

# Washing and Abrasion Resistance of Conductive Coatings for Vital Sensors

Patricia Schäl, Irén Juhász Junger, Nils Grimmelsmann,  
Hubert Meissner and Andrea Ehrmann

**Abstract** In the area of medical textiles, several applications necessitate conductive sensors, such as ECG or pulse measurements, breathing sensors, etc. Additionally, connections between electronic elements, data transfer units, and other parts of sensor networks need conductive paths. The resistance of conductive yarns or coatings against mechanical and chemical influences, however, is often low. Silver particles in coatings or on yarns, e.g., can oxidize during washing. Thin coatings can easily be abraded and offer only a low conductivity due to low layer height, while thicker coatings can be stiff and break during bending. In a recent project, we evaluate different coatings with respect to their resistance against mechanical stress due to abrasion against diverse materials, as a typical demand of sensory shirts or other medical textiles. Conductive silicone rubber, as well as graphite-polyurethane dispersions with different graphite concentrations, were coated on diverse textile fabrics in a defined height. Abrasion tests were performed on these samples using a linear abrasion tester. The electrical resistance of the conductive coatings was measured after each test cycle. Additionally, confocal laser scanning microscopy was used to detect micro-cracks or modifications of the coating surface. The article gives an overview of the results and depicts the advantages and challenges of the conductive coatings under examination.

## 1 Introduction

Conductive yarns or textile coatings have diverse applications in the area of smart textiles [1]. They are necessary to measure vital signs, e.g., ECG or pulse [2–13], pressure [14, 15] or elongation [16–22]. Besides these sensory applications, they are also used to transfer energy or data through conductive transmission lines [23–25] or through textile antennas to an external receiver [26].

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P. Schäl · I. Juhász Junger · N. Grimmelsmann · H. Meissner · A. Ehrmann (✉)  
Bielefeld University of Applied Sciences, Bielefeld, Germany  
e-mail: andrea.ehrmann@fh-bielefeld.de

The main issue in using conductive yarns or textile coatings is their resistivity against mechanical and chemical impacts, i.e., abrasion and washing. This is why novel conductive textile coatings are investigated in many research groups, e.g., consisting of carbon nanofibers [27], reduced graphene oxide, and silver nanoparticles [28], or graphene/poly(vinyl alcohol) [29]. For reduced graphene, another examination found satisfying washing resistance [30]. Nevertheless, it should be mentioned that sodium hydrosulfite, a noxious chemical which can explode, is needed for converting graphene oxide into reduced graphene. Less dangerous coatings, such as Poly(3, 4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS), are known to not withstand UV radiation [31–33].

An alternative to expensive conductive materials, such as noble metals, oxidizing, or other instable materials, such as other metals, or dangerous materials is carbon in the forms of carbon black or graphite. Nevertheless, only little research is published on the influence of mechanical or chemical impact on carbon-based conductive coatings [34, 35].

This is why graphite-polyurethane coatings were prepared on diverse textile materials in a recent project and tested with respect to their abrasion fastness. As a comparison, a commercially available conductive silicone rubber is used which has to be polymerized at high temperatures and is thus not usable on each textile fabric.

## 2 Experimental

For the graphite-polyurethane (PUR) coatings, dispersion were prepared using *bredderpoX®R15 GB-Flex* PUR resin, *bredderpoX®R15 GB-Flex* PUR hardener and diluting agent *Verdünnern XA* (Breddermann Kunstharze, Schapen/Germany). Graphite particles with diameters 3–5  $\mu\text{m}$  (Algin, Neustadt Glewe/Germany) were added in concentrations of 25% and 29%, respectively, since lower graphite concentrations resulted in significantly increased electrical resistances, while higher graphite concentrations led to brittle coatings. In all coatings, 10% silicone oil was added to increase the flexibility of the final layer.

Additionally, the conductive silicone rubber *Powersil 466 A + B* (Wacker Chemie AG, Munich, Germany) was tested after curing in an oven at 200 °C for 2 h.

All coatings were applied using a doctor's knife. The coating dimensions of 10 mm width and 150 mm length, as well as the coating layer height, were defined by adhesive tape glued on the textile fabrics.

Two samples were prepared per coating and base fabric on which three different ranges of 100 mm length each were marked so that each result was averaged over six measurements.

Table 1 shows the four woven fabrics used in this investigation. Material, thickness and areal weight are varied.

Abrasion tests were performed by a sliding block test according to DIN EN ISO 13427. The standard abrasive material, sandpaper with grain size 100, was exchanged by a sandpaper grain size 400 as well as the jeans and the viscose fabrics

**Table 1** Thickness and areal weight of textile fabrics used for coating

| Name  | Material | Thickness/<br>mm | Areal weight/(g/m <sup>2</sup> ) | Warp threads/cm | Weft threads/cm |
|-------|----------|------------------|----------------------------------|-----------------|-----------------|
| CO    | Cotton   | 0.32             | 94                               | 30              | 22              |
| VI    | Viscose  | 0.17             | 67                               | 24              | 40              |
| LI    | Linen    | 0.34             | 141                              | 26              | 24              |
| Jeans | Cotton   | 0.90             | 371                              | 3.5             | 2.5             |

defined in Table 1 to investigate more realistic situations. Additionally, each coating was abraded against itself.

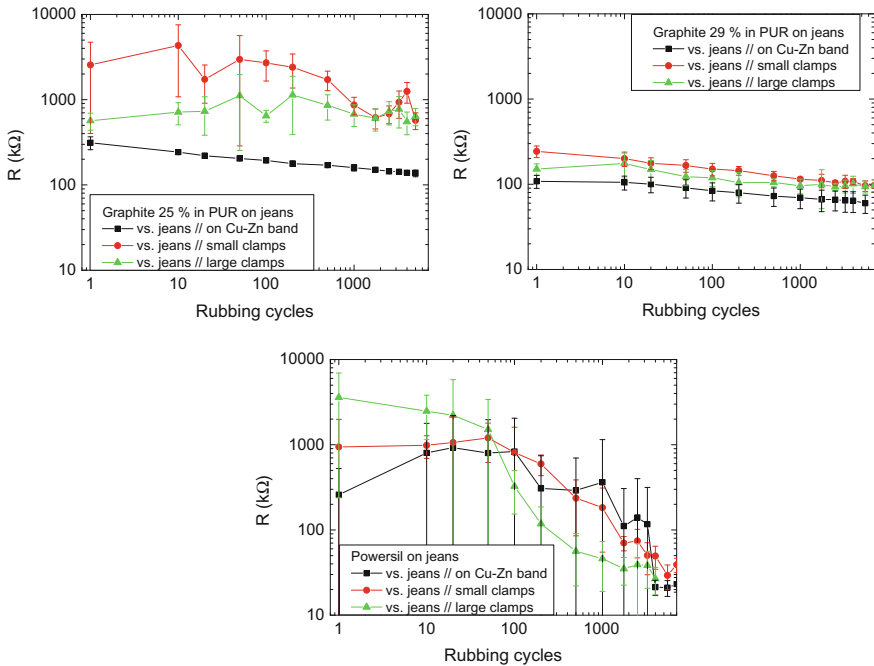
Resistance measurements were performed using a *Mastech PM334* digital multimeter with a maximum measurable resistance of 30 M $\Omega$ . All resistances are measured between two points in a distance of 100 mm.

A confocal laser scanning microscope (CLSM) VK-9700 by Keyence was used for microscopic examination of the coatings before and after rubbing fastness tests. All CLSM images depicted in this article have the same nominal magnification of 2000 x.

### 3 Results and Discussion

One of the biggest challenges in the examination of conductive textile coatings is the measurement of the electrical resistance. Opposite to hard, flat surfaces, such as plastics or metals, measurements on textile surfaces usually depend strongly on the contact area, contact pressure, and also on a possible movement or bending of the conductive fabric. This is why in a first test series three different contacting methods were tested: small (crocodile) clamps with “teeth” pressed into the conductive coatings; large clamps with broad, flat contact areas pressed on the conductive coatings; and conductive Cu-Zn bands which were glued onto a table in the desired measurement distance and on which the sliding block with the fabric under examination below was placed.

Figure 1 depicts the results of these measurements, performed on the three different coatings described above. Comparing all results, it is obvious that the Powersil coating gives relatively high resistances and standard deviations, as expressed by the error bars. For the PUR coating with 29% graphite, all measurements show significantly reduced standard deviations, with the smallest values being measured using the Cu-Zn band. Only for the measurement of the coatings with 25% graphite included, a significant difference between the contacting methods is visible. Here, the measurements with the Cu-Zn band show very small error bars, while measurements with both clamps result in visibly larger standard deviations.



**Fig. 1** Comparison of different electrical connection methods for measurements, tested for graphite/PUR and Powersil coatings on jeans, abraded against jeans. All graphs are depicted with double-logarithmic axes, meaning that apparently linear correlations are in reality exponential

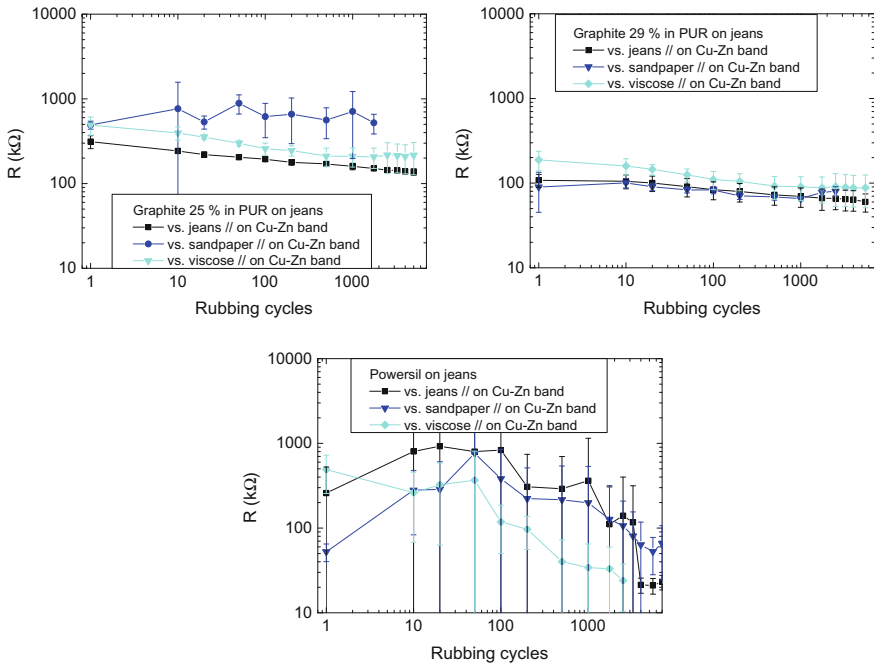
This is why the following tests were performed using the Cu-Zn band.

Next, different rubbing partners were tested: the jeans fabric and the viscose fabric (cf. Table 1) as well as a sandpaper grain size 400. Figure 2 shows the results of these experiments. Again, the coatings with 29% graphite showed the most stable measurements. In all three cases, a slight decrease of the resistance is visible with increasing numbers of rubbing cycles.

For 25% graphite content in the PUR coating, rubbing against jeans or viscose resulted in a resistance decrease again, while rubbing against sandpaper resulted in increased error bars and approximately constant resistance values. Apparently, for this coating, the sandpaper is too harsh.

In the case of the Powersil coating, rubbing against all three materials of choice supported the decrease of the electrical resistance. Only for jeans as rubbing partner, however, the error bars became acceptable after 5000 rubbing cycles. Since this material also showed good results in the tests of the graphite-PUR coatings, it was chosen as rubbing partner for the examination of the conductive coatings on different textile substrates.

In Fig. 3, the results of these experiments are shown. All three coatings were tested on the four textile substrates, rubbed against jeans and measured using the Cu-Zn band.

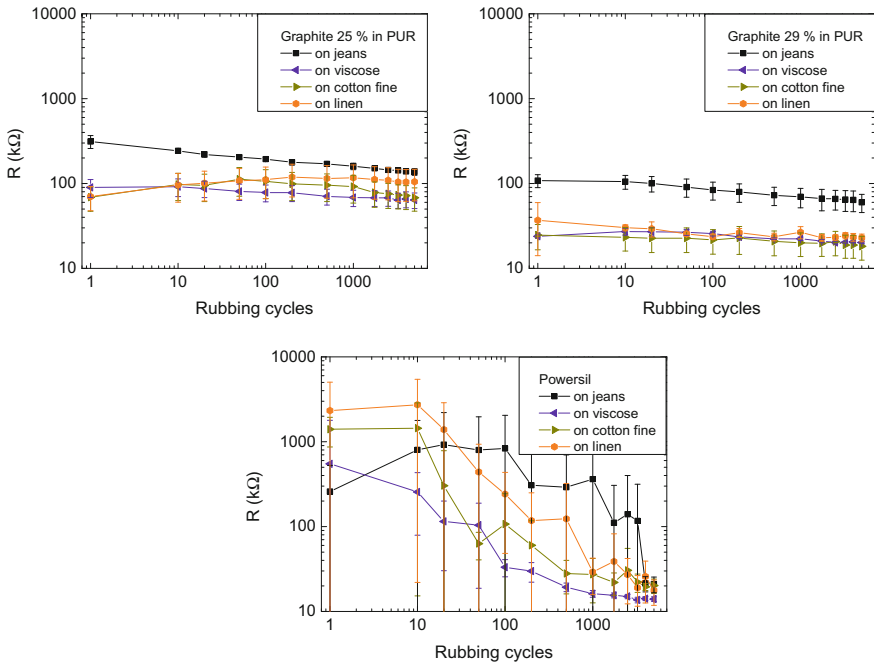


**Fig. 2** Comparison of different abrasion partners, tested for graphite/PUR and Powersil coatings on jeans, measured on Cu-Zn band

Again, the Powersil coatings showed the highest standard deviations, with this coating on viscose giving the best and most stable results. For large numbers of rubbing cycles, however, both the resistances and their standard deviations decrease significantly.

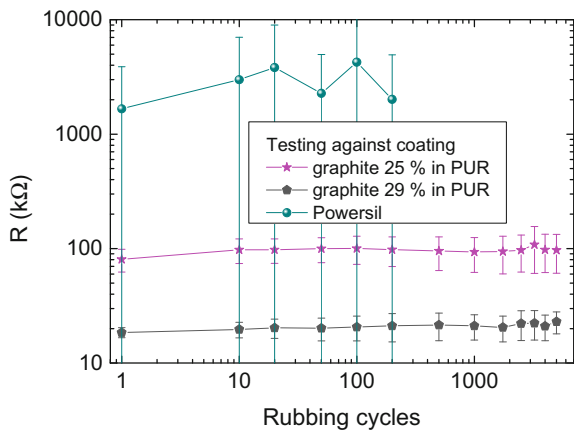
For the more stable measurements on the graphite coatings, it becomes obvious that the resistances on jeans are higher than on the other (thinner and finer) textile substrates. Apparently, not only the coating but also the chosen substrate strongly influences the resulting resistance values. Comparing the three finer fabrics, however, does not reveal significant differences. All of them show an approximately exponential decrease, in the double-logarithmic plots used here visible as apparently linear correlations.

Finally, all three coatings on fine cotton were tested using the respective identical samples as rubbing partners, modeling a situation where such conductive coatings are used as switches, etc. The results are shown in Fig. 4. For both graphite coatings, the resistance is now approximately constant, with a slight increase toward larger numbers of rubbing cycles. For the Powersil coating, the situation is worse—the resistances, as well as their standard deviations, remain high, until after approx. 200 rubbing cycles, the cotton fabrics were partly destroyed, and the experiment had to be stopped.



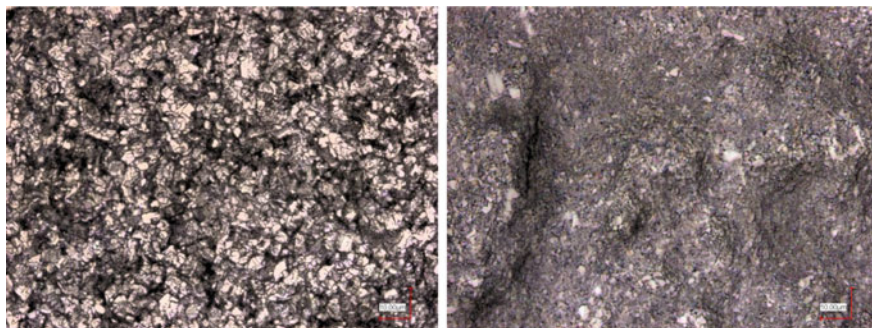
**Fig. 3** Comparison of different textile substrates, tested for graphite/PUR and Powersil coatings abraded against jeans, measured on Cu-Zn band

**Fig. 4** Comparison of the coatings under examination on fine cotton, abraded against themselves, measured on Cu-Zn band

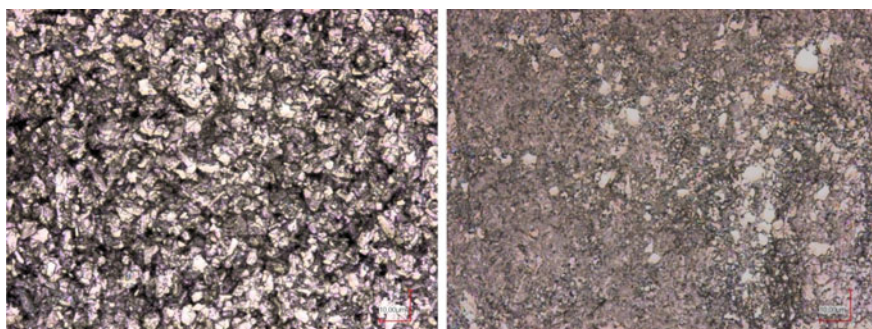


Destroying of this fabric was due to the high friction between both Powersil layers—this resulted in the fabrics being moved with respect to the rough surfaces of the sliding and the rubbing block, leading to destroying them from the backsides.

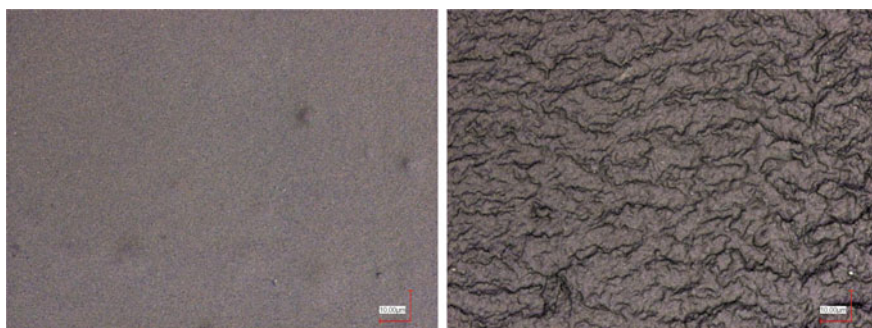
To understand the influences of these rubbing processes better, Figs. 5, 6 and 7 depict the coating surfaces before the abrasion processes and after 5000 rubbing



**Fig. 5** Graphite 25% in PUR before abrasion (left panel) and after 5000 rubbing cycles against jeans

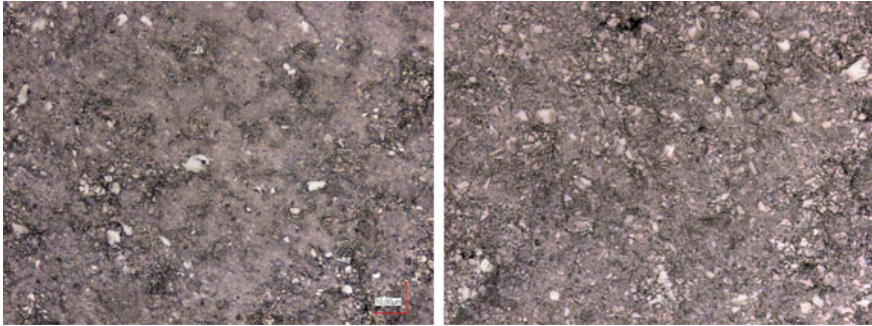


**Fig. 6** Graphite 29% in PUR before abrasion (left panel) and after 5000 rubbing cycles against jeans



**Fig. 7** Powersil before abrasion (left panel) and after 5000 rubbing cycles against jeans





**Fig. 8** Graphite 25% (left panel) and graphite 29% (right panel) in PUR after 5000 rubbing cycles against the identical coatings

cycles against jeans. Both graphite coatings show typical graphite flakes on the surfaces before the abrasion tests which are nearly vanished after the 5000 test cycles.

Apparently, the abrasion cycles rub off all loose material, i.e., especially the graphite flakes laying on the surface. While this seems to be counterproductive at first glance, we assume that it helps contacting the graphite which is really fixed in the conductive layer and has contact to the percolation paths inside the coating, while the original outer layer seems to consist of pure graphite with less contact to the actual conductive bulk material.

For Powersil, another surface modification takes place. Here, rubbing results in a ruffle structure which may be attributed to a stick-slip friction effect between the Powersil surface and the textile rubbing partner. We assume that, opposite to the graphite coatings, the positive effect of rubbing can be attributed to opening the surface toward the more conductive bulk material.

Finally, Fig. 8 depicts images of the graphite coatings rubbed against themselves. Apparently, instead of removing all non-fixed material, here mostly small parts of graphite flakes are exchanged between both rubbing partners, prohibiting the advantageous “cleaning” of the conductive surface.

## 4 Conclusion

In a recent project, rubbing tests were performed on three different conductive materials, coated on four textile fabrics each. Tests revealed that measurements gave most reliable results when performed with the coating under examination being placed on conductive Cu-Zn bands in a defined distance under a defined pressure. Both graphite-PUR coatings showed more stable results than the commercially available, flexible Powersil coating. Additionally, our experiments showed that rubbing the conductive coatings against a suitable partner material supports the absolute values as well as the stability of the conductivity.



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