The Application of an Artificial Body Force to the Selective Laser Sintering Process

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Abstract

An artificial body force generated by a magnetic field is applied to the green powder bed of a ferromagnetic powder during the Selective Laser Sintering process. Preliminary experiments and theory are formed to determine whether the artificial body force is beneficial to the Selective Laser Sintering process and if it is usable within that process. Several applications are discussed including microgravity situations and two phase sintering processes. It is determined that the magnetic body force is beneficial to the Selective Laser Sintering process.

Introduction

The purpose of this experiment is to determine if an artificially generated body force applied to the powder bed during application and sintering will enhance the Selective Laser Sintering process. The force which is currently under consideration is a magnetostatic force applied to ferromagnetic materials. The addition of the artificial body force is expected to increase the green bed and part densities and therefore increase the part strength of the sintered work piece. In addition, the magnetic force is expected to induce a packing structure into the green powder bed. This packing structure generation was exhibited in an electrostatic powder application system, and therefore is expected in a magneto static system. Also, the magnetostatic system has the ability to generate a constant and controllable force during the sintering process.

The magnetostatic system is intended to be used to enhance part quality, replace gravity in a microgravity situation, and aid the powder application and leveling processes. The most important disadvantage of the magnetostatic force generation system is its nonlinearity with respect to radial position from the solenoid. This nonlinearity will eventually have to be designed out of the system in order to produce high quality parts. If a satisfactory field cannot be generated, the use of a magnetic body force in the Selective Laser Sintering process will not be feasible.

Theory

The magnetostatic system is currently being modeled in simple terms. This model will illustrate qualitatively how the particles are expected to behave in the magnetic force field. This information can then be used to design an appropriate core for magnetostatic force field generation.

The first step in generating a workable magnetic force field is to select the core parameters which are desired. The manipulation of the core parameters N, i, a, and d allow for the generation of a useful magnetic force field. A standard model of the magnetic field intensity **H** for a single solenoid on the vertical axis is presented below:

$$H_z = \frac{Ni}{2d}\left[\frac{\frac{d}{2a}-\frac{z}{a}}{\sqrt{1+\left(\frac{d}{2a}-\frac{z}{a}\right)^2}}+\frac{\frac{d}{2a}+\frac{z}{a}}{\sqrt{1+\left(\frac{d}{2a}+\frac{z}{a}\right)^2}}\right] \qquad (1)$$

The magnetic core and sintering platform parameters are illustrated in Figure 1 below.

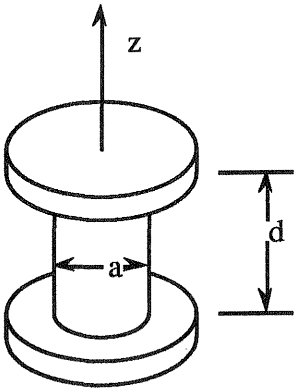

Figure 1
Solenoid calculation parameters
N is the number of turns on the solenoid
and i is the desired current

As the value of $\frac{d}{2a} \ll 1$ the model can be reduced to a more simple form,

$$H_z = \frac{Ni}{2a} \qquad (2).$$

Equation (1) has been simulated to aid in the design of a suitable solenoid for the magnetic process. The parameters of N, a, d, and i were varied, and H_z as a function of z was generated and graphed. Many of the possible combinations of these parameters were simulated, but four general trends are illustrated here. A graph is presented below in Figure 2.

Several important facts can be learned from this simulation. The first fact is simply that the parameters N and i only affect the magnitude of the field. However, this simulation also illustrates that a and d can be manipulated to effect where and how the field breaks from its initial linear behavior to fall to small values of field intensity. This phenomena allows a design to be implemented which will produce a constant linear force by operating in the region before the field breaks.

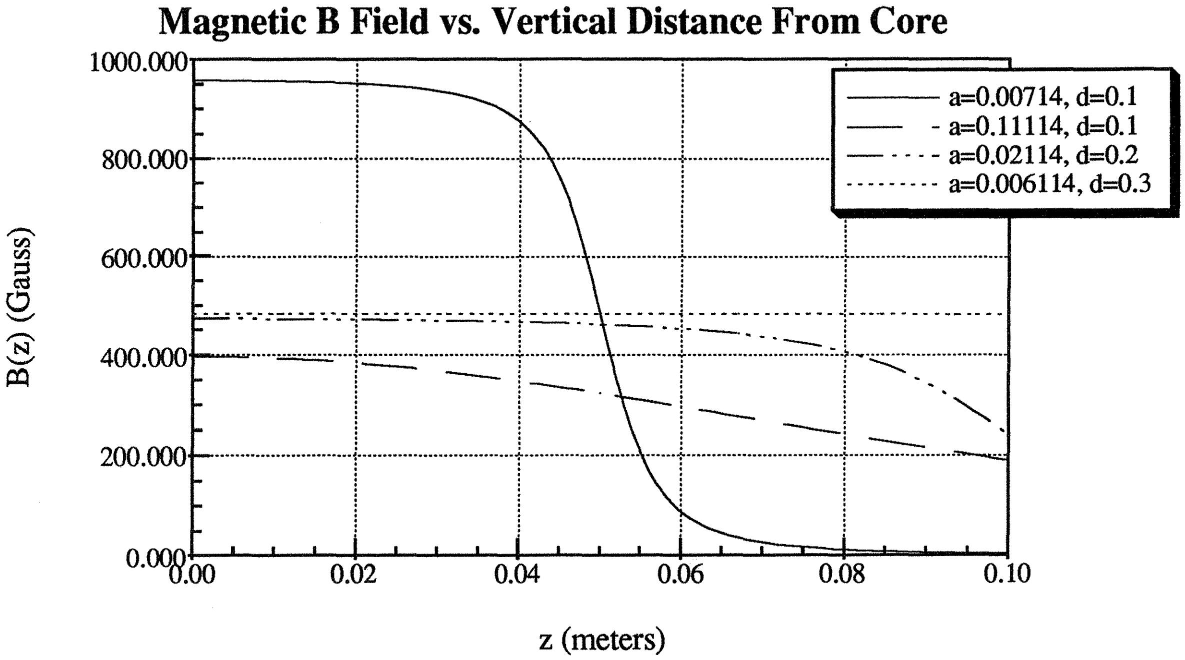

Figure 2
The magnetic field intensity as a function
of vertical displacement along the z axis

The force exerted on a ferromagnetic particle in this magnetic field can also be expressed mathematically. A simple model of the magnetic force is used to understand theses interactions.

$$F_z = \frac{c i^2}{z} \tag{3}$$

The constant, c, is a function of the windings and geometry of the solenoid. This model can be coupled with the magnetic field intensity relationship to produce a force model involving the magnetic field intensity.

$$F_z = \frac{4acH_z^2}{N^2 z} \tag{4}$$

This relationship provides an insight to how the particles are affected along the vertical axis. As the particles are distributed radially further from the axis, the force influencing them will lessen. This fact leads to a potential problem during the application of the particles. It is possible and probable that this effect will lead to nonuniform powder layer distribution and possibly undesirable particle migration during the sintering process. This can be counteracted by designing an axially symmetric field and possibly by designing the Selective Laser Sintering process control software to account for this distortion. However, this problem is beyond the initial investigation which this experiment encompasses, and therefore it will be addressed in later work.

Experimentation

The Initial experiments have been performed on a one kilowatt laser in the High Temperature Work Station at the University of Texas at Austin. A solenoid consisting of 430 coils on a 5 cm long 2 cm diameter iron core was built and put into the part cylinder with a sintering platform of 304 stainless steel affixed to the top and bottom of the solenoid. Nickel powder was applied and leveled by hand to a thickness of 0.020 inches. The parts were then sintered with the laser using no outside heat source. One layer was sintered using either 1.5 A or 0 A current flowing through the solenoid.

Results

The initial results are very positive. Both the magnetized powder and the nonmagnetized powder failed to sinter to the top of the sintering platform on the solenoid. However, the magnetized sinter was 0.0165 in. thick while the non magnetic sinter was 0.011 in. thick. Also, both specimens exhibited ridges along the line of sinter, but the ridges in the magnetized sinter had sharp tops like triangles, while the nonmagnetized sinter has rounded tops. Both specimens were fragile and full of holes which let light shine through the work piece.

Once the sinters were viewed under the Scanning Electron Microscope, more differences appeared. Figure 3 and 4 are SEM photographs of the two sinters. The nonmagnetized specimen had powder grains sintered to one or two other grains while the magnetized specimen routinely had grains sintered to three, four, or five different grains. Also, the bonds on the magnetized sinter were routinely larger than those of the

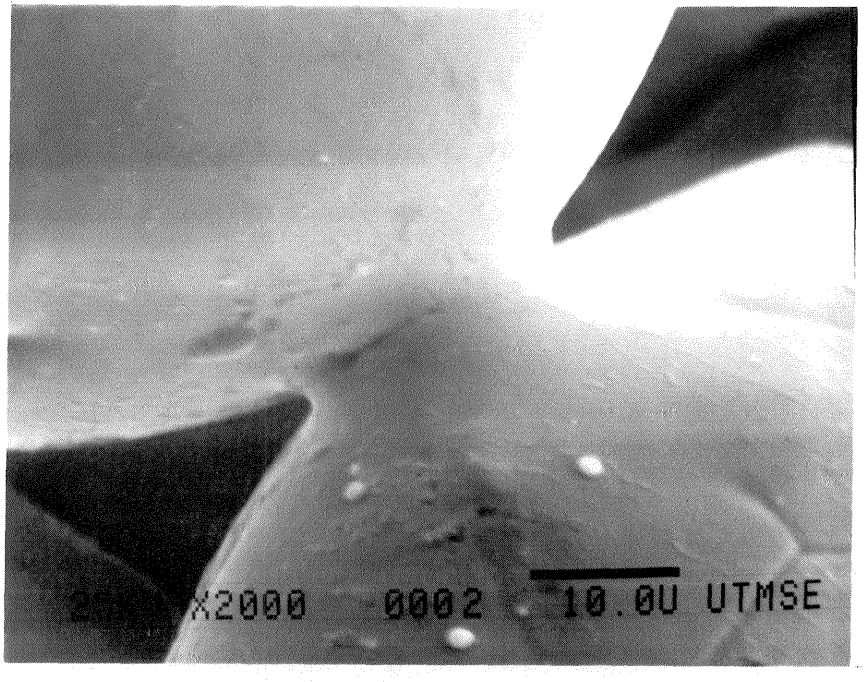

Figure 3
Nickel powder sintered with no magnetic field.
Magnified 2000x

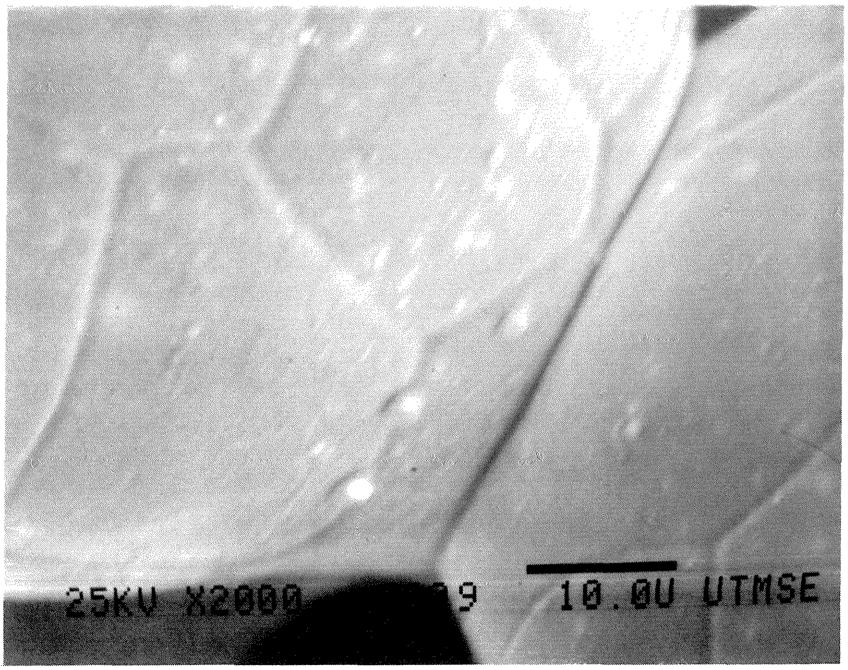

Figure 4
Nickel powder sintered with 1.5 A of
current producing a magnetic field.
Magnified 2000x

nonmagnetized sinter. In addition, there were many nickel particles in the magnetized sinter which had numerous groves in them. However, most of the particles of the nonmagnetized sinter had smooth surfaces, and those which did not had only a small number of groves on them The magnetized sinter also exhibited some ridge like patterns in the sintered work piece.

Experimental Variances

Three different experimental variances may have contributed to the observed experimental results. First, the nonreflective coating was missing from the inside of the zinc solenide window during these experiments. Secondly, the powder was jostled about between the leveling and sintering processes when it was installed into the sintering machine. Finally, the solenoid generates heat which transfers to the sintering area through the sintering platform.

The missing window coating has made the effective sintering power lower than it was set on the machine. For this reason, the balling effect which is exhibited when sintering single layers of nickel was not exhibited and it may be deduced that the entire region being sintered did not change to liquid phase during the heating process. Also, the exact power which reached the sintered surface cannot be determined in a reliable fashion. Because of these problems, these experiments are only comparable to themselves. The other two variances cannot be linked to any effects on the sintered materials without drawing unsubstantiated conclusions.

Conclusions

These initial experiments support the conclusion that a magnetic field produces a beneficial and useful effect upon the Selective Laser Sintering process. The SEM analysis of the different sinters shows that the magnetized sinter is more dense than the nonmagnetized sinter because the particle to particle bonds are bigger, and there are more bonds present in the magnetized specimen. Also, the ridge effect and greater thickness of the magnetized sinter implies that the laser is able to penetrate further into the magnetized layer. This could be because there are less air gaps due to better packing under the influence of the magnetic field. The elimination of these air gaps would allow heat to conduct better between the powder particles.

Applications of a Magnetic Field

The magnetic field has many useful applications to the Selective Laser Sintering process. The immediate applications include densifying parts, replacing gravity in a microgravity situation, two phase sintering, and enhancement of the powder application process. The magnetic field also appears to be imparting a packing structure to the powder. This phenomena allows for specific placement of different material types in the green powder bed during the sintering process.

The applications to two phase sintering and particle placement will lead to advances in the material science of the Selective Laser Sintering process. These two applications could allow for repeatable alloying structures of pure elements during the sintering process. Using this structuring technique, it may be possible to produce exact homogeneous parts which can be designed to meet specific material property requirements.

The magnetic field's effect on part density and its potential in the powder application process are also very promising. The use of the magnetic body force to replace or counteract the gravitational body force during powder application and sintering will allow sintering in many different environments including low gravity and upside down. In addition, the densifying effect of the magnetic field will lead to greater part strength in the sintered materials as well as enabling the production of parts which are closer to traditionally machined parts.

References

Hammond, P., Electromagnetism for Engineers, The Macmillan Company, New York, NY, 1964.

Haus, Herman A., and James R. Melcher, Electromagnetic Fields and Energy, Prentice-Hall Inc., Englewoodcliffs, NJ, 1989, pp. 318-9.

Kuo, Benjamin C., Automatic Control Systems, Prentice Hall, Engelwoodcliffs, NJ, 1991, pp. 180-1.

Melvin, Lawrence S., III, "The Electrostatic Application of Powder for Selective Laser Sintering," Masters Thesis, The University of Texas at Austin, 1991.