

# On covetic nano – composites

## Opinion

In the fields of conductive wire and cable, industries and governments are seeking higher levels of electrical conductivity and lower densities compared to commercial copper and aluminum; these are needed to improve a wide variety of industries which include commercial aviation and space flight systems.<sup>1,2</sup> Carbon in various forms is being considered as a component in Cu- and Al-based composites to increase conductivity and decrease density. One form of carbon that is currently receiving much interest is known as “covetic.” Of materials subjected to covetic processing, this brief review will focus primarily on Cu and Al covetics.

One of the first works published on covetics was due to Scherer et al.<sup>3</sup> Shortly after, process patents were granted to Shugart and Scherer of Third Millennium Metals LLC (now known as GDC Industries LLC).<sup>4</sup> The claims of this and related patents state “Carbon can be incorporated into any of these metals by melting the metal, mixing the carbon into the molten metal and, while mixing, applying a current of sufficient amperage to the molten mixture such that the carbon becomes incorporated into the metal, thereby forming a single phase metal-carbon material.” In a review of covetic materials by Bakir and Jasiuk, it is reported that a conversion reaction occurs with the carbon forming covalent bonds with the host metal, and that covetic processing enables higher carbon solubility and improvements in properties.<sup>5</sup>

Balachandran et al.<sup>6</sup> examined the properties of covetically processed Cu with a nominal concentration of 3wt.% C and found no significant difference in density between the pure Cu control specimen (8.91 g/cc) and the 3wt.% C material (8.89 g/cc) where based on nominal composition, rule-of-mixtures, and full density a density decrease of about 10% was expected;<sup>6</sup> the electrical conductivity of the 3wt.% material was about 6.8% higher than the pure Cu control. Density measurements by Brown et al.<sup>7</sup> were similarly unable to confirm the presence of C in their covetically processed aluminum samples; the slight departures of their samples from theoretical full density were likely due to void fraction.<sup>7</sup> After T6 heat treatment, Brown’s covetic sample had the same electrical conductivity as the sample without C added. The high conductivity of Brown’s as-extruded covetic sample needs to be repeated due to likely errors caused by short sample length, larger sample diameter, and the resulting low resistance; the as-extruded sample results were also not consistent with the other conductivity measurements or density results.<sup>7</sup> Forrest et al.<sup>8</sup> examined Cu covetic material and found negligible density changes, a 20 °C increase in melting temperature, and premature failure in tension believed to be due to porosity in the centrifugally cast specimen.<sup>8</sup> In work due to Isaacs et al.,<sup>9</sup> nominal Cu-4 and 5 wt.% C covetic material was supplied by GDC Industries and then used as target material in evaporation deposition processes to form thin film transparent electrodes.<sup>9</sup> Photoelectron spectroscopy (XPS) and transmission electron microscopy showed carbon structures in the bulk covetic material, but C could not be detected in the deposited films. Still, impressive improvements in transmittance and sheet resistance were observed in the films deposited from the covetic targets. However, this might be due to the presence of additional trace impurities in the Cu from impure C added in the covetic process, where these trace impurities getter oxygen,

or manipulate the production of metal oxides and thus modify film properties.<sup>10,11</sup> The deposited films were between 20 and 70 at.% O, hence property differences caused by variations in the form of various oxides seems more plausible than the effects of covetic C, especially given that no C could be detected in the films. In unpublished work, Balachandran<sup>6</sup> found Fe in C supplies and in a study of Cu covetics De Groh<sup>1</sup> & Balachandran<sup>6</sup> found rather high concentrations of Fe and Al, elements which lower Cu conductivity, with the Fe and Al presumably coming from impure C sources.<sup>12</sup> Salamanca-Riba et al.<sup>12</sup> examined the structure of Cu and Al covetics and found carbon nanoparticles in the diameter range of 5 to 200 nm with EELS (electron energy loss spectroscopy) and the corresponding Raman data characteristic of carbon nanotubes.<sup>13</sup> This is inconsistent with the idea of a “single phase metal-carbon material,” but such a composite would still be expected to have benefits over the pure metals in terms of density and perhaps conductivity depending on the intrinsic conductivity of the carbon phase. Knych et al.<sup>13</sup> examined the chemistry, density, hardness, and conductivity of three covetically processed Cu ingots: nominal amounts of C were measured in the processed ingots and these C additions added about 10 ppm Fe, Ni, and S to the Cu; all densities were greater than 99.3% of pure Cu’s, which was not consistent with measured C composition levels; hardness was lower in the covetically processed ingots; and the electrical conductivity of the covetic material was the same as the pure Cu standard.<sup>14</sup>

Although there is a growing body of work supporting covetic materials, much of it is based on XPS and this method is prone to inaccurate C determination due to background C in the chamber, and the use of SiC polishing papers; also, if elemental C is located in pores, it will be detected, but that does not mean it is an effective component in the matrix. The covetic claim of the conversion of graphite into a highly conductive, covalently bonded, carbon-based nano-structure is extraordinary and thus requires strong evidence. To date, it appears this strong evidence has not been produced. A well-defined procedure for the production of covetic material is also currently lacking. It is hoped the metallurgical community can overcome these challenges and the benefits of more electrically conductive and lighter weight materials realized.

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## Conflict of interest

None.

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