UAM Printing for Rocket Engine Combustion Chambers

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ABSTRACT

Ultrasonic Additive Manufacturing offers the opportunity to dramatically improve the manufacturing cost and schedule of complex aerospace components such as rocket engine combustion chambers.

Keywords: ultrasonic additive manufacturing, low cost, high speed.

1 PROBLEM

Aerospace manufacturing has not been able to significantly reduce costs over the last 40 years. While Operating costs and vehicle performance have consistent improved, product manufacturing has been limited in it's ability to reduce fabrication costs on a $/Lb basis. Numerous approaches (CAM, High-Speed Machining, Composites) have all been fully integrated into the production lines. This is worst in the rocket/flight vehicle end where quantities are small and the ability to understand the system performance is limited to the downloaded telemetry. Rocket Engine Chambers present all the worst challenges in aerospace manufacturing; High temperature, High strain, High bending loads, High thermal stress, complex manufacturing geometry, multiple functional requirements. Designing with sufficient margin to provide assured flight performance and high reliability has resulted in hardware that can take years to manufacture and costs hundreds of thousands of dollars per pound.

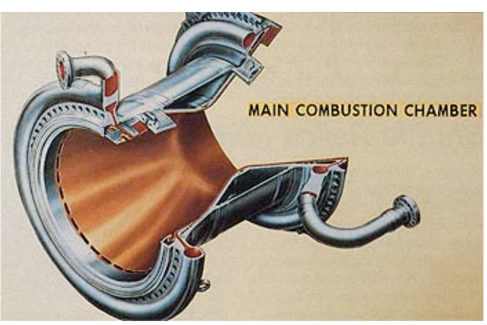

Figure 1: Cutaway of Space Shuttle Main Engine Chamber showing complex construction and multiple materials (Image: Google Images)

2 HISTORY

Conventional manufacturing processes of rocket engine combustion chambers has been to use either brazed stainless steel tube construction or electro-deposited Copper/Nickel with machined channels and welded flanges, manifolds and support jackets. Electro deposition efforts also provides high performance parts but the chamber can take 18-24 months to manufacture assuming no failures and it is not unusual for the chamber to take 36-48 months. Even low performance methods such as film cooling or duct cooling requires large monolithic casting and months of machine time to achieve requisite surface finishes and to install instrumentation and fluid passages.

2.1 Brazed Tube Construction

The first approach was brazed tube construction. Carefully bent tubes were formed on jigs and hand aligned and brazed together. This method was limited in it's ability to grow to meet higher performance requirements of modern engine designs.

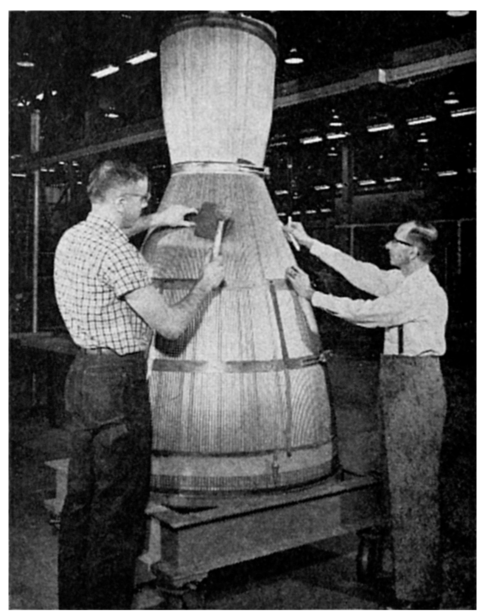

Figure 2 Brazed tube combustion chamber undergoing assembly (Image: Google Images)

2.2 Electrodeposition

Electroplating provided higher performance chambers but at punitive costs to the the manufacturing process. Electroplating required several thousand hours to deposit Copper and then nickel with weekly interruptions for machining operations. This process was measured in years.

Figure 3 Combustion chamber undergoing electroplating. (Image: Google Images)

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2.3 Film Cooled chambers

Even film cooled or duct cooled chambers which are considered low tech approaches present manufacturing challenges.. The chambers need to be machined in bulk from monolithic castings, which require extended time on large machine tools, many of which are heavily booked and can significantly delay delivery to customers.

Figure 4 Even low tech approaches require time on extremely large machine tools (Image: TGV Rockets)

3 ADDITIVE MANUFACTURE

Significant interest has focused on the prospect of additive manufacturing to help solve these problems.. Additive manufacturing has been seen by numerous organizations as a chance to resolve this problem. Significant efforts in powder printing additive manufacturing has had initial success with complex liners being built from copper powders with passages and test ports. The problem of powder processes is that surface finish is challenging, voids and defects are difficult especially in complex passages and incomplete melting often results in loss of material strength and complete melting causes loss of material properties. This approach while faster then electro-deposition still requires 26-39 weeks to complete jacket and manifold attachment

4 ULTRASONIC ADDITIVE MANUFACTURING

The rise of Ultrasonic Additive Manufacturing looks promising to solve this problem. UAM allows the welding of dissimilar materials and the integration of sensors and structure while allowing extremely fast production.

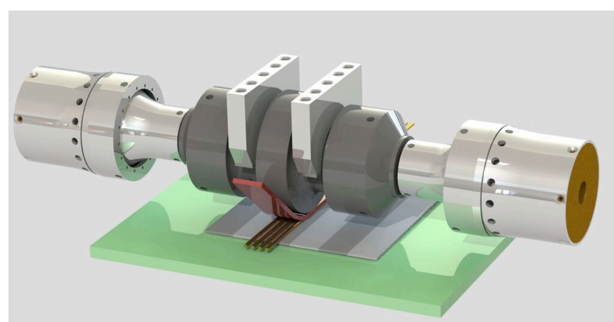

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Figure 5 UAM showing transducer horn laying Copper to Aluminum. (Image: Fabrisonic)

UAM has had great success in cold welding Aluminum to copper foil and in the active creation of passages and embedded sensors.

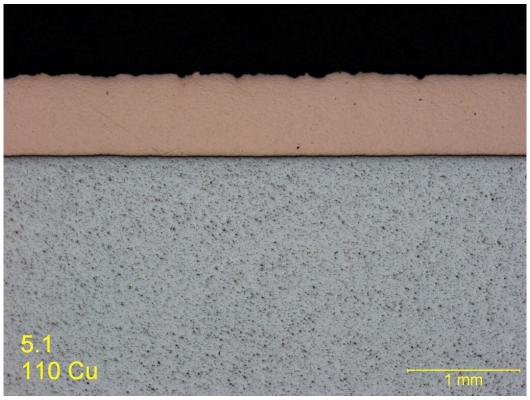

Figure 6 UAM welding of Copper/Aluminum (Image: Fabrisonic)

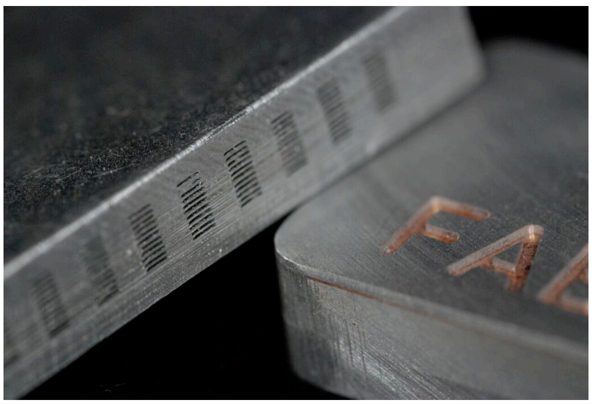

Figure 7: UAM welding showing fine gas passages (Image:Fabrisonic)

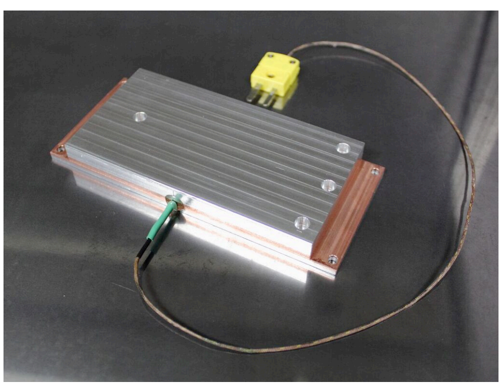

Figure 8 UAM printed sampe with embedded sensor (Image:Fabrisonic)

UAM provides the unique capability of allowing diverse materials to be cold welded without intermetallic formation [1] or loss of material bulk properties which is seen in thermal processes.

6 CHALLENGE

UAM is designed as a radial layup process which has to date limited application to 2-D flat surfaces and simple cylindrical shapes. The challenge is to apply the power of UAM to complex 3-D geometries including Riemann geometries. Further work remains in improving welding of copper to nickel or steel.

7 CONCLUSION

The potential payoffs for UAM in producing high complexity and high cost aerospace components is clear. The ability to rapidly build geometries composed of dissimiliar materials with embedded sensors[2] justifies continued research into application to nickel and steel laminates as well as complex riemann geometries.

REFERENCES

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