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System of Labs Direct Fabrication Technology

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System of Labs Direct Fabrication Technology

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ABSTRACT

The System of Labs Direct Fabrication Technology program was intended to foster cooperation and development in a cooperative effort between Sandia National Labs, Idaho National Energy & Environment Lab and Oak Ridge National Lab. The goal of this program was to bring together LENS (Laser Engineered Net Shaping) from Sandia, INEEL's spray forming process and the alloy development expertise of ORNL. This program investigated the feasibility of combining the LENS and spray forming processes to exploit the best features of both approaches. Further, since both processes were thought to result in a rapidly solidified structure, the alloy design expertise of ORNL offered the opportunity for alloy design or processing options which could more fully utilize the unique capabilities of the processes.

System of Labs Direct Fabrication Technology

Introduction

The System of Labs Direct Fabrication Technology program was intended to foster cooperation and development in a collaborative effort between Sandia National Labs, Idaho National Energy & Environment Lab and Oak Ridge National Lab. The goal of this program was to bring together LENS (Laser Engineered Net Shaping) from Sandia, INEEL's spray forming process and the alloy development expertise of ORNL.

LENS is a laser based direct manufacturing process that starts with a CAD solid model. The model is decomposed into a series of layers of constant thickness. Each layer is then broken up into a series of raster lines of a specified thickness. A 3-axis system is then used to raster a laser beam along the resultant lines. The laser, a Nd-YAG device operated at about 300 watts, is focused on a substrate to form a molten pool. Powder is then injected into this molten pool thereby forming a bead. An X-Y table moves the substrate under the LENS head and the bead is pulled across the evolving part, resulting in the controlled deposition of metal. As the part builds up and a layer is completed, the LENS head is raised one layer height. This process is illustrated schematically in Fig. 1. The molten pool and powder stream can be clearly seen in Fig. 2, which is a photograph during processing.

One drawback of the LENS process is its speed. Present deposition rates are below .25 cc/min and although experiments have shown scale up to be very feasible, there are techniques capable of producing near net shape metal components at much greater rates. The INEEL spray forming process is one such technique.

In the INEEL process, an RTV negative is made from a master part. This mold is then used to cast a ceramic form. The ceramic is cured and placed into the spray-forming device. Once the ceramic is in position, metal is inductively melted and delivered to the spray nozzle. The form is manipulated within the metal spray and a deposition builds up on the ceramic, as shown in Fig. 3. Once the spray process is completed, the ceramic is removed and the excess sprayed material is cut off. Although this process is fast, on the order of 50 cc/min, "shadowing" of the metal spray makes the process unsuitable for high aspect ratio features.

The intent of this program was to investigate the feasibility of using combining these two processes such that the positive features of both might be exploited. Further, since both processes were thought to result in a rapidly solidified structure, the alloy design expertise of ORNL was seen as offering the opportunity for alloy design or processing options which could more fully utilize the unique capabilities of the processes.

PROGRAM DEFINITION

Initial planning meetings resulted a decision to build an injection-molding tool using an optimized alloy. The bulk portions of the tool were to be produced by INEEL using their spray forming process. High aspect ratio features were to be added with the LENS process. The first year tasks included tool design, evaluation of solidification conditions for the two processes, and evaluation of the interface between the two types of deposit. Second year goals were to design an

that alloy's performance to several commercial tool steels. Finally the mold was to be produced and actually used to form plastic parts.

Figure 1. Schematic representation of the basic approach to laser depositing metallic materials.

Figure 2. The LENS process is used to directly deposit metal into precise patterns.

Figure 3. The INEEL spray forming process deposits metal at high deposition rates.

RESULTS

Sample parts of H13 tool steel were produced via the spray-form process. Subsequently, the LENS process was used successfully to add high-aspect ration features, as shown in Fig. 4.

Figure 4. Tool steel (H13) die made by combining thermal spray and LENS processing.

Characterization of a composite part (Fig. 5) at INEEL, ORNL, and SNL has shown that materials fabricated through the combined processing approach exhibit a clear change in the microstructural evolution. Most important was the fact that the parts from the two processes are very different with regards to their thermal histories and solidification structure. While LENS exhibits a fully dense,

rapidly solidified structure, the Spray-formed parts had a coarser, more porous structure. These structures are consistent with process observations which reveal that the entire spray-formed part glows quite hot for an extended period of time, on the order of a minute or more, while the LENS produced material is only glowing hot for a fraction of a second. These empirical observations clearly indicate a very different cooling rate, which is born out by the microstructure. In addition, the spray-formed material exhibits droplet boundaries and porosity, where the LENS material is fully dense, with no prior powder boundaries. However in LENS, the path of the molten pool during the deposition process is indicated by a variation in grain morphology that occurs along the prior molten pool boundaries.

Figure 5. H-13 tool steel, deposited by LENS (top) and spray-forming (bottom). Note altered microstructure and crack at interface.

In addition, metallography has revealed the presence of small cracks at the interface between the spray-formed and LENS deposits and bands adjacent to the interface where the microstructures of both the spray-formed material and LENS deposit have evolved substantially. Further investigation into the interfacial cracking mechanism would be warranted.

Alloy studies conducted at Sandia and ORNL revealed that LENS processed H13 had excellent properties as deposited. The use of LENS as a process for the production of tooling makes good metallurgical sense. Further, there appears to be an opportunity to fine tune the composition of H13 tool steel to take advantage of the rapid solidification environment which is available within LENS. Although no special H13 powder compositions were produced, ORNL did provide some Nickel Aluminate powder of a proprietary composition. This alloy is a hard high strength material that is difficult to work using conventional processes. However with the LENS process, near net shape objects were produced and subsequent testing at ORNL revealed excellent properties.

SUMMARY

The System of Labs effort was plagued in both years by late funding allocations. Lack of support at the INEEL end for the second year also forced them to withdraw from the project prematurely. However, significant and useful results were obtained at both ORNL and SNL as a result of this collaboration. This program helped support the following presentations and publications:

Laser Engineered Net Shaping

Eric Schlienger, Sandia National Laboratories, Albuquerque NM
Automotive Applications of Thermal Spray Technology

Romulus MI June 3, 1998

Near Net Shape Production of Metal Components using LENS

Eric Schlienger¹; Duane Dimos¹; Michelle Griffith¹; Joseph Michael¹; Mike Oliver¹; Tony Romero¹; John Smugeresky²

¹Sandia National Laboratories, Albuquerque, NM USA

²Sandia National Laboratories, Livermore, CA

Third Pacific Rim International Conference on Advanced Materials and Processing
Honolulu, Hawaii - USA : Jul - 12 thru Jul - 16

Thermal Behavior in the LENS Process

M. Griffith, M.E. Schlienger, J.A. Brooks, L. Harwell, M. Essien, Nelson and W. Hofmeister:
Sandia National Labs

Ninth Solid Freeform Fabrication Symposium
Austin TX, August 10-12, 1998

Sacrificial Materials for Complex Geometry Fabrication

M.E. Schlienger, M. Oliver and J.A. Romero: Sandia National Labs
Ninth Solid Freeform Fabrication Symposium

Austin TX, August 10-12, 1998

ACKNOWLEDGMENTS

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- 5 Eric Schlienger, Duane Dimos, Michelle Griffith, Joseph Michael, Mike Oliver, Tony Romero, John Smugeresky, "Near Net Shape Production of Metal Components using LENS", Proceedings of the 3rd Pacific Rim International Conference on Manufacturing, 1999.

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