Presented are applications of new technologies in the textile industries to the design of textile architecture. The process is described in which yarns are coated, the coated yarns are woven to belts, the belts are welded onto coated fabric and the fabric with the belts is used in a demonstration building. The belts have adjustable properties and can be used along boundaries, edges, high or low points in the membrane building.

BELTS in textile Architecture

Introduction

Textile belts are well known and improved in field of lifting and safety technology. Belts are used uncoated, are coated considering abrasion and mechanical wear or are protected by jackets. Available on the market are belts which are coated after weaving with PVC or PUR and are applied to the tarpaulins of trucks. The requirements to these belts are different to belts applied in textile architecture. The strength is lower, the elastic stiffness is nearly irrelevant, varying stresses under tension, creep, relaxation are low and UV-protection is less compared to the term durability of building covers which should last at least 30 years.
Scientific and technical work is still missing to transfer the requirements of building technology to belts for applications in textile architecture. The mechanical properties of the belts are not well known, the influence of the weaving to the stiffness and the material laws are unknown. The length of anchoring the forces in the belts is based on experience. Belts have no specific properties for their use in membranes for building covers and the design methods are less developed.
Normally steel cables are used in membrane structures to carry high forces. Edge details made by belts are limited to small span covers to approximately 8m span depending on the external loads. These belts are normally sewed in textile pockets which are again sewed or welded onto the fabric of the cover. The yarns need to be UV and abrasion resistant as well as weatherproof in case of sewing the belts onto the fabric. The most critical point of sewing is the precise strain of the seam. The seam has to withstand the strain for pretensioning the whole structure without rupture. The stitching has to be carried out while tensioning the membrane and the belt by hand. This causes an uneven strain along the seams depending on the experience of the person using the sewing machine.
The disadvantages of sewed details are the fact that the seam is not watertight, the destroying of yarns and the seam getting dirty over the years. Dirt is collected along the yarns of the seams. If tightness and appearance are important the seams are either protected by an additional tape or coated with liquid coating compound (Fig. 1).
The most common use of belts in the corners is to collect the tangential forces along curved boundaries additional to the boundary cables. The tangential forces are less compared to the stresses in the cables. The function of these tangential belts is to prevent sliding of the membrane along the cables which requires a separate anchoring of both load carrying elements. The belts are added in an additional and costly work procedure; in most cases belts are missing or the membranes are clamped to steel plates in the edges.
Belts are often used in retractable roofs and are improved in several structures in the last two decades. Steel cables are easily to roll up but hardly to fold and are limiting the folding of the membrane in the storing position. Most retractable roofs are for shading and rain protection, they are closed in case of high wind loads or snow loads. The requirements considering load carrying behaviour are less, the forces along the boundaries are lower and belts are suitable in this case.

New development

The weaving technique of belts allows the manufacturing of belts with specific properties related to the different requirements. The warp can be produced with nearly straight yarns and leads to nearly constant stress and strain behaviour with less influence of the change in the geometry of the yarns. Another possibility is the weaving with a stress dependent behaviour and provides advantages for the use of belts in membrane covers. If the stiffness of the belt is increasing in relation to the tension force the belts are flexible during the pretensioning of the membrane and are getting their stiffness if the required tension force is reached. The yarns of the belts can be hardened to increase the stiffness by elongation under thermal treatment. The density of the yarns in weft direction is important for in plane bending of the belts. The belts are more flexible and less bending stiff if the distance of the yarns is higher caused by increasing the shear deformation of the yarns against each other. In the same way the belts can be produced with a given in plane curvature helping to adjust the belts to curved boundaries of the membranes.
The disadvantages of belts such as the extensive sewing, the protection against UV radiation and the fact that belts are not watertight at the stitches are reduced if the yarns themselves are coated providing UV protection and the belts can be welded onto the membrane. The coating of yarns is a well known method to protect yarns against environmental impacts. In a research and development project with two university, one research institution and two industrial partners these method is developed further for applications in textile architecture. The basic idea of the project is the coating of high strength yarns, for example made of polyester or polyethylene, the weaving of belts with the coated fabrics and the welding of the yarns directly to the membranes (Fig. 2). The advantages are obvious, the yarns are fully protected against environmental impacts such as humidity, UV-radiation, pollution etc. The coating can be treated to become flame retardant or can be made of not burnable flour polymers. if this coating has the same or similar chemical compounds as the coating of the membrane, then welding is easily possible. In case of PVC or THV coatings the belts can be applied by HF welding on the membranes. Furthermore the connection is tight against humidity and water and the strain behaviour can be better defined compared to a sewed connection.

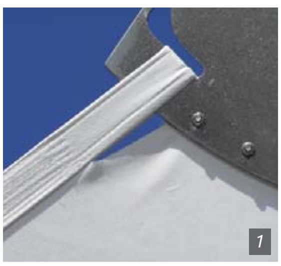
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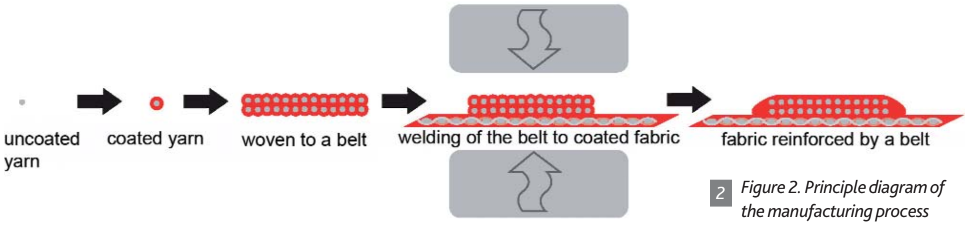
Figure 1. Edge detail with a belt in a sewed pocket
Figure 3. Belt of coated yarns (Weaver: Güth & Wolf, Gütersloh, Germany)
Figure 4. Stress and strain behaviour and Seam strength in an uniaxial tension test (KIT, Labor Bautechnologie)
Figure 5. Demonstration building (manufactured by Walter Krause GmbH, Walheim)



2 *Figure 2. Principle diagram of the manufacturing process*

The breaking strength and the elastic stiffness are determined by the material of the yarns, the texture and the width of the belts. The load transfer between membrane and belts is determined by the stiffness, strength and adhesion of the coating and defines the length of anchoring the belts.
The tasks needed to be solved within the project are derived from the presented idea of producing belts of already coated yarns and welding these belts onto coated fabric. The most important points are:

- Selection of the yarns
- Selection of the coating
- Coating of the yarns
- Weaving of belts with the coated yarns
- Determination of the ultimate strength of the belts
- Stress- and strain behaviour of the belts
- Load transfer between belt and fabric
- Wealdability of the belts
- End terminals of the belts
- Design and construction of a demonstrator

The list of requirements for the yarns is large and some of them are strength, sensitivity against lateral pressure, foldability, flame retardant, adhesion, compatibility of the coating, handling, ecological and economical aspects.
To ensure the success of the project a polyester yarn PES 2200 dtex is chosen.
The parameters for the coating are good behaviour for the application onto the yarns, good adhesion, resistance against lateral pressure, UV resistance, flame retardant and long term durability. A PUR coating is a common method for protecting yarns in the outdoor furniture industry and is used for further steps.
The produced belts have 120 yarns in warp direction and a width of 6cm (Fig. 3).
The belts are tested in uniaxial tension test to get the stress and strain relation, the breaking strength and elongation. For the manufactured belts the maximum force is approximately 7kN.
Up to a force of 400N the belts are very soft and between 400N and 5kN tension force the stress and strain relation is relative constant. At a force of 5kN the belts get softer till they break.
The design force is given by the ultimate force reduced by the safety factor for the material, which is 6 to 7 for belts in the lifting or safety industry. This means the design force of the developed belt is 1kN which is very low. The safety factor is 3 to 4 for the membrane itself.
Further investigations are necessary to develop a design method which allows a higher load carrying capacity of the belts and ensures enough safety against failure.
In the next step the welding of the belts is examined. Different samples are tested with respect to the size and the arrangement of the connection between belt and fabric. The results show a very good adhesion between belt and membrane. In all test the membrane failed before the connection of belt and fabric lost strength. The adhesion between the two coatings is strong enough as well as the adhesion of the coatings to the yarns of the belts and the fabric (Fig. 4).
The critical point of the load transfer from a two directional fabric to a unidirectional belt is the fabric at the end of the belt. The low shear stiffness of the coating of the membrane introduces high stresses in the fabric and causes cracks in the membrane at the end of the belt. This application requires an additional reinforcement of the membrane to ensure a better load transfer into the membrane.
The handling and different solutions for welding the belts onto the membrane is verified in a small membrane cover which is designed and built up. The cover has a size of 10m in length, 3,3m in width and is spanned into a given steel frame. The cover is made of several parts testing and demonstrating the feasibility of the belts. The cover has a low point as well as a valley both are made by the belts welded onto the membrane or between two membranes along the seam of the valley. The boundaries are made in different ways; the belt is welded onto the fabric, welded and folded underneath or guided in a pocket (Fig. 5).
The following gives the field of applications of the developed belts are in the textile architecture:

- Concentrating of high forces in membranes along geometrical and mechanical discontinuities such as high points, low points, valleys, edges, changes in surface geometry or change in the orientation of warp and weft
- Belts help to reduce deformations under external loads and to avoid pounding of water and snow
- The manufacturing can be simplified because no additional pockets are needed to assemble for the boundary cables
- To simplify the construction on site because the whole membrane with all boundary elements can be brought on site.
- To increase the safety of the membranes, in case of a failure belts along the seams can be used for stabilizing the primary structure.
- To widen the range of possible shapes, introducing belts in the surface the shape can be changed.

Belts made out of coated yarns are also of interest in other industrial fields, in which belts are sewed on membranes such as truck tarpaulins, flexible bags, sails etc. The market for the developed product is not limited to the textile architecture and can be more successful if the applications are much wider.

Acknowledgement

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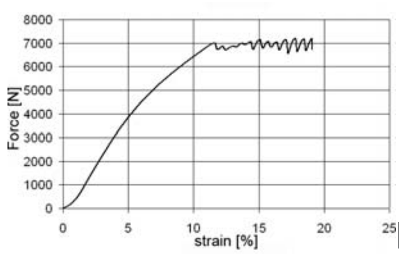

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