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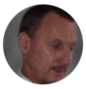

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ANOMALOUS ELECTRICAL RESISTANCE OF HYBRID YARNS CONTAINING METAL FIBERS

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ABSTRACT

The total electric resistance *R* is theoretically linearly increasing function of the conductive wire length *L*, because the electric conductivity *K* or electric resistivity *r* is independent on *L*. It was found [7] that for yarns containing the conductive metal fibres the dependence of electric resistance *R* on *L* is highly nonlinear. Main aim of this contribution is creation of the simple mechanistic model describing this anomalous length dependence. Characteristic parameter of this model is so called specific resistivity α.

Key Words: hybrid yarns, electrical resistance, length dependence, metal fibers

1. INTRODUCTION

Conductive textile characteristics connected with protection against electrostatic field were studied in numerous publications [1-3].The characterization of electric signal transmission through conductive textile was investigated e.g. in the publication [4-5]. Standard assumptions in these publications is validity of basic relations known from area of conductive metals as linear increasing of electric resistance *R* with increase of conductive wire length *L*. This assumption was experimentally supported for the case of conductive filament in the work [6]. In the internal report [7] it was found that for yarns containing the conductive metal fibres is dependence of electric resistance *R* on *L* highly nonlinear. Main aim of this contribution is creation of the simple mechanistic model describing this dependence. Characteristic parameter of this model is so called specific resistivity α.

2. DEPENDENCE OF RESISTANCE ON THE LENGTH

One of the principal characteristics of materials is their conductivity *K* [$\Omega^{-1}m^{-1}$ or S m^{-1}] characterizing ability to conduct electrical current. Typical conductivity values for polymers range from 10^{-14} to 10^{-17} [S cm^{-1}]. In contrast, the metals are typically around 10^{6} [S cm^{-1}].
The inverse of the conductivity is called resistivity *r* [Ω m]. The total electric resistance *R* of a piece of conductive material is proportional to the length *L* and is inversely proportional to its conductivity and cross sectional area *S* i.e.

$$R = \frac{L}{k\,S} \tag{1}$$

The dependence of *R* on *L* is then straight line with slope $(k\,S)^{-1}$. In the case of hybrid yarns i.e. mixtures of conductive materials with insulators it was found (see. fig. 3) that the electric resistance *R* is nonlinear convex increasing function of yarn length *L* [7]. The mechanistic model of this phenomena is based on the very simple assumption that rate of electric resistance R change is directly proportional to the actual yarn length. The corresponding rate equation has the form

$$\frac{dR}{dL} = \alpha \ L^n \tag{2}$$

where α is proportionality factor (specific resistivity factor) and n is factor connected with attenuation of electric conductivity The final model is obtained by integration of eqn. (2) from R_0 to $R(L)$ and from zero to L. This model has simple form

$$R = R(L) = R_0 + \frac{\alpha}{n+1} L^{n+1} \tag{3}$$

The resistance for zero length should be in fact equal to zero and therefore $R_0 = 0$. For the case of ideal conductor is $n = 0$ and resistance is linear function of yarn length.. For the case of $n = 1$ is topical electric resistance quadratic function of yarn length. In this case has factor α dimension [$\Omega\, m^{-2}$]. It is simple to interpret α as resistance at length $L = 1m$ and therefore it is called specific resistivity factor. By using of eqn. (3) it is possible to calculate attenuation of electric conductance between selected lengths L_1 and $L_2 > L_1$ The attenuation $AF(L_1, L_2)$ [dB] of electric conductance between lengths L_1 and L_2 can be expressed in the form

$$AF\left(L_1, L_2\right) = 10 \ n \ \log\left(\frac{L_2}{L_1}\right) \tag{4}$$

It is clear that for selected lengths L_1 and L_2 is attenuation of electrical conductance directly proportional to factor n.

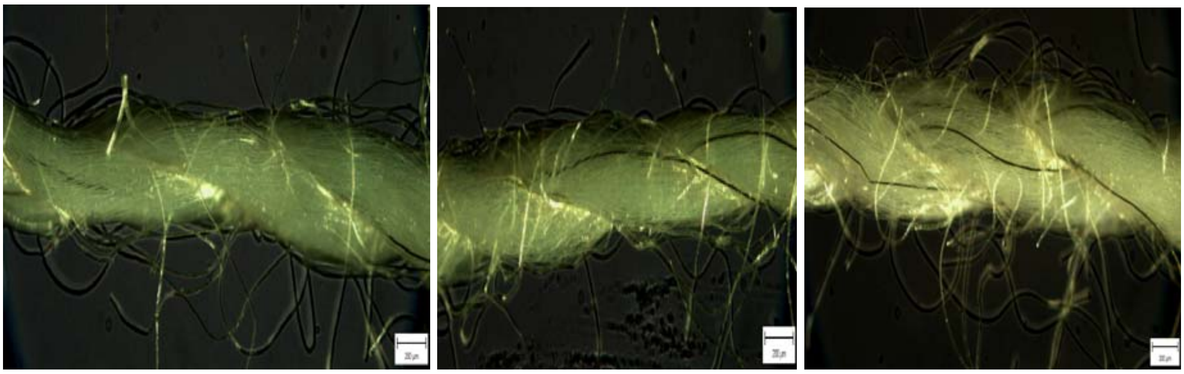
3. EXPERIMENTAL PART

Three yarns composed from polyester (PET) and steel fibers were used for measurements of electrical conductivity R. Calculated yarn fineness from direct weighting was T = 51 tex. Composition of yarns is given in the table 1.

Table 1. Composition of samples and specific resistivity factor

Yarn type	**composition**	**α [$\Omega\, m^{-2}$]**
Ruban 5%	95% PES/ 5% steel	1.2103e+013
Ruban 3%	97% PES/ 3% steel	4.2718e+014
Ruban 1%	99% PES/ 1% steel	2.1094e+014

The microscopic images of individual samples are shown in the figure 1. It is visible that in some portions of yarns are not s conductive component on the yarn surface layer.



1% 3% 5%

Figure 1 Microscopic images of Ruban yarns (numbers are steel fiber percentages)

The yarn resistance R [Ω] at gauge lengths 0,01; 0,05; 0,1; 0,15; 0,20; 0,25 and 0,3 m were measured by the two conductors method . The schematic arrangement of measurements is shown in the figure 2. All measurements were repeated 10 times and for subsequent treatment the sample median was used due to relatively big results scatter.

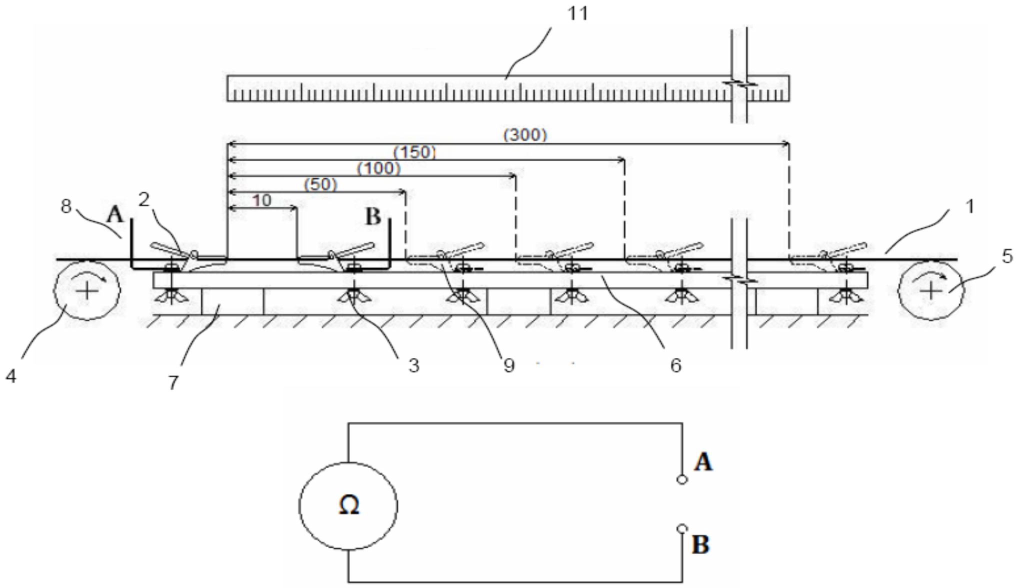


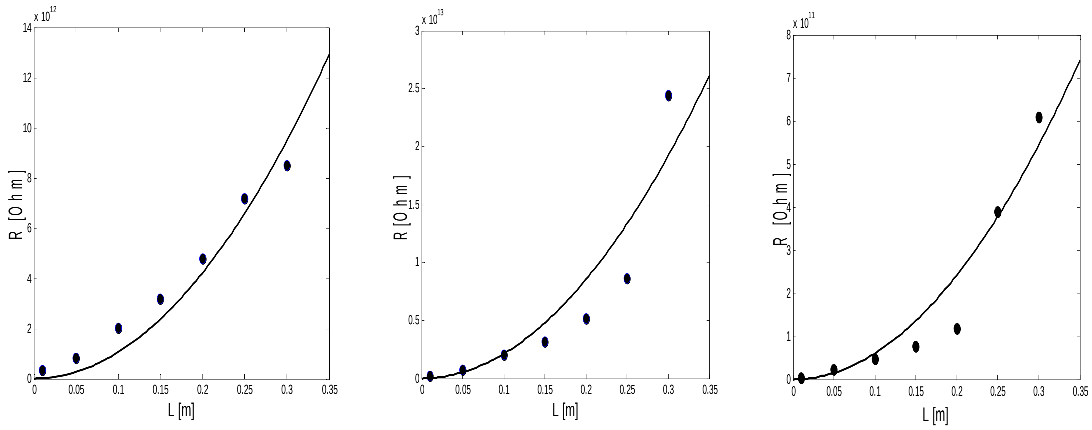
Figure. 2 The schematic arrangement of measurements

(legend: 1. sample, 2 electrodes in the form of clamps, 3. electrodes fixing, 4. yarn delivery, 5. yarn take off, 6. non conductive support,7. device holder, 8. conductors, 9. positions of second electrode, 10. resistance meter and 11. ruler)

4. RESULTS AND DISCUSSION

The dependence of yarn conductivity *R* on the yarn length for individual samples is shown in the fig.3. The nearly quadratic trend is clearly visible. The quadratic model was therefore selected (see eqn (3) for $n = 1$) as suitable.

The $R_0 = 0$ was selected and parameter α was estimated by the linear regression with minimum least squares of residuals criterion. The simple program QUADREG in MATLAB for parameter estimation of quadratic model without linear term and intercept was created. The model curves corresponding to the model (3) with parameters α given in the table 1 are shown in figure 3.



1% 3% 5%

Figure 3 Dependence of electrical resistance on the yarn length (points are sample medians and solid line is quadratic model (see eqn (3) for $n = 1$)

The relatively good fit is visible for all three samples. It is possible by direct comparing the evaluated rate constant to select the marked drop of specific resistivity factor between 3 and 5 % of conductive steel fibers in the yarn.
The percolation threshold is therefore probably between 3 and 5 %. For more precise characterization of percolation threshold it will be necessary to extent range of steel fibers concentration.

5. CONCLUSION

It was shown that dependence of electric conductivity on the length of yarn is highly nonlinear which is in contradiction with behaviour of metals and some composites. For modelling of this dependence the simple mechanistic model was proposed.
It was found that for polyester yarns with some percentage of steel conductive fibres the quadratic model is suitable. The calculated specific resistivity factor can be used for prediction of percolation threshold i.e. optimizing of these yarns composition.

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