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Title: DIRECTED LIGHT FABRICATION OF REFRACTORY METALS

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Directed Light Fabrication of Refractory Metals

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ABSTRACT

Directed Light Fabrication (DLF) is a metal, rapid fabrication process that fuses metal powders to full density into a solid replica of a computer modeled component. It has been shown feasible for forming nearly any metal and also intermetallics to near net shape with a single process. DLF of refractory pure metals is feasible, bypassing the extensive series of conventional processing steps used for processing these high melting point materials. Tungsten, tantalum, and rhenium were processed and show a continuous resolidified microstructure. Porosity was a problem for the tantalum and rhenium powders produced by chemical reduction processes but not for the tungsten powder spherodized in a plasma arc. Chemical analysis of powder compared to the DLF deposit showed reductions in carbon, oxygen and hydrogen, indicating that process parameters may also be optimized for evolution of residual gases in the deposits.

INTRODUCTION

The refractory metals, tantalum, molybdenum, tungsten, chromium, vanadium, niobium, and rhenium are the highest melting point metals. Because of their high melting points powder production is costly requiring chemical reduction and hydride-dehydride methods of producing pure powder, and conventional forming is difficult, requiring multiple steps of powder consolidation and thermal mechanical processing. The Directed Light Fabrication (DLF) process [1-6] provides a means of consolidation and forming refractory metals to near net shape with a single process, eliminating the multiple conventional processing steps. This process compared to sintering and hot isostatic pressing techniques [7] eliminates required tooling, molds and fixtures, eliminates assembly steps, eliminates protective encapsulation, decreases processing time, waste and cost, and eliminates potential contamination from lubricants, binders, and solvents. It can also eliminate the need for joining processes by forming an entire assembly during deposition and provide means of fabricating component features which cannot be machined.

PROCESS DESCRIPTION

The Directed Light Fabrication process (DLF) is being developed to deposit metal directly from a solid model on a computer . Figure 1 shows a schematic representation of the process. A solid model is developed, a tool path program is generated from the solid model information, and then a post processor

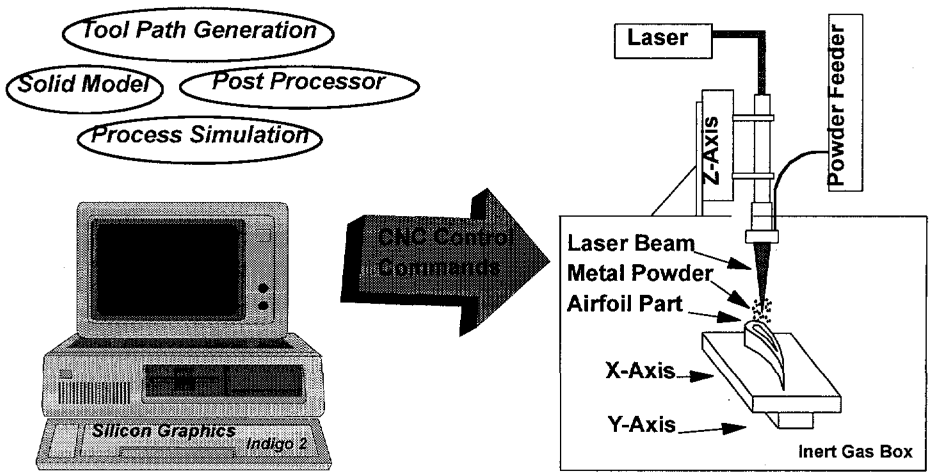

Figure 1. Schematic diagram of the Directed Light Fabrication process depicting the transition from computer solid model to replication in fully dense metal of choice.

is created to drive the laser beam and positioning system. The multi-axis positioning system consists of motion axes which move the deposit or part and motion axes which index the laser beam focal spot upward an amount equal to the deposition layer depth, after each layer is formed. The deposition is first

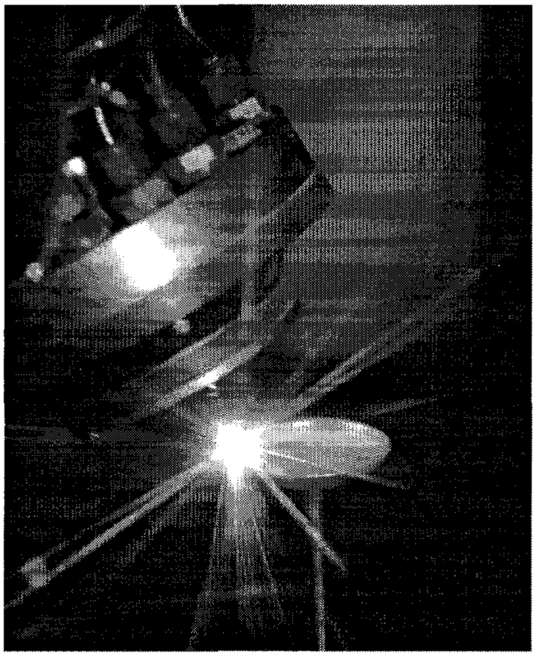

Figure 2. Five axis deposition of a 316 stainless steel cup and support tube showing the laser head tilted perpendicular to the layer being added.

started on a base plate which is later removed from the part, and successive layers of deposit are stacked until the entire part is formed. Both a 3 axis and a 5-axis DLF system have been constructed. The 3-axis system consists of 2 orthogonal axes in a horizontal plane holding the metal deposit and one vertical axis holding the laser focal lens. The 5-axis system has 2 orthogonal axes (X,Y) plus a rotary axis (A) in the horizontal plane moving the part, and a vertical axis (Z) plus a tilt axis (D) holding the laser focus lens.

Deposition of a 316 stainless steel cup with tubular support structure using the 5-axis system is shown in Figure 2. The assembly, tube plus part, was built by first forming the support tube, then tilting the laser head perpendicular (beam axis in the horizontal plant) to the tube and beginning the cup deposit. The laser head is programmed to move outward layer by layer keeping the focal point of the laser beam perpendicular to each deposited layer on a longitudinal trajectory from pole to equator along the cup. In this single process, the entire assembly is made. Conventional processing, in comparison, would require multiple steps of pressing or deep drawing the cup which would require die making combined with precision welding, also requiring holding fixtures and multiple pieces of capital equipment. Besides eliminating process steps, the process applies to essentially any metal by changing only the DLF parameters of speed, velocity, laser power and layer depth. The same equipment is used no matter what metal is required for the desired component.

REFRACTORY METAL DEPOSITION

Tungsten, tantalum and rhenium were deposited using DLF to demonstrate feasibility of using the process for refractory alloys by measuring the resultant properties of the deposit. Only metallurgical results are reported at this time.

Pure tungsten rods, 0.58mm dia. were deposited at 4 mm/min and 70W average power to achieve a fully dense microstructure. Spherical powder that had been plasma arc atomized was 14.8μm average dia. in a size range of 5-30μm. Figure 3 shows a photograph of the powder and fracture surface of a DLF tungsten rod. Figure 4 shows the DLF rod microstructure compared to conventionally processed wire. No porosity was observed in any of the rod deposits.

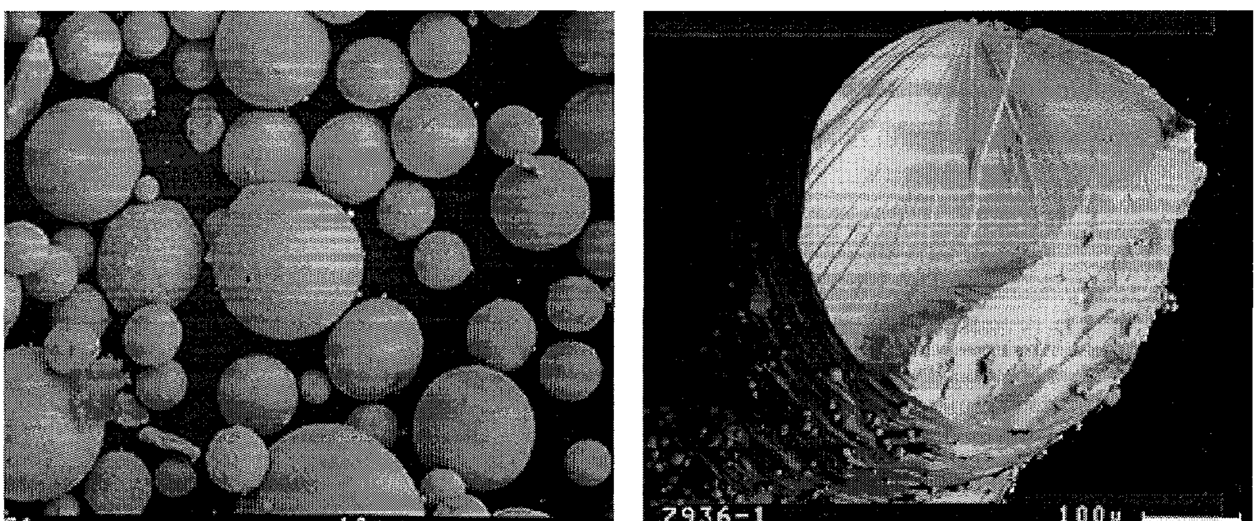

Figure 3. Tungsten spherodized powder (left) and fully dense tungsten rod DLF deposit (right) showing fracture surface.

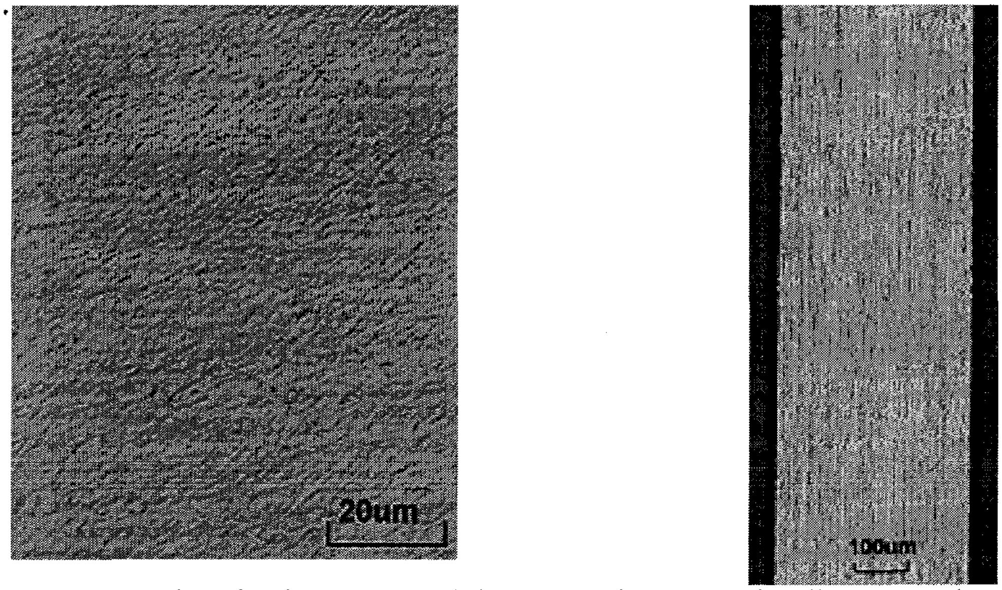

Figure 4. Tungsten deposit microstructure (left) compared to conventionally processed tungsten wire (right). Full density was achieved and a fine microstructure produced.

Rhenium rods were deposited at 450W average power at 0.5-1.5mm/s to full density. The rhenium powder had an average size of 3.12µm and was chemically reduced. Internal porosity of two different sizes were

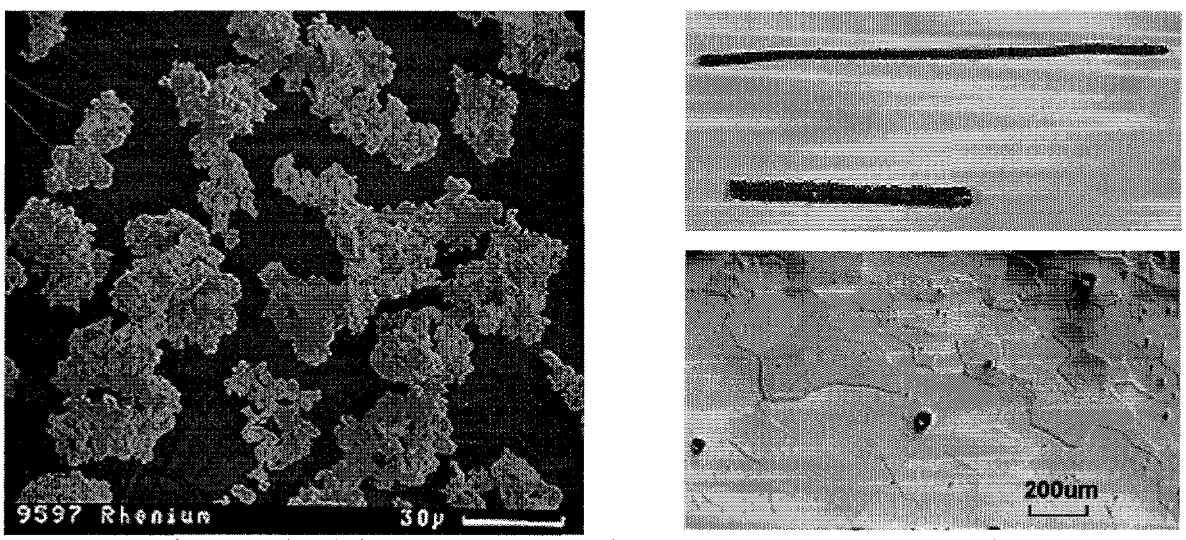

Figure 5. Rhenium powder (left), rod (top-right) and microstructure (bottom right) showing internal porosity.

measured to be 50µm and 2-5µm average diameter. Rhenium powder and the porous microstructure are shown in Figure 5. Figure 6 shows the DLF rod microstructure compared to conventionally processed plate. Grain size of the DLF deposit was ASTM 3 and the plate was ASTM 6.5. Hardness of the plate was 371 HV and the DLF rod 190 HV.

A tantalum bar, .049m-long by .0076m-thick was deposited at 550w average power at a rate of 3.3 cm^3/hr. (0.2 in^3/hr). Figure 7 shows the tantalum powder, chemically reduced. Average particle size was 5-30µm. Figure 8 shows the deposition path a photo of the tantalum bar and microstructure of the

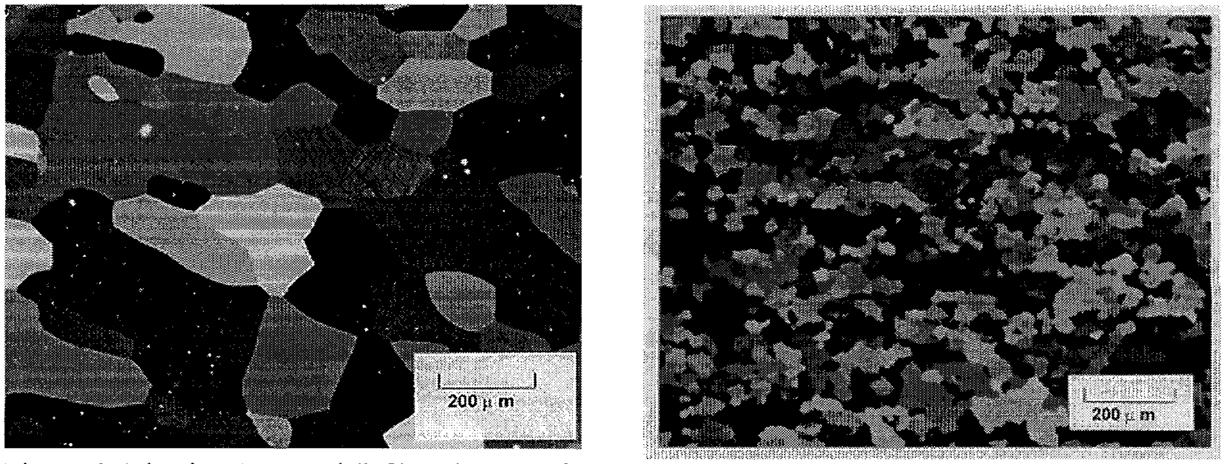

Figure 6. Rhenium DLF rod (left) and conventionally processed rhenium plate (right).

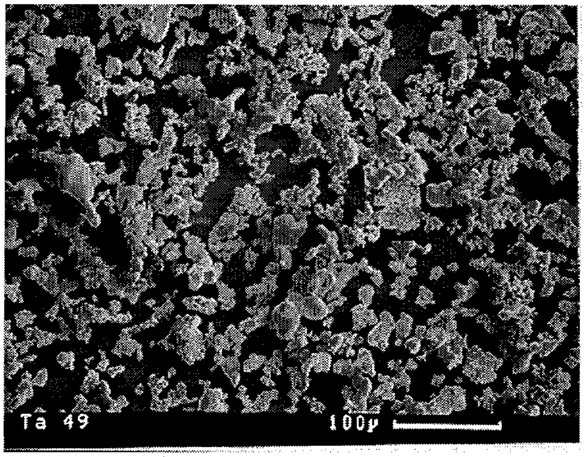

Figure 7. Tantalum powder produced by the sodium reduction process.

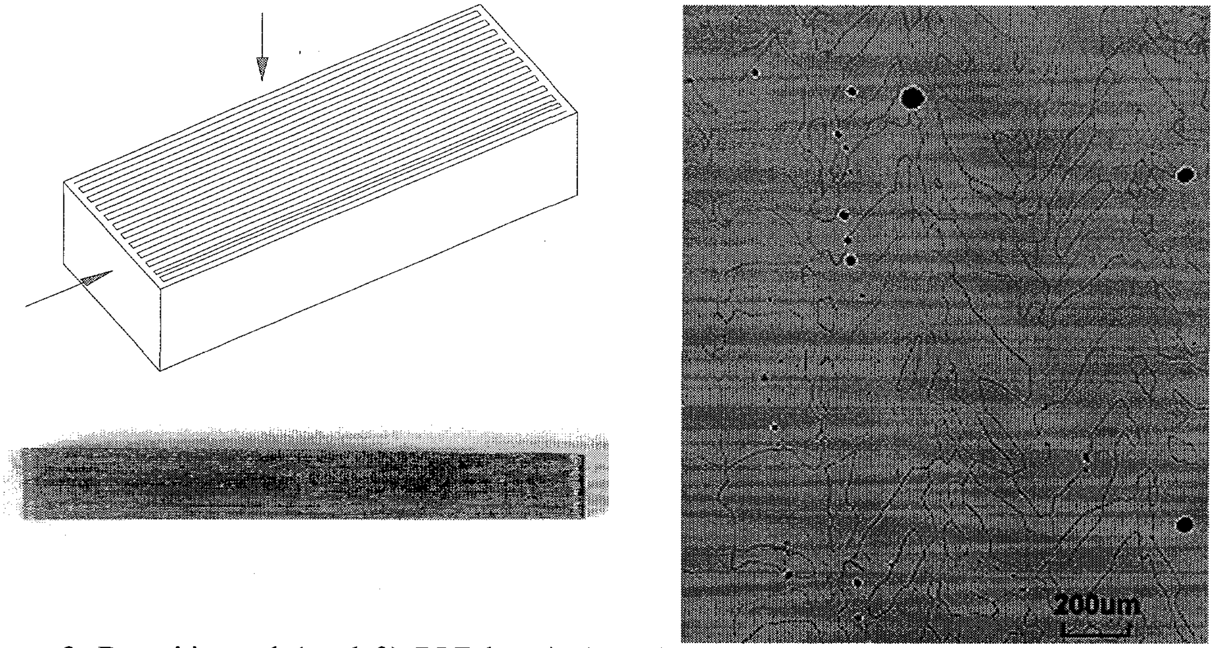

Figure 8. Deposition path (top-left), DLF deposited tantalum bar (bottom-left) and microstructure (right) showing resultant porosity in the resolidified tantalum.

tantalum bar. Side by side traverses of the laser beam across the width of the deposit were made. The material was fully melted and resolidified, however spherical porosity was evident. Gas analysis of the tantalum powder, Table 1, compared to the DLF deposited bar indicated reduced oxygen, nitrogen and hydrogen with slightly higher carbon. The results indicate gas evolution

Table 1. Gas Composition Analysis for Ta Powder and DLF Ta Bar Deposit (ppm).

	C	O	N	H
Ta Powder	72	726	30	21
DLF Deposit	79	646	17	13

during the deposition. With the high cooling rates of the small liquid laser melted pool, porosity may be explained by inefficient time for the gas to be completely evolved. However, this may point to optimization of processing parameters such as deposit traverse speed to allow more dwell time of the laser heat source on the molten pool prior to solidification.

Porosity resulted in all of the refractory metal deposits that used sodium reduced powder. Gas porosity was possible due to residual gas in the powder from the powder making process and possibly from entrapment of the argon environmental gas in the molten pool during deposition. However, the tungsten powder that was plasma spherodized did not have porosity in the deposit, suggesting that the porosity in the other deposits was not caused by mechanical entrapment of argon by the motion of the molten pool. Electron beam bead-on -plate welding in vacuum of the tantalum deposit reduced the amount of observed porosity. Vacuum outgassing of the powders, use of plasma spherodized or hydride-dehydride powders, and optimization of laser velocity and layer depth will be used in the future to try to reduce the porosity in these deposits.

SUMMARY

DLF has been used to fuse refractory metal powders. Complete melting and resolidification occurred resulting in continuous microstructures for tungsten, rhenium and tantalum. Porosity was a problem in the tantalum and rhenium powders produced by chemical reduction processes but not in the tungsten powder spherodized in a plasma arc. Porosity is suspected to occur from residual gas in the powder particles produced by chemical reduction processes.

Application of DLF to refractory metals fabrication will result in lower cost and time savings versus conventional processing because it is a single step to near net shape components. No tooling, molds or fixtures are required. The DLF process produces low waste and does not introduce other contaminants such as die lubricants, binders or solvents used in conventional processing.

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