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Shape memory alloy CuAlBe strands subjected to cyclic axial loads

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ABSTRACT

Structural cables are composed of wires helically wound into strands, which, in turn, are wound around a core. They have high redundancy and can be used to carry large tensile forces in many civil engineering structures. Better dissipation and/or recentering capacity can be expected if the cable is composed of shape memory alloy (SMA) wires in the austenite phase. Tensile tests were performed on strands made of CuAlBe SMA wires to characterize their behavior and demonstrate their potential utility as adaptive or resilient tension elements. In particular, equivalent viscous damping and forward-transformation and maximum stresses were determined for different strain amplitudes. Nearly ideal superelastic properties were obtained up to 3% axial strain. The equivalent damping increased with strain, reaching a value of 4% for a strain amplitude of 5%. Strand experimental results were used to validate a two-dimensional numerical model developed to estimate the strand response to axisymmetric loads within the superelastic deformation range. The model relies on the linearization of the wire geometry and on a multilinear CuAlBe wire stress–strain relationship. The proposed model adequately predicts the maximum strand stress and the residual strains for different strain amplitudes.

1. Introduction

Shape memory alloys (SMAs) are metallic alloys that are able to recover their original shape through a phase transformation in the material caused by the imposition of a temperature (shape memory effect) and/or stress field (pseudoelasticity or superelasticity). These unique thermomechanical properties have made SMAs a promising material for orthodontics, medical, and engineering applications. Basically, there are two phases associated with SMAs, namely the austenite phase and the martensite phase. Austenite is stable at high temperatures and low stresses whereas martensite is stable at low temperatures and high stresses. Four temperatures define the phase transformation limits: martensite start (M_S), martensite finish (M_f), austenite start (A_s), and austenite finish (A_f). Copper-based SMAs possess thermomechanical properties that make them ideal for energy dissipation and recentering devices for structural applications. However, adequate dissipation and recentering characteristics have only been achieved for small-diameter SMA wires and rods tested as single elements in tension, or in small-scale models tested in shaking tables [1–5]. Attempts to achieve the same characteristics for larger sizes required in real structures have been unsuccessful, due in part to the large variability in mechanical properties, depending on the manufacturer and thermal treatment used [6,7]. This variability makes it difficult to define representative material properties, needed for the design of a real structure.

The use of structural cables made of small-diameter SMA wires seems to be an alternative application of this material to civil structures. Cables have high redundancy and can be used to carry large tensile forces. Improved dissipation and/or recentering capabilities can be expected, if the cable is formed by SMA wires in the austenite phase.

Few tests results have been reported in the literature on SMA cables subjected to axisymmetric loads. Reedlunn and Shaw [8] conducted experiments on two commercially available Nitinol cables. The specimens were uniaxially loaded in tension, and infrared imaging was used to monitor transformation activity. The elongation rate was rather low. The response qualitatively matches the typical behavior of NiTi wires when the helix angle is low, but it differs substantially for a larger helix angle. In the latter, the hysteresis boucles are rather small and so is the energy loss per cycle. Additionally, in both cases, residual deformations are apparent.

This paper presents results from experimental and numerical studies conducted on strands made of CuAlBe SMA wires. The objectives of these studies were to characterize the behavior of SMA strands and explore their potential utility as adaptive or resilient tension elements. Parallel and twisted strands were uniaxially loaded considering constant and variable strain amplitudes. Then, the equivalent viscous damping (ξ), and forward-transformation (σ_t) and ultimate (σ_u) stresses were determined from the stress–strain curves, for each maximum strain. In addition, strand experimental results were used to validate a two-dimensional (2D) analytical discrete model to estimate the cable

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