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An algorithm to simulate the one-dimensional superelastic cyclic behavior of NiTi strings, for civil engineering applications

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ABSTRACT

An algorithm to model the one-dimensional cyclic behavior of NiTi strings is addressed. The NiTi alloy belongs to the shape memory alloy class of materials, therefore it presents both shape memory effect, for thermally-induced cycling, and superelasticity, for stress-induced cycles. The superelastic property has been the basis of some devices designed to mitigate the earthquake hazard level in structures. Throughout this paper the implementation of a one-dimensional cyclic behavior algorithm to model the NiTi constitutive relation is presented, supported by the thermomechanical formulation developed by Lagoudas and co-workers. The model was set up in MatLab environment and it accounts for isothermal superelastic behavior, incorporating minor hysteretic transformation loops. The definition of the transformation hardening function allowed for a better adjustment of the numerical model weighted against experimental results. Especial emphasis was given to the process of calibration of the model, regarding the definition of material parameters. The validation process consisted of the comparison between the results achieved with this algorithm and experimental tests performed at the Pacific Earthquake Engineering Research Center at the University of California at Berkeley. Quasi-static tensile tests and shake table tests of a small-scale steel structure with NiTi cross-bracing systems were used as reference. The model was able to simulate the experimental performance. This formulation can be implemented in more robust finite element analysis software, in order to perform studies in more elaborate structures.

1. Introduction

Shape memory alloys (SMAs) are a class of materials, which possess particular thermomechanical, thermochemical or thermoelectric properties, which allows for the phase transition between two solid phases. The Nickel–Titanium (NiTi) alloy is one example of such materials and it has specific properties, which justify its usage in civil engineering applications. Amongst other properties, this alloy has the capacity of undergo large strain deformation and recover its original shape, through stress or temperature induced cycles. Energy dissipation is also associated with this hysteretic cyclic behavior.

This paper intends to develop an algorithm that models the uni-dimensional behavior of NiTi wires, based upon the thermomechanical formulation of Lagoudas and co-workers [1]. Its accuracy was tested against experimental results of works performed at the Pacific Earthquake Engineering Research Center in the University of California at Berkeley [2].

2. Properties

Although there are several different alloys with shape memory properties, the Nickel–Titanium (NiTi) alloy is the one that presents the best performance for civil engineering applications, due to its capacity to recover from significant strain, hysteretic energy dissipation and resistance to corrosion higher than most iron based metals.

The shape memory alloys may exist in two different crystal configurations, the austenitic and the martensitic. The austenitic phase is stable at higher temperatures and it is stiffer. The martensitic phase is stable for lower temperatures and it is more deformable.

A stress-induced deformation of a material in its martensitic state leads to a change from a detwinned form of its crystals to a twinned configuration associated with large strain, which is mostly nonrecoverable. This phenomenon is designated as pseudoplasticity (Fig. 1). In order to recover the undeformed shape, energy has to be introduced in the system through heating. This causes the shape memory effect, where the SMA regains its original austenitic configuration (Fig. 1). At higher temperatures where there is only the austenitic phase for zero stress loading, stress-induced deformation occurs associated with a phase transformation from austenite

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