Smart material

ABSTRACT

The world has undergone two materials ages, the plastics age and the composite age, during the past centuries. In the midst of these two ages a new era has developed. This is the smart materials era. According to early definitions, smart materials are materials that respond to their environments in a timely manner. The definition of smart materials has been expanded to materials that receive, transmit or process a stimulus and respond by producing a useful effect that may include a signal that the materials are acting upon it. Smart materials cover a wide and developing range of technologies.

A particular type of smart material, known as chromogenics, can be used for large areaglazing in buildings, automobiles, planes, and for certain types of electronic display. Smart materials have been around for many years and they have found a large number of applications. There are many types of the materials present some of them listed below:

1. Shape memory alloy
2. Piezoelectric materials
3. Magnetostrictive materials
4. Magneto- and electro-rheological materials
5. Chromic materials Due to the property of responding quickly withenvironmentand many applications in daily life smart materials deserve a great future scope.

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.

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 a stute or 'operating as if by human intelligence' and this is what smart materials are. A and back again when you return inside. This coating is made from a smart material which is described as being photochromic. There are many groups of smart materials, each exhibiting particular properties which can be harnessed in a variety of high-tech and everyday applications. These include shape memory smart material is one which reacts to its environment aby itself.

The change is inherent to the material and not a result of some 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 alloys, piezoelectric materials, magneto-rheological and electro-rheological materials, magnetostrictive materials and chromic materials which change their colour in reaction to various stimuli.

The distinction between a smart material and a smartstructure 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.

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

What are 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. How do SMAs work? 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 one way SMAs. However some alloys can betrained 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. 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 the material is simply heated through the memory 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 temperature anywhere between –100? C and +100? C which makes it very versatile. Where are SMAs used? 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. 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 pen up a blocked vein , blood filters, and bone plates which contract upon transformation to pull the two ends of the broken bone in to closer contact and encourage more rapid healing . 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 SMART exerts enough force as it contracts to move the teeth slowly and gradually.

Surgical tools, particularly those used in key hole surgery may also be made from SMAs. These tools are often often bent to fit the geometry of a particular patient, however, in order for them to be used again they return to a default shape upon sterilisation in an autoclave. 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. Figure 1 – Change in structure associated with the shape memory effect. NASA have been researching the use of SMA muscles in robots which walk, fly and swim! 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 in to 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. 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). Aerospace applications A more high 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. Manufacturing applications SMA tubes can be used as couplings for connecting two tubes. The coupling diameter is made slightly smaller than the tubes 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. Why are SMAs so flexible? In addition to the shape memory effect, SMAs are also known to be very flexible or super elastic, which arises from the structure of the martensite. This property Of SMARTs has also been exploited for example in mobile phone aerials, spectacle frames and the underwire in bras. 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 super elastic properties of these materials is in intelligent fabrics. Very fine wires are woven in to ordinary polyester cotton fabric. Since the material is super elastic 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.

PIEZOELECTRIC 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. What is the 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. 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. What materials 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. Where are piezoelectric materials used? 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.

When a 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 fibre optics and acoustics, in ink-jet printers where fine movement control is necessary and for vibration damping.

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, which exploits both the piezoelectric and electrostrictive effects, is in smart skis which have been designed to perform well on both soft and hardsnow. Piezoelectric sensors detect vibrations (i. e. he 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 . 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 wrist watch.

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. 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. ature of the piezoelectric effect making them invaluable for the niche applications which they occupy.

MAGNETOSTRIICTIIVE MATERIIALS

Magnetostrictive materials are similar to piezoelectric and electrostrictive materials except the change in shape is related to a magnetic field rather than an electrical field. What are magnetostrictive materials? 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.

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. 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.

The originalobservationof 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 twists in the presence of a helical magnet field.

How do 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. 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. Where are magnetostrictive materials used? Magnetostrictive materials can be used as both actuators (where a magnetic ield is applied to cause a shape change) and sensors (which convert a movement into a magnetic 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. 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.

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

MAGNETO-- AND ELECTRO RHEOLOGIICAL MATERIIALS

All of the groups of smart materials discussed so far have been based on solids. However, there are also smart fluids which change their rheological properties in accordance with their environment. What are smart fluids? There are two types of smart fluids which were both discovered in the 1940s.

Electro-rheological (ER) materials change their properties with the application of an electrical field and consist of an insulating oil such as mineral oil containing a dispersion of solid particles (early experiments used starch, stone, carbon, silica, gypsum and lime). Magnetorheological materials (MR) are again based on a mineral or silicone oil carrier but this time the solid dispersed within the fluid is a magnetically soft material (such as iron) and the properties of the fluid are altered by applying a magnetic field. In both cases the dispersed particles are of the order of microns in size.

How do smart fluids work? In both cases the smart fluid changes from a fluid to a solid with the application of the relevant field. The small particles in the fluid align and are attracted to each other resulting in a dramatic change in viscosity as shown in Figure 7. The effect takes milliseconds to occur and is completely reversible by the removal of the field. Figure 8 clearly shows the effect of a magnet on such an MR fluid. With ER fluids a field strength of up to 6kV/mm is needed and for MR fluids a magnetic field of less than 1Tesla is needed. Where are smart fluids used?

Uses of these unusual materials in civil engineering, robotics and manufacturing Electrodes Suspension fluid Particle Figure 7 – Schematic diagram showing the structure of a electrorheological fluid between two electrodes. The top figure shows the structure in a low field strength where the particles are randomly distributed. When a higher field strength is applied, as in the bottom diagram, the particles align causing a change in the viscosity of the fluid. Figure 8 - A puddle of magnetorheological fluid stiffens in the presence of a magnetic field. courtesy of Sandy Hill / University of Rochester) are being explored. But the first industries to identify uses were the automotive and aerospace industries where the fluids are used in vibration damping and variable torque transmission. MR dampers are used to control the suspension in cars to allow the feel of the ride to be varied. Dampers are also used in prosthetic limbs to allow the patient to adapt to various movements for example the change from running to walking. Future Scope: The future of smart materials and structures is wide open.

The use of smart materials in a product and the type of smart structures that one can design are only limited by one’s talents, capabilities, and ability to ‘‘ think outside the box. ’’ In an early work5 and as part of short courses there were discussions pertaining to future considerations. A lot of the brainstorming that resulted from these efforts is now being explored. Some ideas that were in the conceptual stage are now moving forward. Look at the advances in information and comforts provided through smart materials and structures in automobiles. Automobiles can be taken to a garage for service and be hooked p to adiagnosticcomputer that tells the mechanic what is wrong with the car. Or a light on the dashboard signals ‘‘ maintenance required. ’’ Would it not be better for the light to inform us as to the exact nature of the problem and the severity of it? This approach mimics a cartoon that appeared several years ago of an air mechanic near a plane in a hanger. The plane says ‘‘ Ouch’’ and the mechanic says ‘‘ Where do you hurt? ’’ One application of smart materials is the work mentioned earlier of piezoelectric inkjet printer that serves as a chemical delivery to print organic light-emitting polymers in a fine detail on various media.

Why not take the same application to synthesize smaller molecules? With the right set one could synthesize smaller molecules in significant amounts for characterization and evaluation and in such a way that we could design experiments with relative ease. A new class of smart materials has appeared in the literature. This is the group of smart adhesives. We previously mentioned that PVDF film strips have been placed within an adhesive joint to monitor performance. Khongtong and Ferguson developed a smart adhesive at Lehigh University. 0 They suggested that this new adhesive could form an antifouling coating for boat hulls or for controlling cell adhesion in surgery. The stickiness of the new adhesive can be switched on and off with changes in temperature. The smart adhesive also becomes water repellent when its tackiness wanes. 50 The term ‘‘ smart adhesive’’ is appearing more frequently in the literature. A topic of research that was in the literature a few years ago was ‘‘ smart clothes’’ or ‘‘ wearable computers’’ being studied at MIT. The potential of this concept is enormous. This sounds wonderful as long as we learn how to work smarter, not longer.

CONCLUSION

From the abilities of the smart material to respond the environmental changes the conclusion arises that ‘‘ smart’’ in the name do not meet the definition of being smart, that is, responding to the environment in a reversible manner. Due to their properties they must deserve a great future.

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