High porosity micro- and macro-cellular copper foams with semi-open cell microstructure toward its physical and mechanical properties

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Keywords: cellular materials, copper foam, powder metallurgy, physical properties, mechanical properties

Abstract
Herein, a powder compacting method was developed to fabricate high porosity micro- and macro-cellular copper foams using CaCO3 space holder. The cold compacted precursors were heated at different temperatures under the nitrogen atmosphere. The effects of precursor compaction pressure, space holder content and sintering temperature on cell microstructure, relative density, compressive and physical properties were investigated. The scanning electron microscopy (SEM) images showed a uniform distribution of interconnected pores with sizes of pores and channels less than 50 microns formed the semi-open cell structure of the fabricated foams. The evaluation of the foaming agent content, 0 to 20 (wt%), in precursor materials showed relatively large changes in the porosity percentage (27%–50%), with the utilitarian strength (43 MPa) and densification strain (40%) of the copper foams. For specimens having 20 wt% CaCO3, tuning the sintering temperature (600 °C) and compacting pressure (500 MPa) of precursors tailored superior porosity percent (47%), remarkable compressive stress (501 MPa) and high thermal (43.8 W m−1k), and electrical conductivity (0.06 × 108 Ω−1 m−1) owing to a desirable foaming process. A massive gas release during the CaCO3 decomposition and the strengthened cell walls of the copper foams during the sintering resulted in the high porosity and strength of the fabricated foams. The presented fabrication method and our results are the core elements for the development of new high porosity metal foams that can help the development of the future application of copper foams for a long-life anode for lithium-ion batteries, catalysis, and thermal and electrical performances as electronic cooling materials.

1. Introduction

Metal foams have recently attracted much attention in various fields of academia and industry [1–4]. These novel engineering materials have unique combinations of properties such as lightweight, energy absorption, thermal management, sound absorption and electromagnetic shielding [4, 5]. Nowadays, researchers tend to control the fabrication conditions for desirable shape and high porosity of the porous materials due to their exclusive structure in some application such as heat sinks, and lithium-ion batteries, etc. In the previous study, a crack-free mesoporous γ-alumina film with vertical mesoporosity synthesized by a calcination process. The porous alumina materials with uniform voids among the nanowires can be used in a wide range of applications such as adsorption, separation, and catalyst [6]. The mesoporous TiO2 films with vertical pores have been prepared with a spin coating method by optimizing the pore diameter and the thin film thickness for electrochromic applications [7, 8]. Bastakoti et al [9] developed a new pathway toward synthesizing In2O3 nanoparticles within carbon porous materials by a thermal decomposition process of a metal source. These materials with a synergetic contribution of carbon host and metal oxide can be used in the electrochemical applications [9].
Till now, numerous techniques such as casting, electrodeposition or vapor deposition and powder metallurgy (PM) for foaming process have been developed [10, 11]. According to some limitations of casting and deposition methods in control of cellular morphology, microstructures, and economic considerations, the PM method has been introduced [12, 13]. Using modern porous materials in different engineering applications necessitates more concentration on open interconnected foams with acceptable mechanical behavior [14]. For example, Geramipour et al [15] introduced the PM method for production of semi-open cell aluminum foams. According to Geramipour et al research [15], powder compacting method has been used due to several advantages such as high uniformity of the cells, production possibility of near-net shaped parts with complex geometries, and flexibility in alloy choice. In addition, according to Geramipour et al research [15], CaCO₃ has more advantages such as low cost and allows fabrication of designable microstructures (the closed cell or open cell microstructure with a determined pores diameter and the uniform distribution of pores for various applications) in comparison with other foaming agents such as TiH₂. The research also suggests the formation of oxide layers on the pore surface, which can help the cell walls stability of the aluminum foam [4, 15].

Cellular metals are widely investigated because their underlying properties can be adjusted by tuning foaming parameters such as porosity, cell diameter, cell morphology, alloy composition, and microstructure. To date, the copper-based foams are attracting remarkable attention in high capacity and long-life anode for lithium-ion batteries, the catalyst in many organic reactions, the electronic cooling material and, the filler material and, the electronic cooling materials due to excellent thermal and electrical performance [16, 17]. Some efforts have so far been made to investigate the properties of copper foams produced by different space holders such as NaCl, K₂CO₃, and sugar [17]. Moreover, other studies have employed lost carbonate sintering (LSC) method for foaming process [14, 18, 19]. Zhao et al [3] used the LSC method to produce high-porosity copper foams by potassium carbonate space holders.

There have been a few reports on the production of copper-based metal foams using powder metallurgy with the help of calcium carbonate, and evaluation of foaming parameters have not been thoroughly investigated. Koizomi [19] developed the PM method for fabrication of the Al-Cu alloy foam with CaCO₃ and TiH₂ foaming agents and the effect of these different foaming agents on pores characteristics have been investigated. In the previous study [18], the effects of different foaming agents (CaCO₃ and TiH₂) on the foaming process of Al-Cu alloy produced by a melting method have been investigated. Here, we have introduced a simple and easy pathway for the fabrication of copper metal foam with semi-open cell microstructure along with the investigation of pores formation, microstructure characterization, porosity type, and pore morphology, mechanical and physical properties. The research mainly seeks to expand the range of the structures, and as a result, the applications of copper foams.

2. Experimental

2.1. Materials

The atomized copper microparticles (Khorasan powder metallurgy Co., Iran, 99.8% purity, ≤45 μm) and CaCO₃ powder (Farzan Powder Co., Iran, 99.5% purity, ≤50 μm) were used as copper source and foaming agent, respectively. Figure 1 shows the size and morphology of the initial materials.

2.2. Samples production

The PM method was used to fabricate different types of copper foam materials. At first step, the copper microparticles, and CaCO₃ powders were mixed for 4 h with different CaCO₃/Cu weight percent (0%, 5%, 10%, 15%, and 20%) to obtain homogeneous mixtures. The foam precursors were produced by compaction of the mixture on top and the bottom surface with 250 MPa, 374 MPa, 500 MPa and 624 MPa pressures (for 120 s) in a steel mold with 10 × 10 mm² cross section. Figure 2 shows the schematic figure of the compaction process.

The foam precursors were then placed in a cylindrical steel mold (10 mm in inner diameter), which was open only at the top. The sintering of the foams was carried out under nitrogen atmosphere preheated to three temperatures of 800 °C, 700 °C, and 600 °C for 4.5 h with a heating rate of 10 °C/min. Subsequently, the foaming agent was thermally decomposed at 950 °C for two h, and the specimens were cooled naturally up to ambient temperature (figure 3). The processing parameters and the sample names are listed in table 1.

Since the preforms and the mold had the same diameter, the expansions only occurred in height direction. The density value of preforms and samples were calculated from their mass and geometry. Furthermore, the relative density of precursors and foams (\(\rho_R\)), linear expansion (\(\alpha_{LE}\)) and porosity of the foams (\(p\)) were calculated using the following equations [15, 20]:

\[
\rho_R = \frac{\rho_1}{\rho_2} \times 100\% 
\]
Where \( \rho_1 \) and \( \rho_2 \) values are densities of foam precursors or copper foams samples and bulk copper sample, respectively. The \( h_1 \) and \( h_2 \) parameters are the heights of foam and preform samples, respectively.

\[
\alpha_{LE} = \frac{h_1 - h_2}{h_2} \times 100\% \tag{2}
\]
2.3. Characterization

The uniaxial compressive tests were performed on a Zwick (Z250) machine at a preload of 300 N and the constant loading speed of 6 mm min\(^{-1}\). The cell microstructure was observed with a field emission scanning electron microscope (FESEM, TESCAN MIRA3–XMU) using an accelerating voltage of 10 kV with a secondary electron detector. The thermal conductivity coefficient of copper foam samples was evaluated with the electrical energy source of 10 W and the steady-state electrical heating method.

### Table 1. Fabrication parameters of the copper foam materials and samples names

| Sample code | Compaction pressure (MPa) | Wt%CaCO\(_3\) | Sintering temperature (°C) | Sintering time (min) | Foaming temperature (°C) | Foaming time (min) |
|-------------|---------------------------|----------------|-----------------------------|----------------------|--------------------------|-------------------|
| C0          | 250                       | 0              | 800                         | 270                  | 950                      | 120               |
| C05         | 250                       | 5              | 800                         | 270                  | 950                      | 120               |
| C10         | 250                       | 10             | 800                         | 270                  | 950                      | 120               |
| C15         | 250                       | 15             | 800                         | 270                  | 950                      | 120               |
| C20         | 250                       | 20             | 800                         | 270                  | 950                      | 120               |
| T600        | 250                       | 20             | 600                         | 270                  | 950                      | 120               |
| T700        | 250                       | 20             | 700                         | 270                  | 950                      | 120               |
| T800        | 250                       | 20             | 800                         | 270                  | 950                      | 120               |
| S600        | 250                       | 5              | 600                         | 270                  | 950                      | 120               |
| S800        | 250                       | 5              | 800                         | 270                  | 950                      | 120               |
| P2          | 250                       | 20             | 600                         | 270                  | 950                      | 120               |
| P3          | 374                       | 20             | 600                         | 270                  | 950                      | 120               |
| P4          | 500                       | 20             | 600                         | 270                  | 950                      | 120               |
| P5          | 624                       | 20             | 600                         | 270                  | 950                      | 120               |
| T600        | 250                       | 20             | 600                         | 270                  | 950                      | 120               |
| T700        | 250                       | 20             | 700                         | 270                  | 950                      | 120               |
| T800        | 250                       | 20             | 800                         | 270                  | 950                      | 120               |
| S600        | 250                       | 5              | 600                         | 270                  | 950                      | 120               |
| S800        | 250                       | 5              | 800                         | 270                  | 950                      | 120               |
| P2          | 250                       | 20             | 600                         | 270                  | 950                      | 120               |
| P3          | 374                       | 20             | 600                         | 270                  | 950                      | 120               |
| P4          | 500                       | 20             | 600                         | 270                  | 950                      | 120               |
| P5          | 624                       | 20             | 600                         | 270                  | 950                      | 120               |

Figure 4. (a) Differential scanning calorimetry (DSC) data and (b) Thermogravimetric Analysis data of CaCO\(_3\) foaming agent.

### 3. Results and discussion

#### 3.1. Thermal properties of CaCO\(_3\) foaming agent

The thermal properties of CaCO\(_3\) powder were evaluated with differential scanning calorimetry (DSC). The DSC pattern in figure 4(a) indicating two endothermic peaks at 265 °C and 805 °C, which are related to the moisture loss and CaCO\(_3\) decomposition reactions, respectively. The thermal decomposition and CO\(_2\) gas release occurred at approximately 805 °C, and the foaming agent at a temperature of 804 °C (according to a TGA analysis, figure 4(b)) was removed from the green body\([21,22]\).

#### 3.2. Determination of linear expansion, relative density, and porosity

The formation mechanism of porous microstructure during heat treatment is included of two steps: a) bonding of copper particles at 800 °C (The solid state sintering of copper powders (bonding of copper particles and the volume reduction of pores is possible in 800 °C\([1]\)), b) decomposition process of CaCO\(_3\) to gaseous CO\(_2\) and CaO at 805 °C.
The porosity, linear expansion and relative density of all samples are listed in table 2. According to the table 2, samples C20, T600, and P2 showed the highest porosity (50%, 53%, and 54%, respectively), and the lowest relative density (50%, 47%, and 46%, respectively).

Figure 5 shows the relative density and porosity percent of the precursors and foam samples with different processing parameters. The changes in porosity percent in figure 5(a) from 27% to 50% in C0 and C20 samples are due to the higher content of CaCO3 particles and consequently a massive gas release during the foaming process and this is the first report on copper foams with CaCO3 space holder. These data are in agreement with previous works on Al foam fabricated using powder metallurgy with CaCO3 space holder [15].

Table 2. Linear expansion, relative density, and porosity of foam samples.

| Sample code | Porosity/% | Linear expansion/% | Relative density/% |
|-------------|------------|--------------------|-------------------|
| C0          | 27         | —                  | 73                |
| C05         | 32         | —                  | 68                |
| C10         | 34         | —                  | 66                |
| C15         | 41         | —                  | 59                |
| C20         | 50         | —                  | 50                |
| T600        | 53         | —                  | 47                |
| T700        | 51         | —                  | 49                |
| T800        | 49         | —                  | 51                |
| S600        | 32         | —                  | 68                |
| S800        | 35         | —                  | 65                |
| P2          | 54         | —                  | 46                |
| P3          | 47         | —                  | 53                |
| P4          | 47         | —                  | 53                |
| P5          | 43         | —                  | 57                |

Figure 5. Effects of fabrication parameters on relative density and porosity of the copper foams: CaCO3 foaming agent content (a), sintering temperature (b), (c), and compaction pressure (d) on foaming behavior.
Figure 5(b) shows the effect of the sintering temperature on the porosity of the T600 and T800 samples. By increasing the sintering temperature of copper metal foam in the range of 600 °C to 800 °C, the porosity percent slightly decreased (53%–49%) due to the shrinkage and expansion of cell walls in foams concurrently. The expansion and shrinkage mechanisms of T800 porous sample during heat treatment were included of three steps: (a) bonding of copper particles at 800 °C (The solid-state sintering of copper powders), (b) decomposition process of CaCO3 to gaseous CO2 and CaO at 805 °C and expansion of the pores filled with CO2 gas due to increase of the temperature and escape of CO2 gas from the powder metallurgy pores progressively, (c) finally the solid-state sintering of the pores (especially in the smaller pores) due to the heat treatment cycle at a final step (950 °C for 2 h). These steps were suspended for the T600 sample until the sample heat-treated to 950 °C for 2 h and the shrinkage could not be done. Zhao et al [3] reported the high volume shrinkage in the copper foam samples using K2CO3 foaming agent with the small particle size (less than 125 μm). This phenomenon was also observed for metal foams when the sugar foaming agent was utilized [17].

The small difference in porosity percent (32% to 35%) was achieved for S600 and S800 samples due to the faster decomposition of CaCO3 [15]. According to figure 4, the decomposition process was initiated at 670 °C and the maximum rate of this process happened at 805 °C. Therefore, a faster decomposition of CaCO3 occurred with increasing of the temperature from 670 °C to 805 °C.

The compaction pressure compares to sintering temperature had a higher effect on porosity percent and relative density of the materials. The difference in porosity value was from 54% to 43% for P2 to P5 samples resulted from the elimination of the pores between the copper particles during the compacting.

Figure 6 shows the compressive stress–strain curves of the samples produced with different processing parameters. According to figure 6, the compressive curves in all cases showed a typical stress–strain diagram with a division into three parts, a linear increase in stress mainly caused by elastic deformation, followed by a plateau caused by homogeneous plastic deformation and a final steep increase due to the collapse of the cells (densification region) [17, 23, 24]. Due to the strong bonding of copper particles in the sintering step, no sudden failure was observed during the compression test.

According to Hakamada report [16], there were three processes for deformation of foams; (i) buckling and bending in each cell, (ii) localized deformation, localized straining at cell nodes, and discrete bands of concentrated strain, and (iii) complete plastic collapse. On the contrary, in a sample with low porosity content (C0), a few cell walls were found to bent or buckled and most of the cell walls yielded [16]. The results are in line with those of the study conducted on Al foam samples in higher contents of CaCO3 as a foaming agent [15].

Figure 6(d) shows the effect of sintering temperature on the plastic deformation of the foam sample. In other words, reducing the temperature increments the strength. Based on figure 6(e), the greater the compacting pressure led to the longer the plateau region. This would be mainly because of the small pores formed between primary copper particles during the compacting, the higher cell walls strength, as well as uniformity of cell microstructures improved by compaction pressure [24]. The compaction pressure also plays an important role in the improvement of particle bonding [24].

Figure 7 demonstrates the effect of CaCO3 contents, sintering temperature and compacting pressure on the compressive behavior of copper foams. Once CaCO3 content changed from 0% to 20% (figure 7(a)), compression strength fell from 136 MPa to 43 MPa and densification strain dropped from 46% to 40%. Furthermore, strengthened porosity caused a decline in strength (plateau stress (\(\sigma_p\))), elastic modulus and densification strain [25]. According to Gibson and Ashby [25], if the relative density is raised, plateau stress (\(\sigma_p\)) will be amplified, as well. For the strength of the copper foam prepared by powder metallurgy method and using PMMA, K2CO3, NaCl as foaming agents, a similar outcome was observed [12, 14, 24].

The energy absorbed per unit volume (E-energy absorption capacity), which is one of the most important characteristics of copper foams, was determined from the area under the stress–strain plots as follows [4]:

\[
E = \int_0^l \sigma(\varepsilon) \, d\varepsilon
\]  

(3)

Where \(\sigma\) is the compressive stress, \(l\) is the limit of the strain concerned (plateau region) and \(\varepsilon\) is the compressive strain. According to figure 7(b), by ascending CaCO3 contents from 0% to 20%, energy absorption descended because of less strength and more friction during the collapse stage [19, 26]. Despite the C20 sample strength downturn compared with C0, C5, C10, C15 samples, the LSC pathway yielded to an attractive combination of properties like high porosity percentage, ductility, and compressive strength.

By increasing the sintering temperature from 600 °C to 800 °C (T600, T700, and T800 samples with 20 wt% of foaming agent), the compressive strength diminished (from 16.2 MPa to 6.2 MPa). This is due to a large amount of gas release during the foaming process, which can collapse the cellular microstructure and retard the sintering of copper particles. Additionally, more shrinkage and expansion prompted the formation of imperfections in the samples, and consequently, strength diminution. A rise in temperature from 600 °C to 800 °C (S600 and S800 samples with 5 wt% of foaming agent) led to the higher strength of the cellular
microstructure varied from 115 MPa to 163 MPa. This was due to a higher diffusion, more interfaces between copper particles (low amount of foaming agent) during the solid-state sintering process and the higher strength of cell walls [15].

Figure 7(e) shows that the rise of compacting pressure from P2 to P5 (250 MPa to 624 MPa) upgrades the compressive strength of the samples from 324 MPa to 526 MPa because of the lower number of the pores and the strain hardening of copper particles [18]. When preform compacted below 250 MPa, the deficient bonding strength between Cu particles prompted the collapse of the green compact amid handling. Some cracks were originated in the preform samples which compacted at 624 MPa compacting pressure [15].

According to previous research [15], in the preform samples compacted at 624 MPa compacting pressure, the effective stress at the upper and lower zones of the green compacts, induced during the compression phase, is higher than that in the middle zone. Therefore, removing the load (unloading) results in the elastic recovery of the powders near the top and the bottom. Consequently, at a high range of stress, a narrow band with localized

Figure 6. Compressive stress-strain curves of produced samples with different processing parameters (three consecutive regions are marked on the curve of C05 sample in figure (b)): (a), (b) CaCO3 foaming agent content, (c) foaming temperature for C20, (d) foaming temperature for C05, (e) compaction pressure for C20.
intensive shear stress forms at the interface of these two zones, which is responsible for the spalling of the green compacts. So a compacting pressure of 500 MPa was found to be adequate, yielding defect-free green compacts with optimal strength and porosity percent that retain their original shape.

Figure 8 shows the thermal conductivity and electrical conductivity of foams by increasing the compacting pressure. According to the Wiedemann-Franz formula\(^{(4)}\), the electrical conductivity can be calculated by using the thermal conductivity measurements.

\[ k / \sigma = LT \]  

where \(k\) is the thermal conductivity in W/mK, \(T\) is the absolute temperature in K, \(\sigma\) is the electrical conductivity in \(\Omega^{-1}\) m\(^{-1}\) and \(L\) is the Lorenz number, equal to \(2.45 \times 10^{-8}\) W\(\Omega\)/K\(^2\).

As indicated by figure 8, stronger compacting pressure brought about denser precursors and thermal and electrical conductivity values from 41.4 W m\(^{-1}\)k to 54 W m\(^{-1}\)k and 0.057 \(\times 10^8\) \(\Omega^{-1}\) m\(^{-1}\) to 0.074 \(\times 10^8\) \(\Omega^{-1}\) m\(^{-1}\), respectively. The optimum foaming process parameters to meet the highest porosity percent (47%) and desired compressive strength (501 MPa) included CaCO\(_3\) content of 20% wt, the sintering temperature of 600 °C, and compacting pressure of 500 MPa. Michailidis et al\(^{[17]}\) produced open cell copper foams using sugar as a foaming agent with 60%–80% porosity and pore size within the range of micrometers to millimeters. In this study, the optimal strength value of the foam was higher than the one reported by Michailidis et al\(^{[17]}\) in which...
sugar and dissolution were applied as a foaming agent and foaming agent removal method, respectively. It is noteworthy that the optimal amount of strength value obtained in the present study is remarkably higher than those reported by other studies that worked on melting or dissolution route and other foaming agents such as polymer (PMMA), TiH₂, and K₂CO₃ [3, 4, 14, 18]. This may possibly be the result of a higher amount in compacting pressure, as well as applying CaCO₃ as a foaming agent. This research shed light on the fact that powder compacting and LSC methods can rise the structural integrity of the foams and consequently their mechanical strength at least twice in magnitude when compared with previous studies [14, 16, 17, 24]. Herein, the outstanding porosity percentage and strength of copper foams compared with Mg foams [29–31], Steel foams [32, 33], Zn-Mg alloy foams [34], Al foams [15], was influenced by several factors: The optimum amount of weight percent of CaCO₃ and desirable decomposition process of this space holder, the relevant compacting pressure and sintering temperature.

3.3. Cell microstructure
Figures 9–11 show the cross-sectional FESEM images of the copper foam samples. As shown in figures 9–11, the interconnected big pores (white arrows) depicted the macroporosity caused by foaming process or microporosity (full-line circles) with closed cell microstructures formed based on powder metallurgy method [1]. In addition, the size and morphology of macro-pores corresponded to those of calcium
carbonate particles and that all the macro-pores were interconnected. Therefore, it can be concluded that the produced foams suggest a high degree of pore connectivity. On the other hand, it was possible to observe uniform semi-open cell microstructures (Geramipour explained the uniform distribution of the cells, which connected via some channels as a semi-open cell microstructure [15]). Higher contents of CaCO$_3$ (C15) led to the formation of cracks (figure 10) following the expansion and shrinkage concurrently. Occurring at higher CaCO$_3$ contents, agglomeration of CaCO$_3$ particles led to inhomogeneity in the distribution of the pores (figure 10(e)) which in turn caused premature failure in the sample [5, 10, 24]. No crack formations were

Figure 10. FESEM images of (a)–(c) C10 sample, and (d)–(f) C15 sample with different magnifications.

Figure 11. FESEM images of C20 sample with different magnifications.
observed in the C20 sample demonstrating the conquest of the CaCO₃ decomposition mechanism compared with the shrinkage mechanism.

According to microstructural image processing (MIP) software applied on the FESEM results, rising CaCO₃ content from 5% to 20% intensified the macroporosity from 6.45% to 17.75%, indicating the expedition and increment of decomposition process in CaCO₃, and microporosity from 6% to 13%, indicating more pores caused by powder metallurgy method. The formation of channels between the pores can be attributed to the oxide layers on copper particles.

Figure 12 shows the schematic image of the pore formation in the foaming process. As shown in figure 12, the pores of the samples are divide to small pores between copper particles derived from powder metallurgy, big pores due to CaCO₃ decomposition, and the channels from oxide layers on copper particles. Figure 12(d) illustrates some cracks due to expansion and shrinkage of the foam samples.

4. Conclusions

An explicit schedule based on the powder metallurgy was used to produce semi-open cell copper foams. The effects of several parameters including CaCO₃ foaming agent content, precursor compaction pressure, foaming agent content as well as temperature of the foaming process on the cell microstructure, relative density, compressive and physical properties were investigated. The SEM results showed the microporosity comes from powder metallurgy method and the macroporosity resultant of CaCO₃ decomposition. An increase of the CaCO₃ contents from 0 to 20 Wt.%. led to the higher porosity amount (27%–50%) and the compression strength fell from 136 MPa to 43 MPa and densification strain dropped from 46% to 40%. The compacting pressure and sintering temperature effects on mechanical response were clearly apparent for foam specimens having 20 wt.% CaCO₃. It means tuning the sintering temperature (600 °C- 800 °C) resulted in the lower amount of porosity (53%–49%), and decrease of the compressive strength (16–6.2 MPa). Furthermore, a rise in the compacting pressure (250 MPa–624 MPa) led to descend off the porosity content (54%–43%), and the higher compressive strength (326 MPa–524 MPa), an increase of thermal (41 W m⁻¹.k–54 W m⁻¹.k) and electrical conductivity (0.057 × 10⁸ Ω⁻¹.m⁻¹–0.074 × 10⁸ Ω⁻¹.m⁻¹). A combination of sintering temperature (600 °C) and compacting pressure (500 MPa) can provide an acceptable porosity (47%), remarkable compressive strength (301 MPa), and favorable thermal (43.8 W m⁻¹.k) and electrical conductivity (0.06 × 10⁸ Ω⁻¹.m⁻¹) for copper-based foam using CaCO₃ foaming agent. We strongly believe that the simplicity of this synthetic approach will allow us to expand the microstructural properties of copper foams, which will obviously be important for the development of various applications of this group of advanced materials. The copper foam characteristics were markedly higher from the metal foams specifications obtained from other studies. This is the innovative report on the synthesis of copper foams with CaCO₃ space holder.

Conflict of interest

The authors declare that they have no conflict of interest.

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