Building Professional Skills in Mechanical and Materials Engineering: Mechanical and Physical Characterization of Nano Carbon Doped Copper Composite

Jacob Cvetich and C. Virgil Solomon
Youngstown State University, Youngstown, Ohio 44555
Email: vcsolomon@ysu.edu

Extended Abstract

A nano-carbon infused copper material with properties specifically suited for use in electrical, electronic, and thin film applications was developed by Third Millennium Metals (TM^2) of Waverly, Ohio. This material is called "covetic", the product of a melting and casting process that bonds carbon nanomaterial to metals such as copper, silver, and aluminum [1]. It is reported by the Third Millennium Metals that these covetic products show improved mechanical and physical properties over the base metals. The copper covetics, for instance, it is reported to show increased thermal conductivity, and stronger mechanical properties. Research into carbon reinforced metal matrices has been investigated with other forms of carbon through various synthesis techniques [2].

This research work is part of an Ohio Third Frontier grant awarded to TM^2, Ajax Tocco Magnethermic® Corporation of Warren, Ohio, and Youngstown State University (YSU) for the industrial scale development of Cu covetic materials. YSU commitment to the grant is to perform a complete characterization (electrical and thermal conductivity, and mechanical properties) of Cu covetic material and to define, design and test a rapid method for the control of covetic process. A graduate research assistant position in Engineering was budgeted into the YSU proposal. The position was offered to a graduate student with a bachelor degree in physics. In order to be successful in dealing with the project requirements the student was challenged with building professional skills in mechanical and materials engineering. This paper will introduce the student experience in transitioning from undergraduate physics to graduate engineering, through the presentation of the results obtained by working on the Cu covetic materials project, within the first year of graduate studies.

Three as-cast samples were obtained from TM^2. Two covetic samples were to be compared against the copper standard for each experiment. The names of samples and the corresponding nominal carbon content are presented in Table 1.

Table 1: Materials investigated in the present work.

Sample name	Carbon content (by mass)
Copper reference	0.0%
Sample 1 (S1)	2.5%
Sample 2 (S2)	15.0%

Samples of approximately 1 cm x 1 cm x 1 cm were cut from the original ingots using a Buehler IsoMet 1000 precision saw. The samples were sequentially grinded and following metallographic sample preparation methodology [3]. The cross-sectioned samples were imaged by light and electron microscopy. A Zeiss Axiphot light microscope was used for low magnification imaging,

and a JEOL Multibeam JIB 4500 electron microscope was used for high resolution imaging and chemical composition analysis. The crystal structure of the materials was investigated using powder X-ray diffraction (XRD) on a Bruker AXS D8 advance. Mechanical properties of the materials were investigated by sonic testing. The mechanical properties of the materials were analyzed by sonic testing method using Impulse Excitation Technique and an apparatus developed by BuzzMac International, LLC [4]. The impulse excitation technique is described in the ASTM E1876. Samples for sonic testing were machined to experimental guidelines, measuring 6 cm x 24 cm x 1 cm. Sonic testing consisted of striking samples with a mechanical impulse in various locations and directions with resonances recorded and analyzed to non-destructively determine mechanical properties.

Bright field micrographs recorded from cross-sectioned surfaces of the three investigated materials are shown in Figure 1. Morphological differences can be readily observed on the micrographs. At least two different phases can be observed in all samples. A fine dispersed second is observed within the metallic matrix. The amount of the second phase seems to increase with carbon content.

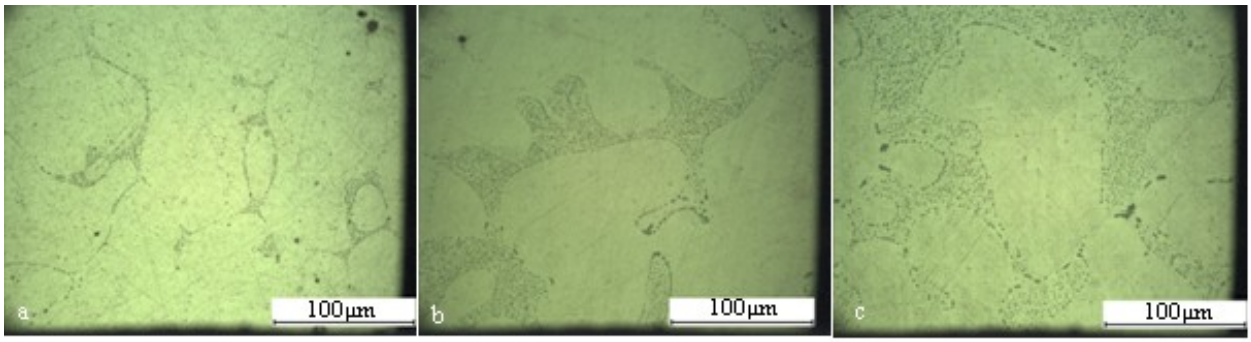

Figure 1. Light micrographs of the cross-sectioned materials: (a) reference material (copper); (b) S1 containing 2.5 wt% carbon; (c) S2 containing 15.0 wt% carbon.

In order to characterize the structure of the observed phases XRD experiments were preformed. All samples exhibited similar XRD spectra that matched database indexed copper. No extra peaks corresponding to a second phase were observed. Moreover, XRD spectra show no observable changes in the lattice structure of the material with increasing of the carbon content. It seems that the amount of the second phase is too small to be detected by the XRD instrument. Further exploration into the structure of the nano carbon and its interaction with the metal matrix is ongoing, with use of SEM and TEM analysis.

Sonic testing showed different mechanical properties between samples. Differences in mechanical properties arising from variable carbon contents are predicted by other researches [5]. The mechanical and physical properties (Young's modulus, shear modulus, Poisson's ratio, density, and sound velocity) of the investigated samples, as obtained by sonic testing, are presented in Table 2.

It must be noted that the density of Cu reference material is slightly lower that the density value for pure Cu presented in the specialty textbooks, 8.94 g/cm^3. The exit sound velocity has similar value with those reported in literature. For pure Cu the modulus of elasticity is 110 GPa, and shear modulus is 46 GPa. These values are quite closed with the ones obtained in the present experiment for Cu reference material.

Further investigation of copper covetics using electron microscopy, thermal conductivity, sonic testing and tensile testing is planned.

Table 2: Average values of mechanical and physical properties obtained using sonic testing.

Sample	Nominal C content (wt%)	Density, g/cm^3	V_{out}, m/s	E, GPa	G, GPa	μ
Cooper reference	0.0 %	8.759	3641	116.1	43.5	0.335
Sample 1 (S1)	2.5 %	8.480	3515	104.8	40.3	0.300
Sample 2 (S2)	15.0 %	8.746	3662	117.3	43.6	0.344

Bibliography

1. L. Brown, P. Joyce, D. Forrest, and J. Wolk, *Physical and Mechanical Characterization of a Nano Carbon Infused Aluminum-Matrix Composite,* Proceedings of the Society for the Advancement of Material and Process Engineering (SAMPE) Fall Technical Conference, Ft. Worth, TX, 17-20 October 2011.
2. Q. Liu, L. Ke, F. Liu, C. Huang, and Li Xing, *Microstructure and Mechanical Property of Multi-Walled Carbon Naotubes Reinforced Aluminum Matrix Composites Fabricated by Friction Stir Processing,* Materials and Design, Vol. 45, pp. 243-248, 2013.
3. G. F. Vander Voort, *Metallography: Principles and Practice*, ASM International, Materials Park, OH, 1999; originally published by McGraw-Hill Book Co., NY, 1984.
4. http://buzzmac.com/
5. D.R. Forrest, I. Jasuik, L. Brown, P. Joyce, and L. Salamanca-Riba, *Novel Metal-Matrix Compositte with Integrally-Bound Nanoscale Carbon*, Nanotechnology 2012: Advanced Materials, CNTs, Particles, Films and Composites, Nano Science and Technology Institute, Vol. 1, pp. 560-563, 2012.