Metal Processing Using Selective Laser Sintering and Hot Isostatic Pressing (SLS/HIP)

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ABSTRACT

In July of 1995 the Office of Naval Research (ONR) awarded a contract to Loral Vought Systems entitled Low Cost Metal Processing Using SLS/HIP. The two-phase, four-year program is co-sponsored by ONR and the Defense Advanced Research Projects Agency, DARPA. The program addresses the DoD and Navy need to improve the reprocurement, remanufacture and repair methodology for high value metal parts. The specific program objective is to develop and demonstrate Selective Laser Sintering (SLS) as a lower cost, flexible and faster method of fabricating spare and replacement, small/medium sized powder metal parts for DoD weapon systems. Current activity is focused on development of a high temperature SLS workstation and on selective laser sintering trials on candidate metal powders including Inconel, molybdenum and titanium.

SLS Background

Selective Laser Sintering (SLS) was conceived in the mid-1980's by staff of the University of Texas as a method for rapidly prototyping solid, functional parts without part specific tooling. SLS converts heat-fusible powders into solid objects by using a laser beam to melt and fuse the powder particles together. The laser is rastered across the powder bed using scanning mirrors which are servo-driven from 3-D CAD data which describes the part to be fabricated. SLS is an additive layer process in which the part is built up in layers approximately 0.005 inches thick. The powder bed provides the support for the part build so that no tooling is needed. SLS is-one of the most versatile rapid prototyping methods in that it is applicable to plastics, ceramics, and metal powders. The SLS process has been commercialized for making plastic parts and metal tools by the DTM Corporation of Austin, Texas.

Our Concept

The Department of Defense has a large number of high value metal parts in service which are produced by hot isostatic pressing. HIP metal parts typically require powder encapsulation in a can or skin, which must be removed after HIPing. This canning and can removal operations are a large contributor to the cost of HIP parts while limiting their complexity. Our technical concept is to use the SLS process to form the integral metal skin which is required for encapsulation of powder metal parts prior to hot isostatic pressing (HIP). Typically the encapsulation skin is a sacrificial layer of a different material which must be removed after the HIP cycle. Our concept is to SLS form the skin integral with the HIP part using the same powder material, as illustrated in Figure 1. In this way the skin becomes the outer surface of the HIP part and does not have to

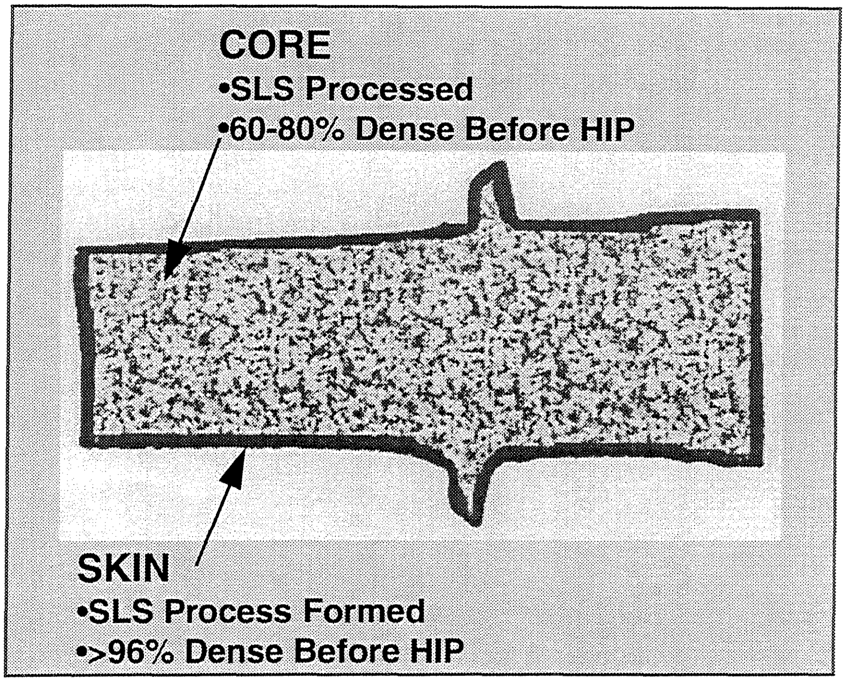


Figure 1 Selective Laser Sintering Concept for Powder Metal HIP Parts

be removed. SLS will be used to liquid phase sinter the powder metal, forming a fully dense skin integral with the core part which has been SLS processed to approximately 70% dense.

To execute the program the following team members have joined forces:

- Lockheed Martin Vought Systems: Prime contractor and responsible for HIP technology development and test and evaluation
- The University of Texas at Austin: SLS equipment development, process development and process modeling.
- Bayside Materials Technology: Economic analyses and component selection trade studies
- MATSYS: HIP process modeling
- DTM Corporation: SLS beta machine development

Program Phases

As shown in Figure 2 the program is structured into 2 phases: Phase 1, SLS/HIP Materials & Process Development, and Phase 2, SLS Beta Machine Development. Phase 1 objective is to develop the materials and processing science to produce functional metal parts using SLS with integrated canning and HIP post processing Key technical issues being addressed in Phase 1 include: impermeability of the SLS skin; wetting of the metal powders and the resulting density; part properties equivalent to baseline; dimensional tolerances and surface finish. The Phase 2 objective is to validate the performance and commercial viability of the high temperature SLS process through demonstration of an high temperature SLS beta test machine.

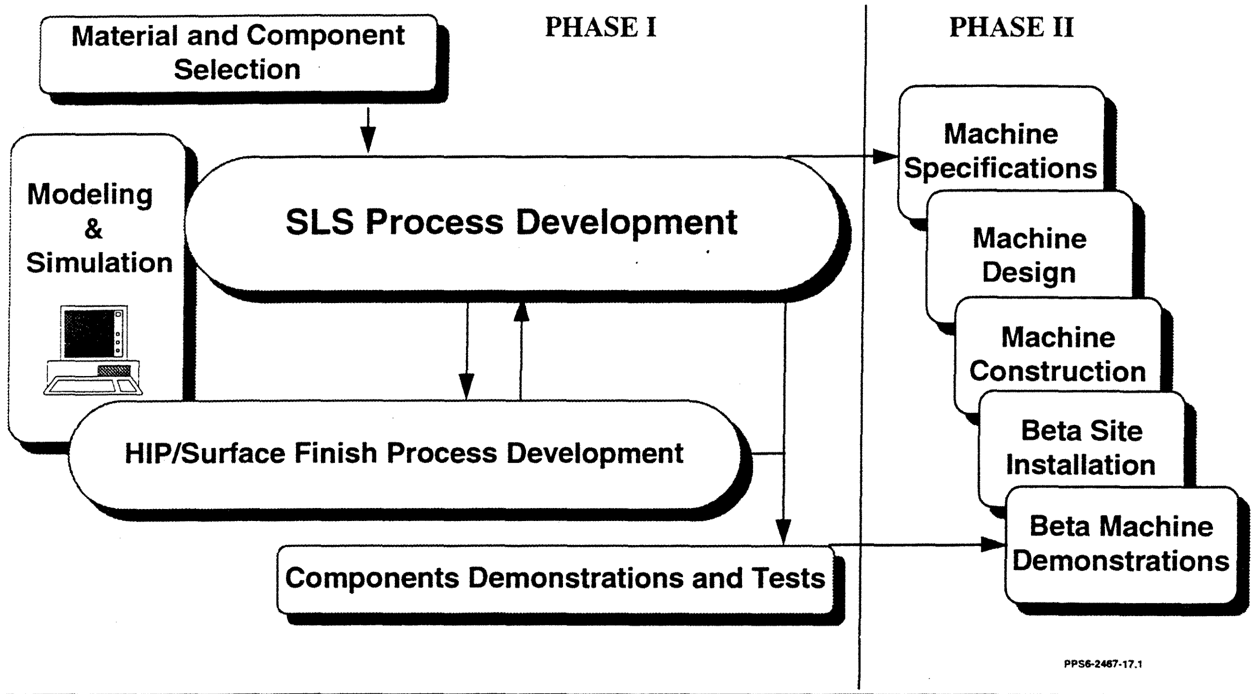


Figure 2 SLS/HIP Program Task Flow Diagram

Current Status:

The initial program task is to select two materials and components on which to demonstrate the SLS technology. To this end a comprehensive survey of Navy installations and Lockheed Martin Vought Systems products is being conducted. From the initial survey candidate materials are being identified for SLS screening trials to aid in downselecting the materials and components to demonstrate. The survey criteria is: sinterable powder metal parts with complex geometry, that can be SLS processed in our current 7 inch by 7 inch processing chamber. We are nearing completion of our survey of Naval installations (depots, centers, shipyards, etc.) to identify demonstration components and materials. We have completed the survey of Lockheed Martin Vought Systems programs to identify candidate demonstration components. To date, based on our survey, the four leading materials/component candidates are:

- Inconel 625 super alloy for an aircraft engine vane
- Molybdenum rotary valve for the MK-46 torpedo
- Titanium guidance section housing for the AIM-9 air-launched tactical missile.
- Stainless steel detent link assembly for an ATACMS ground based missile launcher.

These component are shown in Figure 3.

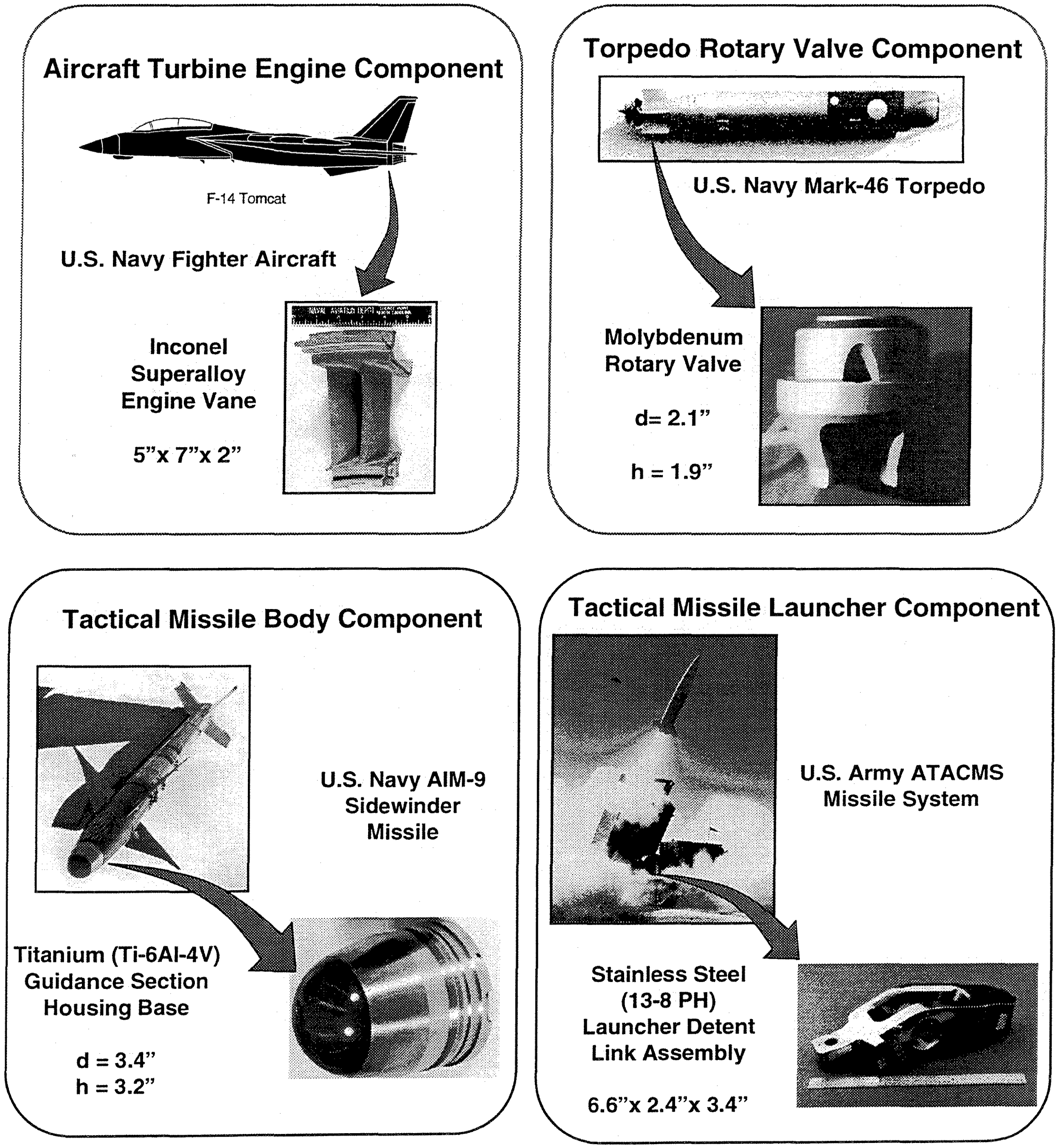
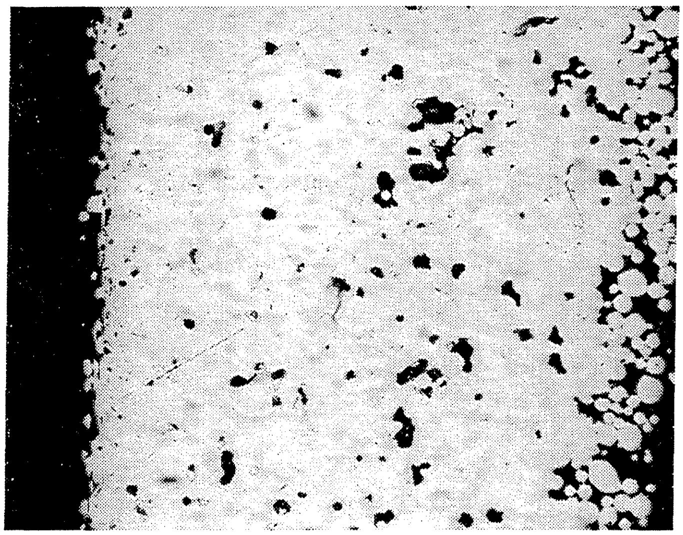


Figure 3 Candidate Demonstration Components and Materials

In preparation for the powder metal SLS screening trials The University of Texas has modified their high temperature SLS workstation with atmosphere controls and laser systems for processing the high temperature powder metals.. The laser scanning control software has been written and validated. Powder metal SLS processing trials are currently underway. Materials processed in the on-going SLS trials include Inconel 625 superalloy, Stainless Steel 17-4PH, Titanium Ti-6Al-4V, and Molybdenum. Fully dense single layer coupons of Inconel 625 were produced by SLS. The single layers of Inconel 625 were leak tested and shown to have a leak rate of less than 10^{-10} atmospheric cc/s, thereby meeting the criterion for HIP post-processing. Multi-layer coupons of Inconel 625 processed by SLS showed closed porosity at the interface layer, meeting the requirement for HIP processing. Initial SLS trials on single layer coupons of 17-4PH stainless steel indicate a nearly fully dense microstructure with closed porosity. Preliminary trials on titanium and molybdenum have demonstrated that these materials can be melted by SLS processing. Research is underway to produce an integrally canned volume of Inconel 625 by direct SLS for HIP post processing.



Inconel 625 Single Layer

Nd:YAG laser power: 31 Watts

Scan speed: 0.7 in/sec

Figure 4 Photomicrograph of SLS Processed Inconel Skin

ACKNOWLEDGEMENTS

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