Sacrificial Materials for the Fabrication of Complex Geometries with LENS

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The direct additive manufacturing of metallic components can present several process challenges. At present, there are several techniques for the accomplishment of this goal[1,2], each with its own set of strong points and limitations. At Sandia, Laser Engineered Net Shaping, or LENS, is a process which has been developed for the direct additive manufacturing of fully dense three dimensional parts. In LENS, a Nd-YAG laser is focused onto a metallic substrate or onto previously deposited material. The laser melts the metal and a small pool of metal forms. Powder is injected into the pool and a bead forms. By rastering an x-y table to which the part is affixed in a controlled fashion, the bead is pulled and a fully dense metal part is formed. As currently configured, LENS is a $2^{1}/_{2}$ D process.

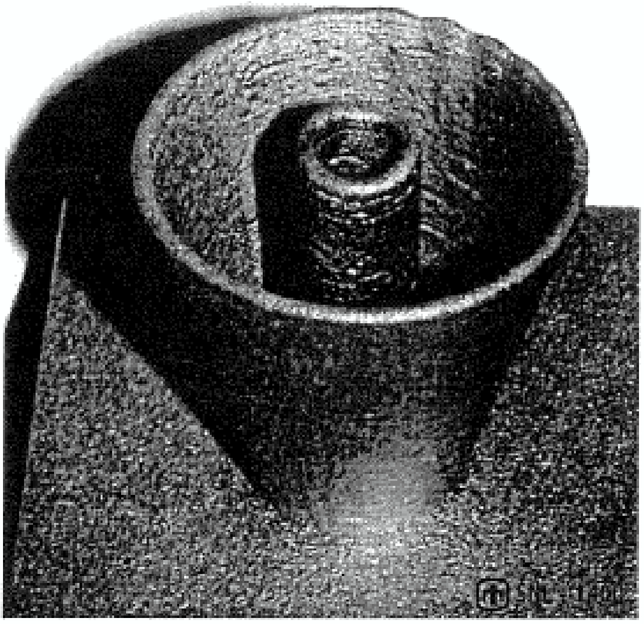


Figure 1
Example of Overhang Capability in a $2^{1}/_{2}$D LENS System

A potential drawback of this technique is that in order for deposition to occur, a substrate must be present. This limitation defines the degree of overhang that can be achieved with this process. Since LENS deposition is based within an orthogonal coordinate system, the degree of overhang that can be achieved seems to be related to surface tension issues. At present, an overhang of about 15° is what may be readily achieved, and Figure 1 is an example of the sort of geometries that may be produced.

Although similar processes utilizing movable deposition heads[3] are more effective at producing overhangs, there will always be applications where some form of support structure is required to produce the desired geometry. One example of such a geometry might be injection molding tools with conformal cooling passages. In such a case, closing off the top of the cooling channel represents a process challenge. However, there are several ways of accomplishing this task. In Figure 2, the image on the left illustrates the manner in which cooling passages may be built into a part simply by utilizing the overhang capacity inherent in the system. Whereas the picture on the right demonstrates that tubing can be readily incorporated into LENS produced components.

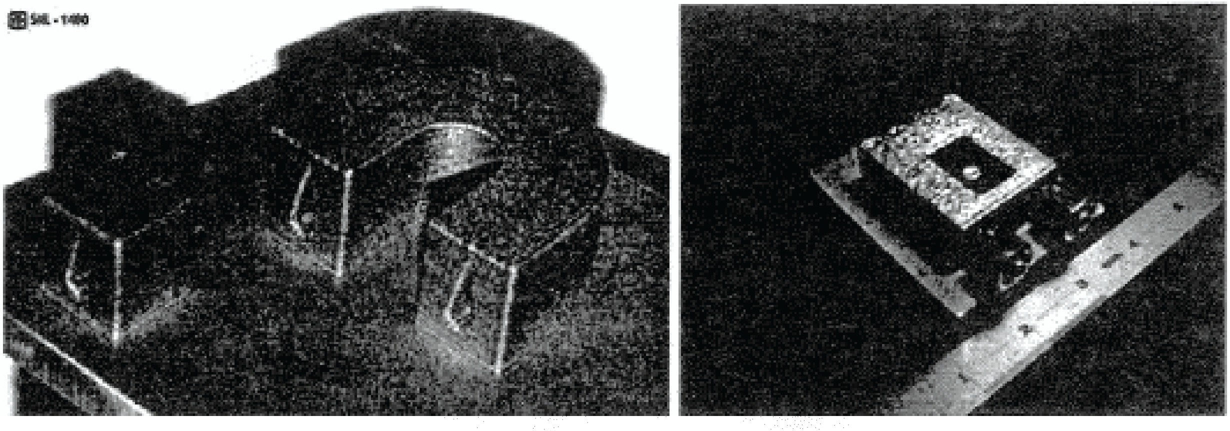
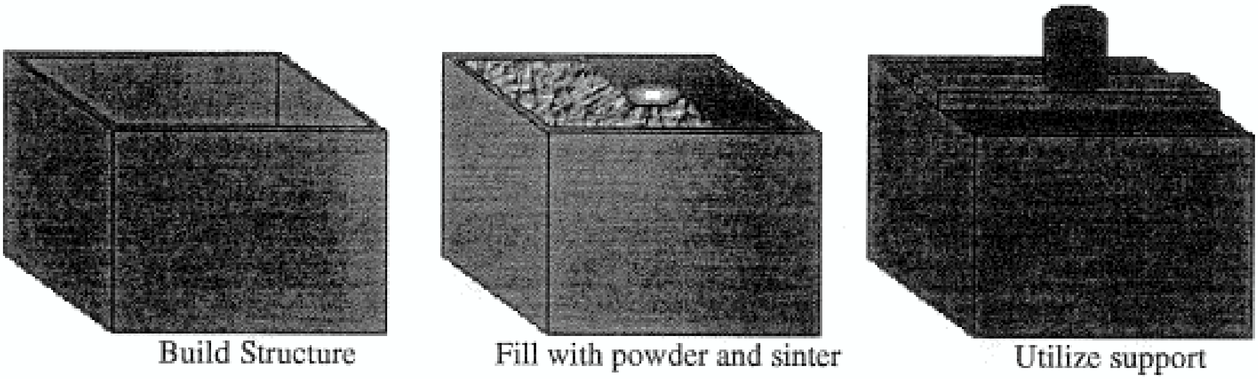


Figure 2
Cooling channels built with overhang and inserted tube.

Both of theses techniques have applications in the production of many different types of parts. Further, manipulation of the deposition head can provide an even greater overhang capability and further extend the ability of the process to produce enclosed shapes. However, even with these various capabilities, some shapes are most readily produced if some form of underlying support is available.

Such a capability is typically achieved by using a sacrificial material. The requirement for such a material is that it must be readily placed, and easily removed from the finished part. Typically, this means that the sacrificial material must not bond to the main structure, or it must be readily removed through some process such as acid etching. Finding a material that is readily deposited via LENS, can withstand molten metal deposition, and not bond to such a deposition is a challenge. The removal of support structures via acid also has some complications associated with it, and since LENS is a melting process, acid etching is not expected to produce good interfaces at the boundary of the sacrificial material.

These problems have been addressed by using powder of the parent material as the necessary support structure. The mechanics of this process are shown in Figure 3. Typically, a part is built up to the point where a support structure is needed. In the case of cooling passages or internal voids, this leaves a cavity in the part. For other types of structures, a form is required to hold the powder in place. Once a cavity is available, it is filled with powder up to the level of the existing deposition. At this time, the laser is defocused (by increasing the standoff) and the beam is then played over the entire part. This action sinters the powder, resulting in a thin sintered surface layer on the top of the powder bed. This surface layer serves two purposes. First, it delivers the obvious advantage of providing a substrate for subsequent deposition. Additionally, it provides a protective layer that prevents the powder from being blown away by the argon gas used to deliver the powder to the laser spot during the deposition operation. It should be noted that the deposition process after sintering fully melts the sintered layer.


Build Structure

Fill with powder and sinter

Utilize support

Figure 3
Using Sintered Powder as a Support

Initial experiments were conducted using simple shapes as shown in Figure 3. The initial material used for these experiments was stainless steel, with subsequent experiments conducted using titanium. Typical processing parameters for stainless steel were 380 watts, 500 mm per minute travel speed, .5mm hatch spacing and .5mm vertical slice thickness.

During the initial experiments, it was found that the sintering operation needed to be conducted with care lest the sintered layer curl up. Typically, such conditions occur when too much power is applied and the powders begin to melt. Subsequent solidification then pulls the top surface, causing the sintered layer to raise upward. Once the sintered layer curls, powder, which resides beneath it, can be blown away by the deposition process. This action results in a void below the sintered surface. When such a void occurs, the sintered layer no longer has a heat sink beneath it and the passage of the laser burns a hole into the cavity beneath. Subsequent deposition passes fill this void. This results in a finished structure that looks fine from the exterior, but has a significant irregularity in the internal cavity.

Similar experiments, conducted using titanium, indicated that titanium served as a better support than stainless steel. During the sintering operation, the titanium seemed to form a more robust sintered layer that was less prone to curling. The titanium was processed at 450 watts, 500 mm per minute travel speed, .5mm hatch spacing and a .5mm vertical slice thickness. The higher power has been found to be necessary in order to obtain sufficient melting, however, it is not responsible for the better sintering behavior. This is born out by experiments with stainless steel that illustrated that above a certain power level, the sintered layer began to curl and actually burn off. As a result, increasing the power during the sintering operation actually proved to be detrimental to the production of a good substrate for subsequent deposition operations.

The results of the titanium experiments are shown in figure 4. These hollows were built using the above processing parameters and were produced via a process similar to that illustrated in Figure 3. Once the parts were built, the ends were cut off to to allow the powder to be removed and the internal cavity to be observed. Although the top surfaces are not completely flat, they do demonstrate the ability to produce a fairly regular cap.

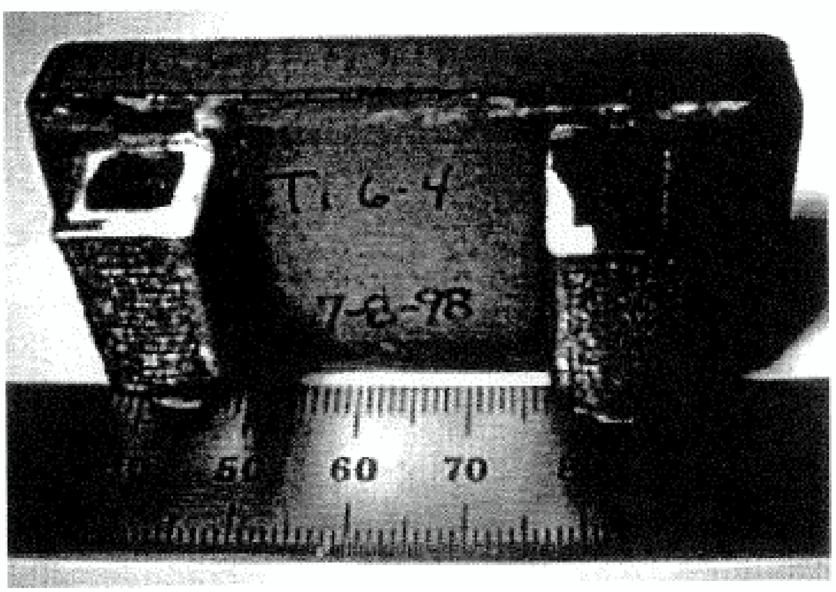


Figure 4
Titanium hollows produced using powder as a sacrificial material.

Once confidence had been gained that small structures could be produced, a larger item was designed. As a demonstration, a backwards "S" shaped tube was built out of stainless steel.

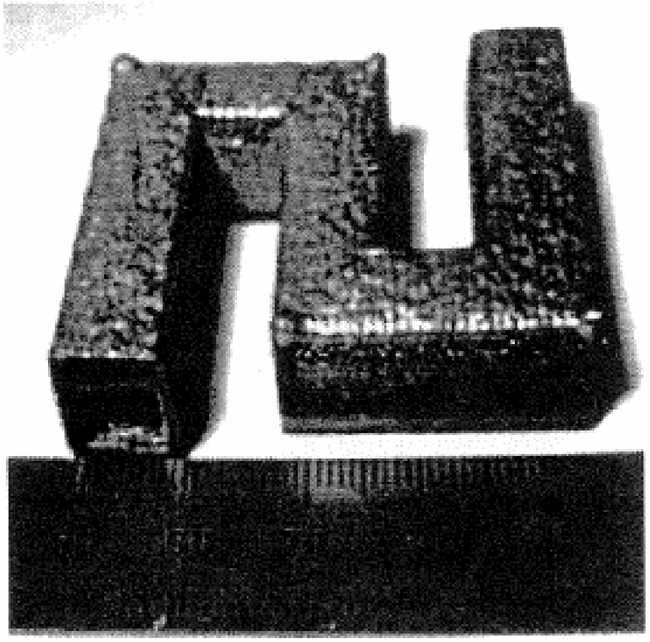


Figure 5
Stainless steel S-Tube built using powder as a sacrificial material

As may be seen in Figure 5, this technique is suitable for producing internal passages of moderately complex geometry. The most significant challenge is adherence of the sintered layer to the object side walls. If there is a gap between the sintered cap and the part wall, powder is blown out from underneath. Without the heat sinking capacity of the powder, the sintered surface layer burns through and the integrity of the cavity is compromised.

In summary, the capability of LENS and similar processes can be extended by using powder as a sacrificial support material. Since the sintered layer becomes fully melted during subsequent deposition the resultant microstructure maintains the fully dense and melted aspect that is characteristic of this process.

Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

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[1] D.M. Keicher, J.L. Jellison, L.P. Schanwald, J.A. Romero and D.H. Abbott, "Towards a Reliable Laser Powder Deposition System Through Process Characterization", 27th International SAMPE Technical Conference, Vol. 27, Diversity into the Next Century, Proc., od SAMPE '95, Albuquerque, NM, Oct. 12-14, 1995, p. 1029.

[2] J.L. Koch, J. Mazumder, "Rapid Prototyping by Laser Cladding" presented at ICALEO 1993, Orlando FL, 1993.

[3] G.K. Lewis, J.O. Milewski, R.B. Nemec, D.J. Thoma, M Barbe, D. Cremers, "Directed Light Fabrication", Los Alamos Laboratory Publication LA-UR-95-2845, Los Alamos, NM, 1995.