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Compression mechanics of nickel-based superalloy metal rubber

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ABSTRACT

The work describes the manufacturing and testing of metal rubber (MR) samples produced from nickel-based superalloys, and subjected to compression loading in quasi-static regime, three batches of MRs with different relative densities have been fabricated, and their mechanical properties (tangent modulus, loss factor and Poisson's ratio) have been investigated at different maximum strains, and under cyclic loading. The experiments show the significant effect of the MRs' relative density over the global mechanical compression properties, with the tangent modulus increasing and the loss factor from the hysteretic cycles decreasing in samples with higher density. At low strain level, metal rubber appears to behave like a zero Poisson's ratio material. The results show the effectiveness in controlling the mechanical properties of nickel-based metal rubber by careful adjusting of the relative density during manufacturing.

1. Introduction

Metal rubber (MR) is a form of a tangled metallic mesh manufactured via a process of wire-drawing, weaving and compression molding. The term metal rubber [1–4] arises from the similarity between the properties of MR and those of elastomeric rubber, although some authors do prefer to use the term of entangled metallic wire material (EMWM) [5–7] or metal wire mesh [8–10] to define this type of porous material. MR samples have exhibited high levels of mechanical damping at both low and high temperatures, therefore making metal rubber a strong candidate for applications in extremely harsh environments, such as the vibration damping of pipes in gas engines, isolation mounting of instruments in aircrafts, vibration damping of inertial platform in missiles [11]. In recent years, MR has been also used within active vibration dampers in rotors vibration applications. Ma and Hong [12] have developed an adaptive squeeze film damper which adjusted the oil film clearance automatically with the change of the oil film force. The MR element made from normal steel was used to mitigate the effects of the high non-linearity of the oil film and to suppress sudden imbalance responses. Ertas [10] investigated the nonlinear stiffness and damping of MR dampers made from copper used in the rotor bearings, and high-speed rotating tests showed good damping and low vibration levels through the first two critical speeds. Several experimental studies have been carried out so far to understand the effects of the various manufacturing parameters on the overall mechanical performance of MR solids. It is in general acknowledged that the sliding friction existing at the contact points between individual wires dominates the damping performance of MR products. The relationship among the micro-structure, porosity, relative density, and the mechanical properties has been well established for metal rubber made from normal steel [13–15], aluminum [6] and titanium [5,16] in the works carried out by He and collaborators. In particular, the compressive yield strength and the elastic modulus of steel-based MR exhibit a significant dependence versus the porosity or relative density - both decrease as the porosity increases. However, metal rubber solids made from nickel based superalloy have not been investigated at large. Moreover—and to the best of the authors' knowledge—previous research work on metal rubber has not focused on the behavior of the Poisson's ratio, which is also a significant material parameter [17,18].

The objective of this study is to investigate the compressive mechanical properties and the hysteresis behavior of MR materials based on nickel-based superalloy wire, and with different relative densities. Special focus has been dedicated to obtain experimental results related to the loss factor, tangent modulus and secant/tangent Poisson's ratio of the MR samples, and to establish guidelines between these properties and the relative density imposed during the manufacturing.

2. Metal rubber specimens

2.1. MR manufacturing

The MR samples have been produced using a nickel based superalloy wire with a diameter of 0.12 mm (Anping dongsheng hardware and wiremesh CO., LTD, PRC). The nominal chemical

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composition and the reference mechanical properties are listed in Tables 1 and 2 respectively.

The manufacturing of the MR samples can be summarized as follows [19]. The nickel based superalloy wire has been initially encircled into a tight helix by distorting and twisting the wire. The helix obtained has been then tensioned at both ends (wire drawing) to provide an initial pre-tension. The drawn wire is then weaved in a crisscross pattern to obtain a rough porous base material. Finally, the rough samples are placed into a specially designed mold and formed in a device by applying a compressive force ranging between 20 kN and 60 kN for at least 1 min. The compression loading is tailored to provide a specific relative density for the specimens. Heat treatments applied to compacted samples have been proven very useful to obtain stable mechanical characteristics, albeit with a significant stiffness increase [5,6]. The MR samples produced for this work have been not heat-treated, in view of possible use within applications in which low stiffness is required.

Table 1
Chemical compositions (wt%) of the wire.

Fe	Ni	C	Si	Mn	S	P	Cr
Balance	52.26	0.032	0.13	0.06	0.005	0.005	18.89
Mo	Al	Nb	Ti	Cu	Co	B	Mg
3.04	0.41	5.05	0.95	0.05	0.01	0.004	0.001

Table 2
Mechanical properties of the wire.

Tensile strength (MPa)	Elongation δ%	Brinell Hardness HB
1400	24.0	40.5

2.2. Characterization of the MR specimens

Three batches of metal rubber samples with rectangular geometry and different nominal relative densities have been produced, with each batch composed by 5 specimens (Fig. 1(a)). A SEM view of the surface contact between wires is also featured in Fig. 1(b), clearly showing the tangling existing between wires. Fig. 2 is obtained by a computed tomography (CT) scan. It is possible to evince from the 3D image the high interconnectivity existing within the porous structure between wires, and the presence of connective micropores between tangled wires.

The dimensions, mass and relative density of the three batches of MR samples are listed in Table 3. The height is defined along the molding direction during the manufacturing. The same direction represents also the one related to the compression loading for all the experiments shown in this work. The relative density has been calculated as the ratio between the density of the porous, and the density of the core material MR samples.

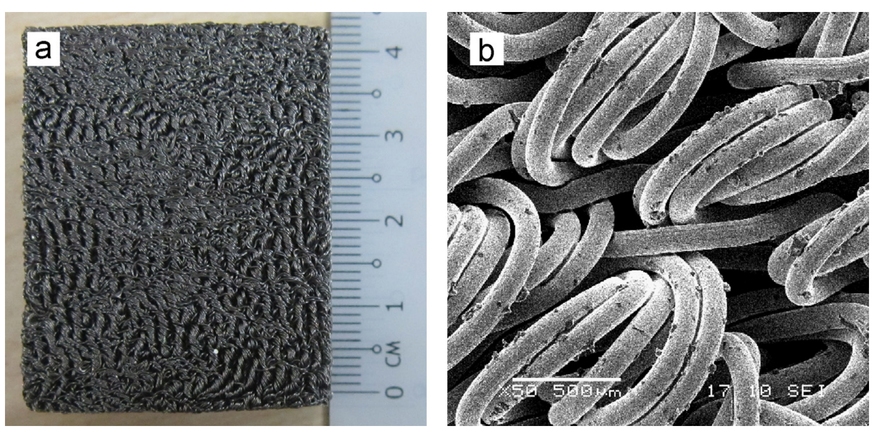

Fig. 1. (a) A rectangular MR specimen with relative density 0.212 and (b) SEM image of the specimen (50 X enlargement).

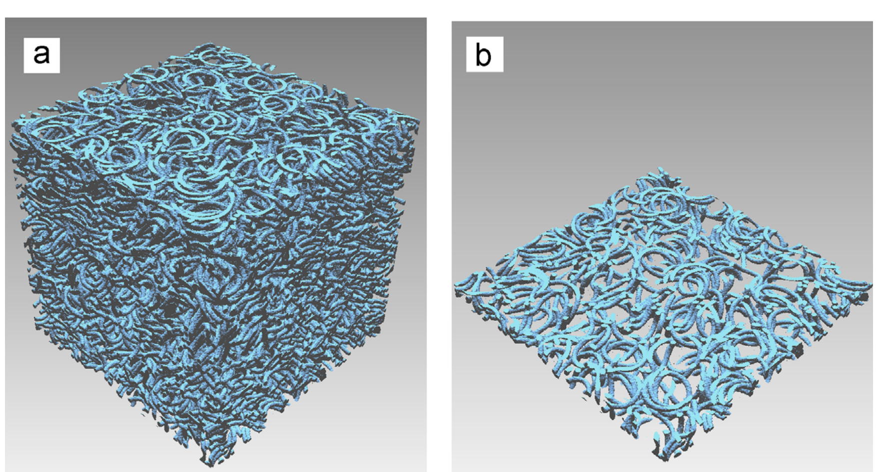

Fig. 2. (a) 3D image of the internal volume of a MR sample (10 mm × 10 mm × 10 mm) from a μ-CT scan and (b) detail of one slide of the internal volume.