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Commentary

An Overview on a Novel Material like Shape Memory Alloy

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1. Description

A Shape Memory Alloy (SMA) is a type of alloy used in metallurgy that may deform while cold but returns to its previously deformed shape when heated. It can also be referred to as muscle wire, smart metal, smart alloy, memory metal or memory alloy. Shape memory alloy components can be solid state, lightweight substitutes for common actuators like hydraulic, pneumatic and motor based systems. In order to create hermetic couplings in metal tube, they can also be employed.

Copper aluminum nickel and Nickel Titanium (NiTi) are the two most common shape memory alloys, but SMAs can also be made by alloying zinc, copper, gold and iron. Even though NiTi based SMAs are more stable, practical and have better thermo-mechanic performance than iron and copper based SMAs such Fe-Mn-Si, Cu-Zn-Al and Cu-Al-Ni. These materials are commercially available and less expensive than NiTi. SMAs can go through six distinct transformations, three different crystal forms and two different phases of existence.

Martensite finish (Mf) is the temperature at which the transition from austenite to martensite in NiTi alloys is complete after cooling, austenite being the initial state. Accordingly, the temperatures at which the conversion of martensite to austenite begins and ends during heating are As and Af. The characteristic transformation temperatures may alter as a result of the shape-memory effect being used repeatedly. The SMAs become irreversibly distorted at Md, the highest temperature at which stress can no longer be applied to them. Since there is no diffusion involved, the transition from the martensite phase to the austenite phase depends simply on temperature and stress, rather than time as with most phase shifts. Similar to this, steel alloys with a similar structure give rise to the name austenite. Special features are produced by the reversible diffusion less transition between these two phases. Although carbon steel may be rapidly cooled to transform austenite into martensite, this process is irreversible; hence steel lacks shape memory qualities.

A temperature-induced phase transformation reverses deformation, which leads to the Shape Memory Effect (SME). The martensitic phase is typically orthorhombic or monoclinic. These crystal structures deform through twinning or more accurately, detwinning, because they lack sufficient slip systems for simple dislocation motion.

At lower temperatures, martensite is thermodynamically preferred, whereas at higher temperatures, austenite is preferred. The cooling of austenite into martensite contributes internal strain energy into the martensitic phase due to the differing lattice sizes and symmetry of these structures. The martensitic phase creates several twins, known as “self-accommodating twinning,” to lower this energy. This is the twinning equivalent of geometrically essential

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dislocations. SMAs start strongly twinned since the shape memory alloy will be produced at a higher temperature and is often tailored so that the martensitic phase is dominant at operating temperature to benefit from the shape memory effect.

These self-accommodating twins offer a simple channel for deformation when the martensite is loaded. Applying stresses will cause the martensite to detwinning, but no atomic bonds are destroyed or formed because every atom remains in the same position in relation to its neighbors. Thus, all of the atoms rearrange to the B2 structure, which also happens to be the same macroscopic shape as the B19 pre-deformation shape, when the temperature is elevated and austenite becomes thermodynamically preferred. SMAs have a noticeable “snap” due to the incredibly fast phase transition that occurs.

SMAs exhibit a phenomenon that is frequently referred to as superelasticity but is actually more properly referred to as pseudoelasticity. The term “superelasticity” refers to atomic bonds that may stretch to extremely long lengths without undergoing plastic deformation. Although pseudoelasticity relies on more complicated mechanics, it nonetheless produces significant, recoverable strains with little to no permanent deformation.

The variable geometry work was created by Boeing and general electric aircraft engines utilizing a NiTi SMA. Future jet engines would be able to be quieter and more effective due to the Variable Area Fan Nozzle (VAFN) design. Boeing tested this technology successfully in the air in 2005 and 2006.

SMAs are being investigated for use as launch vehicle and commercial jet engine vibration dampers. SMAs are able to absorb energy and attenuate vibrations due to the significant degree of hysteresis seen during the superelastic effect. These materials have the potential to significantly reduce the enormous vibration loads placed on payloads during launch as well as on the fan blades in commercial jet engines, enabling the development of designs that are lighter and more efficient. Ball bearings and landing gear are two other high shock applications where SMAs show promise. SMAs could be used in a number of actuator applications in commercial jet engines, which would greatly lower their weight and increase their efficiency. However, before they can be successfully applied, the transformation temperatures must be raised and the mechanical characteristics of these materials improved. Diverse wing morphing technologies are also under investigation.