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Mechanical behaviors of wire-woven metals composed of two different thickness of wires

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Abstract

Wire-weaving is virtually only a practical method to fabricate multi-layered truss type cellular metals, except for stacking multiple single layered structures. To date, the wire-woven metals have been fabricated of wires of a uniform thickness. In this work, variations of wire-woven metals fabricated of two different thickness wires in out-of-plane and in-plane directions are introduced. The mechanical properties subjected to compressive or shear loading are investigated.

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Keywords: Cellular metal; Sandwich core; WBD(Wire-woven Bulk Diamond)

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1. Introduction

Metallic wires have several merits as a raw material for cellular metals. That is, the wires are easy to obtain high strength at low price and defect. Piano wire is a good example. And also, the wires are easy to handle and make into a shape during fabrication. Since 2006, Kang and his colleagues have developed a series of wire-woven metals (Lee et al. (2007)). Wire-woven Bulk Kagome (WBK), Wire-woven Bulk Diamond (WBD), Wire-woven Bulk Cross (WBC) are the representatives (Lee et al. (2012) and Lee et al. (2013)). In fact, wire-weaving is only a practical method to fabricate multi-layered truss type cellular metals, except for stacking multiple single layered structures. To date, the wire-woven metals have been fabricated of wires of a uniform thickness. When a truss-like structure such as the wire-woven metals are used as a sandwich core, struts in out-of-plane directions are generally subjected to the higher stress than those in in-plane directions. Therefore, a combination of two different thickness wires would be

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desirable to achieve the maximum strength or stiffness per a given weight. Recently, preliminary studies were performed on two different thicknesses (Song et al. (2012)).

This paper studies wire-woven metals named bi-WBK, bi-WBD and bi-hemi-WBD. They are fabricated of two different thickness wires in out-of-plane and in-plane directions. Their mechanical properties subjected to compressive or shear loading are investigated. The experimental and FEA results are compared with those of the conventional wire woven metals to examine feasibility of the bi-wire-woven metals.

2. Experiments

2.1. Preparation of specimens

The material for the core wires and face sheets is stainless steel SUS 304. The diameter of the wires in in-plane is d = 0.5, 0.78, 0.98 and 1.18 mm for bi-hemi-WBD, respectively. The all diameter of the wires in out-of-plane are d=1.18. The pitch, which is twice the strut length, c, is 2c=16.2mm. Figure 1 shows the specimens. Specimens were prepared in the same way as in the previous study (Lee et al. (2007) and Lee et al. (2012)). Two face sheets of 3mm thinness were attached to the top and bottom surfaces of each core for the compression and shear test. Figures 2(a), 1(b), 1(c) show specimens of bi-WBK, bi-WBD, and bi-hemi-WBD, respectively. The number of cell and layer are 5x5 and two layers, respectively.

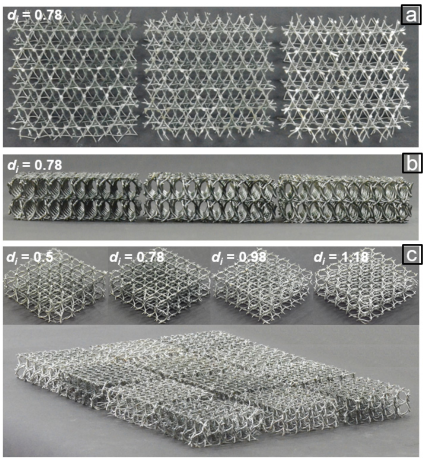

Figure 1: Specimens for compression and shear; (a) bi-WBK (di=0.78mm, do=1.18mm), (b) bi-WBD (di=0.78mm, do=1.18mm), (c) bi-hemi-WBD (di=0.5, 0.78, 0.98 and 1.18 mm, do=1.18mm).

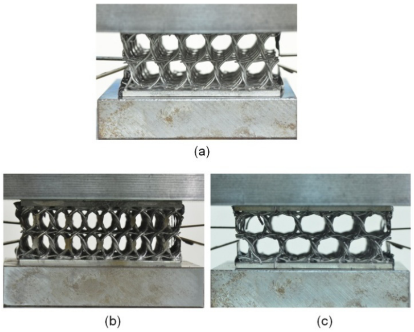

Figure 2: compression test of (a) bi-WBK, (b) bi-WBD and bi-hemi-WBD.

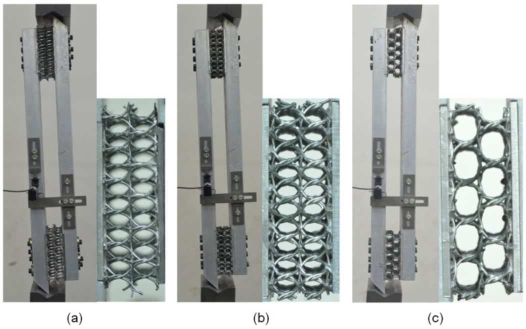

Figure 3: Specimens and jigs for shear tests of (a) bi-WBK, (b) bi-WBD and bi-hemi-WBD.

2.2. Compression and shear test

The universal testing machine Instron-Satec TC-55 was used for the uniaxial compression and shear test. The displacement was recorded by data acquisition (DAQ) system. Load cell was used 25KN and 250KN for the compression and shear test, respectively. For compression test, all the specimens were compressed between two steel circular platens. The diameter of each circular platen, D=200mm, was sufficiently larger than the specimen sizes. Two clip gages were mounted on opposite sides of a specimen by knife edges. The displacements measured by the two clip gages were averaged to give the mean strain data over the volume of the specimen. Shear tests were performed similarly to those presented in the ASTM standard C273. Instead of a single long specimen, two separate square specimens were mounted at both ends of the jig. Figure 3 shows the specimens installed on the jig. The actual displacement of each specimen was measured by an extensometer installed between the two thick plates. The load was applied by displacement control at 0.005 mm/s. The equivalent Young's modulus and shear modulus of core of each specimen was obtained from the linear part of stress-strain curve measured during unloading, which was carried out before the load reached to the peak.

3. Finite Element Analysis

The models of bi-WBK, bi-WBD and bi-hemi-WBD were made by HyperMesh Ver10 so as to be similar to the real specimens in the dimensions and shape. FE analyses were performed using the commercial code ABAQUS 6.9. For the wires and filler metals, 15-node quadratic triangular prism elements were used. A unit cell model was made first, and it was repeatedly copied and pasted in 3D space to construct the same configurations as the real specimens. The thick plates were attached by "Tied Contact" on the upper and lower surfaces of a wire-woven core, and were modeled by using 8-node linear brick elements. The total number of elements of a specimen model was about 1,200,000. For technical details such as material properties, refer the authors' previous articles (Song et al. (2012)).

4. Results

Figures 4 and 5 show the stress-strain curves estimated by FEA and measured from the experiments for the bi-WBK and bi-WBD cores (with d_i=0.78mm, d_o=1.18mm) under compression and shear, respectively. The horizontal lines indicate the strengths estimated by the ideal analytic solution with d_i=d_o=1.18mm. The measured stress-strain curves both for the bi-WBK and bi-WBD are located lower than those estimated by FEA under compression and shear loading. The strength of bi-WBD under compression decreased before reaching to peak strength estimated by FEA or analytic solution. The low strengths measured from bi-WBD and bi-WBK were due to early break at the brazed joints which have never been observed in ordinary WBK or WBD composed of wires of uniform thickness.

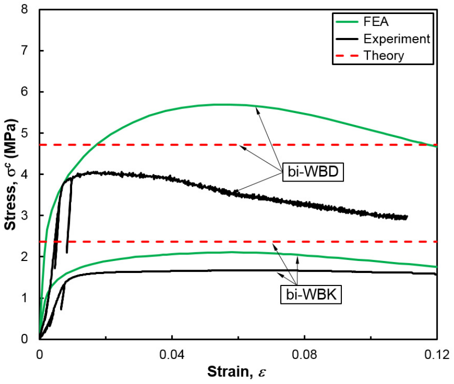

Figure 4: Stress-strain curves by FEA and experiment for bi-WBK and bi-WBD (di=0.78mm, do=1.18mm) under compression.

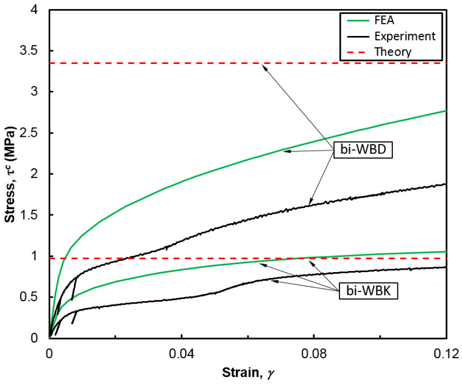

Figure 5: Stress-strain curves by FEA and experiment for bi-WBD and bi-WBK (di=0.78mm, do=1.18mm) under shear.

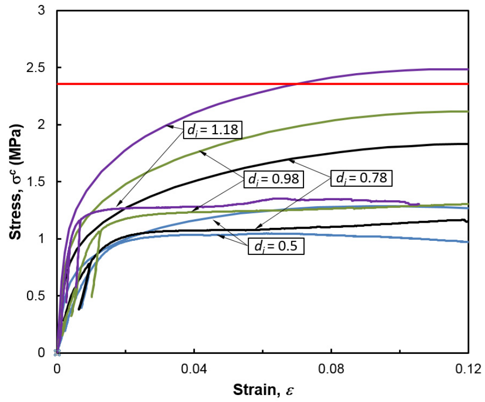

Figure 6: Stress-strain curves by FEA and experiment for bi-hemi-WBD under compression.

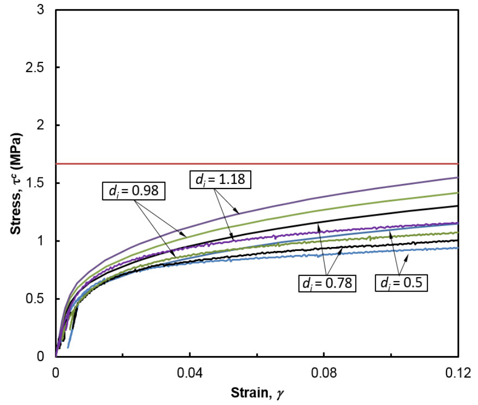

Figure 7: Stress-strain curves by FEA and experiment for bi-hemi-WBD under shear.

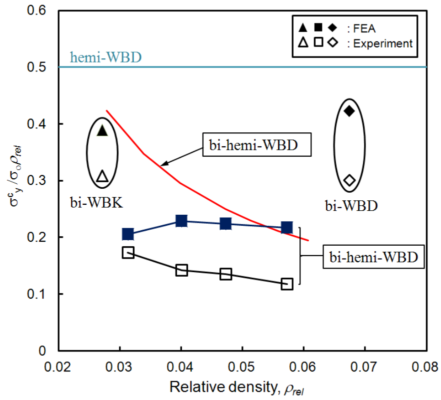

Figure 8: Normalized equivalent strength of bi-hemi-WBD according to the relative density under compression.

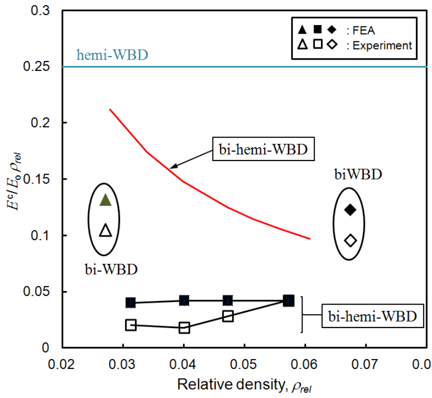

Figure 9: Normalized equivalent stiffness of bi-hemi-WBD according to the relative density under compression.

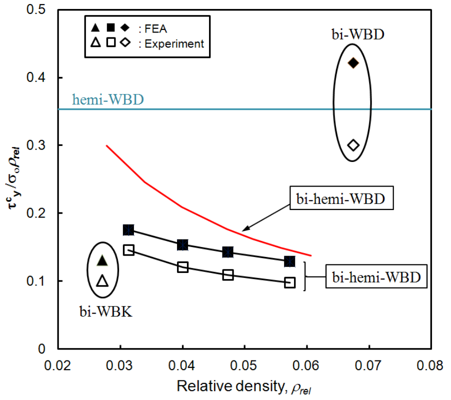

Figure 10: Normalized equivalent strength of bi-hemi-WBD according to the relative density under shear.

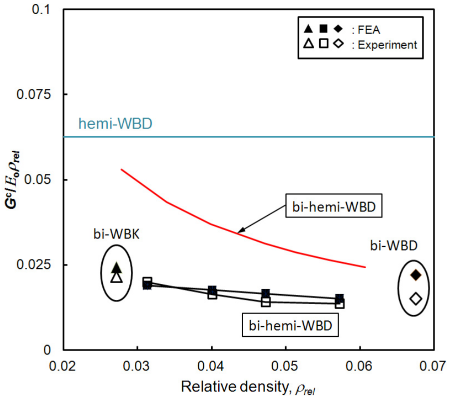

Figure 11: Normalized equivalent stiffness of bi-hemi-WBD according to the relative density under shear.

Figures 6 and 7 show the stress-strain curves by FEA and experiment for bi-hemi-WBD with four different wire diameters in in-plane directions under compression and under shear, respectively. In compression, the strength estimated by FEA steadily rose even after the initial yield point, but the measured strengths by experiment remained almost constant after the early peaks, which was also due to the early break at the brazed joints. In Figure 7, the stress-strain curves measured under shear strength agree fairly well with those estimated by FEA. The equivalent shear strength was defined as the equivalent stress at $\gamma^c = 0.015$. Figures 8 and 9 summarize the equivalent strengths and Young's moduli of the bi-WBK, bi-WBD and bi-hemi-WBD under compression, respectively. Both properties are normalized by the yield strength or Young's modulus of the raw wires and the relative density. In the figure, open symbols indicate those estimated by FEA and solid symbols indicated those measured from the experiments. For purpose of comparison, the values estimated theoretically for the corresponding ideal configurations are plotted together. Both FEA and the experiment showed that bi-WBK and bi-WBD have almost the same level of the strength or modulus when they are normalized by the relative densities. FEA estimated that the normalized strengths and moduli of the bi-hemi-WBD were almost constant regardless of the relative density. However, the experiments revealed that the normalized strength decreased with the relative density, while the normalized modulus increased with the relative density.

Figures 10 and 11 summarize the equivalent strength and Young' modulus, respectively, according to the relative density of the wire-woven metals under shear. In Figure 10, the normalized shear strength by FEA and experiment slowly decrease with relative density. In Figure 11, the normalized shear modulus estimated for FEA and experiment agree with each other and slowly decreases with relative density. It is noticeable that the normalized shear strengths of bi-WBK are much lower than those of bi-WBD.

5. Conclusion

- The strength and modulus of bi-hemi-WBD under compression or shear tests were inferior to those of bi-WBD or bi-WBK, even if the relative densities were taken into account.
- The main reason of the low strengths of bi-wire-woven metals compared to estimation by FEA was early break at the brazed joints among wires.
- The normalized strength of bi-hemi-WBD under compression or shear decreased with the diameter of wires in in-plane directions.

Acknowledgements

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