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Title of PhD subject: *Experimental study of the thermomechanical behaviour of shape memory alloys using coupled full-field measurements*

Context

In response to current ecological challenges, the development of lighter materials is a major research topic. Shape memory alloys (SMAs) are among the materials of interest, particularly due to their superelastic properties and shape memory effect. Some SMAs, for example, help reduce vibrations in aircraft engines, allowing for more compact and lightweight designs.

However, SMAs are particularly difficult to study experimentally due to the thermo-metallurgical-mechanical couplings induced during their phase transformation [1]. Investigating these couplings requires rich datasets to distinguish the effect of each mechanism and to identify constitutive laws, which often depend on numerous parameters. Full-field measurement techniques are thus favoured over local measurements to assess heterogeneities that may appear during testing.

Nevertheless, despite the well-established expertise in thermal and kinematic field measurement techniques, simultaneously measuring both quantities with high metrological performance remains a major challenge. Thermal and kinematic measurement methods require different measurement approaches and assumptions to be applied under optimal conditions.

Recently, Jones proposed in [2] a method combining thermophosphor (TP) paint and digital image correlation (DIC) for coupled measurements (TP + DIC). This method uses TP paint to create a speckle pattern on the sample surface. The thermal field is then obtained using standard cameras by exploiting the paint's photosensitivity to temperature variations when excited by ultraviolet radiation. This technique enables the simultaneous measurement of both fields on high-resolution images without interpolation. However, the pattern obtained with this paint is very coarse, significantly reducing the metrological performance of the kinematic field measurements.

Challenges

This thesis is divided into two parts, addressing two distinct challenges. First, a coupled kinematic and thermal field measurement method will be developed based on Jones' work. This coupled method will be applicable to a wide range of materials used in various industries. The research team involved in this thesis has recognised expertise in field measurement techniques and is beginning to work on these coupled measurements [3].

Once the method is developed, it will be used to study the austenite-martensite phase transformation during the cooling of an SMA sample. The combined kinematic and thermal data will provide a better understanding of the mechanisms involved in the phase change. Energy balances will be established based on the richness of the obtained data.

Methods

From an experimental perspective, the Localized Spectrum Analysis (LSA) [4], developed by the Experimental Mechanics team at Institut Pascal, will be used to address the speckle challenges encountered in Jones' work. This thesis first aims to extend the (TP + DIC) concept to (TP + LSA). The TP paint grid engraving will provide an optimal speckle pattern on the sample surface while remaining sensitive to temperature variations. Once the method is developed, a study on its metrological performance will be conducted.

In the second phase, this method will be applied to study the austenite-martensite transformation during the cooling of an SMA. This phase will rely on the involvement of the Centre des Matériaux at Mines-Paris in the thesis. The obtained data will first help enrich the currently available datasets and improve our understanding of the physical phenomena involved in the phase transformation. Subsequently, energy balances will be conducted to quantify stored energy levels and energy barriers to be overcome during the phase change. This will involve identifying heat sources present during the transformation process.

This multidisciplinary thesis will, therefore, be based on experimental developments (experimental protocol and testing), numerical methods (coupled field measurement method developed in Python), and materials science (energy balances, analysis of transformation mechanisms).

References

[1] Maynadier A., et al. Procedia Engineering (10), 2011.
[2] Jones E. M., et al. Strain, (58), 2022.
[3] Jailin T., et al. BSSM conference, Liverpool, United Kingdom, 2024.
[4] Grédiac M., et al. Experimental Mechanics (59), 2019.