ABSTRACT

Multi-walled carbon nanotube-reinforced Cu matrix composites (Cu/MCNTs) present a challenge in achieving high strength and good ductility along with balanced thermal and electrical conductivity. Primarily, this work addresses the issue of the wettability behavior of CNT with Cu by providing a coating on the CNTs by a wet chemical reduction method. Detailed optimization experiments reveal the effect of the reduction speed (0.12, 0.23, 1.4 mL/s) of the precursor on the morphology of the copper-based nanostructures (spherical, rod, sea urchin) and their efficacy in achieving uniform coating on the CNTs. The dependence of mechanical properties on the particle morphology (Cu-spherical, Cu-rod, Cu-sea urchin) of the precursor nanostructures was also examined. Among the three variants, spherical nanostructures show the best results in terms of uniform coating. Further, this coating was fixed for a further studies.

A coupled wet chemical route - spark plasma sintering (WCR-SPS) process was employed to produce integrated Cu/$MCNT_x$ composite powder (x = 0.5, 0.7, 1.0 and 1.5 wt. %) that allows strengthening of Cu matrix. Among tested variants, the Cu/$MCNT_{1.0}$ composite exhibits the presence of a strong (111)γ-texture along with homogenous dispersion of Cu-coated MCNTs in the Cu matrix and thereby delivering improved strength (282 MPa) along with balanced thermal conductivity (287 W/mK) and electrical conductivity (82.1% IACS). All the composites were reinforced with 1 wt.% CNT for further studies.

In an effort to further enhance the properties of the Cu/$MCNT_{1.0}$ composite, the matrix microstructure was modified by introducing bimodal grains, i.e, coarse and fine grains of Cu. The bimodal structure composites were fabricated by vacuum mixing of coarse Cu powder (Cu_m) and fine Cu powder (Cu_w) along with Cu-coated CNTs followed by spark plasma sintering (SPS). Two sets of bimodal composites with 1 wt.% Cu coated CNTs were fabricated by varying the proportion of fine to coarse Cu powder (70:30 and 30:70). The unimodal composite was prepared by mixing Cu_m and 1 wt.% functionalized CNTs in a ball mill for 1 h followed by SPS. Using electron backscatter diffraction (EBSD), the microstructure of the prepared composites was examined, and the influence of coarse grain and fine grain, along with CCNTs, on the structure-property correlation in the composites was investigated. The results show that the bimodal composites outperform the unimodal counterpart, and the bimodal composite with fine-to-coarse Cu grain ratio of 70:30 has the highest compressive strength (323 MPa), ductility (18.8%), electrical conductivity (85.4±0.6% IACS), and thermal conductivity (295.4±5W/mK). The increase in strength along with good ductility of the bimodal composite is attributed to the Cu coated CNTs and the tuning between the coarse and fine grain ratio. Load transfer, aided by the Cu coating on the CNT surface, is revealed to be the primary strengthening mechanism for bimodal composites. This work sheds light on strengthening mechanisms and structure-property correlations in bimodal composites.

Further, the effect of different morphologies of Cu-based nanostructured on the sensitivity of detection of different forms of sugar was evaluated by depositing them on a stainless steel substrate by electrophotetic deposition technique. The electrochemical behavior of the resulting electrophoretically deposited porous CuO thin films was then examined to detect various forms of sugar. Of the nanostructures studied, the spherical CuO (CuO-S) thin film demonstrates superior sensitivity and a reduced response time to several sugar types in comparison to the rod-like CuO (CuO-R) and sea-urchin-like CuO (CuO-U) nanostructured thin films. Additionally, both K-nearest neighbor (KNN) and multiple linear regression methodologies are employed to classify different types of sugar and determine the concentration of a specific type of sugar.

Keywords: *Copper oxide, nanostructures, Cu metal matrix composite; Carbon nanotubes; Chemical synthesis; Spark plasma sintering;Bimodal structure; Mechanical properties.*