National Aeronautics and Space Administration

Laser assisted additive manufacturing of reaction bonded ceramics

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Program: FY22 R&TD Innovative Spontaneous Concepts

Objectives:

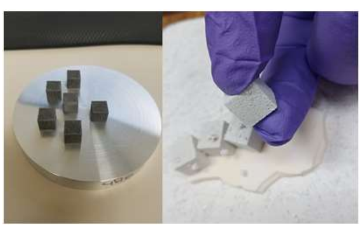
The objective of this project was to utilize laser powder bed fusion (L-PBF) additive manufacturing (AM) of aluminum metal, loaded with aluminum oxide and zirconium oxide, to generate a highly dense and crack free Al_2O_3/ZrO_2 composite material for advanced structures.

Background :

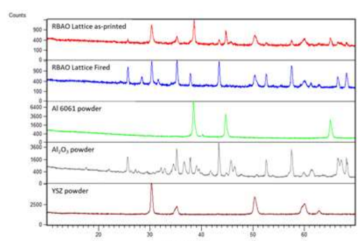
There is significant interest in the use of engineering ceramics for spaceflight applications, but the combination of low-rate production and inherent complexities with processing ceramics makes their introduction challenging for many applications. The current state of art for ceramic AM typically requires the use of a binder to allow printing (SLA, binder jet, etc.) of a "green" geometry which must them undergo de-binding and sintering steps often resulting in large amounts of shrinkage and related implications for part geometry and crack susceptibility. Reaction bonded aluminum oxide (RBAO) is a conventional ceramic powder processing approach in which $Al/Al_2O_3/ZrO_2$ are mixed together, and subsequently sintered, resulting in high-density, fine microstructure parts with significantly reduced shrinkage [1]. In this work we apply the RBAO technique to laser powder bed fusion (L-PBF) additive manufacturing to examine the feasibility of directly printing ZrO_2/Al_2O_3 ceramic composites.

Approach and Results:

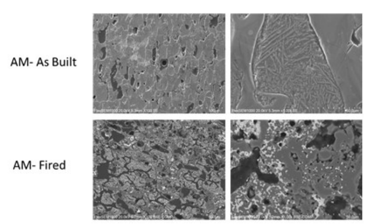
Elementum Al6061RAM2 powder was used as a base and blends were created with addition of spherical alumina (Al_2O_3) and yttria stabilized zirconia (YSZ) powders to achieve a target composition [1] in volume percent of 45 Al – 20 ZrO_2- 35 Al_2O_3. Printing parameters were developed and optimized using an EOS M100 LPBF printer such that robust 9mm x 9mm x 9mm cubes could be printed. The As-printed material consisted of an aluminum metal matrix with ZrO_2 and Al_2O_3 ceramic phases. After firing at 1600 °C in air, crack free cubes were converted to Al_2O_3/ZrO_2 composites.



As-printed (left) and fired (right) cubes. Color change to white is indicative of ceramic conversion



X-ray diffractogram comparing AM as-built cube, AM cube after firing and precursor powders. After firing the Al peaks disappear indicating conversion of Al to Al_2O_3



Cross-sectional scanning electron micrographs of as-built and fired AM cubes. The cubes appear to be free of cracks while some porosity remains after firing

Significance/Benefits to JPL and NASA:

This study demonstrates the feasibility to produce high-density aluminum oxide/zirconium oxide composites that achieved net shape by adopting RBAO methods to L-PBF with conventional powders. There are a variety of applications that would benefit from RBAO ceramic AM that are of significant interest to NASA, including leading edges with embedded coolant loops, advanced refractories ceramic alloys for thermal protection systems, as well as functional devices such as dielectric channels for Hall Effect Electric propulsion systems and low magnetic background magnetometer housings.

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Poster Number: RPC#

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[1] Sheedy, P.M., H.S. Caram, H.M Chan, and M.P. Harmer, J. Am. Ceram. Soc. 84 [5] 986-90 (2001)