- SEMIFLEXIBLE COMPOSITES - DESIGN OF AN ENDLESS WARP-KNITTED REINFORCED THERMOPLASTIC ELASTOMER

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SUMMARY: A design concept for elastomeric profiles is presented. These profiles can be used for conveying and other driving purposes. Their stiffness and strength are improved by a warp-knitted textile structure. The matrix consists of a thermoplastic elastomer. To obtain sufficient resistance against abrasion and aggressive media in a severe environment an adequate thermoplastic elastomer has to be specified. Additionally**,** the surface energy of the TPE has to correspond to that of the fibre material to obtain a sufficient adhesion to the reinforcement. The textile structure consists of a complex warp knitted structure of polymer fibres of different yarn thickness, fibre twist and textile pattern.

The mechanical properties of the designed composite were characterised by finite element analysis (FEA) and experimental work. Finally**,** the composite was manufactured by extrusion.

KEYWORDS: TPE, Warp-knitting, Textile pattern, Semiflexible, Bending behaviour, Twist, Aramides, Polyesters.

INTRODUCTION

Conventional design of semiflexible profiles

Due to high requirements regarding mechanical strength and durability, conventional fibre-reinforced elastomeric profiles fulfilling these (like conveyor belts, V-belts and handrails for escalators) consist of rubber. They have an overall design consisting of discrete reinforcing layers of steel cord or high-modulus polymer fibres along the longitudinal-axis. If a certain stiffness of the profile in the cross

section or torsion stiffness is needed, fabric layers of polymeric fibres are commonly embedded in the transverse direction.

These complex parts have to be manufactured by vulcanisation pressing to compress the different layers for good adhesion and to crosslink the rubber.

In addition to the cost-intensive manufacturing process and high capital investment in this conventional technology, the design of conventional rubber-composites has other disadvantages:

- corrosion and high thermal expansion of the steelcord,
- quality gaps due to the discontinuous pressing-process of endless parts,
- difficult and large-scale splicing of the ends of the parts.

Furthermore, most of the used rubber materials like SBR (styrene butadiene rubbers) and NBR (acryle nitrile butadiene rubbers) are affected by ozone corrosion so the parts have to be replaced mostly due to ageing fatigue. Finally the recycling ability of rubber goods is still insufficient.

Advanced design of semiflexible profiles

The main functional requirements of a profiled semiflexible composite can be listed as follows [1]:

- mechanical durability and environmental resistance,
- high stiffness and strength along the longitudinal-axis,
- low bending stiffness around cross-axis,
- and a high cross-sectional stiffness of the profile.

Secondary requirements can be

- good aesthetics, high class surface,
- adequate haptic,
- low sliding coefficient on one side of the composite if it slides on a hard surface (such as handrails and guided conveyor belts).

To reduce the assembly and preassembly efforts all these functional requirements have to be fulfilled using only a few elements.

High manufacturing costs can be reduced by continuous processing. A high productivity is guaranteed by extrusion, if the periphery has a high degree of automation. But to use the extrusion technique for profiled semiflexible composites, its design has to be reduced to only a few layers.

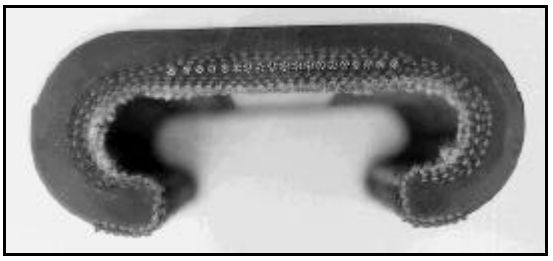

Fig. 1: Profile of a conventional semiflexible profile - a handrail for escalators

MODULAR DESIGN

The advanced design consists of two modules only. The elastic layer mainly provides mechanical and chemical resistance. The second layer, a warp-knitted textile structure, provides reinforcing characteristics in the longitudinal-axis, in the cross section, and shows sliding characteristics on its bottom side.

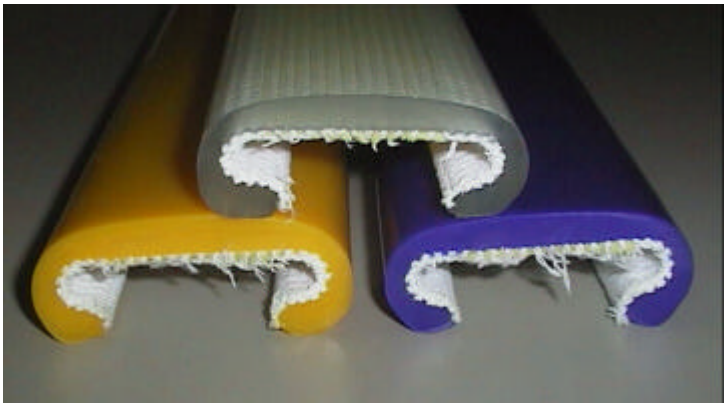

Fig. 2: Design of the advanced semiflexible profile – a handrail for escalators

Module 1: Elastomeric layer of TPE

TPEs are polymers which combine the mechanical properties of elastomers with the manufacturing characteristics of thermoplastics. In contrast to elastomers with covalent crosslinks TPEs show a reversible physical network. Due to this they can be manufactured by conventional processing methods for thermoplastics.

The main advantages of TPEs in comparison to rubber materials are:

- low manufacturing costs due to
  - no vulcanisation,
  - no mixing,
  - shorter processing time cycles,
- easy recycling of scrap and used parts.

Some disadvantages are the following:

- higher mechanical hysteresis,
- TPEs cannot be used close to their melting point because of a decrease in mechanical stiffness,
- higher compression set, especially at higher temperatures, which means limited bending ability and lower impact toughness.

Due to their morphology, TPEs can be divided into two groups: copolymers with alternating different chain-segments and blends of a continuous thermoplastic hard phase and an elastic soft phase (Fig. 3).

Copolymer **Polymerblend**

Fig. 3: Morphology of thermoplastic elastomers [1]

In this project the TPE groups:

- styrenic block copolymers (TPS),
- polyether-and polyester-polyurethanes (TPU),
- polyether-esters (TPEE),
- and EPDM-PP blends

were investigated. The commercial TPE types are shown in Table 1. For the design of the semi-flexible composite following properties were of interest:

a) mechanical properties under static load,
b) mechanical properties under dynamic load,
c) mechanical properties under chemical and physical ageing,
d) and interface properties to polymer fibres.

This paper only deals with the test procedures in c) (Fig. 4).

Table 1: Investigated thermoplastic elastomers

Mechanical properties	TPS	TPU		TPEE	TPV
	Thermolast® TC8 AAE, Kraiburg GmbH	Elastollan® 1185A, FHF Elastogran GmbH	Pearlthane® D11T85, Merquinsa GmbH	Arnitel® PL380N, DSM	Sarlink® 4180N, DSM
hardeness [Shore A]	82	89	85	89	67
stress at 100% strain [%]	3,2	7	4,7	7,5	3,4-4,8
ultimate tensile strain [%]	550	600	600	450	-

Qualitative change of the mechanical properties of TPE under ageing conditions

For modelling the mechanical behaviour of elastomers by Finite-Element-Analysis (FEA), their quantitative and qualitative mechanical behaviour was needed (see chapter *FEA modelling of the semi-flexible composite*). The TPEs in Table 1 were subdued to following ageing tests:

- ozone (DIN 53 509),
- UV-radiation (DIN 53 387),
- high temperature (70°C, DIN 53 508),
- humidity (DIN 53 521),
- acid solution (10% citric acid, DIN 53 521),
- and alkaline solution (10% soda lye, DIN 53 521).

In most publications the degradation of the mechanical properties of elastomers are investigated for high loads (f.i.100%, 200% strain). But semiflexible composites show lower deformations. Because of this, mechanical tests were performed up to 50% strain after ageing to obtain a high resolution in this range. In this deformation range the ageing effects on different TPEs were compared (Fig. 5).

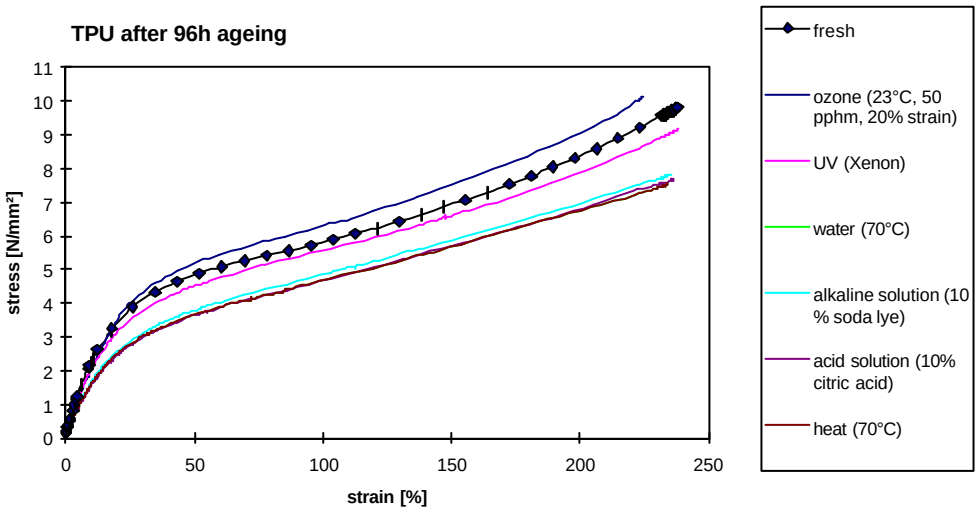

Fig. 4: Change of the mechanical behaviour of a TPU under ageing conditions

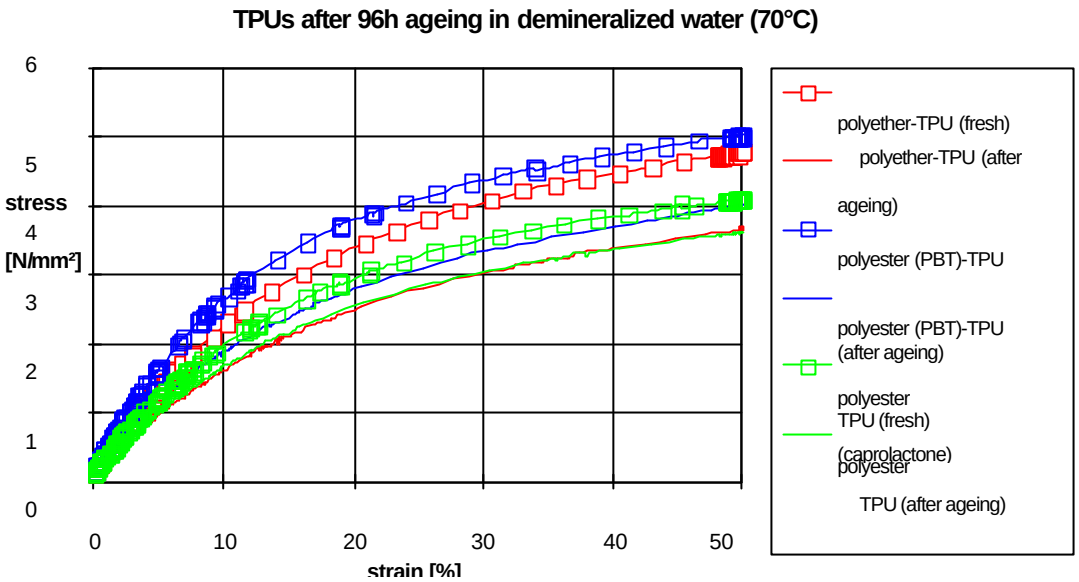

Fig. 5: Different TPUs after 96h ageing in demineralised water at 70°C

Module 2: Warp-knitted reinforcing structure

Warp-knitted textile structures offer the possibility to combine several functions, such as longitudinal and cross sectional reinforcement within one textile layer, and can easily be manufactured as well.

For handrails especially, a textile structure was designed by variation of

- fibre-material,
- yarn-thickness,
- yarn-twist,
- and warp-design.

The aim was to achieve a composite with sufficient longitudinal stiffness and strength, form stiffness in cross section and a low sliding characteristic on its lower surface.

FEA modelling of the semiflexible composite

For the FEA-design of the composite, the numerical description of the non-linear time-independent behaviour of TPE was needed. Due to the low examined strain, the work of deformation (w) can be characterised f. i. by Eqn.(1) with the help of the Invariants I_i of the strain tensor λ [3]:

$$\begin{aligned} w &= C_{10}(I_1 - 3) + C_{01}(I_2 - 3) \\ I_1 &= l_1^2 + l_2^2 + l_3^3 \\ I_2 &= l_1^2 l_2^2 + l_2^2 l_3^2 + l_3^2 l_1^2 \end{aligned} \qquad (1)$$

Parameters for the analytic description of the TPEs were found by unidirectional tear and compression tests and biaxial tear tests. For easy validation of the FEM calculations, composite-specimen with unidirectional fibre-reinforcement were made and tested in a 3-point-bending-test (Fig. 6). The reinforcement-layer was modelled in three different ways [4]:

1. anisotrophic thin-shell-elements,
2. composite-elements,
3. rebar-elements.

In a previous experimental work, the bonding characteristics of the material partners were analysed to achieve a high penetration of the matrix in the fibre bundles. This allows the assumption of a perfect glued contact.

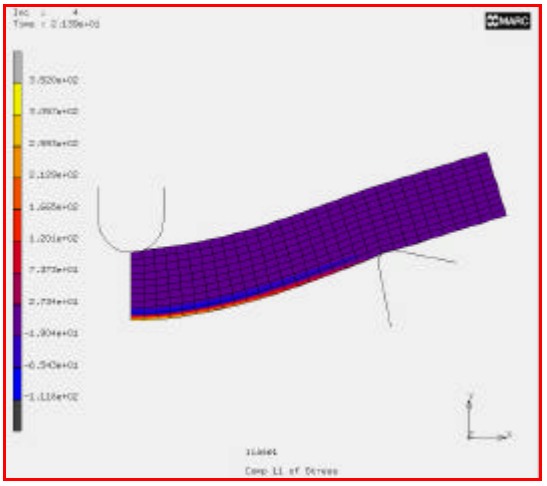

Fig. 6: FEA model of a semiflexible composite in a 3-point-bending-test in MARC-Mentat®

Following validation of the numerical results with the experimental data, a complex profile was designed in FEA and its textile reinforcement layer was optimised for the mentioned mechanical requirements

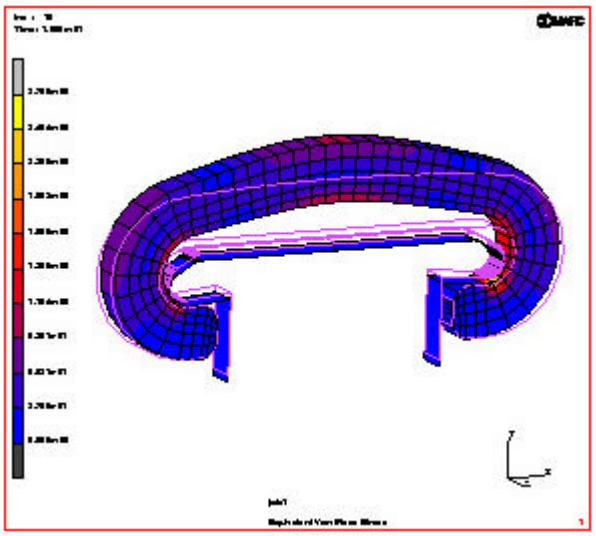

Fig. 7*: Semi-flexible profile in a complex deformation state*

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