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Multiscale energy analysis of phase change localization in monocrystalline shape memory alloys

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1. Topic

The present work deals with solid-solid phase change and is founded on the global and local construction of energy balance during load-unload cycles. Such a construction requires information derived from infrared thermography (IRT) and digital image correlation (DIC). During cyclic tensile tests, the energy fields associated with a CuAlBe single crystal allowed the propagating bands of phase change front to be exhibited. The heat involved in the transformation was essentially made of latent heat of phase change, the mechanical energy dissipation remaining of low intensity. A 3D modeling was then proposed in the framework of the generalized standard material formalism in which the phase change appears as an anisothermal coupling mechanism accompanied by a low intrinsic dissipation. The good qualitative agreement between experiments and simulations legitimated the physical interpretation proposed for the phase change.

2. Rough outline

The literature proposes various approaches to model the behaviour of shape memory alloys (SMA). Some authors based their models on the crystallographic origin of the solid-solid phase change [1, 2], whereas others developed phenomenological models taking into account classical thermodynamic descriptions of state change [3]. Finally, models using material plasticity concepts can be found [4].

In order to improve the solid-solid phase change understanding, the present communication intends to show that a better characterization of the energy effects and localization mechanisms accompanying the phase transformation is necessary. In this perspective, we briefly introduce the thermomechanical framework used to describe the experiments will be briefly introduced. The energy balance associated with a load-unload cycle has to be particularly detailed in order to show the different possible energy contributions that can lead to a hysteretic behaviour.

Then, some experimental results obtained during a uniaxial testing of single-crystal CuAlBe samples are presented. Kinematic and calorimetric effects associated with the phase change inception and with its localized propagation were monitored using full-field DIC and infrared IRT measurements. Global and local energy balances confirme the predominance of latent heat of phase change with respect to the dissipated energy, as already observed with polycrystalline SMA [5].

Finally a voluntarily simple mono-variant thermomechanical model, taking into account the previous energy properties, is proposed. Several numerical simulations show the main role played by

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temperature variation during stress-induced phase change. The thermo-sensitivity of CuAlBe SMA (material effect) together with the heat diffusion (structure effect), give the material a rate-dependent behaviour, generate hysteretic responses and contribute to the localized development of phase transition.

Figures 1 and 2 propose a qualitative comparison between experimental and simulated results, extracted from uniaxial load-unload cycles. Local stress-strain responses are plotted in Fig.1a. They illustrate the heterogeneous character of the transformation associated with the propagation of phase change fronts that move throughout the specimen gauge part. The size of the hysteresis loops indicates the phase change advance at a given location. In Fig.1b, the corresponding paths are plotted in the phase diagram. During the phase change, the anisothermal responses are grouped within a narrow domain that corresponds to the so-called transition domain (dashed zone). From a modelling standpoint, the hysteretic responses shown in Fig.2a are induced by : (i) a strong thermosensitivity of the material during the phase change, (ii) the existence of a latent heat and (iii) the diffusion mechanisms. No intrinsic dissipation was introduced and the transition domain was voluntarily reduced to a transition line, clearly visible in Fig.2.b. The model also provides fields of phase change proportion that progress similarly to the experimental ones.

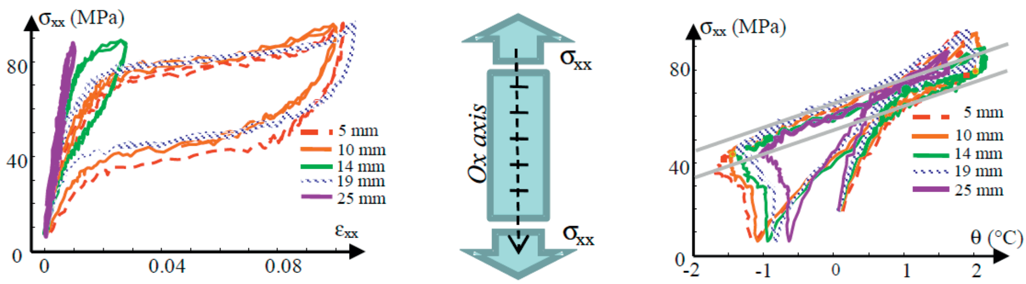

Fig. 1. (a) Experiments: local stress-strain responses at different locations chosen along the longitudinal *Ox* axis ; (b) corresponding paths in the phase diagram.

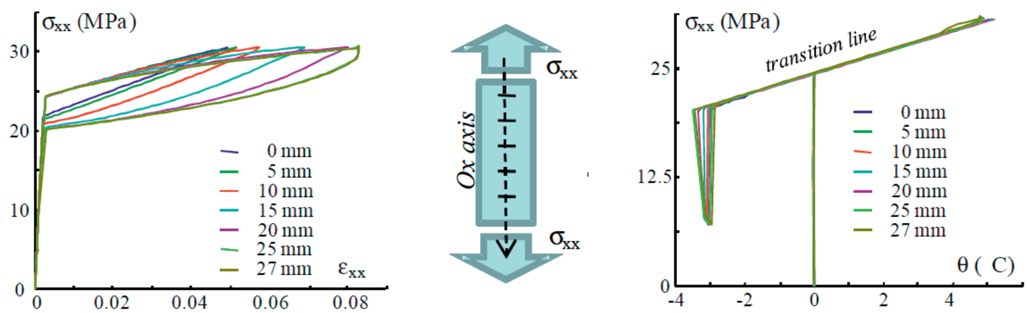

Fig. 2. (a) Simulations: local stress-strain responses at different locations chosen along the longitudinal *Ox* axis ; (b) corresponding paths in the phase diagram.

References

1 R. Abeyaratne, S. Vedantam, Int. J. of Non-Linear Mechanics 40, 177-193, (2005)
2 N. Bubner, Continuum Mech. Thermodyn., 8, 293-308, (1996)
3 B. Chang, J. Shaw, M. Iadicola, Continuum Mech. Thermodyn., 18, 83-118, (2006)
4 B.Vieille, J.F. Michel, M.,L. Boubakar, C. Lexcellent, Int. J. of Mech. Sci, 49, 280-297, (2007)
5 R. Peyroux, A. Chrysochoos, C. Licht, M.Löbel, Int. J. of Engng Sci., 36, 4, 489-509, (1998)