THE FUTURE OF THE WESTERN CAPE AGRICULTURAL SECTOR IN THE CONTEXT OF THE 4TH INDUSTRIAL REVOLUTION

Review: Smart Materials

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1. What are Smart Materials?

Introduction

The term Smart Materials is used to describe any kind of material that is able to react actively to its environment. The change is inherent to the material and not a result of some electronics. The kind of 'smartness' shown by these materials is generally programmed by material composition, special processing, introduction of defects or by modifying the microstructure, so as to adapt to the various levels of stimuli in a controlled fashion.[1]

The reaction may exhibit itself as a change in volume, a change in colour or a change in viscosity and this may occur in response to a change in temperature, stress, electrical current, or magnetic field. In many cases this reaction is reversible, a common example being the coating on spectacles which reacts to the level of UV light, turning your ordinary glasses into sunglasses when you go outside and returning to normal when indoors. This coating is made from a smart material which is described as being photochromic.[2] These technologies have been around for decades, however, as we create new and more effective smart materials, the potential use cases for them increases exponentially.

Types of Smart Materials

Shape-memory Alloys

For most materials, if they are bent out of shape, they stay that way. However, if a part made from a shape-memory alloy (SMA) is bent out of shape, when it is heated above a certain temperature it will return to its original shape. This property is useful for building objects that take heavy wear and tear, as dents and other superficial damage such as bends, can be easily repaired through heat treatment.[3]

Piezoelectric Materials

When a piezoelectric material is stressed rapidly, it produces a small electrical voltage for a moment. The reaction also works in reverse, If a voltage is put across the material it makes a tiny change in shape. Piezoelectric materials are being used for contact sensors for alarm systems and in airbag sensors to trigger release on impact.[4]

Quantum-tunnelling Composite

Quantum-tunnelling composite (QTC) is a flexible polymer which contains tiny metal particles. It is a composite patented by Paratech. Put simply, QTC changes its electrical resistance based on changes in applied force. The more force the less resistance.[5] QTC is by default an insulator, but when stressed it becomes conductive. QTC can be used to make membrane switches like those used on touch mobile phones, pressure sensors and speed controllers. The materials allows any surface to become a touch interface.

Magneto Restrictive Materials

Similar to piezoelectrics, Magneto restrictive materials, respond to magnetic fields rather than electric. They are typically used in low-frequency high-power sonar transducers, motors and hydraulic actuators, along with the shape-memory alloy. This type of material is used in automotives for dynamic shock absorbers.[6]

Colour-change Materials

Thermochromic materials change colour as the temperature changes. These are used on contact thermometers made from plastic strips and test strips on the side of batteries (where the heat comes from a resistor under the thermochromic film). They are also used as food packaging materials that show you when the product they contain is cooked to the right temperature.
Photochromic materials change colour according to different lighting conditions. They are often used for security markers that can only be seen in ultraviolet light. The technology is also used to help actively change the colour of objects coated with photochromic film, such as in the sunglasses example above.

2. Why are Smart Materials important now?

While smart materials have been around for quite some time, the growth of IoT has spurred a new demand for smart materials that can be used to integrate sensor technology into objects. These materials can be used in IoT applications without constructing separate sensor components which take up space and are less durable.[7] Smart materials can detect (and react) to changes in temperature, light, pressure and other environmental factors. This information can be relayed through electronic impulses given off by the material itself. In this way, almost every component in a machine or aircraft could be connected through smart films coated over the parts which could conduct electricity needed to change behaviour of parts or relay information back to a controller.

3. What are the applications of Smart Materials today?

There are increasingly more possibilities for smart materials as a result of the advent of connected devices and the internet of things. The nature of smart materials lends itself to being used for sensory feedback where it is impractical to use bolt on sensors, or in applications that require build materials to take on different characteristics in different environmental conditions.

Transportation Technology

As mentioned above, magnetically reactive smart materials are used for dampers and shock absorbers in vehicles. Audi Magnetic Ride technology uses magnetorheological dampers with an electronic control unit for the suspension that will automatically adjust its damping properties depending on the current road conditions and driving manner.[8]

Using materials that react to stress to build vehicles that are more reactive in accidents, using smart materials to trigger airbag release or other safety features. For example, the HARKEN project is developing a prototype seat and seatbelt that uses smart textiles with built-in sensors to detect a driver's heart and breathing rates, so it can alert drivers to tell-tale signs of drowsiness.[9]

Infrastructure

Embedding sensors within structures to monitor stress and damage can reduce maintenance costs and increase lifespan. This is already used in over forty bridges worldwide.[10] This is done through the use of smart concretes and other composites which provide sensory feedback on the state of the construction. There is a major project currently underway at the Massachusetts Institute of Technology (MIT), called ZERO+, that aims to reshape the construction industry with exactly these types of advanced composite materials.[11]

Agriculture

Many use cases of smart materials in agriculture are centred around IoT and the utilisation of the sensory capability of many smart materials. These kind of usages have been discussed in the reviews on IoT, AI and robotics.

Non-IoT use cases include diverse range of polymer compositions that have been used to create agrochemical delivery devices. These can involve the use of smart gels that are able to deliver pesticides while at the same time enhancing soil water retention.[12] Another important use of smart materials directly in agriculture is the decontamination of soil which has high concentrations of heavy metals such mercury. Smart materials are being developed which perform this decontamination in an efficient way.[13]

Desertification and drought are increasing problems in certain agricultural regions and the water retention of soil is a key aspect of crops' ability to withstand extended dry periods. Smart materials are being being developed which can be used in soils to improve water retention as well as limit the need for irrigation in water short areas.[14]

A major emerging use for smart materials is in food packaging. The materials ability to detect and change for different temperatures, moisture levels, light, and pressure have numerous positive possibilities for food packaging such as detecting when milk is going off. There is also the field of smart packaging, where embedded sensors give users information about the products they are purchasing. Although this use-case falls more into the internet of things.

4. What is the Future of Smart Materials?

Self-Repair

One use case of smart materials in development involves embedding thin tubes containing uncured resin into materials. When damage occurs, these tubes break, exposing the resin which fills any damage and sets. Self-repair could be important in inaccessible environments such as underwater or in space. This could be combined with IoT technologies to automatically sense when this is required and initiate the self-repair of large structures through electronic impulses. This kind of development will be crucial to highly sensitive underwater structures that need to prevent leaks or weaknesses in the integrity of the structure.

Another use that is being explored by Airbus, is the use of piezoelectric materials to repair dents and small imperfections in aircraft bodies which will allow for better aerodynamics while in flight. At the high speeds and long distances over which these aircraft fly, small improvements to the drag of the plane can yield large cost savings over time.

Energy Harvesting Materials

There are many reasons to prefer smart, energy harvesting materials to battery technology. For instance there are many batteries needed to power sensors in technology such as tyres and other mechanical parts. This could be eliminated by utilising the heat and vibration generated by the part to power a sensor. Examples of piezoelectric energy harvesting systems are:

- Battery-less remote control – the force used to press a button is sufficient to power a wireless radio or infrared signal
- Piezoelectric floor tiles – there is much interest in harvesting the kinetic energy generated by the footsteps of crowds to power ticket gates and display systems
- Car tyre pressure sensors – sensors attached inside the tyres continuously monitor the pressure and send the information to a display on the dashboard utilising the vibrations in the tyres themselves.

While the above examples are not immediately useful in everyday applications, the ability of materials to power embedded electronics have important uses for equipment that needs to be used in remote areas where batteries and other power sources are unavailable. Emergency equipment is a clear beneficiary of this as well as technology embedded in military equipment for soldiers.

With smart materials we are able to select uses and have our materials adapt to those uses. Before this, we had to select materials that had certain properties that suited a use case. The difference is important. One is static, the other is dynamic. This is the direction in which the technology is heading - expanding the range of multipurpose materials, like those which can be hard or soft, dark or light depending on what is needed.

5. Smart Materials Application Life Cycle

Smart materials are still very early in their application lifecycle. The technology is not yet cost effective to use at scale and needs to mature before it will gain widespread adoption. How long that will take is very difficult to predict, but these developments often move faster than we realise. We believe smart materials will start to become economically viable in the next 5 to 10 years.

6. Business Eco-System View

The business ecosystem is very limited for smart materials, particularly in South Africa. Whilst some work is being done at the likes of the CSIR, this technology is too early in its lifecycle for an ecosystem to have formed yet.

7. Benefits and Risks

The major test of smart materials will be in performance. If materials can self-mend, for example, then the benefits will be huge. Savings on maintenance costs alone would be a significant advantage. However, the risk of malfunction will also be significant. If a material is supposed to mend on its own and it doesn't, it could be a long time before that issue is found. This could lead to larger problems that could have been avoided without the complacency bred through reliance on an "infallible" material.

8. Potential Economic, Social, Ecological and Political Developments and Impacts

We view this technology as being too early for these impacts to be accurately predicted. It is conceivable that smart materials would affect employment by reducing maintenance staff, as an example. But the smart materials industry might counter such effects by provided many other jobs. Once the technology becomes affordable on a wide scale, these impacts will become more reliably predicted.

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