Additive Manufacturing of Functionally Graded Materials from Lunar Regolith

Executive Summary

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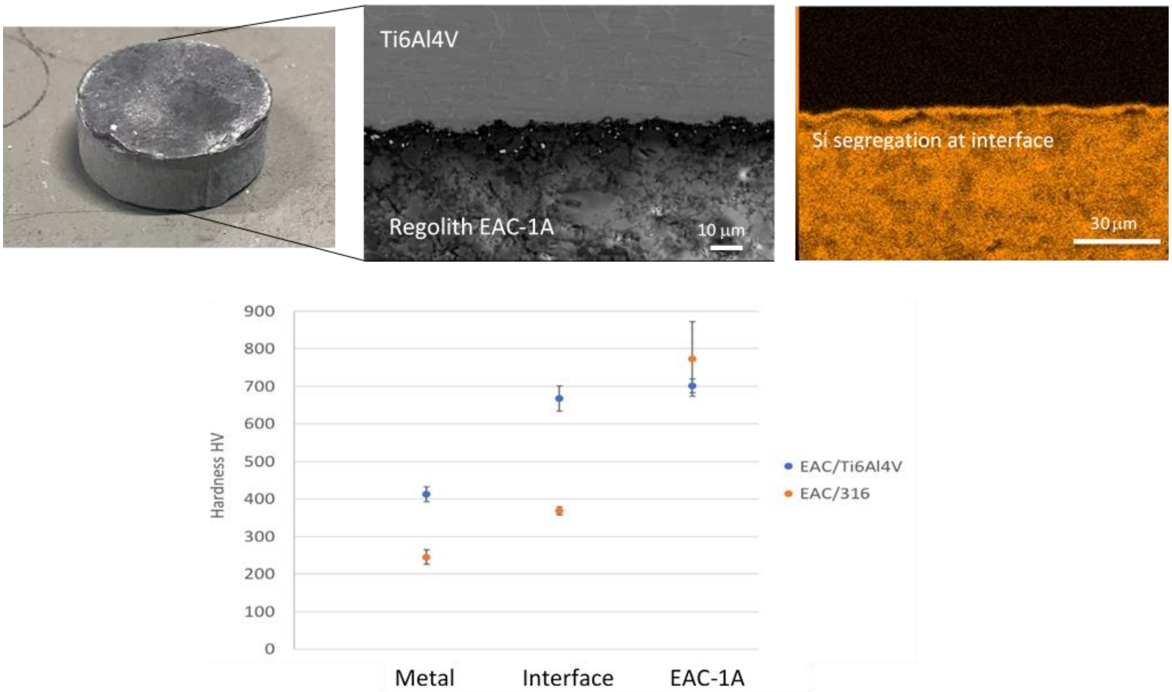
Picture:

Additive Manufacturing of Functionally Graded Materials with Lunar Regolith and Metallic Alloys



Motivation:

This study investigates the feasibility of producing a functionally graded material (FGM) composite from lunar regolith simulant and metallic alloys using additive manufacturing (AM).

Optimal processing conditions were determined to produce FGMs at concept validation level, for application in ISRU manufacture of habitats and aerospace components.

Methodology:

Lunar regolith simulants were characterised based on their thermal behaviour, particle size distribution and composition, in order to inform the choice of consolidation method for FGMs *(powder characterization results are provided in Deliverable "conference paper").*

An extensive literature review study (deliverable Literature Review) identified Digital Light Processing (DLP) and Spark Plasma Sintering (SPS) as promising consolidation techniques.

Initial experiments focused on consolidating regolith alone using the selected processes, in order to find optimal processing parameters. DLP was utilised to print sieved regolith into the desired shape. SPS was then used as a post-process to achieve full sintering. Regolith samples were also consolidated with SPS alone, and the influence of sinter temperature, particle size and composition on sintering was investigated. Two metallic powders – Ti6Al4V and stainless steel 316L – were also sintered individually with SPS and the optimal processing parameters for each powder were found.

Finally, FGMs were consolidated with both Ti6Al4V and stainless steel, based on the optimal regolith and metal sintering parameters. XRD, SEM and optical microscopy were conducted on consolidated samples to characterise their morphology. Density and Vickers microhardness measurements were also taken.

Results:

- Three Lunar regolith simulants were characterised based on their thermal behaviour, particle size distribution and composition, in order to inform the choice of consolidation method for FGMs (powder characterization results are provided in Deliverable "conference paper").

- Lunar regolith simulants were successfully printed and debinded with Digital Light Processing. However, post-sintered samples showed poor necking and thus DLP optimisation of the sintering step was further required.

- DLP regolith samples were subsequently successfully sintered with Spark Plasma Sintering at 1050°C under 80 MPa. Densification and Vickers micro-hardness were found to increase with increasing temperature and reduction of particle size.

- Metallic powders were also successfully densified with SPS at relatively low temperature and a pressure of 50 MPa. Both stainless steel and Ti6Al4V showed homogeneous structures without precipitates or carbides.

- FGMs were made using the established optimal AM parameters. The combination of lunar regolith and Ti6Al4V was shown as the most promising. The hardness profile showed a gradual transition between the two layers and the interface was found to be strong and without any cracking or delamination (*results can be found in Deliverables: journal paper and final report*).

Publications:

1. I. Cheibas, M. Laot, V. A. Popovich, B. Rich, and S. R. Castillo, '*Additive Manufacturing of Functionally Graded Materials with In-Situ Resources'*, Aerospace Europe Conference, Bordeaux, February 2020.

2. M. Laot, B. Rich, I. Cheibas, J. Fu, J. Zhu, V.A. Popovich, '*Additive Manufacturing of Functionally Graded Materials from Lunar Regolith'.* SPOOL, [S.l.], v.4, n. 1. (Journal paper – under review, Nov 2020)

3. M. Laot, Master Thesis, TUDelft, December 2020. Available online through TUDelft repository from December 11th.

Recommendations for future work:

SPS consolidation of lunar regolith simulant and Ti6Al4V was shown to be a promising technique for ISRU FGM manufacture. However, the given method requires a two-step sintering process to achieve full densification of both material layers. Further work is required in order to achieve a fully graduated material in a one-step process. Additionally, results from this study indicate that laser-based additive manufacturing techniques could be a feasible method for application of FGM coatings, which presents a topic for further study of wear, corrosion and thermal resistant ISRU coatings.