ISRU IRON ALLOYS: PROPERTIES AND TESTING ON IRON PRODUCED BY HYDROGEN REDUCTION OF LUNAR REGOLITH SIMULANT. P. E. Corwin[1,2], Z. Yu[1], [1]Colorado School of Mines, 1500 Illinois St., Golden, CO 80401, [2]pecorwin@mines.edu

Introduction: In-situ metals extraction from lunar regolith has been discussed as a potential space resource for decades as a byproduct of oxygen production [1] [2]. However the actual extraction, separation, and production of these metals has only recently received dedicated attention [3]. Lunar water has certainly captured the majority of near-term interests, but most space powers continue to invest in oxygen production from lunar regolith [4][5]. Of note, NASA's recent 2023 BIG Idea challenge "Lunar Forge" and 2023 LuSTR "Extraction of Metals from Lunar Regolith for Additive Manufacturing" have specifically focused on lunar metals extraction and processing. It is clear that in-situ derived metals are being considered as a potential long-term capability in need of further development. Understanding the properties and constraints of these metals will be key to determining how to produce a useful metal raw material.

Lunar Iron Alloys: The work presented here examined an iron alloy produced by hydrogen reduction in Pioneer Astronautic's MMOST system. This alloy was tested and chemically analyzed, and also compared to a set of similar alloys with simulated compositions.

Phosphorus Contamination and Mitigation: Initially delievered samples revealed very high phosphorus contamination within the iron. Phosphorus segregates to grain boundaries in iron alloys, weakening the strength and leading to intergranular brittle failure. The standard practice in the primary metals industry to counteract this detrimental behavior is to remove phosphorus from the ore or from liquid steel during melting. Neither process is readily transferable to lunar applications; ore processing typically utilizes chemical leaching, requiring both water and consumbable reagents, while melt processing utilizes limestone, a mineral not available on the Moon, to produce a calcia-rich slag and draw phosphorus out of the liquid.

A review of literature suggested two potential avenues for mitigating the effects of phosphorus within the iron which may be suitable for the Moon: heat treatment and boron microalloying. Heat treatment utilizes a long high temperature soak to diffuse phosphorus out of grain boundaries. The advantage of heat treatment is that it requires no consumables except for the additional equipment. Alternatively, microalloying utilizes part-per-million level additions of boron to reduce the impact of phosphorus. For very low carbon steels/irons, such as those produced by hydrogen reduction, boron segregates to the grain boundaries and occupies intergranular sites, blocking phosphorus and strengthening the grain boundary. Boron microalloying does require boron be brough from Earth, however, at a 40ppm level within the iron, a single kilogram would enable the production of 25 tonnes of iron, likely justifying the mass.

Experimental Work: This research produced four iron alloys, varying phosphorus and boron. These alloys were cast to 9 cm diameter ingots and heat treated under several different conditions, with the goal of reducing the detrimental effects of phosphorus. Microsctructure, tensile, and hardness samples were cut from produced material to sample across heat treatments and compositions.

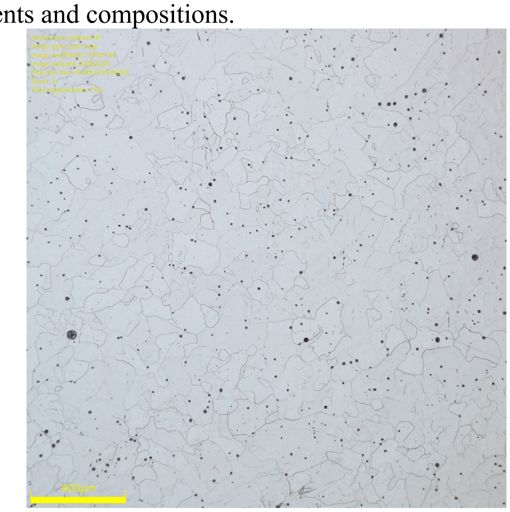

Fig. 1 Heat treated, phosphorus-contaminated iron alloy microstructure, analogous to ISRU iron.

Impact of the Reserach: This work represents some of the first chemistry and mechanical property data available for a potential in-situ produced metal. Phosphorous contamination within lunar iron will be a key hurdle to overcome to enable the in-situ resourse utilization (ISRU) of these alloys. This research provides a first attempt at mitigating these detriments while taking into consideration the unique challenges of the lunar environment.

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