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Applications of smart materials in the era of industrial 4.0: A review

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Abstract:

Smart materials or Stimuli response materials are commonly used in different industrial sectors, i.e., aerospace, medical implants, artificial muscle microelectromechanical systems, sensitive valves etc. Meanwhile, one of the most common smart materials, called shape memory, gained attention due to its shape recovery under external stimuli. Several scientists have recently done extensive research on these types of materials. The SMAs gained a tremendous amount of industrial applications, i.e., robotics, actuators and sensors, cardiovascular stents etc. Meanwhile, SMPs, either thermosets or thermoplastic, found massive attention in the field of smart materials. Shape memory polymers (SMPs) have become one of the important class of polymers, and their applications have been increasing significantly. The last two to three decades have witnessed explosive growth in the subject. The SMPs, also known as stimuli responsive soluble–insoluble polymers or environmentally sensitive polymers, have been used in biotechnology, medicine, and engineering. This study focused on the industrial applications of shape memory alloys (SMAs) and shape memory polymers (SMPs). Furthermore, try to find the research gap in the field of smart materials.

Keywords: Smart materials, SMAs, SMPs

Introduction:

The categories offered in the timeline of human civilization history based on the materials used throughout the period of Stone Age, Bronze Age, Iron Age, and Silicon Age. Each of these time steps progressed technologically and culturally to the next, owing largely to advances in materials science. The innovation and discovery of fresh materials have marked the eras' progression, ushering in a new era for each. The research of multifunctional materials has evolved from the quest for lighter, stronger, and more reliable materials. Smart materials are a subgroup of these materials that have the ability to sense, process, and respond to external inputs. Smart materials, or combinations of materials, change physically or chemically in response to specific environmental stimuli such as heat, electricity, moisture, etc., and then revert to its original configuration when the stimuli are removed [1-4]. Shape memory alloys are alloys that, after being subjected to stress or temperature cycling, return to their original shape (SMAs). SMAs have the ability to switch from one crystallographic structure to another in response to a temperature or stress stimuli. This structural change means the material has one shape at one temperature or stress level and another at another. The low-temperature martensite and high-temperature austenite phases are the two crystallographic structures of SMAs.

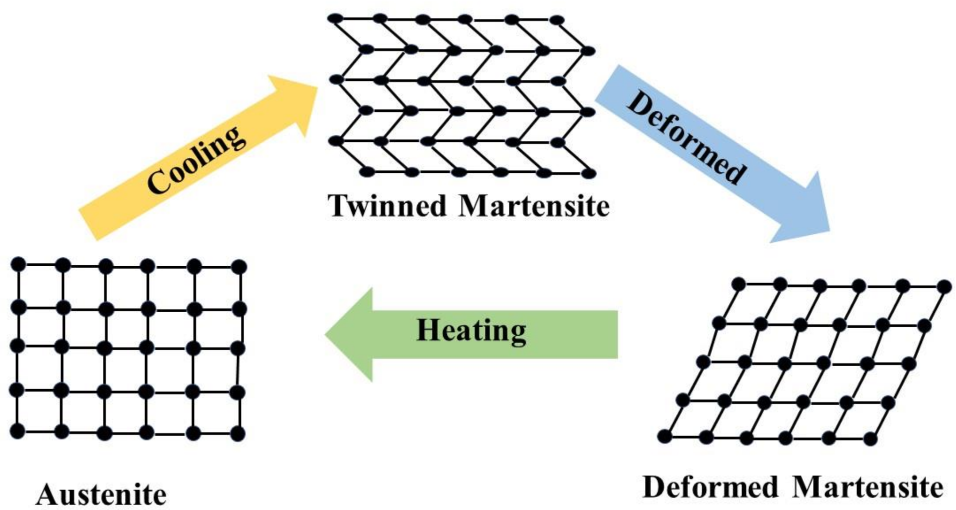

Figure 1. Phase transformation of the smart materials

Nickel-titanium (Ni-Ti), copper-zinc–aluminium–nickel, and copper–aluminium–nickel are the most frequent varieties of SMAs, with Nitinol (Ni-Ti, invented by William J. Buehler and his team at the US Naval Ordnance Laboratory) being the most popular. Nitinol (Ni-Ti) was discovered by William J. Buehler and his team at the US National Institute of Standards and Technology. Many comprehensive research of Ni-Ti and its applications is available worldwide, and Ni-Ti-based SMAs have been recognised to have particularly good anticorrosive properties. When the external environment changes slightly, a smart polymer can experience reversible or irreversible changes in its physical properties and/or chemical structure [5-8]. Figure 1 showed the phase transformation of the smart materials. Changes in pH, temperature, ion concentration, light, mechanical force, electricity, magnetism, sound field, and added distinctive compounds are examples of tiny changes in the external environment. In this study, we focused on the applications of smart materials precisely to SMAs and SMPs.

SMAs and their Applications

The enormous strains caused by loading a SMA are recovered upon unloading, a phenomenon known as superelasticity or pseudoelasticity in SMAs. In SMAs, superelasticity is similar to stress-driven shape memory. The martensite in SMAs can be isothermally produced by applying stress above the Ms temperature; this is known as stress-induced martensite (SIM). The shape memory evaporates when the stress is removed, and the original shape is remembered as an elastic substance, which is mechanical rather than thermal shape memory [9-10].

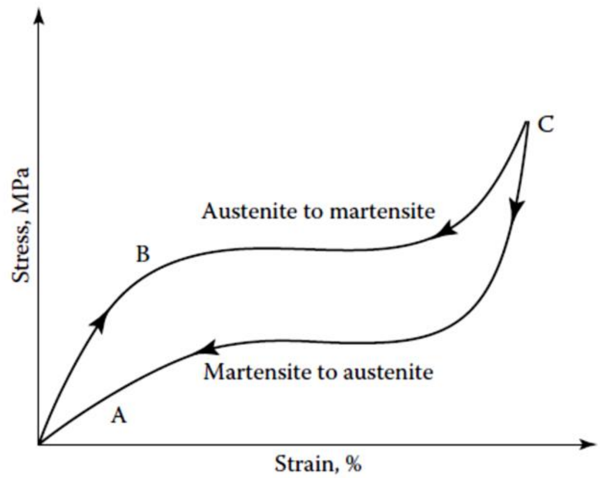

Figure 2. Superelasticity curve of SMA

SMAs' capacity to alter the shape in response to temperature changes has a variety of applications, including aeronautical actuation, medical applications, and popular consumer devices like mobile phone antennae, spectacle frames, and underwire bras. Nickel-titanium–iron (Ni-Ti–Fe) alloy rings/couplers are expanded and fitted over the coupling portions of the pipes at low temperatures. As a result, the human body is unquestionably one of the largest places in which systems may be developed. By experimenting on it, you have the freedom to investigate, mimic, and learn from its integrity. As a result, smart materials/actuators can even be used to replace/supplement biological tasks. The usage of Ni-Ti SMAs in angioplasty cardiovascular stents. Figure 2 shows the Superelasticity curve of SMA.

SMPs and its Applications

Smart polymers are adaptive and intelligent materials and active structure systems that are now commonly used to construct groundbreaking smart gadgets, sensors, or actuators; their functions arise from their capacity to respond to environmental stimuli with a measurable reaction. Depending on the responsive substance under investigation, the triggering stimuli can be physical, chemical, or biological [11-12].

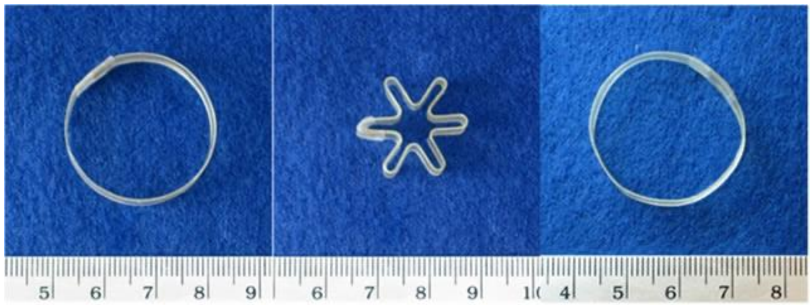

Figure 3. Transformation of SMPs

This desired trait has led to the widespread use of shape memory polymers (SMPs) and alloys in a variety of industrial and engineering applications, as well as intelligent systems, in recent years. Polytetrauoroethylene (PFTE), polylactide (PLA), ethylene-vinyl acetate (EVA), and polyurethanes are examples of SMPs that are significant engineering applications. Figure 3 showed the transformation of SMPs

Conclusions

It has been concluded that smart materials have covered a tremendous amount of industrial applications. Furthermore, it has been found that these materials have special requirements in the field of sensors, actuators, recycling of materials. Meanwhile, it enhances different thermomechanical properties by varying the composition of different materials.

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