Some considerations on using a different range of flexible substrates – such as fibres, fabrics, non-woven or foams.

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Introduction.

There is great interest in being able to wear flexible electronics. The starting point was to stick or laminate on existing rigid or flexible electronic devices of which simple devices are readily available through craft suppliers (1-3). This add on approach has limitations such as how to fasten them to the fabric, how to power them, make connections and then in use the flexibility tends to be less than ideal. The goal is to be able to make devices directly onto the fibres or fabrics including devices to power the electronics (4). Work is being done to produce a continuous fibre that has either a photovoltaic or a supercapacitor coated onto it which when woven together enables the fabric to convert light into electricity and to store the power for later use (5,6). Another hybrid technology uses piezo and photovoltaic coatings (7). Others are looking to coat the fabric as a whole whilst maintaining the performance of the fabric. This not only includes the mechanical performance such as flexibility or drape but it must also be aesthetically pleasing.

This paper will highlight some of the problems and possible solutions for coating these less often used substrates.

Fabrics

Fabrics made up of fibres allow the fibres to move over each other when the fabric is flexed. When the fabric is coated there can be a tendency for the fibres to be stuck to each other by the coating where the individual fibres touch. Once the fibres are stuck to each other they lose some of the flexibility and become stiffer and less elastic. Coating individual fibres would allow the fibres to remain separate but then the coated fibres would be subject to more abrasion. With fibres there is also a difference if the fibre is a monofilament or multifilament. If the fibre is made up of multiple finer fibres these too will rub against each other and if the individual fibres are coated would need to be robust against abrasion damage. Multifilament fibres can aid flexibility which may also be compromised if the coating is added where the coating sticks the individual fibres together. To maintain flexibility of the final textile it can be useful for the fibres to stretch and this would require a high level of adhesion between coating and fibre.

Depending on the use of the fabric there may be other considerations to be taken into account. If the fabrics are to be worn then they would need to withstand washing without degradation of their function.

Basic conducting fabrics have been produced using stainless steel fine wire that is used as a core and covered with cotton which is then used in the weave. The stainless steel fibres are spaced and the sheath can be removed to provide contact points where electronic devices can be soldered (6). An alternative approach is to spin the yarn and to then spiral around the yarn a conducting fine wire and others spin the fine wires in with the fibres to make the yarn. Yet another approach is to metallise fabrics with silver or silver plus other layers such as tin, nickel or copper where the whole fabric surface is conducting. In some cases the fabric was not specifically designed for use as a conducting fabric but was silver coated as a medical wound dressing material.

To obviate the need for washing work is being done to use photocatalytic cleaning such as using copper or silver nanocoated fabrics that under light spontaneously clean themselves. (8)

The simplest fabrics utilising conducting yarns were developed for the military for a number of applications such as making the fabric capable of electromagnetic interference shielding, inclusion of antenna in fabrics and to provide infrared shielding as part of blast protection fabrics. This development has continued to include sensors and active circuits. An extension of the antenna technology is to build in to clothing radio frequency identification devices rather than add tags after manufacture is complete. Simple conducting fibres have also been used for decades for reducing the static charge problems in carpets. The inclusion of carbon conducting fibres in the tufts would enable the dissipation of static charge but could be aesthetically a problem for pale coloured carpets as the black of the carbon could detract from the appearance. Fibres coated with a conducting coating or alternatively fibres plasma modified to give change the surface resistivity were also used. This use of conducting fibres and fabrics to minimise static problems continues to be an active area such as for filters including use for oil and fuel filters. With clothing developments have continued with piezo-resistive sensors for measuring and mapping pressure, bend and stretch including intelligent footwear to monitor balance, gait and fitness. Others have developed capacitive fabrics for touchscreen compatible apparel, data gloves that respond to movement allowing performers to control special effects with gestures and full robotic exoskeletons (4,9). Medical applications have used silver coated fabrics or non-wovens for wound treatment as well as for drapes for patients during operations. Resistive fabrics that enable radiant heating are also available as blankets to warm patients during surgery. A number of devices have been designed with stretch in mind (10) with the conductive tracks being produced in a serpentine pattern to allow the substrate to stretch with the metal conductor bending but not needing to stretch to the same amount.

A number of offerings do not use materials that were developed for the use they are being sold for but the materials have been taken from other industries and applications and put together differently to offer a different use. Many may be regarded as trivial but this cherry picking of materials is enabling more rapid development. The silver coated fabrics used in medical applications where antimicrobial properties are required (11) are also being offered on hobby websites as one electrode that may be combined into clothing to provide some other functionality.

Vacuum coating fabrics and fibres

As the substrates can vary between single monofilament fibres, bundles of fibres or woven or non-woven rolls of fabric there are many possible coating techniques that are possible.

Materials such as fabrics, foams or non-woven webs can have the problem that they are not optically opaque and so if a vacuum deposition process is used there can be a problem of depositing some coating onto the deposition drum. The contact of the fabric to the deposition drum tends to be poor and so the removal of heat is limited. To prevent the deposition drum from being coated it may be wrapped with foil or a polymer film which will collect any material that passes through the fabric. This protective layer will also reduce the heat transfer coefficient as there is an additional interface with another heat transfer coefficient. With this in mind it has been suggested that there can be advantages of using free span deposition processing. If the substrate requires to be coated on both sides then passing the fabric free span between facing magnetron cathodes may be possible always provided the heat load on the fabric is acceptable.

Plasma treatment of fibres of fabrics has been done for many years such as the plasma treatment of wool to modify the dye uptake or for the increase the hydrophobicity of fibres used in carpeting or to modify the wetting of fibres used in fibre reinforced polymers. A key part of the process is to try to separate the individual fibres such that the whole surface of each fibre can be treated. The pressure of the treatment is often increased so that the mean free path is reduced such that the plasma can engulf the fibre of fabric. As the atmospheric plasma technology has been improved over recent years and the option for atmospheric plasma deposition has been developed this is giving new opportunities for modifying fibres and fabrics. Where polymer fibres are used the shape of the fibre may be modified by having something other than a circular hole in the spinneret that the polymer is extruded through. In carpeting some fibres used were trilobal and this shape gave a different optical scattering and packing allowing dirt to fall through the pile to cavities at the base of the pile and so modifying the aesthetic appearance to the carpet. Teijin have a variety of different monofilament fibres that are available from hollow square shaped to fibres having eight fins and hollow. These different fibre shapes can affect how the fibres pack together and so will also affect how easily they may be opened up to allow plasma or ALD processing. In polymer fibre manufacturing one processing option was to use a stuffer box to change the fibre. The multiple fibres from the extrusion spinneret passed into a stuffer box that was heated so that the fibres softened. The rate at which the fibres were allowed to pass out of the stuffer box was delayed. This caused the fibres to bunch up and so when they were then allowed out of the box and cooled they were no longer straight but where randomly crinkled up. In effect this was the polymer fibre industry trying to copy nature. Wool fibre has a natural waviness known as crimp which can help the twisted fibres hold together. This same type of process may be used to open out fibres to make treating or coating uniformly easier to achieve.

Atomic layer deposition (ALD) too can operate at near or even above atmospheric pressure. ALD that has been found to have benefits for depositing barrier coatings has also found to have more benefits when depositing onto this range of substrates. ALD has the benefit that the nature of the coating technique is that the whole surface is coated monolayer by monolayer. It does not matter that there are curved surfaces and several overlaying fibres. Using a winding system where the fibre passes between the different zones it is possible to pass the fibre from an unwind and then multiple times over two rollers before removing to a rewind and so build up the coating thickness in a compact system. Particularly if the fabric is wound through the process free span then the deposition occurs from both sides simultaneously and so will maximise the uniformity of coating through the fibre. If a fabric is to be coated this would require a bigger system the same as the shown schematically in the presentation. As ALD coatings can be continuous at thinner layers they are also more flexible and so if the adhesion can be maximised the coated fibres or fabrics should offer a maximum flexibility without loss of functionality.

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