Material Development for Advanced Manufacturing of Gasification Systems

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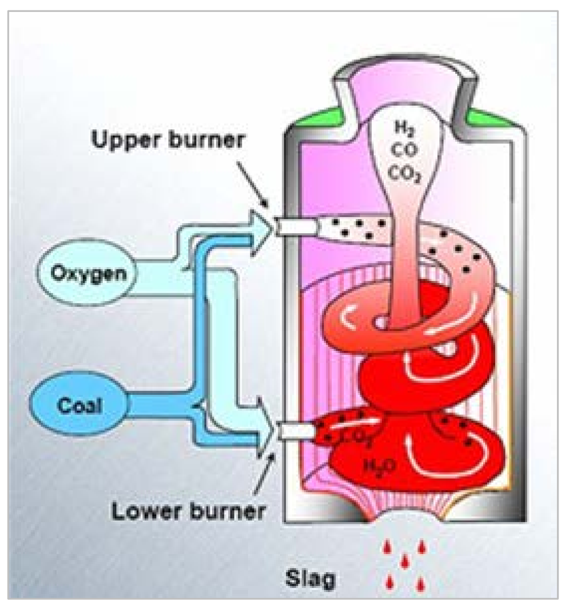
BACKGROUND

Traditional Gasifier Liner Removal/Rebuild



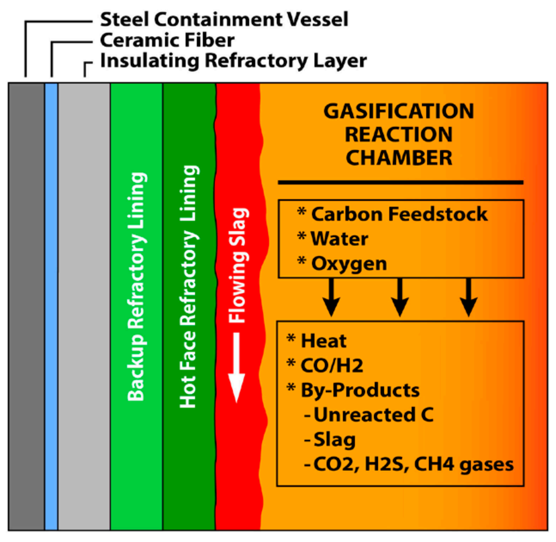
New Gasifier Designs built using AM

NETL is designing and evaluating smaller, efficient, and less costly gasification systems than those currently used by industry. The objective of this effort is to identify/evaluate materials of construction and develop manufacturing technologies to build small-scale, computer-modeled Advanced Reaction System (ARS) gasification modules. Additive manufacturing (AM) and/or advanced conventional constructions techniques are being studied so proposed gasification system designs can be rapidly prototyped to validate system performance against design criteria, with changes made as necessary. Research efforts are directed at: 1) material selection for the gasification chamber, and 2) the development of technologies to rapidly build prototype chambers.

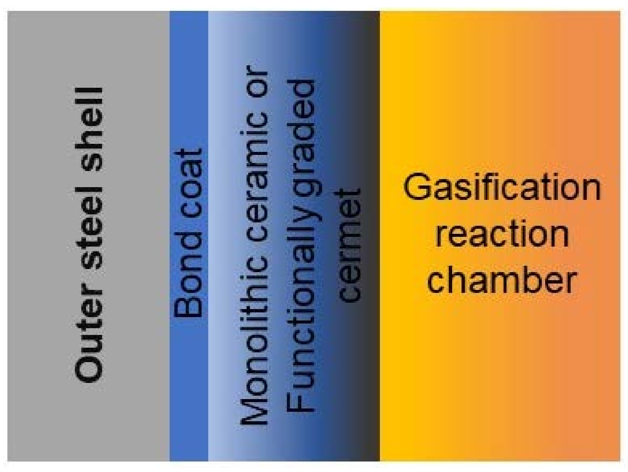
Hybrid manufacturing building CAD/CAM-enabled three-dimensional structures on existing metal pre-forms made using traditional metal forming methods. (Image from DM3D Technology)

NEED

Prototype vessels may have the hot face refractory liners exposed to temperatures up to 1,200 °C, with higher temperatures possible in later system designs. The sidewall of the modules will require a temperature drop of 500 °C to 700 °C across their thickness. Because of the elevated temperature at the center of the gasification chamber, the lining must be ceramic-based. With specifics dependent on the gasification technology, how the gasifier is constructed, and its materials of construction - the technology to develop thick ceramic sidewall components and deposit them on metal shells must be developed.



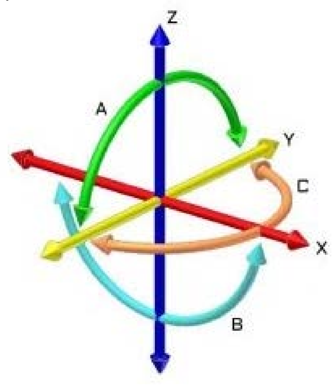
Current gasification chamber construction technology.



Use of AM technology and/or advanced conventional technology to manufacture gasification chambers.

APPROACH

The project approach is to develop the capability of using powder feed AM to deposit ceramics.



A 5-axis machine is capable of moving on the X, Y, and Z planes, and the A and B rotation axes.

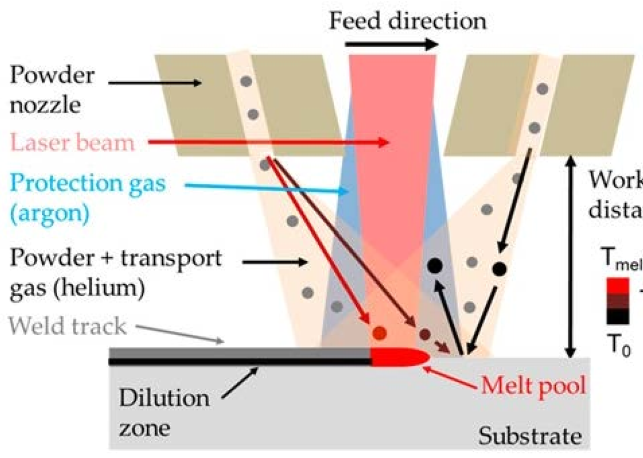


Image from *Metals* **2018**, *8*(9), 659; https://doi.org/10.3390/met8090659

Two primary hurdles exist in using AM processes to build gasifier liners:

1) Existing processes for depositing ceramics on metals are not applicable to reactor scale and shape requirements.

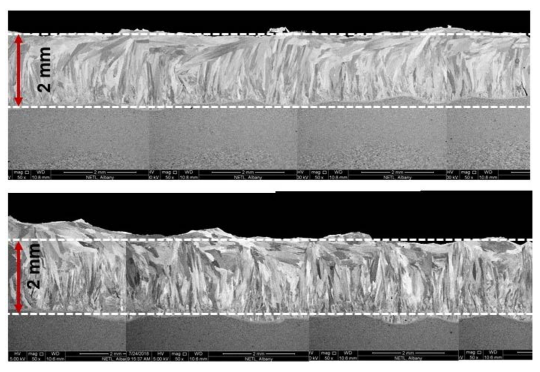
2) The building of thick thermal barrier coatings (TBCs) has to date been stymied by poor adhesion and cracking during deposition. The stresses leading to these defects were modeled to determine how materials and processing parameters might be modified.

RESULTS

Lattice misfit between substrates and coating had been largely disregarded as the stresses arising from them are much less than those resulting from thermal expansions mismatch. However, modeling by NETL has shown that lattice misfit can have a profound effect on the generation of defects at the interface [1]. These in turn may control AM coating delamination.

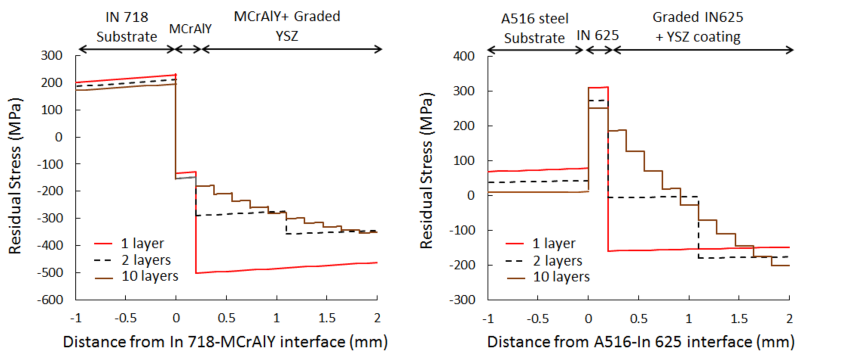
Interface characteristics of a 1 nm thick cubic YSZ film on Ni substrate for a range of lattice misfits.

Misfit	Dislocation density	Mean strain (ε_m)	Interface characteristics
$f < -0.0986$	$N_{EQ} >> N_{SF}$	$\lvert\varepsilon_m\rvert > \lvert\varepsilon^C_{fail}\rvert$	Semi coherent interface with high dislocation density expected to result in fracture of film under compressive stress.
$-0.0986 \le f \le -0.0213$	$N_{EQ} > N_{SF}$	$\lvert\varepsilon_m\rvert < \lvert\varepsilon^C_{fail}\rvert$	Stressed semi-coherent interface, the film under compression.
$-0.0213 \le f \le -0.0203$	$N_{EQ} < N_{SF}$	$\lvert\varepsilon_m\rvert < \lvert\varepsilon^T_{fail}\rvert$	Stressed semi-coherent interface, the film under tension.
$-0.0203 \le f \le -0.0146$	$N_{EQ} << N_{SF}$	$\lvert\varepsilon_m\rvert > \lvert\varepsilon^T_{fail}\rvert$	Film expected to rupture under tension despite dislocation nucleation
$-0.0146 \le f \le -0.0012$	NA	$\lvert\varepsilon_m\rvert = \lvert f\rvert > \lvert\varepsilon^T_{fail}\rvert$	Film expected to rupture under tension without dislocation nucleation
$-0.0012 > f \le 0.0146$	NA	$\varepsilon_m = f$	Stressed coherent interface (in tension when $f < 0$ and in compression when $f > 0$)
$0.0146 < f \le 0.0213$	$N_{EQ} < N_{SF}$	$\lvert\varepsilon_m\rvert < \lvert\varepsilon^C_{fail}\rvert$	Stressed semi-coherent interface, the film under compression.
$0.0213 < f \le 0.0228$	$N_{EQ} > N_{SF}$	$\lvert\varepsilon_m\rvert < \lvert\varepsilon^T_{fail}\rvert$	Stressed semi-coherent interface, the film under tension.
$f > 0.0228$	$N_{EQ} >> N_{SF}$	$\lvert\varepsilon_m\rvert > \lvert\varepsilon^T_{fail}\rvert$	Semi coherent interface with high dislocation density expected to result in fracture of film under tensile stress.



Demonstrated feasibility of thicker ceramic and cermet deposition via laser deposition powder feed AM

Modeling also suggested processing modifications and compositional gradients as means of achieving more favorable residual stress states, creating a structure with reduced cracking [2,3].



BENEFITS AND FUTURE WORK

In addition to the benefits of enabling the building of ARS reactors, the capability of depositing thick ceramic-based coatings is of interest for aerospace applications and specialized marine engines. For example, increasing the TBC thickness by 25 µm can reduce temperatures at the underlying metal surfaces by 4-9 °C in turbine engines, which might result in efficiency improvements of 0.5% to 1.0%.

While current work suggests that thicker TBCs than those produced to date by other methods are feasible, the liner thickness needed for ARS reactors may require alternate processing. The potential for installation of ceramic liners via chemical gunning in combination or independently of AM metal or cermet surfaces is also being evaluated.

Anchors (left, image from TFL Houston) might be installed using powder feed or wire feed AM, while gunning (right, image from Kiltas) might be controlled via robotics.

ACKNOWLEDGEMENTS

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