Mechanical Engineering Doctoral Defense

Fundamentals of Liquid Metal Foams and Emulsions

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Abstract

Gallium based room-temperature liquid metals (LMs) have special properties such as metal-like high thermal conductivity while in the liquid state. They are suitable for many potential applications, including thermal interface materials, soft robotics, stretchable electronics, and biomedicine. However, their high density, high surface tension, high reactivity with other metals, and rapid oxidation restrict their applicability. This dissertation introduces two new types of materials, LM foams, and LM emulsions, that address many of these issues. The formation mechanisms, thermophysical properties, and example applications of the LM foams and emulsions are investigated.LM foams can be prepared by shear mixing the bulk LM in air using an impeller. The surface oxide layer is sheared and internalized into the bulk LM as crumpled oxide flakes during this process. After a critical amount of oxide flakes is internalized, they start to stabilize air bubbles by encapsulating and oxide-bridging. This mechanism enables the fabrication of a LM foam with improved properties and better spreadability.LM emulsions can be prepared by mixing the LM foam with a secondary liquid such as silicone oil (SO). By tuning a few factors such as viscosity of the secondary liquid, composition, and mixing duration, the thermophysical properties of the emulsion can be controlled. These emulsions have a lower density, better spreadability, and do not induce corrosion of other metals as is the case with the original LM and LM foam. LM emulsions can form by two possible mechanisms, first by the secondary liquid replacing air features in the existing foam pores (replacement mechanism) and second by creating additional liquid features within the LM foam (addition mechanism). The latter mechanism requires significant oxide growth and therefore requires presence of oxygen in the environment. The dominant mechanism can therefore be distinguished by mixing LM foam with the SO in air and oxygen-free environments. Additionally, a comprehensive analysis of foam-to-emulsion density change, multiscale imaging and surface wettability confirm that addition mechanism dominates the emulsion formation. These results provide insight into fundamental processes underlying LM foams and emulsions, and they set up a foundation for preparing LM emulsions with a wide range of fluids and controllable properties.

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