THERMOELASTIC ANALYSIS OF PHASE TRANSITION IN NI-TI SHAPE MEMORY ALLOYS

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The thermoelastic effect states that, when applying a tensile load to an isotropic material with positive thermal expansion coefficients, as most metals are, the material undergoes cooling. Beyond the point at which inelastic deformation occurs, often referred to as the *thermoelastic limit*, the dissipation of mechanical energy acts in a sense opposite to the thermoelastic effect, thus heating the material [1]. In metals, the detection of the thermoelastic limit allows one to measure with great accuracy the yielding point [2]. The thermoelastic effect can be also applied to measure the effective stress distribution during mechanical loading. This method involves the application of a cyclical load at a rate sufficient to exclude the effect of heat conduction [3]. The measurement of the temperature variations during a monotonic quasi-adiabatic loading has also been related either to the presence of damage [4] or to the non-homogeneous presence of different phases in the material [5]. Dealing with shape memory alloys (SMA), these present a shape recovery effect, with a slight residual deformation [6]. This effect may induce significant forces as far as the austenite-martensite transformation proceeds [7]. Moreover, the single crystals of the alloy undergo different deformations, which contribute to the anisotropy of the metal and generate significant gradients of temperature [8].

Point-like thermoelastic measurements were performed during tensile tests on Ni-Ti (50.8%) coupons with a grip length of about 40 mm. For this alloy, Ms temperature was around 10°C. Loading was carried out in displacement control mode using a Zwick 1488 thermomechanical testing machine with hydraulic jaws. Different loading rates between 2 and 15 mm/minute were applied. The tests were monitored by thermal emission using a thermistor with a 30 Ω resistance. The temperature data were acquired using the DITE (Damage Investigation by Thermal Emission) system, which is capable to control simultaneously also the tensile machine and described in [4]. The sensitivity of the DITE is around ± 2 mK, after insulating the test chamber with a Plexiglas structure. The tests indicated that the phase transformation occurred at an average stress of approximately 520 MPa. The strain at the end of the transformation was approximately 7.2 % and the residual strain was around 0.3 %. The cooling down due to the thermoelastic effect was clearly observable at different loading rate and the measurement of the thermoelastic limit was possible in the whole range between 2 and 15 mm/min (Fig.1). The test conditions remain therefore quasi-adiabatic even at the lowest loading rate applied. This ensures the possibility to perform thermoplastic measurements not only during very fast loading, a condition far removed from that encountered during the operation of the material, but also with more usual loading rates.

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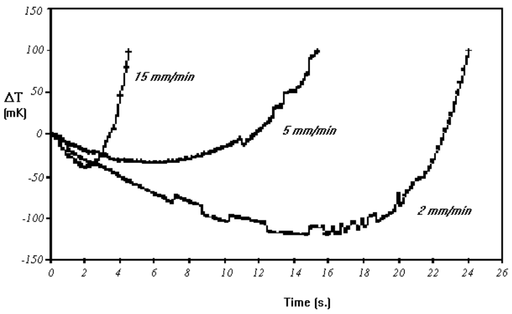

Fig.1 Variation of temperature during loading at different rate

A possible analysis of thermoelastic data consists in observing the modification of the temperature-time curve during the reloading of a material already loaded to yielding and unloaded. In the case of aluminium alloys, during reloading, the decrease of temperature due to the thermoelastic effect was less evident during reloading [9]. This is true also in Ni-Ti alloys and can be explained by the presence of some residual strain and by the increase in material toughness due to the incipient phase transformation (Fig.2). Again in Fig.2, a sudden heating is measured approximately around the thermoelastic limit. This indicates the presence of residual stresses, which are gradually distributed during subsequent loading. The sudden heating is clear during the loading and also during the first reloading, whilst it disappears in the second reloading. This effect can be also due to the incipient presence of some martensite that contributes to the non-homogeneity and hence to the anisotropy of the alloy. A similar behaviour is indicated also by the thermoelastic measurements during the phase transformation at constant stress (Fig.3). In this case, a first loading up to a strain of 1.5% indicated a continuous oscillation of temperature. After discharging it, the material was reloaded a second time. During reloading, the increase of temperature was constant for all of the specimens tested. This most probably indicates that the martensite formed during the first loading has diffused and hence stress concentration is disappeared. Another possible cause of stress concentration can be nevertheless the presence of surface defects due to machining (Fig.4). From these results it may be observed that the point-like thermoelastic analysis can be a useful tool for materials investigation. In the case of shape memory alloys, a further development can be the stress monitoring on the whole surface of the material. A number of systems are today available for this analysis [10].

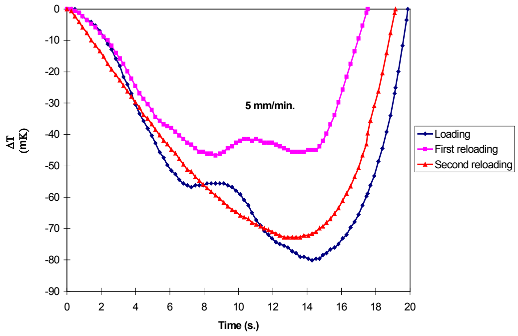

Fig.2 Variation of temperature during repeated elastic loading

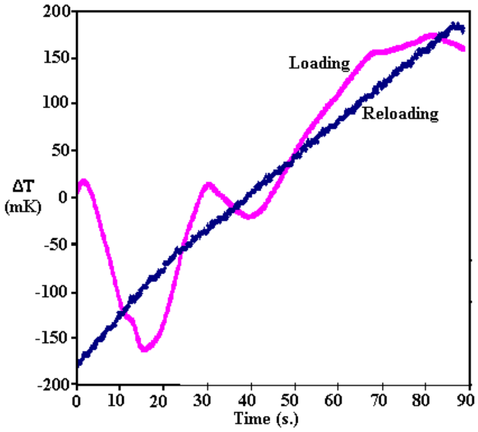

Fig. 3 Variation of temperature for repeated loading during phase transformation

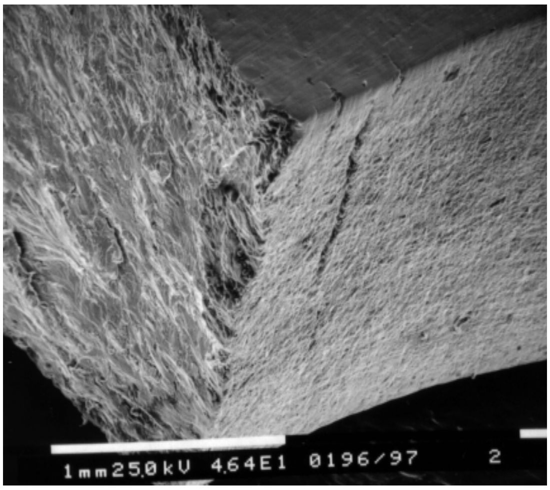

Fig.4 Fracture surface (46x) of the alloy

REFERENCES

1. E.H.Jordan, B.I.Sandor, *J. Testing Eval.* **6**, 1978, 325-331.
2. M.G.Beghi, C.E.Bottani, G. Caglioti, *Res Mech.* **19**, 1986, 365-379.
3. J.M.Dulieu-Barton, *Strain* **35**, 1999, 35-39.
4. A.D.Melvin, PhD thesis, Loughborough 1991.
5. A.D.Melvin, A.C.Lucia, G.P.Solomos, *Comp. Sci. Tech.* **46**, 1993, 345-351.
6. T.W.Duerig, K.N.Melton, D.Stoeckel, C.M. Wayman, *Engineering aspects of shape-memory alloys* (Butterworth-Heinemann, London, 1990)
7. P.Olier, J.C.Brachet, G.Guenin, *Journal de Physique IV*, C2 **5,** 1995, 217-223.
8. M.Somerday, R.J.Comstock, J.A.Wert, *Phil.Mag. A* **75,** 1997, 1193-1207.
9. N.Rajic, A.K.Wong, Y.C.Lam, *Exp. Tech.* **20**, 1996, 25-27.
10. G.C.Calvert, *Strain* **35**, 1999, 67-71.