Advances in the smart materials applications in the aerospace industries

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Abstract

Purpose – Smart materials also called intelligent materials are gaining importance continuously in many industries including aerospace one. It is because of the unique features of these materials such as self-sensing, self-adaptability, memory capabilities and manifold functions. For a long time, there is no review of smart materials. Therefore, it is considered worthwhile to write a review on this subject.

Design/methodology/approach – A thorough search of the literature was carried out through SciFinder, ScienceDirect, SpringerLink, Wiley Online Library and reputed and peer-reviewed journals. The literature was critically analyzed and a review was written.

Findings – This study describes the advances in smart materials concerning their applications in aerospace industries. The classification, working principle and recent developments (nano-smart materials) of smart materials are discussed. Besides, the future perspectives of these materials are also highlighted. Much research has not been done in this area, which needs more extensive study.

Originality/value – Certainly, this study will be highly useful for academicians, researchers and technocrats working in aerospace industries.

Keywords Smart (intelligent) materials, Classification, Applications, Nano-smart materials, Future perspectives

Paper type Literature review

1. Introduction

It is interesting to note that the number of passengers will be approximately doubled in 2036; totaling 7.8 billion yearly as per International Air Transport Association. To complete this requirement, the aerospace industry is supposed to do great efforts continuously. In July 2018, Airbus predicted the need for approximately 37,400 new aircraft with $5.8tn in costs during the next 20 years (Matthew, 2018). For such a huge number of passengers and the demand for the aircraft, there is a great need for advanced technology to meet out the requirements economically with safety. Among various parts/components of the aerospace industries, the material is one of the most important components. Many types of materials are being used in aerospace industries but the smart materials are gaining importance continuously because of their unique features. Basically, the smart materials are new generation constituents exceeding the conventional functional and structural materials. These materials are called smart ones because of their self-sensing, self-adaptability, memory capabilities and manifold functions (Ritter, 2007). The self-adaptation features of smart materials are of great value in embedding the adaptations of smart materials. Nowadays, there is a great demand for the smart materials in various industries because of their capabilities to alter physical properties in a precise way in reaction to the change in the environmental factors (stimuli responses). These factors are temperature, stress, magnetic fields, chemicals, electricity, nuclear radiation, acidity and hydrostatic pressure. The changes may be in the size and shape of the objects, rigidity, restraining and viscosity (Schwartz, 2002). All these alterations are responsible for providing the various necessary functions of the smart materials as per the environmental changes. The common smart materials and related stimulus responses are shown in Figure 1.

The smart materials are also called as intelligent ones because of their intellectual performance during the environmental variations. The smartness of these materials lies in the facts of the manifold applications in structural, aerospace, bionics, mechanical and environment engineering (Bashir, 2017; Addington and Daniel, 2005). Besides, these materials can detect the errors and fissures and are working as diagnostic tools and, consequently, self-repairing capabilities – called a self-repairing effect. In aerospace engineering, most of the applications are carried out in the open environment with exposure to various changes and, hence, smart materials are gaining great attention in the aerospace industries. In this way, there is a great demand for smart materials, related structures and instruments in the aerospace industries. A thorough search of the literature was carried out and no article was found on the advancement of smart materials in the aerospace industries during the past decade. It was also realized that there are some advances in the smart materials in aerospace industries during the past few years. Therefore, the efforts are made to write an article on the latest developments and applications of smart materials in the aerospace industries. This article describes the classification, working principle, applications, recent developments (nano-smart materials) and future perspectives. Certainly, this article

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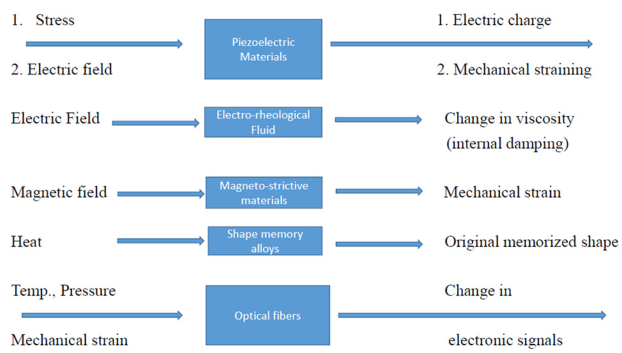
Figure 1 The common smart materials and related stimulus responses



will be highly useful for academicians, researchers and technocrats working in the aerospace industries.

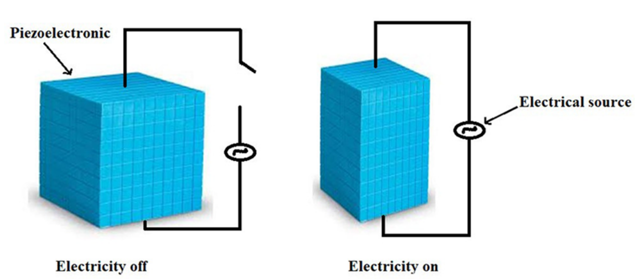
2. Classification of smart materials

The classification of smart materials is based on their properties. The most important properties exploited are thermal, electric, magnetic, etc. The smart materials are classified as per the approaches of Addington, Schodek and Ritter. These materials are classified based on the changes occurring in shape, phase, color, energy, matter, adhesion and rheology. It is not possible to discuss all these materials classification but the most important materials used in aerospace industries are discussed in brief.

2.1 Piezoelectric materials

These are the materials reacting against the change in electric properties. These are relatively linear at low fields and bipolar (positive and negative strain) exhibiting hysteresis. These materials are of polymeric and ceramic types. These have properties of wide bandwidth, electromechanical response, high generative force and comparatively low-power requirements. These materials undergo mechanical alterations in changing the electric field (Figure 2). These produce voltages when stress is applied. Contrarily, if voltage is applied, stress is produced in the materials. Consequently, a structure made of these materials can be bent, expand and fold by applying voltage. These have good applications in the magnetic heads, optical tracking devices, dot-matrix printers, high-frequency stereo speakers, computer keyboards, microphones, transducers, sensors, actuators and igniters for gas grills. The most widely used piezoelectric materials are piezoceramics (e.g.

Figure 2 Piezoelectric material showing the exchange of electrical and mechanical energy



lead zirconate titanate [PZT]), lead magnesium niobate and polyvinylidene fluoride polymer. The other piezoelectric materials are PbZr0.52Ti0.48O_3-PZT, $Bi_4Ti_3O_{12}$-BiT and PZT-BiT composites. These are frequently presented in thin sheets and may be easily anchored or fixed in the composite structures or loaded to form separate piezoelectric actuators.

2.2 Magnetostrictive materials

These are the materials reacting against the change in the magnetic properties. These materials are mono-polar and non-linear, showing some hysteresis but lesser than piezoelectric materials. These materials undergo mechanical strain and work as actuators and sensors. These materials produce low strains and modest forces across a varied frequency range. These are the best materials for the actuators because of the required coil and magnetic return path. Generally, these materials contain sensors and actuators and are of nickel, iron and cobalt. Briefly, these materials work as permanent magnetic bars. The major applications of these materials include motors and hydraulic actuators and small-frequency high-power sonar transducers. The best known magnetostrictive material is Terfenol-D, which elongates on exposing to the magnetic field.

2.3 Thermo-responsive materials

These are the materials reacting against the change in temperature. These materials are also called as temperature-responsive. Generally, these are polymers and show a miscibility gap in their temperature-composition diagram. These materials are shape memory polymers and shape memory alloys (SMAs) and can be changed in different shapes by changing temperature. Nitinol is a nickel and titanium alloy and works as anti-corrosion comparable to stainless steel; useful for many applications. The major applications of such types of alloys are in super elastic spectacle frames and hot-pot thermostat. The major applications include thermostat, air vehicles, shock absorbers, breaks and automotive dampers.

2.4 Shape memory alloys

SMAs are the materials belonging to the thermo-responsive materials class. These materials react in the response to the temperature. They change the shapes at changing the temperature. They deform to their martensitic conditions and regain their original shapes to their austenite conditions when heated. The remarkable feature of these materials is their large changes of modulus of elasticity on heating above the phase change temperature i.e. two to four times low-temperature value. A variety of alloys have been found to show this effect by recurrent heat treatments. Examples are of nitinol (NI-Ti alloy), NiTiCu, CuAlNi, CuZnAl, Fe-Pt and Au-Cd. In the 1980s and early 1990s, some companies started to produce Ni-Ti materials, the different components and many other products (DesRoches, 2002). These are the best materials for manufacturing actuators because of the option of attaining large displacements and excitation forces. These materials are available in the standard stocks of wires, rods, tubes, springs, bands, strips and sheets.

2.5 Electrostrictive materials

These are the piezoelectric materials but the mechanical changes are directly proportional to the square of the electric

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field. These are also very sensitive to temperature but show tiny hysteresis. In these materials, the dislocations are always in the same direction. The most important example is magnesium niobate. It requires an electric field to cause induced stress and has the same induced stress ability as piezoelectric materials. These are available in the form of stacks, which may be used to form any device easily.

2.6 Rheological materials

These are liquid materials reacting against the change in electric or magnetic or both properties. These are also termed as electro-rheological fluid and magneto-rheological fluids as per the changes because of change in electric and magnetic fields. The reactions of these materials against stimuli are very fast. The changes are in the dynamics of liquid and solid phases. The major applications include shock absorbers, breaks and automotive dampers.

2.7 Photochromic materials

These are the materials reacting against the change in the optical properties. The major applications include liquid crystal displays, lithium batteries and other electrochromic devices. The most important photochromic materials are spiropyranes, naphthopyranes, spirooxazines, chromenes, spirodihydro-indolizines, fulgides, diarylethenes, bacteriorhodopsin and azo compounds. The different types of smart materials with input and output are given in Table 1.

3. Working in the smart materials

Fundamentally, the smart materials act against certain effects such as electricity, pressure, temperature, light, magnetic fields, acidity and mechanical loads. The responses of the smart materials are observed in terms of change in shape, viscosity, composition, color, etc. Fundamentally, the smart structures include five key essentials, i.e. structural material, distributed sensors and actuators, power conditioning electronics and control strategies. These materials work by changing their physical properties. The first smart material transformation observation was recorded in 1932 on gold–cadmium. Later on, Hodgson and Brown (2000) observed transformation and shape memory effect in nickel–titanium alloy at Naval Ordinance Laboratory.

Basically, the materials may exist in two different phases at various temperatures. These are austenite (exists at high temperature) and martensite (exists at low temperature). These two phases transform into each other at the external temperature or stress condition alters. Besides, martensite exists into two different forms, i.e. twinned and detwinned (Figure 3). The smart materials show some special features during the

Figure 3 The different phases of smart materials

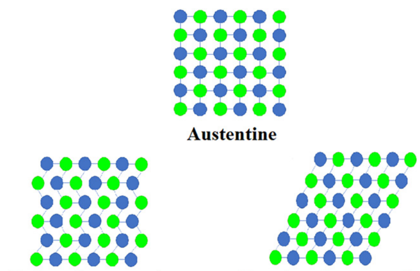


Table 1 The different types of smart materials with input and output

Sl. no.	Types of smart materials	Input	Output
Type 1: Property changing			
1	Mechanochromics	Twist	Color variations
2	Electrochromics	Electric potential variations	Color variations
3	Photochromics	Light (radiation)	Color variations
4	Thermochromics	Temperature changes	Color variations
5	Liquid crystals	Electric potential variations	Color variations
6	Chemochromics	Chemical quantities	Color variations
7	Suspended particles	Electric potential variations	Color variations
8	Magnato-rheological	Electric potential variations	Stiffness and viscosity variations
9	Electrorheological	Electric potential variations	Stiffness and viscosity variations
Type 2: Energy exchanging (reversible)			
10	Piezoelectric	Deformation	Electric potential difference
11	Thermoelectric	Temperature difference	Electric potential difference
12	Pyroelectric	Temperature difference	Electric potential difference
13	Magneto-restrictive	Magnetic field	Twist
14	Electro-restrictive	Electric potential difference	Twist
Type 2: Energy exchanging (reversible)			
15	Photoluminescence		Radiation (light)
16	Electroluminescence	Electric potential difference	Radiation (light)
17	Thermoluminescence		Radiation (light)
18	Chemoluminescence		Radiation (light)
19	Light-emitting diodes	Electric potential difference	Radiation (light)
20	Photovoltics	Radiation (light)	Electric potential difference

transformations. These are the super-elasticity effect, shape memory effect and two-way memory effect. The super-elasticity materials also have some other significant properties such as hysteretic damping, excellent fatigue properties, very dependable energy dissipation ability through repeatable phase conversion and good corrosion resistance. The austenite occurs at low stress while it is converted to detwinned martensite at high stress. Figure 4(a) depicts a usual stress–strain curve of smart materials at these two phases. Figure 4(b) depicts the stress–strain relationship of the usual phase changes of super-elasticity smart materials under pressure. The upper plateau shows an alteration from austenite to martensite in pressure while the lower plateau shows the reverse phenomenon with pressure release. The super-elasticity materials also have some other significant properties such as hysteretic damping, fatigue properties, reliable energy intemperance capability via repeatable phase transformation and excellent resistance to corrosion.

In the case of the piezoelectric materials, the transducer between mechanical stress and electricity property is because of the crystalline structure. In a crystal, each molecule is polarized having one end negatively charged and the other positively charged, i.e. just like a dipole. This arrangement is affected by the changes in the mechanical stress and electric field; leading to transducer property. Briefly, the simple piezoelectricity concept is to alter the alignment of the polarization of the molecules. It is well-known that smart structures are made of different combinations of smart materials. Basically, these smart structures involve the distribution of the actuators and sensors, processors, control logic and power electronics. The various smart structures are discussed below.

3.1 Adaptive structures

These are the structures having the distribution of the actuators to change the characteristics in a prescribed way. They include conventional aircraft wings with ailerons and flaps and rotor blades with servo flaps.

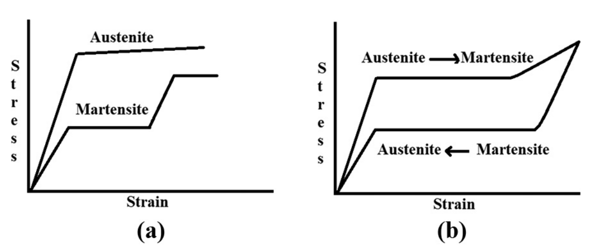
3.2 Sensory structures

These are the structures having the distribution of the sensors to screen the characteristics of the structure i.e. strain, temperature, electromagnetic properties, displacement, damage and acceleration.

3.3 Controlled structures

These are the structures having the distribution of the sensors and actuators. These are used to actively regulate the characteristics of the structure.

Figure 4 Strain–stress relationship of austenite and martensite



Notes: (a) Stress-strain curve; (b) superelastic behavior

3.4 Active structures

These are the structures having the distribution of the integrated sensors and actuators. These have load-bearing capacity i.e. structural functionality.

3.5 Intelligent or smart structures

These are the structures having a sub-set of active structures. These are used for the extremely integrated control logic and power electronics.

4. Applications

The applications of the smart materials and structures are increasing continuously in various sectors such as civil structures, automotive systems, robotic systems, space vehicles, rotary-wing aircraft, fixed-wing aircraft, machine tools, marine systems and medical systems. The increased uses are through technological revolutions in actuators, sensors, damping of vibrations, shock absorption, shape control, stability and damping increase, structural integrity, operational maintenance, automatic on-off switch, image processing and coatings because of special features of these materials such as self-adaptation, self-sensing, self-adaptability, memory and multiple functionalities. These materials can detect faults and cracks, and hence, are useful as diagnostic tools. These materials may be used to repair the fault during any mechanical operation – the phenomenon is called the self-repairing effect (Liang and Rogers, 1992; Ghandi, 1995; Soroushian and Hsu, 1997; Lagoudas *et al.*, 1999). Of course, these materials have a wide range of applications but in this article, the efforts will be made to restrict their applications in aerospace industries only. The features of aircraft applications are given in Table 2 while Table 3 summarizes various smart materials used in aerospace industries.

The aerospace industries are facing great economic pressure to lower down the costs, with augmenting the performance and sustaining important protection standards. Therefore, the defense, commercial airline and space exploration industries are searching smart materials for these purposes. These should be consistent, robust and meet the requirements of highly specialized applications. The smart materials have good industrial and commercial applications. The engineering applications may be categorized into sensors or sensing devices and motors and actuators. The smartness of these materials is developed by changing their compositions, special processing, inducing defects and modification of microstructures.

The smart materials have been used as load-bearing actuators in some composite structures such as aircraft wings and rotor blades (Liang *et al.*, 1996; Garner *et al.*, 1999; Jardine *et al.*, 1996). There are smart materials that are used to overpower vibrations and variation in helicopter rotor blades shape. Smart material-actuated rotor technology is being used in Boeing, which reduces about 80% vibrations, improving flight performance. Airbus Helicopters SAS (formerly Eurocopter Group) has also developed similar systems. Similarly, various adaptive regulator surfaces are produced for airplane wings. Also, recently, research is going on to emphasize the new control techniques for smart materials and design procedures for the locations of the actuators and sensors. The other applications deal with the ability to regulate

Table 2 The features, requirements and the effects of aircraft applications

Sl. no.	Requirements	Applicability	Effects
1	Light weight	All aerospace schemes and programs	- Semi-monocoque fabrication (thin-walled boxes or reinforced structures) **- Use of low-density materials (wood, alloys and composites)** **- High strength/weight and high stiffness/weight**
2	Passenger safety	Passengers carriers	- Use of fire retardant materials **- Extensive testing: crashworthiness**
3	High reliability	All aerospace schemes and programs	- Strict quality control **- Extensive testing for consistent data** **- Certification: proof of design**
4	Degradation (radiation and thermal)	Spacecraft	- Damage issues and life span and extensive testing for varied environment **- Thin materials with high reliability**
5	Sturdiness- exhaustion and corrosion	Aircraft	- Extensive exhaustion testing/analysis (alloys do not have exhaustion limit) **- Corrosion inhibition plans**
6	Aerodynamic presentation	Reusable spacecraft	- Deformed shape aero-elasticity **- Dynamics** **- Compound contoured shapes** **- Manufacturability (molding and machining)**
7	Aerodynamic presentation	Aircraft	- Greatly complex loading **- Thin bendable wings and regulating surface**
8	Weather operation	Aircraft	- Lightning protection **- Erosion resistance**
9	Multi-role functions	All aerospace schemes and programs	- Efficient design **- Composites with varied functions**
10	Fly-by-wire	Fighter and passenger Aircraft	- Configuration control exchanges (aero-servo-elasticity) **- Wide use of computers and electronics** **- Electromagnetic shielding**
11	Stealth	Specific military aerospace uses	Specific surface and shape of aircraft **Stealth coating**

Table 3 Various smart materials used in aerospace industries

Sl. no.	Requirements	Materials	Purposes
1	Design of smart materials for actuators for rotor control	Magneto-responsive materials	- Cyclic and active control - Lead to reduced maneuver envelop because of weight and volume constraints
2	Control panel as extending to wings of aircraft	SMAs	- To solve limits of aircraft wing design
3	Shape-changing technology	Shape-altering smart materials	For military aircraft (next to new generation aircraft)
4	Shape-changing technology	SMAs	Engineering bending and stretching abilities in wings and hingeless systems
5	Shape-changing technology	Piezoelectric	Engineering bending and stretching abilities in wings and hingeless systems

the aero-elastic form of an aircraft wing to decrease the pull and increase working efficiency, to regulate vibration of satellites' lightweight structures and to observe structural reliability in space structures and aircraft.

The piezoelectric and dielectric materials (electro ceramic materials) are used to make aerospace sensors and transducers such as gyroscopes and accelerometers. The gyroscopes are used for measuring the pitch of aircraft, acceleration, satellites and missiles, while accelerometers are used for vibration measurements. The sensors are used to measure the levels of fuel tanks. For example, Boeing 777 has piezo ceramic material in 60 ultrasonic fuel tanks. The smart ceramic materials are used in aircraft because of their capability to bear high vibration and mechanical shock and temperature variations. These are used to manufacture various aircraft parts such as fuel line assembly, thermocouples and gas turbine engines. Alumina is used to make aircraft parts for thermal shock resistance and high temperature, which occur in plasma ignition. Besides, alumina is light in weight and decreases the costs related to the launching of satellites. The piezoelectric actuator may execute a mechanism of the control system by increasing the maneuverability and performance owing to good flexibility. Besides, these materials are used to reduce the vibrations and noise in the aircraft. The ceramic fibers are used as heat shields for fire protection and thermal insulation in aircraft and space shuttles because they resist heat, and are lightweight and do not corrode. Other significant characteristics include high melting temperature, resiliency, tensile strength and chemical inertness. Besides, aircraft windshields are heated by a transparent, electric-conducting ceramic coating embedded in the glass to keep them clear from fog and ice.

The SMAs are used to overcome the limits of normal airplane wing designs. Generally, wings for high speeds fail to work at low speed and vice versa. But SMAs integration to airplane wings may solve this problem. The SMAs have a good future to be used in the wing structure to minimize aerodynamic losses and to maximize speed–wing concordance. These may be exploited for sound reduction, load reduction and to meet the motion necessities of the helicopters. Dong *et al.* (2008) reported the application of SMA as an actuator for an adaptive airfoil. SMA springs are used to actuate precisely some points on the skins to reach the target airfoil. It was observed that SMA could get good actuating results, based on the simulation studies. Similarly, Hutapea *et al.* (2008) reported a sample of a smart actuation structure for an adaptive airfoil by regulating the flaps. SMA springs were stationary at one terminal to the wing box toward the primary edge of the airfoil whereas the other end was involved tangentially to a revolving cylinder fixed to the flap. The spring actuators were controlled by supplying an applied current. As per the authors, the sample prepared showed a sturdy prospective for future uses.

5. Nanotechnology and smart materials

Of course, nanotechnology has emerged as an independent research area (Ali, 2012, 2018). But recently, there is growing interest to apply nanotechnology in the smart materials to augment their performance and new designs or/and applications. Nanotechnology is a tool to take smart materials to the next level. Nanotechnology-enabled smart materials exhibit superior performance in their functions (Coyle *et al.*, 2007). The stimuli responses of the nanomaterials are better than the conventional smart material because of small size, surface active sites and, sometimes, larger surface area (Dahman *et al.*, 2017). These features sense the change in the environment even at low magnitude. The advantages of smart and nano-materials are as given below:

- Optimization of the responses of complex systems. This is carried out by creating early cautionary systems, increasing the range of survivability situations and/or giving adaptive responses to manage unexpected situations and conditions.
- Minimizing the alteration of the responses, augmenting the exactness and providing good control of the system. This might lead to improving designs and performances for special applications.
- Improvement in the functionality of the system by an appropriate defensive maintenance and presentation optimization.
- Noteworthy influence on engineering and processing techniques.
- Improvement in the health monitoring of the system and good control of its dynamic and addictiveness.
- All these features will open the entry to use more nano-smart materials for multifold applications in aerospace industries.

The combination of nanomaterials' properties and smart materials' features are the best combinations to achieve the heights in success. These materials will create innovation in aerospace engineering. For example, the body of aircraft and satellites made of a nano-smart material could possibly alter the surface texture depending on temperature, pressure, electric current and other features. The smart nanomaterials (especially composites), comprising sensors and actuators in the layers of composites may detect any crack in the aircraft. The smart nanomaterials can be prepared with layered composition and printed circuit-board techniques. Ihn and Chang (2004) developed this sort of technique using smart layers to detect and monitor hidden fatigue crack growth using a built-in piezoelectric sensor/actuator network. Similarly, Akhras (2012) used smart and nano-systems for applications in non-destructive evaluation and perspectives. In this system, actuators stimulate the composite material and produce waves when a crack is developed. These waves are sensed and detected by the pilot for alarming the necessary action. The SMAs are being made in a nano-frame for wings for flapping in manners similar to birds (Figure 5). Li *et al.* (2009) described the different ways to prepare polymer modified gold nanoparticles. The authors studied their thermal and pH sensitivities. Such nanomaterials may be important in designing and developing future nano-electronics and nano-sensors. The author described the changes in the morphology of the gold nanoparticles as pH change response (Figure 6).

Kuilla *et al.* (2010) prepared graphene-based piezoresistive smart nanomaterial and tested its piezoresistive features for finding out a possible application in the graphene-based sensors. The authors compared the results with CNTs strain sensors. As per the authors, it was observed that the strain response of the graphene/epoxy sensor was better than CNTs and also symmetrical and along with reversible behavior. Furthermore, the graphene composites exhibited a higher gauge factor than strain gauge made of high-quality graphene film. High gauge factor may be because of the larger inter-contact areas among the graphene nano-fillers because of their two-dimensional structure. Csetneki *et al.* (2006) develop new

Figure 5 The embedding of smart nanomaterials in composite structure using printed circuit technology

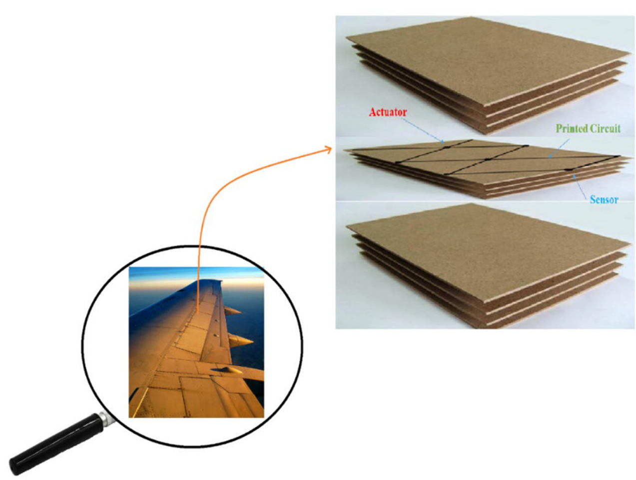


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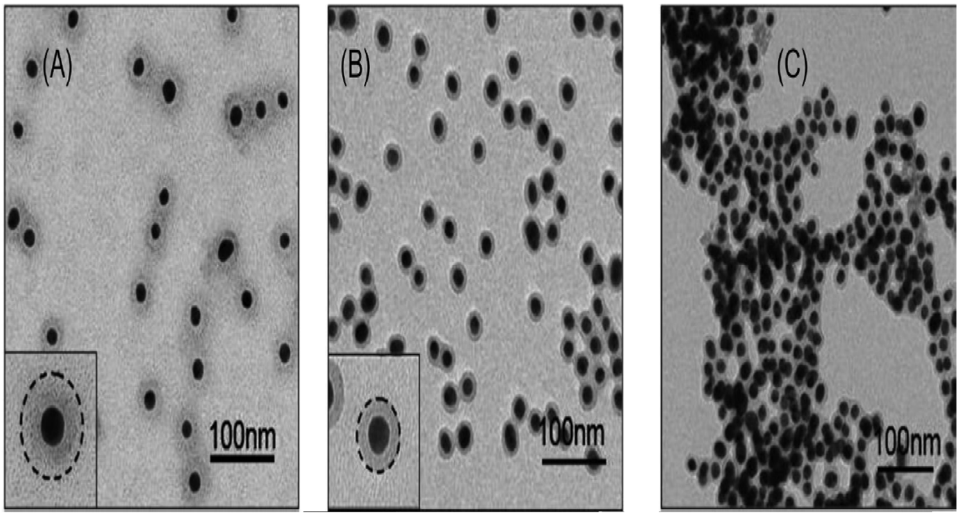
Figure 6 Change in morphology of gold nanoparticles



Notes: (a) pH: 3.1; (b) pH: 4.4; (c): pH: 7.5. Reproduced with permission

composite gel membranes having nano-channels, which can regulate membrane permeability in response to the external stimuli. With increased temperature, the membrane permeability increased. The channels have a well-ordered array of the magnetic polystyrene latex particles, which underwent to alteration in volume in reaction to outside stimuli. Ventura *et al.* (2017) described stimuli-responsive materials digitization via integration of a network of conductive nanomaterials into an elastomer matrix. The sensors with a wide range of detection abilities become promising. The authors monitored the rate and degree of material's expansion downhole – such as in sand screens or packers. The authors claimed that the developed approach may be used to detect degradation, tool deployment status and chemical detection. Besides, it was observed that the authors claimed the detection of the presence of water, oil or precise chemicals using their work.

Hwang *et al.* (2013) reported the preparation of nano-smart material of multi-walled carbon nanotubes (MWCNTs), exfoliated graphite nano-platelets (xGnPs) and nano-graphene platelets (NGPs). The authors prepared these sheets of various lateral dimensions and lengths using different compositions and combinations. These materials showed piezoresistive characteristics and indicated a variation in electrical resistance on applying the strain. The dependence resistance variations on strain were directional in nature. The different mixtures of xGnP size, MWCNT length and MWCNT-to-xGnP/NGP ratio showed various specific surface areas and nanoparticle interactions. The authors claimed these serving as important factors for regulating the sensitivity of the hybrid sheets. The sensitivity was inversely proportional to the thicknesses of the sheets.

5.1 Synthesis of nano-smart materials

The smart nanoparticles are produced by physical processes, based on manufacturing particles from pre-synthesized polymers (cross-linking among polymers and cores). The second method is a chemical synthesis of nanoparticles by

Table 4 The advantages and disadvantages of the synthesis of nano-smart materials

Sl. no.	Method	Advantages	Disadvantages	Reference
1	Microwave	- Reduced reaction or synthesis time **- Small particle size dispersal**	Sometimes poor dispersion	Liu *et al.* (2007)
2	Electron beam lithography	- Well managed inter-particle spacing	High complex paraphernalia	Lin and Samia (2006)
3	Gas phase deposition	- Practical approach	Size control of nanoparticles	Cuenya (2010)
4	Supercritical fluids	- Good control of nanoparticles **- No use of toxic chemicals**	Need critical temperature and pressure	Zhang and Erkey (2006)
5	Pulsed layer ablation/laser ablation in liquid	- Facile and simple method **- Geometry control possible** **- No need of any other chemical**	Low manufacturing rate	Zeng *et al.* (2012)
6	Flow injection	- Reproducible and homogeneous	Continuous mixing of solvents	Salazar-Alvarez *et al.* (2006)
7	Biological (microbial incubation)	- Reproducible, scalable, good yield and low cost	Time-consuming	Narayanan and Sakthivel (2010)

heterogeneous polymerization. Some methods are discussed below.

5.1.1 Polymer adsorption on nanoparticles

This is the classical and simple method for the preparation of stimuli-responsive nanoparticles. In this approach, a polymer is sorbed on the particle surface and it controls interactions in the colloidal suspension owing to different effects (electrostatic, steric, depletion bridging and mechanisms).

5.1.2 Amphiphilic block copolymers and micelles self-assembly

The block copolymers make different types of self-assembled arrangements from micelles to constant bilayers (subject to solvent selectivity). The swelling and packing of particles occurred because of solvent compatibility. The common physical deviations within the particles are in the collective size. The changes to the collective architecture, structure and stimuli responses to ionic strength, pH, thermal and redox stimuli are among those which are usually measured most. Examples are of shear flow, ionic exchange and osmotic shock. The advantages and disadvantages of the synthesis of nano-smart materials are summarized in Table 4.

6. Future perspectives

The smart materials are probably to be the most recent opening of humankind for a significant leap to a hopeful future. This century will be dominated by a wide variety of smart materials. These will be the frontier materials in the aerospace industries. There is a need to develop smart materials for manufacturing air vehicles with the capabilities of altering their shapes as per the requirements and specifications. There is also a great demand of elastomeric matrix materials and CMT structures for morphing technology. The properties of smart materials accept the challenges in aerospace industries. Therefore, the research on smart materials is a promising field. Certainly, the market for smart materials will increase in the future. The importance of smart materials will attract the researchers toward solving aerospace engineering problems. Innovative research is expected for making the control surfaces and adaptive wings, which may significantly augment the maneuverability. There is a great need to develop compact smart materials for controlling noise and vibration control.

Despite great demand and future applications of smart materials, there are certain challenges in the development of smart materials. These are the qualities and inexpensiveness. The researchers are supposed to improve quality without an increase in cost. Still, there is a need to make smart structures feasible by developing excellent smart materials, ease of anchoring in laminated structures, couplings between mechanical and electrical properties, increase in performance at low price and advances in microelectronics, information processing and sensor technology.

Nowadays, nanotechnology is gaining importance in almost every sphere of life. The oil and gas industry already uses stimuli-responsive nano-smart materials for the numerous technologies including swellable elastomers in reactive packers and heat/fluid-activated expandable screens. The smart environmentally sensitive nano-hydrogels with the ability to sense changes in pH, temperature or the concentration of metabolite can release their load as a result of such a change.

The smart nanomaterials may be used in SMAs. These may be highly useful materials in changing the shape of wings for flapping the need for smooth and economic performance. The smart nanomaterials are the need for the future and these should be prepared in a more advanced way to meet the needs of future aerospace technology. The future is looking for automatic damage arrest, shocks absorbers, self-healing and thermal mitigation through nano-smart materials. The nano-smart materials will be highly beneficial and useful in future space missions, and certainly, will help to make our dreams true. But nano-smart materials are just new ones and, thus, only a few industrial products are available in the market. Because of patent restrictions, it may take many years for a proposed nanomaterial to go from conception to desired application.

7. Conclusion

The development of smart materials is an interdisciplinary area. Smart materials are the new generation materials, which have great latent to introduce a revolution in many areas including aerospace industries. The manufacturing of the nano-smart materials and understanding of the working mechanism will improve the properties and applications in aerospace industries. The nano-smart materials will be highly useful in our space missions. These may be the starting materials to initiate life on other planets. These smart materials are the hope of the future and, certainly, will enhance the quality of our living. For a true revolution into aerospace industries, collaborative efforts are necessary among the academicians, researchers, engineers and designers.

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