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Towards commercialization of graphene-based end-of-life sensors for fire-protective fabrics

Towards commercialization of graphene-based end-of-life sensors for fire-protective fabrics

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Abstract. Fire-resistant (FR) fabrics used in protective clothing experience a reduction in performance as a result of exposure to various ageing conditions, for instance: heat, ultraviolet (UV) light, moisture, abrasion and laundering procedures. However, there are few visible clues to indicate if the deterioration of the protective clothing has reached a dangerous level. To address this issue, graphene-based end-of-life sensors (heat, UV light, and moisture) are being developed at the University of Alberta in collaboration with five industry partners, including Davey Textile Solutions, Inc (DTS). DTS has the production capacity to manufacture the graphene-based end-of-life sensors, including weaving, finishing, conductive track application, fusing, and product assembly. The lifetime of fire-protective clothing is an important parameter to monitor, and the graphene-based end-of-life sensors are a straightforward, non-destructive, and effective tool for this purpose. The plan is to fabricate, integrate and commercialize the sensors. DTS, alongside academic researchers from the University of Alberta, are in the process of scaling up the manufacturing and testing of the sensors. The health and safety of firefighters will be improved by bringing graphene-based end-of-life sensors to the market.

1. Introduction

Firefighters and other first responders are exposed to a range of hazards while at work, for instance, thermal, chemical, biological, mechanical and nuclear hazards [1]. Furthermore, firefighters are more at risk of exposure to open flame, radiant heat, steam, hot fluids and hot surfaces. Fire-protective clothing contributes to the safety of firefighters by protecting the wearer against heat and flame threats [2]. For this reason, fire-protective clothing must maintain its performance throughout its lifetime.

However, fire-protective clothing can be affected by many ageing conditions, such as heat, UV light, moisture, and abrasion, along with laundering procedures [3]. The mechanical performance of the fire-protective clothing may be reduced due to ageing [4–5-6]. Yet, the loss in performance as a result of ageing can reach a dangerous level before any visual changes are detectable via the human eye [7]. This raises important concerns regarding the firefighters' safety, as well as the safety of workers who wear protective clothing.

At the University of Alberta, in partnership with five industry partners including DTS, as well as the financial support of NSERC, graphene-based end-of-life sensors (heat, UV light, and moisture) are being developed to address this issue [8]. Each sensor consists of several layers, including a conductive track fixed to a sacrificial polymer that is encapsulated in a polymer film. Additionally, each sensor is laid on a textile substrate which will be attached as a patch to specific areas of the outer shell fabric of the firefighter's protective garment.

The sacrificial polymers behave similarly to the outer shell fabrics of firefighters' protective garments when exposed to the ageing conditions of heat, UV light, and moisture [9–10]. The exposure to ageing conditions will initiate a degradation in the sacrificial polymer layer of the sensor, ultimately disrupting the conductivity of the conductive track [8]. The changes in the electrical conductivity will be measured through contacts located on the surface of the sensor using a multimeter during regular protective gear assessment, determining if the fire-protective clothing is safe for further use or not.

2. Manufacturing process

The fabrication of the graphene-based end-of-life sensors includes weaving, treating the textile substrate, putting the sensors' elements together as well as mounting the sensor to the textile substrate. DTS encompasses the production capacity to fabricate these sensors: weaving, finishing, conductive track application, fusing, and product assembly.

2.1. Weaving

The textile substrate is the key component for the development of graphene-based end-of-life sensors. A comprehensive research study was conducted at the University of Alberta to assess and determine the best choice for a textile substrate for the sensors [11]. The purpose of the assessment was to identify a fabric that can resist ageing conditions that are known to be damaging to fire-protective clothing and retain most of its mechanical strength. Moreover, this assessment helped to ensure that the textile substrate does not interfere with the operation of the sensor throughout the life of the garment.

Upon extensive investigation of a wide range of FR fabrics, it was found that Nomex® IIIA, which is a blend of 93% meta-aramid, 5% para-aramid and 2% anti-static fibres, is optimal for the sensor textile substrate as it retains most of its mechanical strength following the exposure to accelerated thermal and hydrothermal ageing, as well as accelerated laundering. DTS utilizes narrow-width looms to manufacture fabrics for highly visible reflective trims (Figure 1). These looms will be utilized for producing the Nomex® IIIA textile substrate for the sensor patches.

2.2. Finishing

Results have shown that Nomex® IIIA demonstrates excellent resistance against heat, moisture, and laundering procedures; however, the fabric is sensitive to UV light, resulting in reduction in mechanical strength [11]. It is necessary that the textile substrate retains its mechanical strength and does not fail before the sensor elements. Hence, surface treatments, such as UV light blockers and absorbers, are being investigated to protect the textile substrate from UV light degradation. DTS currently applies surface treatments for dimensional stability, increased hand, and UV light stabilization using the finishing unit (Figure 2). The finishing unit will be utilized to apply surface treatments to the textile substrate for UV light stability.

2.3. Conductive track

The conductive tracks will be applied as a layer on the sacrificial polymers using different methodologies of application for each sensor [12]. DTS recently purchased a laser scriber, which will be utilized for preparing the conductive tracks.

2.4. Fusing

To protect the sensor components from normal use conditions, such as abrasion and laundering procedures, they will be encapsulated with a polymer film [12]. DTS uses fusing machines to adhere reflective tapes to woven fabrics (Figure 3); these machines will be used to encapsulate the sensor elements, as well as mount the sensor to the textile substrate.

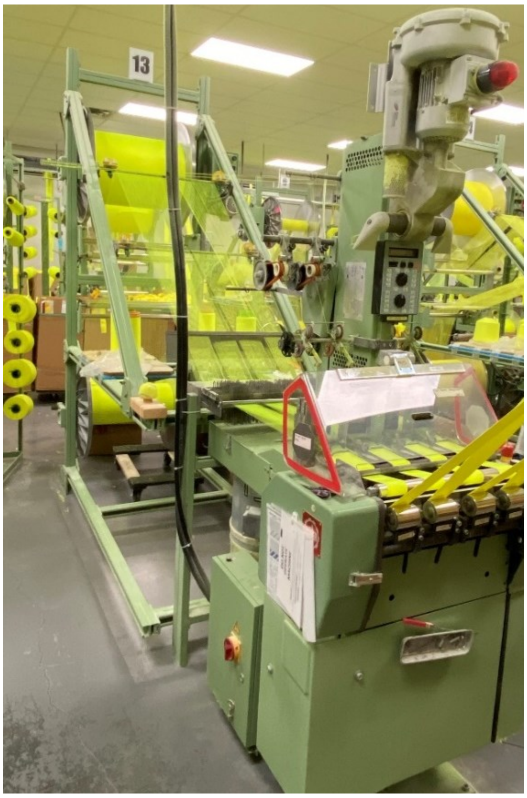

Figure 1. Narrow width loom at DTS.

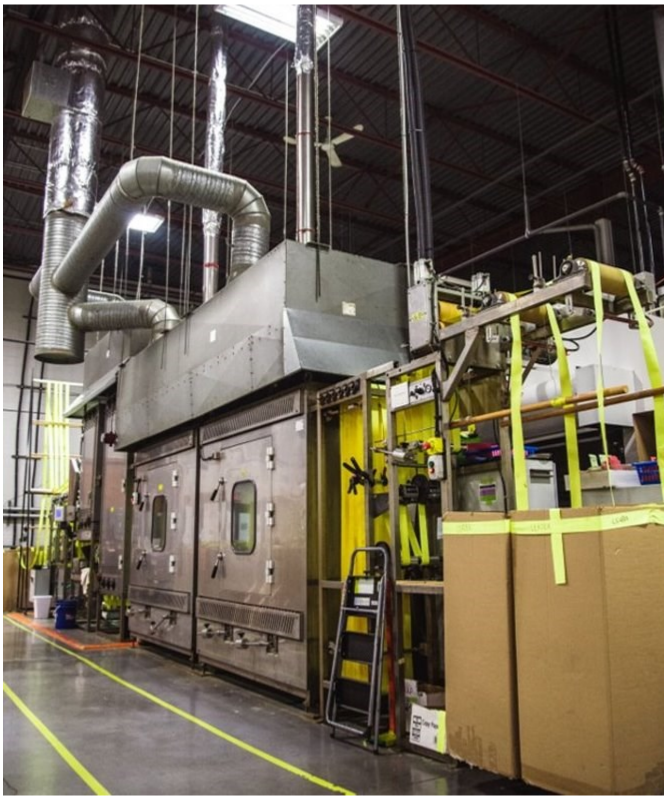

Figure 2. The finishing unit at DTS.

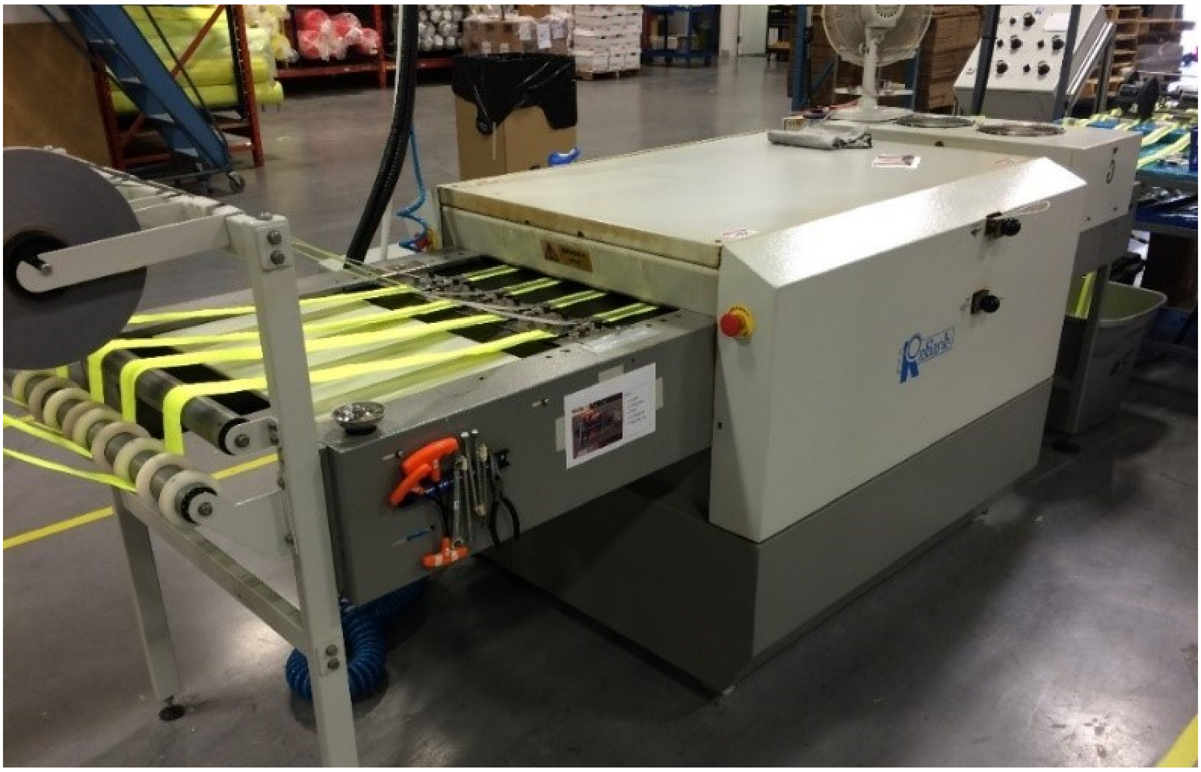

Figure 3. Narrow fabric and reflective trim entering the fusing machine at DTS.

2.5. Product assembly
DTS is committed to innovation and automation. The goal is to manufacture a continuous strip of sensors, laminate the strip to a continuous band of Nomex® IIIA substrate, and then slit the composite trim down to individual sensors. This production technique will allow for larger capacity production, leading to commercialization.

3. Discussion
Prototypes will be produced at DTS over the next months, and field trials will be completed by the University of Alberta's research team. Once the sensors are deemed viable, DTS will present the sensors to the market, completing the final step of commercialization.

4. Conclusion
Fire-protective clothing is fundamental for the safety of firefighters and is considered the first line of defense against hazardous elements. Hence, monitoring the condition of the fire-protective clothing will help determine its lifetime and verify if it is safe to use or not. A simple useful tool to achieve this goal is the graphene-based end-of-life sensors.

The successful development and commercialization of the sensors will take place at DTS in cooperation with academic researchers from the University of Alberta. Introducing the graphene-based end-of-life sensors to the competitive market of wearable technologies will enhance the safety of firefighters and other users who rely on fire-protective clothing for their wellbeing.

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