SAMPLE CONTAINMENT FOR IN SITU ANALYSIS ON THE MOON: TESTING SEALING MATERIALS IN THE PRESENCE OF DUST.

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Introduction: The lunar regolith is formed by high velocity micrometeorite impacts, which have pulverised the lunar surface into highly angular lithic fragments and impact melt. The impact melt solidifies to form silica-rich glass rinds around grains, which become brittle and shatter, resulting in sharp, angular particles that are highly abrasive and can interfere with the operation of equipment on the surface [e.g. 1]. Lunar regolith is also easily disturbed and electrostatically charged [2], which is particularly problematic when it is necessary to form gas tight seals in-situ, as it is highly likely that the sealing surfaces would become contaminated with dust.

ESA's PROSPECT (Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation, and Transportation) is due to fly on the Russian Luna 27 mission to the lunar south pole with the goal of identifying the presence and distribution of water in the subsurface. The ProSPA (PROSPECT Sample Processing and Analysis) package [3] is a miniaturized chemical analysis laboratory consisting of a gas processing system and two mass spectrometers, designed to provide information on the abundance, nature, and distribution of lunar volatiles, as well as to demonstrate In Situ Resource Utilization (ISRU). Samples of icy regolith will be sealed within miniature ovens, heated and then analysed. A wide range of temperatures will be experienced, from the approx. -100°C of the lunar surface, through to the maximum operating temperature of the ovens at ~1000°C. However, the oven design will allow for the seal to only have to withstand up to ~300°C. An effective seal will need to be maintained across the temperature range, most likely with dust particles embedded on the surface of the sealing material. Whilst dust mitigation strategies for gas-tight seals do exist (such as those used on NASA's MSL rover [4, 5] and the upcoming ExoMars rover [6]) these involve relatively complex, large-scale, heavy sample handling hardware and are therefore prohibited by the mass limitations of ProSPA (10 kg). Given these limitations, the sealing mechanisms are modelled on the Rosetta Philae SD2 sampling system [7], designed to be small and lightweight, but meaning only low sealing forces (<400 N) are able to be exerted.

Methods: Experimental work has been undertaken to assess the leak rate of seals using different materials and a range of sealing forces. This work builds on the results from Abernethy et al. [8], which assessed the efficacy of Kalrez®7075 and indium as a single-use sealing material. Both materials are highly deformable, enabling seals to be made at relatively low forces (<400 N), and were tested clean and contaminated with the lunar simulant JSC-1A.

To extend the scope of this work, new measurements of the leak rate of seals have been made. These were conducted using two metal alloys manufactured by Indium Corporation (Indalloy 164, chemical composition 5% indium, 92.5% lead and 2.5% silver; and Indalloy 171, composed of 95% lead and 5% tin), and the fluoropolymer resin Polytetrafluoroethylene (PTFE). The sealing potential of these materials has been tested using two different circular knife edges, with cross-sectional profile angles of 45° and 90° at the tip of the knife edge (see Fig. 1) in order to also assess the effect of seal geometry on seal quality.

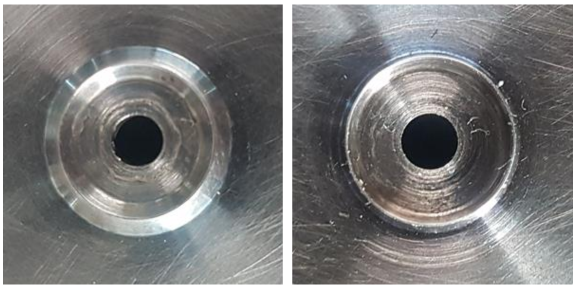

Figure 1. Circular knife edges used to perform sealing tests. *Left* 90°, *right* 45°. Both 10 mm diameter at the peak of the knife edge, and 1 mm in height.

A custom rig was used to test the leak rates of sealing materials. A force, measured by a load cell, was applied to the sealing material against the knife edge. The applied force was then gradually increased and the sealed volume within the knife edge evacuated, and the leak rate tested incrementally until a good quality seal was achieved, as per the methods detailed in Abernethy et al. [8]. A leak rate of 10^{-6} mbar.l.s^{-1} is the requirement for the ProSPA ovens, and so seals with a leak rate equal to or less than this threshold is deemed to be a "good quality" seal. Fig. 2 depicts the equipment set-up used to pump down the sealed volume and then measure the rise in pressure due to leaks in the seal. Valve 1 (V1) leads to a vacuum pump; valve 2 (V2) to a 1 Torr Baratron™ capacitance manometer; valve 3 (V3) to the seal testing apparatus; and the final valve (V4) is kept closed. Once the volume was evacuated, the valve to the pump was closed off, leaving the Baratron and seal test apparatus valves open. The pressure on the Baratron was sampled over a 45s period, or until the Baratron reached the maximum pressure reading. The leak rate was then calculated from the rise in pressure over time within the sealed volume through the ideal gas equation.

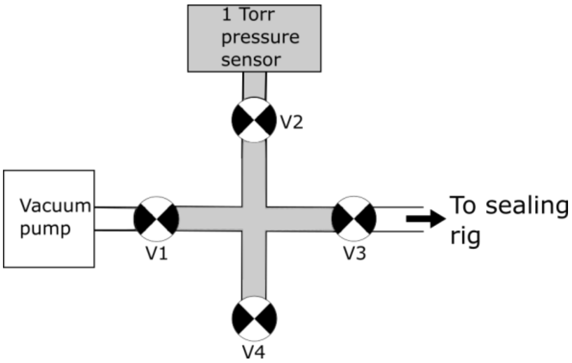

Figure 2. Schematic of equipment used to measure pressure rise in sealing tests [4].

Results: Leak rate measurements have been undertaken on three candidate seal materials: Indalloy 164, Indalloy 171 and PTFE. These were performed using a circular knife edge of 45° and 90° in profile. Measurements were then repeated with the seals contaminated by JSC-1A lunar regolith simulant, in order to get an initial assessment of how these seals could perform in a dusty environment, such as the lunar surface (see Fig. 3 for examples of sample materials after sealing achieved). For these tests the extent of dust coverage was not quantified, just visually assessed to be evenly coated in a thin layer of dust.

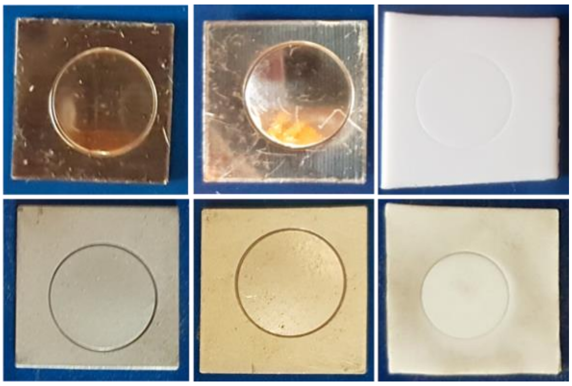

Figure 3. Samples of tested seal materials. *Top row:* clean seals; *Bottom row:* seals loaded with JSC-1A dust. *Left to right:* Indalloy 164, Indalloy 171, PTFE.

Analysis of the data so far has shown that the broader 90° angled knife edge achieves the required leak rate of 10^{-6} mbar.l.s^{-1} more consistently and at lower sealing forces than when using the 45° knife edge. Additionally, the 90° knife edge forms a seal with a lower leak rate than the 45° knife edge when the seals are contaminated with simulant dust. It is likely that this is due to the larger surface area over which a seal is made with the broader knife edge, which causes the simulant grain to be encapsulated in the seal completely. Room temperature tests so far show that PTFE is the most promising candidate seal material, forming a good seal at low sealing forces (<300 N) when clean, and requiring ~400 N sealing force to achieve the required leak rate when dusty. The softer Indalloy 171 performed within the requirements when clean, achieving the leak rate of 10^{-6} mbar.l.s^{-1}at a sealing force of ~400 N, but required >500 N sealing forces when dusty, whilst the harder and least deformable Indalloy 164 performed the least consistently across all scenarios.

Further Work: This investigation is ongoing. A new sealing rig is being assembled to enable testing of seal materials under vacuum conditions and over the temperature range from that experienced at the lunar pole, to oven operating temperatures. The system will be automated for greater reproducibility of the results. Different materials may perform better at higher or lower temperatures, and so further sealing materials will be tested, in addition to the two alloys and PTFE tested so far. A range of knife edge sealing geometries will be used, and tested on both sides of the seal (the knife edge, as tested here, and the oven side of the seal). Additionally, a dust distribution system has been developed to more evenly distribute lunar simulant dust onto the samples, and assess the quantity and distribution of the dust coating prior to experiment commencement.

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