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High productivity and near-net shape manufacture of textile reinforcements for concrete

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Summary

Textile reinforcements have been successfully applied in various concrete products such as pipes, panels, masts and bridges. This paper presents recent developments in the manufacture of textile structures. Established processes such as leno-weaving and stitch-bonding have been thoroughly modified. It is now possible, with an improved leno-weaving machine, to produce textiles from glass fibres without any fibre crimping. Leno-weaves, which up to now showed inferior strength compared to stitch-bonded fabrics, can now be implemented in the same applications at a very competitive price. At the same time, modifications to conventional stitch-bonding machines have been completed so that near-net shape manufacturing of complex shapes, such as an elbow pipe or a reduction in pipe diameter, becomes possible in one process step. Additional modifications involve layer arrangement and textile patterning and are aimed at increasing bond strength between textile and concrete. To improve handling and strength, the textiles are equipped with surface coatings.

1. General principles and practical examples

1.1. Introduction

Textile reinforced concrete (TRC) can be used as an alternative or in combination with traditional building materials, such as stee-reinforced concrete or short fibre-reinforced concrete. It is suitable for the production of precast building elements as well as renovating already existing elements. In order to function as a tensile force transducer, the textile reinforcing material must be composed of alkali-resistant glass (AR-glass) or carbon long fibres bonded in the concrete and aligned in the load direction. However, due to the numerous possible applications, the use of continuous fibres is only effective if implemented as a standard semi-finished product, which can be economically produced in a modern fabric-forming process. First and foremost it is imperative to maintain all advantages of the material's properties, not only in the technical development and manufacturing of the textile but also extending to the resulting construction element. The advantages of TRC are foremost in the slenderness of individual construction elements and their reinforcing layers, resulting in the reduced weight of each component. This opens new possibilities and aesthetic standards in construction.

TRC is a composite material made of fine-grained concrete and high-performance filament yarns, composed of AR-glass or carbon. Before the filament yarns are added to the concrete, they are formed into textile lattice structures and embedded into thin layers of concrete. The concrete bears the compression forces and the textile bears the tensile forces. A fibre count relative to just 1% of the building component volume is enough to ensure the required structural response.

The reinforcing textile should be of an open yet rigid structure. An open structure allows the concrete to penetrate through the textile and ensures a complete coating of the threads, essential for a successful transfer of forces from concrete to the reinforcing textile. Thread orientation is not only influenced by the maximum particle size in the concrete matrix and the required amount of fibers but also largely by the manufacturing process. Sufficient shape retention capabilities of the textile (flexural deformation and displacement stability) are a prerequisite for easy handling and high strength.

Stitch-bonded fabrics, such as those developed by the TU Dresden, can be used in multiple applications. The following examples in renovation, prefabricated elements, hydraulic engineering and bridge construction provide an overview.

1.2. Examples of use

Renovation and strengthening of existing building elements

Steel-reinforced concrete and pre-stressed concrete masts are exposed to extreme weather conditions. The load-bearing capacity of the members must be retained and upheld for decades. However, many masts already show deficiencies or damage after just 15 years. While axial cracking does not pose such a problem, the repair of torsion damage proves to be more challenging. Encasing the masts in a multi-ply stitch-bonded fabric and applying a thin coat of shotcrete can reliably repair the torsion and flexural damage. Additionally, the load-bearing capacity of the masts is increased by over 80% with improved ductility. The financial savings from repairs and maintenance to existing masts compared to erecting replacements or underground routing are considerable [1].

Uses in hydraulic engineering

Sediment that is transported with the fluids leads to wear and ultimately destruction of hydraulic construction elements. As an alternative to the traditional protective concrete layer, alkali-resistant glass (AR-glass)-reinforced concrete layers can be applied near the surface of the hydraulic elements. These protective layers not only greatly reduce surface cracking but also improve resistance to other destructive factors. The protective layer can be applied to existing construction members as well as integrated into new components. In combination with short fibre materials, abrasion resistance can be increased by 50% as compared to that of just textile-reinforced concrete elements. Improved crack spacing owing to the short fibres and a transfer of tensile forces by the textile reinforcement generates an optimal utilisation of materials [2].

Textile-reinforced concrete for precast elements

A textile-reinforced panel, engineered as a parapet for a parking garage, was developed by TU Dresden. Slender TRC members are especially suitable as precast elements. The glassfibre textile is non-corrosive, therefore requiring no minimum concrete coverage, resulting in up to a 75% thinner construction element and a weight reduction of up to

80%. This clearly reduces transportation and assembly costs. Endless design possibilities ensure state-of-the art aesthetics [3].

Textile-reinforced prefabricated concrete pipes

Due to their beneficial properties, plastic pipes and tubing have practically replaced traditional materials such as steel, ceramic and concrete for piping used in water and gas distribution. However, their limited structural strength remains a weak point. Along with notch sensitivity, reduced resistance to cracking and the spread of cracks as well as low impact resistance, time and temperature stress–deformation behaviour should be carefully examined.

To expand the implementation of plastics in hydraulics and civil engineering projects, pipes are currently reinforced with additional protective layers. High-performance marketed plastic pipes with large diameters (can handle inner pressures up to 100 bar) are equipped with built-in reinforcements made of steel or criss-crossed embedded high-performance fibres. The reinforcements are applied in the manufacturing process to standardised polyethylene pipes and coated with a protective plastic envelope. The complex manufacturing process of these types of pipes is cost and material intensive, making them economical only in exceptional circumstances.

Concrete piping is still considered to be an economical and practical solution. However, its applications are often restricted since building elements are often heavy and cumbersome due to existing production technology, load-bearing requirements, and attempts at crack reduction.

A revolutionary reinforcement process of standard plastic pipes involves enveloping them in a thin textile-reinforced fine-grained concrete layer. This allows the combination of the benefits of plastics (excellent hydraulic characteristics, longevity and resistance to corrosion, incrustation and aggressive media) and those of TRC, such as clearly increased structural stability. The idea behind a composite pipe is as follows: the inner plastic pipe with its above-mentioned advantages is used as the fluid transport 'layer' and sealant, while the outer protective TRC pipe takes over the task of carrying the outer loads (such as live loads and geological loads) and resisting inner pressure. As a result, the plastic wall thickness of the inner layer can be reduced (minimising costs) while the overall stability and structural response of the pipe is increased. With a protective textile-reinforced fine concrete layer of 10–20 mm and appropriate reinforcement, inner pressures of 27–57 bar in plastic pipes with an inner diameter of 130 mm can be withstood. These pipe composites can be implemented in areas where up to now only expensive steel and cast pipework could be implemented [4].

2. Machine technology in the production of textile reinforcements for concrete

2.1. Stitch-bonded fabrics

Introduction

The stitch-bonding technique is an established production process utilised to manufacture textiles for the reinforcement of concrete. Stitch-bonded fabrics or multi-plies are multiple layers of yarn sheets bound by a stitching yarn. Non-crimped yarns, an endless combination of fibre layer angles (multiaxial), user-defined arrangements and

combinations of each layer, as well as optional weight per unit area are just some of this technique's obvious advantages. A stitch-bonded multiaxial fabric is composed of multiple layers of differently aligned reinforcing yarn sheets and a threaded mesh structure. These fabrics contain up to eight layers, each layer's reinforcing yarns being laid at various angles (i.e. 0°, 90°, +45°, –45°) to one another, and can be user-defined. The 0° orientation is called the warp sheet and corresponds to the working direction of the machine. The other layers are called weft sheets.

We use mainly two machines at ITB to produce our stitch-bonded fabrics – a multiaxial knitting machine Malimo 14024 and a biaxial stitch-bonding machine Malimo 14022/c P2-2S from KARL MAYER Malimo. These machines mainly differ in the number and orientation of the reinforcing thread systems, the manner of inserting the weft threads, the stitching process and the positioning angles. The biaxial machine produces stitch-bonded fabrics with two reinforcing yarn layers and the multiaxial machine fabrics with four layers, where the positioning angles of 0° (working direction) and 90° are pre-programmed. The other yarn sheets on the multiaxial machine are infinitely variable between ±45° und 90° angles.

Manufacture of curvilinear reinforcements

Stitch-bonded reinforcing textiles are generally finished with stretched reinforced threads. Incorporating axially offset warp threads can form preset contours. The warp offset technique allows for a variable introduction of perpendicularly pre-laid loose warp threads or warp sheets. In this manner various angles or wave-like arrangements of the reinforcing threads with different amplitude and frequency in the warp direction can be produced [5]. However with this method, conforming the reinforcing structure to the requirements for each individual construction member is limited.

The ground-breaking method of 'variable metering of the warp thread length' developed at ITB has opened up new possibilities. This development is based on a stitch-bonding machine from Malimo with a parallel weft inserting system and weft insertion in line with the courses. By utilising this method, contour-compatible reinforcing textiles can be produced 2D for 3D cylindrical surfaces or 3D free forms, which would otherwise not be feasible in a biaxial layer.

By pre-measuring the warp thread, the lengths of the warp thread sections can be specifically varied between two consecutive weft threads. This allows us to vary the length of the loop and the thread spacing perpendicularly to the lattice structure. Now it is possible to design and produce lattice-type reinforcements where the reinforcing thread alignment is compatible with the stress loads. As an example, a load-aligned textile reinforcement was developed for the above-mentioned composite pipe elbow.

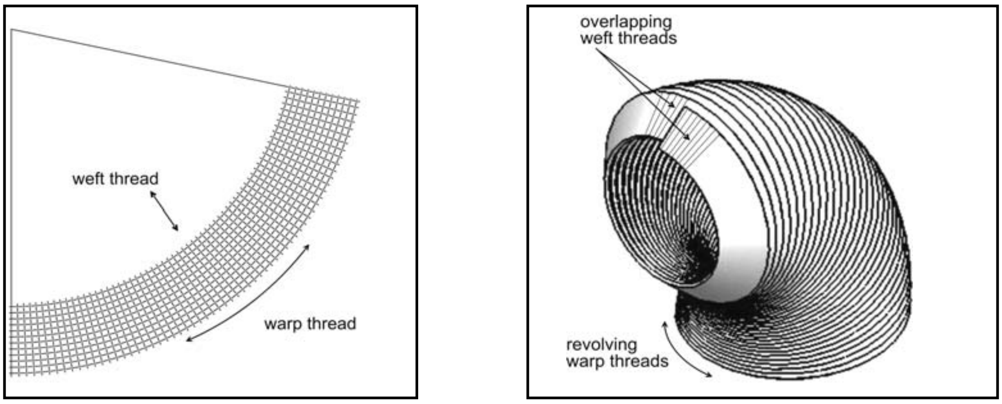

Fig. 1: Contour compatible semi-finished textile product for a 3D reinforcement in concrete element - (a) narrow fabric as a developed view of a truncated cone - (b) „thread flank structure"

The basic form is a spiral-formed narrow fabric, which winds around the circular cross-section of the pipe similar to a thread flank (Fig. 1). The width of the fabric band, the distribution and amount of warp and weft threads as well as the necessary thread lead can be taken from the calculations for the usage and construction requirements. The tangential reinforcement of the textile is formed from 12 threads, linear density 2400 tex (g/km), spaced at intervals of 7.2 mm. The weft at a linear density of 1280 tex (g/km), which functions as the longitudinal reinforcement in the element, is also positioned at intervals of 7.2 mm.

The reinforcement material utilised was pre-treated with a polymer coating for strength and was composed of either AR-glass or carbon filament yarn. In contrast to common practice, we pre-treated the individual reinforcing threads before knitting rather than treating the finished textile. This process provides the possibility of marginal thread displacement at the crossing points that will occur during the winding process.

The production of the structure on the parallel-weft knitting machine by means of differing warp thread lengths was made possible by constant, stationary gradual increments programmed in the warp feed roller. The reinforcing thread material was taken from individual spools. This simple process allows for only one geometric structure for a predetermined pipe diameter. To change diameters or for complicated shapes it is necessary to set up separate control drives to feed individual threads.

The production of the pipe elbow follows in a continuous winding process in which a stationary plastic pipe is placed on a rotating table where the concrete container and the spool for the narrow band textile is also located. The textile spool spins planetary-like around the plastic pipe. In its rotation, the lattice-shaped textile passes through the concrete container and is sprayed with fine-grained concrete and is positioned around the plastic pipe similar to a thread flank. The combination of lowering the pipe and the rotation of the textile ensures the pre-defined lead. This solution allows for reductions but also expansions to pipe diameters, as well as reinforcing 'endless' pipes with textile coatings (Fig. 2).

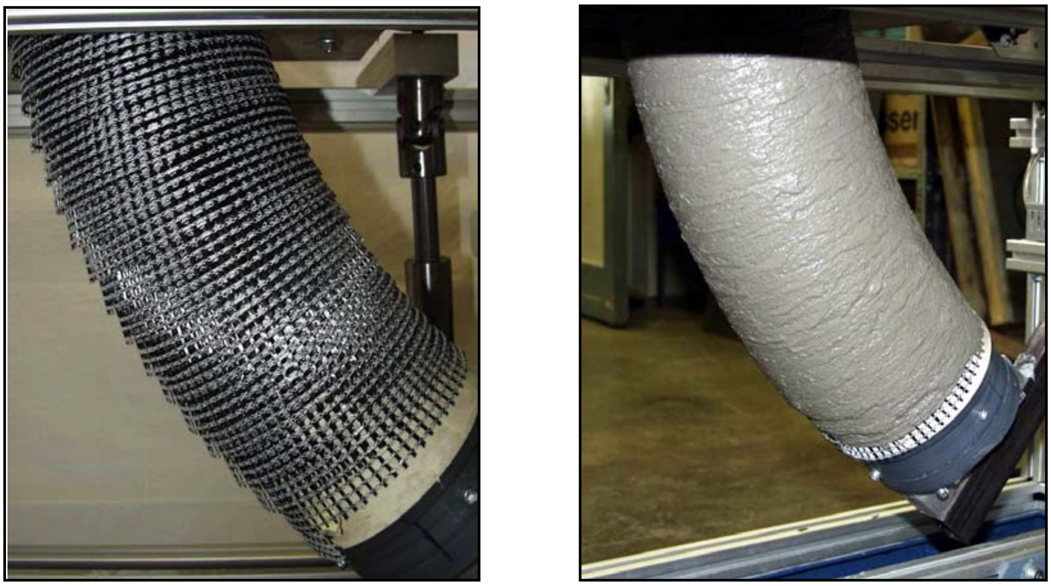

Fig. 2: Production of component at the Institute for Building Materials TU Dresden
- (a) Reinforcing process - (b) Completed pipe elbow (right)

Production of symmetrical fabrics

In the production of planar stitch-bonded fabrics, the production process has, until now, limited the arrangements of the workable textile layers. This is especially true for the backing of individual warp layers and both the outer warp layers of a multi-ply fabric. Until now a symmetrical layer arrangement has not been possible [6].

The stitch-bonding process presented here eliminates the restriction placed on layer positioning. An additional step was incorporated into the knitting machine's cycle that allows threads running parallel to the working direction to be fixated on both outer layers of fabric (Fig. 3). The first machine trial of this new method was accomplished on a prototype based on a standard Malimo 14022 stitch-bonding machine. The prototype served to optimise production speed, thread feed, shogging and movement of the work elements.

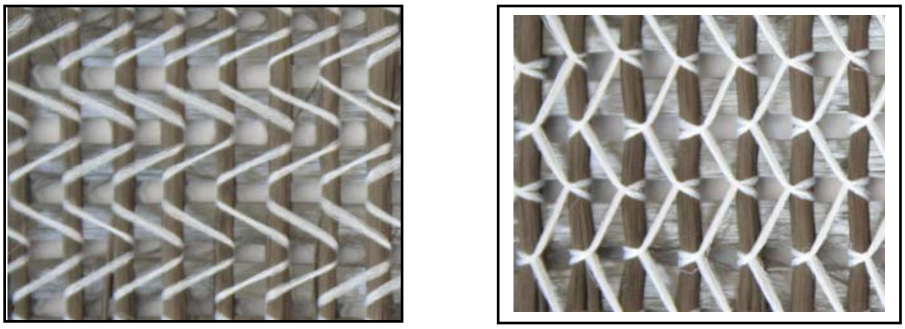

Fig 3: Symmetrically stitch-bonded fabric made of carbon filament threads
– (a) front and (b) back view (right)

After the successful conversion of the expanded stitch-bonding process, the prototype machine has been equipped to produce uni-directional and multi-ply symmetrical stitch-bonded fabric. Comparable symmetrically layered fabrics could only be attained on common warp knitting machines by reworking the fabric a second time. The first procedure secured the warp thread on the one side and the second procedure secured it on the other. As well as low productivity, other disadvantages included an increase in binder thread usage as well as the extensive damage to the reinforcing threads. Further advantages in the new process, as compared to chemical binding of the reinforcing threads, is that all materials which the compound needle is able to penetrate can be bound to the fabric in one procedure.

The advantages of using symmetrical stitch-bonded fabrics in concrete reinforcements lie in their uniformity of bonding properties as well as an increased fibre volume at the same level of openness in the textile lattice structure, which translates in practice to a reduction in the required number of reinforcement layers.

2.2. Leno weave technique

Leno weaves have been present in construction technology for some time as textile lattices for reinforcing stucco. What signifies a leno weave is that the warp and weft are not held together by interweaving them, but rather by a separate binding thread system. The binder threads wrap around the warp and weft threads a half rotation each time, and after each weft thread change their rotational direction crosses to the opposite side. The binder thread can run simultaneously with the warp or can be fed separately. When the binder thread is fed with the warp, it causes the warp

to undulate. When the binder thread is fed separately, the warp threads can be worked up straight (Fig. 4). To create the leno bind, special threading mechanisms are employed. In a classical leno weave, known as weaving with heddles, the yarns undergo extensive damage as the warp and the binder threads are forced to pass simultaneously through one heddle. The modern gill bar leno weave machines separate the warp from the binder thread thereby minimising damage to the threads.

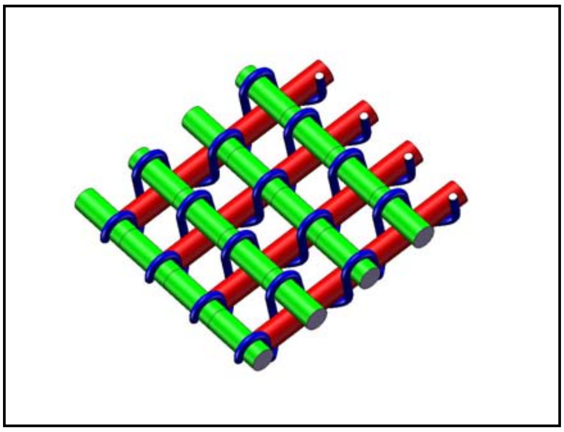

Fig. 4: Model of leno weave with stretched warp (red) and weft thread (green) and binder threads (blue)

Up until now, due to the above-mentioned disadvantages, leno weaves were not generally considered for concrete reinforcements. However, newly developed machine platforms make possible the production of tight and open structures with straight weft and warp and minimal thread damage without sacrificing productivity.

Before the new leno weave technique can be employed to produce high-performance textiles for reinforcements, it is imperative that the fabric forming process be modified to ensure that the high standards required of the yarn are met.

The main goals of research can be broken down into three tasks:

- Increasing pattern variability
- guaranteeing minimal damage to the high-performance fibres during the feeding process
- stabilising the structure beyond the fabric-forming process

all while maintaining machine productivity.

The Institute of Textile and Clothing Technology (ITB) at TU Dresden has developed a new drive concept, called Multileno, to increase pattern variability [7]. This concept enables unlimited patterns. We are currently in the product-testing phase and are working on the premise that the patterns can be varied, while clearly minimising yarn damage and without compromising productivity.

As a rule, yarns can be strengthened by twisting; the individual filaments support one another, thus ensuring a more uniform load transfer. This effect can also be observed in high-performance fibres. However, the more the yarns are twisted, the more the roving bunches together and is subsequently inadequately coated by the cementitious matrix. The loads are then carried only by the outer filaments. The more the filaments are twisted, the more the overall strength of the composite member is reduced. This means that it is essential that the high-performance yarns be fed without twisting.

The separately controlled warp beams on the EasyLeno 2T weaving machine allows manufacture of a high-performance leno weave with straight weft and a straight warp thread. However, a temporary crossover of the warp threads is unavoidable leading to a bunching up of the warp threads, causing them to roll back and forth. The minimally twisted yarns fray and the existing filament breaks tend to quickly split or roll over. By modifying the warp feed this effect could be minimised.

Along with the established stitch-bonded fabrics as concrete reinforcements, a further fabric-forming process has been created whose product in biaxial strengthened semi-finished textile products has found its niche between multi-plies and weaves. The properties of these textiles are greatly improved over the simple leno weaves and require less investment in machine technology than those of stitch-bonded fabrics.

3. Coatings

Research in practical construction studies concerning reinforcements and maintenance has shown that the potential of the mechanical properties of AR-glass and carbon fibres employed in composite members are not optimally utilised. Furthermore, observation shows that the placement of the reinforcing threads within the textile structure is disrupted during handling and later processing.

In an attempt to improve the structural stability of open stitch-bonded fabrics, our research has concentrated on creating a process integrating coating technology on the multiaxial stitch-bonding machine Malimo 14024. After analysing different methods of improving structural stability, a direct coating of a watery polymer dispersion applied by roller and infrared drying was chosen. A dipping roller applies the coating to the underside of the textile structure. A passive roller is placed across from the dipping roller to ensure direct contact between the textile and the coating roller (Fig. 5).

Fig. 5: Coating process on the multiaxial knitting machine

The coating on the textile structure is controlled by the relative speed between the circumferential speed of the dipping roller and the transport speed of the multiaxial knitting machine, as well as the amount of organic substance in the watery dispersion. Both methods allow for reproducible results.

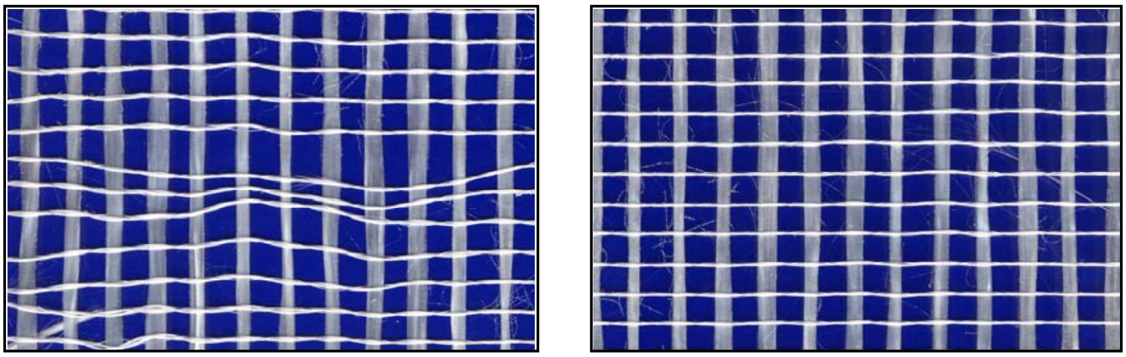

Fig. 6: Effects of coating on material stability of leno weaves
- (a) uncoated leno weave - (b) coated leno weave (right)

Expanding on the knowledge gained in the coating of multiaxial fabrics, an online coating aggregate was integrated into the EasyLeno 2T weaving machine manufactured by Lindauer Dornier Limited. By directly integrating the coating process on the weaving machine, the weave could be stabilised before leaving the machine, thereby mitigating against possible thread displacement. This addition greatly increased the displacement stability, reaching the standards required in concrete reinforcements (Fig. 6).

4. Summary

Stitch-bonding technology and the new leno weave method offer two efficient fabric-forming processes in the production of concrete reinforcements composed of glass and carbon filament yarns. By considerably modifying standard machines on the market, semi-finished textile products fitted to various reinforcing requirements can be produced. An additional coating process can decidedly improve the products' handling and reinforcing properties.

5. Acknowledgements

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