Development of a Selective Laser Reaction Sintering Workstation

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Abstract

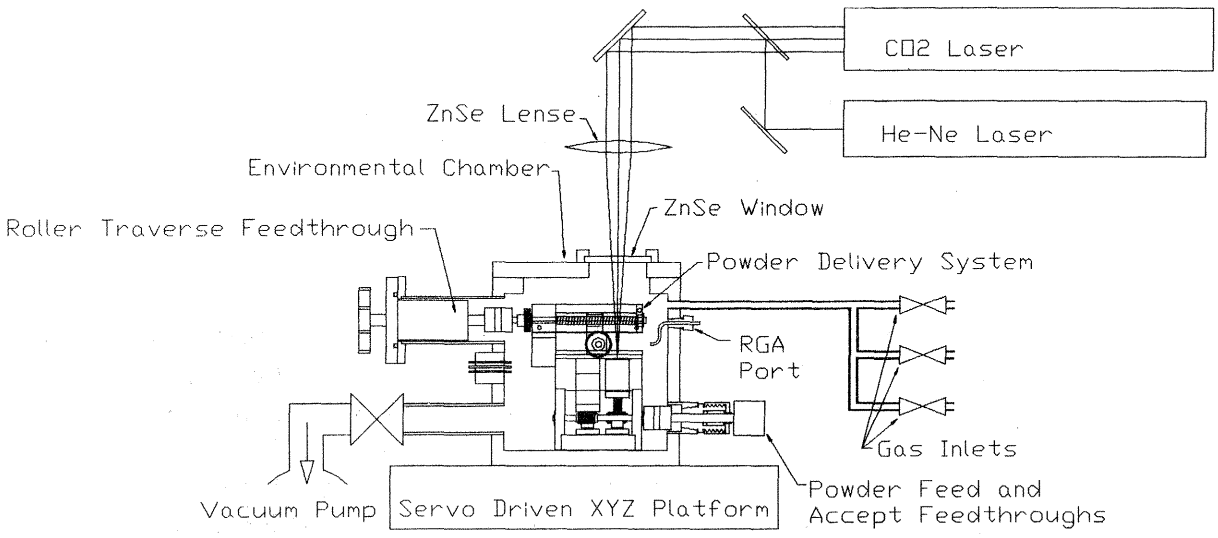
The purpose of this paper is to describe the design and operation of a Selective Laser Reaction Sintering workstation developed at The University of Texas. The workstation allows the study of solid freeform fabrication of reaction sintered materials on a research scale. The mechanical and control systems of the workstation are detailed, and Selective Laser Reaction Sintering as a technique is discussed including example material systems that are currently under study.

Introduction

Solid freeform fabrication (SFF) is any manufacturing process that produces a three dimensional part without the use of standard or part specific tooling. One form of SFF, Selective Laser Sintering (SLS), uses a laser to sinter selected areas of a powder bed. Additional layers of powder are spread on top of the first, and specific areas of each layer are scanned and sintered by the laser before the next layer is spread. In this way, a three dimensional sintered part is built up layer by layer. At the end of the process, the manufactured shape may be removed from the surrounding loose powder. Parts have been made from various polymers, metals and ceramics using this technique [1,2]. Selective Laser Reaction Sintering (SLRS) combines SLS with a simultaneous gas/powder reaction process known as reaction sintering or reaction bonding [3]. This simultaneous reaction typically involves the decomposition of a gas to solid or a gas interacting with a liquid or solid to produce another solid. The SLRS process has the potential of producing parts made of monolithic materials and composites that are difficult or impossible to sinter using SLS as well as producing microstructures that are unobtainable using standard sintering techniques.

Equipment

To be successful a SLRS system must accomplish three basic functions. These functions are 1) supply controlled laser power to a selected area, 2) provide multiple layers of a powder bed having proper thickness and density and 3) provide the appropriate gas environments including vacuum. An overall schematic of the SLRS system is seen in figure 1.



Selective Laser Reaction Sintering Workstation

Figure 1.

With the exception of the powder delivery mechanism, the basic arrangement of this system has been previously described in the literature [4]. The laser beam from a 25 watt CO_2 laser is directed onto a substrate that is located in an environmentally controlled chamber. A motor driven X-Y table moves the chamber/substrate under the stationary beam effectively "scanning" the beam. Both laser power and X-Y table controls have been upgraded for this workstation. Laser power fluctuations have been reduced to less than 5% of setting by using a pulse width modulation controller developed at the University [5]. Power level can be adjusted manually or by computer. Positional accuracy of the table/beam is now better than 20μm and repeatability better than 5μm at scan speeds to 3mm/sec using a computer controlled dc servo system.

Environmental control is achieved by locating the powder delivery mechanism/substrate inside a vacuum chamber. The chamber has three independent gas inputs with the emphasis on flexibility due to the research nature of the system. The gas inputs have allowed for the introduction of a variety of gases including N_2, N_2/H_2, NH_3, Ar, H_2, O_2, CH_4, and C_2H_2. The chamber is currently set up for static gas environments, but minor modifications could easily make it a flowing gas system if desirable. Mechanical pumping initially provides 10^{-3} Torr vacuum to minimize gas impurity content. Mechanical and resistance vacuum gauges monitor system pressure. Power and thermocouple feedthroughs provide the ability to heat substrates and monitor and control temperature using a PC based data acquisition system. A gas sampling port has also been included to enable connection to a gas analyzer system(RGA). This will be used to gather information about reactants and by-products during the reaction sintering process. Mechanical feedthroughs currently enable manual operation of the powder delivery mechanism. The mechanism will be automated in the future.

The powder delivery system is similar in concept to one previously reported [6], but considerable miniaturization was required to fit the entire mechanism inside the available five inch diameter by 5 inch in height vacuum chamber . A schematic and photograph can be seen in figures 2 and 3. Two rotation feedthroughs marked Powder Feed and Powder Accept are coupled to worm/gear/leadscrew arrangements that ultimately drive the powder feed and powder accept pistons up and down in their respective cylinders. The rotation feedthrough marked Roller Traverse drives a spur gear/leadscrew arrangement that causes the roller to traverse across the top of the stage.

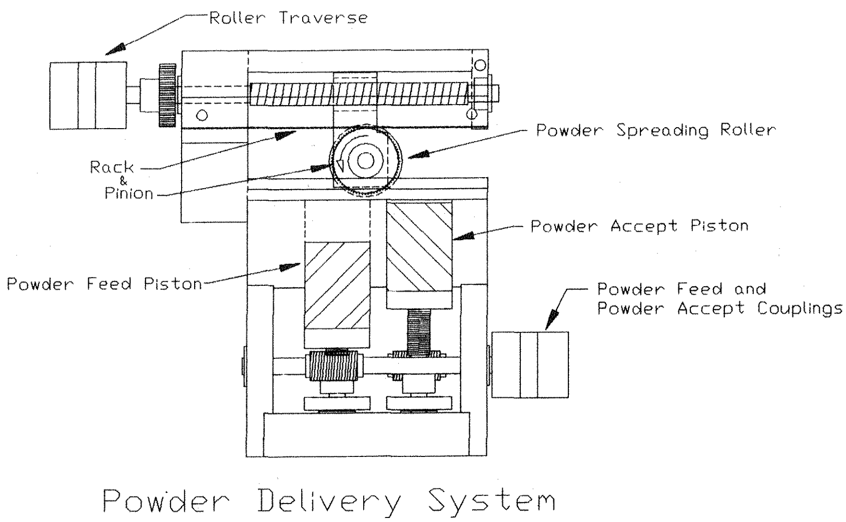


Figure 2.

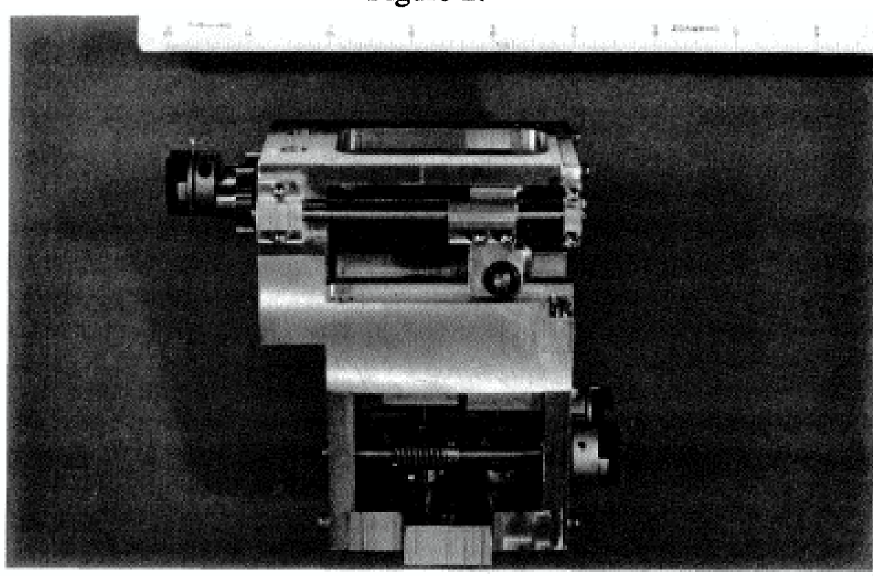


Figure 3.

During a standard production cycle the system starts with the traversing roller to the far left, the powder feed piston would be down and its cylinder full of powder, and the powder accept piston would be up. Powder is made available to the roller by raising the powder feed piston an incremental amount. The roller is then traversed across the stage and then back, spreading the powder into a thin layer. As the roller traverses, a rack and pinion causes the roller to spin so that the roller surface in contact with the powder is actually moving in a direction opposite to traverse direction. This is done for improved powder spreading. After the new powder layer is spread, a laser scan is performed, sintering specific areas of the powder layer above the powder accept piston. When the scan is complete, the powder accept piston is lowered some specified layer thickness. The powder feed piston is again raised, providing another incremental amount of powder. The roller is brought across the stage, spreading a fresh layer of powder over the powder accept piston and the previously sintered layer. The laser is scanned again resulting in a second sintered layer. The powder accept piston is lowered and the process is repeated until the part has been built up layer by layer. Maximum part size from this mechanism is roughly a 1.5cm by 1.5cm by 1.5cm cube. The gearing of the mechanism enables layer thickness control to within a few microns. Working on this scale is advantageous when using difficult to make, hazardous or expensive materials because of the small amounts of precursor required to load the system. When the materials systems have been proven on this scale they can easily be adapted to a larger system.

Applications

Laser reaction sintering can be used in a variety of ways to produce a variety of results. The following discussion is by no means all inclusive, but is meant to give examples demonstrating some of the interesting aspects of this technique.

Standard pressureless sintering of oxides, nitrides, and carbides is difficult. However, formation of an oxide, nitride or carbide may be achievable by reaction sintering in the corresponding oxygen, nitrogen, or carbon rich atmosphere. One example is the reported success of sintering an aluminum/alumina mixture in the presence of oxygen to form an alumina pre-form [7]. These pre-forms will be infiltrated to create a metal-ceramic or ceramic-ceramic composite part.

Composite structures can be produced directly by partial conversion of powder by reaction. A multi-layer Cu-TiN part was produced by this SLRS system using a Cu-10Ti alloy as base material. Reaction sintering in a nitrogen atmosphere caused the Ti to migrate to the surface of the alloy particles where it reacted with nitrogen to convert to TiN. The result was a copper matrix with a sub micron TiN layer on each of the original powder particles. TiN presence was confirmed by x-ray diffraction and the dispersion of Ti rich areas(TiN) was mapped using EDS. Figure 4 shows a side view of a 6mm by 6mm by 3mm thick Cu-TiN rectangular solid made using SLRS. Note that the part is composed of 15 layers. The delamination observed can be eliminated with proper substrate pre-heating. The microstructure of the part can be seen in Figure 5, which contains a backscattering electron micrograph and a Ti element map of the same region. The element map clearly shows the Ti migration to the surface of the alloy particle where it formed a nitride coating on the particle. It is believed that proper control of powder size and operating parameters can result in very fine microstructures unobtainable by standard sintering techniques.

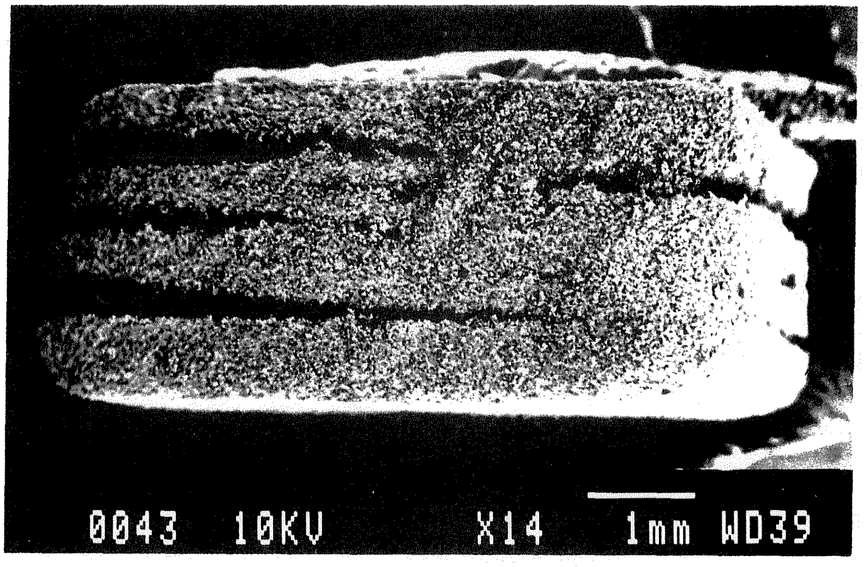


Figure 4.

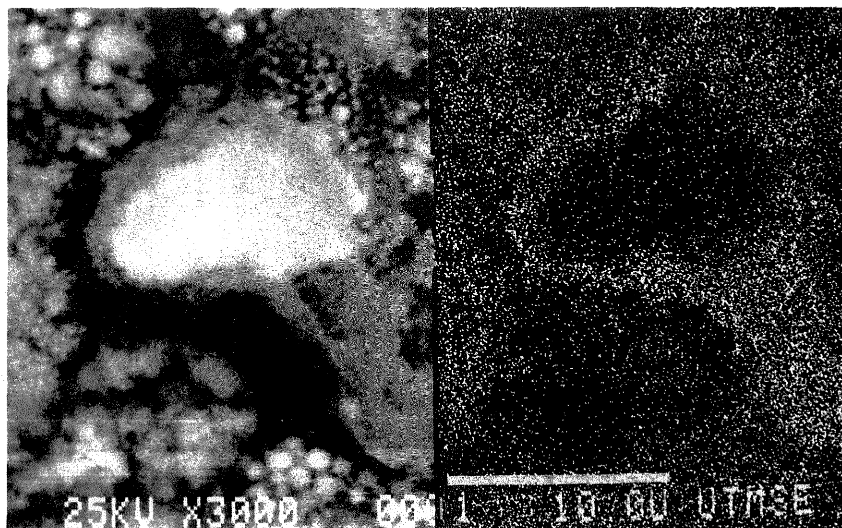


Figure 5.

A third technique involves laser sintering and simultaneous vapor deposition and infiltration. One system currently under study combines the pyrolitic formation of SiC from an organometallic gas precursor with the sintering of a SiC base powder. The pyrolitically produced SiC infiltrates the SiC base powder and binds it together. Single and multi-layer parts have been formed in this fashion. Figure 6 shows the side view of a single layer of SLRS SiC. Starting powder was 16μm SiC. Note the density variation through the layer. Figure 7 is the top view of a 6mm square by 1mm thick SiC rectangular solid. The six layer part was also made using 16μm SiC. Bonding between the layers is limited, but it is believed this can be improved by optimization of process parameters including laser power, gas pressure, powder size and layer thickness.

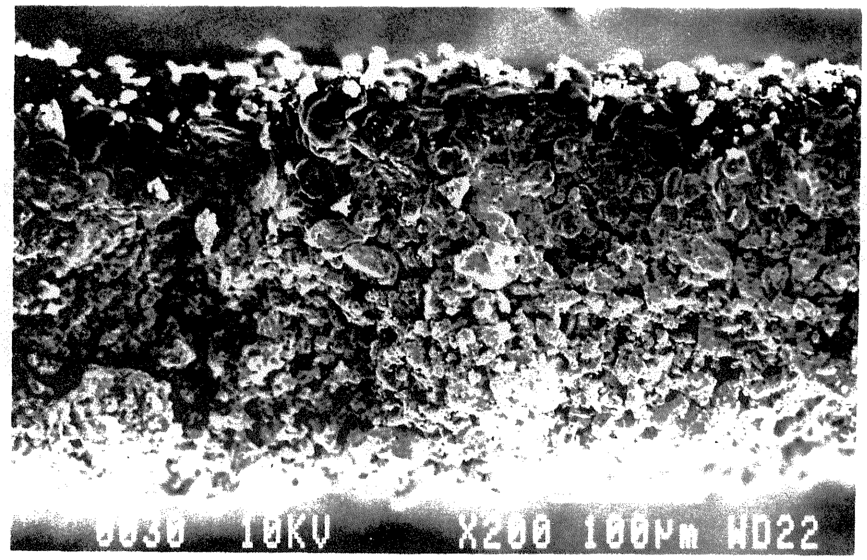


Figure 6.

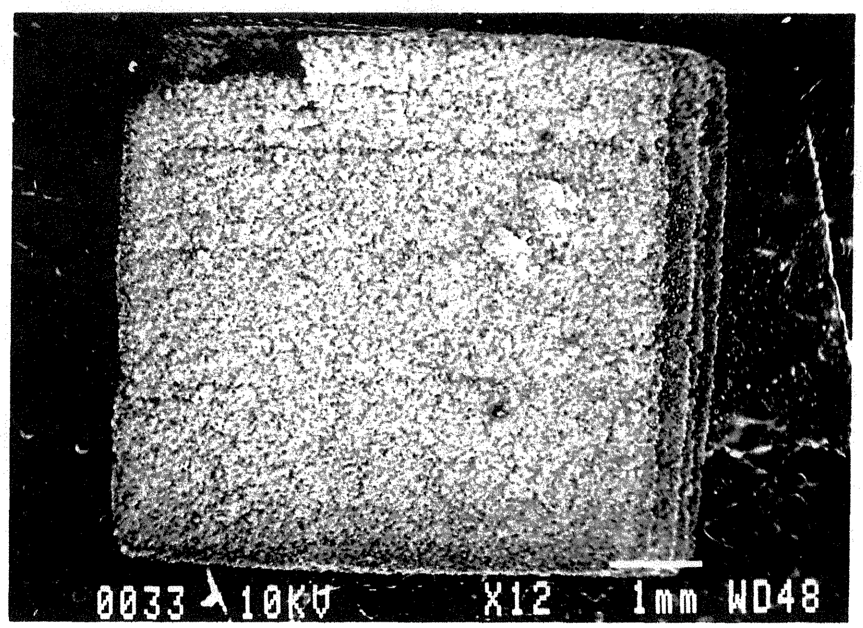


Figure 7.

Conclusions

A Selective Laser Reaction Sintering workstation is in place and operational. It is capable of producing multi-layer solid freeform parts in an environmentally controlled chamber. This will enable the study of laser sintering combined with gas phase/powder reactions. It is believed that this combination is capable of producing materials and structures unobtainable by standard sintering techniques. Preliminary studies are positive.

Acknowledgments

Thanks go to Dr. Uday Lakshminarayan for his early work on this program, Ed Barth, and Dr. Michael Schmerling for their microscopy assistance and to the Texas Advanced Technologies Program (ATP) project 323 and the Office of Naval Research grant N00014-90-J-1164(Cu-Ti) and N00014-92-J-1514(SiC gas/ SiC solid) for funding this effort.

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