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Mechanical performance of electronically functional smart textiles

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Abstract: With advancements in electronics technology, the new-era of devices are flexible and bendable. This has given rise to new smart textiles as wearables. Printed electronics enables to put down electronics on textiles without affecting the flexibility of the fabric. We have developed dry electrodes on healthcare stockings to stimulate muscles to preserve muscle mass in COVID-19 patients. The fabric does not allow direct printing of electronics. Thus, various layers are used. This paper investigates the mechanical strength of these layers on the stocking to remain functional for daily usage. We also discuss washing results on the layers.

I. Introduction

Futuristic smart wearables will ensure seamless and conformal integration of electronics in fabrics. Printed electronics (PE) provides a seamless and time-effective route to achieve it by printing nanomaterial inks directly on the textile surface[1]. The technology has opened doors to integrate sensors and stimulating devices in the textiles without rigid components[2]. However, given the variety of textiles available in the market, there is not one recipe that fits all. Depending on the texture of the fabric, pre- and post-treatments are necessary to put down electrical circuits on the fabric.

One of the obvious areas of application for PE is the healthcare sector, where new-age sensors and devices can be incorporated in a wide range of healthcare textiles namely coats, patient gowns, aprons, socks etc. Loss of muscle mass, referred to as muscle wasting, is a common complication for patients admitted to intensive-care units (ICU)[3]. Loss of muscle mass during hospitalization can be counteracted by early treatment with neuromuscular electrical stimulation (NMES), but the current treatment route is time-consuming and requires specialist care[4]. The motivation of this project was to replace a stand-alone NMES device in anti-embolic compression stockings for patients. Owing to the stocking fabric, an interfacial layer is required that must be biocompatible and adhere well to the fabric. Smart textiles are subjected to severe bending, twisting and stretching during usage. We investigate the mechanical properties and washing behavior of the layers required for PE in this paper.

II. Material and methods

CAP stockings from Carolon were used for the work. Matte finish polyurethane sheets (BFPRINT01, B-Flex) was used as the interfacial layer. The sheet was heat treated at 140 °C for 3 min under pressure to attach to the stockings. Peeling tests were performed on Zwick Roell material testing machine. Washing was carried out at standard program (1400 rpm, 1.15 hr, 95° C) in LG P4AOVN0W washing machine.

III. Results and discussion

A pre-requisite for printing electronics on any surface is low surface roughness. This ensures good and homogeneous printing. Hence, an interfacial layer is used. Moreover, the printed patterns need to be protected, hence another encapsulation is required on top. A T-peeling test is performed on the interface layer to measure the adhesion between the layer and stocking (fig 1). It can be seen that the force applied to the layer is linearly proportional to the strain, thus suggesting that the material is elastic. This is further supported by the calculated elastic modulus, which has a low value of 2.99 Mpa (table 1). Furthermore, even at low force we were able to strain the textile for more than 20% without observing any peeling of the interface layer, suggesting strong adhesion to the textile.

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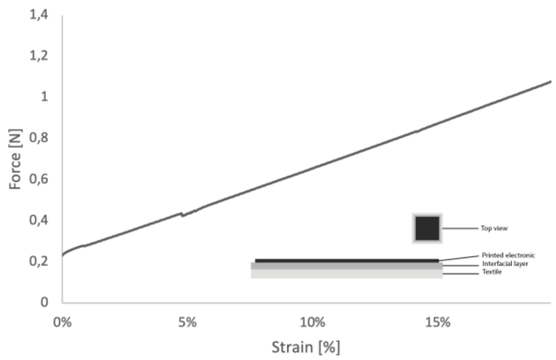

Figure 1: Force versus strain graph for one layer of encapsulation applied to the stocking. Inset is the top and side view schematic of the payout of the interfacial layer on the fabric.

We also employed the same layer as encapsulation for PE electrodes on the textile. Here, the peeling test measured the force required to peel of the interface layer when adhered to itself (fig 2). The top interfacial layer could be stretched to approximately 440% without any peeling. This indicates a strong adhesion, also confirmed by the small value of E_T.

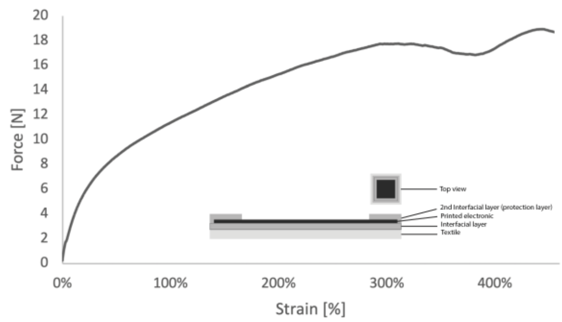

Figure 2: Mechanical behavior of two polyurethane sheets attached to each-other on top of the fabric. The first layer works as interfacial layer while other as encapsulation layer. Inset is the top and side view schematic of the payout of the sheets.

Table 1: Measurements from the peel test on the two models of polyurethane sheets.

	E_t (Mpa)	s_x (Mpa)	s_m (Mpa)	e_m (%)
Model 1	2.99	0.27	0.53	20.48
Model 2	30.16	1.53	7.96	446.55

All kind of textiles require washing and thus it is important for PE to be able to withstand this process. Washing becomes even more critical for healthcare textiles to avoid contamination and bacterial growth. We tested the interfacial layers for normal washing cycle with laundry detergent at high temperature (90 °C) to eliminate bacteria. Fig 3 shows the images of the stocking before and after one-cycle of washing. The interfacial layer is able to withstand 8 washing cycles without any damage. No cracking or delamination of the interfacial layer was observed. This result suggests that neither the wearable fabric nor the interfacial layer will be the limiting factor for the printed electronics.

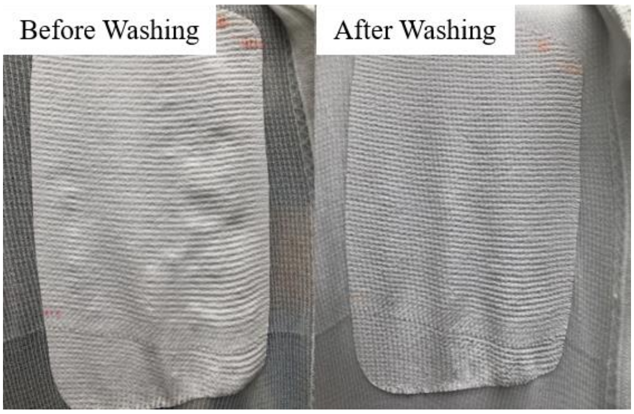

Figure 3: Image of single layer of polyurethane interfacial layer before and after washing cycle.

IV. Conclusions

This study is a step towards realizing smart electronic textiles for new-class of wearables. We demonstrate pre-processing required to print electronic circuits on the healthcare stockings. There is no one solution that fits all and different textiles may require different pre- and post-processing steps. We investigate mechanical properties of polyurethane based encapsulation layer for compression stockings. They demonstrate good adhesion without compromising the flexibility of the fabric. The paper also studies the effect of washing cycle on the encapsulation layer.

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AUTHOR'S STATEMENT

Conflict of interest: Authors state no conflict of interest.

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