Paper ID: NITETMECH14

SHAPE MEMORY ALLOYS:A REVIEW

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ABSTRACT

Nowadays along with conventional metals or materials, there is a need of smart materials in the industries. Shape memory alloys (SMAs) are considered as smart materials. They have been used for a wide variety of applications in various fields like aircraft, aerospace, medicine, telecommunication, etc. This paper consists of a review on “Shape memory alloys”. The unique behavior of SMAs is being discussed in this paper thoroughly. This paper includes the characteristic properties of shape memory alloys along with Shape memory effect, brief introduction of SMAs, its crystal structure and its applications are also explained in detail.

KEYWORDS-Active materials, Austenitic phase, detwinning, Martensitic phase, Shape memory effect, shape memory alloys, twinning.

INTRODUCTION

For centuries, metals have played an important role in our day to day life. Conventional metals are used for rolling, smelting, forging, etc. But new materials with advanced science and technology are making an effective impact on industries. The demands for lighter, stronger material with improved properties are required in the industry which can also be used for sensing, actuation, etc. have introduced a new branch of materials known as “multifunctional materials”. The specialized subgroup of multifunctional materials with sensing and actuation capabilities is called as “active materials” [1]. There are various types of active materials like piezoelectric and electrostrictives, piezomagnetic and magnetostrictive, piezoceramic, piezoelectric polymer, magnetostrictive ceramic, shape memory alloys and magnetic shape memory alloys. In this article, shape memory alloys (SMA), their crystal structure, their properties and applications are described. Shape memory alloys are the coupling of thermal field with mechanical field [1]. This article is mainly based on Ni-Ti based SMAs.

HISTORY AND NEED

A Swedish physicist Arne Olander discovered “the shape memory effect” (SME) in gold cadmium alloy (AuCd) in 1932. The alloy could be deformed when cool and then heated to return to original “remembered” shape [2]. The metal alloys having SME are called as shape memory alloys (SMA). Researchers of U.S. Naval Ordnance Laboratory found SME in nickel-titanium (NiTi) alloy in 1961 by accident, while studying the heat and corrosion resistance of NiTi [2]. Today, the NiTi alloys are commonly referred as “Nitinol”, for NiTi Naval Ordnance Laboratory [2].

As compared to conventional metals, SMAs are lighter in weight and also strength is high. It has improved fatigue life and low cost associated with this material system made it suitable for a wide variety of engineering applications and increases its demand in market.

SHAPE MEMORY EFFECT AND CRYSTAL STRUCTURE OF SMA

Shape memory effect (SME) is nothing but the effect due to which the alloys regain their original shape known as shape memory alloys. The SME occurs due to a temperature and stress dependent shift in the crystalline structure of material between low temperature phase martensite and high temperature phase austenite [2].
SMA has two phases, each with different crystal structures and therefore different properties. There are two phases involved in operation of SMA. One is “austenite”, having high temperature. Second is “martensite”, having lower temperature. Both the phases have different crystal structure than each other. Austenite is generally having cubic structure whereas martensite is having tetragonal or orthorhombic or monoclinic crystal structure. The transformation from one structure to the other structure occurs by shear lattice theory instead of diffusion of atoms. Such a transformation is known as Martensitic transformation. Each Martensitic crystal formed can have different orientation direction, called “variant”. The assembly of Martensitic variants can exist in two forms i.e. “twinned” martensite (M^t) and “detwinned” or “reoriented” martensite (M^d). Twinned martensite formed by combination of “self-accommodated” Martensitic variants. In detwinned martensite specific variant is dominant. The reversible phase transformation from austenite to martensite and vice versa forms the basis for the unique behavior of SMAs [1]. Upon cooling in the absence of an applied load, crystal structure changes from austenite to martensite. The phase transformation from austenite to martensite is termed as “forward transformation”.
Figure1 clearly shows the actual working view of shape memory alloys. According to the fig.1, high temperature austenite under certain load on cooling gets transformed into twinned martensite and at the same temperature, if load is increased; it then gets transformed into detwinned martensite. Then again on heating, detwinned martensite gets transformed into its parent phase i.e. austenite.

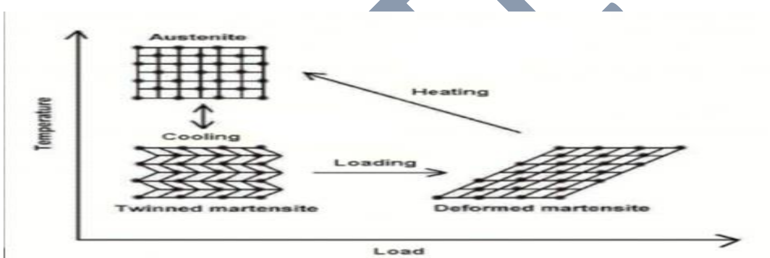

Fig.1 Working view of SMAs

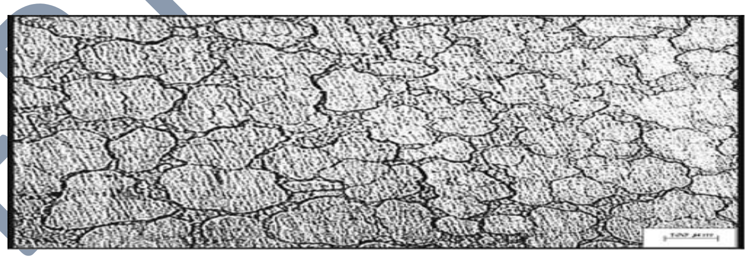

Fig.2 Microstructure of Ni-Ti alloys after annealing at 500^0C

Figure2 shows the microstructure of Ni-Ti alloys after annealing at 500^0C for checking its tensile strength. In this structure we can clearly see the two different phases [3].

MANUFACTURING OF Ni-Ti ALLOYS

As this article is concerned to Ni-Ti based SMAs, there are various ways to manufacture Nitinol. SMAs can be manufactured by hot working processes as well as cold working processes. In hot working process, SMAs are typically made by casting using vacuum melting techniques such as electron-beam melting, vacuum arc melting or vacuum induction melting. The cast ingot is press-forged or rotary forged prior to rod and wire rolling. Hot working to this point is done at temperatures between 700°C and 900 °C. Cold working of Nitinol causes marked changes in the physical and mechanical properties of SMAs [4].

A] PROPERTIES OF SMAS

Properties of Nitinol vary according to particular composition and the way it was processed.

- Melting point of Nitinol ranges from 1240 °C to 1310 °C [3].
- Density of Nitinol is around 6.5 g/cm^3 [3].
- Mechanical properties of Nitinol include hardness, impact toughness, fatigue strength and machinability [3].
- The yield strength of shape-memory alloys is lower than that of conventional steel, but some compositions have a higher yield strength than plastic or aluminum.

Superelasticity: SMAs also shows Superelastic behavior if deformed at a temperature slightly above their transformation temperature [2]. This effect is caused by the stress induced formation of some martensite above its normal temperature. Because it has been formed above its normal temperature, the martensite reverts immediately to undeformed austenite as soon as the stress is removed. This process provides a very springy, rubberlike elasticity to these alloys [2].

B] APPLICATIONS

SMAs have wide range of applications in various fields. First devices made from these alloys are fasteners, couplings and electrical connectors [2]. Then SMA devices started to perform dynamic tasks as actuators like ambient temperature controlled valves, clutches, actuators with resistive heating and electrical controls used in micro-robotics [2]. Due to its superelastic property, SMAs are used in eyeglass frame [2]. Shape-memory alloys are applied in medicine, for example, as fixation devices for osteotomies in orthopedic surgery, in dental braces to exert constant tooth-moving forces on the teeth [4]. SMAs are being explored as vibration dampers for launch vehicles and commercial jet engines [4]. The large amount of hysteresis observed during the superelastic effect allow SMAs to dissipate energy and dampen vibrations. SMAs find a variety of applications in civil structures such as bridges and buildings. One such application is Intelligent Reinforced Concrete (IRC), which incorporates SMA wires embedded within the concrete. These wires can sense cracks and contract to heal macro-sized cracks [4]. Recent interest in the development of iron based SMAs has challenged the concept that long-range order and thermoelastic martensitic transformation are necessary condition for shape memory effect [5].

CONCLUSION

The many uses and applications of shape memory alloys ensure a bright future for these metals. Research is currently carried out at manymaterials science departments. With the innovative ideas for applications of SMAs and the number of products on the market using SMAs continuously growing.It is observed that the Ni Ti alloys have higher yield strength than plastic. As these materials shows superelastic nature they will be very effective where the elastic properties of material is needed. It also shows improved fatigue strength, machinability, impact toughness, etc. advances in the field of shape memory alloys for use in many different fields of study seem very promising.

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