A Comparative Study of Natural Fiber and Glass Fiber Fabrics Properties with Metal or Oxide Coatings

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Abstract. Rapidly growing global demand for technical textiles industries is stimulated to develop new materials based on hybrid materials (yarns, fabrics) made from natural and glass fibres. The influence of moisture on the electrical properties of metal and metal oxide coated bast (flax, hemp) fibre and glass fibre fabrics are studied by electrical impedance spectroscopy and thermogravimetry. The bast fibre and glass fiber fabrics are characterized with electrical sheet resistance. The method for description of electrical sheet resistance of the metal and metal oxide coated technical textile is discussed. The method can be used by designers to estimate the influence of moisture on technical data of new metal coated hybrid technical textile materials and products.

1. Introduction

Rapidly growing global demand for technical textiles (woven and non-woven) for a variety of applications in different industries [1] is stimulated to develop new materials based on hybrid textiles materials (yarns, fabrics). The new materials for the technical textiles are products based on the natural and glass fibre fabrics. They each would assure a certain technical requirements together. The technical textiles fabrics with metal and metal oxide coatings are used, for example, for electromagnetic radiation (EMR) shielding, electromagnetic interference (EMI) and electrostatic discharge (ESD) prevention. The sheet resistance is main technical parameter for EMR, EMI and ESD materials. The fabric applications associated with their electrical properties - resistance and dielectric permeability. The electrical properties are used to characterize coatings and to calculate sheet resistance. The electrical impedance spectroscopy (EIS) is used to measure electrical properties of fabrics. The textiles as porous material have large specific surface area with adsorption capability of moisture from environment. Such textiles are used for production different construction or building materials. In practice are used coated technical textiles with sheet resistance from $10^2$ to $10^7$ Ohm/sq [2].

For a comparative analysis of metal and metal oxide coated natural and glass fiber fabrics are used EIS versus influence of moisture. The fibers, yarns and fabrics are porous with high surface area for adsorption water molecules. There are differences on the macro, micro and nano level between constitutions and structures of the natural fiber and glass fiber fabrics. The water absorption is dependent on the moisture in the environment. The moisture has influence on electrical characteristics of coated fabrics. The same time water is active component in some types of electrochemical
processes. Fabrics as a porous medium must be characterized before textile fabric applications. The functionalizations with coatings are associated with the distribution of metal or oxide nano particles in a porous medium as well as moisture uptake and corrosion of composite components [3 - 5]).

2. Experimental

A comparative study had been done of bast (flax, hemp) fiber and glass fiber fabrics coated with Al, Ni, Cu, NiO and CuO by DC magnetron sputtering (power 300-580 W, Ar=5,0-6,5 sccm, for oxides Ar=5,0-6,0; O2=1,5 -2,0 sccm).

The bast fiber fabric (BFF) from “Limbužu Tine, SIA” and E-glass fiber fabrics (GFF) from “Valmiera Glass Fiber, JSC”. BFF surface density \(D_{BFF}= 500 \text{ g/m}^2\) and thickness \(t_{BFF}=1,4 \text{ mm}\) and GFF surface density \(D_{GFF}=200 \text{ g/m}^2\) and thickness \(t_{GFF}=0,4 \text{ mm}\).

![Fig.1. Impedance spectra for dry samples](image1.png)

![Fig.2. Impedance spectra for wet BFF samples direct from desiccator](image2.png)

![Fig.3. Weight loss for dry samples](image3.png)

![Fig.4. Weight loss (WL) for wet BFF samples direct from desiccator](image4.png)
The bast fiber fabric (BFF) and glass fiber fabrics (GFF) samples before coating had been treated (etched) in argon plasma and after that in the DC magnetron sputtering process had been coated with metal or metal oxide.

Electrical impedance spectroscopy (EIS) and thermogravimetric analyzer (TGA) data are used for characterization of coated fabrics and influence of moisture. For EIS measurements had been done on impedance analyzer HP 4194A (Hewlett-Packard) with HP 16451B sample test fixture (electrode area S=11.34 cm²) and TGA measurements had been done on DTG-60W (Shimadzu). For analyses [Z] spectra was used ZView program (Scribner Associates, Inc).

To characterize the metal coating is a problem in itself. First of all, to functionalize fabrics is to examine the content of moisture and its role on physical properties. The impedance spectroscopy has been used to study moisture in non coated BFF and GFF as well as in coated fabrics. The impedance spectra of such samples are complicate due to heterogeneous and non-homogeneous constitution and dependency from humidity. For humidity studies were prepared two groups of samples: one was to stand at room conditions (dry samples), the other was kept in a desiccator at 100% RH (wet samples).

The moisture content has strong influence on impedance modulus |Z| spectra (Fig.1, 2, 5). The moisture has been measured by weight loss with TGA instrument (Fig.3, 4, 6).

The coating as well as the humidity shifts the dry BFF sample |Z| curves to the smaller resistance values (Fig.1 & 2). For wet samples (Fig.2) have a significant impact of moisture on the |Z| values from 100 Hz to 2 MHz’s. The |Z| values from 2 MHz to 15 MHz are similar to dry samples. The metal oxide coated BFF have higher water absorption capability then metal coated (Fig.3 & 4).

In general |Z| spectra of the GFF and BFF samples have similar behaviour. The coating as well as the humidity shifts the GFF sample |Z| curves to the smaller resistance values (Fig.1 & 2). For wet samples (Fig.5) have a significant impact of moisture on the [Z] values from 100 Hz to 2 MHz’s. There are small differences between |Z| spectra of GFF coated with metal Al, Cu or Ni and grouped 3 groups according TGA data of moisture content (Fig. 6).

The electrical impedance $Z=Z'-jZ''$ of fabrics (BFF and GFF) have complicate charge carrier response for frequencies 100 Hz -15 MHz, i.e., representing their complicate contribution to the resistivity $Z'=\text{Real} \ Z$. Therefore, the value of sheet resistance in the range of frequencies will vary over a wide range depending on the humidity and will be calculated from the equivalent circuit resistance.
components. The sheet resistance can be estimated from $|Z|$ spectra by analyses of simple equivalent circuit:

\begin{equation}
Rs \quad \text{CPE} \quad Rp
\end{equation}

where $Rs$, $Rp$ - serial and parallel resistance, CPE – constant phase element. The $Rp$ values had been measured in frequencies region (1-15) MHz. The $Rp$ have been used to calculate BFF and GFF sheet resistance $R_{sh}$:

\begin{equation}
R_{sh} = Rp*S/t,
\end{equation}

where $S = 11.34 \text{ cm}^2$ – electrode area of the sample test fixture, $t$ – fabric thickness. $t_{BFF}$ and $t_{GFF}$. To characterize the moisture influence on fabrics sheet resistance ratio $\Delta R_{sh}/\Delta m$:

\begin{equation}
\frac{\Delta R_{sh}}{\Delta m} = \frac{1}{D*t^2} * \frac{\Delta R_{sh}}{\Delta WL}
\end{equation}

where $\Delta m$ - mass of lost moisture from TGA data, $D$ – fabric surface density $D_{BFF}$ and $D_{GFF}$. The experimental data of BFF and GFF for comparison are summarized for dry and wet fabrics in Table 1

| Sample      | $Rp$, Ohm | WL, % | $R_{sh}$, Ohm/sq | $\Delta R_{sh}/\Delta m$, Ohm/(sq*g) |
|-------------|-----------|-------|------------------|-------------------------------------|
| 1BFF        | 9.7E+06   | 2.0   | 5.6E+11          | Reference                           |
| 11GF00-00[28] | 3.9E+06   | 1.9   | 2.8E+12          | Reference                           |
| 2BFF wet    | 3.5E+05   | 8.3   | 2.0E+10          | Reference                           |
| 10GF00-00[14] wet | 2.3E+01 | 9.2   | 1.6E+07          | Reference                           |
| 3BFF-Ni     | 1.7E+06   | 7.1   | 9.8E+10          |                                     |
| 5BFF-NiO    | 5.5E+06   | 7.9   | 3.2E+11          |                                     |
| 4BFF-NiO wet | 1.5E+05   | 8.4   | 8.7E+09          | 1.2E+06                             |
| 6BFF-NiO wet | 2.4E+04   | 8.4   | 1.4E+09          | 4.9E+05                             |
| 3GF70-Ni[41] wet | 6.9E+01 | 12.3  | 4.9E+07          | Reference                           |
| 3GF70-Ni[45] wet | 1.8E+03 | 7.2   | 1.3E+09          | 1.1E+05                             |
| 3GF70-Ni[48] wet | 1.0E+04 | 4.8   | 7.1E+09          | 1.4E+06                             |

The dry coated BFF and GFF samples have a significant influence of moisture on sheet resistance than for dry non coated fabrics. The wet coated BFF and GFF samples have a similar influence of moisture on sheet resistance for dry coated fabrics.

3. Conclusions

The bast fibre and glass fibre fabrics are characterized with electrical sheet resistance. The method for description of electrical sheet resistance of the metal and metal oxide coated technical textile is developed. The EIS and TGA data are useful for characterization of production hybrid technical fabrics based on natural and glass fibres. The method can be used by designers of a new metal coated hybrid technical textile materials and products to estimate the technical data as well as the influence of moisture on the technical data.

References
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