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Virtual development and numerical simulation of 3D braids for composites

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Abstract. The 3D maypole braiding process is characterized with complex and often variable tracks for the carriers. During the last years smaller size (4x4 horn gears or larger) variable track machines become available on the market and the areas of industrial application of these increased. The design of the new products and the controlling of such machine is complex task, possible only with process simulation. The latest development of the algorithms and their implementation in the TexMind Braiding Machine Configurator software allows numerical simulation of any configuration of maypole braiding machine, with variable tracks. For the simulated geometry of the 3D braids an automated FEM mesh generator is developed, so that the input file for LS-Dyna is created automatically from the machine configuration. This speeds up significantly the preparation process of the FEM data and allow rapid numerical simulations of the mechanical properties of the different configuration of braided structures for composites

1. Introduction

The 3D braiding process allows production of complex profiles with larger changes in their dimensions and form [1]. Shell structures can be created during the overbraiding of complex mandrels and solid structures can be created if more carriers with several interlacing tracks are used. 3D Braiding allows as well development of mesh type structures and any combinations. There are different 3D braiding techniques, depending on the practical realisation of the carrier motion – row and column (cartesian) braiding [2], 3D braiding based on the lace principle [3–5], maypole 3D braiding [6][7]. The first two principle are implemented in a few single machines and the last one – the maypole 3D braiding principle become larger industrial application during the last time [8, 9]. The maypole 3D braiding has advantage against the two other principles in the productivity – the braiding process can (but should not) stop only, when the switches have to change their state, the remaining time they can run with 100 or more revolutions per minute of the horn gears, where the speed depends on the material and not on the machine limitations. The profiles, produced on such machines can have complex cross section without any stitching process – and because of this a lower danger of delamination is expected. Actually, the design of such profiles is complex task. This paper demonstrates the process of numerical simulation of the braiding process, generation of the idealized forms of the profiles and the relaxation of this geometry using FEM software LS Dyna.

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2. Emulation of the braiding process and generation of idealized 3D braids

The motion of the carriers of any maypole braiding machine can be predicted numerically, as presented in [10]. All process related parts of the braiding machine – horn gears, carriers, switches – are modelled as objects in C++ language, and their motion laws are integrated in the time. The coordinates of each carrier in the x-y plane are obtained as result of this simulation. The idealized braid is received, as to each calculated position a z-coordinate is assigned

$$z(t) = V_{Take\_off} \cdot t \tag{1}$$

Where v_{Take_off} is the take-off velocity and t is the current time. The horn gears have significantly larger diameter $D_{HornGear}$ than the yarns, which means, that if the motion of the carrier is taken as basis for the yarn coordinates, the braid would be ticker than in the reality. To avoid this, x-y coordinates are scaled, based on the relation between the size of one ridge in the braid D_{Ridge} and the horn gear diameter [11]:

$$\xi = \frac{D_{HornGear}}{D_{Ridge}} \tag{2}$$

The scaling lead to the following set of coordinates for each point:

$$\left| \begin{array}{l} x_{scalled} = \dfrac{x_{Carrier}}{\xi} \\ y_{scalled} = \dfrac{y_{Carrier}}{\xi} \\ z_{scalled} = V_{Take\_off} \cdot t \end{array} \right. \tag{3}$$

All these coordinates are used as centre lines for the yarns, which are visualised in the form of tubes, sweeping circular cross section within the C++ and VTK based software TexMind Configurator. After the first report about the developed software in 2014 [12], its practical application for development of complex braided profiles for composites was demonstrate in [13, 14]. The latest development of the algorithms and the user interface allow simulation of braids with variable cross section [15], where the state of the switches and the time of their change is recorded and used in the simulation.

3. Application examples

Figure 1 demonstrates configuration of braid, similar to 6-track based solid braid, but with small differences in the configuration. All yarns in the central area of the braid are connected, but the yarns, working on the edges build separate small regions, which can be used for simpler connection to another parts. The edges are in this case thinner and allow for instance stitching with reduced resistance of the needle. Figure 2 demonstrates the simulated profile in top and side view.

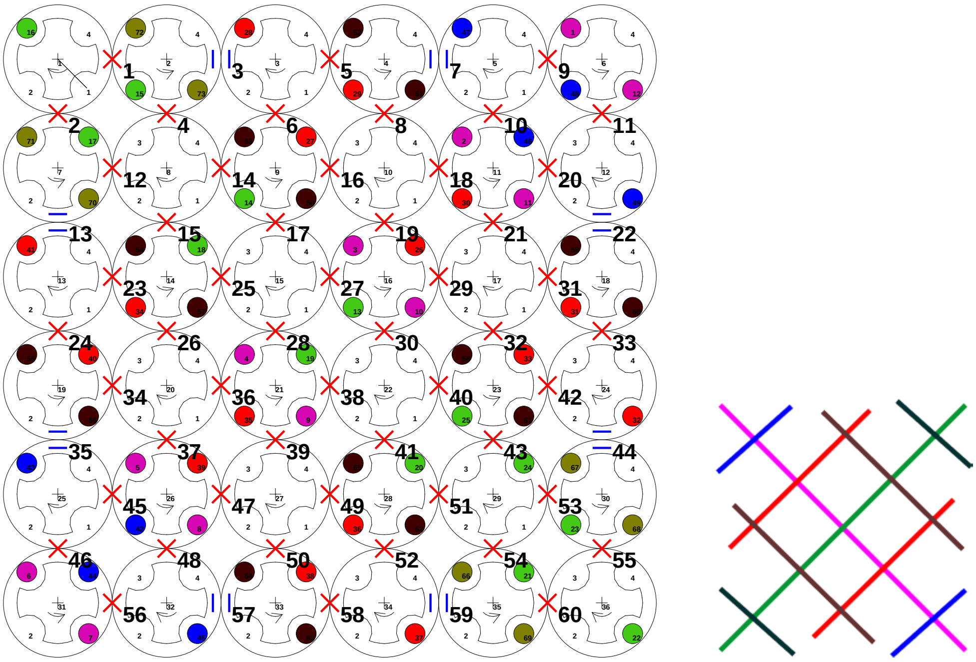

Figure 1. Braiding machine configuration for production of solid braided structure with not full connected 10 tracks

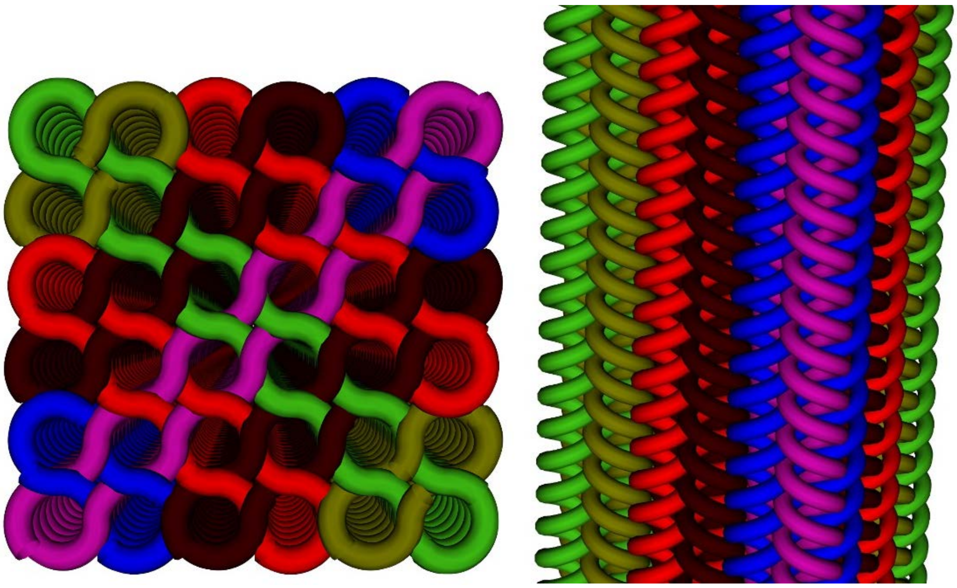

Figure 2. Idealized 3D simulation of the braided structure from the machine, presented in Figure 1

Figure 3 presents a configuration for the production of T-profile, based on one track. As found in [13], such configuration require not only gears with five slots on the turning points, as usual for flat braids, but as well five slots gear in the point, where the two tracks are crossing. In other case the arrangement of the carriers is not possible with that density. The 3D simulated structure in this case is based on less number of key-points. From the motion of one carrier along an angle, corresponding to one slot, only two points are taken into the structure. In this way the topology of the braid is preserved, but the simulation at the next steps can be performed faster, with less number of elements.

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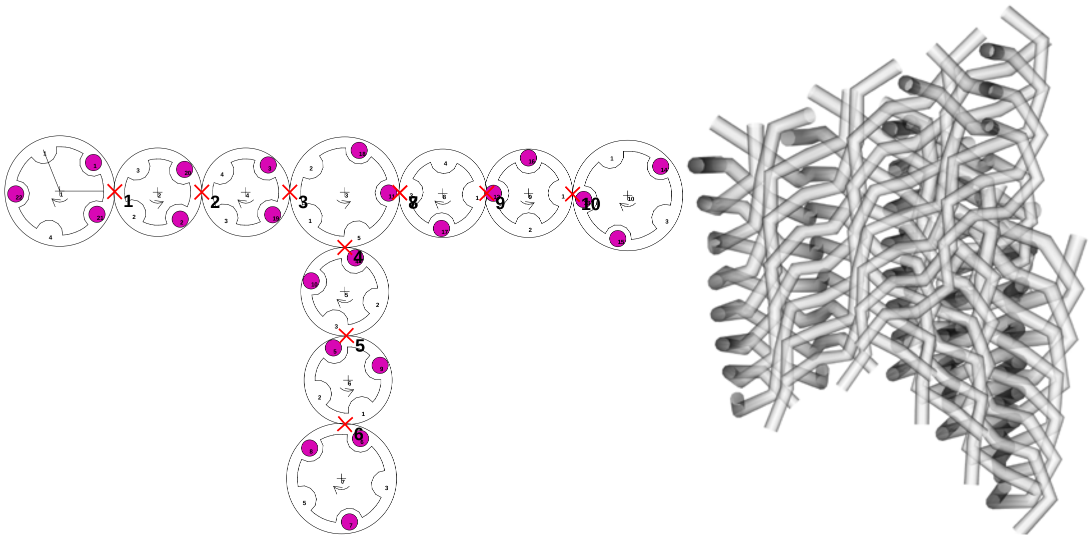

Figure 3. Configuration for production of short T-Profile with one track and the simulated 3D structure

4. From geometry to FE Mesh

The created braids with the software present idealized state of the real products only. The accuracy of the geometry can be improved by the use of different methods for mechanical or at least contact-detection algorithms. In the current case and automated export to LS-Dyna (LSTC) is implemented and tested (Fig.4). The yarn axis points from the 3D viewer are taken and the corresponding commands for LS-Dyna are created. The complete export is implemented as C++ library within the TexMind 3D Viewer.

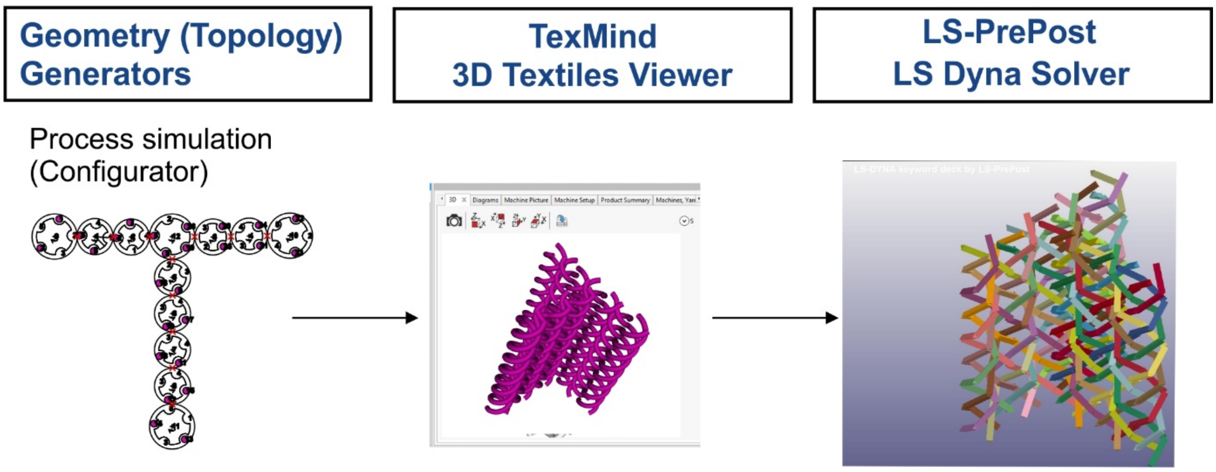

Figure 4. Simulation line from machine configuration, trough idealized geometry to FEM mesh

5. Export tests

The exporting interface is tested first with a tubular braid (Fig 5) with which as well tensile test simulation is performed. The deformed state of tubular braid are visualised in Fig. 6. The simulation results demonstrates the capability of the method and the correctness of its implementation in the software.

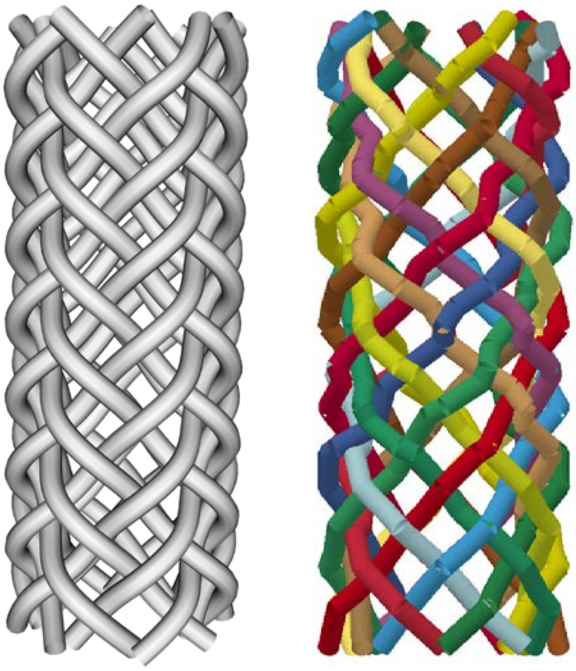

Figure 5. Tubular braid, generated with the TexMind software after import in the LS-Dyna as beam mesh.

Figure 6. Stages of the simulation of tensile test of the tubular braid

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6. Complex profile example

Figure 7 demonstrates simulation of the deformation of the T profile, presented in figure 3. Such one deformation will happens for instance during the pultrusion process, where the product works under tension. The sample demonstrate that the outer areas of the structure have larger displacements in Y direction compared to the middle yarn pieces of the profile.

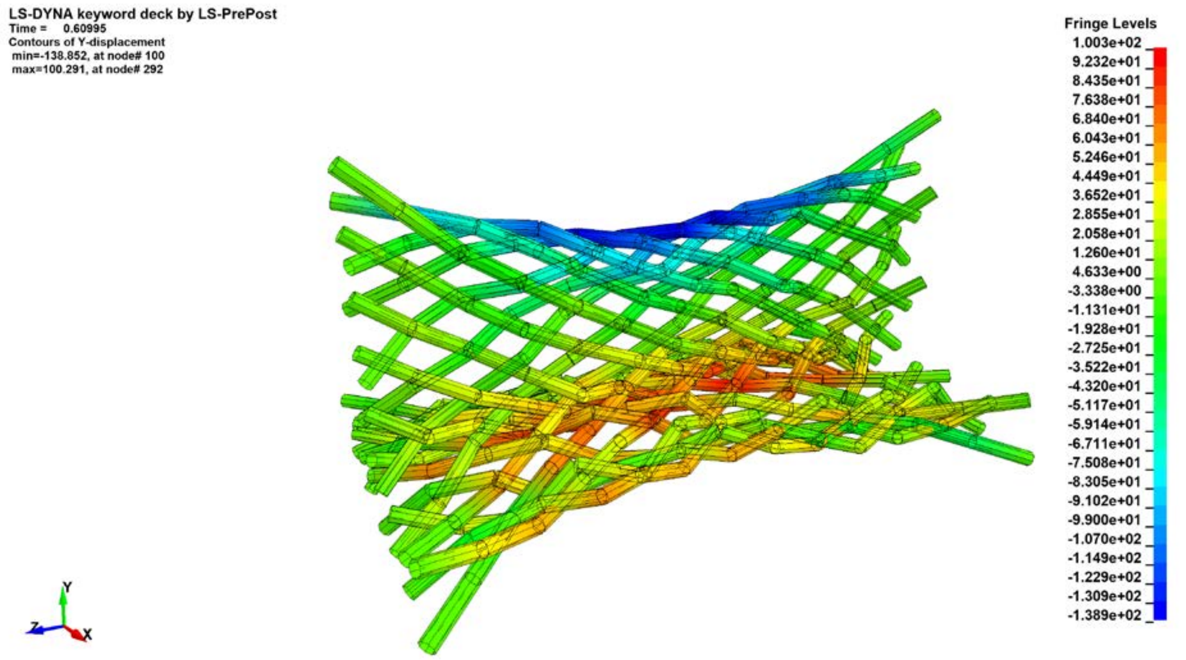

Figure 7. Deformation of braided structure with T-form of the cross section, simulated with the LS-Dyna

7. Conclusions

This work presents method for automated preparation of the simulation data of complex braided profiles for composites. The workflow starts with the common for the braider interface, where the machine and its carrier arrangement are defined and leads automatically to the input file for LS Dyna simulation software. The export is tested and verified with simple tubular structure. The developed tools can be used for any braid, created on 3D maypole braiding machine. The only disadvantage of the method is, that the generated mesh is based on not relaxed geometry, so initially a relaxation step with proper material data for the yarn has to be performed, if high accuracy of the simulation results is required.

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