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A passive damping device with TiNi shape memory alloy rings and its properties

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Abstract

TiNi SMAs possess a high damping capacity both in the austenite and martensite state and can be used for energy absorbing and vibration damping applications. The main research object has turned to develop damping devices which contain SMAs members now. However, most SMAs damping elements in the energy dissipating devices are in the form of wires. A new kind of passive damping device that is composed of TiNi shape memory alloy rings was manufactured in this paper. The rings are made of TiNi strip with 1 mm thick and 25 mm wide. The inelastic properties of the device were investigated and its damping capacity analyzed. There still exist hysteresis loops during loading and unloading when the deformation of the rings is restricted properly, but the nominal stress–strain curves are titled and not parallel to the abscissa in the superelastic range. It may be of benefit to over loading that nominal stress–strain curves vary with the load and do not maintain in a constant value during the whole loading and unloading process. Otherwise, the damping properties of the device may be changed by adjusting the movable parts of the device to apply a pre-strain on the rings or by using different pieces or sizes of rings.

Keywords: TiNi; Shape memory alloy; Superelasticity; Hysteresis; Damping capacity

1. Introduction

Near-equiatomic TiNi Shape memory alloys (SMAs) possess some advantageous properties including the shape memory effect (SME), pseudoelasticity or superelasticity, high damping capacity and corrosion resistance [1,2]. The high damping capacity is considered as one of the important functional properties of TiNi SMAs and can be used for energy absorbing and vibration damping applications [3–5]. TiNi SMAs possess a high damping capacity both in the austenite and martensite state. When used in the range of SME, the heating and cooling are needed because the phase transformation is temperature-induced. But in the pseudoelastic state, the austenite–martensite phase transformation is induced by stress/strain loadings above a critical temperature. So the superelastic SMAs which have both high-energy dissipation capacity and large reversible deformations have attracted increasing attention as a damping material where the heating and cooling are difficult to realize, especially in various mechanical, civil and aerospace applications [1,4–11].

The damping mechanism of SMAs has been studied extensively and it is well-known that the high damping capacity of shape memory alloys is closely related to the thermomechanical internal friction of the materials [12–16]. Nowadays, the main research object has extended to the area of damping devices which contains SMAs members. However, SMAs wires are used as damping elements in the most energy dissipating devices [1,4,11,16–18]. Because there is limitation of properties of SMAs wires, the damping elements in other forms were also investigated, such as solid and hollow bars [10,18–21]. In this paper, a new kind of passive damping device which is composed of TiNi ring is manufactured. There are two sliding blocks in the device, which can act a pre-stress to the TiNi rings. The inelastic properties of the device were investigated and its damping capacity analyzed.

2. Experimental procedure

2.1. Alloy

TiNi shape memory alloy with Ni 50.8 at%, Ti 49.2 at% was used in this study. The SMA strips were annealed at 823 K

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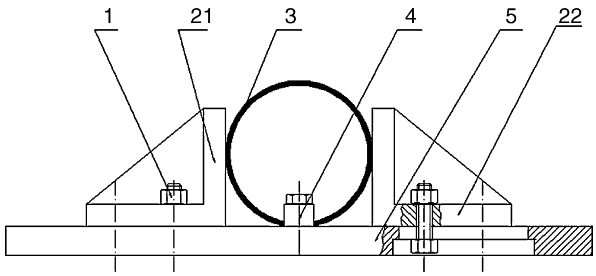

Fig. 1. Scheme of damping device: (1) bolts for the fixation and adjustment of sliding blocks, (21 and 22) sliding blocks, (3) shape memory alloy rings, (4) fastening bolt of the rings and (5) foundation plate.

for 30 min in order to low their stiffness, and the softened strips were fixed in a mould to form the designed round ring shape. The samples in the mould were solubilized at 1173 K for 20 min and quenched in water at room temperature, then annealed at 523 K for another 20 min and cooled in water too. The measured transformation temperatures were $M_s = 283$ K, $M_f = 265$ K, $A_s = 273$ K and $A_f = 289$ K.

2.2. Design of damping device

TiNi rings as damping element used in the damping device were made of a strip with 1 mm thick and 25 mm wide. The free ring's diameter is 96 mm and the scheme of damping device is shown in Fig. 1.

In this device, the deformation of SMA rings may be restricted by the two sliding blocks (21 and 22). By adjusting the two blocks' interval, the rings may be in stress-free or pre-stressed form, i.e., shortening of the distance between the two sliding blocks by shifting them together will produce a pre-strain in SMA rings. Furthermore, there may be more than one piece of SMA ring used in the device when needed. These variations will cause the change of output force and damping capacity and make the device suitable for more wide uses.

2.3. Loading–unloading tests

The loading–unloading tests of the device were conducted on a fatigue testing machine. A press force is applied vertically on top of the ring, and the cross head with a diameter of 35 mm moves at 20 mm/min. The test temperature was 285 K and the alloy would exhibit pseudoelastic properties at this temperature.

TiNi rings undergo a nonuniform strain when a force applied and generate nonuniform stress in them. The nominal strain and stress are used to describe the response of the device during loading and unloading test. The nominal strain is the displacement of the rings divided by the original diameter of the free rings and the stress is the applied force divided by the cross-section area of a ring or total area of the rings used.

The figures of nominal stress–strain curves in the following text are the second circle results of the loading and unloading test, which the maximum nominal strains are 10.42% and 15.63%, respectively.

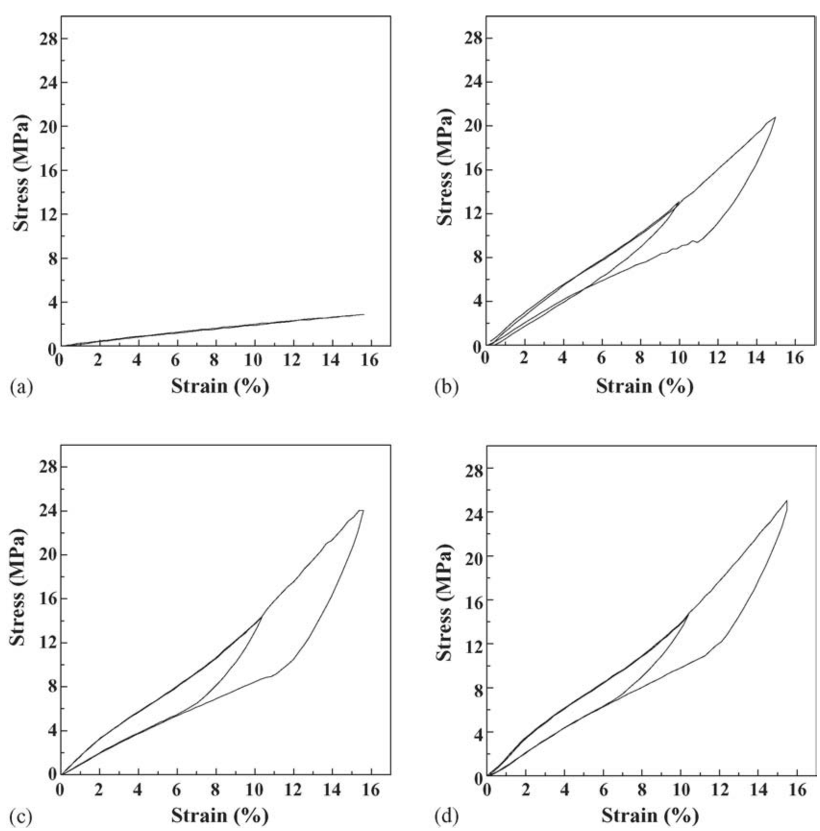

Fig. 2. The nominal stress–strain curves generated by single TiNi ring in different pre-strain states, without sliding blocks (a) and the pre-strains of the ring are 0 mm (b), 4.17% (c) and 8.33% (d), respectively.