Smart Actuator for Aeronautical Application

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Summary

The development of a hingeless wing by means of shape memory alloy (*sma*) system is the aim of a CIRA research project (HIWIN). In this study a suitable actuator sma wire based, named *muscle device,* has been investigated and designed in order to perform the actuation of a typical hingeled flap of a scaled wing model. Once *muscle* will finish the tests on the flap-hinged actuation and good results will be obtained, it could be used in the *adaptive wing* goal.

The *muscle device* has been designed according to the functionality requirements imposed by CIRA unmanned aerial vehicle named CR/X2. The requirements have been given in terms of max flap deflection, response time and capability to carry out external loads. The architecture of *muscle device* has been designed and modeled by means of CAD and kinematical software in order to minimize the device size. In order to choice the best *sma* alloy in the muscle device building the data of mechanical and thermal tests, performed during the activities of HIWIN project, have been used and post processed. A finite element analysis has been used to evaluate the performance of *muscle device* in terms of total stroke and maximum stress in the sma wire. The actuator has been analyzed also in the case of wrong assembly and the estimation of failure has been done. Finally a prototype of *muscle device* has been built.

Introduction

An internal CIRA project is focused on the development of an adaptive wing. This project aims at demonstrating new wing design methods and concepts, to improve aircraft performance (aerodynamic drag, structural weight, reduced size control surfaces, better control effectiveness) by adaptive structural deformations [7]. The study of an actuation system based on *sma* materials device able to actuate the flap of a small scale wing is included in this project.

In the international scenario there are many studies focusing on the adaptive wing. Into the DARPA “Smart Wing” program a scaled model of the Northrop-Grumman UCAV for aeroelastic reduction in aileron rolling moment was developed [1, 2].

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USAF and Boeing tested fin buffeting suppression systems, based on the use of piezoelectric-based macro fiber composite and active fiber composite.

In addition to collaborative efforts, NASA's Langley Research Centre is also pursuing wing concepts that allow unprecedented shape changes without surface discontinuities through internal efforts. In this concept, referred to as the fish spine concept, the main load-bearing component resembles the spinal cord of a fish covered with an elastomeric material to transfer pressure loads to the main structure. The trailing edge ribs can deflect up to ± 20 degrees in camber and ± 25 degrees spanwise. The development of new, more efficient actuation systems is complementary to the concept design efforts. NASA's Langley research continues to develop actuation systems using shape memory alloys and piezoelectric materials. Many studies has been conducted to understand the behavior of smart materials such as *sma* and piezoelectric ones in order to develop and control [3, 4, 5] the actuation system. Many attributes of SMAs are yet to be fully understood. Great attention has been used to *sma* materials that, for example, shown a complex tensile behavior depending on thermo-mechanical history.

According to the aims of the CIRA "adaptive wing" project the applicability of SMA device for controlling a classical flap surface has been evaluated. Using the sma material it would design and built an actuator sma based in order to check the compatibility with the flight loads and assure the correct reliability during the tests.

The activities will be divided in two main-milestones. The first one will evaluate the applicability of the actuators based on SMA wires on an existing wing-hinged flap scaled model. The second one will have as aim the implementation and verification of this functionality concept on a defined full scale wing-flap model.

Also the defined design of wing-flap model has been prepared highlighting the structural architecture of wing box and flap according to the sma based actuation requirements. Moreover the physical behavior knowledge of SMA alloys will be improved by means of experimental tests and measurements. Integration and optimization of the system for a CR/X2 type aircraft will be considered.

DSC analysis

Thermo-kinetic tests has been performed (by the IMBC, CNR Italy) to evaluate the principal parameters of the martensite – austenite transformation. The analysis have been done using Differential Scanning Calorimeter (DSC) technique on the following alloys:

NITINOL alloy M (produced by Memory-Metalle GmbH): wire ∅ 0,5 mm; Flexinol (produced by Memory-Metalle GmbH): wire ∅ 0,38 mm.

From the DSC curve the typical transformation temperature have been detected as reported in the following figures:

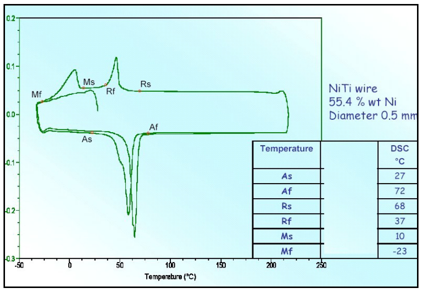


Figure 1: NITINOL alloy M DSC curve

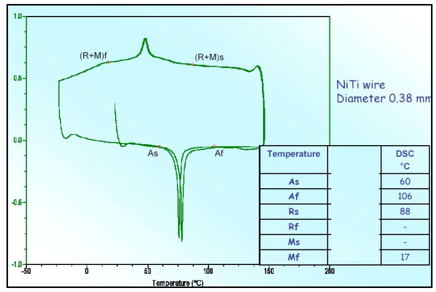


Figure 2: Flexinol DSC curve

Mechanical test

Two types of mechanical tests (by Smart material Group at CIRA, and Department of Aeronautical Design of the University of Naples) have been performed in order to evaluate the stress–deformation curve at room temperature and the sma wire behaviour under applied load. For this second test it has been analyzed the capability of the sma wire in deformation recovery during the transformation under applied load. Moreover the tests have shown the sma wire behaviour during thermal cycling.

The mechanical tests for stress – strain curve determination have been performed for NITINOL alloy M wire ∅ 1 and elastic modulus E, yield stress and max stress have been evaluated. The curves are shown in the following figure.

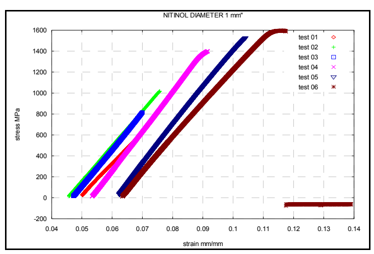


Figure 3: Stress – strain curve

Mechanical tests able to define the capability of sma wire to recovery the imposed deformation using the *martensite – austenite* transformation have been carried out applying constant load on the wire during the thermal - transformation cycle. The displacements and the temperatures have been respectively detected by means of a LVDT and a termocouple. In the following figures the results in terms of total displacements at the first thermal cycle, during the transformation cycles and the hysteretic recovery for NITINOL alloy M ∅ 0,5 mm and Flexinol ∅ 0,38 mm are shown.

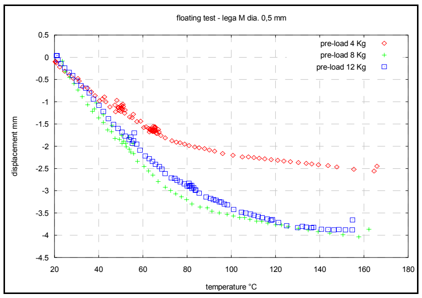


Figure 4: NITINOL recovery (1st cycle)

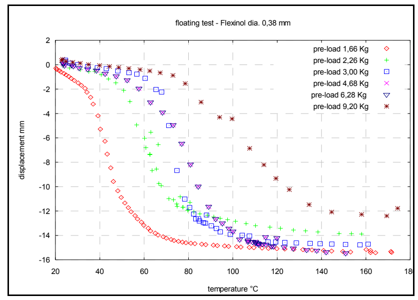


Figure 5: Flexinol recovery (1st cycle)

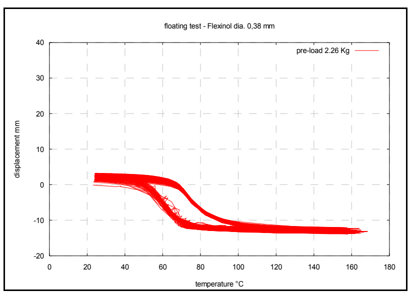


Figure 6: Flexinol recovery (cycled)

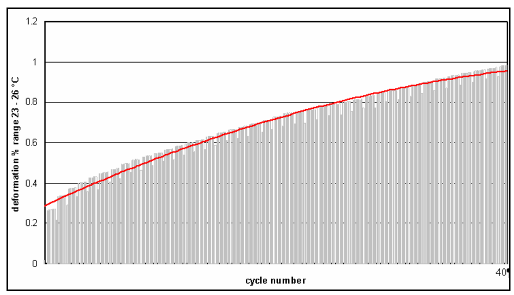


Figure 7: Flexinol hysteretic recovery

Muscle device design

The design of smart actuation of a wing flap model has needed the flap kinematism definition. In the first stage, the CR/X2 flap hinge moment has been evaluated and scaled on the experimental wing model. Using a kinematic software the flap kinematism has been optimized in terms of actuator stroke to achieve the flap rotation requirement ($\theta = 40°$). In the next figure the 3D CAD (developed by Department of Aeronautical Design at the University of Naples) model of the test article.

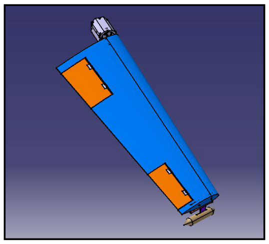


Figure 8: Wing model

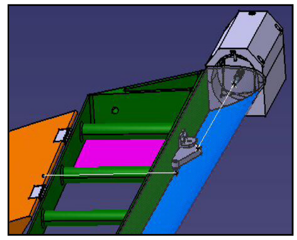
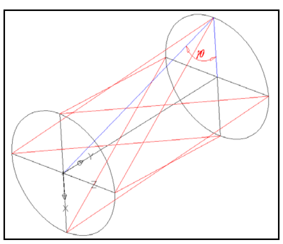


Figure 9: Detail of muscle device

Once defined the load and the flap kinematism the efforts have been focused on design of the sma actuator: *muscle device*. The muscle must be a device able to move an arm along a direction (linear actuation) using the sma wire. The recommended maximum recovery strain for the sma wire recovery is about 3% of the total wire length therefore the muscle device dimensions have been imposed by the evaluated actuator stroke. To achieve the goal of muscle device minimum size, the developed configuration has been based on a woven sma wire [6]. Regarding to the scheme in figure 10 the amplification factor ***K*** measuring the ratio between the effective stroke Δd and the sma wire displacement Δs according to the following equation:

$$K = \frac{\Delta d}{\Delta s} = \frac{d_0 - \sqrt{\left(s_0^2 \cdot (1 - \varepsilon_{sma})\right)^2 - 2 \cdot r^2}}{s_0 \cdot \varepsilon_{sma}} \quad (1)$$



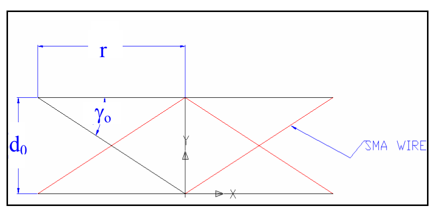
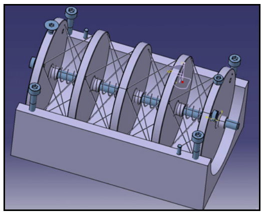
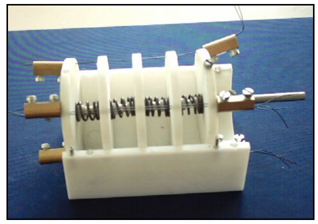


Figure 10: Muscle device scheme

Muscle device has been verified in terms of force compatibility and maximum stroke using FE analysis. Finally the active element (sma wire alloy type) has been chosen on basis of the most suitable transformation temperatures (M_s, M_f, A_s, A_f) and of the maximum recovered deformation. From the experimental tests and aircraft requirements, the most suitable alloy has been singled out in Flexinol wire ∅ 0,38 mm produced by Memory-Metalle GmbH. Muscle device has been definitively defined in terms of dimensions and parameters of preloading spring. The device has been modelled and prototyped as shown in the following figures.





Conclusions and further developments

The knowledge of the sma wire behavior needs of further investigation. The muscle device will be investigated during the flap actuation test.

Acknowledgments

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Reference

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