Journal of Materials Science & Surface Engineering Vol. 5 (1), 2017, pp 520-523

Contents lists available at http://www.jmsse.org/

Journal of Materials Science & Surface Engineering

Smart Materials for Smart Cities and Sustainable Environment

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Article history

Received: 03-Jan-2017
Revised: 28-Jan-2017
Available online: 02-Feb-2017

Keywords:
Smart city, smart materials, sustainable environment, Magnetostrictive Materials, Piezoelectric Materials, Shape Memory Alloys.

Abstract

The paper presents significant applications of smart materials and their uses in modern structures towards to develop and plan a smart city. City's infrastructural development plays an important role in the development of smart cities. The smart infrastructures support to the nation's economic and social development with sustainable environment. Shape memory alloys, piezoelectric and magnetostrictive smart materials are discussed in this paper for their use to develop smart cities. It also defines the architectural development directly supports the smart cities program in order to assess smart materials.

Introduction

Smart cities, referring to smart and sustainable environments, smart communication spaces, city-based sensor networks, embedded systems into buildings, smart materials, and smart devices. The key factors to building a smart city are a spatial intelligence based on real-time interaction, data and information-based innovation ecosystems and the use 0f smart materials and system with increasing levels of functionality. Smart materials are useful in creating a sustainable environment which is eco-friendly systems and leads to less energy consumption which is a boon to our society. Materials science and engineering provide us a solution to develop a smart city with smart materials. Smart materials have a wide range of applications due to their very specific properties with eco-friendly nature and long-term solutions to infrastructures of a city. The scientific utilization of smart structural mechanics in the design, construction, and preservation of infrastructures needs attention in civil engineering aspect. Smart meters are important components of next generation structures because they enable remote metering of energy consumption.

A smart system or material is the one which has built-in or intrinsic sensor(s), actuator(s) and Control mechanism(s) whereby it is capable of sensing a stimulus, responding to it in a predetermined manner and extent, in a short/ appropriate time, and reverting to its original state as soon as the stimulus is removed [1]. The idea of 'smart' or 'intelligent' structures has been adopted from nature, where all the living organisms possess stimulus-response capabilities [2]. However, the smart systems are much inferior to the living beings since their level of intelligence is much primitive.

The various materials that have been used in different applications have a significant impact on environment as well as on economy. Hence, the need of adroitness to make environment friendly and economically suitable smart materials without affecting materials efficiency, structural integrity, longevity, cost and industrial probity [3]. At present new advanced technologies and high performing materials are being investigated and developed to fulfil these needs, offering more promising solutions for long term problems of smart cities and sustainable environment. New developing smart materials provide benefits and promising solutions, whether it is repairing to structure, strong structural firmness, environmental, and for maintenance [4]. The applications of smart materials in the smart structures have been reported by several authors. Smart materials like shape memory alloy, heat resistant coating material, anti corrosive materials, magnetostrictive materials, materials for water proof effect, piezoelectric materials, materials for reflecting ultraviolet rays, titanium dioxide coated nano materials, having many architectural applications are discussed here.

Classifications of smart structures

Smart structures can be defined in following terms based on the level of sophistication [2]. Fig. 1 shows the relationship between these structures.

a) *Sensory Structures*: These structures possess sensors that enable the determination or monitoring of system states/ characteristics.
b) *Adaptive Structures*: These structures possess actuators that enable the alteration of system states or characteristics in a controlled manner.
c) *Controlled Structures*: These result from the intersection of the sensory and the adaptive structures. These possess both sensors and actuators integrated in feedback architecture for the purpose of controlling the system states or characteristics.
d) *Active Structures*: These structures possess both sensors and actuators that are highly integrated into the structure and

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exhibit structural functionality in addition to control functionality.

e) *Intelligent Structures*: These structures are basically active structures possessing highly integrated control logic and electronics that provides the cognitive element of distributed or hierarchic control architecture.

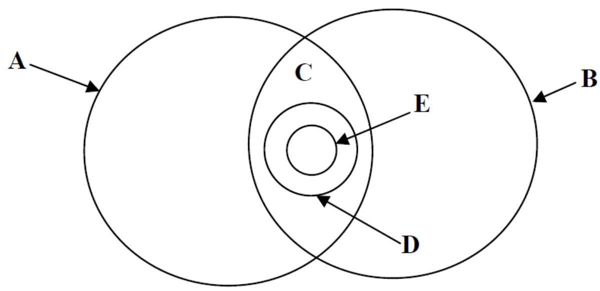

Figure 1: Classification of smart structures (A) Sensory structures; (B) Adaptive structures; (C) Controlled structures; (D) Active structures; (E) Intelligent structures [2].

Smart Materials

"Smart materials" can be defined as materials that can detect and respond immediately to any change in electricity, magnetic waves or heat [5]. In other words, smart materials are able to observe and react to any kind of changes happened in the environment. Smart materials are not only smart in chemical composition but also smart in adjusting with the structural changes [5]. Moreover, they are able to conserve the states of material under consideration [6]. The stimuli could be pressure, temperature, electric and magnetic fields, chemicals or nuclear radiant and the associated physical properties of structural changes could be shape, stiffness, viscosity or damping.

The advantages of using smart materials are cost effective, high strength, toughness, increased durability, having high resistance to chemical corrosion, wear and abrasion, tough against natural disasters, manufacturing and installation procedures are easy [3]. Optical fibres, piezoelectric polymers and ceramics, electro-rheological (ER) fluids, magnetostrictive materials and shape memory alloys (SMAs) are some of the smart materials. Fig. 2 shows the 'response' associated 'stimulus' and of common smart materials. Because of their special ability to respond stimuli, they have found numerous applications especially in the field of sensors and actuators. A broad literature on smart materials is reported by Gandhi et al. [7].

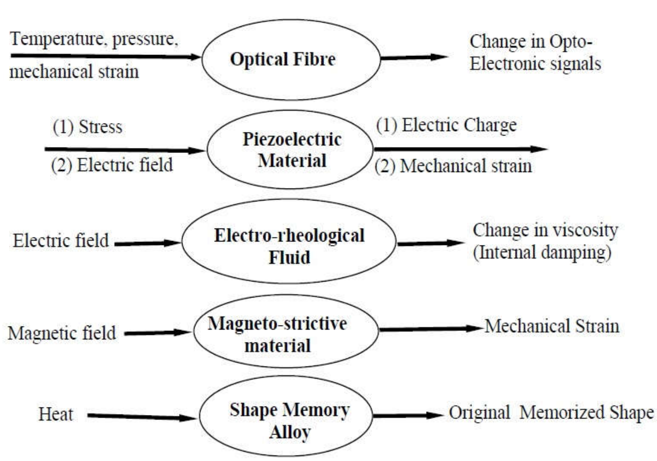

Figure 2: Common smart materials and associated stimulus-response.

Classifications of smart materials and their uses

Active and passive smart materials

There are two types of Smart materials, active and passive. Fairweather [8] has reported and defined active smart materials as "smart materials, having the characteristics to modify their shape or material properties under the applied electric, thermal or magnetic fields, thereby gaining an inherent capacity to transduce energy". Piezoelectric materials, SMAs, ER fluids and magnetostrictive materials are active smart materials. Being active, they can be used as force transducers and actuators.
Passive smart materials; "smart materials, which are not having the inherent capability to transduce energy". Fibre optic material is a well-known example of a passive smart material. This type of smart materials can act as sensors but not as actuators or transducers.

Optical fibres

Optical Fibres have been recognized as the most advanced smart material that use in polarization, phase, intensity or frequency to determine strain, temperature electrical/magnetic fields, pressure, displacement, chemical composition and other measurable parameters. They are known to be excellent sensors [9]. These are made of silica and glass. The basic principal of is that utilize its fibre properties to provide optoelectronic signals, which are indicative of the external parameters to be measured.

Piezoelectric materials

The word 'piezo' is comes from a Greek word meaning pressure. The phenomenon of piezoelectricity was discovered in 1880 by Pierre and Paul-Jacques Curie [10]. It occurs in non-centro symmetric crystals, such as quartz (SiO2), Lithium Niobate ($LiNbO_3$), PZT [Pb(Zr1-xTix)O_3)l and PLZT [(Pb1-xLax)(Zrl-yTiy)O_3), in which electric dipoles (and hence surface charges) are generated when the crystals are loaded with mechanical deformations. These when directed to an electric charge or a fluctuation in voltage, piezoelectric material will go through some mechanical change and vice versa. This phenomenon is called the direct and converse effects.

Piezoelectric ceramic (PZT) patches are made up of materials that generate a surface charge in response to an applied mechanical stress. Conversely, they undergo a material deformation in response to an applied electric field. This unique capability enables the material to be used both as a sensor and as an actuator. Smart system applications of these materials range from developing a skin like sensor (with high temperature and pressure sensing capabilities) to robotic applications.

Applications of Piezoelectric Materials in Smart Structures

- Active Vibration Control: Distinct piezoelectric patches help to regulate the vibration associated with thin plates in smart structures.
- Active Sound Control: It was used to eradicate or eliminate the different types of sounds produced. The significance of active sound control in the work place is of utmost importance as because hearing loss can occur from long term exposure to workplace sound.
- Active Control for Shape: Used as reflectors and antennas that maintains accurate dimension for best possible results. It's of primary importance in 3D structures comprising light weight material and is allowed to thermal distortion.
- Active Health Maintenance: Structural panel consisting of a series of actuators and sensors actively regulate the structural

integrity and identify defects earlier, hence providing information on structural defects and its life span.

Electro-Rheological (ER) fluids

Electro-Rheological (ER) fluids are typically the suspensions of micron-sized particles in suitable hydrophobic carrier liquids. These types of liquids have ability to undergo an abrupt and reversible change in viscosity when subjected to electrostatic potentials. Vibration control using ER fluids has been reported using hollow graphite epoxy cantilever beams filled with various ER fluids [7]. By applying voltage across the beam, internal damping could be increased and vibrations could be suppressed.

Magnetostrictive materials

Magnetostriction is a characteristic property of ferromagnetic materials which possess them to alter their shape, dimensions in the process of magnetization. The magnetostrictive materials can change magnetic energy to kinetic energy and vice versa, can be used to build actuators and sensors. If the magnetic field is given in the direction of an applied stress, the resultant magnetostriction will be larger than that without pre-stress. Iron, nickel, and cobalt were the first three magnetostrictive materials. Legvold and Clark discovered giant magnetostriction in the rare earth materials Dysprosium and Terbium. Later alloys called Terfenol-D comprises of Terbium, Dysprosium and Fe which shows the best option between a greater magnetostriction and a lower magnetic field, at normal room temperature. A definite magnetostriction of 1000-2000 ppm is achieved with fields of 50 kA/m-200 kA/m. Terfenol-D is most available material for use in many fields. Lead Zicronate Titanate (PZT) is a piezoceramic material that has low cost, light weight, high energy density, and easy to implement [11].

Shape Memory Alloys (SMAs)

Shape Memory Alloys (SMAs) are types of alloys which recovers their normal shape and that when deform comes back to its original state. The material is of less weight, solid state option to habitual actuators such as hydraulic, pneumatic, motor based systems5. SAMs are used in couplings, actuators and smart materials.

Couplings are known for its effective use of SMAs. Applications as actuators in various fields like in electrical components, automobile, robotics etc are performed. Thermal conductivity of SMA is better, leading to excellent response on application of heat. SMAs which are used as an actuator mentioned above act both as actuators and sensors. Thus, SMAs are called smart or intelligent materials [12].

These shape memory alloys which are commonly available are Cu-Al-Ni and Ni-Ti alloys. Besides the SMAs can be made by alloying zinc, copper, gold, iron etc. SMAs exists in various forms having three different crystal structures such as twinned martensite, detwinned martensite and austenite. These are characterized by recovery of usually large strains. In response to temperature the phase transformation between the martensite and austenite phases can be induced to mechanical stress. They are typically made by casting, induction melting.

The large recovery force associated with the return to the memorized shape has been exploited to create distributed SMA actuators, which are also used as shape controllers. The SMAs find application in the fields of robotics, active shape control of large antenna reflector surfaces, active vibration control of large flexible structures and also heat engines. For example, shape memory materials could be used in food packaging that automatically opens on heating for people with arthritis [13].

High Temperature Shape Memory Alloy

The Zr-based quasibinary intermetallics are considered as more advanced, as they have high temperature upto 1100 K, related to a seemly higher temperature shape memory phenomenon. To carry out an evaluation of high temperature shape memory alloy behaviour with their associated characteristics as in Ni–Ti–Zr, Ni–Ti–Hf and Zr–Cu-base quasibinary intermetallics, as these are the most promising advantage among all of the less expensive HTSMA [14].

Energy Saving Coating Technology (ESCT)

TiO_2 based white pigmented powders are used in industries due to low cost, low toxicity, high chemical stability and availability. These materials are used to produce surface with photo-catalytic, antibacterial, self-cleaning nature based on its photoinduced hydrophilicity/hydrophobicity and decomposed photo reactions. It helps to increase the light absorption capacity due to the surface/ volume relation of nano grains. This is very advantageous because even a small amount of water would be sufficient to form a water thin film on the buildings as well as decreases the supply of electricity by traditional air conditioning [6].

Zero Energy Building (ZEB)

Zero Energy Buildings (ZEBs) are mentioned as buildings which are having zero carbon emissions on yearly basis. In practice this is achieved by decreasing the energy requirement of the infrastructure by exploiting RES by appropriate technologies to fulfill energy requirements. Thus, definitions vary due to discrepancies in the absolute level of energy consumption in a low energy building, and also to differences of the minimum requirements as stated in the national building regulations [15].

The most dominant terms for defining a ZEB are: Use of zero site energy, Use of zero source energy, Total zero energy discharges, Total cost, Off-grid, Energy plus [16].

ZEB is a type of building that consumes a total zero energy from non-renewable sources. The ZEB buildings are very much energy effective and can rely on renewable energy generated on site.

ZEB as Integral Part of Smart Cities

The methodology of the analysis intends to demonstrate the potential of ZEBs in contributing to the development of smart cities. Primarily, the provisions of a ZEB that will be considered as an integral part of a future smart city will be identified and presented in Figure 14. Following are the identification of the elements of ZEBs that can significantly contribute to the development of smart energy cities, this paper will attempt to quantify this contribution. The concepts formulating the analysis include: Environmental design and building practices, Renewable Energy Sources (RES), Labeling of technical building systems, Intelligent Energy Management [17].

Future development directions

The following development directions could be considered in the field of smart materials and structures.

- Smart Materials which can recover the generation of cracks by automatically producing compressive stresses around them.
- Smart Materials, which can observe the type loading (static or shock) and able to react and generate a large force against shock stresses.
- Smart Materials having self-repairing capabilities, which can recover damages in due course of time.

- Smart Materials which can be used at ultra-high temperatures (i.e. fusion reactor and aerospace applications), by changing composition through transformation.

Conclusions

The smart materials technology has been adopted for sustainable development of smart cities. Here it is the necessity to utilize most recent innovations and finding to build smart cities. An attempt has been made to enlist the application of smart materials for smart cities. SMAs have smart characteristics as they have ability to change in shape at low temperature and once heating they can come in its original shape. The ability to change magnetic energy into kinetic energy and vice versa makes more special to magnetostrictive materials in the application of actuators and sensors for buildings. The piezoelectricity is a state of smart materials which becomes electrically charged when directed to mechanical stresses and vice versa. Now these days TiO_2 also considered as a smart material as it has low toxicity, high chemical firmness. The use of zero energy building (ZEB) provides a solution as less consumption of electricity with zero carbon emission which directly means environment friendly.

References

1. Ahmad, I., "Smart Structures and I Materials', proceedings of U.S. Army Research Office Workshop on Smart Materials, Structures and Mathematical Issues, edited by C. A. Rogers, September 15-16; Virginia Polytechnic Institute "& State University, Technomic Publishing Co. Inc, 1988, pp. 13-16.
2. Rogers, C. A., "Intelligent Material , Systems and Structures", Proceedings of U.S.- Japan Workshop on Smart,/ Intelligent Materials and Systems, edited by I. Ahmad, A. Crowson, C. A. Rogers and M. Aizawa, March 19-23, Honolulu, Hawaii, Technomic publishinq Co. Inc., 1990, pp. 11-33.
3. Mohamed S, Elattar S. Smart structures and material technologies in architecture applications. Scientific Research and Essay. 2013 Aug; 8(31):1512–21.
4. Hurlebaus S, Stocks T, Ozbulut OE. Smart structures in engineering education. Journal of Professional Issues in Engineering Education and Practice. 2012 Jan; 138(1):86– 94.
5. Otsuka K, Ren X. Recent developments in the research of shape memory alloys. Intermetallics. 1999; 7:511–28.
6. Carneiro JO, Vasconcelos GA, Azevedo S, Palha C, Gomes N, Teixeir V. he evaluation of the thermal behavior of a mortar based brick masonry wall coated with TiO2 nanoparticles: An experimental assessment towards energy efficient buildings. Energy and Buildings. 2014 Oct; 81:1–8.
7. Gandhi, M. V and Thompson, B. S. (1992), "Smart Materials and Structures" Chapman and Hall.
8. Fairweather, J. A. (1998), "Designing with Active Materials: An Impedance Based Approach", Ph.D. Thesis, Rensselaer Polytechnic Institute, New York.
9. Bhuvaneshwari B, Sasmal S, Baskaran T, Iyer N R. Role of nano oxides for improving cementitious building materials. Journal of Civil Engineering and Science. 2012 Jun; 1(2):52–8 .
10. Curie, Jacques; Curie, Pierre . "Développement par compression de l'électricité polaire dans les cristaux hémièdres à faces inclinées" [Development, via compression, of electric polarization in hemihedral crystals with inclined faces]. Bulletin de la Société minérologique de France. **3**: (1880) 90–93.
11. Zhang Y, Lu LW. Introducing smart structures technology into civil engineering curriculum:education development at Lehigh University. Journal of Professional Issues in Engineering Education and Practice. 2008 Jan; 134(1):41–8.
12. Takahashi K, Namik K, Fujimura T, Jeon EB, Kim HS. Instant electrode fabrication on carbon-fiber-reinforced plastic structures using metal nano-ink via flash light sintering for smart sensing. Composites Part B. 2015 Feb; 76:167–73.
13. Kamila, S. (2013), "Introduction, Classification and Applications of Smart Materials: An Overview" American Journal of Applied Sciences, 10 (8), pp 876-880.
14. Kylili A, Fokaides PA. European smart cities: The role of zero energy buildings. Sustainable Cities and Society. 2015 Jul; 5:86–95.
15. Angeliki Kylili, Paris A. Fokaides, European smart cities: The role of zero energy buildings, Sustainable Cities and Society, Volume 15, July 2015, Pages 86–95.
16. Pless S, Torcellini P. Net zero energy buildings: A classification system based on renewable energy supply option. National Renewable Energy Laboratory; 2010 Jun. p. 1–21.
17. Chou JS, Yutami GN. Smart meter adoption and deployment strategy for residential buildings in Indonesia. Applied Energy . 2014 Sep; 128:336–49.