LENS Deposition of Complex Geometries

D.D. Gill, M.L. Griffith, D.E. Reckaway, C.F. Briner, D.G. Abrams
Manufacturing Science & Technology Center, Sandia National Laboratories
Albuquerque, NM 87185

Abstract

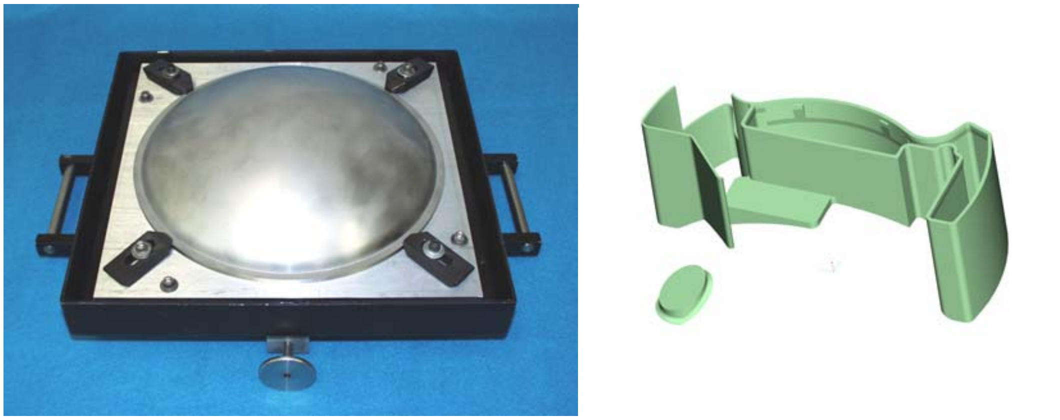
The Laser Engineered Net Shaping (LENS®) system at Sandia National Laboratories, a laser-based direct metal deposition process, was recently used for the fabrication of a complex prototype. The LENS process involved the challenges of adjacent areas of thick and thin cross section, overhanging unsupported features, high aspect ratios, and a hemispherical substrate. These challenges were overcome through the use of closed-loop weld pool control, height monitoring, a strong understanding of build parameters, and unique process planning strategies. The near-net shape LENS part was completed with annealing and conventional machining to produce the complex components in a reduced timeframe.

Introduction

Three prototype components were needed in a reduced timeframe recently for pre-production testing. These stainless steel components are approximately 280mm diameter with a hemispherical base and have features that include 2mm thick walls as tall as 110mm and solid blocks as large as 41cm^3. The conventional methods of fabrication have been conventional machining from a billet of material and investment casting followed by finish machining. It was proposed that the prototypes could be completed by the LENS process more quickly than either of the traditional methods of production. LENS is a laser metal deposition system that focuses a laser on a substrate creating a small weld pool, and then deposits powdered metal into the weld pool [1]. As the substrate is moved by a set of computer controlled axes, the deposited metal builds a part line by line and layer by layer. The conventional machining of the desired prototype components takes around 350 hours of machine time. These parts are very difficult to machine due to the high aspect ratio of 55 for the wall structure and the very narrow 4mm space between the walls. Equally difficult is the location of casting facilities interested in producing very small quantities of parts at reasonable costs. LENS is a perfect match for this need. The LENS system at Sandia has sophisticated process planning software to convert a triangulated version of a solid model file directly into modified M&G code for the LENS machine. Several challenges needed to be overcome for this project to be a success however. The process planning software required the addition of a secondary clearance plane due to the hemispherical shape of the substrate, and strategies developed for accurate building on surfaces that are not perpendicular to the incoming laser beam. Additionally, the system had to build thick blocks directly adjacent to thin wall structures maintaining accurate dimensions as both were constructed. This was accomplished utilizing a closed loop weld pool monitoring system [2] in conjunction with height monitoring and control. Finally, once the LENS deposition was completed, methods of stress relieving heat treatment were developed along with the utilization of conventional machining to complete the components.

Process Planning and LENS Metal Deposition

The deposition utilized hybrid building techniques in which the substrate becomes an integral part of the final component. In this case, the substrate was a 40mm tall dome of approximately 280mm diameter. The substrate is shown in Figure 1(a) as it is ready to go into the LENS machine. Figure 1b shows a solid model of the features to be LENS deposited on the substrate.

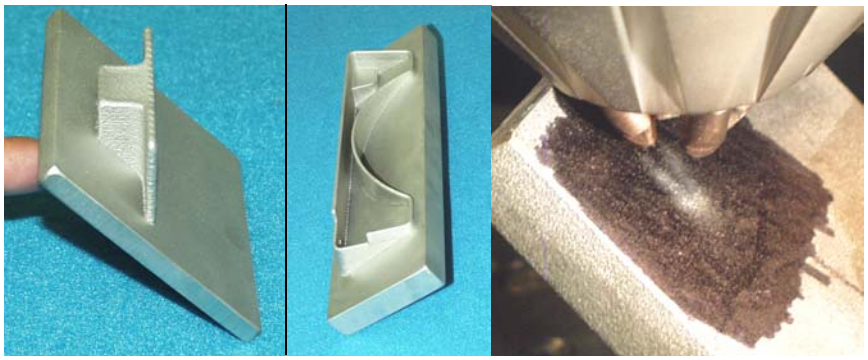


(a) (b)

Figure 1. (a) Dome Substrate Ready for LENS Deposition and (b) Solid Model of Features to Be Deposited by LENS

Because the substrate is dome shaped, it was necessary to develop a secondary retract plane in the process planning software that represented a safe distance at which the LENS deposition head could retract to clear the center of the dome as it traversed from one side of the build to the other. A strategy for using the secondary retract plane was developed so that the head would only retract when traversing the dome, but not at other times when it would waste time. The process planning software also has optimization strategies for determining when to switch from one feature to another. All features were done with multiple passes in which the laser first traversed the borders of the geometry and then returned to fill in or hatch between the borders. Because the geometry contains discontinuities between the different features, the process planning software must choose when to switch from one feature to another. The software attempts to follow the longest continuous path possible while building and attempts to then build the closest remaining feature whenever it finishes building a previous geometry. This strategy causes the long traverses and use of the secondary retract plane to be minimized to help speed the building process.

The knitting of the LENS deposition to the substrate occurred on angled surfaces due to the dome substrate. Typically, this knitting is one of the most critical steps of the LENS building process determining the strength of the interfacial bond. In this case, tests of representative geometry on steeply angled substrates showed that it was important for the area of the weld pool to be increased during the deposition of the interfacial layers, especially due to the angled substrate. One of these test blocks is shown in Figures 2(a) and 2(b). Further testing, shown in Figure 2(c) was also required to determine the effects of the angled substrate on the incident powder cone which deposits the powdered metal in the weld pool. The process planning software was amended so that it gave a special notation to the interfacial geometry that notified the closed loop monitoring system of the need for a different set of weld pool parameters at these times.



(a) (b) (c)

Figure 2. (a, b)Test LENS Features Deposited on a Substrate Positioned at a 45º Angle to the Incident Laser Beam and (c)Test of Powder Cone Geometry on Angled Substrate

As the component's metal features were being deposited, the weld pool monitoring system actively maintained the appropriate weld pool for the different conditions encountered in the part geometry. This was especially important as the build transferred from the very thin wall structures to the thick block sections due to differences in heat conduction pathways which severely influence the build parameters of the deposition and must be carefully controlled by the weld pool monitoring system to assure a fully dense build with uniform material properties in all features regardless of geometry.

A separate system monitored the height of the deposition throughout the building process and helped to maintain a uniform and accurate feature height. The greater heat retention of thin wall structures causes them to grow taller than the neighboring blocks if not controlled through the height monitoring system. This monitoring allowed all geometry to be built to 1.5mm taller than the height of the computer model, leaving plenty of material for the machining processes to remove.

During the deposition process, the waste powder that did not become entrained in the weld pool was removed from the build environment manually and was reintroduced into the material hoppers. This greatly reduced the overall quantity of powder required for the deposition process.

Deposition Results

The deposition of each component was completed at a rate of $13cm^3/hr$ with the entire build process requiring 33 hours. The final geometry had good accuracy with respect to the original model. The wall straightness was accurate and the wall thickness error was 0.13mm as compared to 2.5mm for typical castings. During the length of the build, a significant amount of heat was introduced into the deposition features and substrate. As is expected, this heat causes the final geometry to be somewhat smaller than the model due to shrinkage upon cooling. For this geometry, the outside walls were 0.5-1mm inboard of the model's walls. Also, the shrinkage caused some warp in the dome section. The dome was deflected 1mm at two points around the perimeter, well below typical casting errors. The warp in the dome was not a problem because the dome used for the substrate was significantly thicker than the final design thickness to impart strength in the substrate during the deposition process. This excess thickness was removed from the dome by machining the dome after LENS deposition was completed.

Post Deposition Annealing and Machining

Once LENS deposition was completed, the components required heat treatment and finish machining. Because of the heat induced during the LENS deposition process, it was necessary to anneal the parts to remove residual thermal stress before machining. The annealing process was difficult to predict due to the diverse features present on the components. Two small plates were tack welded to the top of the freestanding thin walls to prevent movement during the annealing process and the temperature of both the wall structures and the block features was monitored. The component is shown ready for heat treatment in Figure 3(a). Though the heat treatment cycles developed worked adequately, this is an area of research that needs to be pursued in the future.

Once the residual stress had been removed, the components were finish machined using traditional milling, turning, and die-sink EDM. The final test of the accuracy of the build was the fit of several concurrently produced components that were electron beam welded to the wall structure. The final part is shown in Figure 3(b).

(a) (b)

Figure 3. (a)LENS Built Component Ready for Heat Treatment and (b)After Completion of Finish Machining

Conclusion

The use of LENS deposition for the manufacturing of 3 prototypes showed the ability of this process to produce complex, accurate, fully functional, components directly from CAD solid models in a reduced timeframe over the competing technologies. The process showed the capabilities of the Sandia National Laboratories' LENS system to deposit complex geometry while maintaining high accuracy in the features. The post deposition annealing and finish machining completed the prototyping process.

References

[1] Griffith et. al., *Understanding the Microstructure and Properties of Components Fabricated by Laser Engineered Net Shaping (LENS),* Materials Research Society, V625, Symposium Y Proceedings, April 2000.

[2] Hofmeister et. al., *Solidification in Direct Metal Deposition by LENS™ Processing*, JOM-Journal Of The Minerals Metals & Materials Society, v. 53(#9) pp. 30-34 Sep 2001.