Mechanics of Materials 57 (2013) 1–14

Contents lists available at SciVerse ScienceDirect

Mechanics of Materials

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

Equivalent material properties of a wire-woven cellular core

Ki Won Lee, Jong-Sun Park, Insu Jeon, Ki-Ju Kang *

Department of Mechanical Engineering, Chonnam National University, 300 Yongbong-dong, Buk-gu, Gwangju 500-757, Republic of Korea

A R T I C L E I N F O

Article history:
Received 16 November 2011
Received in revised form 14 September 2012
Available online 17 October 2012

Keywords:
Sandwich plates
Truss core
Buckling
Plastic yielding
Wire-woven structure
Brazed joint

A B S T R A C T

New analytic solutions are derived for the relative density, equivalent strength under compression and equivalent Young's modulus of WBK (wire-woven bulk Kagome). The three dimensional curvature of struts and the considerable size of the brazed filler metal joining the struts are unique to a wire-woven structure and therefore, must be taken into account. The solutions are verified by comparison with the results of CAD models and finite element analysis as well as with experimental data. The effects of the slenderness ratio of struts, the size of the brazed joint, and the hardening exponent of the wire material are investigated. Sources of the discrepancy with the experimental results, limits in application, and engineering significance are discussed.

1. Introduction

Wire-woven bulk Kagome (WBK) is a cellular metal having Kagome truss-like structure (Lee et al., 2007). WBK has benefits from using wires, which are easy to handle, of high strength, and low cost, as the raw material. And WBK has an additional benefit because of its structure being similar to Kagome truss, which has low anisotropy due to its geometry being identical in six directions in 3-D space and has higher resistance against failure due to strut buckling and more stable post-peak behavior than the octet truss at a given density (Hyun et al., 2003). Moreover, WBK can be mass-produced (Kim and Kang, 2010).

In recent few years, Kang and his colleagues have developed variations of WBKs such as concave and convex types (Li and Kang, 2008), tube WBK (Lee and Kang, 2009; Park et al., 2011), hybrid WBK (Li et al., 2011), semi-WBK (Lee et al., 2012) and partially-filled WBK (Kang, 2009). They have investigated the mechanical and thermal properties of these WBKs, and their feasibility as load bearing light structures, highly efficient heat dissipation media, and even catalyst supports in exhaust gas purifiers. And also, they investigated the effects of geometric parameters and material properties of the wires and the filler metal used to fix the wire cross points on the strength of WBK (Choi et al., 2010). Fig. 1 shows the variations of WBKs.

The analytic solutions of the strength and stiffness of WBKs have been derived based on the idealization of the geometry of WBK as an equivalent Kagome truss consisting of straight struts and frictionless ball joints. However, such idealization has been found to result in substantial errors in the estimations of the mechanical properties, particularly of the stiffness, when compared with experimental measurements. For example, the measured stiffness, i.e., equivalent Young's modulus is often as low as only half of that estimated by the analytic solution (Lee et al., 2007). The compressive strength of the concave type WBK is 5 to 20% higher than that of the convex type WBK (Li and Kang, 2008), although the analytic solution has never identified any difference in the strengths between the two types. It seemed obvious that the errors were due to idealization of the WBK geometry. In reality, WBK is composed of curved struts and joints fixed by filler metals. That is, a WBK specimen is assembled of helically formed wires so that three wires pass by one another at each cross point. Hence, the wires should have a helical radius of $a = (\sqrt{3/3})d$ at least (Ko et al., 2010).

* Corresponding author. Tel.: +82 62 530 1668; fax: +82 62 530 1689.
E-mail addresses: kjkang@jnu.ac.kr, kjkang@chonnam.ac.kr (K.-J. Kang).

0167-6636/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.mechmat.2012.10.005

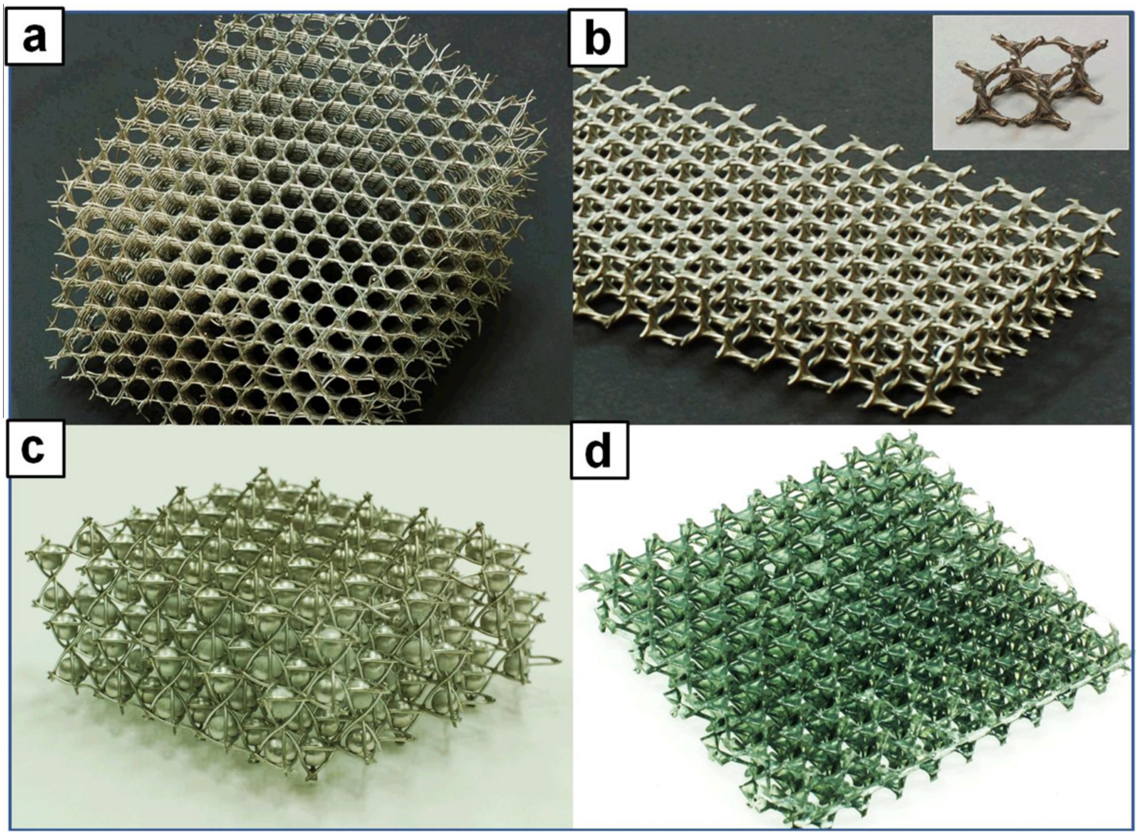

Fig. 1. Variations of WBKs, (a) ordinary concave WBK, (b) partially filled WBK, (c) hybrid WBK, (d) semi-WBK composed of carbon FRP rods, carbon yarns, and epoxy.

Queheillalt et al. (2007) derived the equations of strength and stiffness of a lattice core fabricated by stacking woven textile meshes. Elementary solid mechanics was applied for a strut with periodic in-plan curves, i.e., waviness. The equations gave very accurate estimations compared with those by finite element analysis and measurements. In this study, analytic solutions are derived for relative density, equivalent strength and equivalent Young's modulus of WBK under compression. An approach similar to that taken by Queheillalt et al. (2007) is applied, but the three dimensional curve of struts and the considerable size of the brazed filler metal joining the struts, which are unique to a WBK structure, make the derivation of the analytic solutions more complicated. The solutions are verified by comparison with the results by finite element analysis and the experimental data. The effects of the slenderness ratio of struts, the size of brazed joint, and the hardening exponent of the wire material on the strength and stiffness of WBK are investigated.

2. Analytical solutions

2.1. Basic equations

For an idealized configuration of WBK, i.e., the equivalent Kagome truss composed of straight struts connected with ball joints so that force is transmitted to the struts only in the longitudinal (axial) direction, as shown in Fig. 2, the relative density, ρ_{rel}, the equivalent compressive strength, σ_y^c, and the equivalent Young's modulus, E^c, are given by the following equations (Lee and Kang, 2009);

$$\rho_{rel} = \frac{3\sqrt{2}\pi}{8}\left(\frac{d}{c}\right)^2, \quad (1)$$

$$\sigma_y^c = \frac{\sqrt{2}}{8}\pi\sigma_{os}\left(\frac{d}{c}\right)^2 = \frac{1}{3}\sigma_{os}\rho_{rel}, \quad (2)$$

$$E^c = \frac{3\sqrt{2}}{40}\pi E_s\left(\frac{d}{c}\right)^2 = \frac{1}{5}E_s\rho_{rel}, \quad (3)$$

where c, d, σ_{os}, and E_s are the length of the struts and the diameter, yield strength and Young's modulus of the wires, respectively. The equivalent compressive strength of Eq. (2) is derived for plastic yielding of the struts. In these equations, it is seen that all the properties, i.e., the relative density, the strength, and the modulus are expressed as simple functions of d/c which is defined as the "slenderness ratio of struts".