Materials Science & Engineering A ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

High temperature mechanical behavior of tube stackings – Part II: Comparison between experiment and modeling

V. Marcadon *,[1], D. Lévêque, A. Rafray, F. Popoff, D. Mézières, C. Davoine

Onera - The French Aerospace Lab, F-92322 Châtillon, France

ARTICLE INFO

Article history:
Received 18 July 2016
Received in revised form
13 September 2016
Accepted 14 September 2016

Keywords:
Metallic tube stackings
Cellular materials
High temperature behavior
Mechanical characterization
FE-modeling

ABSTRACT

This paper is the second part of a set of two papers dedicated to the mechanical behavior of cellular materials from room temperature to high temperatures. For that purpose, some monotonic and creep compression tests have been performed on a small tube stacking structure. In parallel, a finite-element model of these experiments has been proposed, using the constitutive elasto-viscoplastic behavior identified for the tube material in Part I [1] as input data. The comparison between the experiment and the modeling has provided many items of information regarding the collapse mechanisms of this kind of cellular structure at high temperatures and the role of the contacts created between the tube walls at large deformations. Especially, a competition between both relaxation and hardening phenomena locally has been revealed at high temperatures, resulting in some softening of the stacking effective behavior.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

For several years metallic cellular structures, such as metal foams, honeycombs, truss lattices, and hollow-sphere or tube stackings, for instance, have been abundantly studied because of their potential for various applications. Indeed, these materials present higher specific mechanical properties (i.e., mechanical properties divided by density) than the bulk and multi-functional capabilities are expected [2,3], which could be used to develop lightweight aeronautical frames. However, whereas quite an abundant literature exists regarding the mechanical behavior of these materials at room temperature, their behavior at high temperatures has not been investigated much. This is particularly true for tube stacking structures, considered here as a 'model' cellular structure. In the literature, other cellular structures that exhibit similar collapse mechanisms based on localized plasticity are metal foams and hollow-sphere stackings.

Many studies deal with the mechanical behavior of metal foams or hollow-sphere structures at room temperature. For instance, among others, Friedl et al. [4] performed a very interesting study under both compressive and tensile loads. Their results provided many items of information on the mechanisms that govern the mechanical response of hollow-sphere structures. Caty et al. [5,6] also provided significant results on the mechanical behavior of hollow-sphere structures, especially undergoing fatigue [5,7]. Fallet et al. [8] and Lhuissier et al. [9] used X-ray tomography to characterize the damage mechanisms that govern the collapse of such stackings. Two complementary mechanisms were identified: the crushing of the hollow spheres and the creation of new contacts between neighboring spheres. Sanders and Gibson [10,11] have shown that the mechanical properties of such regular stackings strongly depend on the load direction; mechanical properties are stiffer along the densest direction of the stacking. Our previous work can also be referred to [12,13]. They have shown that the effective plastic behavior of hollow-sphere stackings depends not only on their architecture, but also to a large degree on the hardening capabilities of their constitutive material and the presence or absence of defects in the architecture. The mechanical behavior of metal foams is governed by localized plasticity and the collapse of the constitutive cells also; see for example the work of Brothers and Dunand [14] on zirconium foams, or those of Paul and Rammamurty [15] and Ruan et al. [16] on aluminum foams. All of these studies also agree with the fact that several elastic and plastic mechanical properties of the foams strongly vary with their density according to a power law; the higher the density, the stiffer the mechanical response. The influence of the loading rate on the mechanical response of metal foams is a more controversial issue. According to Paul and Rammamurty [15], the foam strength increases with an increasing loading rate due to viscosity phenomena, whereas for Ruan et al. [16] and Rakow and Waas [17] no effect of the loading rate exists;

DOI of original article: http://dx.doi.org/10.1016/j.msea.2016.07.088
* Corresponding author.
E-mail address: Vincent.Marcadon@onera.fr (V. Marcadon).
[1] Metallic Materials and Structures Department.

http://dx.doi.org/10.1016/j.msea.2016.09.052
0921-5093/© 2016 Elsevier B.V. All rights reserved.

Please cite this article as: V. Marcadon, et al., High temperature mechanical behavior of tube stackings – Part II: Comparison between experiment and modeling, Materials Science & Engineering A (2016), http://dx.doi.org/10.1016/j.msea.2016.09.052

all of these works were performed on aluminum foams. Gibson and Ashby [18,19] have proposed an analytical model to predict the mechanical properties (Young modulus and yield stress essentially) of a foam as a function of both the constitutive material mechanical properties and the densities. This model, developed for both open- and close-cell foams, assumes that the foam edges are loaded under pure bending. A similar approach has been proposed by Hodge and Dunand [20] assuming that the foam edges work in compression.

With regard to high-temperature applications, Andrews et al. [21,22] performed tensile tests on close-cell aluminum alloy foams between 275 °C and 350 °C. For the lowest temperatures (below 300 °C), they found that the effective Norton exponent and activation energy were the same as those of the constitutive material. On the contrary, for temperatures higher than 300 °C, a strong increase in the effective Norton parameters was identified compared to those of the constitutive material. This could be explained by stress concentration phenomena at some edges of the foam, resulting in a strong heterogeneity of the creep rates in the cellular material, which are potentially very high locally. In the case of compression creep, Cock and Ashby [23] have shown that the deformation of foams is governed by the bending and the buckling of their edges. Also, for reasons of local stress concentration, buckling occurs mainly along the edges, where the stress is the highest. Complementary works by Andrews and Gibson [24] and Huang and Gibson [25], or more recently by Su et al. [26], have also investigated the influence of both the defects and the curvature of the cell walls on the creep behavior of foams. NiAl open-cell foams have been studied by Hodge and Dunand [20] in creep under compression. In agreement with the works of Andrews et al. [21,22], the effective creep parameters appeared also similar to those of the constitutive material. More recently, Diologent and co-workers [27–29] studied open-cell replicated foams under tension creep and fatigue creep. They have shown that the creep response of foams is similar to that of its constitutive material. It is characterized by a significant primary creep regime, followed by a pronounced steady-state secondary creep regime, then followed by a final tertiary regime of accelerated creep. The effective activation energy of the foams studied remained very close to that of the constitutive aluminum, whereas the effective Norton exponent was higher than that of the constitutive aluminum. Such a difference was explained by the specific microstructure of aluminum in the foam struts. Contrary to the bulk, they consisted of few grains only. Soubielle et al. [28,29] also observed the influence of oxidation on the creep behavior of the foams in long creep duration tests. An approach mostly based on 'material' considerations has been proposed by Chos and Dunand [30,31], studying NiCr, NiAl and NiCrAl foams. They investigated the influence of the alloy compounds on the mechanical properties and the oxidation resistance of the foams, in order to develop superalloy foams. Comparison with the predictions of the analytical model by Gibson and Ashby [18,19] on the one hand, and that of Hodge and Dunand [20] on the other hand, has shown that the second model is better suited for their foams. More recently, De Fouw and Dunand [32] addressed the case of nickel-based superalloy foams. Various modeling approaches have been proposed to take into account the various mechanisms observed during the creep of foams, and to predict their effective properties [18–23,33–36]. Although most of the studies have investigated the creep behavior of metal foams under uni-axial compression only, the works of Fan et al. [35] and Kesler et al. [37] can be cited, who addressed the multi-axial and flexural behaviors of foams, respectively. In contrast to the case of metal foams, there are few studies addressing the mechanical behavior of hollow-sphere stackings at high temperatures, either by modeling or experimental. Nevertheless, another of our previous works can be referred to [38], it aimed at investigating the influence of the stacking architecture on its creep behavior.

This work is dedicated to both the experimental characterization and the modeling of the effective mechanical behavior of tube stackings at high temperatures. This Part II of a set of two complementary papers focuses on the behavior of the cellular structure, whereas Part I [1] addresses its constitutive material properties. After a brief description of the cellular structure and the test conditions considered (see Section 2), the experimental results obtained from both quasi-static monotonic and creep compression tests are discussed in Section 3. Various temperatures (room temperature, 600 °C and 800 °C) have been considered. Various strain rates and stress levels have been applied also for the monotonic and creep tests, respectively. Then, Section 4 addresses the finite-element modeling of the aforementioned tests. The simulations have been performed accounting for large deformations and contacts. Their predictions are compared with the experimental results, in order to assess the modeling assumptions and to discuss the experimental results obtained.

2. Mechanical test campaign

The aim of the test campaign detailed here was to investigate the effective elasto-viscoplastic behavior of the tube stacking structure studied. For that purpose, two different tests were considered: monotonic compression tests and compression creep tests. All of these tests were conducted between room temperature and 800 °C (600 °C and 800 °C only for the creep tests).

2.1. Sample geometry

As already described in Part I [1], the cellular structure considered here was a 5×5 stacking of tubes, brazed to each other and to two metallic skins following a square pattern (Fig. 1). As a reminder, the constitutive material of the tubes and the skins was Inconel®600 and they were brazed together using Ni-1.5B-19.0Cr-7.3Si-0.08C (wt%) braze foils. Theoretically, each tube had an outer diameter of 4 mm and a wall thickness of 250 μm. The skin thickness was 1 mm and the mean braze joint length was 1.43 mm. The length of the samples was equal to 20 mm after electro-discharge cutting. Their density was 2.29 g cm^{-3} compared to 8.25 g cm^{-3} for Inconel®600.

The actual geometry of the tube stacking samples, after the brazing step and before testing, is listed in Table 1, where the height includes the two brazed skins and the width was measured along the tube direction. The three letters A, B and C correspond to three contiguous samples, which were successively cut by electro-discharge machining from the same manufactured bar (associated with the two first digit numbers). The width of the sample is a very precise value, considering that it was imposed by the cutting process. The height and length show more scattered values (the standard deviation values are about 1% of the mean values) due to the irregularly spaced structure of the tube stacking, considering that it was not so obvious to keep a perfectly aligned structure during the entire brazing process. In some cases, some braze joints were missing, or some sliding between tubes rows were observed. The consequence of such defects on the mechanical behavior of the tube stacking samples is discussed subsequently when the results of the tests are detailed.

2.2. Test conditions

A specific compression test device has been designed in order to conduct the monotonic tests, as well as the creep tests, under

Please cite this article as: V. Marcadon, et al., High temperature mechanical behavior of tube stackings – Part II: Comparison between experiment and modeling, Materials Science & Engineering A (2016), http://dx.doi.org/10.1016/j.msea.2016.09.052

Download English Version:

https://daneshyari.com/en/article/5456705

Download Persian Version:

https://daneshyari.com/article/5456705

Daneshyari.com