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CONTROLLED COOLING APPARATUS FOR EVALUATING LUNAR HEAT TRANSFER CONDITIONS IN ISRU ALUMINIUM PROCESSING

Abstract

Humanity's ambitions for a permanent lunar base will necessitate extensive in-situ operational infrastructure. A significant portion of this infrastructure, including communications, power delivery, habitats, and robotics, has the prospect to be manufactured from metals extracted from lunar soil. Current literature explores multiple options for reducing regolith, the first step towards in-situ resource utilisation (ISRU) of lunar metal. To date, however, comparatively little focus has been placed on processing ISRU metals into finished or semi-finished products – an area we refer to as Lunar Metal Manufacturing (LMM).

It is logical that early LMM developments will focus on high-volume, standardisable components, such as electrical wire, structural beams, or additive manufacturing feedstock. It is also plausible that LMM methods for these components could be adapted from terrestrial batch- or mass-manufacturing, but system design will need to account for in-situ environmental conditions. For metallurgical processing, control of heat transfer phenomena is a primary objective, determining material properties, surface quality, defect formation, processing time and machinery life. On the Moon, heat transfer is hampered by the extreme-high vacuum, which precludes convective and conductive air cooling, and lack of abundant liquid coolant. Any LMM process on the exposed surface will therefore experience very slow cooling rates without an active cooling mechanism.

This paper details a custom apparatus for measuring heat transfer under vacuum and controlled-cooling conditions. The purpose of our study is to evaluate the impact of the lunar thermal environment on aluminium LMM, and investigate the feasibility of a passive-cooled LMM system. A lumped capacitance model was used to estimated cooling rates for a lunar aluminium caster, then an experimental apparatus was designed to replicate those rates. The average cooling rate calculated was 2 K/min for molten pure aluminium, <1% of typical rates seen in sand or direct chill casting. Our apparatus is capable of recreating these cooling rates in a tube furnace under vacuum and ambient atmosphere, whereby controlled cooling is achieved via linear actuation of a crucible with a magnetically-coupled sample holder. The design also incorporates six embedded thermocouples to measure heat transfer coefficients (HTC) at the mould-metal interface. Preliminary results from this apparatus demonstrate how a process-structure-property relationship can be examined for lunar alloys at very low cooling rates, and HTC measurements can be

used to validate numerical models of lunar metal processing. These outcomes will deepen understanding of the challenges associated with LMM, enabling more efficient strategies for developing ISRU-metal infrastructure.