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Modeling of Selected Properties of Spatial A-Jour Knitted Structures

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Abstract
In this study, innovative technology and a group of spatial 3D knitted fabrics were established. The structures of the new group of knitted fabrics, especially the a-jour structures, will be applied in knitted 3D composites. Using numerical analysis based on the finite element methodology, one can optimise the properties of knitted composites in terms of both rearranging the component elements of the beams and the spatial distribution of their tensions.

Key words: *warp-knittings spatial products, spatıal a-jours, knitted composites, construction elements, numerical analysis by the finite element method – FEM.*

Introduction

Up till now knitted spatial products have been manufactured in the form of distance knitted fabrics built of two external layers and one internal layer between them. These products are manufactured on warp-knitting machines equipped with two needle combs, and their thickness depends on the distance between the needle combs of the machine, which can be equal to 2 ÷ 67 mm [1 - 3].

Nowadays, more and more popular are composite constructions in which the elements of woven fabrics, knitted fabrics or non-wovens are formed after the production process is finished. The 3D knitted fabrics presented are ready-made products which only undergo stiffening with epoxide resin. In the authors' opinion the products presented below can be applied in the building industry and as construction elements of machines and devices.

The novelty is spatial warp-knitted fabrics in the form of regular and irregular solids which are built of more than two external layers and at least one internal layer [4, 5].

The external layers are built of warp-knitted plain stitch fabrics, whereas the internal layer consists of thread segments running between the external layers. The geometry of the knitted solid is strictly defined by the number of external layers. Two different structures can be distinguished in the construction of spatial knitted products: "open", in which the product is neither limited at the top nor at the bottom by the external layers, and "closed", in which the external layers completely close the internal knitted structure.

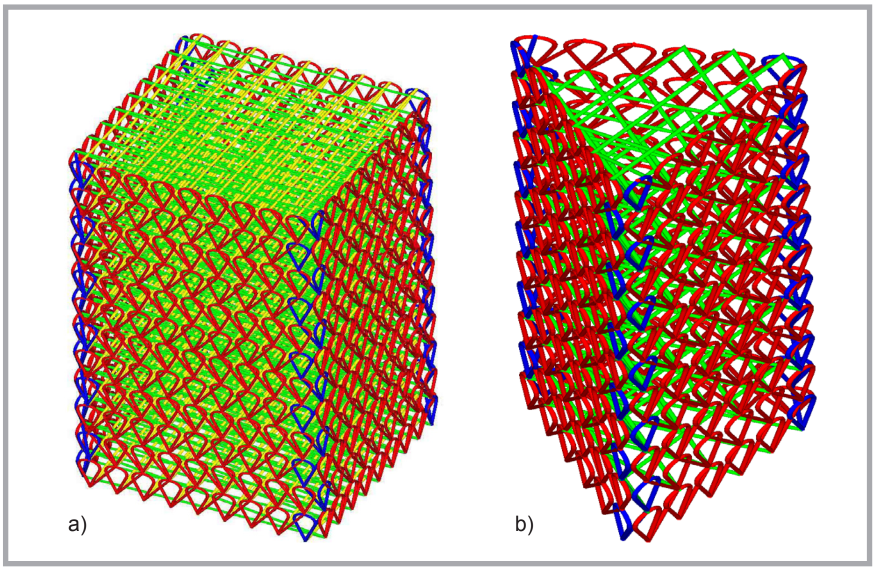

Figure 1. Knitted spatial products a) tetragonal base b) triangular base.

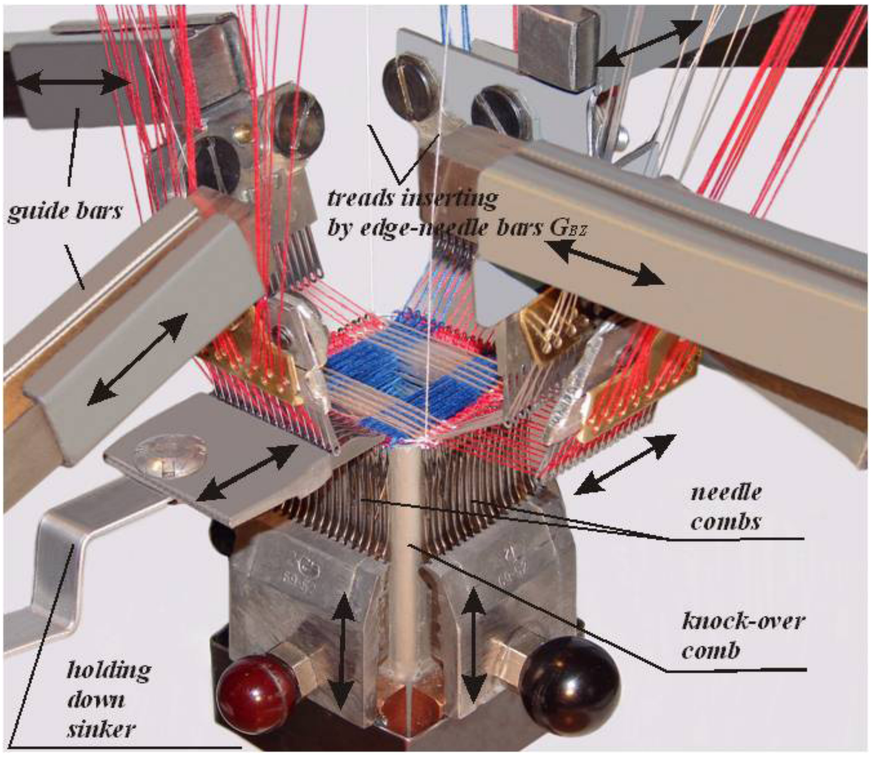

Figure 2. Construction concept of a warp-kintting machine equipped with four needle combs.

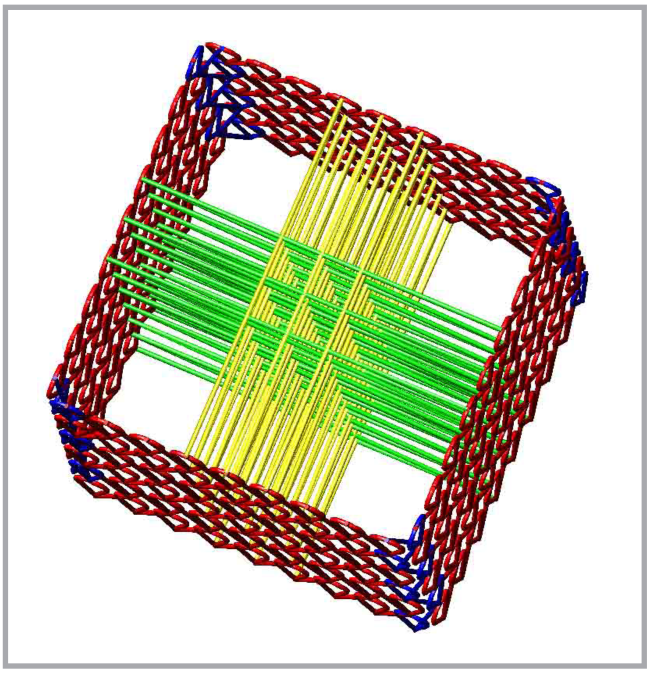

Figure 3. *Spatial warp-knitted fabric with vertical channels of identical geometrical parameters .*

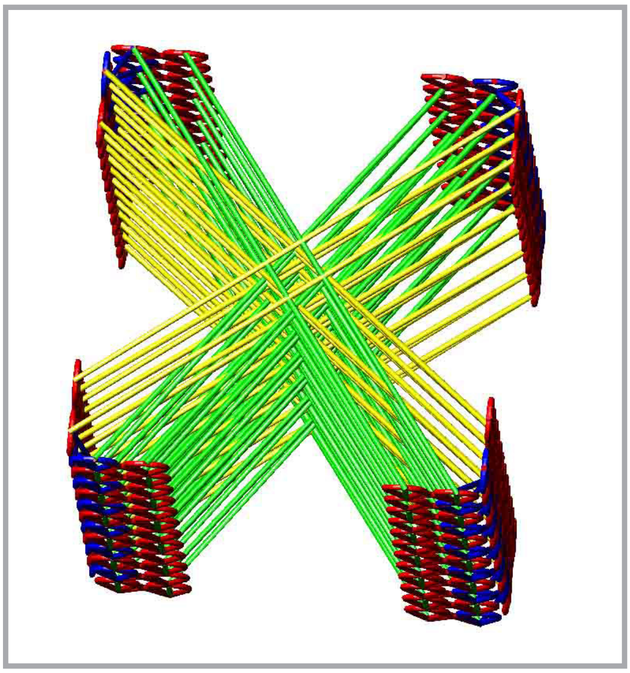

Figure 4. *Knitted spatial product with a cruciform construction of the internal layer.*

Spatial knitted solids can have basic geometrical figures with triangles, tetragons or polygons of their cross-section or base (***Figure 1,*** see page 61). They may also take the form of more complex figures, creating solids in the form of spatial reliefs, which in their structure resemble well-known construction elements like channel bars, tee bars or double tee-bars. Increasing the number of external layers makes it possible to produce spatial warp-knitted fabrics in the form of regular prisms similar to a cylinder. A different variant of spatial warp-knitted fabrics are products in the form of a spatial arc.

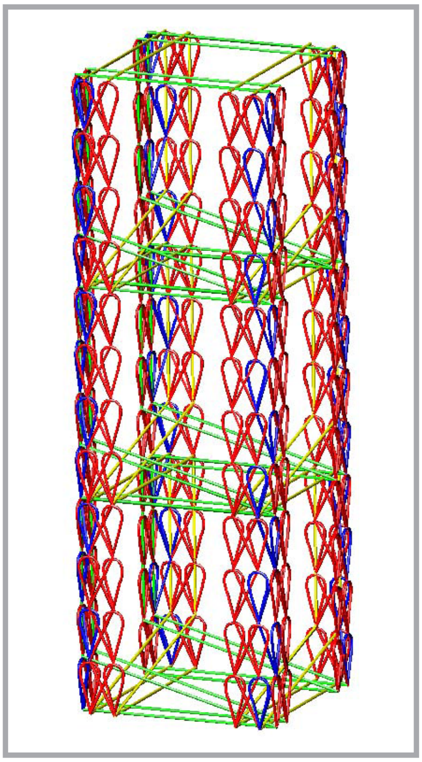

Figure 5. *A-jour spatial knitted fabric connecting the vertical and horizontal channels of the internal layer with the incomplete structure of the external layer.*

The structures of the 3D knitted fabrics and the manufacturing technology are the subject of patent applications. Spatial warp-knitted structures are currently manufactured on new, multi-needle comb warp-knittng machines. There are two types of such warp-knitting machines- those with an even number of needle combs and those with an odd number. In the case of machines with an even number of needle combs, the opposite pairs of combs work interchangeably. In machines with an odd number of needle combs, the combs work one after the other or simultaneously (***Figure 2,*** see page 61).

Additionally, the machines are equipped with individually controlled needle boards which close the edges of the spatial knitted fabrics formed. The warp-knitting machines are also equipped with a take-up device, which does not deform the ready-made product when receiving it.

A-jour structures in spatial solids

In the whole group of spatial knitted solids, one can distinguish two types of a-jour structures: flat a-jour - characterised by a flat structure of the external layers, and spatial a-jour - with a characteristic construction of the internal layers.

Flat a-jours are fabrics with openings in the external layers of the fabric formed by not connecting the loops of two neighbouring wales. Spatial a-jours, which have channels instead of openings, take the form of free spaces in the compact structure of threads of the internal layers. These spaces can be situated along the product, thus creating vertical channels (***Figure 3***).

The channels are created by partial threading of the guide bars, and they may be characterised by a different width. The free spaces created not only decrease the mass of the product but are also technological openings (through which, for example, electric wiring can be led in the building beam). The warp-knitted solids can contain one or several longitudinal channels in their structure. Spatial a-jours may take different shapes in the cross-section of the knitted beam. The construction of a-jours formed by partial threading is different from the construction of those formed by internal planes, which can be situated perpendicularly or at any different angle to the external layers. The full and empty planes of the internal layer may be situated at identical or different heights, forming a so-called "shelf" structure. The stitches of the internal layers may be the same or different, thereby forming a more complex structure of the spatial knitted fabric received. ***Figure 4*** presents a warp-knitted fabric of cruciform structure. The internal layer connects the opposite edges formed of threads of the external layer.

Spatial a-jours of knitted solids appear only in a vertical or horizontal direction, or in both these directions simultaneously. Warp-knitted spatial fabrics can also join in their structure spatial a-jours of the internal layer with flat a-jours of the external layers, as a result of which one can receive products of a construction similar to frameworks used in the building industry and in steel or wooden objects. An example of such a knitted beam is presented in ***Figure 5.***

It is also possible to produce spatial knitted fabrics by the full threading of the guide bars, in which the internal layers interlace, as a result of which one receives an a-jour structure in the form of a set of interpenetrating elements (***Figure 6***). Such structures in the composite arrangement are resistant and, at the same time, characteried by a small mass and small volumetric filling of the internal layer. The threads of the internal layers can be situated at a freely selected angle.

The knitted composite beams in a longitudinal direction can be formed in axial isotropy, in which the structure of the product is the same along its whole length, or in axial anisotropy, in which the structure of the spatial fabric is extremely diverse. Spatial a-jours in the cylindrical structures of warp-knitted fabrics can take the form of different solids, such as cones, cylinders and spheres. These channels can be connected with one another in different ways.

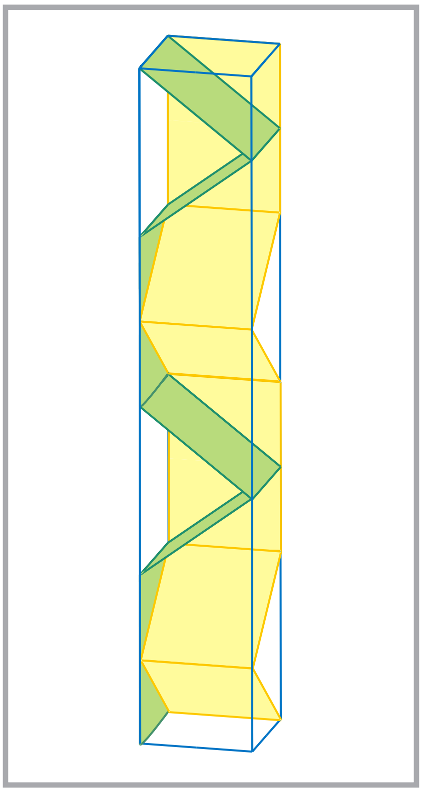

Figure 6*. A-jour spatial knitted fabric with interlacing internal layers.*

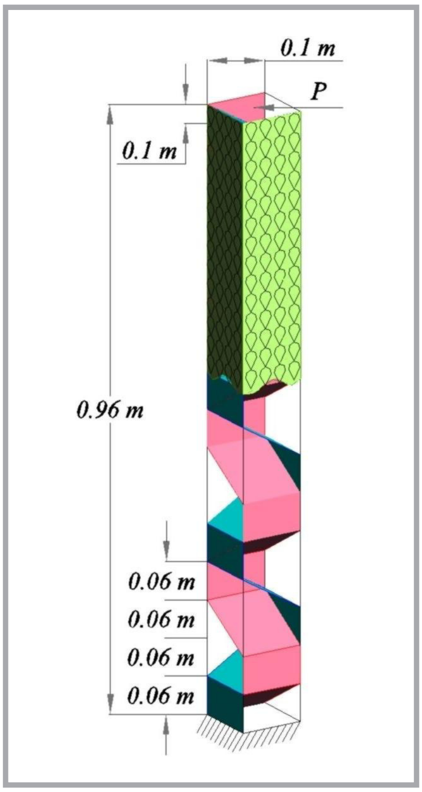

Figure 7*. Diagram of the knitted beam tested.*

Numerical analysis of the mechanical properties of spatial knitted composites

A very important feature of the knitted structures analysed are the mechanical properties of the curving process. A warp-knitted solid in a composite arrangement, a diagram of which is presented in ***Figure 7***, underwent numerical analysis of the mechanical properties of the bending process on the basis of FEM methodology. The diagram in ***Figure 7*** presents two internal layers. The beam also contains external layers in its construction surrounding the inside of the solid. The cross-section of the beam is 0.1 m × 0.1 m, it is 0.96 m long and consists of 16 segments each of 0.06 m height. The thickness of the walls of individual layers is 3 mm. One end of the beam was immobilised by permanent

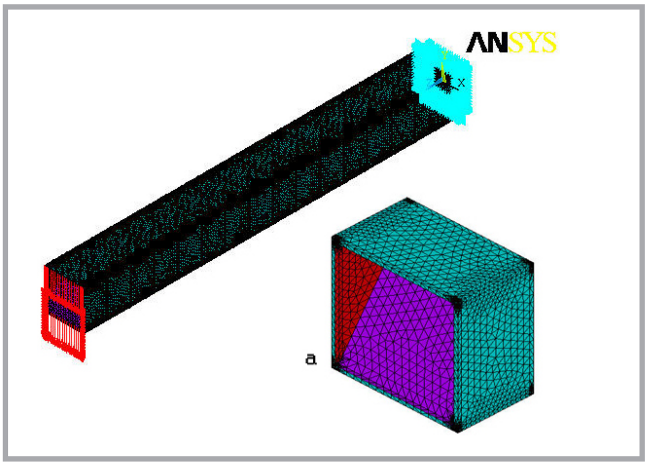

Figure 8. *Tetrahedra net of the product.*

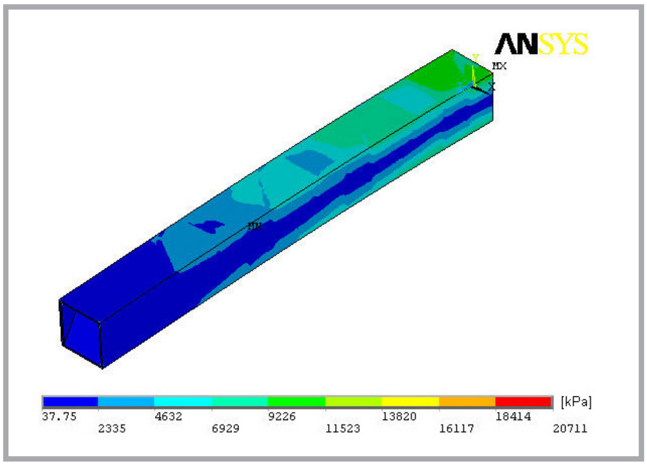

Figure 9. *Diagram of displacements towards the axis OY.*

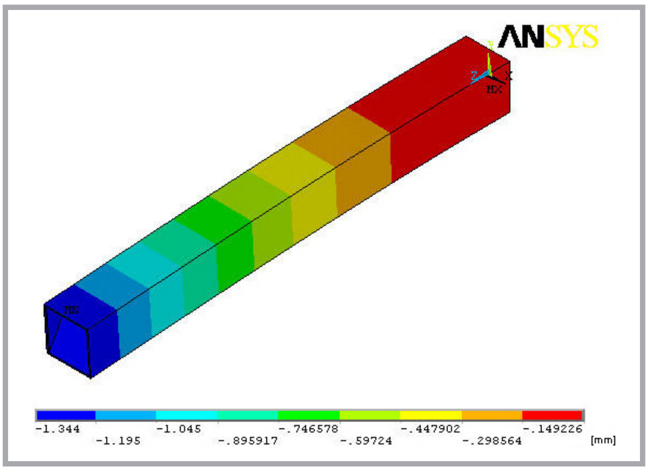

Figure 10. Diagram of resultant tensions of the knitted composite solid.

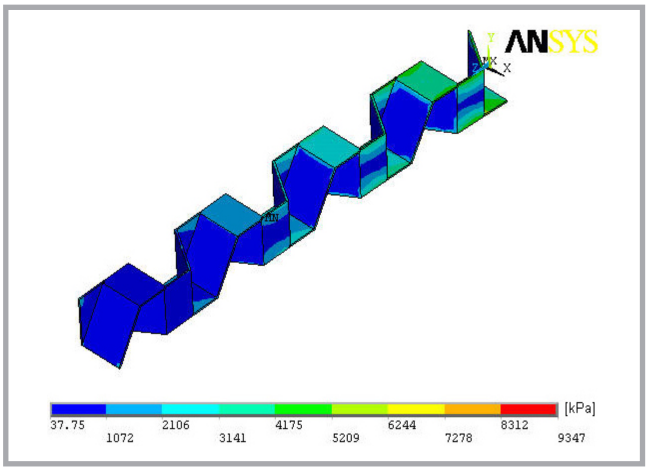

Figure 11. Diagram of resultant tensions of the internal layers.

supports, and the other end was affected by the force P = 414 N.

It was assumed that the materials of the component layers of the composite were of an isotropic character. On the basis of available literature [7, 8] the following material parameters were adopted: Poisson coefficient = 0.305, Young modules in the external layers = 45 720 MPa and in the internal layers = 30 480 MPa.

Analysis of the model of the bending process was carried out with the use of ANSYS v.11.0. For the model considered a net of finite elements was generated (***Figure 8***). An 8-knot finite element SOLID 185 was used for the analysis. In each knot there were three levels of freedom, which were the displacements in directions XYZ, according to the global coordinate system adopted. ***Figure 8.a*** presents an enlarged fragment of the net generated. Internal layers are denoted with red and violet colours, and external layers with green. The whole structure of the net was divided into triangular elements. The model of the knitted composite solid analysed was fixed at the level z = 0 and loaded uniformly in all the knots situated in areas z = 960.

As a result of numerical calculations, a diagram of displacements towards axis OY was obtained (***Figure 9***). The maximum value of those displacements was 1.344 mm. ***Figures 10*** and ***11*** present the resultant tensions of the model, which ranged from 37.75 to 20711 kPa. The largest tension values were observed in areas close to the place where the beam was fixed. The diagram of tension distributions in the internal layers (***Figure 11***) proves that the character of the distribution is similar to the tension distribution in the whole model, the value range for which varied from 37.75 to 9347 kPa.

Conclusions

- An innovative grup of warp-knitted fabrics forming spatial structural solids was established. Those products are characterised by more than two external layers and at least one internal layer. They are produced on a newly designed machine equipped with more than two needle bars. The knitted fabrics are characterised by a diverse geometrical form directly obtained during the production process on a warp-knitting machine. The structures of the 3D knitted fabrics and the manufacturing technology are the subject of patent applications.
- A-jour spatial structures are an important group of warp-knitted solids. They can contain flat a-jours of external layers and spatial a-jours of internal layers. An a-jour structure guarantees a small mass and low coefficient of the volumetric feeling of the internal layers, therefore less raw material is used than in the case of fully filled structures.
- After being hardened with epoxide resins, spatial warp-knitted fabrics are ready-made composite products in the shape of beams or frameworks which can be applied in the building industry and as elements of machines and devices. Because they are light and at the same time highly resistant, they can be competitive towards traditional wooden, steel or concrete products.
- An attempt was made to model the mechanical properties of the curving process of a spatial composite knitted beam with the use of an ANSYS programme. The following parameters were determined: displacement of the segments of the beam designed in relation to the OY axis, and the distribution of component tensions of the beam in its internal and external layers. The results of the numerical analysis of the properties of the spatial knitted composite obtained determine the optimisation possibilities of the qualities of the composites tested.

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