4.2. Reliability of E-Textile Conductive Paths and Passive Component Interfaces

Julie Hladikova, Martin Hirman, Jiri Navratil

Department of Materials and Technology, Faculty of Electrical Engineering, University of West Bohemia, Pilsen, Czech Republic, jhladik@fel.zcu.cz

ABSTRACT

E-textiles are subjected to harsh environmental conditions such as perspiration, mechanical abrasion, repeated washing and drying cycles, stretching, moisture, and temperature fluctuations. This study focuses on evaluating the durability of stretchable textile conductive ribbons composed of silver-coated microwires, particularly the electrical resistance of these ribbons and their connections to passive components after repeated washing. The washing process exposes textile electronics to combined mechanical, chemical, and thermal stress.

Different types of samples were prepared, each incorporating SMD resistors mounted using UV-curable adhesive. Various protection strategies were applied across the sample groups: no protection, basic protection (encapsulation of components), additional protection (including textile tape), and the use of insulated ribbons. The change in resistance was monitored and compared. In a separate experiment, the resistance of bare ribbons—without any mounted components—was also tested across three ribbon types: uninsulated, insulated, and uninsulated with additional protection.

INTRODUCTION

E-textiles represent a rapidly growing field in modern electrical engineering, combining electronic functionality with textile materials. These smart textiles are finding increasing use in sectors such as healthcare, telemedicine, sportswear, personal protective equipment, wellness, and military systems. A wide range of sensors can be integrated into textiles, including respiration monitors, electrocardiographic electrodes, and edema monitoring sensors. Other potential applications include textile-based heating elements and flexible interconnections.

Unlike conventional electronics, e-textiles must maintain functionality while also being flexible, washable, stretchable, and comfortable for the wearer. Consequently, it is essential to evaluate the performance of textile electronics under realistic environmental conditions.

E-textiles incorporate specialized conductive materials such as yarns, threads, and ribbons, often in combination with standard passive components like resistors. However, traditional assembly techniques such as soldering are unsuitable due to the thermal limitations of textiles. As an alternative, SMD components can be attached to fabric using UV-curable non-conductive adhesives, which cure at low temperatures and preserve textile integrity.

This adhesive-based connection process includes three main steps: (1) applying a layer of UV-curable adhesive to the textile surface, (2) placing the SMD component with adequate pressure to ensure contact between the component pads and conductive textile elements, and (3) curing the adhesive under UV light while maintaining pressure.

references [1], [2], [3]

EXPERIMENT

The primary objective of this study was to assess the electrical resistance stability of conductive textile ribbons and their component interfaces after repeated washing cycles. Two types of stretchable conductive ribbons were used: one composed of uninsulated silver-coated copper microwires, and another with polyurethane-insulated microwires. Ribbons were cut into 2 cm sections for testing.

Four sample groups were prepared:

1. No Protection – SMD resistors were mounted directly onto uninsulated ribbons using UV-curable adhesive, without any encapsulation (Fig. 1).

2. Basic Protection – Identical to the previous group, but with encapsulation of the component using UV-curable adhesive. This did not cover the ribbon's conductive paths but provided mechanical protection for the component (Fig. 2).

3. Additional Protection – Combined basic encapsulation with iron-on textile tape covering the conductive paths. Crimp contacts were applied to allow electrical measurement (Fig. 3).

4. Insulated Ribbon – Ribbons with polyurethane-insulated conductive paths were partially laser-stripped to expose the connection area. SMD resistors were mounted as before and encapsulated with basic protection. Crimps were added on both sides for measurement access (Fig. 4).

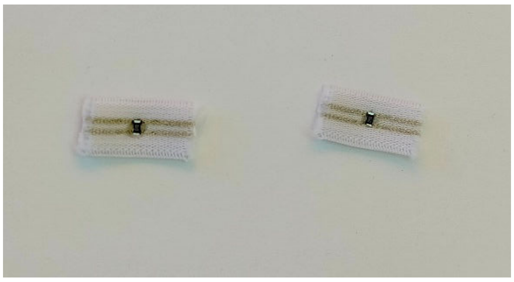

Figure 1 Samples without any protection

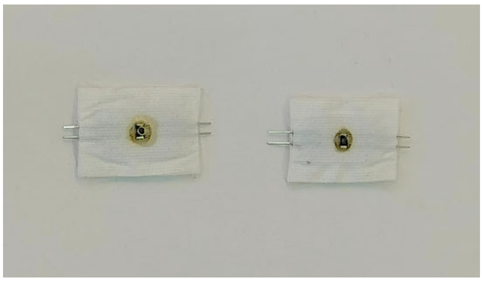

Figure 3 Samples with additional protection

Figure 2 Samples with basic protection

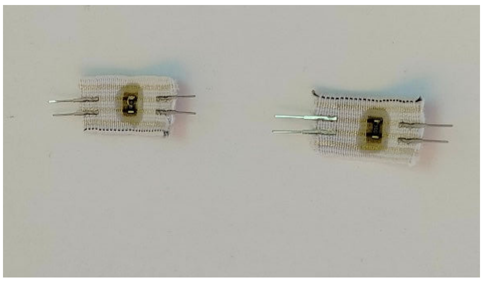

Figure 4 Samples with insulated ribbon

Ribbon-Only Samples:

To evaluate the durability of the ribbons themselves (without components), three 50 cm samples were prepared:

- Uninsulated ribbon
- Uninsulated ribbon with iron-on tape (additional protection)
- Insulated ribbon

Samples with iron-on tape and insulated ribbon intended for resistance measurement were equipped with crimped contacts.

Figure 5 Samples of ribbons from left insulated, uninsulated, additional protection

All samples were subjected to machine washing, using a washing machine type A, according to the standard EN ISO 6330. The testing cycles were 4N (40±3) °C. The used detergent was standardized Non-Phosphate SDCE ECE detergent powder. The experiment consisted of six washing cycles, each comprising five washing rounds. After each cycle, samples were dried at 40 °C and 20% relative humidity for 48 hours before measurement. Resistance measurements were performed using a four-point probe method with a Keithley DAQ6510 data acquisition system. In total, each sample underwent 30 washing cycles.

RESULTS

The results of the washing cycle tests clearly demonstrate that the type of protection applied to the conductive textile ribbons with SMD components significantly affects their long-term resistance stability.

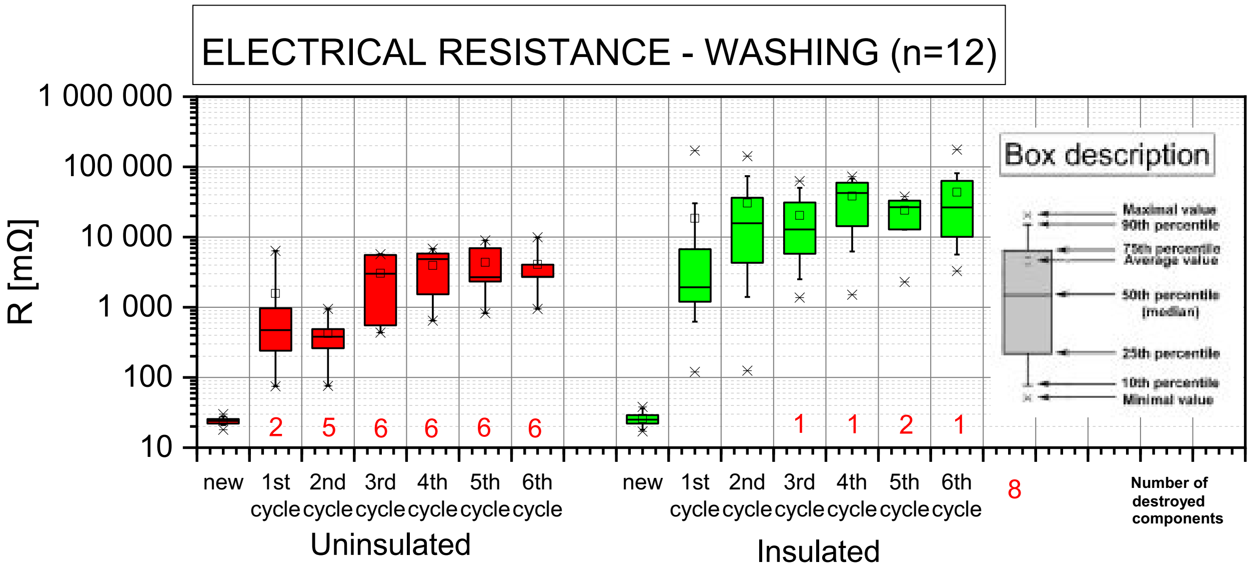

Figure 6 Boxplot graph for electrical resistance after washing

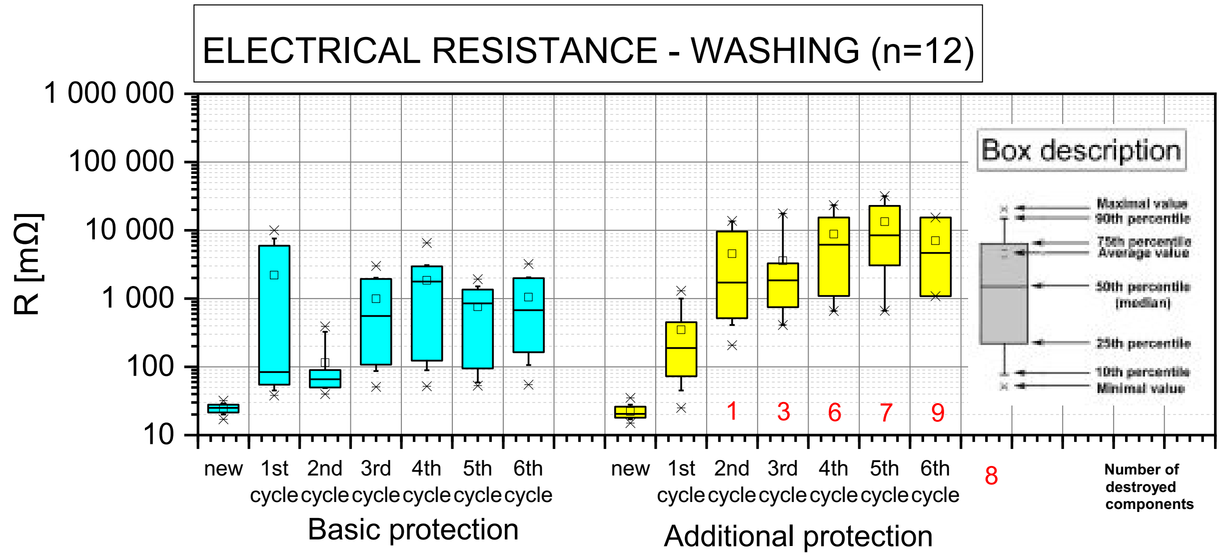

Figure 7 Boxplot graph for electrical resistance after washing

Surprisingly, the group with insulated ribbons (Fig. 4) showed the worst performance among all variants. Resistance increased consistently across washing cycles and exhibited considerable variability. This may be due to imperfections in the laser-stripping process, resulting in unstable contact surfaces or residual insulation layers at the connection point. The insulation itself may also trap moisture near the exposed areas, accelerating degradation. Unprotected samples (Fig. 4) also performed poorly, with a progressive rise in resistance and large variability. However, their degradation was not as pronounced as in the insulated group. This confirms that, while lack of protection exposes the connection directly to mechanical and chemical stress, some ribbon designs may inherently tolerate such conditions better than others if no sealing layers trap contaminants. In contrast, the group with basic protection (Fig. 5) exhibited a noticeable increase in resistance after the first washing cycle but remained relatively stable in the following stages. The UV-curable encapsulation likely hardened into a semi-rigid structure that resisted further ingress of moisture or detergents, effectively preserving the connection. Samples with additional protection (Fig. 5) showed a gradual but continuous increase in resistance across all washing cycles. While the added iron-on tape was expected to improve sealing, it may have unintentionally allowed microleakage, trapping water and detergent underneath the layer, which then slowly deteriorated the conductive path.

Figure 8 Samples after 30 washing (from left to right without protection, basic, additional protection, insulation)

These results suggest that the combination of proper encapsulation and controlled material layering is more effective than relying solely on insulation or extensive sealing. Basic UV protection appears to offer the best trade-off between simplicity and reliability in washable e-textile assemblies.

The second part of this study compares the electrical resistance behaviour of three types of conductive ribbons—uninsulated, insulated, and protected—across 30 washing divided into 6 cycles.

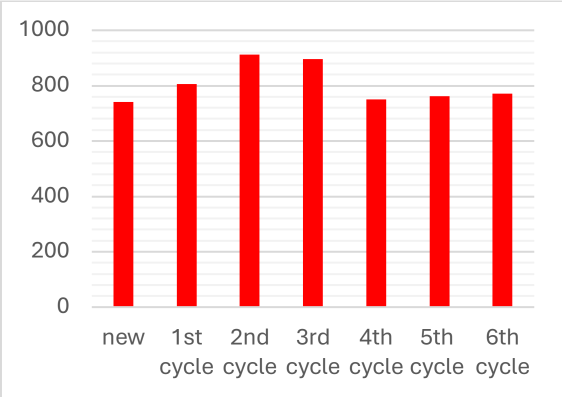

Figure 9 Graph of resistance after each cycle of uninsulated ribbon

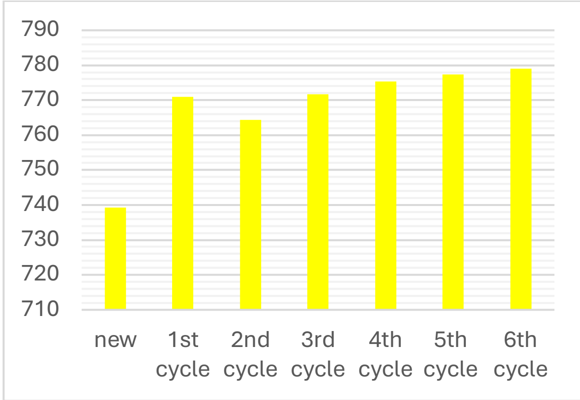

Figure 11 Graph of resistance after each cycle for samples with additional protection

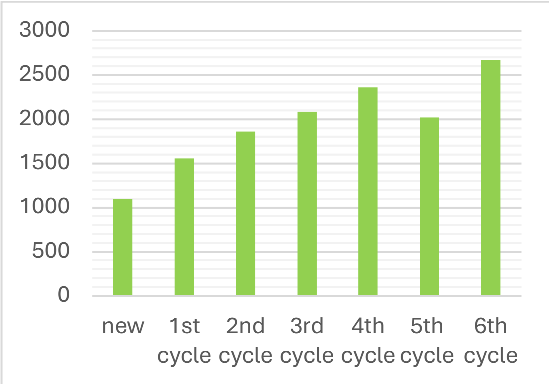

Figure 10 Graph of resistance after each cycle of insulated ribbon

The uninsulated ribbon demonstrates relatively stable resistance, suggesting minimal degradation and reasonably consistent electrical performance. The insulated ribbon, however, exhibits a marked and continuous rise in resistance. This pronounced increase likely results from degradation mechanisms such as trapped heat, oxidative effects, or delamination within the insulating material. The ribbon with additional protection starts at a slightly lower resistance and shows a gradual, monotonic increase by the final cycle. While this trend indicates the slow but steady rise suggests mild aging or interaction at protective interfaces over time. Added iron-on tape may have unintentionally allowed microleakage, trapping water and detergent underneath the layer, which then slowly deteriorated the conductive path.

CONCLUSION

This study investigated the durability of stretchable conductive textile ribbons with mounted SMD components under repeated washing cycles, focusing on the effect of different protection methods. The results demonstrated that the type of protection significantly influences the stability of electrical resistance during laundering. Surprisingly, the worst performance was observed in samples with insulated ribbons, which exhibited the most pronounced increase in resistance. This suggests that imperfections in the insulation stripping process or moisture retention near the contact area may compromise reliability**.** Unprotected samples also showed degradation, but to a lesser extent. Basic protection using UV-curable adhesive provided the most stable performance after an initial resistance increase, likely due to effective sealing of the component area. In contrast, additional protection combining encapsulation with textile tape did not yield further improvement and resulted in a gradual resistance rise, possibly due to microleakage and trapped moisture beneath the tape. Overall, the findings indicate that effective and minimal encapsulation can outperform more complex protective methods if carefully applied. The choice of materials, contact preparation, and protection strategy must be aligned to ensure long-term reliability of washable e-textile systems. Future work will focus on optimizing encapsulation design and improving insulation processing to minimize degradation during use.

Among the tested samples, the uninsulated ribbon shows the most stable resistance and thus the best electrical endurance under cycling. The ribbon with additional protection performs comparably well but with a detectable increasing trend, while the insulated ribbon exhibits the poorest stability, making it the least favourable for applications requiring long-term electrical reliability.

ACKNOWLEDGEMENT

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