

# Innovative cellular distance structures from polymeric and metallic threads

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**Abstract.** Knitting allows a high individual adaptability of the geometry and properties of flat-knitted spacer fabrics. This offers advantages for the specific adjustment of the mechanical properties of innovative composites based on highly viscous matrix systems such as bone cement, elastomer or foam and cellular reinforcing structures made from e. g. polymeric monofilaments or metallic wires. The prerequisite is the availability of binding solutions for highly productive production of functional, cellular, self-stabilized spacer flat knitted fabrics as supporting and functionalized structures.

## 1. Introduction

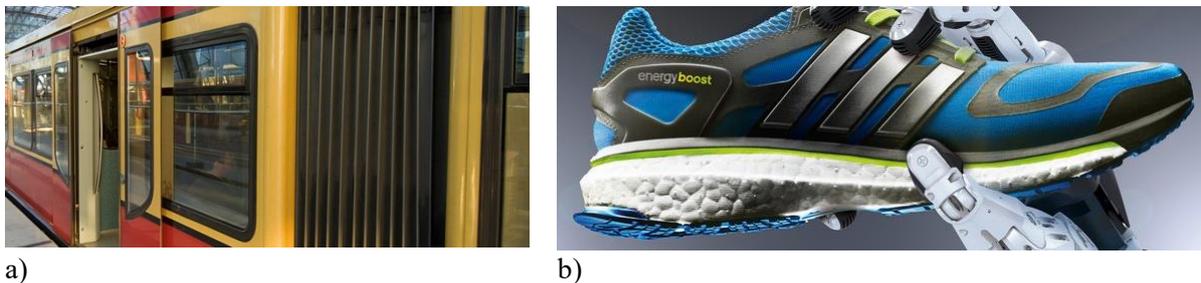
Conventional flat-knitted spacer fabrics (SF) are used as padding material in protectors, clothes or mattress covers due to their adjustable pressure stability and air permeability [1]. SF consist of two surfaces layers and one connecting spacer layer. The adjustable distance between the surface layers in connection with the near-net shape production possibility make SF particularly interesting for composite. The SF however, even so the spacer layer is formed by bridges or pile yarns, is not inherently stable immediately after textile production. This requires either consolidation or using elastic yarn materials within the surface layers to generate the required tension for erecting the pile yarns. However, both methods do not result in inherently stable, open knitted fabric structures as cellular distance structures for composites.

In order to extend the use of SF beyond the already named areas also for medical applications there is a crucial need for research into the development of solutions to produce stable cellular spacer structures with open net like surface layers (iSF). Consequently, the main focus of this research is the development of a manufacturing technology for structures based on process-integrated shaping of monofilament or wire yarns during the structure production. The aim is to enable flexible and reproducible manufacturing of dimensionally stable cellular 2D and 3D net shape knitted spacer fabrics (iSF). Solving these complex tasks requires the development of innovative technological principles for the textile-technical manufacturing of cellular spacer structures with a compression-rigid spacer area between the surface layers and a surface topography adjusted to the matrix system. At the same time, it is aimed to triple or quadruple the productivity of the production rate compared to conventional closed SF. The cellular surface layers are a decisive advantage of these innovative, cellular spacer structures while used in composites, as it enables usage of high viscous matrix systems (e.g. bone cement, rubber or foam) while ensuring homogeneous infiltration. The fibre volume content can easily be adjusted by binding-technology design without decreasing permeability of the surface



layers and the thickness of the iSF. The fields of application to be derived from this technique are conceivable in many industries. As exemplary applications, two examples (Figure 1) are shown.

- Folding bellows (Figure 1a) - The iSF serves as a separating layer between two rubber surfaces and forms an air-filled cavity through the spacer layer, which is intended to contribute to the acoustic insulation. The iSF supports the flexibility of the rubber while reinforcing the textile structure.
- Sports shoes (Figure 1b) - Due to the novel iSF, the sole construction can be individualized, so that the soles are easily adaptable to each foot, locally different thicknesses of the iSF form the basis for this. This (scaffolding) framework is finished by a consolidation of the structures using e. g. polymeric foam.



**Figure 1.** Possible fields of application of iSF a) folding bellow in passenger trains b) Soles of sports shoes [2, 3]

In summary, it can be conducted that conventional SF are not suitable for a use as reinforcing or functional structures in composites. Both the surface and the spacer layer are too tight and prevent a homogeneous infiltration. For this reason, it is necessary to develop a novel iSF. The parameters material and bonding technology are examined.

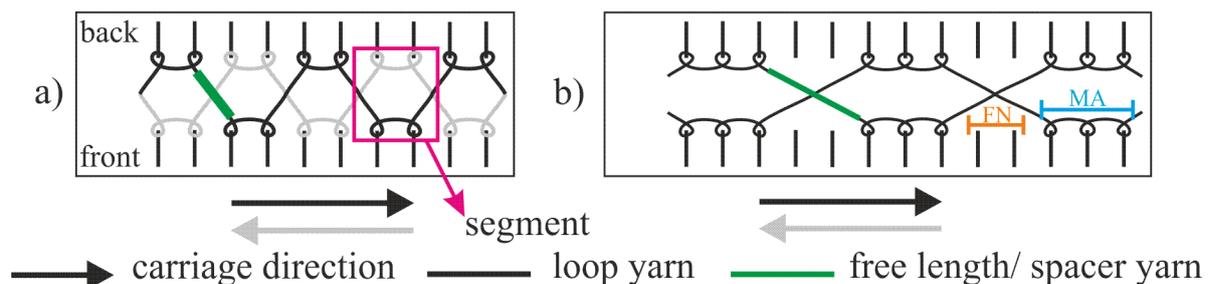
## 2. Materials and Methods

### 2.1. Materials

The examinations are undertaken with monofilament polymer yarns and metallic wires. The main tests are carried out primarily with monofilaments, since these ensure a gentler processing. Only in the case of fault-free bindings the textile wire is used.

### 2.2. A subsection Binding technology

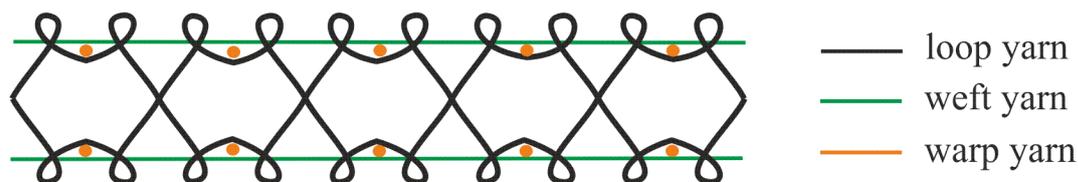
**Geometrical properties:** The goal is to develop a binding, which allows a freely thickness adaption of the knitted fabrics during production while realizing the iSF with only one thread system. An effective and productive method to accomplish this is to achieve the distance by a subsequent different binding of the yarns on the two needle beds, as can be seen from Figure 2.



**Figure 2.** Binding scheme of iSF a) small distance without FN b) changed thickness with FN

The adjustment of the thickness must be carried out by fastening measures. The free length (fL) of the thread piece between the front (fNB) and the rear (bNB) needle bed can be achieved by means of a corresponding stitch formation. For this purpose, the thread material is alternately integrated on the fNB and bNB. The stresses induced during the binding process cause the structure to shorten and thus the webs are set up and since the spacing layer is formed with only one thread material, the tubes are produced in the direction of the wales. Exemplary, a binding scheme for a SF with a small thickness is compared with an increased thickness in Figure 2. The small thickness (Figure 2a) results from the use of each needle within the structure (loop = MA), thus the fL is limited to the distance between the needle beds. An increase in the fL (Figure 2b) is achieved by introducing of free needles (FN).

**Mechanical Properties:** As can be seen in Figure 2, the structure has no continuous covered surface. A force applied to the top surface can only be absorbed locally and is not distributed over the entire top surface. This effect reduces the pressure stability of the structures. In order to prevent this effect, the cover surface must be modified in such a way that a continuous connection of the segments takes place without reducing the porosity of the cover surface. This is provided by the integration of straight reinforcing threads as warp and weft yarns. By incorporating the warp and weft yarns (Figure 3), the structural elongation is reduced to a minimum and thus the structures can be subjected to a higher load transversely and longitudinally to the production direction. Weft threads, warp threads and stitches form a solid grid so that the surface is fixed and can no longer pull apart.



**Figure 3.** Binding scheme with elongated reinforcing threads

### 3. Results

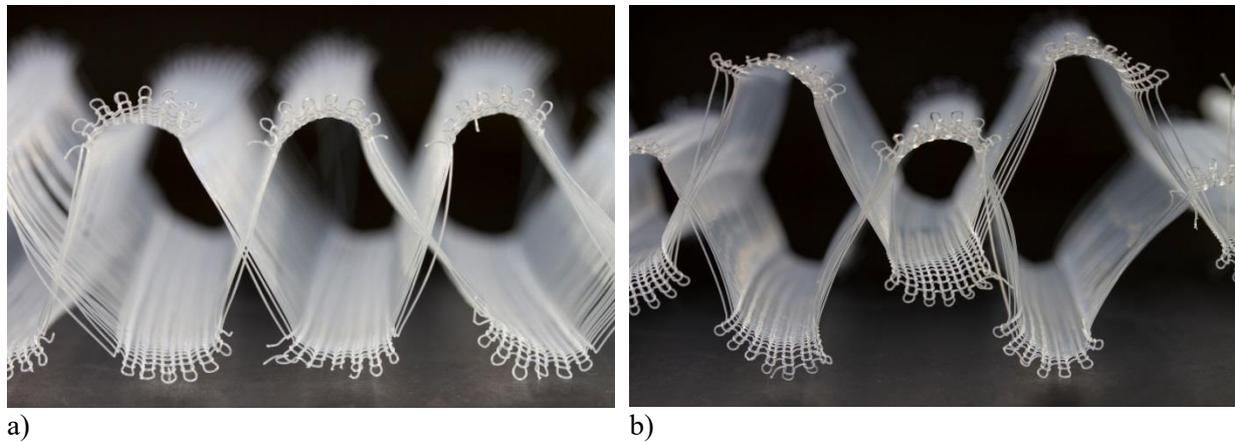
During this project work first cellular iSF were developed. These could be produced on a flat knitting machine STOLL CMS320 TC, gauge E10 with a considerable reduction in knitting time, as the necessary number of carriage strokes per series could be reduced dramatically. The produced samples are up to 40 mm thick. The thickness does not depend on the fineness of the yarn materials used. This is contrary to the pressure stability, which is directly related to the fineness of the materials. These achievements are a basis for the development of further innovative iSF. New variants are expanded by an additional use of reinforcement yarns in warp and weft directions to increase stability and thus improve mechanical properties.

**Table 1.** Overview of used materials

No.	manufacturer's designation	diameter [mm]	tensile strength [N]
1	Perlon/ PA 6	0,20	15,5
2	Perlon/ PA 6	0,25	24,6
3	Perlon/ PA 6	0,30	35,3

According to the developed binding technique, the knitting tests are carried out using polymeric monofilaments. The extensive investigations include, in particular, the appropriate machine settings (i. a. stitch cam adjustment, pull-off values, thread tension). From these investigations connections between the appearance of the surface, the number of FN and the trigger value can be recognized during the knitting process. The correlation between the number of FN and the appearance is striking. The higher the number of FN, the more uneven the surface becomes, which is more visible in the

stretched state, as the intersecting points of the distance threads shift. A clear difference can be seen between a structure with 7 MA - 7 FN (Figure 4a) and one with 7 MA - 10 FN (Figure 4b).



**Figure 4.** Overview of structures samples a) 7 MA and 7 FN b) 7 MA and 10 FN

The pressure stability is also influenced by the bond. A comparison of samples with 0FN (Table 2, 2MAx0FN) and 7FN (7MAx0FN) shows higher pressure stability by 223.52% for samples with a lower FN. This can be attributed to the higher number of pile threads as well as a more even top surface and a smaller fabric thickness. The pressure stability decreases with an increasing thickness through to the non-continuous cover surface and an early separation of the individual segments. In order to increase pressure stability this needs to be prevented by the use of reinforcing threads. The pressure stability at SF must be so high, because this is not used in composite. iSF is used as a reinforcement in a matrix, therefore a not so high pressure stability is required.

**Table 2.** Comparison of SF with iSF

	iSF 2MAx0FN	iSF 7MAx0FN	iSF 7MAx7FN	iSF 7MAx10FN	SF
thickness [mm]	4,30	13,90	30,82	38,03	13,80
loop density[1/cm <sup>2</sup> ]	49,00	41,58	48,94	56,10	17,70
grammage [g/m <sup>2</sup> ]	408,20	411,00	678,00	812,00	2392,00
pressure stability [N]	89,92	40,23	37,18	49,06	1299,2

#### 4. Outlook

Within the scope of the investigations it is planned to develop further innovative structures. The previous variants will be additionally enhanced by the integration of reinforcing threads in warp and weft direction in order to ensure a higher stability of the cover surface and thus improved mechanical properties. In addition, attempts will be made to show a possibly better and more uniform infiltration due to the cellular structure. In addition, further material tests will be carried out. For example, is there a difference of the results (thickness, loop density, etc.) when the structure is out of monofilament with a diameter 0,10 mm (double feed way). The well-found structures are additionally made of metallic wires.

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