SIMULATION OF CARBON-ROVING-STRUCTURES – EXTREME LIGHT AND STRONG BY FILAMENT WOUND REINFORCEMENT

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KEYWORDS –

CFRP, rovings, natural beam behavior, flux of forces, filament wound reinforcement, ANSA-scripting, optimization

ABSTRACT –

Actual high-tech carbon fiber technology using 24k and 48k rovings allow high performing structures of optimal weight and strength in tracing directly main fluxes of forces.
The application of local forces is managed by using metallic socket inserts embedded into loops of rovings.
A new strategy of filament wound reinforcement of endless rovings, represented by a path of beam elements, is presented, using ANSA's scripting capabilities to automatically generate a cohesive composite, ready to use for FE-analysis. This modelling technique is based on the traces (curves) of the winding.
The bonding between the rovings is performed using a statistically distributed mesh of short beams that represent the resin characteristics.
With a prior optimisation step, using a simple truss-based structure, the needed minimal amount of rovings can be estimated.
An estimation of the limit load of each roving is performed using a set of natural generalized beam forces as yielding surface.

TECHNICAL PAPER –

1. INTRODUCTION

Ultralight framework-like structures made of carbon rovings offer a wide range of applications in all kind of industry, including robotics, aero- and space-technology or even agricultural machines deploying liquid fertilizer with large spanwidth frames.
The specific advantage of a roving-wound frame is its capacity to represent all main paths of forces that are needed as a minimum set. The spatial paths may be detected by optimization procedures, using, for example, a standard framework model indicating the required cross sections for a specific design-stress.
Modern roboting-machines will allow in the future to wind and place the roving material automatically exactly on the intended paths.
We present a tool, integrated in ANSA, to model these kinds of filigran constructions in an easy way, using simple beam elements which are based on CAD curves. These threads of beams are automatically interconnected by interlacing randomly arranged beam elements, representing the bonding synthetic resin. Any surrounding FE structure is glued in the same way to the framework.
The functionality for standard 24k rovings has already been proven by some test specimens and will be tested intensively in the near future to allow a prediction of reliability for force-deflection behavior as well as for failure-prediction.

2. MODELING TECHNIQUE

As there is no economic way to model e.g. 24000 single filaments within a real structure of rovings, a path of beam elements for the entire roving is used. This proved to represent a pragmatic and quite exact abstraction of the force-displacement-behavior of a complete carbon roving.
The natural beam deformations together with the carbon stiffness may be exhaustively described with the following definitions (Figure 1):

- elongation by a normal force
  (→ shortened, extended)
- symmetric bending in two orthogonal planes by symmetric moments
  (→ symmetric bending angles)
- asymmetric bending in two orthogonal planes by asymmetric moments
  (→ asymmetric bending angles)
- twisting along the beam axis by torque moment
  (→ twist angle)

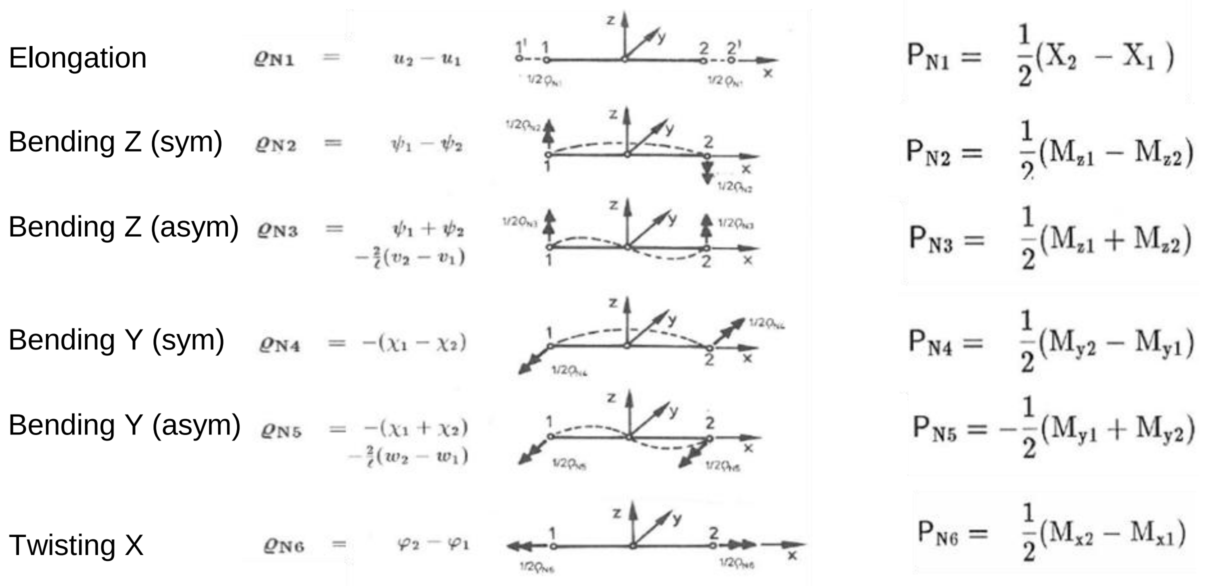

Figure 1 - Set of natural modes and natural forces [1]

The second asymmetric bending mode is needed for the transversal stiffness.
As the elastic behavior of a beam is well represented (Figure 7) the failure behavior can be modelled, using a yield-surface which is formed by normed moments and normed forces. As shown in [1] the yielding of beam frames may be represented as an interaction of normal forces and bending moments, which refer to a yielding force or a yielding moment, respectively.
For different beam cross sections the failure behavior under stretching and bending of homogeneous material is well known and follows parabolic surfaces as shown in Figure 2 where three kinds of cross sections are mentioned.
In this presentation the roving beams are restricted to circular and rectangular cross sections.

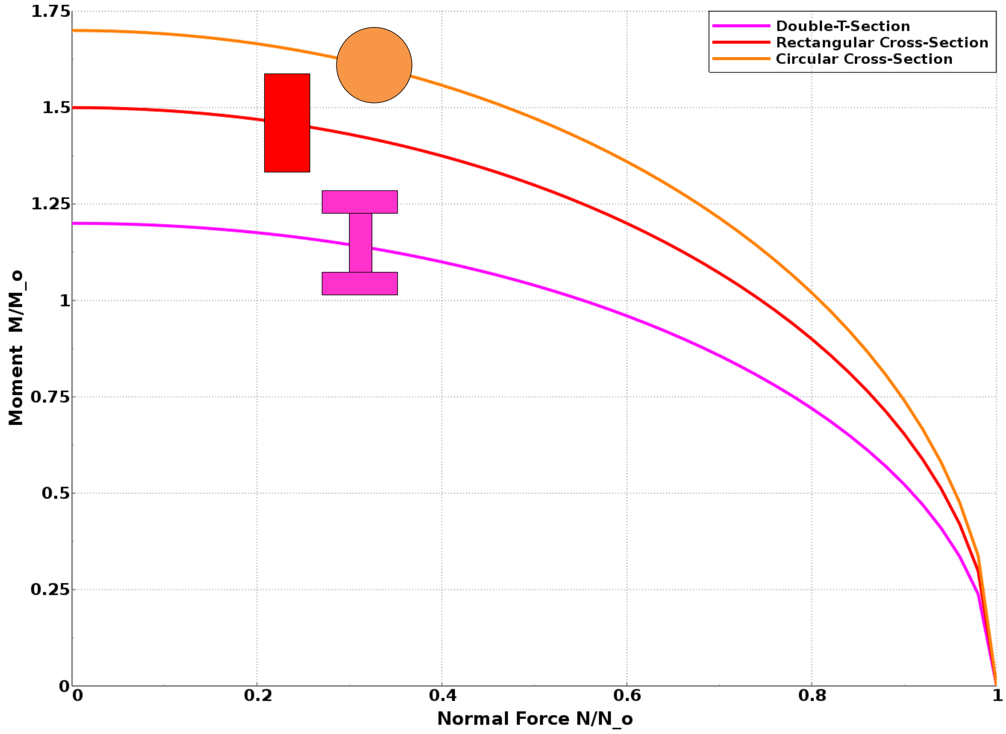

Figure 2 - Beam yielding surface [2]

3. FROM GEOMETRY CURVES TO THE BEAM MODEL

A Python script has been developed in order to create the roving beam elements of the appropriate diameter and orientation out of existing CAD curves in ANSA (Figure 3).

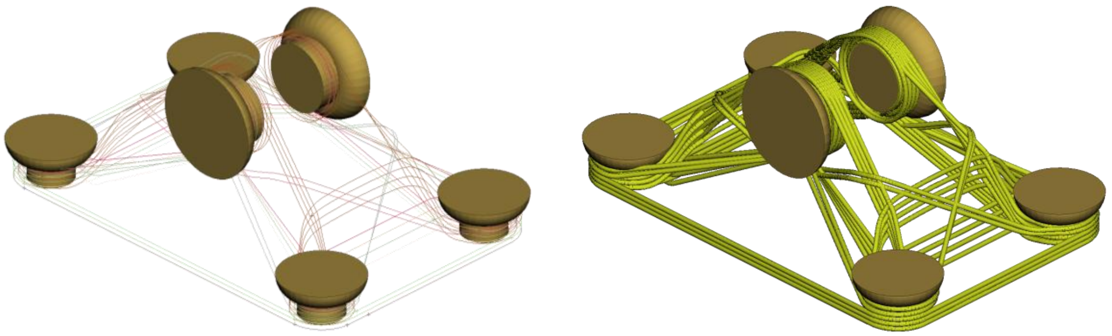

Figure 3 - Roving beams from CAD curves

Different standard roving sizes like 6k, 12k, 24k or 48k (the name depicts the number of single filaments within the roving; 24k means 24000 filaments), among some other adjustments, can be specified via a small GUI.
As the fiber volume fraction of a completed carbon thread is between 60 and 65% the resulting beam diameter is calculated accordingly for the different sizes.
The connectivity between the roving beams and socket inserts or other underlying parts as well as between the roving beams themselves is realized by small circular beam elements with a resin stiffness (Figure 4). These tentacles are first created as perpendicular beam spiders along the roving path and finally auto-pasted to connect the FE structure.

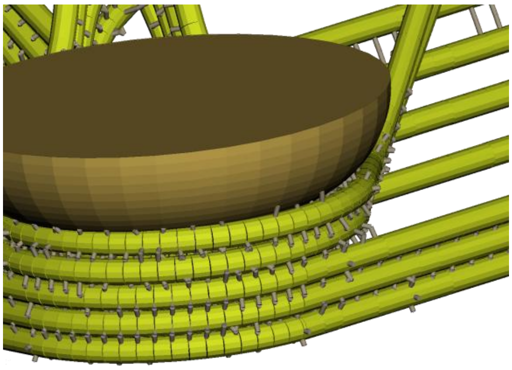

Figure 4 - Connecting beams

The roving beam cross section is assumed to be circular. In areas of roving crossings and where rovings are attached to the inserts or additional parts, the cross section of the roving beams can be adapted to a rectangular shape in order to capture the local flattening of the roving. The z-axis of the local beam element coordinate system is always oriented normal to the surface or to the crossing in these cases (Figure 5).

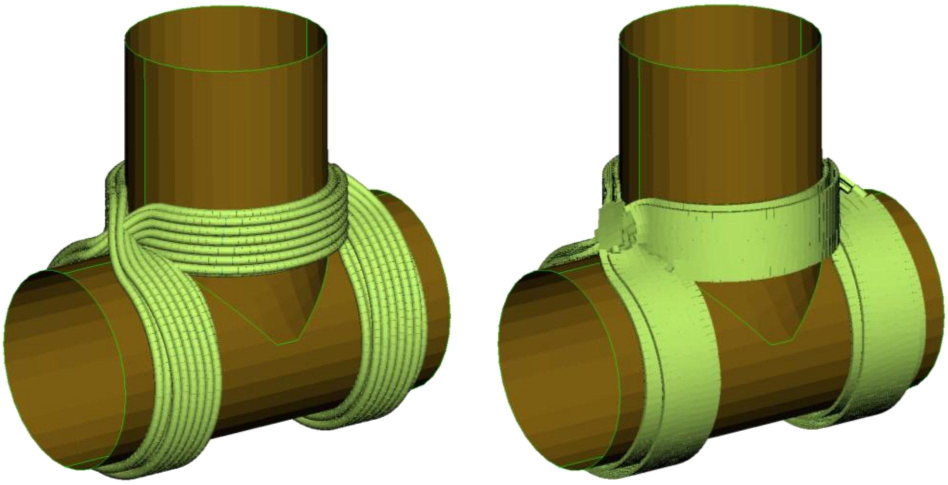

Figure 5 - Roving beams with circular and rectangular cross section

4. EXAMPLES

The calibration of the connecting spider beams is performed by using different specimen of simple structures as depicted in Figure 6 and Figure 7. Many types of roving crossings, squeezing the roving cross section into different shapes, have to be tested and used for the calibration of the presented roving modelling for bending, stretching and twisting.

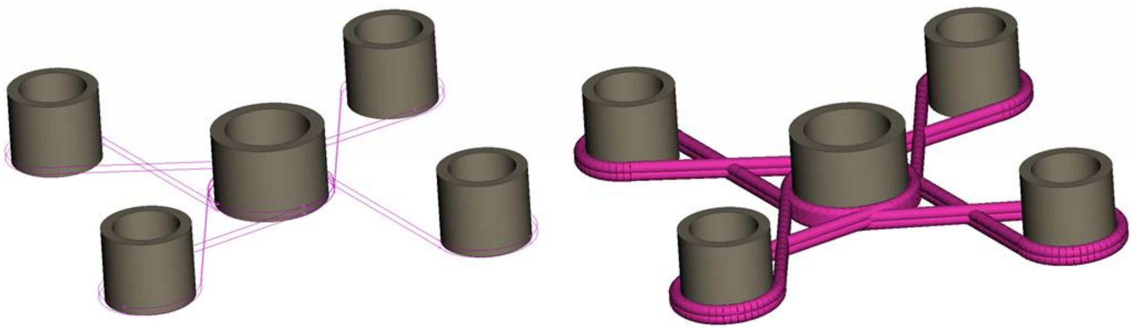

Figure 6 - Test specimen for bending, torsion and failure aspects

For the calibration of shear stiffness a standard 3-point bending test of a slender rectangular CFRP rod is used which consists of densely packed roving material. The model of the rod is built by a set of regular arranged curves which are automatically and randomly connected by the spider beams. Their stiffness may now be used for the calibration of shear behavior, see Figure 7.

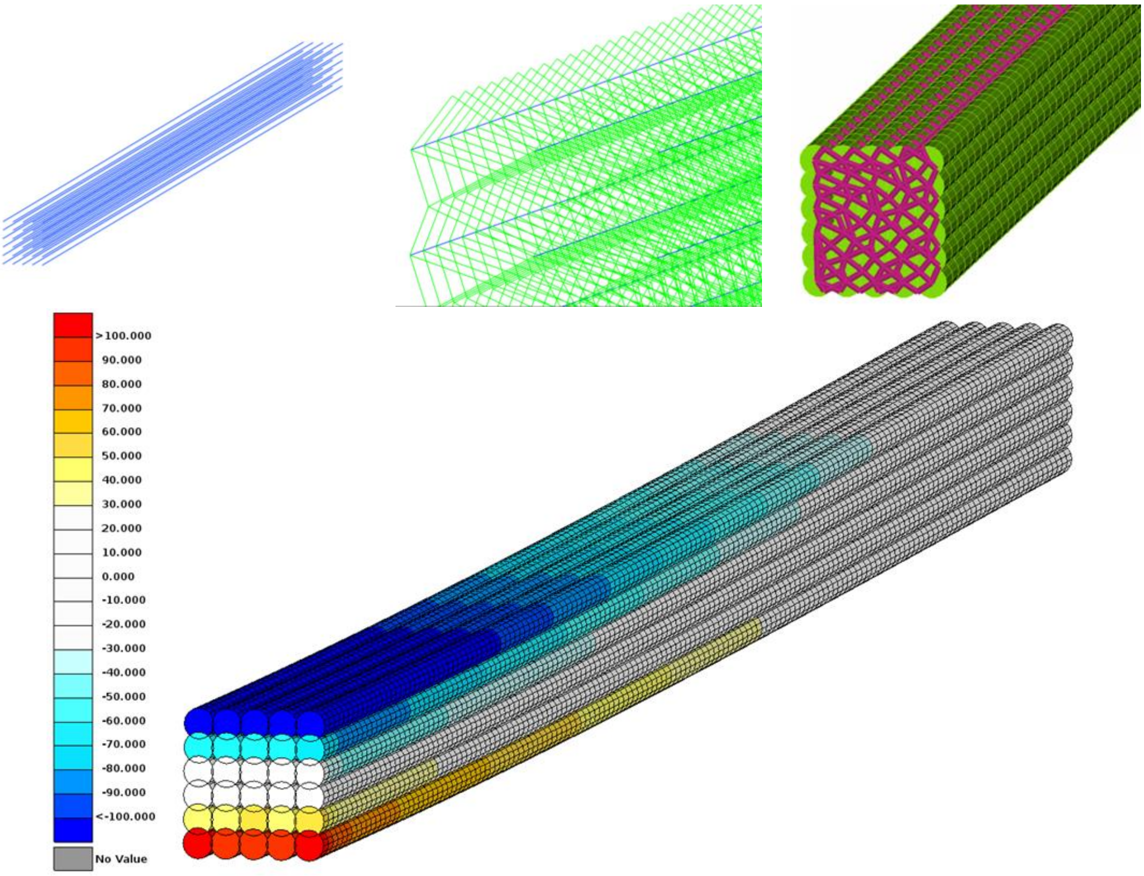

Figure 7 - Bending of rectangular strut, load 40N, deflection 2.1mm (measured 2.0mm)

An actually manufactured CF-bracket, whose structure was experimentally optimized, was modeled with the presented method (Figure 8). The test was in a good agreement with the nonlinear simulation, especially the stiffness agreed very well. This small bracket with a weight of about 50g could sustain a loading of 2t. The failure of the structure appeared as expected at some high curvatures of the roving paths.
An optimization is therefore using the above mentioned bending moments and shear forces of the beams as failure indicator and optimization constraint.

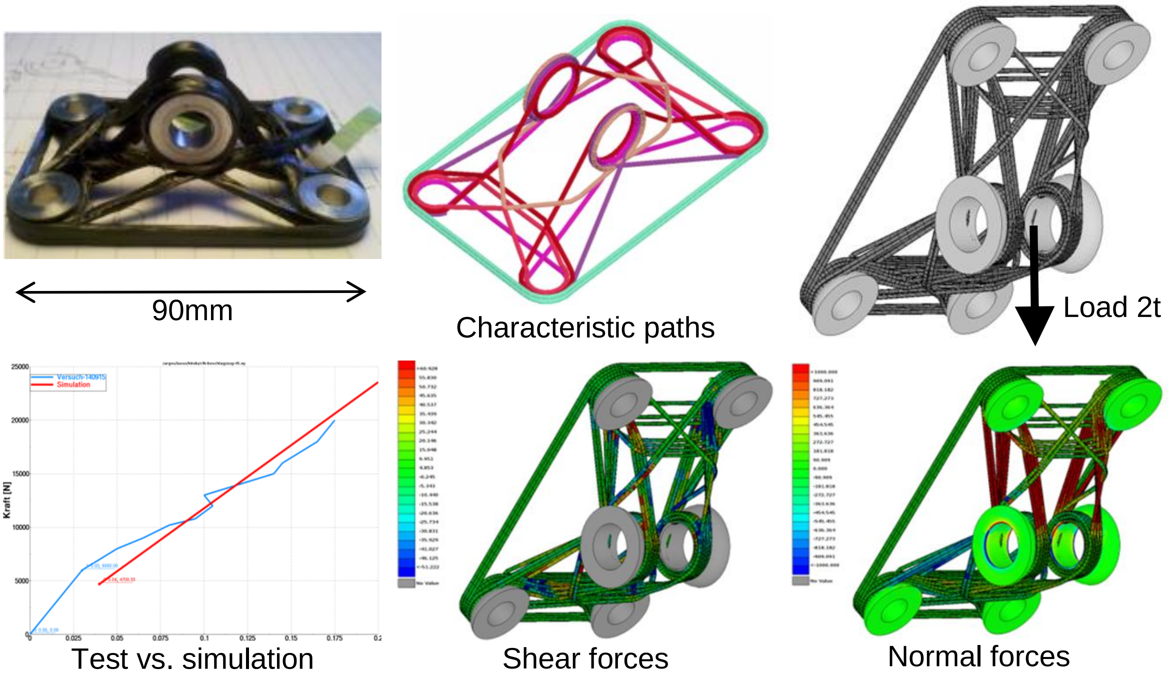

Figure 8 - CF bracket

The junction of prefabricated CFRP tubes of different size and stiffness may be connected by a minimal set of roving loops as shown on Figure 9. The automation of the fabrication (winding-process) as well as the optimization procedure is object of current research.

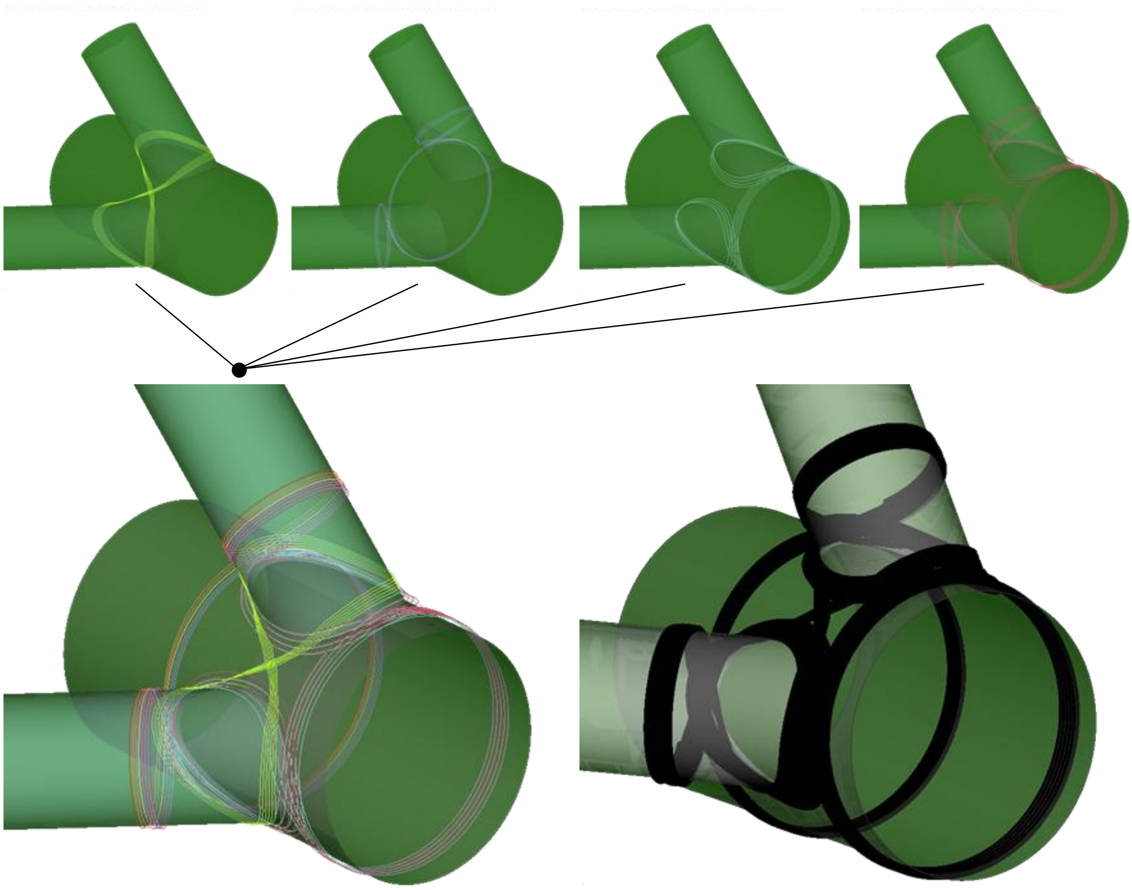

Figure 9 - Connection of CFRP tubes, realized by a combination of different roving loops

The special properties of roving wound structures where known force paths are used for example in torsional twisting of thin-walled tubes as shown in picture (Figure 10) may now be easily implemented. Here the typical winding in regions of load transmission is modelled in a very discrete way. The anisotropic behavior of the uniformly manufactured tube may be represented by a standard shell structure with anisotropic layer definitions.

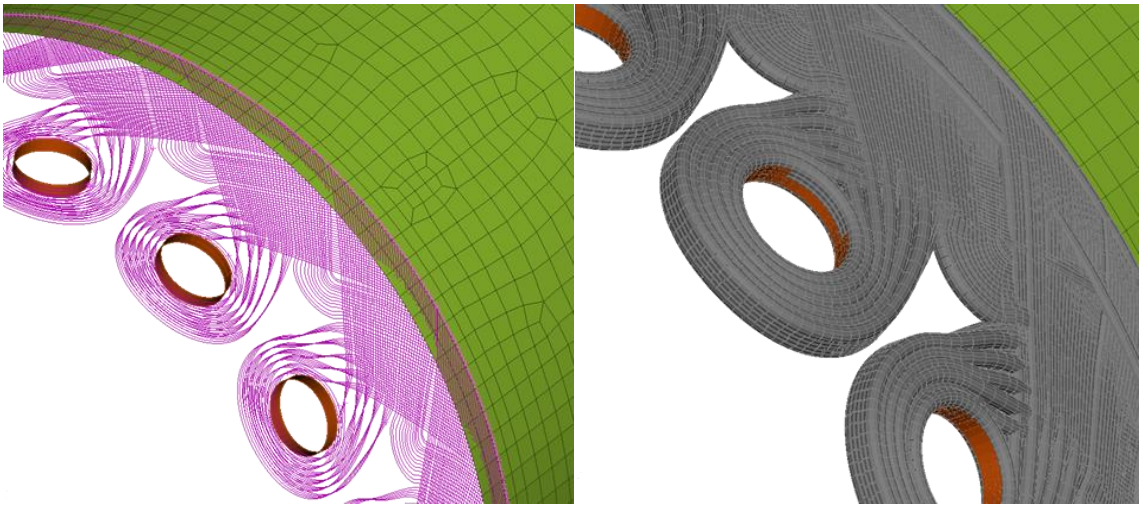

Figure 10 - Torsion rod

Finally a simple example of a bracket, modeled via a framework of beams, is used to demonstrate a pragmatic optimization procedure, using the solver independent optimization tool LS-OPT in conjunction with ANSA, META and ABAQUS (Figure 11 - Figure 13).
Two different load cases are considered to minimize the weight of the structure by varying the beam diameters and having the normal stresses of the beams as constraints.
With this information a winding procedure may be defined afterwards which creates a set of rovings according to the required diameters along the different force paths.

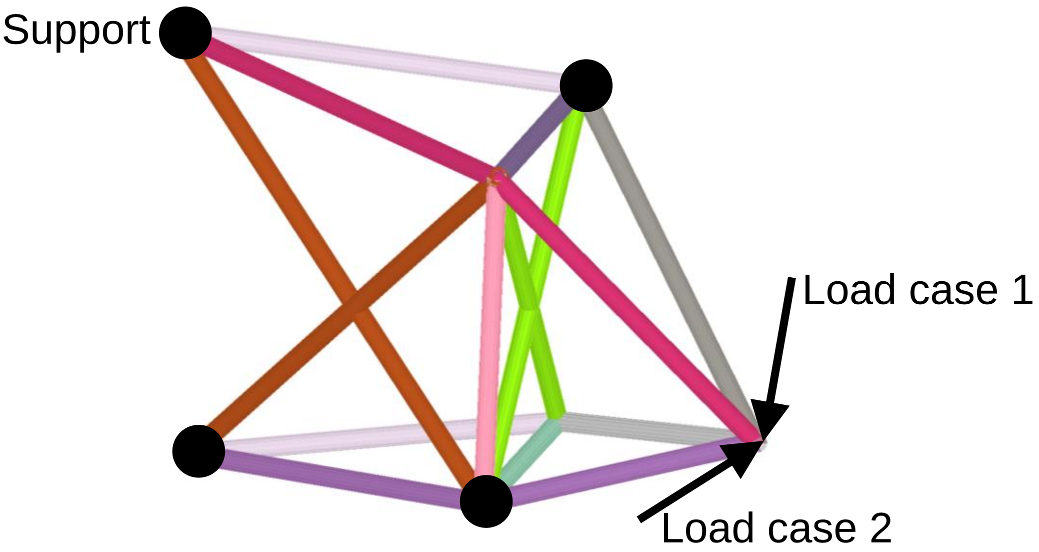

Figure 11 - Bracket, beam framework, starting design with constant diameters

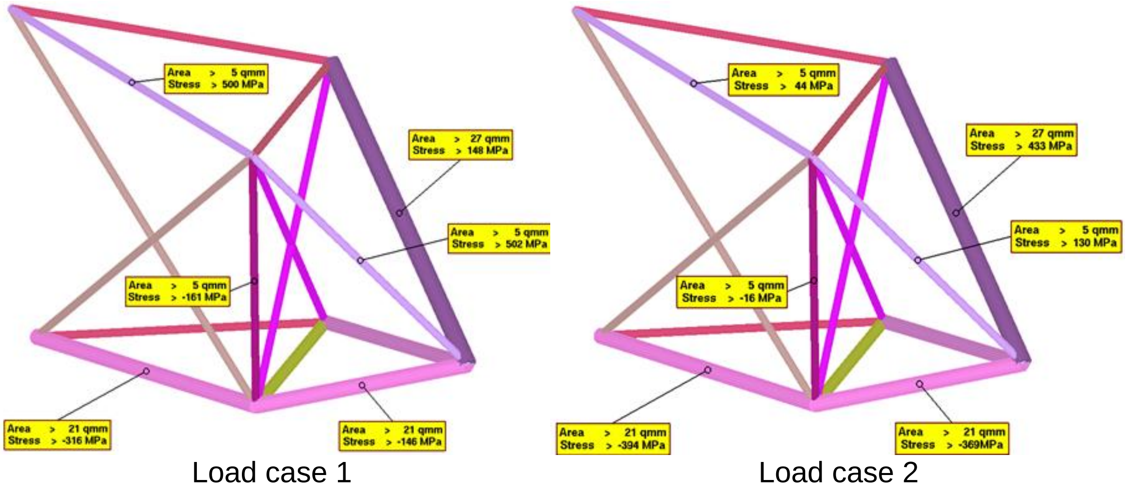

Figure 12 - Optimized bracket

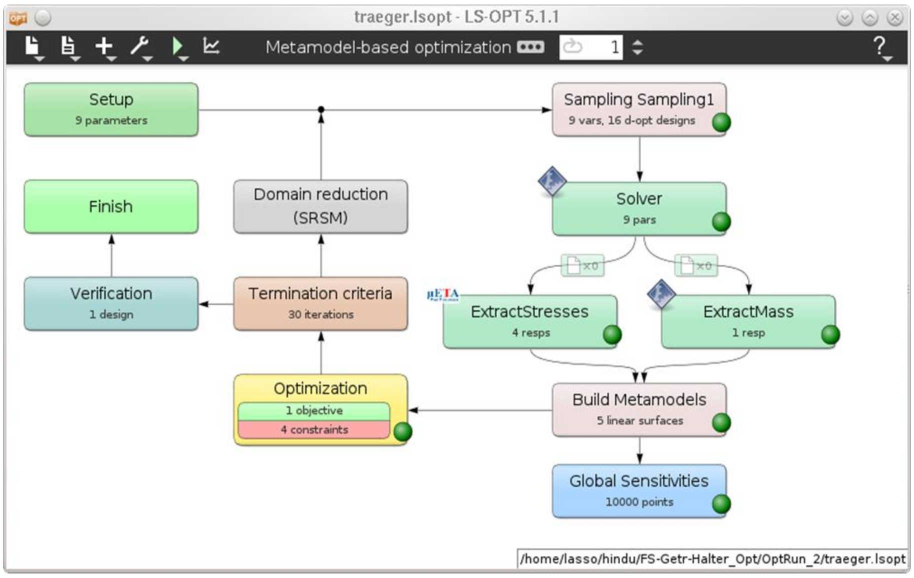

Figure 13 - LS-OPT optimization scheme for bracket

5. CONCLUSIONS

The above presented modeling technique is actually under intensive development. Especially the deformation behavior of the rovings at internal crossings has to be investigated further and certified. The brittle failure of the rovings under these special conditions has to be widely tested and calibrated to existing material laws.

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