Course Name: Building Materials as a Cornerstone to Sustainability

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Lecture 02

Types of Smart Materials

Hello everyone. In the last class, I had given a brief introduction to smart materials. We have already seen what are traditional materials and the materials with examples. We have seen alternate building materials, many with examples. We have seen innovative building materials; we have seen advanced building materials; and now we move on to this domain of smart building materials. The last class I gave a brief introduction.

Today we will go a little bit in depth into the types of smart materials. In this class, we will see what smart materials are and the various types of smart materials. I am just giving four examples: piezoelectric materials, shape memory alloys, magnetostrictive materials, and some other type. We will see the features and uses of smart materials before we conclude.

So what are smart materials? Smart materials are materials that are manipulated to respond to a controllable and reversible way modifying some of their properties as a result of external stimuli such as certain mechanical stress or a certain temperature among others. Because of their responsiveness, smart materials are also known as responsive materials. These are usually translated as active materials, although it would be more accurate to say reactive materials. Smart construction materials which also known as intelligent materials, active materials and adoptive materials are those that have the capability to respond to changes in the condition of their environment. Wherever they are exposed to that environment, they will change themselves as a response, and this will be a useful response.

The input that caused the change in smart material properties may be in the form of mechanical stress or strain, electrical or magnetic field or changes in temperature, moisture, pH and light. Their unique properties make them a crucial material in many fields of engineering and science. They are used in civil engineering projects and contribute in increasing performance, comfortability and energy efficiency of structure. Now let us see what these are. So, smart materials can be defined as materials that sense and react to environmental conditions or stimuli.

The stimuli could be mechanical, chemical, electrical or magnetic. For some time, smart materials found their primary use in interesting but specialized engineering and scientific applications or at the other end of the spectrum in novelty applications. For example, thermochromic coffee cups. Now these cups change their colors when filled. So, these are an example of a thermochromic cup, which indicates whether the coffee mug is filled or not.

Recently, a whole host of new products have found their way into the market, some interesting, some not so, as designers began to discover them. Many exciting smart products have become possible not so much because of innovations at the basic material level but rather because of the improved manufacturing technologies. Many of the production technologies developed have allowed many smart materials that were heretofore only laboratory curiosities to become usable to the design community. There are many types of smart materials that can be classified on the basis of their input-output reactions. Now they can be classified or listed like this.

Based on temperature difference, we have thermochromic. The output is colour change. Photochromics, based on stimulus as light or radiation, the output is a colour change. Mechanochromic, based on deformation the output is a color change. Chemochromic, due to chemical concentration the output is a color change.

Electrochromics, electric potential difference causes color change. Use of liquid crystal When the input is electric potential difference, it causes colour change. Suspended particle, electric potential difference gives colour change. Electro-reological material due to electric potential difference gives stiffness or viscosity change. Magneto- rheological materials due to electric potential difference gives stiffness or viscosity change.

There are certain energy-exchanging materials. The electroluminescent material when the input is electric potential difference the output is light. photoluminescent materials when input is radiation output is light. Chemoluminescence: when the input is chemical concentration, the output is light. Thermoluminescence when the input is temperature difference output is light.

Light emitting diodes, when the input is electric potential difference, output is light. When we use photovoltaics, input is light or radiation, and output is the electric potential difference. Then there are certain reversible energy-exchanging types of materials. which again comes only under energy exchange, as we had already seen in the previous class. There are two types of classification is two types.

So, we have the piezoelectric material, which, when deformed, gives an electric potential difference. The pyroelectric material, when temperature difference is given, produces an electric potential difference. The thermoelectric material, upon giving a temperature difference, gives an electric potential difference. The electrorestrictive material, when given an electric potential difference, deforms itself, and the magnetostrictive material, when subjected to a varying magnetic field, deforms itself. So, these are the basic ways in which smart materials react to various inputs by giving an output.

Let us look at the broad classification of types of material as we had already seen, but we would classify it further. So, based on the type of stimuli we are classifying here,. Piezoelectric materials are a class of smart materials that exhibit the piezoelectric effect, which refers to the ability of the material to generate an electric charge in response to applied mechanical stress or pressure. Conversely, these materials can also undergo deformation when an electric field is applied. This phenomenon is reversible, which means that the material will quickly convert mechanical energy into electrical energy and vice versa.

The piezoelectric effort has been extensively utilized in technology and engineering for its ability to provide precise and responsive control in various applications. The unique properties of piezoelectric materials make them valuable in the development of sensors, actuators, and energy-efficient devices. The key characteristics of piezoelectric materials include the direct piezoelectric effect. When mechanical stress is applied to a piezoelectric material, it causes the material to produce an electric charge. This effect is used in various applications such as sensors, actuators and energy harvesting devices.

Converse piezoelectric effect When an electric field is applied to a piezoelectric material, it induces a mechanical deformation or displacement. This property is utilized in actuators and devices that require precise mechanical movement. Then there is crystal symmetry. The piezoelectric effect is most pronounced in crystals that lack a centre of symmetry. Common piezoelectric crystals include quartz, rochelle salt, and tourmaline.

Let us look at the broad applications of piezoelectric materials. So, piezoelectric materials find applications in a wide range of fields. Sensors are used; piezoelectric sensors are used to detect vibrations. Piezoelectric materials are used in sensors, and piezoelectric sensors are used to detect vibrations, pressure, and acceleration. Further actuators, so piezoelectric actuators are employed in precision positioning system and also in micro robotics.

They are also used in energy harvesting. So, piezoelectric materials can convert mechanical vibration into electrical energy, making them suitable for energy harvesting in various devices. They are also used in ultrasonic transducer. So, piezoelectric materials are used in ultrasonic devices for medical imaging. cleaning and industrial applications.

Besides crystals, certain ceramics, polymers, and composites can also exhibit piezoelectric properties. So these are used in intruder alarms These are used in intruder alarms, in medical devices, in pin pads, in key fobs, in alarm clocks, in wrist watch alarms, in fire alarms, in carbon monoxide detectors, in exercise equipments, microwave ovens, computer motherboards, ultrasonic insect and rodent detectors, and in ultrasonic pet training collars. Let us now look at some shape memory alloys. So, in shape memory alloys, when the stimulus is temperature change, the behavior that the material exhibits is that it regains a predefined shape after deformation when subjected to a specific temperature. Key features and characteristics of shape memory alloys include the shape memory effect.

The most distinctive property of shape memory alloys is the ability to return to a predetermined shape when subjected to a specific temperature change. This change can be triggered by heating or cooling the material. Then two phases. So, shape-changing alloys had two distinct phases.

martensite and austenite. A lower temperatures the material is in the martensite phase and it is more deformable. Upon heating, the material transitions to an austenite phase, and it regains its original shape. This material can have super elasticity in addition to the shape memory effect. Shape memory alloys also exhibit superelasticity, which allows them to undergo large deformations and return to their original shape when the external force is removed. They also have temperature sensitivity.

The transformation between martensite and austenite phases is highly temperature-sensitive, and the transition temperature can be tailored by adjusting the alloy composition. If we look at their applications, These can be used in bridge reinforcement. So, shape memory alloys, specifically iron, manganese, silicon, and chromium rods, were used to reinforce a highway bridge in Michigan with sizable cracks, enhancing its structural integrity. Repair of heritage structure. The ISTEK project developed a nickel-titanium-shaped memory alloy device for repairing architectural heritage structures.

Pretensioned wire with super elasticity were utilized to prevent deformations or collapses in various ways tailored to the specific needs of each structure. These were also used in improving seismic performance of buildings. Shape memory alloys have been employed in devices to protect buildings from earthquakes, preventing excessive deformation and collapse after shocks. Now, when we look at magnetostrictive materials, let us look at what this material does. So, when the stimulus is magnetic field, its behavior changes shape in response to an applied magnetic field.

These materials are those types of smart materials that undergo mechanical deformation in response to an applied magnetic field. Now, the phenomenon is known as the magnetostrictive effect. The deformation is typically reversible, meaning that the material returns to its original shape when the magnetic field is removed. The degree of deformation is proportional to the strength of the applied magnetic field. Magnetostrictive materials play a crucial role in the development of devices and systems that require controlled mechanical motion and sensing capabilities.

Their applications range from industrial actuators to advanced sensor technologies contributing to innovation in fields such as robotics, aerospace, and mechanical devices. Their applications are in structural health monitoring. Magnetostrictive sensors can be embedded in concrete structures to monitor the structural health and integrity over time. These sensors can detect changes in the magnetic properties of the material, providing insights into potential structural damage or stress.

Next is smart infrastructure. Magnetostrictive materials can be incorporated into smart infrastructure systems to enable real-time monitoring of bridges, dams, and other critical structures. Continuous monitoring allows for early detection of structural issues, helping to prevent major failures and ensuring the longevity of the infrastructure. Third is vibration control and damping. Magnetostrictive actuators can be used to control and dampen vibrations in buildings and bridges. By applying a magnetic field to the magnetostrictive material, it can induce controlled mechanical motion, helping to counteract and reduce unwanted vibrations.

Some other types of smart materials quickly in brief, but we will look at these in detail in the forthcoming classes. Thermochromic material. So, stimulus is temperature change, and when the temperature changes, the behavior changes color in response to temperature variations. photochromic materials when the stimulus is light, which is UV or visible light, the behavior changes color in response to exposure to light. We have electrostrictive materials when the stimulus is electric field there are changes in the shape in response to an applied electric field.

Hydrogels When the stimulus is either pH, temperature, or moisture content, their behavior is to swell or contract in response to changes in surrounding conditions. We also have electro-rheological fluids. When the stimulus is an electric field, the behavior changes viscosity in response to an applied electric field. There are magnetorheological MR fluids. When the stimulus is a magnetic field, the change in viscosity in response to an applied magnetic field happens.

Conducting polymers. When the stimulus is an electric field, the behavior manifests as conducting electricity and changing properties in response to an electric field. There are hydrogels. Hydrogels have the ability to cool a room down, and that is why they can be placed between wall panels. Moreover, hydrogel is an environmentally friendly material that reduces the energy cost that otherwise would be used by supplementary devices to cool down buildings.

Then there are photochromic smart glasses. This is usually implemented by applying a self-adhesive photochromic film to existing glass and does not need any electrical power. Hence, it is considered a passive smart glass technology. Then there are uses of these smart materials. These can be used in self-healing concrete. So, embedding smart materials such as shape memory polymers or micro capsules with healing agents in concrete to enhance durability and self-repair capabilities.

Sensors for structural health monitoring. Integrating sensors made of smart materials into buildings and infrastructure for continuous monitoring of structural conditions, detecting potential issues early on. There are adaptive facades using shape memory alloys in facades to create adaptive and responsive building envelopes that can adjust to changing weather conditions. Energy-efficient buildings implementing smart materials with energy harvesting capabilities to generate power from ambient sources contribute to the energy efficiency of buildings. earthquake-resistant structures, employing smart materials like magnetorheological dampers to enhance the seismic performance of structures, reducing the impact of earthquakes. Then there are thermal regulations, integrating material with phase change capabilities to regulate temperature, contributing to improved energy efficiency and comfort in buildings.

temporary support structure using smart materials in the form of gels or polymers for temporary support structures during construction, offering flexibility and easy removal. Green roofs with hydrogels. Incorporating hydrogels in green roof systems to enhance water retention and support plant growth in sustainable construction practices. We will just take a quick and small example of the Italy Pavilion at Milan Expo 2015. This project takes advantage of the use of sustainable technology and materials.

The use of photovoltaic glass on the roof and photocatalytic concrete on the facade put forth the idea of flexibility in the creativity and technical design. The I-active biodynamic concrete provides three times greater fluidity than usual to design complex geometries and to resist high strength compression and flexion. The active component of the material acts as a catalyst in sunlight to trap air pollutants and convert them into inert salts to prevent smog. The building envelope is more than 700 panels of this smart concrete in years gives back to the environment more than it has consumed in the construction. In conclusion, while the use of smart materials in construction is still evolving, ongoing And a lot of research and development efforts continue to expand the range of applications and improve the cost effectiveness of these technologies.

As the industry embraces these advancements, smart materials are poised to play an increasingly vital role in shaping a future where construction is characterized by durability, efficiency and environment consciousness. The continued exploration and integration of smart materials into construction practices hold the potential to revolutionize the way we design, build and maintain structures for a more sustainable and resilient built environment. So, today we have seen the types of smart materials and a brief glimpse of what all they can do. After understanding the classification from the forthcoming classes we will go into each material separately in depth. With this, I conclude today's class and we will meet with another interesting smart material in the next class. Thank you.