Development of a manufacturing process for a robust electronic yarn

A.M. Shahidi*, T. Hughes-Riley, M.N. Nashed, K. Marasinghe, C. Oliveira, T. Dias

Nottingham Trent University, Advanced Textiles Research Group, School of Art & Design, Bonington Building, Dryden St, Nottingham NG1 4GG, UK; *Correspondence to: arash.shahidi@ntu.ac.uk

Introduction

The physical properties of textile materials make them an excellent choice for embedding electronics to create wearable devices. While there are many different methods to integrate electronics with textiles this work focused on the manufacturing of electronic yarns (E-yarns) which can be knitted or woven to create electronic textiles (E-textiles).

E-yarns are created by first soldering a component onto thin copper wires, the component is then encapsulated with a supporting yarn within a polymer resin micro-pod, and finally the wires and micro-pod are covered in packing fibres and a knit braid. A semi-automated process for producing this type of E-yarn has been described elsewhere [4].

Textiles containing E-yarns are fairly mechanically robust and can survive multiple machine washing-drying cycles [1], earlier E-yarn designs had some key limitations including a difficultly in wiring devices once in textile form due to the components typically being soldered in series, some fatigue failures during high mechanical loading during post-soldering processing [2], and failures in high-sweat environments [3].

This work presents a new E-yarn design that overcomes these identified issues. Further, work toward an automated production line that can produce these E-yarns is discussed.

Proposed production process

In order to produce a robust E-Yarn that addressed the issues identified in earlier work, a new production process was required. The following production steps were implemented:

1. A mechanically strong and flexible Litz wire (including enamelled multi-strand copper wires) was used, replacing the multi-strand copper wire used in earlier work. The outer insulating coating on the wire had to be removed at the point to where the component was to be soldered. This was achieved using a focussed infra-red (IR) beam.
2. Solder paste was dispensed onto parallel Litz wires and the component was subsequently placed on top of the wires using a pick-and-place machine. IR reflow soldering was used to solder the component (see **Figure 2**).
3. The soldered component was pre-encapsulated using an ultra-violet (UV) curable resin immediately after soldering to facilitate further processing (see **Figure 3**).
4. The soldered component was fed into a mould along with a number of reinforcing yarns (up to eight strands). UV curable resin was injected into the mould and cured, creating a discrete micro-pod (see **Figure 4**). This improved the strength of the E-yarn and enhanced the uniformity (the exact number of reinforcing yarns would depend on the size of the micro-pod and/or the end-application).
5. A suture braider was used to cover the final ensemble providing an excellent level of coverage, producing a final E-yarn that was highly mechanically robust and with a normal yarn appearance (see **Figure 5**).

By soldering components in parallel, the necessity to cut the copper wire between the solder pads on many electronic components (i.e. light emitting diodes) was also eradicated, which further increased the mechanical strength of the E-yarn and simplified the wiring of components for many applications (i.e. pressure sensing). The Litz wire was mechanically stronger than the copper wire previously used and also would prevented failures when exposed to liquid with a high salinity (i.e. sweat) [3]. By introducing a pre-encapsulation step, the solder joints were strengthened, which reduces breakages at the solder point during further processing.

The apparatus used to produce the E-yarns is shown in Figure 1.

Soldering onto parallel wires

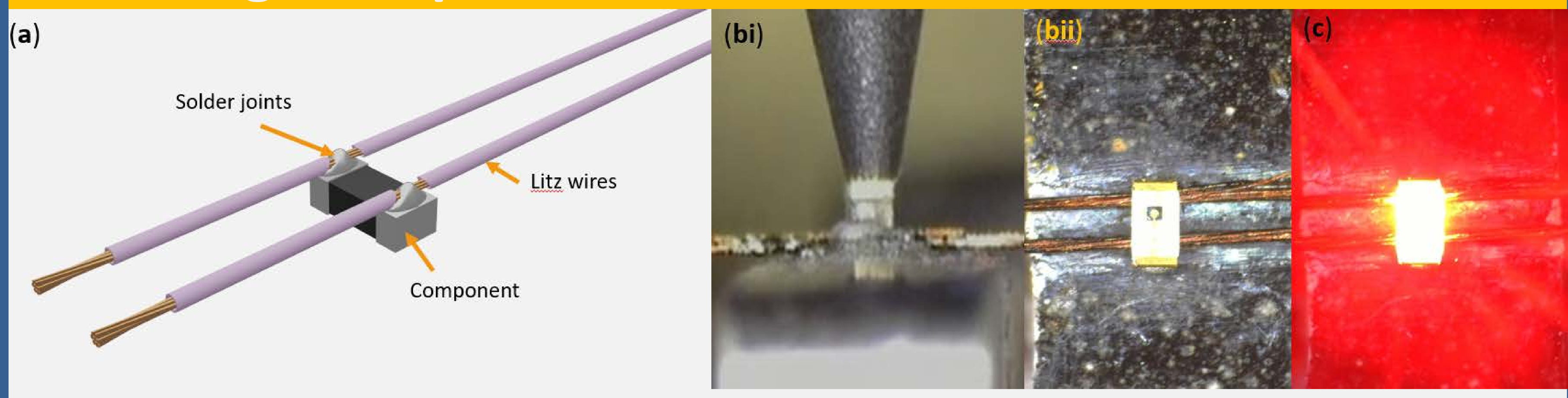


Figure 2. Parallel-soldering stage: (**a**) Schematic of a soldered component. (**b**) A soldered light emitting diode (1.0 mm × 0.5 mm × 0.5 mm surface mount device LED) placed onto parallel wires. (**c**) Quality assurance of functioning component following soldering.

Preliminary encapsulation

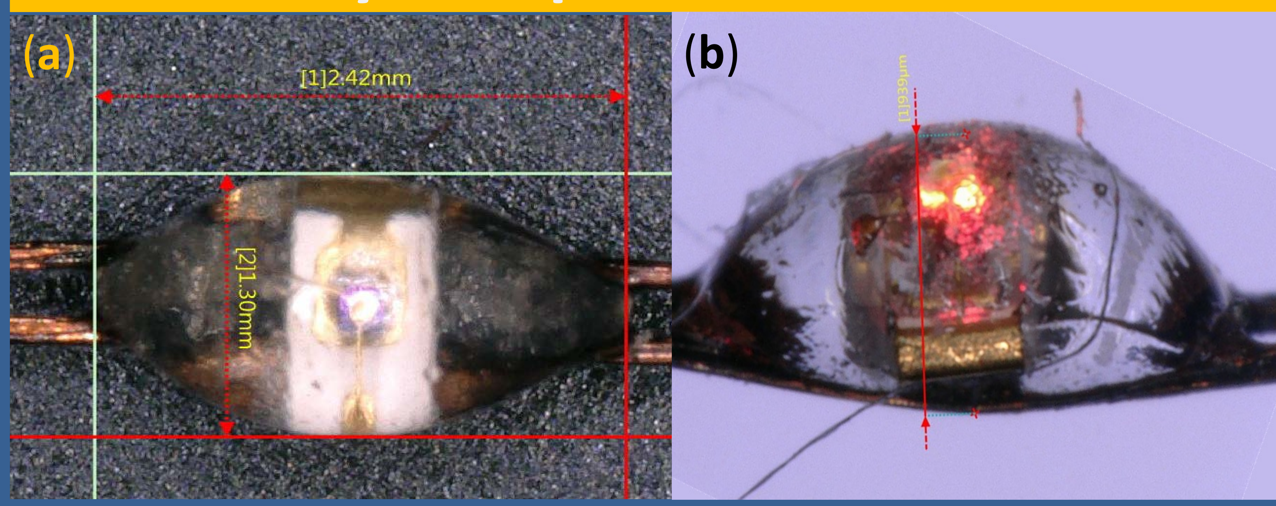


Figure 3. Preliminary encapsulation: (**a**) Microscope image of the pre-encapsulated light emitting diode. (**b**) Powered pre-encapsulated LED.

Refined encapsulation stage

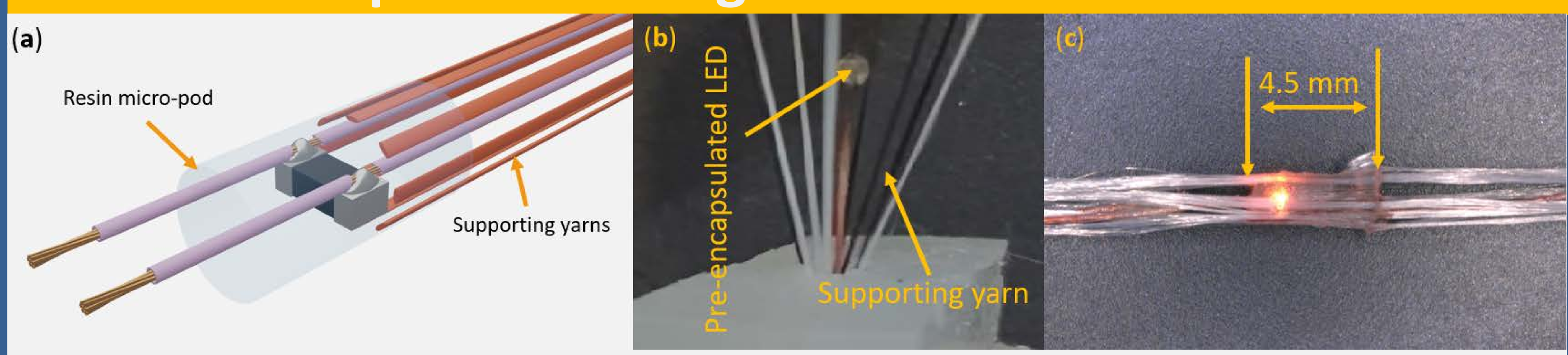


Figure 4. Encapsulation stage: (**a**) Schematic of the encapsulated component. (**b**) Pre-encapsulated component entering the encapsulation mould along with supporting yarns. (**c**) Encapsulated LED. The micro-pod includes eight Polyester supporting yarns.

Covering stage (braiding)

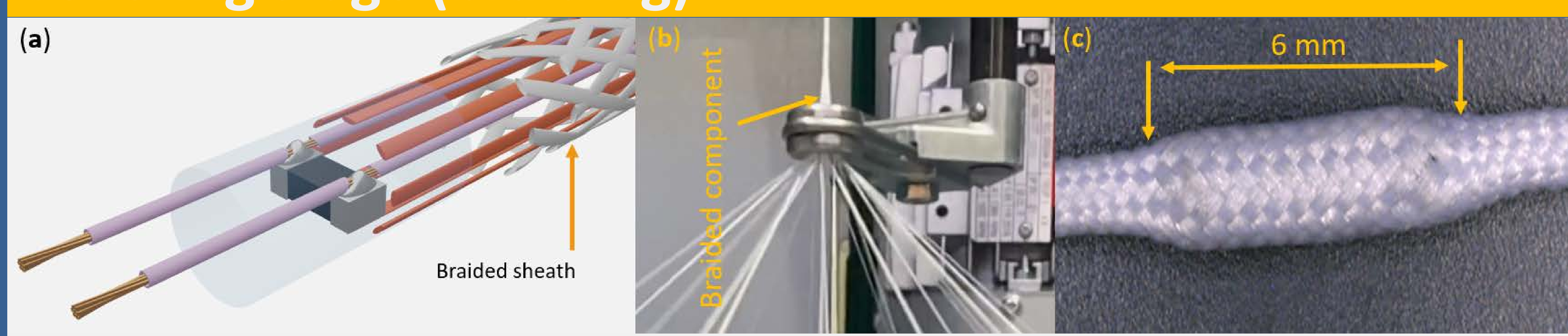
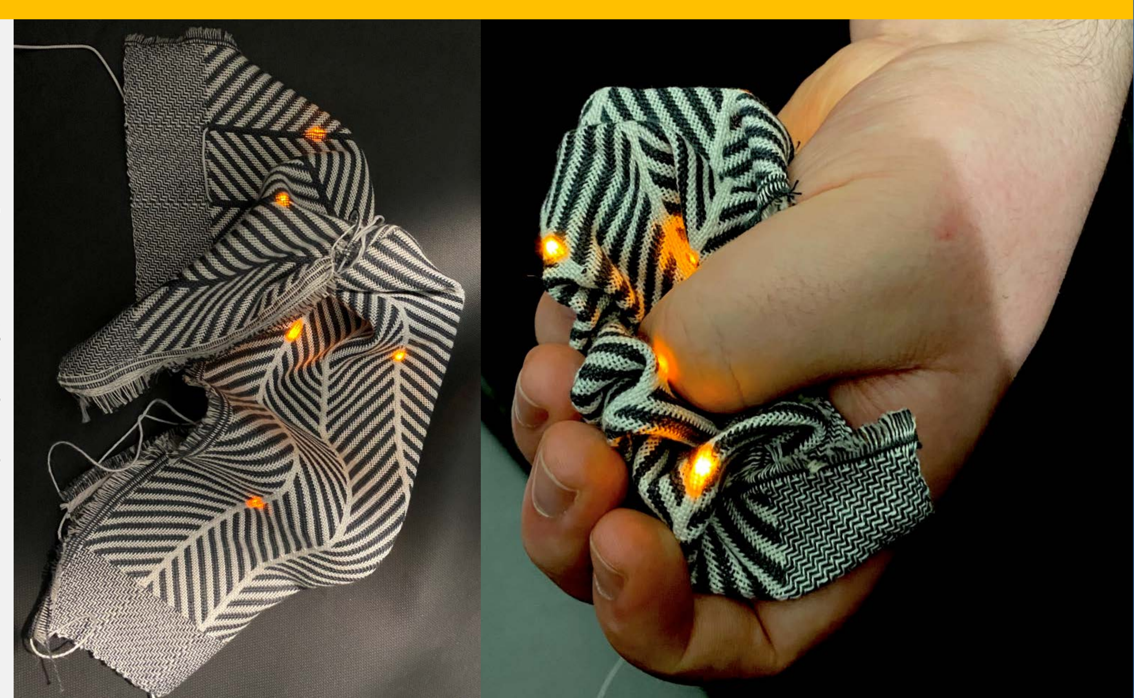


Figure 5. Braiding: (**a**) A schematic of the final E-yarn. (**b**) Image of an encapsulated component after having seen covered in a braid. The encapsulated component, supporting yarns and copper wires, are covered using a suture braider. 12 or 24 ends of yarn are used depending on the final intended application.

Textile construction

Figure 6. Woven textile produced using E-yarns with embedded LEDs. Textiles produced using electronic yarns have normal textile properties and are highly deformable.



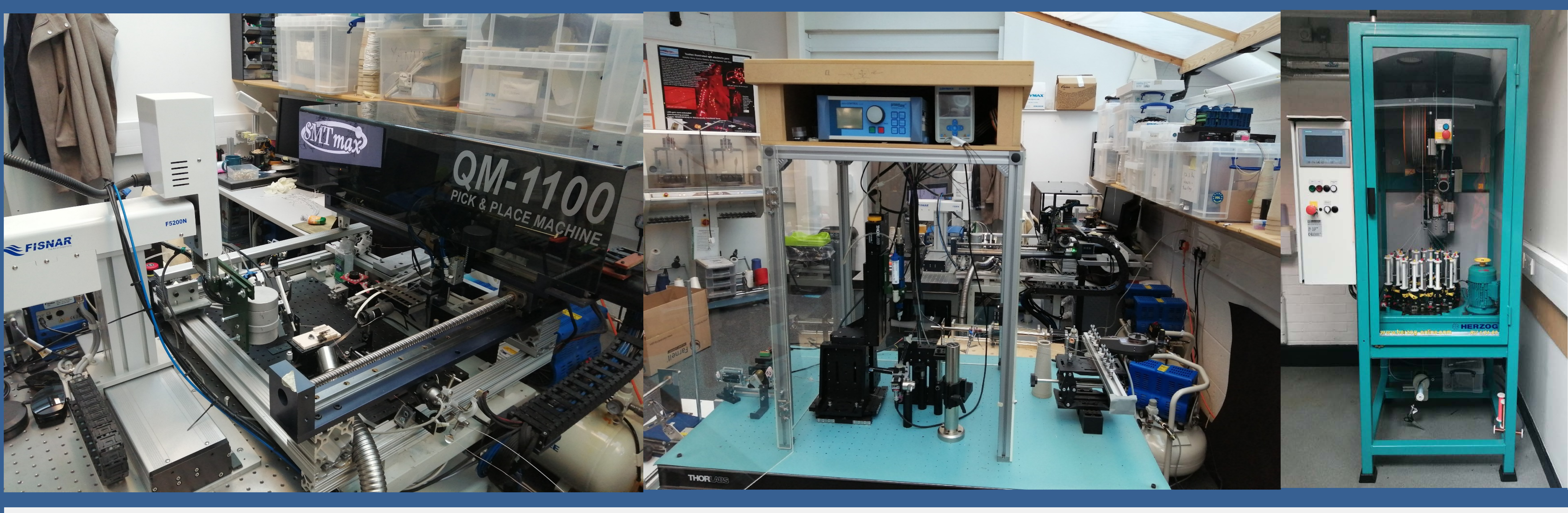


Figure 1. Apparatus used to produce the electronic yarns. (**a**) Soldering station including an IR reflow soldering head, wire handling and feeder systems, and pick-and-place machine. (**b**) Automated encapsulation machine. (**c**) Suture braider.

References:

1. Hardy, D. A., Rahemtulla, Z., Satharasinghe, A., Shahidi, A., Oliveira, C., Anastasopoulos, I., Nashed, M.N., Kgatuke, M., Komolafe, A., Torah, R., Tudor, J., Hughes-Riley, T., Beeby, S., Dias, T. 2020. Wash Testing of Electronic Yarn. Materials, 13(5), 1228.
2. Hardy, D.A., Moneta, A., Sakalyte, V., Connolly, L., Shahidi, A., Hughes-Riley, T. 2018. Engineering a costume for performance using illuminated LED-yarns. Fibers, 6(2), 35.
3. Hughes-Riley, T., Jobling, P., Dias, T., Faulkner, S.H. 2020. An investigation of temperature sensing textiles for temperature monitoring during sub maximal cycling trials. Textile Research Journal, 91(5-6).
4. Hardy, D., Anastasopoulos, I., Nashed, M-N., Oliveira, C., Hughes-Riley, T., Komolafe, A., Tudor, J., Torah, R., Beeby, S., Dias, T. 2019. Automated insertion of package dies onto wire and into a textile yarn sheath. Microsystem Technologies, 1-13.

Acknowledgements: This research was funded by the Engineering and Physical Sciences Research Council (EPSRC) grant EP/T001313/1 entitled *Production engineering research for the manufacture of novel electronically functional yarns (E-yarn) for multifunctional smart textiles*. The authors would like to thank Matholo Kgatuke for weaving the sample shown in Figure 6.

Nottingham Trent University

www.e-yarns.com

THE ADVANCED TEXTILES RESEARCH GROUP