Abstract

Metal foams are used in several industries for their high strength to weight ratio, low density, high surface area, and enhanced damping properties. Open-cell metal foams with interconnected pores are used as functional structures, in filtration, sound absorption, and heat exchangers. However, fabrication of open-cell metal foams with uniform pore morphology and porosity is challenging. Among the developed methods, sintering and dissolution is commonly used to fabricate open-cell metal foams with desired pore morphology. Conventional sintering methods used to sinter metal-spacer mixture have limitations including sintered parts shape and size, lower heating and cooling rate, inert sintering environment, etc. Friction stir processing (FSP), which can generate high temperatures and pressure, can be used to sinter metal powder and metal-spacer mixtures. However, FSP has many drawbacks including wastage of die material, joining of sintered parts with the die, breakage of spacers during processing, and involvement of many steps.

In this work, sintering is done using a friction processing method where the tool does not come into direct contact with the powder mixture but generates pressure and temperature needed for sintering. Powder mixture was prepared by mixing copper powder with NaCl spacers using a mechanical stirrer. Electrolytic copper and cuboidal NaCl spacers were used as the starting materials. Three different setups were developed for fabrication of small cylindrical, large plate, and hollow cylinder copper foam parts using sintering and dissolution process. Setups and tool paths were chosen to get the desired shape and size of sintered parts. The setups have four essential parts: (i) top sheet or outer pipe, (ii) middle block, (iii) bottom plate or inner pipe, and (iv) the tool. For small cylindrical parts, powder mixture was compacted using die, punch, and support to get the green compacts. For large plates and hollow cylindrical parts powder mixture was manually rammed to the desired shape. Pressure and temperature needed for sintering were obtained by plunging a rotating tool into the top sheet in the setup. Other than the top sheet, the setup is reusable. Metal-spacer mixture insertion in the setup and removal of sintered metal-spacer parts after sintering from the setups were straightforward. 3-axis and 6-axis friction stir welding machines were used for friction processing.

NaCl was removed from the sintered parts using dissolution process. Dissolution time depends on the sample size and the volume fraction of NaCl. Almost all NaCl was removed during the dissolution process. K-type thermocouples and FLIR thermal imager were used to measure the process temperatures. Post-processing was done to investigate the microhardness, porosity, microstructure, and mechanical properties of sintered parts. Porosity and pore morphology were found to depend on the volume fraction of NaCl and shape and size of NaCl particles, respectively. Number of passes and plunge depth per pass affected the sintering temperatures and pressure. As the plunge depth increases pressure applied on the top sheet also increases. Plunge depth higher than critical value results in machine vibration, whereas lower plunge depth leads to lower pressure and higher sintering time. Microstructures of fabricated copper pellet and copper foams were studied using scanning electron microscopy and microcomputed tomography. Pore morphology of metal foams was similar to that of NaCl spacers. Collapse of copper wall was not observed during the removal of NaCl, indicating good copper bonding during processing. Mechanical properties were studied using the compression tests. With the increase in porosity, plateau stress decreases. This was due to lower copper wall thickness and higher interconnected porosity. A detailed study was conducted on effect of tool traverse speed on microstructure, porosity, and mechanical properties. The fabricated foams were found to be of partially open-cell type with interconnected pores.

Keywords: Friction processing, sintering and dissolution, metal foam, copper pellet, solid-state sintering, NaCl spacers.