STRESS-INDUCED MARTENSITE TRANSFORMATION IN TINI SMA - EXPERIMENTAL ESTIMATION OF ENERGY BALANCE

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An equation for energy balance of the martensite forward and reverse transformation in shape memory alloy (SMA) on the basis of the laws of thermodynamics, applied to homogeneous thermodynamical processes [1], under some assumptions was obtained:

$$c_p dT + dq = \frac{\gamma\sigma(z)}{\rho} dz + \frac{1}{2}\gamma\frac{c_M}{\rho}(M_S + A_S)\,dz - \alpha\frac{T\Delta\sigma}{\rho},$$ where:

$c_p dT$ - the heat related to the SMA specific heat; dq - the heat exchange with surroundings;

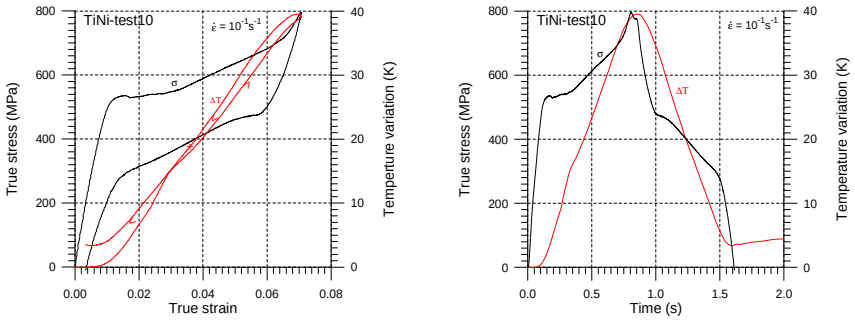
$\gamma(\sigma/\rho)\,dz$ - the work done by testing machine in order to deform the specimen;

$\frac{1}{2}\gamma\frac{c_M}{\rho}(M_S + A_S)\,dz$ - the term of thermomechanical couplings, related to martensite formation.

The last part of the equation, called piezocalorimetric effect, is neglected in the analysis, since its value is not significant. For example, for 39K, recorded for the highest strain rate $10^{-1}s^{-1}$, is as follows:-10x10^{-6}/K x 312K x 800MPa/ 6.45g/cm^3 =0.38 [J/g]. So as average contribution, 0.19 [J/g].

Parameters of the martensite transformation; c_M , M_S , A_S , γ were identified from tension test carried out on the TiNi shape memory alloy at three various temperatures with very low strain rate. As a result, it was found: $c_M = 5.62\,MPa/K, M_S = 228K, A_S = 282K, \gamma = 0.07$. The value of $\alpha = 10\text{x}10^{-6}$/K has been given by the TiNi SMA producer - Furukawa Electric Co., while the material density $\rho = 6.45\text{g/cm}^3$ was measured by the author. Basing on the above equation, completed by the estimated material parameters as well as by the thermomechanical data found for the TiNi shape memory alloy tension tests performed with various strain rates, an energy balance for the stress-induced martensite transformation has been calculated. Thermal data, namely the temperature increase accompanying the exothermic martensite forward transformation, and the temperature decrease, accompanying the reverse endothermic transformation, were recorded in contact-less way by a high quality infrared camera. The calculations have been made for three various strain rates; $10^{-1}s^{-1}$, $10^{-2}s^{-1}$ and $10^{-4}s^{-1}$. Finally, the following data, depending on the strain rate, were estimated.

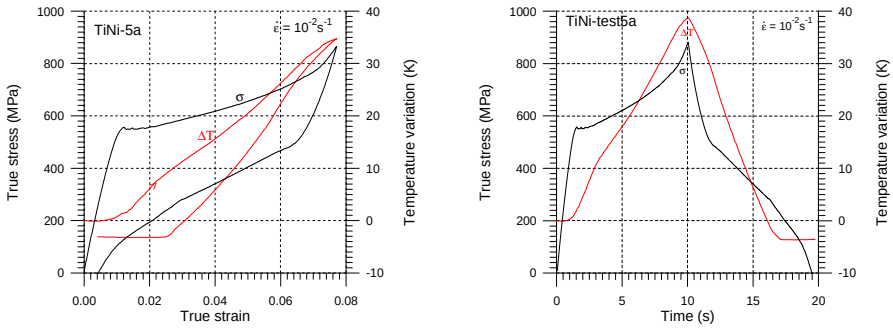
$\dot{\varepsilon} = \mathbf{10^{-1}s^{-1}}$; $\Delta T_{MARTENSITE}$ =39K, $\Delta T_{REVERSE}$ =36K, γ =0.07, z=0.95, c_M =5.62MPa/K, M_s=228K, A_s=282K



During the martensite transformation:
17.94 [J/g] + q = 6.17 [J/g] + 14.77 [J/g]; so the estimated heat exchange q = 3.0 [J/g].

During the reverse transformation:
-16.56[J/g] + q=-3.28 [J/g]-14.77[J/g], so the estimated heat exchange q =-1.49 [J/g].

$\dot{\varepsilon}$ =10^{-2}s^{-1}; $\Delta T_{MARTENSITE}$ =34K, $\Delta T_{REVERSE}$ =35K, γ=0.07, z=0.95, c_M =5.62MPa/K, M_s=228K, A_s=282K



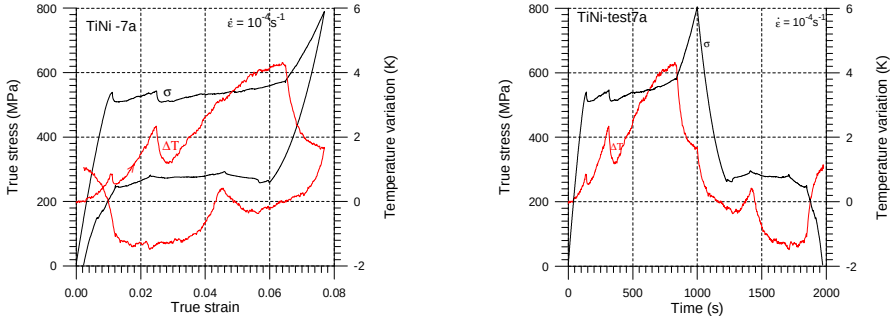
During the martensite transformation:

15.64 J/g + q = 5.89 J/g + 14.77[J/g]; so the estimated heat exchange q =5.02 [J/g].

During the reverse transformation:

-16.1 [J/g] +q =-2.89 [J/g]-14.77 [J/g]; so the estimated heat exchange q =- 1.56 [J/g. K].

$\dot{\varepsilon}$ =10^{-4}s^{-1}: $\Delta T_{MARTENSITE}$ =4.2K, $\Delta T_{REVERSE}$ =-1, γ=0.07, z=1, c_M =5.62 MPa/K, M_s=228K, A_s=282K



During the martensite transformation:

1.93 [J/g] + q = 4.59 [J/g] + 15.55 [J/g]; so the estimated heat exchange q = 18.21 [J/g].

During the reverse transformation:

-0.46J/g+ q =-1.17 [J/g]-15.55 [J/g]; so the estimated heat exchange q= - 16.25 [J/g].

One can notice that irrespective of the strain rate applied, the heat of the new phase formation is much higher than those, supplied by the testing machine in order to deform the TiNi specimen, so the obtained results confirm the prediction of the phase transformation in SMA theory [1]. Furthermore, as it was found from comparison of the obtained results, the higher the strain rate, the higher the temperature changes and the lower the heat that transfers to the surroundings. So the obtained data of the martensite transformation energy balance seem to be reasonable.

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