Improving the thermal behaviour of steel tendons by shape memory alloys

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Summary

Steel cables, tendons and tie-rods are the key components of many structures including long span bridges, roof structures and other post-tensioned steel/concrete structures. In this paper, a device concept based on the superelastic properties of Cu-based Shape Memory Alloys (SMA) is proposed to enhance the thermal behavior of post-tensioned steel elements. The effectiveness of SMA, in limiting force changes due to temperature variations, has been verified through experimental tests.

Keywords: Steel cables, tendons and tie-rods; Post-tensioning; Shape memory alloys; Superelasticity; Device concept; Air temperature variations; Experimental tests.

1. Introduction

Post-tensioned steel cables, tendons and tie-rods are used in several structures (arches, vaults, cable-stayed bridges, roof structures, etc.) against wind-induced or seismic-induced effects. Nevertheless, they suffer some limitations under service and ultimate conditions. The most important is related to the effects of air temperature variations, due to seasonal weather or radiation from sunshine, which can produce significant changes in the tensile force acting in such structural elements under service and ultimate conditions. Shape Memory Alloys (SMA) show the potentials to overcome this limitation. The basic idea is to put a proper number of superelastic SMA wires, in series with traditional steel cable/tendon/tie-rod, the length of SMA wires being little compared to that of the steel element, due to the large working strain range of SMA's. The main performance objective of the proposed SMA system is to limit force changes in steel cable/tendon/tie-rod due to air temperature variations. Additional features are related to the possibility of: (i) calibrating the stress in the system during the post-tensioning process, (ii) dissipating energy during both seismic- and wind-induced structural vibrations, (iii) avoiding buckling under negative displacements. The achievement of the aforesaid performance objectives is related to the superelastic properties of SMA's. The thermal behavior of SMA results antagonistic compared to that of steel tie-rod. Indeed, as soon as air temperature increases (decreases) the steel tie-rod tends to elongate (shorten). The consequent reduction (increase) of tension force, however, is counterbalanced by the increase (reduction) of the stress levels in the SMA wires. Concerning wind- and seismic-induced structural vibrations, improvement is related to the hysteretic energy dissipation capacity of pre-strained SMA wires. In the paper, the effects of temperature variations on the mechanical behavior of steel tendons equipped with Cu-based SMA wires are evaluated, through comprehensive experimental tests in thermal chamber. The tests have been performed considering different temperature-time histories, compatible with the temperature seasonal variations recorded in Italy in the last 30 years.

2. Results

Fig. 1 shows the test apparatus, sensor set up and typical experimental results of tests in thermal chamber. In particular, in Fig. 1(c) the performances of a steel tendon (11mm diameter, 5m length) with and without the proposed SMA unit (consisting in two 1.23mm diameter wires of 180 mm

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length) are compared. The two systems are subjected to the same air temperature-time history (see Fig. 1(b)), resembling the monthly maximum and minimum temperatures recorded in Italy in the last 30 years. As can be seen, in case of steel tendon without SMA device, the maximum increment/decrement of force result of the order of 60% and -45%, respectively. In presence of SMA device, the maximum force excursions are significantly lower, being of the order of 2% and -25%, respectively.

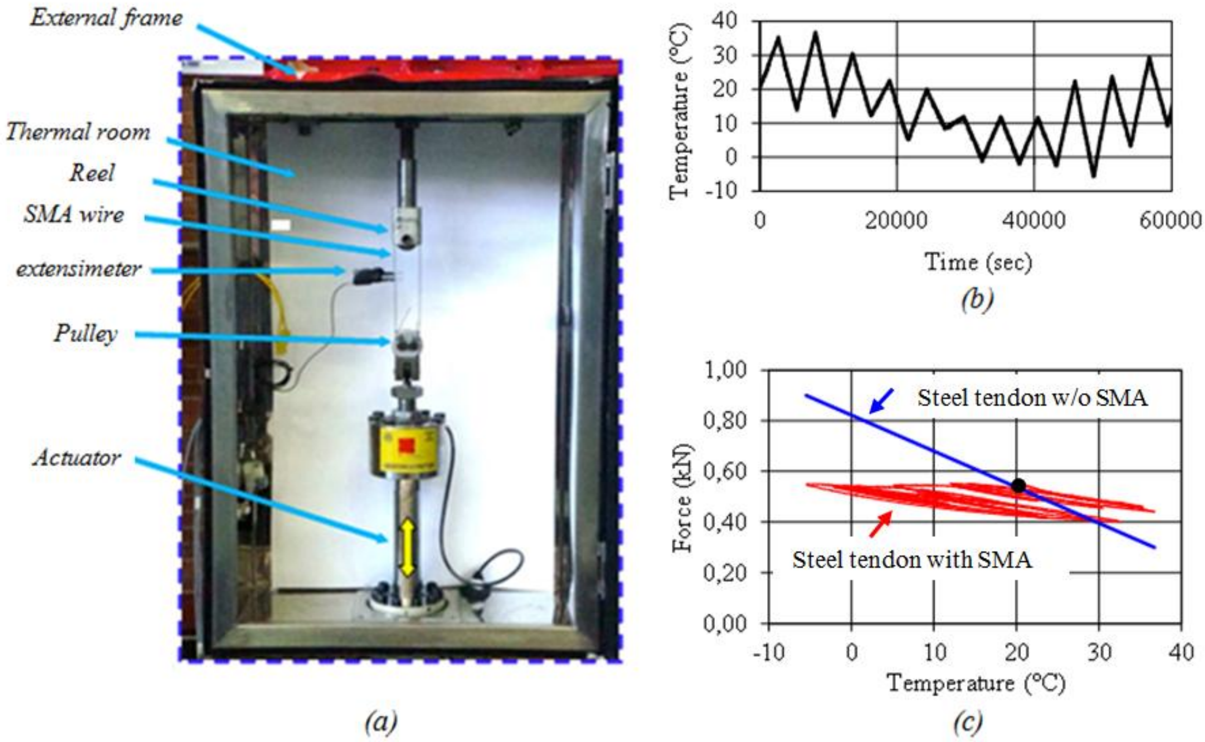

Fig. 1: (a) Test apparatus and sensor setup; (b) imposed temperature-time history; (c) comparison between the thermal behavior of steel tendon with and without SMA unit.

3. Conclusions

The experimental results of this study prove the great effectiveness of the proposed device concept in enhancing the thermal behavior of steel tendons. Using SMA, indeed, the force changes in the steel tendon, due to air temperature variations, result 80-90% lower than without SMA. The wider the operating temperature range is, the greater the advantages of the proposed solution are. The performances of Cu-based SMA turns out to be better than Ni-Ti SMA, due to their lower hysteretic behavior. The effectiveness of the proposed device concept is significantly influenced by the length ratio between steel tendon and SMA wires. The choice of the optimal length ratio shall be made taking into account both the thermomechanical properties of SMA, the work rate of steel tendon and the order of magnitude of possible effects due to wind- or seismic-induced vibrations. Based on the results of this study (in which possible effects due to wind- and seismic-induced vibrations have been neglected), legth ratios (SMA wires/steel tendon) of the order of 5% appears to be suitable.