Microelectronics Reliability 54 (2014) 2956–2960

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Research note

Predicting conducting yarn failure in woven electronic textiles

Hans de Vries [a,*], Ron Peerlings [b]

[a] Philips Research, High Tech Campus 34-6, 5656AE Eindhoven, The Netherlands
[b] Department of Mechanical Engineering, Eindhoven University of Technology, PO Box 513, 5600MB Eindhoven, The Netherlands

ARTICLE INFO

Article history:
Received 27 March 2014
Received in revised form 7 July 2014
Accepted 7 July 2014
Available online 14 August 2014

Keywords:
Smart textiles
Failure prediction
Conductive yarns
Failure mode
Endurance test

ABSTRACT

Smart, electronic textiles are often exposed to tensile stress which can lead to fracture of the interwoven conducting yarns. In this study, a model is proposed to relate the extensibility of the conducting yarns to the weaving pattern of the textile – in particular to the thickness and pitch of the textile yarns. The model is validated by simultaneous mechanical and electrical tests on bare yarns extracted from several textiles. The results show that mechanical failure precedes electrical failure. Thus, a lower and conservative bound for electrical failure can be obtained from the extensibility prediction as a function of the structure of the weave.

1. Introduction

Integration of electronic functionality in textiles has paved the way for novel and widely different application areas, ranging from light-therapy to signage and decoration [1–5]. In case of monitoring physiological functions or applying medical therapy, the advantage of using textile-based devices is their comfort of wearing. In the second place, because of the textile's compliance and breathability, it is possible to carry out such measurements and therapy close to the skin. Several fabrication methods are used, among which weaving, stitching and embroidery of conducting yarns in or on the fabric have gained much attention. In principle, standard manufacturing methods are used to incorporate the conducting yarn in the textile. In the case of stitching the yarn is added by guiding it with a needle through the textile. It is held in position by a counter thread that can be either conducting or not. In the embroidery process the yarn is fixed on the surface of the textile by a separate thread. In these two methods the conducting yarn is thus applied after the textile has been made, or even after the product has received its actual shape. This is quite different in weaving on a loom, where the conducting yarn is woven simultaneously with the entire textile. The yarn thus follows the weave pattern. Subsequently, rigid components such as light emitting diodes or sensors are mounted onto the textile and electrical contact is made with the conducting yarns by soldering or applying conducting adhesives. For further details on the technologies and applications, we refer to the abovementioned publications.

Since textiles are meant to be worn, washed, and stored, they will be bent, folded, etc., and thus specific mechanical loads are invoked in the above-mentioned applications, apart from the usual environmental stresses. For instance, textile fibers can be exposed to bending radii of less than 1 mm [6], forces up to a few thousands Newton per meter [7], and strains of 20% [8]. Therefore specific failure modes may influence the reliability of devices based on the so-called electronic-textile technology. In particular breaking of the attachment between component and conducting yarn requires attention, as the materials used for this purpose (e.g. solder materials) are generally soft and sensitive to stress. Special structures have been designed which protect the attachment against excessive loading. In the electronics industry globtop and underfill are frequently used to reinforce the components' attachment to the substrate. On flexible foil substrates this is often done in combination with conductive adhesive interconnections [9]. Also for textile substrates protective measures have been proposed, such as globtop to strengthen the adhesive attachment of LEDs [10], or an intermediate textile layer to shield the conductive yarn from bending over a sharp edge [11].

In this contribution, however, we focus on the reliability of the conductive yarns – and in particular on a class of yarns which are composed of a bundle of metallic filaments. We consider a woven textile with embedded conducting yarns and aim to understand how the electrical and mechanical failure of the conducting yarns depends on the parameters of the textile, i.e. the thickness and spacing of the textile yarns. Prior experimental results on free-

* Corresponding author.
E-mail address: j.w.c.de.vries@philips.com (H. de Vries).

http://dx.doi.org/10.1016/j.microrel.2014.07.008
0026-2714/

standing conducting yarns show that the onset of mechanical failure precedes their electrical failure. It may thus be possible to make a – conservative – prediction of the electrical failure by means of a suitable model that describes mechanical failure. Such a model would be useful for designers as it would allow them to select conductive yarns and weaves which guarantee reliability a priori – i.e. without the need for prototyping and (electrical) measurement. In order to systematically address this question, conductive yarns have been extracted from different types of woven electronic textile and subjected to tensile tests in which also their resistance is measured. This allows us to simultaneously measure the electrical and mechanical response of the individual yarns, without any influence of the surrounding textile. Based on earlier work on the mechanical modeling of the conducting yarns, a simple model for yarn failure is formulated, as a function of the yarn thickness and spacing of the textile substrate. The trends predicted by the model are confronted with the measured mechanical and electrical data in order to establish the validity of the predictions.

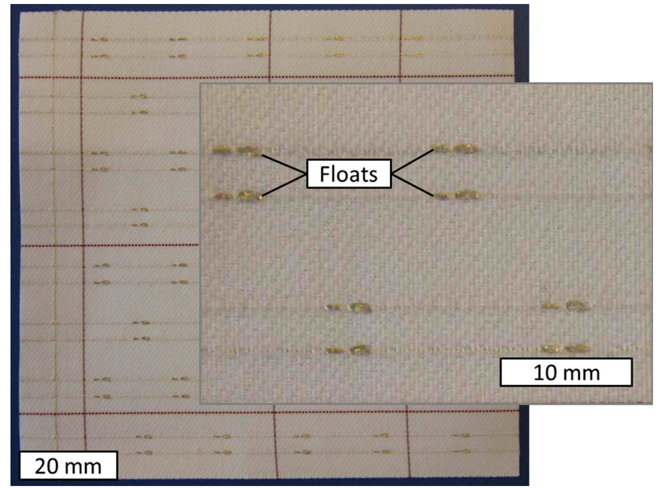

Fig. 1. Textile (circa $100 \times 100\ mm^2$) with conducting yarns and detail showing floats. Warp is in the horizontal direction. Scale bars are shown.

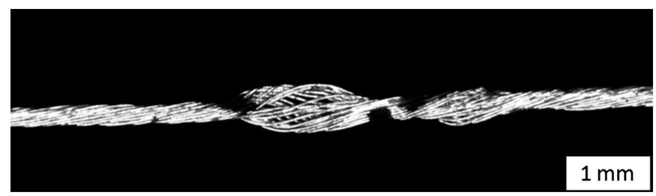

Fig. 2. Bare conducting yarn with float, prepared from woven textile. Scale bar is shown.

2. Experiments

To be able to study the extensibility of conducting yarns that have been deformed by weaving them into textiles, single conducting yarns were carefully extracted from the woven fabric by cutting away the textile yarns surrounding them. A number of textiles differing in two main characteristics, but containing identical conducting yarns, were used for the tests. These characteristics are the "dtex" – the mass in grams of 10,000 m of the textile thread – and the "picks per centimeter" – the number of weft threads per centimeter. Table 1 shows these parameters for the different textiles considered. Fig. 1 shows a typical textile with woven conducting yarns; in Fig. 2a de-engineered yarn (i.e. after being extracted from the textile) with float is shown. A float is a not-woven part of the conducting yarn lying on top of the fabric to facilitate electrical contact with components.

The conductive yarn is Elektrisola litze [12] yarn that consists of 20 silver plated copper filaments with a diameter of 0.04 mm, each wrapped with a twist of approximately 240/m. The non-conducting multifilament threads of the textile are made of polyester (PES spun fiber yarn). The textile samples were made by the Institute for Special Textiles and Flexible Materials (TITV Greiz, Germany).

Tensile tests were done on the de-engineered conducting yarns while simultaneously measuring their electrical resistance. The tensile tests were carried out on an Instron 5566 tensile tester. The yarns were stretched at a rate of 1.7–2.1 $\times$ 10^{-3}/s until electrical failure was observed. In order to prevent slipping of the samples from the clamps, dummy pieces of printed circuit board were laminated with adhesive tape to the bare yarns. In addition, in order to establish the relevance of the single-yarn measurements, pieces of textile with integrated conducting yarns were tested. The four-point resistance measurements were done with an Agilent 34970A-datalogger equipped with a 34901A-multiplexer. Output signals monitoring the load and the displacement of the tensile tester were also connected to the multiplexer unit. In this way all relevant parameters could be simultaneously recorded. Data logging was done with an interval of 0.5 s. Four yarns of each of the above mentioned types (A–D) were tested in this way.

Table 1
Characteristic data of the textiles. Dtex (D): g per 10,000 m thread. Picks/cm (p): number of weft threads per centimeter.

Type	D	p
A	50	33
B	145	28
C	167	22.8
D	145	22.8

3. Model

It has previously been established by de Boer [13] that the extensibility of the conductive yarns extracted from the textile samples is lower than that of the unwoven conducting yarns. This loss of extensibility is due to the plastic deformation which the yarns undergo during weaving. The conducting yarns, which are predominantly in warp direction (see Fig. 1) are bent around the weft textile yarns during weaving and this induces plastic (bending) strain in the conducting yarns. Part of their ductility is thus lost in fabrication and the remaining plastic strain which they can still undergo is reduced. One could argue that the spring-like shape which the conducting yarns adopt upon weaving actually enhances their extensibility, as they first need to be straightened again before being stretched. But for realistic textile yarn thicknesses and spacings it was found that this effect is secondary to the loss of ductility by bending strains induced during weaving [13].

A simple model for the effect of bending strains due to weaving may be obtained by assuming that the individual filaments in the conducting yarn adopt a harmonic shape:

$$y(x) = A \cos \frac{2\pi x}{\lambda} \tag{1}$$

where x is the coordinate along the length of the filament and y denotes its out-of plane displacement due to the weaving pattern; A and λ denote the amplitude and the wavelength of the pattern, respectively. The above expression neglects the spiraling shape of the filament within the conductive yarn. This is justified since the wavelength of the weave (λ) is much smaller than that associated with the internal twist in the yarn – and the plastic strain induced by it thus much larger.