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Study on energy absorbing composite structure made of concentric NiTi spring and porous NiTi

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Abstract

An energy absorbing composite structure made of a concentric NiTi spring and a porous NiTi rod is investigated in this paper. Both NiTi spring and porous NiTi rod are of superelastic grade. Ductile porous NiTi cylindrical specimens are fabricated by spark plasma sintering. The composite structure exhibits not only high reversible force–displacement relation for small to intermediate loading but also high energy absorbing property when subjected to large compressive load. A model for the compressive force–displacement curve of the composite structure is presented. The predicted curve is compared to the experimental data, resulting in a reasonably good agreement.

Keywords: Energy absorbing material; Composite structure; NiTi spring; Porous NiTi; Spark plasma sintering

1. Introduction

Recently, the energy absorbing structures and materials attracted strong interests in various fields of applications ranging from vehicles, ballistic armor, helmet, sports equipment to clothing. There are two approaches to design high energy absorbing materials and structures: One is to optimize the structures by using ordinary materials, for example thin composite sandwich panels by Kassapoglou (1996), and sandwich plates with truss cores by Xue and Hutchinson (2004) and Wicks and Hutchinson (2004). The other is to design new energy absorbing materials, such as Miyoshi et al. (1999) produced aluminum foam, porous NiTi shape memory alloys. Since the density of porous NiTi is less than that of the solid NiTi, while the

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porous NiTi can absorb almost the same energy as the solid NiTi does when they have the same volume, the porous NiTi can be good candidate for energy absorbing material in various fields of applications ranging from aerospace and naval to surgical instruments and medical implant and fixtures. There have been some attempts to design and process porous NiTi, but the porous NiTi in the earlier works proved to be very brittle. Recently we processed a ductile porous NiTi rod by using spark plasma sintering (SPS) method by Kang et al. (2001) where starting NiTi powder of superelastic (SE) grade were used. Due to short processing time inert environment, as-SPS processed porous NiTi was found to be ductile and exhibited SE behavior.

In this paper, we will incorporate both approaches mentioned above, i.e. to design a high energy absorbing composite structure by not only optimizing the structure design, but also designing of energy absorption porous shape memory alloy. We proposed to design a composite structure made of concentric NiTi spring and porous NiTi cylinder where both NiTi are of SE grade. Let us consider a composite structure made of a concentric spring and porous cylinder, both are of superelastic NiTi, Fig. 1. The composite structure is subjected to compressive loading F along the z-direction. In order to design a high energy absorbing material to cover a wide range of compressive loading, we set our criteria: (i) for low to intermediate compressive loading, the composite structure exhibits superelasticity, i.e. the whole structure recovers to its original shape after unloading. (ii) For high compressive loading, the composite structure can absorb a larger amount of energy. Therefore, the proposed composite structure has dual purposes, (i) usable as an impact every absorber repeatedly for low impact energy, and (ii) extra high energy absorber for much larger impact loading. We design the composite structure such that there exists a horizontal gap between the outer spring and inner cylinder and the initial height of the spring is larger than that of the cylinder, Fig. 2(a). Upon compressive loading to the composite structure, the spring supports the compressive loading initially until both of the spring and cylinder have the same height, Fig. 2(b). Under increasing compressive load, the spring shrinks while the cylinder shrinks vertically but swells transversely, then it touches the spring, Fig. 2(c). For further loading, to cope with larger impact loading, the deformation of the composite structure is strongly influenced by the constraint between the spring and cylinder with constrained inner pressure acting on the interface, thereby absorbing a large impact loading.

So far, a lot of modeling work were proposed to simulate the mechanical behaviors of energy absorbing structures and materials. For example, Bart-Smith et al. (2001) proposed a model to simulate the bending deformation of a cellular metal sandwich construction made of aluminum foam. Wicks and Hutchinson

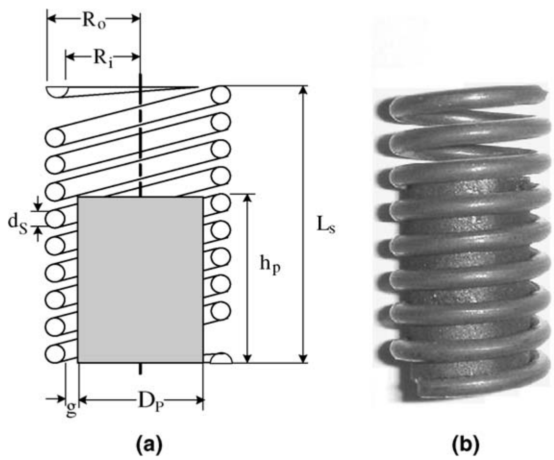

Fig. 1. (a) Sketch and (b) actual picture of the composite structure.