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Smart Materials an Overview and Their Applications

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Abstract— “Smart Materials” are materials that change their shape, color, or size in response to an externally applied stimulus. While smart materials have already made a tremendous impact on our lives through their applications in liquid crystal displays, headphones, fuel injection systems, flexible cell phone antennas, and many other commercial products, they also have the potential to help many pediatric patients. Now in this research focuosed on the application of smart materials in several branch and using this material in many imaportant applicatios.

Index Terms— Smart materials, Overview, Applications, Shape, Color. Size. Change.

1 Introduction

Smart materials have been around for many years and they have found a large number of applications. The use of the terms 'smart' and 'intelligent' to describe materials and systems came from the US and started in the 1980‟s despite the fact that some of these so-called smart materials had been around for decades. Many of the smart materials were developed by government agencies working on military and aerospace projects but in recent years their use has transferred into the civil sector for applications in the construction, transport, medical, leisure and domestic areas. [1]

The first problem encountered with these unusual materials is defining what the word „smart‟ actually means. One dictionary definition of smart describes something which is astute or 'operating as if by human intelligence' and this is what smart materials are. A smart material is one which reacts to its environment all by itself. The change is inherent to the material and not a result of some electronics. 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 back again when you return inside. This coating is made from a smart material which is described as being photochromic. [1]

There are many groups of smart materials, each exhibiting particular properties which canbe harnessed in a variety of high-tech and everyday applications. [4] These include shape-memory alloys, piezoelectric materials, magneto-rheological and electro-rheological materials, magnetostrictive materials and chromic materials which change their colour inreaction to various stimuli.

The distinction between a smart material and a smart structure should be emphasised. A smart structure incorporates some form of actuator and sensor (which may be made from smart materials) with control hardware and software to form a *system* which reacts to its environment.

Such a structure might be an aircraft wing which continuously alters its profile during flight to give the optimum shape for the operating conditions at the time.

2 Shape Memory Alloys

Shape memory alloys (SMAs) are one of the most well known types of smart material and they have found extensive uses in the 70 years since their discovery.

2.1 What Is SMAs

A shape memory transformation was first observed in 1932 in an alloy of gold and cadmium, and then later in brass in 1938. The shape memory effect (SME) was seen in the gold-cadmium alloy in 1951, but this was of little use. Some ten years later in 1962 an equiatomic alloy of titanium and nickel was found to exhibit a significant SME and Nitinol (so named because it is made from nickel and titanium and its properties were discovered at the Naval Ordinance Laboratories) has become the most common SMA. Other SMAs include those based on copper (in particular CuZnAl), NiAl and FeMnSi, though it should be noted that the NiTi alloy has by far the most superior properties.

2.2 Smart Materials Alloys Works

The SME describes the process of a material changing shape or remembering a particular shape at a specific temperature (i.e. its transformation or memory temperature). Materials which can only exhibit the shape change or memory effect once are known as oneway SMAs. However, some alloys can be trained to show a two-way effect in which they remember two shapes, one below and one above the memory temperature. At the memory temperature the alloy undergoes a solid state phase transformation.

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That is, the crystal structure of the material changes resulting in a volume or shape change and this change in structure is called a „thermoelastic martensitic transformation".

This effect occurs as the material has a martensitic microstructure below the transformation temperature, which is characterised by a zig-zag arrangement of the atoms, known as twins. The martensitic structure is relatively soft and is easily deformed by removing the twinned structure. The material has an austenitic structure above the memory temperature, which is much stronger. To change from the martensitic or deformed structure to the austenitic shape thematerial is simply heated through thememory temperature. Cooling down again reverts the alloy to the martensitic state as shown in Figure 1. The shape change may exhibit itself as either an expansion or contraction. The transformation temperature can be tuned to within a couple of degrees by changing the alloy composition. Nitinol can be made with a transformation temperatureanywhere between –100ºC and +100ºC
which makes it very versatile.

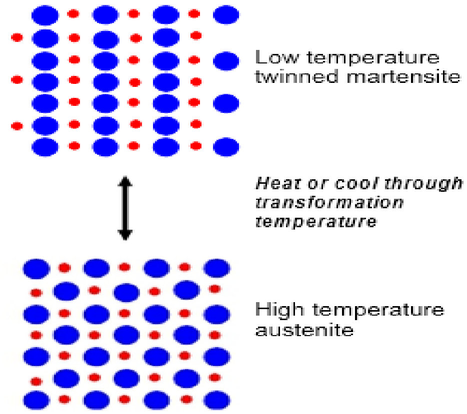

Figure 1 – Change in structure assoccaited with the shape memory effect.

2.3 Ueses of Smart materials alloys

Shape memory alloys have found a large number of uses in aerospace, medicine and the leisure industry. A few of these applications are described below.

3 Applications

3.1 Medical Applications

Quite fortunately Nitinol is biocompatible, that is, it can be used in the body without an adverse reaction, so it has found a number of medical uses. These include stents in which rings of SMA wire hold open a polymer tube to open up a blocked vein (Figure 2), blood filters, and bone plates which contract upon transformation to pull the two ends of the broken bone into closer contact and encourage more rapid healing (Figure 3).

Figure 2 – This reinforced vascular graft contains rings of SMA wire which openout the polyester tubeon warming with warm saline solution once in-situ. (Courtesy of Tony Anson, Anson Medical Ltd).

It is possible that SMAs could also find use in dentistry for orthodontic braces which straighten teeth. The memory shape of the material is made to be the desired shape of the teeth. This is then deformed to fit the teeth as they are and the memory is activated by the temperature of the mouth. The SMA exerts enough force as it contracts to move the teeth slowly and gradually (Figure 4). Surgical tools, particularly those used in key hole surgery may also be made from SMAs.

Figure 3 – This NiTi bone plated has been heat treated such that the central part changes from its deformed shape (top) to its memory shape (bottom) when warmed with saline solution, thus drawing the two ends of the fracture closer together. The modulus of this material has also been closely matched to that of human bone. (Courtesy of Tony Anson, Anson Medical Ltd).

These tools are of an often bent to fit the geometry a particular patient, however, in order for them to be used again they return to a default shape upon sterilisation in an autoclave.

Figure 4 – SMA wire has been used here to close the gap between two teeth. Two parallelograms of NiTi wire are attached to the teeth using stainless steel brackets which are glued to the teeth (left). After six months the gap between the teeth has decreased noticeably (right). (Courtesy of Tony Anson, Anson Medical Ltd).

Still many years away is the use of SMAs as artificial muscles, i.e. simulating the expansion and contraction of human muscles. This process will utilise a piece of SMA wire in place of a muscle on the finger of a robotic hand. When it is heated, by passing an electrical current through it, the material expands and straightens the joint, on cooling the wire contracts again bending the finger again. In reality this is incredibly difficult to achieve since complex software and surrounding systems are also required. NASA have been researching the use of SMA muscles in robots which walk, fly and swim!

3.2 Domestic applications

SMAs can be used as actuators which exert a force associated with the shape change, and this can be repeated over many thousands of cycles. Applications include springs which are incorporated into greenhouse windows such that they open and close themselves at a given temperature. Along a similar theme are pan lids which incorporate an SMA spring in the steam vent. When the spring is heated by the boiling water in the pan it changes shape and opens the vent, thus preventing the pan from boiling over and maintaining efficient cooking. The springs are similar to those shown in Figure 5.

(a) (b)

Figure 5 – Showing the two memory shapes of a memory metal wire coil or 'spring'. In (a) thespring is at room temperature and in (b) the higher temperature state has been activated by pouring on boiling water.

SMAs can be used to replace bimetallic strips in many domestic applications. SMAs offer the advantage of giving a larger deflection and exerting a stronger force for a given change in temperature. They can be used in cut out switches for kettles and other devices, security door locks, fire protection devices such as smoke alarms and cooking safety indicators (for example for checking the temperature of a roast joint).

3.3 Aerospace space

A higher tech application is the use of SMA wire to control the flaps on the trailing edge of aircraft wings. The flaps are currently controlled by extensive hydraulic systems but these could be replaced by wires which are resistance heated, by passing a current along them, to produce the desired shape change. Such a system would be considerably simpler than the conventional hydraulics, thus reducing maintenance and it would also decrease the weight of the system.

3.4 Manufacturing applications

SMA tubes can be used as couplings for connecting two tubes. The coupling diameter is made slightly smaller than thetubes it is to join. The coupling is deformed such that it slips over the tube ends and the temperature changed to activate the memory. The coupling tube shrinks to hold the two ends together but can never fully transform so it exerts a constant force on the joined tubes.

4 The felixible ability of SMAs

In addition to the shape memory effect, SMAs are also known to be very flexible or superelastic, which arises from the structure of the martensite. This property of SMAs has also been exploited for example in mobile phone aerials, spectacle frames and the underwires in bras. [2]

The kink resistance of the wires makes them useful in surgical tools which need to remain straight as they are passed through the body. Nitinol can be bent significantly further than stainless steel without suffering permanent deformation.

Another rather novel application of SMAs which combines both the thermal memory and superelastic properties of these materials is in intelligent fabrics. Very fine wires are woven in to ordinary polyester / cotton fabric. Since the material is superelastic the wires spring back to being straight even if the fabric is screwed up in a heap at the bottom of the washing basket! So creases fall out of the fabric, giving you a true non-iron garment! In addition, the wires in the sleeves have a memory which is activated at a given temperature (for example 38 C) causing the sleeves to roll themselves up and keeping the wearer cool.

7 PIIEZOELECTRIIC MATERIIALS

The piezoelectric effect was discovered in 1880 by Jaques and Pierre Curie who conducted a number of experiments using quartz crystals. This probably makes piezoelectric materials the oldest type of smart material. These materials, which are mainly ceramics, have since found a number of uses. [2]

7.1 Piezoelectric effect

The piezoelectric effect and electrostriction are opposite phenomena and both relate a shape change with voltage. As with SMAs the shape change is associated with a change in the crystal structure of the material and piezoelectric materials also exhibit two crystalline forms. One form is ordered and this relates to the polarisation of the molecules. The second state is nonpolarised and this is disordered. [2]

If a voltage is applied to the non-polarised material a shape change occurs as the molecules reorganise to align in the electrical field. This is known as electrostriction.

Conversely, an electrical field is generated if a mechanical force is applied to the material to change its shape. This is the piezoelectric effect.

The main advantage of these materials is the almost instantaneous change in the shape of the material or the generation of an electrical field.

7.2 Materials that exhibit this effect

The piezoelectric effect was first observed in quartz and various other crystals such as tourmaline. Barium titanate and cadmium sulphate have also been shown to demonstrate the effect but by far the most commonly used piezoelectric ceramic today is lead zirconium titanate (PZT). The physical properties of PZT can be controlled by changing the chemistry of the material and how it is processed. There are limitations associated with PZT; like all ceramics it is brittle giving rise to mechanical durability issues and there are also problems associated with joining it with other components in a system.

7.3 Uses of piezoelectric materials

The main use of piezoelectric ceramics is in actuators. An actuator can be described as a component or material which converts energy (in this case electrical) in to mechanical form.
electric field is applied to the piezoelectric material it changes its shape very rapidly and very precisely in accordance with the magnitude of the field.

Applications exploiting the electrostrictive effect of piezoelectric materials include actuators in the semiconductor industry in the systems used for handling silicon wafers, in the microbiology field in microscopic cell handling systems, in fibreoptics and acoustics, in ink-jet printers where fine movement control is necessary and for vibration damping. [2]

The piezoelectric effect can also be used in sensors which generate an electrical field in response to a mechanical force. This is useful in damping systems and earthquake detection systems in buildings. But the most well known application is in the sensors which deploy car airbags. The material changes in shape with the impact thus generating a field which deploys the airbag.

A novel use of these materials, whichexploits both the piezoelectric and electrostrictive effects, is in smart skis which have been designed to perform well on both soft and hard snow. Piezoelectric sensors detect vibrations (i.e. the shape of the ceramic detector is changed resulting in the generation of a field) and the electrostrictive property of the material is then exploited by generating an opposing shape change to cancel out the vibration. The system uses three piezoelectric elements which detect and cancel out large vibrations in real time since the reaction time of the ceramics is very small. [2]

By passing an alternating voltage across these materials a vibration is produced. This process is very efficient and almost all of the electrical energy is converted into motion. Possible uses of this property are silent alarms for pagers which fit into a wristwatch. The vibration is silent at low frequencies but at high frequencies an audible sound is also produced. This leads to the concept of solid state speakers based on piezoelectric materials which could also be miniaturised.

7.2 Do polymers exhibit these effects?

Ionic polymers work in a similar way to piezoelectric ceramics, however they need to be wet to function. An electrical current is passed through the polymer when it is wet to produce a change in its crystal structure and thus its shape. Muscle fibres are essentially polymeric and operate in a similar way, so research in this field has focussed on potential uses in medicine.

8 MAGNETOSTRIICTIIVE MATERIIALS

Magnetostrictive materials are similar topiezoelectric and electrostrictive materials except the change in shape is related to a magnetic field rather than an electrical field. [4]

Magnetostrictive materials convert magnetic to mechanical energy or vice versa. The magnetostrictive effect was first observed in 1842 by James Joule who noticed that a sample of nickel exhibited a change in length when it was magnetised. [4] The other ferromagnetic elements (cobalt and iron) were also found to demonstrate the effect as were alloys of these materials. During the 1960s terbium and dysprosium were also found to be magnetostrictive but only at low temperatures which limited their use, despite the fact that the size change was many times greater than that of nickel. [5]

The most common magnetostrictive material today is called TERFENOL-D (terbium (TER), iron (FE), Naval Ordanance Laboratory (NOL) and dysprosium (D)). This alloy of terbium, iron and dysprosium shows a large magnetostrictive effect and is used in transducers and actuators. [6]

The original observation of the magnetostrictive effect became known as the Joule effect, but other effects have also been observed. The Villari effect is the opposite of the Joule effect, that is applying a stress to the material causes a change in its magnetization.

Applying a torsional force to a magnetostrictive material generates a helical magnetic field and this is known as the Matteuci effect. Its inverse is the Wiedemann effect in which the material wists in the presence of a helicalmagnet field.

8.3 magnetostrictive materials work

Magnetic materials contain domains which can be likened to tiny magnets within the material. When an external magnetic field is applied the domains rotate to align with this field and this results in a shape change as shown in Figure 6. Conversely if the material is squashed or stretched by means of an external force the domains are forced to move and this causes a change in the magnetisation. [7]

8.4 Uses are magnetostrictive materials

Magnetostrictive materials can be used asboth actuators (where a magnetic field is applied to cause a shape change) andsensors (which convert a movement into a magnetic field).

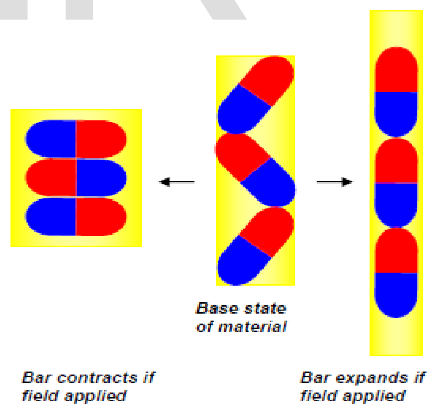

Figure 6 – Magnetostrictive materials are made up from domains (represented by red and blue bar magnets). If a magnetic field is applied the bar either decreases in length from its base state (centre to left) or increases in length (centre to right) depending on the polarization of the applied field.

In actuators the magnetic field is usually generated by passing an electrical current along a wire. Likewise, the electrical current generated by the magnetic field arising from a shape change is usually measured in sensors. [8]

Early applications of magnetostrictive materials included telephone receivers, hydrophones, oscillators and scanning sonar.

The development of alloys with better properties led to the use of these materials in a wide variety of applications. [9]

Ultrasonic magnetostrictive transducershave been used in ultrasonic cleaners and surgical tools. Other applications include hearing aids, razorblade sharpeners, linear motors, damping systems, positioning equipment, and sonar.

8 Conclusion

Smart materails are very important materials using in many applications like to generate electricity or mainatnce cars any also used in more applictions. These are just a few of the possible uses for shape memory alloys. However, it is likely that as more research is carried out and these materials are better understood, more applications will be developed.

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