LASER PROCESSING REGOLITH FOR LUNAR BASE CONSTRUCTION: IMPLICATIONS OF EXPERIMENTAL TRAILS. K. W. Farries[1] and P. Visintin1[1], S. T. Smith[1, 1] kevin.farries@adelaide.edu.au, Lunar Construction Group, School of Architecture and Civil Engineering, The University of Adelaide, SA 5005, Australia.

Introduction: If a permanent lunar base is to be established in the next two decades, there is an urgent need to identify and develop methods of producing construction materials from in-situ raw materials. The obvious raw material is lunar regolith, which can be sintered or melted to form construction materials without the need for imported or refined binders. Although sintering or melting is energy intensive, at high latitudes near the lunar poles solar arrays can be used to harvest the almost constant incident solar energy.

The various processes that have been trialed to melt or sinter lunar regolith simulants were reviewed and evaluated in a previous paper [1]. Options include using laser energy to produce construction materials by selective laser melting (SLM); melting the surface of the regolith in-situ by direct laser sintering (DLS); and welding together cast regolith masonry units produced by traditional methods. This abstract provides an overview of past and ongoing experimental work conducted by the Lunar Construction Group (LCG) at the University of Adelaide and summarizes key implications of these trails with respect to applying laser processing to lunar base construction.

Equipment: A CO_2 laser cutter was used as the power source for the experimental trails. The cutter supplied a pulsed laser with a wavelength of 10.6 μm, power of up to 100 W and a frequency of 1 – 60 kHz.

Materials: Lunar mare regolith simulants LMS-1 and DG-2, and highland simulants LHS-1 and AN-1 were used for the SLM and DLS trials. Further details of these simulants and a discussion of their fidelity to mare and highland lunar regolith can be found previous papers [2, 3]. For the welding trials, as an analogue for cast regolith masonry units, blocks cut from cast basalt tiles were welded together.

SLM: SLM is an additive manufacturing process which is illustrated in Figure 1. The LCG trials extended the preexisting body of knowledge on SLM of lunar regolith simulants by adopting a CO_2 rather than fiber laser; using unscreened simulant; pre-compacting the raw regolith powder to avoid the need for a substrate; applying a wide range of laser energy intensities; and including multiple highland and mare simulants in the study. Product density, flexural strength and compressive strength were tested so that the influence of the process parameters on material properties critical to construction could be assessed. Three objects produced from regolith simulant are shown in Figure 2.

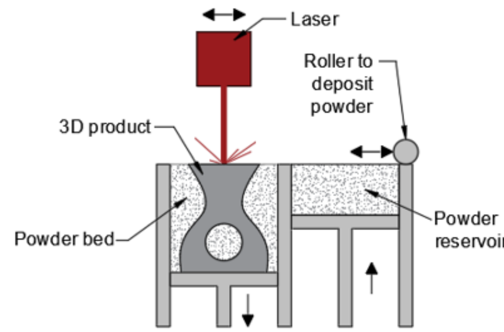

Figure 1: SLM process [3]

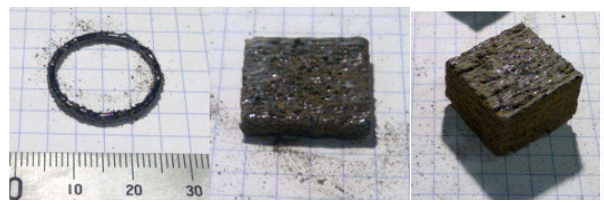

Figure 2: Typical SLM Products [3]

DLS: DLS uses a similar process to SLM, but rather than producing a 3D object, laser energy is used to seal the lunar surface as illustrated in Figure 3. Such a process could be valuable for dust control. The experimental trials of DLS built upon the results of the SLM experiments and took advantage of the large build area afforded by the laser cutter to produce a 120 × 120 mm sintered crust on compacted simulant as shown in Figure 4.

Figure 3: Direct laser sintering the lunar surface. © Andy Thomas Centre for Space Resources, used with permission.

Welding: Given the difficulties of using grout or adhesives in lunar vacuum, welding was considered as a means of joining masonry units cast from molten regolith using traditional methods. Blocks cut from cast basalt tiles were used as an analogue of cast mare lunar regolith and welded with and without preheating using the CO_2 laser. Welded blocks are shown in Figure 5.

Figure 4: 120 × 120 mm sintered crust produces on LHS-1 simulant.

Figure 5: A pair of laser-welded cast blocks

Key outcomes of experimental trials: Laser light can be focused to extremely high intensities. As a result, it is possible to melt raw or cast regolith at relatively low laser output powers. The trials identified an optimal power for all processes of only 40 to 60 W. This might require a system power of around 1 kW and could be powered by a small solar array.

The ability to melt regolith with a low-power system might be crucial in the pioneering stages of ISRU development. However, low power is achieved at the cost of increased processing time: the production rates for SLM in the trials were in the range 0.25 – 2 g/minute, and product strength dropped rapidly as the production rate was increased. For example, the compressive strength of SLM blocks dropped from around 50 MPa at 0.25 g/min to around 15 MPa at 0.5 g/min. Even at the higher rate it would take around 5 days to produce a standard, solid 3.5 kg brick. It is not possible to increase the production rate for SLM, DLS and welding simply by increasing the laser power and scanning speed. It was found in the trials that such an approach reduced efficiency and increased the risk of damage to the laser optics.

Furthermore, the size of the melt pool, and so the penetration depth, in all three processes is limited by the thermal properties of the material being melted. For DLS and SLS penetration was limited to approximately 4 mm, while the higher thermal conductivity of cast basalt limited the weld penetration to around 1.5 mm. This constraint, which cannot be overcome by changing the welding parameters, places and absolute limit on scalability.

Nonetheless, it was possible to produce a DLS sintered crust capable of supporting light traffic under lunar gravity. To achieve this result, the trials clearly demonstrated the need for regolith sintering or melting pilot studies to consider scale effects. In the trials, as the dimensions of tiles produced using DLS were increased, cracking became more pronounced as illustrated in Figure 6. To overcome this issue, it was necessary to develop a staged scanning pattern which gives rise to the checkerboard pattern visible in Figure 4. This scanning strategy would allow the sintered crust to be extended indefinitely. If sufficient power were available, the most viable means of increasing the production rate for DLS would be to use an array of lasers at the optimal power level as shown in Figure 3.

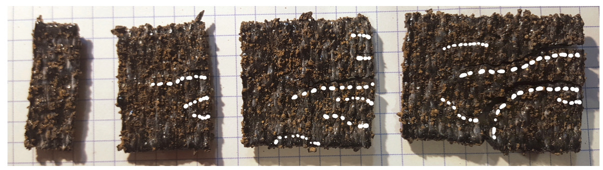

Figure 6: Development of cracking as the width of a 30 mm long tile is increased from 10 to 40 mm. Cracks are highlighted by dotted white lines under the cracks.

Welding trails conducted to date have also produced informative results. When the welded blocks were heated and annealed in a furnace at 750 °C, it was possible to produce a weld with a transverse tensile strength of the order of 16.5 N/mm (≈ 13 MPa). It is possible that preheating could be achieved for short stitch welds without a furnace by modulating the laser power, though further trails are needed to confirm this. If thermal crack control using modulated laser power is not possible, cracking in the weld or parent material is unavoidable. Nonetheless, welds made without preheating still had a residual strength of up to 0.8 N/mm, which would be sufficient to support the self-weight of small masonry units during construction to avoid the use of falsework when constructing domed or vaulted structures.

Conclusions: Experimental trials by the LCG at the University of Adelaide have highlighted physical limitations on the scalability of laser processing for lunar base construction. Nonetheless it has been shown to be possible to produce a DLS crust at scale and that laser welds could be sufficiently strong to support the self-weight of small masonry units during construction.

References:

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