Reliability Testing of Recycled SMD Components Reused in E-Textiles after Ageing by Washing Cycles

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***Abstract*— This paper presents a method for recycling and reusing SMD chip components in e-textiles using a special contacting technique. The method involves using a UV-curable, non-conductive acrylic adhesive to connect SMD components onto electrically conductive textile stretchable ribbons. At the end of the product's life-cycle, the components are removed from the ribbon and reused to manufacture new products. The recycling procedure involves several steps, including disassembly, inspection, cleaning, repair, and reassembly of components. The results of an experiment testing the electrical resistance of new and reused components after washing and drying cycles showed that electrical resistance of reused joints did not significantly deteriorate compared to new joints. The reused components maintain their functionality and performance, suffering no significant impairment. They perform comparably to new components, even after repeated washing and drying cycles. The method offers several benefits, including conservation of raw materials, minimization of waste, and reduction of production costs. It can also help mitigate component shortages. However, it is found that the suitability of this remanufacturing method varies with different types of components. Certain component types may be more susceptible to damage or even unsuitable for this method. The method is particularly beneficial for higher-value or components experiencing market shortages, demonstrating its potential to address urgent industry challenges while contributing to environmental sustainability.**

Keywords—e-waste, SMD chip components reuse, e-textiles, non-conductive adhesive, recycling.

I. Introduction

Recent reports from the European Commission and the World Health Organization indicate an exponential increase in the generation of electronic waste (e-waste) [1]. Data from a survey conducted by the Global E-waste Statistics Partnership corroborates this trend, revealing that 53.6 million metric tonnes of e-waste were generated in 2019 [2]. Projections suggest that this figure will continue to rise, with estimates indicating that up to 74 million metric tonnes of e-waste could be generated by 2030. Furthermore, it was determined that only approximately 17.4% of the total e-waste generated in 2019 was recycled. This implies that valuable materials such as gold, silver, and copper present in these devices were predominantly discarded or incinerated rather than reused.

Several factors have contributed to the rapid increase in e-waste observed in recent years. These include population growth leading to increased demand for and consumption of electronic products as well as the short life cycle and low repair rate of these products [3]. The constant development of new technologies has also played a role. Additionally, the Covid-19 pandemic has further increased interest in electronics among individuals who have had to work from home and businesses that have had to modernize their production significantly in order to remain competitive [4]. The amount and rate at which e-waste is produced poses a serious global issue with implications for both the environment and human health. As a result, an increasing number of countries are addressing this problem by implementing their own legislation and directives as well as adhering to supranational ones. Companies are now required to include environmental considerations in the development and design of new products. However, companies are currently facing another challenge: a shortage of electronic components such as chips and microcircuits necessary for producing these devices. This shortage has been caused by the closure of many factories dedicated to producing these components in 2020 due to efforts to combat the spread of Covid-19 [5].

It follows that the reduction of carbon footprint, saving of natural resources, reducing the amount of newly consumed materials and striving to reuse used materials and product parts are global trends. These trends are widely supported and they are in line with the overall ecologic ideas. Manufacturers in the electronics industry will have to adapt to these new conditions and look for innovative solutions for this trend. A possible way is using circular economy which is a sustainable model that aims to extend the life-cycle of products, reduce waste and minimize the use of new raw materials. One of its key principles is designing products with the potential for reuse. After a product reaches the end of its life-cycle, it can be recycled and some parts can be reused [6]. A central component of the circular economy is remanufacturing. This process involves disassembling, cleaning, inspecting, repairing, replacing and reassembling components in a product to extend its lifespan [7]. The remanufacturing process consists of several steps. First, products are collected from customers after their life-cycle ends. These products are then disassembled into individual parts. Next, these parts are inspected and tested to determine their current state and sorted into three groups: functional, repairable and destroyed. The functional and repairable components are then cleaned and repaired if necessary. The prepared components are reassembled into a new product and these products are thoroughly tested. Finally, the products are sold to new customers. This cycle can be repeated several times until the components are too worn and discarded [8]. The refurbishing is a form of remanufacturing where modules from returned products are disassembled, cleaned, replaced or restored, and reassembled into refurbished products. These products mainly come from secondhand goods, demo units, open-box products, those with shipping or exterior damage, or production defects. The refurbishment is a commonly used method in which whole used modules are used [9].

Also, e-textiles have been an important and growing market sector in recent years. In the paper, a procedure for the recycling and subsequent reuse of components contacted by a special method on e-textiles will be proposed and verified. Our long experience in this field (e.g. [10]) shows that e-textile product (in our case the conductive ribbon) or electrical connection itself are usually degraded, but the component remains intact. The important parameter to consider in the case of e-textiles is that the sweat from any activity is absorbed by the e-textile, and it has to be washed periodically for hygienic reasons. But the washing and drying can significantly affect the electrical parameters and reliability of e-textiles. They have to be also taken into consideration in the smart textile design [11], [12].

From the theoretical assumptions, two primary objectives of the investigation delineated in this manuscript were established. Firstly, to establish the feasibility of our method for reusing SMD (Surface Mount Device) chip components in e-textiles. Secondly, to evaluate the integrity of specimens containing reused components following a washing and drying cycle test.

The structure of this manuscript is as follows. In the preceding section, the significance of our topic matter and the fundamental principles of the circular economy were delineated. Also the aims of this paper are established in that section. Chapter II is devoted to the methodology and materials used in this research. Chapter III presents the outcomes of the experiment, which entailed 4 iterations of aging and reusing specimens. Each iteration consisted of 5 laundering and drying processes.

II. Materials and Procedures

A. Textile ribbons

The experiment utilized electrically conductive textile stretchable ribbons protected by a national patent (308614) [13]. The ribbons are composed of PES threads (A) in warp and weft for strength and durability, rubber threads (B) in warp for stretchability, and hybrid conductive threads (C) in warp for electrical conductivity, see Figure 1. The hybrid threads contain PES monofilaments and 8 Ag plated Cu microwires per thread. The ribbons are woven in a stretched state and then shrunk, with the yarns inside the threads arranged in a horseshoe pattern to allow for repeated stretching without damage. The ribbon has conductive traces with electrical resistance sufficient for standard e-textile applications.

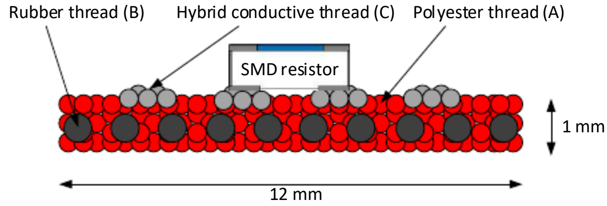

Fig. 1. Schematic cross-section of electrically conductive textile stretchable ribbons used in the experiment

B. SMD components

In the experiment, 15 SMD chip resistors with a case size of 1206 and a resistance of 0 ohms were used for their easy availability and the ability to evaluate the quality of the conductive joint by measuring the electrical resistance. However, our method of reusing components is especially suitable for more expensive or unavailable components on the market. For this reason, experiments were carried out with different components during which their functionality was evaluated.

C. Conductive connection technique

The method for the electrical connection of SMD components, specifically resistors with 0 ohm resistance and a case size of 1206, to conductive lines on ribbons is realized by our special contacting technique [10] utilizing a UV-curable, non-conductive acrylic adhesive (NCA) – specifically Loctite AA 3926 by Henkel Company. The procedure (see Figure 2) begins with dispensing the adhesive onto the space between the conductive lines on the ribbon. Carefully, the component is then placed into the adhesive, typically with the assistance of a tweezer for precision. The component is then pressed into the adhesive with a pressure around 24 MPa using a thorn. This pressure causes the adhesive to be squeezed outside the component pads or into the ribbon, and pushing the component into the ribbon, creating an intimate, direct electrical and mechanical contact, see Figure 3. Once this state of contact is achieved, the adhesive is cured by exposure to UV light for around 30 seconds, while still under pressure. This process ensures fixing the component in its connected position. Finally, the pressing thorn is carefully removed, and the hole left behind, along with the rest of the resistor, is fully encapsulated by the same adhesive for added stability and protection. The advantage of this process is that it provides a simple and reliable way for the mechanical and electrical connection of SMD components, realized through direct physical contact with the conductive pattern on the ribbon, facilitated by the UV-curable adhesive.

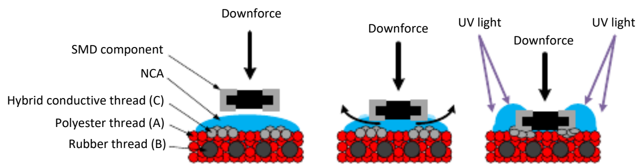

Fig. 2. The principle of SMD resistor electrical connection onto the ribbon by NCA technology.

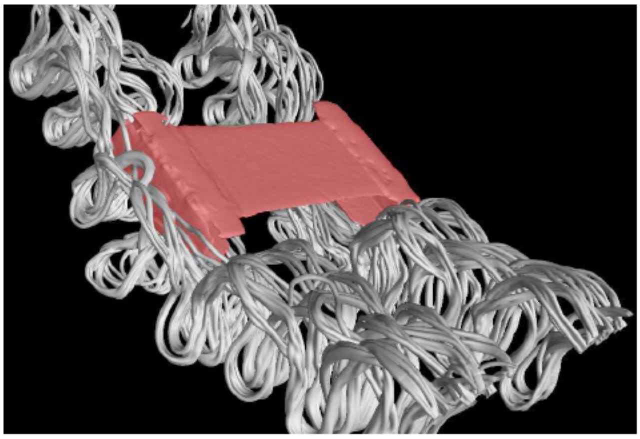

Fig. 3. An example of how an SMD component is connected to conductive ribbons using NCA.

D. *Washing and drying cycles*

To simulate the aging of the samples during their normal life cycle, washing and drying test according to the standard EN ISO 6330 was used. The washing cycles were chosen 4N (40±3)°C using a washing machine type A and 20 grams of standardized Non-Phosphate SDCE ECE detergent powder for each washing. Drying in an unfolded state, type C was realized (21°C, 63% RH, 24 hours). Overall, 5 cycles consisted of washing and drying process were realized for each reusing cycle. The whole testing procedure can be seen in Figure 4.

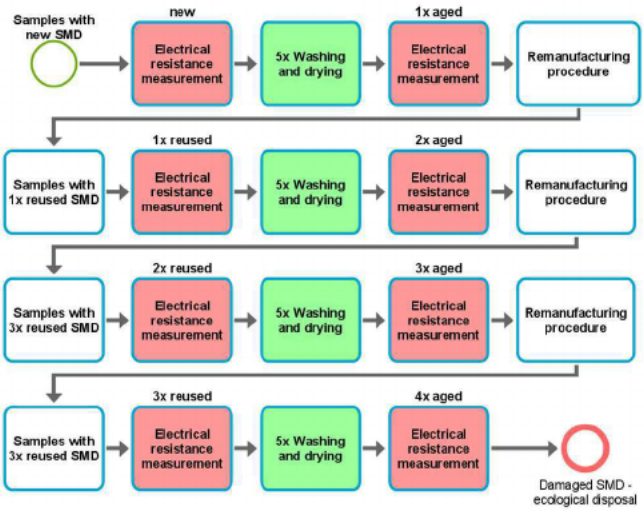

Fig. 4. Testing procedure

E. *Recycling procedure*

After significant deterioration in the characteristics of the ribbons in use, the product is collected according to the circular economy principle and the remanufacturing procedure is started. The remanufacturing procedure involves several steps, see Figure 5. First, the ribbons are removed from the collected e-textiles and placed onto a surface with acetone for 60 minutes with the component facing upwards. The component is then removed from the ribbon, either manually by a tweezer or automatically by an industrial robotic arm. The used ribbon and glue residues are then environmentally friendly disposed of. In the next step, the removed components undergo visual and functional control and are sorted into three groups: perfect components, components with minor mechanical damage without affecting their function, and damaged components. The broken components are disposed of and the rest of the components are cleaned from residues by isopropyl alcohol. These components are then reused and contacted onto new ribbons using the same contacting technique as before. New e-textiles are created using these remanufactured samples. The remanufactured samples undergo functional testing and are sorted into two quality categories: perfect (perfect components with perfect function) and second quality (the product is functional but does not meet the demanding specifications set by the manufacturer for its products). In our experiment, the recycling procedure was realized three times, each after the five washing and drying cycles. It follows that four live cycles of components were realized.

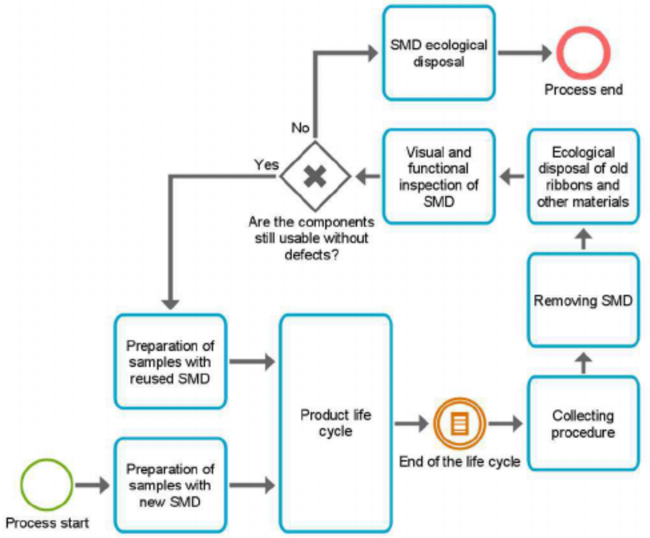

Fig. 5. Recycling procedure used in the experiment.

F. *Electrical resistance measurement*

The electrical resistance of tested joints was measured for new or reused samples and after aging using the four-point probe method with the Keithley DMM 7510 device. The conductive threads in ribbons were cut off in some places for resistance measurement using an electric discharge generated by a resistance spot welder from Sunstone company. The measured values consisted of the electrical resistance of two joints plus the electrical resistance of the resistor itself.

III. RESULTS AND DISCUSSION

The measured values of electrical resistance were statistically analyzed and presented in the boxplot diagram (see Figure 6). This graph type is important for understanding the distribution of values.

The results show that the electrical resistance of new samples is between 20 to 40 mΩ. The values for the new reused samples are fully comparable and show no degradation compared to the new components.

The results after five washing and drying cycles show that the electrical resistance of bonded joints increases as they are stressed by washing, confirming our previous research on the effect of washing on the reliability of bonded joints [14]. A comparative analysis of the electrical resistance of new and reused joints following washing and drying procedures indicates no significant difference or deterioration in the values of the reused joints.

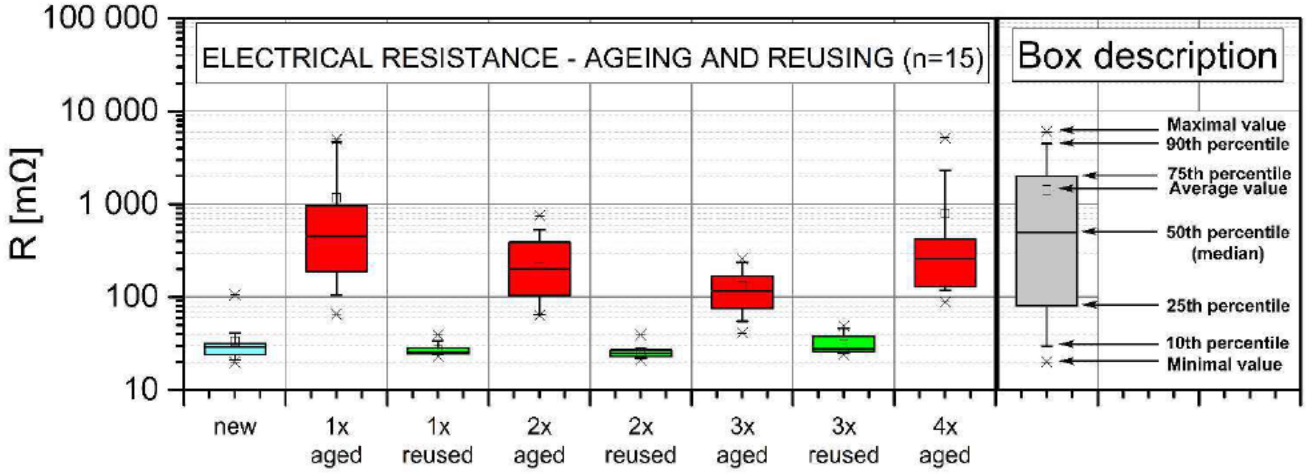

Fig. 6. Boxplot diagram of joints electrical resistance during the reusing after washing and drying cycle test.

However, our component reuse method is particularly suitable for more expensive or unavailable components. For this reason, initial experiments with various other components were also conducted and evaluation of their functionality was carried out. The results showed several generally valid findings. The non-conductive adhesive bonding method used is applicable provided that the components have sufficiently protruding pads compared to the rest of the component. If the pads are in the same plane as the body of the component or even embedded in the component, contacting them using this method is problematic or even impossible. The method of reusing components can be used if the components are sufficiently resistant to acetone and will not be damaged by it. In our experiments, for example, the power LED tested proved to be unsuitable because the transparent acrylic chip cover was degraded. However, it is possible to find LEDs that can withstand exposure to acetone without damage. Furthermore, the method of reusing components is not suitable for components that are too fragile to mechanically withstand the process of removing components from the old ribbon. Finally, it is important that there is a way to test the proper function of the component after it has been removed from the ribbon.

IV. Conclusion

In conclusion, this paper has successfully demonstrated the feasibility of our proposed method for reusing SMD chip components in e-textiles (first objective). As described in chapter II, our method involves the use of a special non-conductive adhesive bonding technique to connect SMD components onto electrically conductive stretchable textile ribbons during the production of a new product. At the end of the product's life-cycle, our recycling method is employed to manufacture a new product using the same (reused) components. The results indicate that our method is both possible and effective, with reused components remaining functional without any impairment to their performance (electrical resistance or functional test).

The second objective of this article was to assess the integrity of specimens containing reused components following a washing and drying cycle test. The results of the experiment demonstrated that our method is usable and that reused samples remain functional, even after undergoing washing and drying testing. Furthermore, the results indicated that our method can be used for multiple life-cycles (ideally no more than four). However, it was also observed that certain component types may be more susceptible to damage or unsuitable for our method, necessitating slight variations in the procedure depending on the specific type, size, shape, and material of the component.

Our method offers several benefits, including the conservation of raw materials, minimization of waste, and reduction of production costs. Additionally, it can help to mitigate component shortages, which have become a significant issue in many manufacturing lines due to the SARS-CoV-2 pandemic and ongoing supply problems related to the Ukrainian conflict. While the applicability of our method may vary depending on various factors, it is particularly well-suited for use with higher-value or shortage components.

Acknowledgment

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