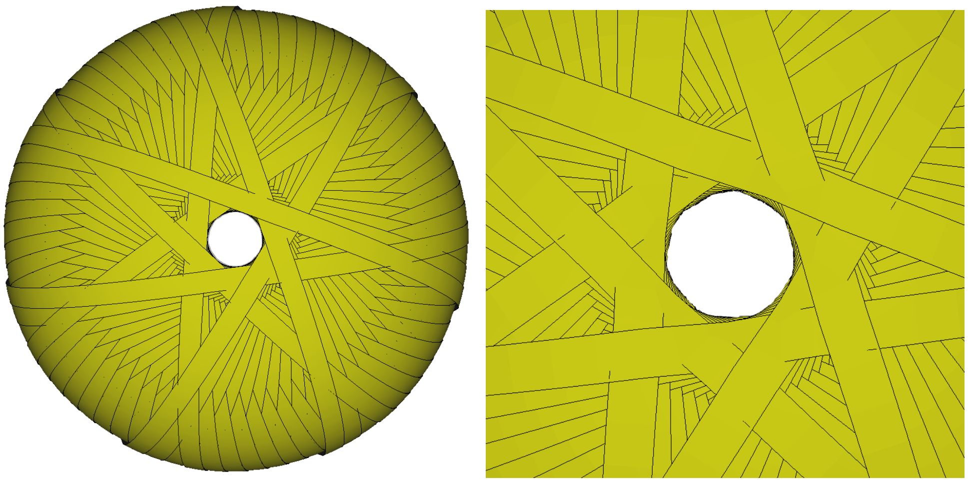

**Figure 1**: A filament wound composite pressure vessel not easily modeled using CLT [3]

The fiber-bundle approach may be the appropriate bridge between micro and macro descriptions of the composite structure resulting from filament winding and braiding. Furthermore this may be the basis for the transition from finite element to a mesh-free or particle descriptions for the investigation of fragmentation phenomena which govern final failure and severe impact events of composite pressure vessels. In this contribution the fiber-bundle approach is explored and compared with modeling strategies based on layered solid elements. The fiber-bundle approach may be extended to filament wound, fiber-placed or braided structures with partial surface coverage which are even more difficult to describe by CLT. Applications are in the safe and economic design of high-pressure hydrogen tanks for automotive applications.

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