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TECHNICAL PAPER

HYBRID SOLUTION FOR TWO-WAY INDUCED SHAPE MEMORY ACTUATOR

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ABSTRACT

The actuation capability and the reliability of hybrid composites activated by shape memory alloys (SMA) are discussed in this work. The manufacturing of compact and safe actuators has been possible employing thermo-activated SMA which allows the polymer-based matrix to undertake many geometries. Different technological procedures are proposed for the manufacturing of this type of composites and the problems related to the production of such elements are discussed too. The adoption of non-metallic materials as deformation recovery elements, even if at present they do not allow a complete reversibility of the imposed deformation, represent an interesting research field, due to their properties of lightness, flexibility and low cost.

Keywords: hybrid actuators; shape memory alloys; smart materials

INTRODUCTION

Among the smart materials shape memory alloys hybrid composites play an important role thanks to their mechanical properties and their ability to act as the thermal sensors or actuators. Indeed they can modify the geometry according to the temperature increase and they are able to recover the original position after cooling. The working principle of such materials is based on an active element, sensible to the temperature changes, inserted in a matrix of polymeric material which represents the element used for the shape recovery. As active element Ni-Ti shape memory alloys are usually adopted in form of sheets or springs. Ni-Ti alloys are widely employed in the field of thermo-activated sensors and actuators, thanks to their stability and strength when subjected to bound recovery. Ni-Ti wires are able to recover up to 10% strain in uniaxial tensile tests and also higher values in form of springs. They show a satisfactory compromise in terms of costs, weight reduction and dimensions of the activation systems. In this work the main technological problems, arisen during the manufacturing of an hybrid-composite actuator and solved, are reported. Many actuators have been designed, built up and checked in order to test the shape recovery performance [1]. Shape memory alloys show three different properties depending on the temperature and on the thermomechanical treatment they have been subjected to: One Way Shape Memory Effect (OWSME), Two Way Shape Memory Effect (TWSME) and Super Elasticity (SE) [2-3]. The shape memory mechanism is based on a reversible thermoelastic martensitic transformation. During cooling of SMA element, from a temperature such that its structure is completely austenitic, the formation of martensite will be evidenced. This phase grows inside the austenitic matrix in the form of lamellae that cause a plastic arrangement of the surrounding matrix (Fig. 1).

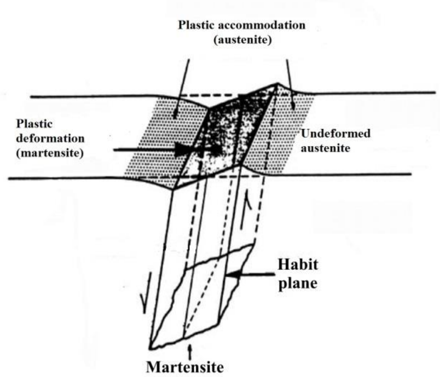


Fig. 1 Sketch of the martensitic transformation

During the subsequent heating of the alloy the recovery of the deformation will be caused by the transformation of martensite into austenite (OWSME). The two-way shape memory effect is instead completely similar to the previous one with the difference that the alloy is able to recover a different shape also during cooling (Fig. 2).

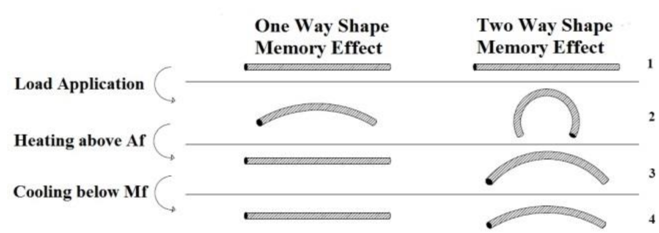
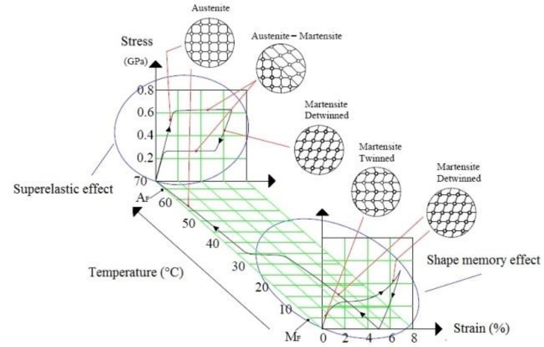


Fig. 2 Comparison between OWSME and TWSME

Finally in the superelastic alloys heating is not required for shape recovery: they are able to recover the deformation just upon stress removal (Fig. 3). This phenomenon is evident at temperatures in which the austenite is the only stable phase. The properties of the SMA just described are exploited in different fields: in the biomedical field through the realization of self-expanding stents and filters, in the safety field and fire prevention they are used in the sprinklers construction and valves, or in the civil engineering sector [4-5]. Superelastic alloys are also employed as dampers of seismic stresses, through the realization of reinforcements for masonry structures [6-7].

Fig. 3 Temperature ranges for Shape Memory Effect and Superelastic Effect



SMA’s with two-way shape memory effect allow more interesting applications than a one-way memory effect one, and it is for this reason that this property is investigated in order to understand the complex mechanisms occurring during the phase transformations [8]. However, many studies and experiments have shown that the TWSME is very unstable and tends to deteriorate after a few stress cycles. For this reason they can't be employed in industrial applications in which many activation cycles are required [9-10]. In the solar sail field a possible application has been identified too [11-15], solar power production [16] as well as in aircraft wings [17-20] and in general space applications [21-22].

MATERIAL AND METHODS

In this work it has been decided to overcome the problem of the stability of TWSME alloys by coupling OWSME alloys that allow to recover the deformation imposed, with a polymeric sheet. In this way a mechanically induced two-way memory effect has been obtained. One of the most used techniques to study shape memory alloys, in order to characterize their behavior and observe the phase stability as a function of temperature, is the resistivity test [23]. Through this technique, used with Nickel-Titanium samples, it has been possible to determine the transformation temperatures and the beginning of the shape recovery for the actuator. The temperatures characterizing a shape memory alloy (Fig. 3) are the Austenite start (As) temperatures, at which the formation of the austenitic phase begins, to which the start of the shape recovery is associated, and the Austenite finish temperature (Af), limit beyond which the alloy is completely transformed into austenite. Similarly for the martensitic phase it is possible to identify the characteristic temperatures: the martensite start temperature (Ms), in correspondence of which the formation of martensite begins while cooling within the austenitic matrix and the martensite finish temperature (Mf), temperature below which the martensitic transformation is completed. With reference to the fig. 4 it is also possible to detect the formation of a third phase in addition to those already mentioned when the alloy is cooled. This is the so-called R phase, characterized by a crystalline structure with a rhombohedral lattice, which grows as an intermediate transition phase between austenite and martensite and whose behavior and properties are still being studied.

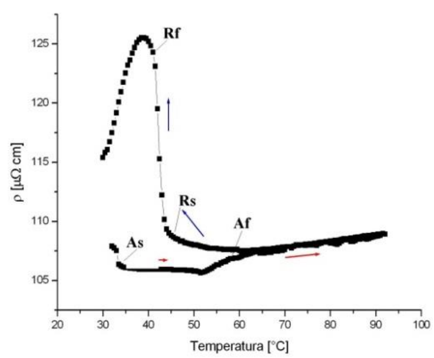


Fig. 4 Rs and Rf temperatures of rhomboedral phase on cooling (resistivity test on Ni-Ti shape memory alloys)

However, under appropriate training conditions of the alloy it has been observed that the TWSME effect is associated with the phase R in cooling, regulated by the arrangement and the number of dislocations induced in the material. The R phase also appears in heating under appropriate conditions of fatigue of the material. One of the advanced hypothesis is that this phenomenon can be associated to the degradation of the SME as this phase transformation is not associated with a thermoelastic transformation. This type of analysis provides important data on the state of the alloy, its activation temperatures, fatigue behavior and relative degradation of the shape recovery with the number of cycles [3].
The actuator proposed in this study works according to the principle of a bending sheet and is based on an active element made of NiTi alloy wire of 1.5 mm rolled to obtain a 0.5 mm thick tape, heat treated at 500° C for 5 minutes, in order to give the actuator its operational shape, and finally water quenched. The sheet thus obtained is inserted inside a 3 mm thick epoxy resin matrix, which is the element able to move back the actuator to its original configuration while the device is cooled down (fig. 5 a, b).

Fig. 5 top) undeformed – bottom) deformed shape of the NiTi sheet inside the resin matrix. Both pictures illustrate the conditions after a few activation cycles, thus involving not complete flatness of the starting configuration, increasing with the number of activation cycles.

The main purpose of the first series of samples was to test the real capacity of the resin to recover the deformation imposed by the active element. Therefore no reinforcements have been used in the matrix at this preliminary stage. The injection of the resin into the mold was followed by polymerization, with the sheet under a moderate tensile stress, in order to keep it in place during the resin polymerization (fig. 6).
After extracting the sample from the mold, it has been possible to activate the element by placing it in hot water at 60° C, temperature higher than Af in the free shape recovery, and performing several heating-cooling cycles. Fig. 5b shows the maximum deformation reached by the actuator in the hot stage and the maximum deformation recovered by cooling. A loss of the mechanical characteristics of the resin was observed due to the overcoming of the glass transition temperature during the test.

Fig. 6 Shape memory sheet under polymerization in the tensile machine

An attempt has been made to reduce the polymerization times of the resin with a heat treatment at 100° C for 2 hours. It has been decided to move in this direction in the attempt to compensate for the loss of the mechanical characteristics of the resin, providing a more rigid structure. However, the treatment causes stiffening and weakening of the matrix only at room temperature, while during the test the same behavior occurred as in the previous case.
With the aim of compensating for the loss of stiffness of the resin it has been attempted to make samples with a fiberglass reinforcement inside the matrix arranged as shown in fig. 7. At the end of a 4-day polymerization period the samples have been tested, and the composite structure immediately exhibited some problems to reach the operative configuration due to an excessive stiffening of the matrix caused by the high number of fibers placed on the upper side (tension). Therefore, a part of these has been removed, leaving the arrangement of the fiber on the compressed side unchanged. At a subsequent test, the actuator has broken down because the fibers stressed under compression, on the lower side have caused failure in the resin during the deformation.
The successive step has been the analysis of the behavior of the dispersion inside the matrix of a fine and homogeneous distribution of glass microspheres (100 μm average diameter), in order to obtain an improvement of the mechanical characteristics. The preparation of the samples has been preceded by a series of analyses on the sedimentation dynamics of the spheres inside the matrix in order to avoid deposition on the bottom side due to the difference in density between

resin and spheres (fig. 8). The samples thus obtained have been tested; no substantial improvements in the mechanical characteristics have been detected in comparison with the unreinforced resin although they are characterized by a good recovery of the deformation and stability for several activation cycles.

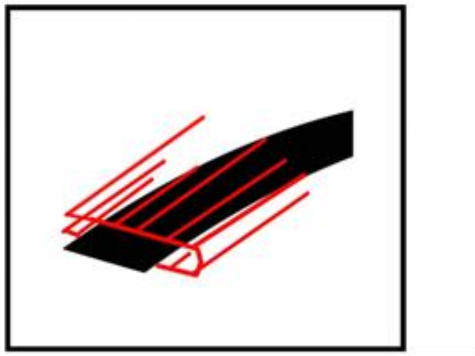


Fig. 7 Sketch of the shape memory sheet with fiber glass reinforcement inside the matrix

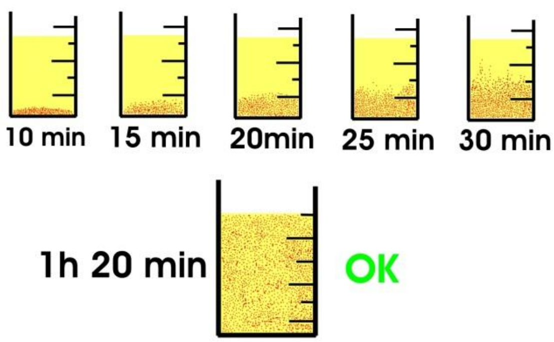


Fig. 8 Sedimentation analysis of the glass microsphere inside the resin

DISCUSSION

The experimentation carried out, in order to realize a hybrid SMA / polymer actuator, has highlighted some problems. It is possible to obtain a good stability for applications at high activation cycles, even if the shape recovery at room temperature is partial. The result of a stable mechanically induced two-way shape memory effect can be achieved. This aspect is important because the main limit of the TWSME is that the shape "memorized" at lower temperature is not stable and is gradually loss as the activation cycles proceed.

CONCLUSIONS

In order to overcome the problems associated with the degradation of the intrinsic TWSME of the alloy, with good precision and operational stability, hybrid SMA / polymer actuator have been investigated. The solution based on the use of only resin without any kind of reinforcement showed partial shape recovery. One of the possible applications of the hybrid SMA/polymer actuator could be in fire protection, starting from the concept of an actuator associated with a optic fiber to be used in the tunnels [24]. The adoption of hybrid technologies can be developed in a solution which can be reset in case of activation due to fire detection or periodically in case of test. Mounted together with a fiber cable, the SMA element would be able to bend it if the activation temperature exceeds the safety value and causing an attenuation in the signal passing through the cable is able to generate the alarm. On very long installations it is possible, by appropriately spacing the sensors, to obtain accurate informations about the position in which the alarm was generated and to observe the direction and speed of propagation of fire. The use of non-metallic materials as deformation recovery elements, even if at present they do not allow a complete reversibility of the imposed deformation, represent an interesting research field, due to their properties of lightness, flexibility, low cost.

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