# FUNCTIONALISATION OF HIGH-STRENGTH FIBRE ROPES BY EXTRUSION

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## Abstract

Investigations at Technische Universität Chemnitz have shown that friction is, in multi-layer winding tests, causing relevant mechanical damages to fibre ropes and therefore is limiting the working life of fibre ropes. Further, the sensitivity to pressing forces and kinking of high-strength polymer fibres, which are mostly geared to maximum strength, is considered to be an additional, important degradation mechanism beside the surface wear. The inferior dimensional stability of fibre materials, compared to steel wire ropes, is promoting kink effects at a rope's edge area. To avoid these effects, research objectives are focussed on applying a monolithic extruded sheath to rope structures, which have been optimised regarding flexural fatigue strength. These extruded sheaths are meant to counteract against the low dimensional stability of the fibre materials and, in same time, to ensure appropriate drivability of the ropes in traction drives.

## Introduction

In technical applications, synthetic fibre ropes are mostly bent over sheaves or wound on rope drums, in one single layer or a multiple-layer stack. In these cases, double braids, consisting of a braided core and a braided cover, have proven to be most suitable. Due to their better dimensional stability while being bent over a sheave, kinking effects in the pressure-sensitive HM-HT-fibres (HM-HT = high-modulus high-tenacity) are reduced, as shown in figure 1.

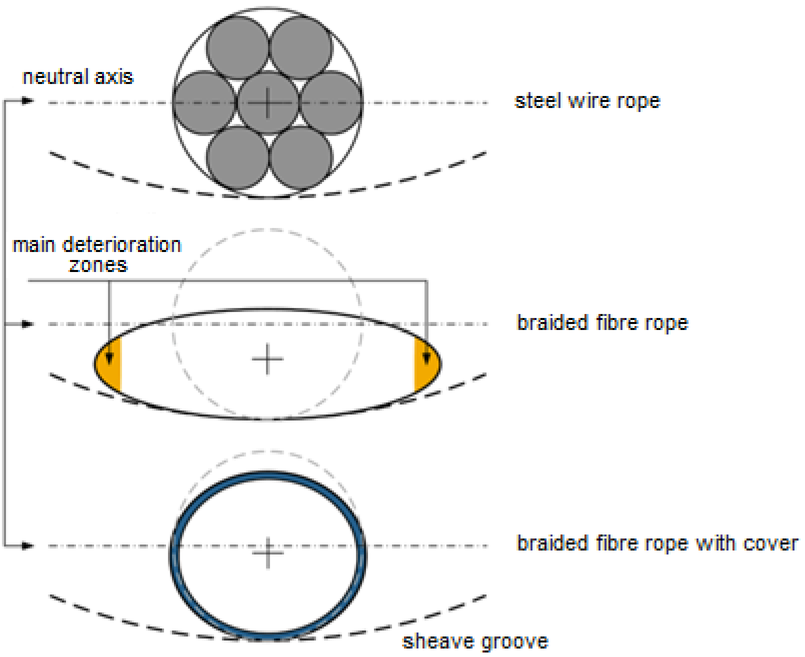


*Figure 1 Dimensional stability of steel wire ropes and fibre ropes*

The monolithic design of an extruded cover or a coated, braided cover is, in addition, assuring that no lubricant is emerging from the fibre rope and that no foreign particles or objects can intrude the rope. A rope design containing such a monolithic cover is enabling a precisely fitting design of a tension member with the potential of totally exploiting the performance potentials of synthetic fibre ropes.

In case of the process of extruding sheaths and covers, there is a differentiation in high-pressure extrusion process and tubing-extrusion process. Both process types are consisting of sheathing tools with an outlet nozzle of circular cross section (cf. fig. 2). The rope to be sheathed is, in both processes, guided through a mandrel, which is circulated around by polymer melt.

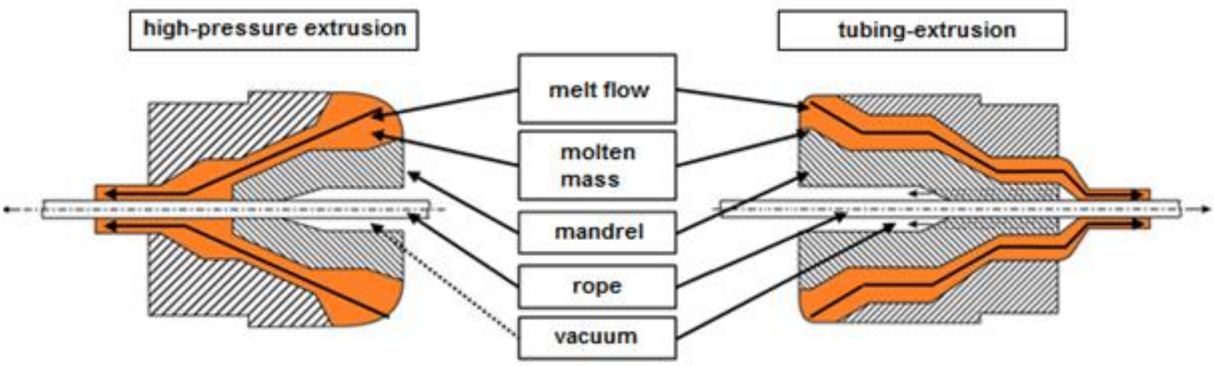


*Figure 2 Tools for extrusion of cover layers according to [1]*

During high-pressure extrusion, the rope is guided directly through the molten polymer mass and the molten mass can partly penetrate the textile structure of the rope. Beside adhesion forces, mechanical grouting is in action, so adhesion is significantly improved on the fibre rope's surface. A disadvantage is the fact that relative movement between the strands at the rope's surface, which is necessary for running fibre ropes, is partly limited.

During tubing-extrusion, rope and molten polymer mass are joint outside the extrusion tool. For enabling a homogeneous extrusion layer, a vacuum is generated between rope and molten polymer mass. Main advantages of this process are a short time of thermal exposure and a good concentricity of rope and extrusion layer. A disadvantage to be named is the inferior adhesion between rope and extrusion layer.

In general, the tubing-extrusion process is used for processing extruded covers around ropes, used as running ropes. The process is shown in figure 3. A fibre rope is supported to the extrusion process by a winder, and is positioned by a guiding device. Inside the tool, the rope is running through a mandrel and is coated with the molten extrudate inside a piston ring at the tool's end. A vacuum exhauster is generating a partial vacuum of about 0.2 bar and is thereby extracting the air from mandrel and piston ring. Just before entering the cooling zone, the extruded cover is calibrated according to the required final dimensions. Within this step, the extruded cover is plastically deformed for another time. In the cooling zone, the derived geometry is permanently stored to the final product, a rope with extruded cover layer. The final product is wound onto another winder and can be used for assembly.

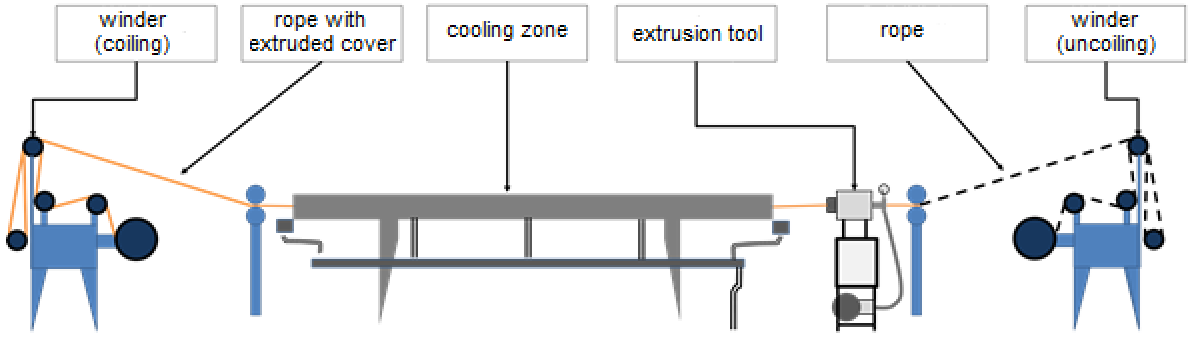


*Figure 3 Scheme of tubing-extrusion for fibre ropes*

**Experimental**

Within the experimental investigations, the geometry of the fibre core and the extruded cover have been determined. It was found that, due to the calibration right before the cooling zone, the final diameter of the product is differing from the expected diameter by just about 5%. The nominal deviation of the values in the measuring directions X and Y is about 0.31 mm. The rope in the core of the final extruded product is showing a significantly elliptical geometry, the mean deviation of the diameters in measuring directions X and Y is about 2.72 mm, as shown in figure 4.

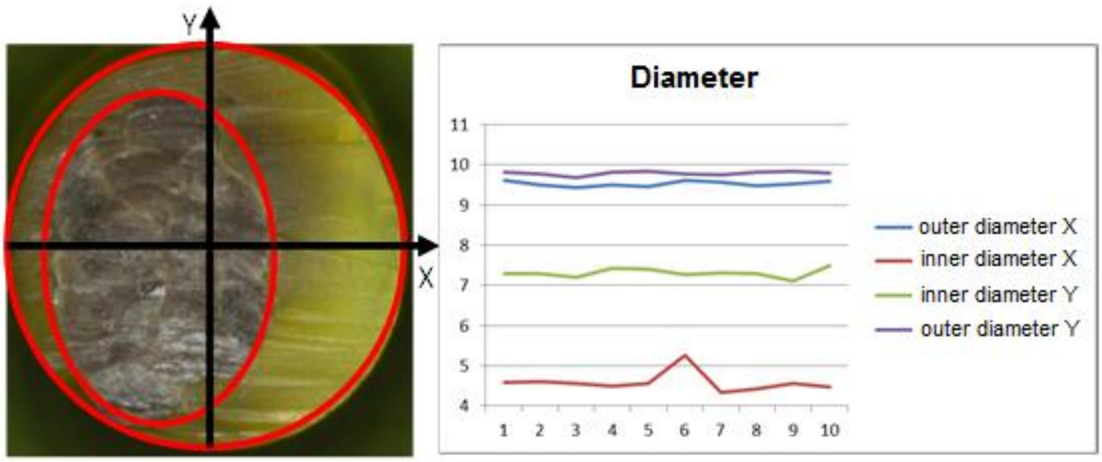


*Figure 4 Effects occurring in the cross section of extruded fibre ropes*

Main cause for the effect shown in figure 4, is the fact the load dependent geometry of the cross section in fibre ropes, as found by *Heinze* and displayed in [2]. At high loads, the stacking factor of a fibre rope is increasing. Thereby, the deviation of the outer diameters in the two measuring directions is decreased and the fibre rope is changing from an elliptical to a nearly circular shape, as shown in figure 5.

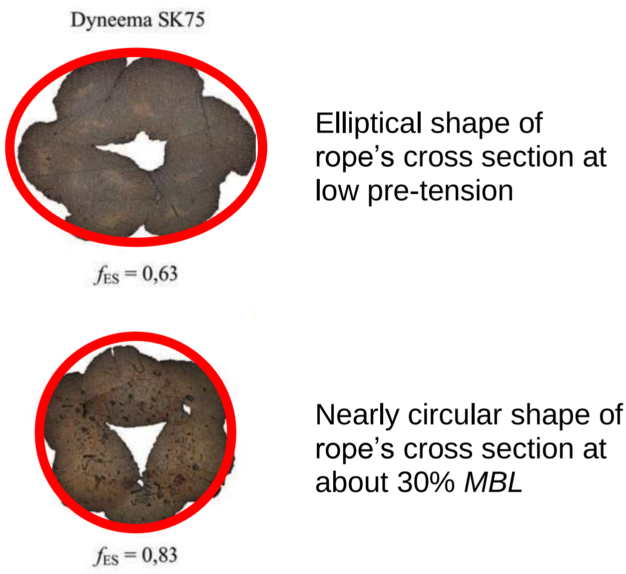


*Figure 5 Effects occurring in the cross section of fibre ropes under varying load*

The shape of fibre ropes is, during extruding covers onto fibre rope, similar to the rope cross section, shown above. A further influence to the shape of the rope cross section is the radial force, applied to the rope. Looking at a braided fibre rope with a braided polyester cover, a nearly circular shape of the cross section is found, as shown in figure 6.

*Figure 6 Cross section of a braided fibre rope with braided cover*

In conclusion, the load on the rope is to be increased during the process of extruding a jacket, in order to avoid the big differences in the shape of the cross section between extrusion tool and fibre rope. In addition, the effective radial load is also to be increased. Because of the fact that a maximum pressure in the molten mass of about 1 bar can be applied in the process of tubing-extrusion, extruded cover layers on fibre ropes have to be established by high-pressure extrusion, in the future. In the process of high-pressure extrusion, process pressures of up to 250 bars can be applied.

When used in applications as a running rope, high-strength fibre ropes are mostly stressed by abrasion. Especially in multiple-layer winding and spooling, friction and wear are occurring between the single layers. Further, the base layers are exposed to high compressive, transversal forces, what leads to deformations of the rope's shape of cross section. To avoid these deformations and to protect the fibre rope from abrasive influences, the fibre rope can be protected by an extruded polyurethane cover.

At Technische Universität Chemnitz, a fibre rope made from aramid fibres, containing an extruded polyurethane cover, was tested in a special winding and spooling test bench. The rope has been wound on the drum and uncoiled from the drum in multiple-layer winding for 3500 cycles, at a tensile load of 5 kN.

**Results**

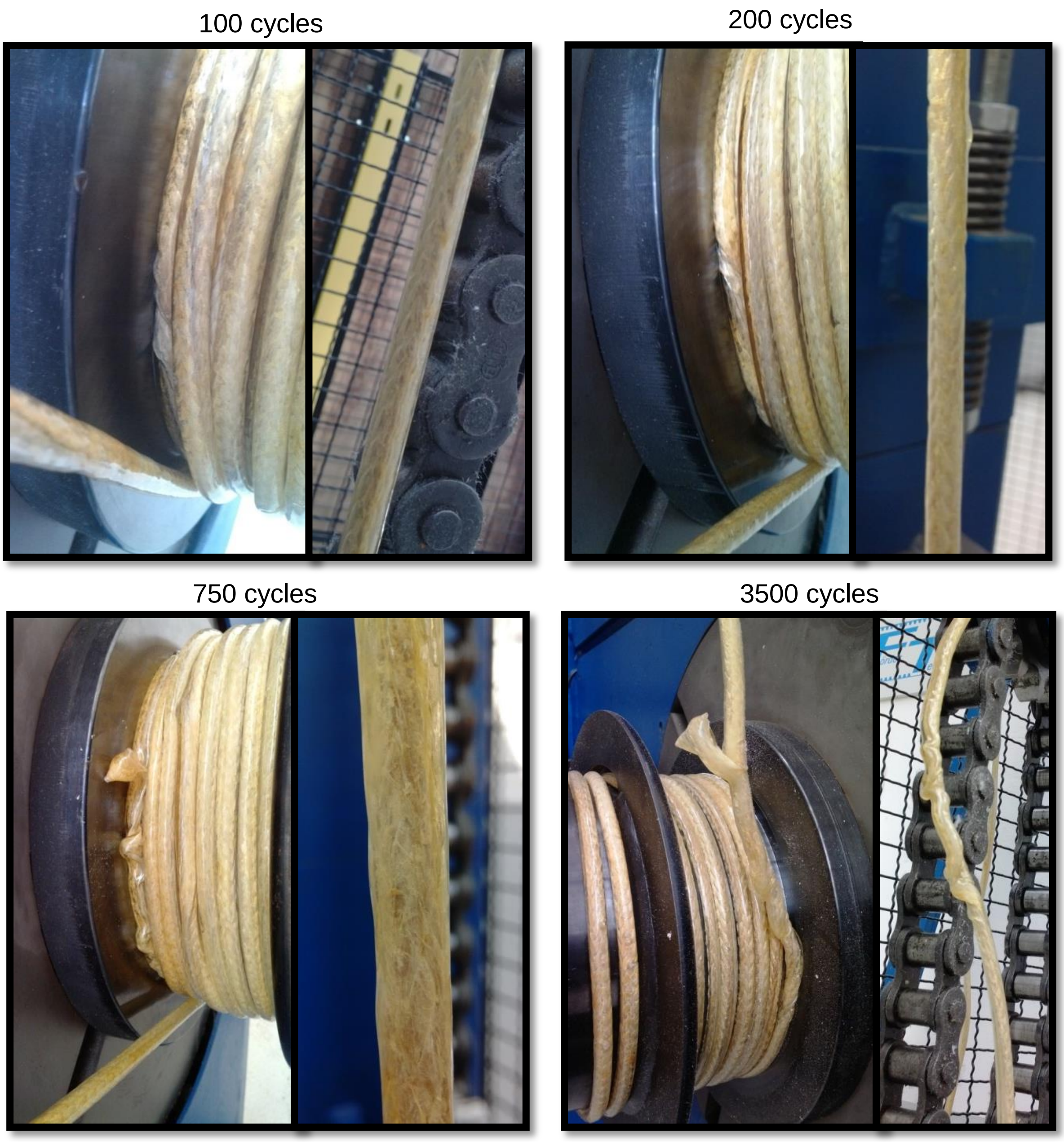


*Figure 7 Winding tests on a fibre rope with a polyurethane cover (tubing-extrusion)*

After almost 100 cycles in the test bench, the extruded cover was separating from the core rope, what became visible by an opacity of the extruded cover, as shown in figure 7. At about 750 cycles, local material accumulations occurred in the rope sections close to the change between 1st and 2nd layer and from 2nd to 3rd layer. After 3500 cycles, it was found that the layer was extruded cover was already broken along the rope axis, in the areas where the thickness of the extruded layer was, due to the oval shape of the rope, only about 0.5 mm to 0.8 mm.

## Summary

The linkage between core rope and extruded cover is, in case of tubing-extrusion, limited to a local form fit. The extrudate is not penetrating the rope, but is laying on the rope's surface and forming a negative print of it, as to be seen in figure 8. This linkage, based on physical effects, is annihilated by widening of the extruded cover by bending forces and the multiple-layer winding. A fulling of the extruded layer occurs and results in local breaks of the extrusion layer. To avoid such effects, the thickness of the extruded cover should be almost constant. By this, local stress peaks and their resulting deformations can be eliminated. Further, the form fit can be improved by a penetration of the extrudate into the textile structure of the outer area of the rope's surface, what leads to the recommendation of creating extruded rope covers by high-pressure extrusion.

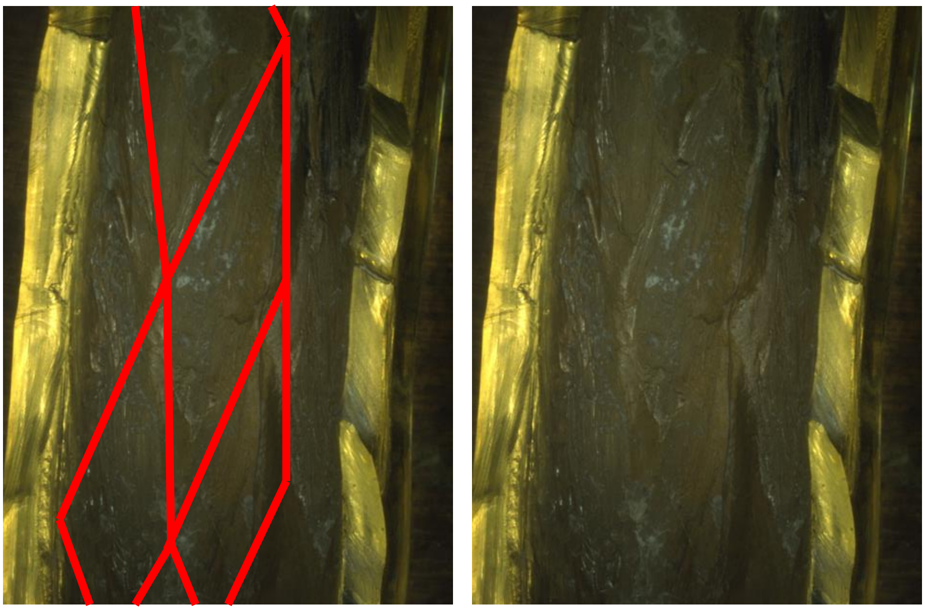

*Figure 8 Tubing-extrusion layer separated from the core rope*

## Literature

1. Michaeli W., Extrusionswerkzeuge für Kunststoffe und Kautschuk; 3rd Edition, (2009).
2. Heinze T., Zug- und biegewechselbeanspruchte Seilgeflechte aus hochfesten Polymerfasern; Doctoral Thesis, (2013).