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MODELLING THE CONSTITUTIVE BEHAVIOUR OF MARTENSITE AND AUSTENITE IN SHAPE MEMORY ALLOYS USING CLOSED - FORM ANALYTICAL CONTINUOUS EQUATIONS

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Summary: Shape Memory Alloys (SMAs) are attractive materials for a variety of applications and are particularly promising in the creation of compact and powerful actuators due to their high energy density and high specific actuation stresses. Additionally, they offer various other advantages such as high reversible strains, smooth and silent actuation, scalability (down to micrometers) etc. SMAs, however, are characterized by extreme non-linear and hysteretic behaviour and therefore designing actuators for sophisticated applications, e.g. position control, is non-trivial. One of the approaches used to facilitate the development of control algorithms for SMA actuators is model-based design, where mathematical models that predict the non-linearities are directly included online in control strategies.

While several models describing SMA behaviour from various domains have been proposed over the past decades, there is a divergence between model accuracy and computational efficiency i.e. the models that are accurate are computationally expensive and although some numerical solutions exist, they are still not conducive to be used in control loops. On the other hand, the models that are computationally inexpensive are often too elementary and their implementation, while straightforward is error-prone because of the use of series of conditional statements.

This paper presents a phenomenological constitutive model for martensite and austenite in SMAs with a focus on computational efficiency, implementational simplicity and the model's eventual use in a control strategy. The model is built around the mathematical description of the typical form present in stress-strain curves in SMAs using closed form, continuous, differentiable equations and continuity conditions imposed when the strain changes direction. The parameters are few, physical and easy to identify from a monotonic tensile experiment and a simple parameter identification process. The model is able to predict the behavior of martensite and austenite when exposed to both monotonic as well as cyclic loading and unloading. Tensile iso-thermal experiments are then performed for validation and the model predictions are shown to be in good agreement with experimental data. Since the model is based entirely on continuous analytical equations, it is extremely computationally efficient and, thus, can be used as a basis towards the development of model-based control algorithms.