24th International Symposium on Automation & Robotics in Construction (ISARC 2007)
Construction Automation Group, I.I.T. Madras

3D LOOM – AUTOMATED DESIGN AND MANUFACTURING OF TAILOR-MADE HIGH-TECH FABRICS

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ABSTRACT

Today high-tech fibres such as glass or carbon fibre are used for a wide range of applications, e.g. aviation, navigation, and even astronautics. Innovative ultra-light flexible membranes and stiff shells are utilized wherever the combination of lightweight and high rigidity is needed.

A even newer area will be the construction sector, introducing high efficiency in relation to stability, thermal insulation and of course weight for completely new levels of innovative freeform and high-tech architecture.Unfortunately nowadays' production of these materials has little relation to high-tech, but mostly to handcraft. To utilize theses materials even for cost effective applications an new way of automated and efficient manufacturing has to be developed: By bringing together latest standards of computer simulation and innovative robotics, the efficient production of mass customised high-tech fabrics can be realized.

KEYWORDS

High-Tech Fibres, Composite Materials, FEM, CAD/CAM, Robotics

1. INDUSTRIAL BACKGROUND

The invention of high tech fibres such as carbon or glass fibre has been revolution nary for various fields of engineering. Especially the industries focusing on an efficient power-to-weight-ratio (e.g. vehicle and aircraft construction) profited by these new ultra-light and rugged materials.

1.1 Types of Fibres/Composite Materials

There is a wide range of high tech fibres and composite materials available for all kinds of application, featuring very little weight combined with high stiffness, braking strength and abrasion resistance.

All are based on small extremely strong fibres, such as glass fibre or carbon fibre, as well as aramid fibres (e.g. Kevlar or Nomex).

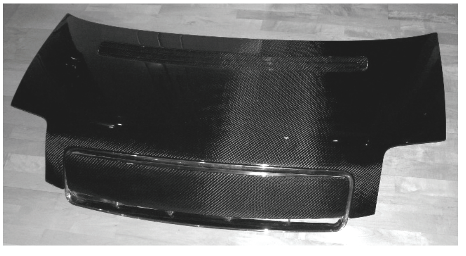

Figure 1 Lightweight Race Car Hood Made of CFRP

They can be used for two general types of applications: Flexible Membranes (e.g. clothing) and stiff shells (e.g. car parts, Fig. 1).

In the majority of cases these fibres or fabrics are combined with other materials in a composite or sandwich structure. Often Membranes are based on layers of different fibres and added foils or coatings for impregnation or UV resistance. To produce stiff shells, several layers of fabrics are compounded with liquid plastics such as epoxy, polyester or nylon combined with hardeners (so called fibre reinforced plastics, e.g. glass fibre reinforced plastic (GRP) or carbon fibre reinforced plastic (CFRP)).

1.2 State of the Art in Manufacturing Fabrics and Composite Materials

The fibres itself as well as semi-finished products are manufactured by full automated production lines, enabling stable quality and cost effectiveness at the same time.

The final products however are mostly handcrafted as unique or limited lot production. The main reason for that is the complex handling of the materials: All composites and many membranes consist of several layers of fibres, foils or fabrics, which have to be separately glued, sewed or cast. Reinforcing the almost homogeneous components means extra layers of holohedral or pre-cut material, which have to be processed the same way.

Due to the small number of units the formwork for the composites is mostly handcrafted as well.

1.3 Possible Use of Prefabricated Fabrics in the Construction Sector

The relevance of using high tech fibres as structural component in architecture is obvious. Keen architectural design as well as the need for higher and bigger high tech structures can only be realized by using modern materials and instruments.

Stability and stiffness combined with durability were sought-after features from the beginning of construction industry, but now theses fibres can add “light-weight” as an additional value.

Self-supporting facades, freeform bearing structures or long-span membranes are only a few of the multiple applications in architecture.

2. CUSTOM-TAILORED FABRICS WITH ORIENTED FIBRES

The fabrics and semi finished products today available all have a preferably homogeneous structure to fit as much applications as possible. The fibres are either woven to a tight fabric or scattered to a more or less unoriented mesh. (e.g. CFRP and GRP; Fig. 2)

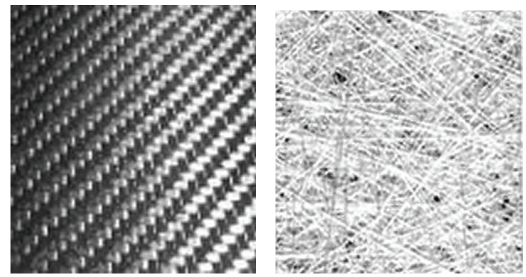

Figure 2 Conventional Orientation of Fibres (CFRP and GRP)

The tear proof fibres are structured preventative in every direction to balance every possible loading condition. This universal approach works for rather small work pieces, but realizing larger structures for the construction sector will become very inefficient by causing lots of cut-off waste and unnecessary working steps for layering etc.

2.1 FEM-Simulation

Simulations based on the finite-element method (FEM) are well proven in many engineering disciplines, such as mechanical or aeronautical engineering. It is used to solve complex structural analysis problems, incorporating for example elasticity or torsion under various load cases (Figure 3).

Architects and civil engineers started using these simulations few years ago to handle new architectural challenges by far too complex for conventional methods of static calculation.

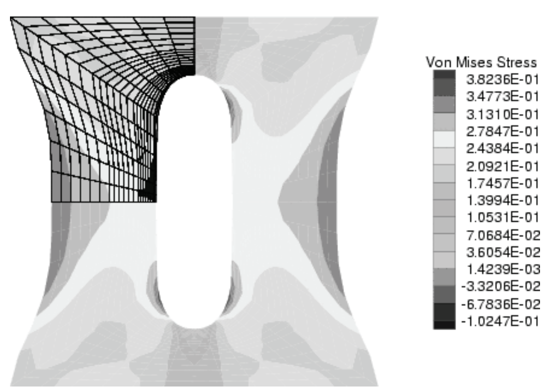

Figure 3 FEM Analysis of Structural Element

2.2 From Stress Splines to Fibres

Software using the finite element method (FEM) for structural analysis can determine exactly the progression of torque and stress for every individual application or loading condition. Translated into a mesh plot the principle stress distribution can be shown in diagram-like lines, providing the basic scheme for the run of the fibres in the fabric(Fig. 4). So instead of a homogeneous fabric or tissue (Fig 2) the amount of fibres and alignment of every single strand is defined by the results of the structural analysis.

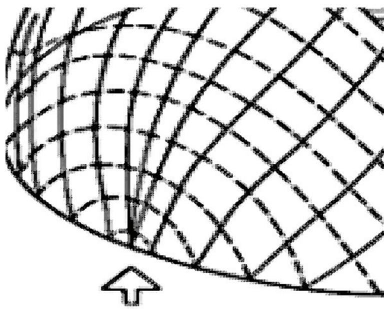

Figure 4 Simplified Scheme of Stress Splines in Cupola Segment

3. TECHNICAL IMPLEMENTATION

3.1 Link-up of CAD, FEM and CAM

The connection between Computer Aided Design (CAD), Finite Element Method (FEM) and Computer Aided Manufacturing (CAM) is well established in many industries. And even the construction sector uses the link between FEM and CAAD to analyse complex designs and structures. There is a variety of data formats supporting the exchange of information between theses different types of industrial software applications.

The new Industry Foundation Classes data model (IFC) will simplify the implementation of the needed information even more, providing a detailed and open object-oriented 3D model, which will contain every general data, for instance the layer composition and layer thickness.

The only difference is that in addition to the conventional 3D information of the component itself the results from structural analysis are implemented into the 3D data model as well, defining the precise run of fibres.

While the basic component data is mainly used for the formwork, the mesh plot of stress splines is translated almost one-to-one by the CAM manufacturing unit (Fig. 5).

Figure 5 Alignment of Membrane Fibres Based on the Stress Splines

3.2 Technical Production Setup

3.2.1 3-Axis portal with 6-axis robot

A 6-axis articulated arm robot mounted on a 3-axis portal can translate the mesh plot into a individual fabric, following the simulated tension lines with a “endless” flexible fibre. Trimming of the fibre where needed and injection or spraying of e.g. epoxy or polyester can be done during the same work step. The alignment and amount of single fibres as well as laminated layers is exactly determined by the demands of the it’s future application.

A feeder system provides endless fibres from movable coils and liquids (epoxy or resin and hardener etc.) from tanks (Fig. 6). Depending on the amount and number storage containers, the feeder system can be either mounted on the movable portal or placed separately beside the unit, supplying the robot tool via flexible tubes and ducts.

Covering with foils are additional ready-made fabrics can be realized by a second movable portal, similar to a industrial roll paper feeder.

The speed an precision of this “all-in-one” unit allows a fast and accurate production, the dimensions of the workpiece are only limited by the dimensions of the portal and assembly table.

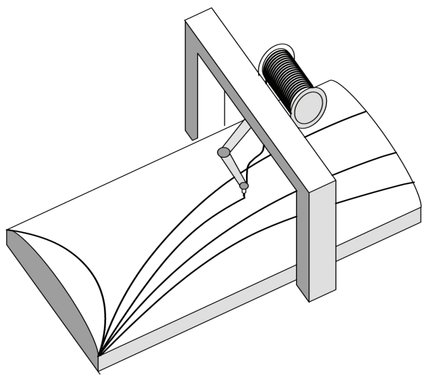

Figure 6 Scheme of Manufacturing Robot Unit

3.2.2 Formwork

Efficient automated fabric production requires a rational way of fabricating formwork as well.

The easiest way is a single-serving mold made of expanded polystyrene. Mounted on the assembly table of the robotic unit it can be processed in a similar way the fabric is manufactured later on. By establishing a milling tool for the robot or even a second robot arm, the Formwork can be millcut with the same 3D information used for the fabric as well. A non-adhesive foil plus a release agent or wax is applied on top.

A more elaborate way to create complex formwork for freeform shells and membranes is a automated formwork table. Under a tense air filled cushion a grid of free addressable pneumatic punches is installed, defining designated points of the form in a 3-axis coordinate system The cushion provides a flush non-adhesive surface and smoothes the 3D Form provided by the punches. Once again a release agent separates mold and workpiece. Vacuum will help to fix the fabric.

4. CONCLUSION

By using this modern technologies of simulation and manufacturing it is possible to produce tailor-made high efficient fabrics for flexible wide span membranes as well as highly rugged and stiff 2D and 3D components like domes or shells with outstanding capacities. Using a seamless chain from FEM simulation to automated CAM production the fabrics will be even more affordable. Setting a new standard in composite production, this development may be compared to the gain of efficiency when hand-looms had been replaced by automatic looms during 19th century industrialization.

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