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Optimización de Materiales Compuestos Laminares orientado por la Fabricación

Manufacturing Oriented Design Optimization of Layered Composite Structures

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Un laminado compuesto es típicamente formado por varias capas reforzadas por fibra que tienen diferentes propiedades direccionales, grosores y materiales. Las avanzadas herramientas de modelado y cálculo de compuesto definen el modelo basándose en el proceso de fabricación. Este artículo describe la optimización versátil para las capas del laminado con diferentes orientaciones, grosores y materiales, con el concepto de garantizar que todos los diseños generados puedan ser fabricados. La metodología ha sido aplicada con éxito a varios diseños reales.

A composite laminate is typically formed by a number of fiber-reinforced layers having directional properties, thicknesses and materials. Advanced composite modeling tools provide pre-processing procedures, which allow setting up the model by laying the plies in the way that they are introduced in the manufacturing process. This article describes a lay-up optimization problem for a laminate with different layer orientations and materials that can be described in a versatile way. The concept guarantees that all designs generated by the optimization procedure can be manufactured. The methodology has been successfully applied to several real-life design problems.

A composite laminate is typically formed from a number of fiber-reinforced layers having directional properties. Basically, for each layer of the laminate, design variables are the choice of material system, thickness of the layer, and orientation of the layer. In practice, laminate design is more constrained. Only a few material systems are readily available for which the thickness is usually determined by the processing. However, in sandwich panels the thickness of the core material can be chosen quite freely. The choice of layer orientations is often constrained to 0, 90, +45, and -45 deg. Typically other constraints exist as well. Symmetry with respect to the laminate mid-plane may be required and due to manufacturing, some regularity may be desired in the laminate lay-up. Also, thick sections of unidirectional layers may be undesirable.

In a previous study [1] it has been demonstrated that the lay-up optimization problem for a laminate with three different layer orientations can be described in a versatile way:

$$[(\zeta)(m_\zeta)x_\zeta,\ (\eta)(m_\eta)x_\eta,\ (\xi)(m_\xi)x_\xi] \qquad (1)$$

where ζ, η, and ξ, $\zeta \neq \eta \neq \xi$ define the locations of the three layer orientations in the laminate stack, respectively. Variables m_ζ, m_η, and m_ξ are material type pointers and they correspond to the associated layer orientations. Respectively, variables x_ζ, x_η, and x_ξ are layer multipliers.

In this approach, a layer orientation can be fixed, it can be selected from a range, or it can be one from a specific set of orientations. The material type can be fixed or it can be selected from a set of suitable material systems.

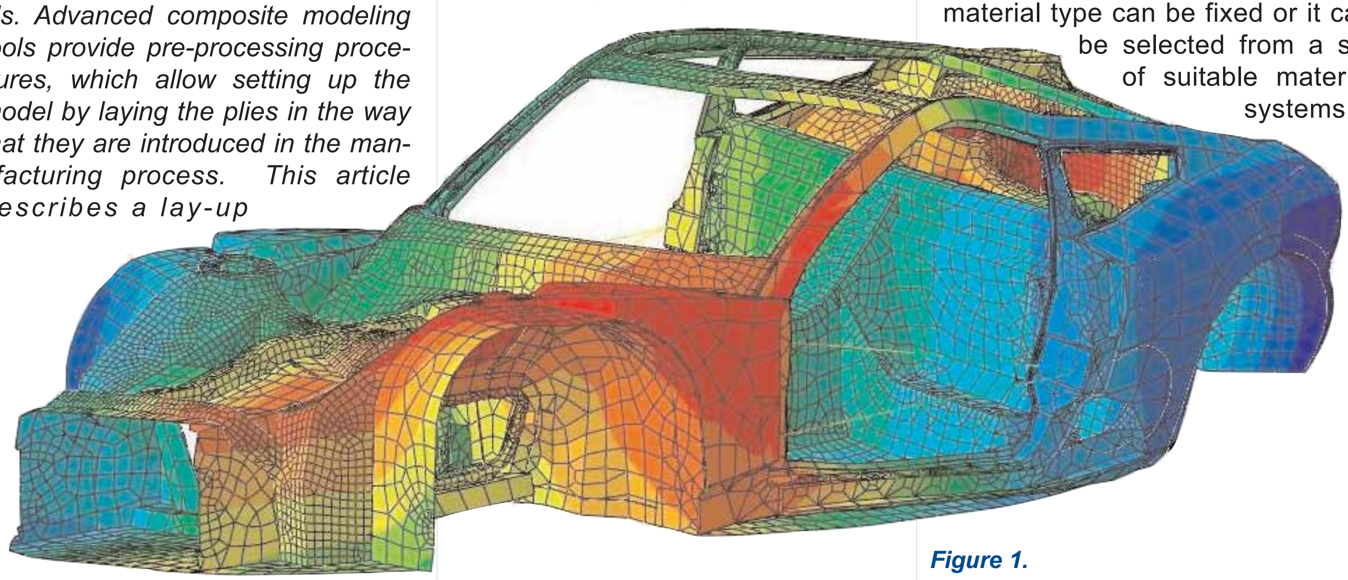

Figure 1.

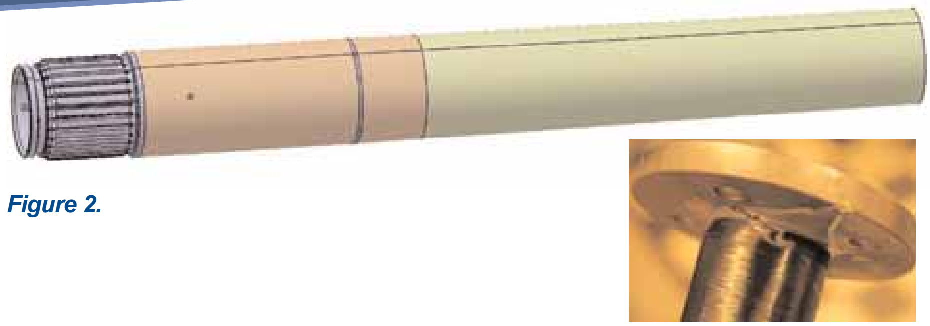

Figure 2.

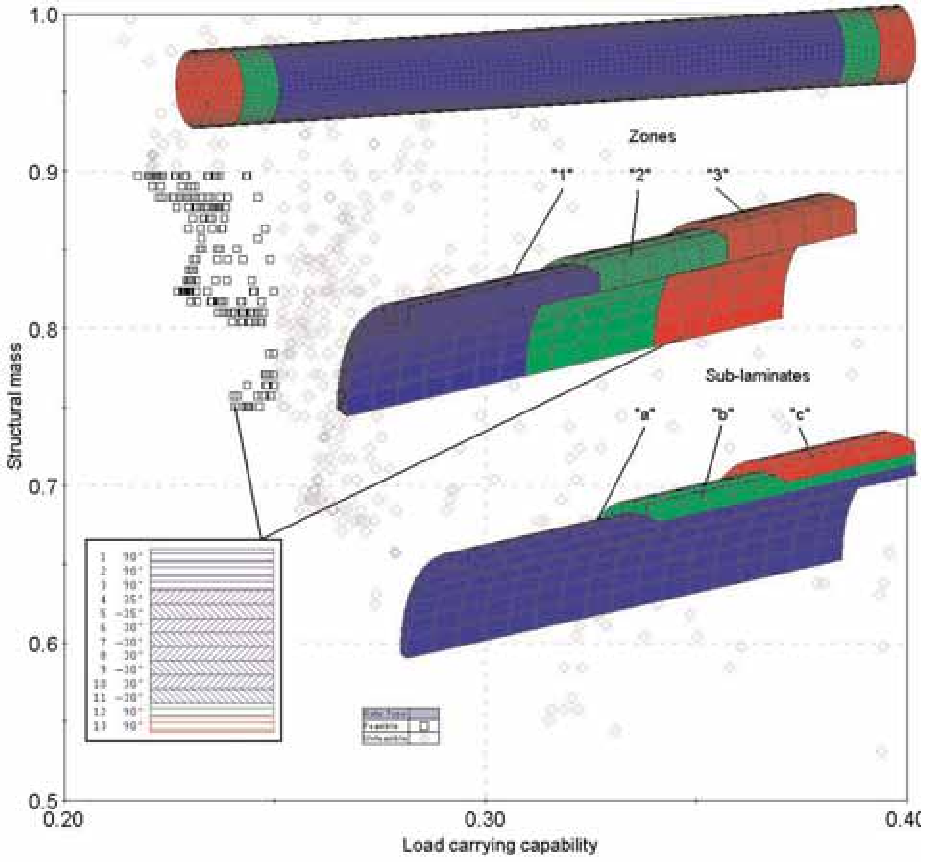

Figure 3.

Furthermore, the layer multiplier can be fixed or it can be selected from a range. The presented approach provides several benefits. When the stacking sequence vector (ζηξ) is considered, the best solution for each loading condition can be found. The stacking sequence is especially important in bending and out-of-plane shear dominated problems. With the possibility to choose the material from a preselected group, the best combination of the material system and the layer thickness can be found. Allowed layer orientations may need to be limited because of the selected manufacturing technique.

In practice, the presented lay-up formulation concept does not constrain the design space. For thicker laminates, in the order of ten layers or more, the concept can be further extended. The presented formulation in Eq. (1) can be considered as an elementary laminate, which is then multiplied a number of times. Several elementary laminates can be introduced in the same laminate definition. It has been shown that this approach allows significant reduction in the number of design variables [1], but has little effect in the performance of the optimal designs compared to the best attainable solutions [2]. Only laminate lay-ups with certain regularity in the lay-up pattern are considered, which is also desirable in the manufacturing point of view.

In FEA, composite problems are internally solved with zone-based approach. This means that areas of the model that have specific laminate lay-up have also specific section data specifications. More advanced composite modeling tools provide pre-processing procedures, which allow setting up the model by laying the plies in a way they are introduced in the manufacturing process. Part of the simulation process converts the ply-based input data to zone-based solution data. Typically, several plies are introduced in the same application regions. This stack of plies that is common for a specific region can be considered as a sub-laminate for which the laminate lay-up optimization problem is defined, for example, as formulated in Eq. (1). The design optimization scheme also includes the linking of the zone-based simulation with the sub-laminate based optimization [3]. This association between the real plies and the FE model ensures that changes in the ply level update automatically in the FE model. Zone- and sub-laminate based modeling are illustrated in Figure 3.

The composite optimization scheme has been implemented using ESAComp [4] and modeFRONTIER [5] software together with a general FE solver. ESAComp is software for analysis and design of composite structures. Respectively, modeFRONTIER is a design optimization and process integration software package. ABAQUS, ANSYS and NASTRAN have been used as FE solvers, but the methodology itself is FE solver independent.

The concept guarantees that all designs generated by the optimization procedure can be manufactured. The methodology has been successfully applied to several real-life design problems, see examples in Figures 8, 9 and 10. Three case studies are presented in this article: multi-objective design optimization

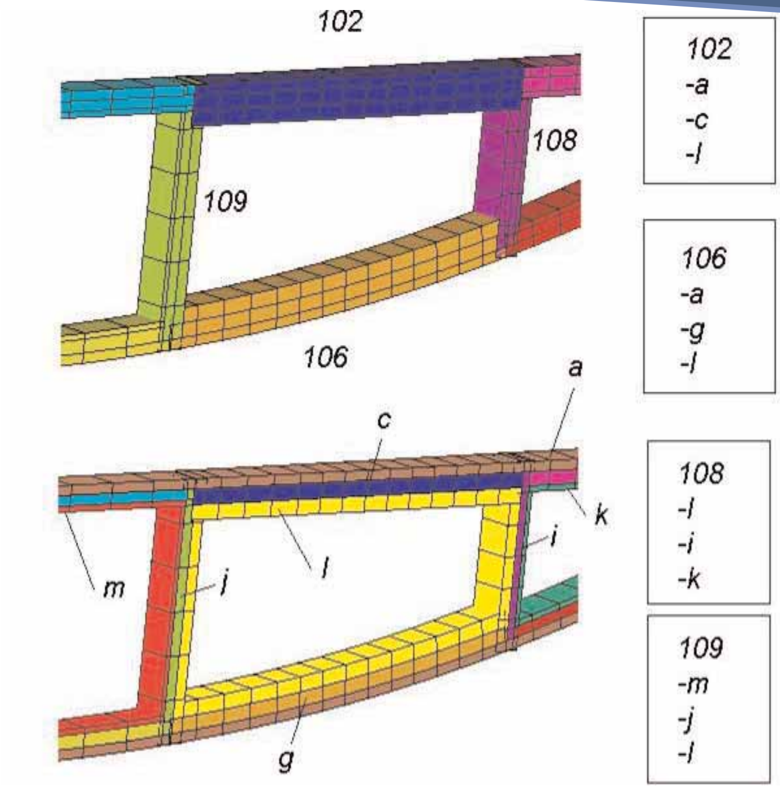

Figure 4.

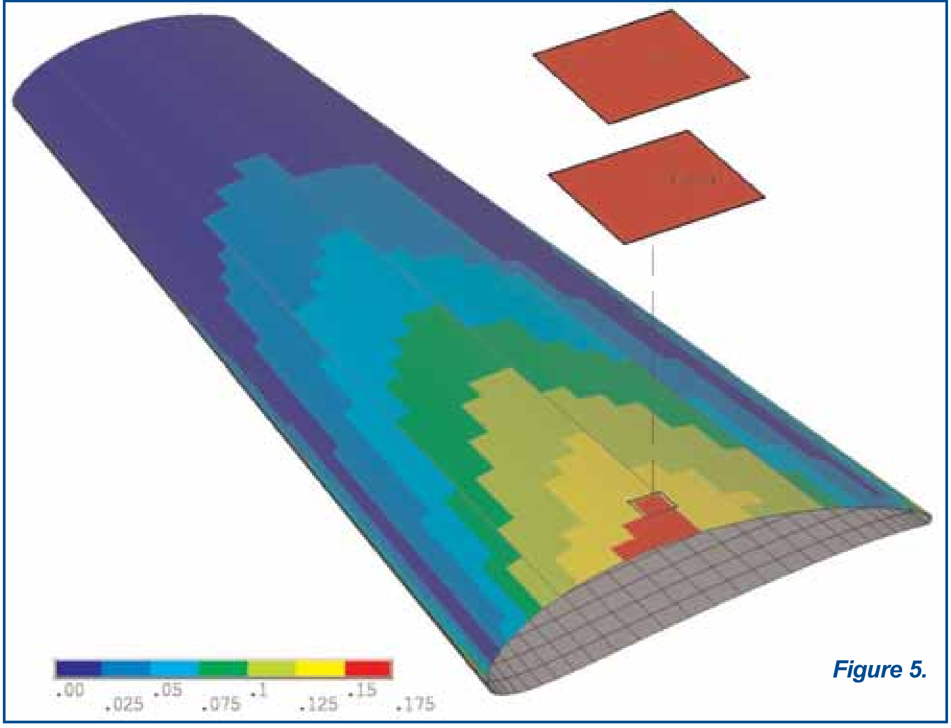

Figure 5.

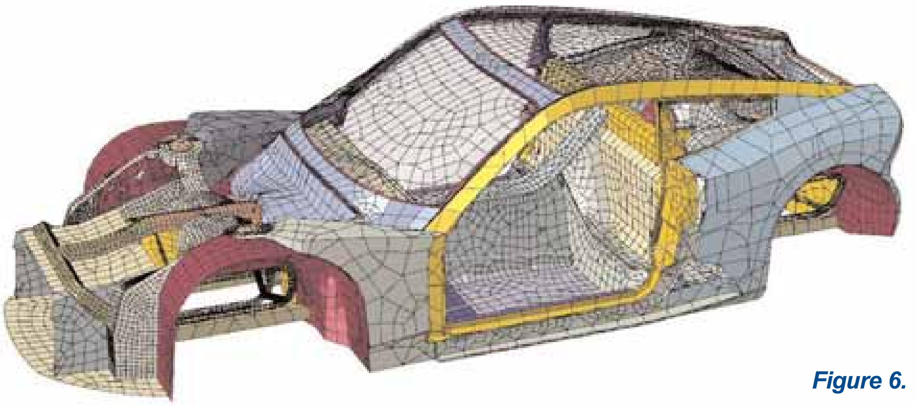

Figure 6.

of a drive shaft (Figure 2), weight minimization of a high-performance wing (Figure 5) and the weight minimization of a sports car chassis structure (Figure 6).

The first design study carried out was a multi-objective design optimization of a drive shaft, shown in Figure 2. The drive shaft was locally reinforced at the ends and the lay-up was defined for sub-laminates, which are manufacturing-related components and which are used to assemble laminate sections for the FEA as shown in Figure 3. The mass was minimized while maximizing its load carrying capacity and in this multi-objective optimization the user makes the final trade-off between the best designswhich was a compromise between mass and safety.

Another design example is the minimization of the mass of a high-performance aircraft wing. Constraints were imposed on the stiffness and strength and several load cases were considered. This application had approximately 150 design variables. Figures 4 and 5 show a simplified model of the wing and its internal support, the actual application confidential.

The final application is the design of a composite monocoque chassis for a sports car, Figures 7 and 8, called the Electric Race About (ERA) and developed by the Helsinki Metropolia University of Applied Sciences team for the Progressive Automotive X-Prize Competition [6]. This is considered a next generation sports car, noiseless and clean. With electric powertrain and ultra light body construction, both based on the latest technology, the energy consumption will be extremely low. The composite monocoque is constructed from carbon-epoxy prepregs and PVC foam core (Gurit SPRINT and Corecell). ABAQUS and ESAComp were used for FEA and laminate analysis/design, the models shown in Figures 1 and 6. Manual design iterations provided

Figure 7.

Figure 8.

Figure 9.

Figure 10.

first design with a final weight of 93.8 kg (4 material systems used). Then a modeFRONTIER + ESAComp optimization approach was used for refining the design using 3 material systems with 2 reinforced plies and 1 core material. This resulted in 39 Sub-laminates and 28 different laminates over 41 regions/shell sections. For the optimization the number of design variables was 137 and almost 4.000 were designs computed automatically. This produced a composite monocoque chassis design with a torsion stiffness of 14.500 Nm/deg and an optimized weight 83.7 kg, reducing the original design weight by 10.1kg or 10.8%. This was very successful but it indicated that there is still potential for further weight reduction by increasing the number of material systems and using thinner layers.

Images produced courtesy of Electric RaceAbout Team, Helsinki Metropolia University of Applied Sciences and SMG Werft AG.

Literature

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[5] modeFRONTIER web site at www.modefrontier.com

[6] ERA, Electric Race About (www.raceabout.fi/era/) developed by the Helsinki Metropolia University of Applied Sciences team for the Progressive Automotive X-Prize Competition (www.progressiveautoxprize.org).