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Deformation energy of NiTi shape memory wires

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ABSTRACT

Deformation energy of NiTi wires with B2 and R phases was studied by the multiple tensile testing (MTT) method. In traditional materials, the total energy required to tear specimens is assumed to be the sum of elastic, uniform plastic, and post-uniform or tearing energy components. For the shape memory alloys, however, this classification is not valid due to their unusual superelastic/shape memory characteristics. Using a modified MTT method, different energy components were calculated by plotting different combination of deformation energies divided by the specimen cross-sectional area against the gage length of the specimens. The slope of the obtained straight line demonstrates the summation of the elastic, superelastic/shape memory, second elastic, and plastic energy per unit volume and its intercept gives the value of tearing energy. It was found that the uniform plastic energy per unit volume for the R-phase wires was considerably higher than that for the B2-phase wires. This caused a marked enhancement in the total deformation energy of the R-phase wire, as compared to the B2-phase wire. The effect of strain rate on the tensile behaviour and deformation energies of these materials was also investigated. Except the plateau stress of the tensile curve which was raised for both wires, the B2-phase wires were almost strain-rate-independent, whereas the R-phase wires were significantly influenced by the variation in strain rate.

1. Introduction

NiTi alloys have been subject to extensive researches because of their unusual characteristics such as superelastic and shape memory effects. The applications of these alloys in various fields of engineering and medicine have made them one of the most controversial materials. Shape memory effect is the ability of a material to remember its shape, even after quite severe deformations, by increasing temperature. Another interesting characteristic of NiTi alloys is the superelastic effect which causes large recoverable strain after unloading the B2 parent phase [1,2]. Near-equiatomic NiTi alloys exhibit three different phases: parent phase (B2) with cubic crystal structure, martensitic phase (B19′) with monoclinic crystal structure and intermediate phase (R) with trigonal crystal structure [3,4]. Among many possible ways of obtaining R-phase, aging at different conditions seems to be more common [5,6]. Different studies on NiTi alloys have reported pseudoelasticity [3] and shape memory effects associated with B2 → R transformation [7–9]. The concept of multiple transformations is very popular due to the importance of variation in the microstructure. For example, B2 → B19′ transformation presents considerable superelastic effect and produces detwinned B19′ at the end of plateau region. Moreover, the same phase is formed due to R → B19′ transformation with a considerable shape memory effect [1,3].

Tensile stress–strain curves of NiTi wires having different initial states of B2, R, and B19′ have been investigated [8–11]. Due to the unusual characteristics of these wires, the classification of different parts of the tensile diagrams is rather different from that of the traditional materials. Depending on the initial microstructure, stress–strain curves of NiTi wires can exhibit linear elastic, shape memory/superelastic, plastic, and tearing or failure regions. The observed variety of the deformation energy components together with the high level of strain recovery caused by the shape memory/superelastic effects, introduce these wires as potential candidates for energy-absorption applications.

The study of ductile plastic and tearing energies has mainly been focused on sheets and tubes, and rarely on wires. Among all experimental methods, there are two techniques that are applicable in the determination of the plastic and tearing energies of wires. In the single tensile testing (STT) method, which uses a single tensile specimen, tearing energy is obtained by subtracting uniform plastic deformation energy from the total energy absorbed by a specimen [12,13]. In the multiple tensile testing (MTT) method, different test-pieces of various gage lengths are employed and tearing energy is calculated by plotting the total energy divided by the specimen cross-sectional area against the gage length of the specimens [14]. This method has been used previously for the determination of the plastic deformation energy and tearing energy of aluminium, copper and brass [15,16], and recently for AZ31 magnesium sheets [17]. The use of MTT method in wires, however, is confined to the study of austenitic and martensitic NiTi

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