Net Shape Components Through Automated Selective Inhibition Sintering Process (Sisp) for Small Armament Applications by using 3d Modeling

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ABSTRACT

Selective Inhibition of Sintering (SIS) is a Rapid Prototyping process that makes parts in a layerbased method by using polymer powders. Current SIS machines accomplish this layer-based method by heating a fixed area of polymer powder. The current process is an area of concern because the entire fixed area of each layer is cured, resulting in large amounts of polymer powder being wasted. This paper explains the design of an automated, mechanical system that will mask off areas of polymer powder with heat-resistant fingers, allowing for the adjustment of the heated area in order to cure minimal amounts of polymer powder at each layer. Test results of a prototype model showed significant reduction in polymer powder usage. Selective Inhibition Sintering (SIS) has been proven effective in producing polymeric and metallic parts. Due to the low cost and high quality of SIS printing, the impact of SIS printing in the 3D printing industry could be disruptive. The potential of SIS is further extended to ceramics, an important but hard to print material, by the same mechanism of creating an easy-to-break sacrificial mold. Due to the high sintering temperature of ceramics, fluid based inhibitors delivered by inkjet printing tend to not be effective in SIS for ceramics. Accordingly, the new concept of inhibition by dry powder delivery is implemented. Preliminary experiments have shown the feasibility and ease of printing of simple ceramic parts. Additional experiments are underway to increase the possible part complexity and accuracy, and to optimize the sintering process.

Keywords: Additive Manufacturing (AM), Selective Inhibition Sintering (SIS), Sintering Inhibitor, Ceramics 3D Printing Selective Inhibition of Sintering, SIS, Waste saving, Heater Design.

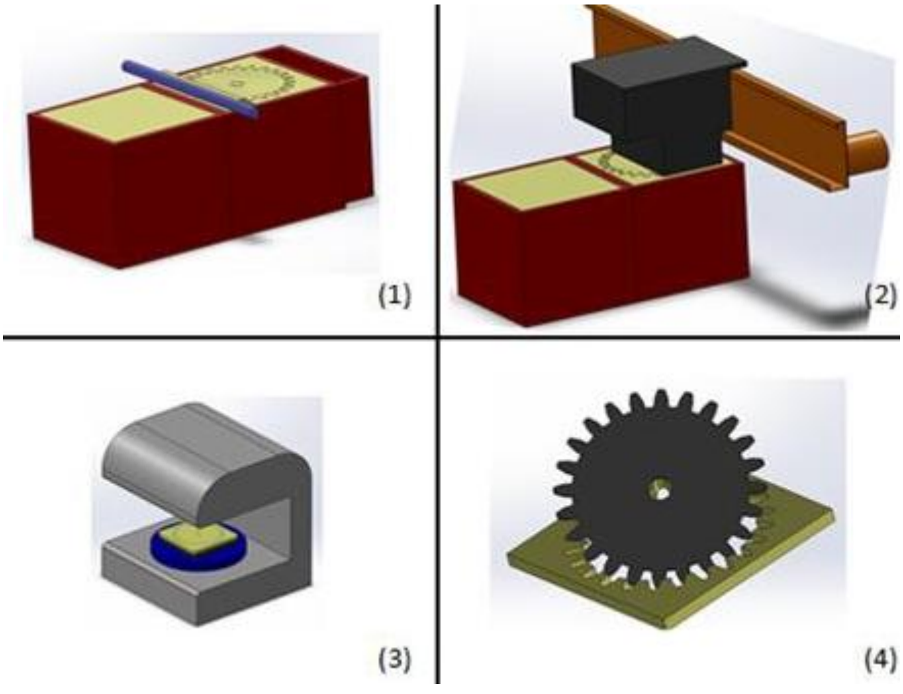
I. INTRODUCTION

As a new approach for powder based Additive Manufacturing (AM), SIS has been proven efficient in producing 3D printed parts of high quality with polymers and metals

 ISBN: 978-93-86171-56-6

SIS Printed Metallic PartsFig-1

Current AM methods for metals and ceramics use high density energy (like EBM and SLS) or post sintering of binder-consolidated green parts. The print time in the current methods depends on the size of the parts hence printing large parts requires significantly longer print time. Furthermore, for printing large parts, the high density energy beam of laser and electron beam lose focus at peripheral regions of layers causing reduced energy density and poor quality.The SIS process is fast and guarantees uniform part quality. As the powder layer is paved (Figure.2), the inhibitor is deposited along the part layer profile, often a 2D border line that shortens the printing time. The inhibitor is deposited layer by layer As the printing process is completed, the green part is moved into a sintering furnace where the inhibitor coating serves as a temporary sacrificial mold, separating the parts from the redundant powder. As the sintering process is completed, the part is taken out from the furnace and the redundant materials are removed by means of sand blasting. The fabrication resolution depends upon the precision of deposition of inhibitor and base powder particle size and does not degrade as part size increases.



1. **Powder pavement; 2. Inhibitor deposition; 3. Sintering in the furnace; 4. Part separation(Fig-2)**

The original SIS technology has been satisfactory for fabrication of polymeric and metallic parts,however, in production of parts made of metals with high sintering temperature as well as in production of ceramic parts (which often require high temperature to sinter), the inkjet-printed liquid inhibition approach seems to have some limitations with respect to ease of separation of the adjacent uninhibited powder regions. Also for 3D printing in space and on the Moon and asteroids where the vacuum environment evaporates fluidic inhibitor solutions the use of nonfluidic inhibitors is necessary. In fact the need for printing inter-locking ceramic tiles for Lunar landing pads in a NASA supported project has motivated the development of the new SIS process.For additive manufacturing of ceramics, SIS has some obvious advantages over competing technologies. Electron beam cannot be used for ceramics as most ceramics are not conductive.Laser beam works in heating up the ceramic powder but the energy requirement is high. Finally,binder based sintering methods could lead to high shrinkage rate [3] and the remnants of the binder in the matrix weaken the ceramic parts.Application of SIS upon ceramic parts manufacturing is proven feasible and large volume manufacturing of low cost ceramic parts are possible.

II. PRINCIPLE OF OPERATION OF SIS_CERAMICS AND EXPERIMENTAL SET UP

In the new SIS process the inhibitor material is fine dry powder form of a ceramic (such as magnesium oxide which has a sintering temperature of over 1500 C) or other material with sintering temperature that is higher than that of the base powder material. Controlled delivery of the inhibitor powder within the base material powder of which the 3D part is to be fabricated can be done using a vibrating nozzle. High-resolution deposition of thin walls of inhibitor powder

within loose base powder is quite possible with a fine nozzle. Using this approach the desired geometry of the part layer boundary may be created within the base material powder. Note that a rotary axis actuator can be used to pivot the nozzle so that its orifice is always positioned on the opposite side of the nozzle motion direction. The entire nozzle assembly may be moved in the three dimensional space by means of a motion control platform. This way the inhibitor powder may be deposited according to any straight or curved path. Inhibitor material may be deposited for each successive powder layer spread by a powder spreading mechanism until all layers are completed. The entire loose powder layer vat may then

be placed in a powder sintering furnace which may be operated by means of resistive heating,microwave or other heating means that sinters the base powder but leaves the inhibitor powder intact because of its higher temperature sintering heat requirement. After sintering the final part

may be separated from the rest of the sintered material. In case of complex part geometries separation lines may be created by the nozzle outside the part geometry connecting selected points on the layer boundary to the edge of the powder volume to ease part separation. A prototype SIS-Ceramic .

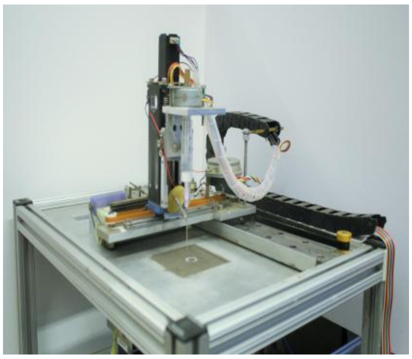


Fig-3

Prototype machine of SIS-Ceramics

To separate the sintered parts from the redundant material, the inhibitor powder must remain loose after sintering. Therefore, the inhibitor needs to have a higher sintering temperature than the ceramic powder that makes the part. The inhibition mechanism (Figure 4) illustrates the inhibition mechanism. As the inhibitor is deposited into the base layer, a thin wall is formed between the inside and outside sections of the base material that constitute the part. Before sintering, both base material and inhibitor material are loose powder. During sintering, the building material gets sintered and hence shrinks and forms the solid part while the furnace temperature is well below the sintering temperature for the inhibitor powder. After the part is taken out from the furnace, the loose inhibitor is easily removed and the desired part is extracted.

In our preliminary experiments, lunar regolith simulant (JSC-1A1) is used as the building material and aluminum oxide is used as the inhibitor. The lunar regolith simulant is sifted through a 60 meshes sieve and the powder size is below 250 um. The sintering of JSC-1A is carried out at 1150 °C in the ambient environment for 1 hour and then the part is cooled down to the room temperature. The sintering temperature for JSC-1A is about 1100 °C and the sintering

temperature for aluminum oxide is about 1400 °C [4]. Near-spherical aluminum oxide powder is used for ease of deposition through the thin nozzle channel.

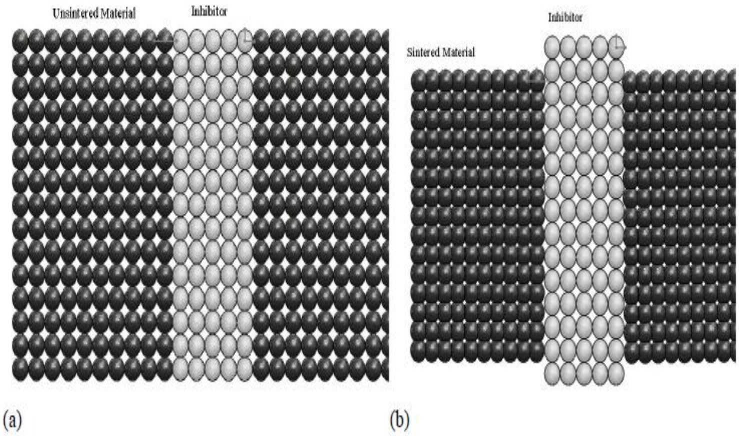


Figure 4 Inhibition Mechanism for SIS-Ceramic (a) Simplified powder distribution before sintering; (b) Shrinkage of building material with inhibitor almost untouched. (The black spheres represent the building material and the white spheres represent the inhibitors)

Fig-4

IV. RESULTS

Results show easiness in separating the printed parts from the redundant material. As can be seen in Figure 5, the block taken out from the furnace has been well sintered. While the area deposited with inhibitor (the white curves in the figure) is not sintered at all. The redundant material sintered can be broken away by hand easily along the separation lines. The inhibitor powder on part surface could brushed away with ease.

Sintered Ceramic Parts and Separation from the redundant material (*Fig-5*)

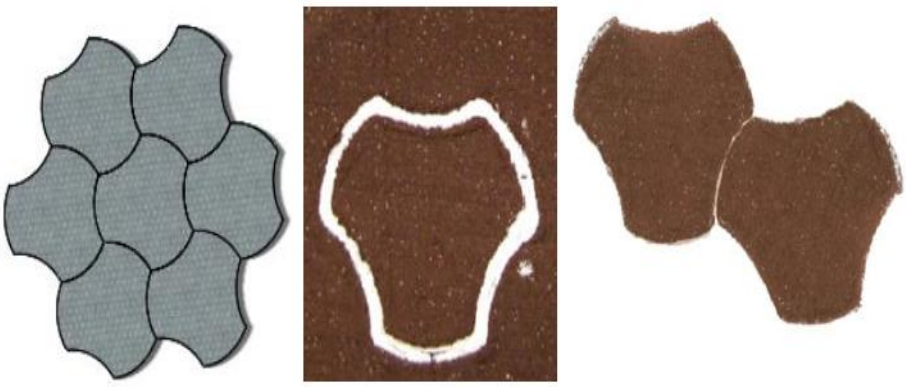
Due to oxidation, the raw black powder has turned red.

V. ANALYSIS

Our tests show that the printed parts are strong and have high impact strength. The extreme ease of separation guarantees the feasibility of the process for complex part geometry. Much thinner inhibitor walls may be built to increase part resolution. As long as the inhibitor has a distinctly higher sintering temperature than the base material for making the part, the inhibitor would be a qualified candidate for use.

VI. APPLICATIONS

The SIS-Ceramics process may be used to manufacture complex ceramic parts with high quality.The temporary sacrificial mold protects the part from deformation and the built parts can have high strength with no internal impurities. Ceramic parts generally have higher service temperature and are oxidation resistant. SIS printed ceramic parts could resist very high temperature as the process allows the sintering of ceramics with very high melting point. For outer space fabrication of objects such as landing pad tiles the materials need to sustain high temperature exhaust plume of the landers. The sintered lunar regolith could well satisfy this purpose. The SIS process described here can utilize in-situ resources to create a variety of ceramic objects in outer space. In Figure 6, interlocking tiles built with lunar regolith simulant
are shown.



Printed interlocking brick (left) Interlocking pattern for lunar landing pad; (middle)Sintered brick; (right) Printed Bricks Fig-6

VI. CONCLUSION

SIS-Ceramic has been proven effective and efficient in producing ceramic parts. The fabricated parts are free from contaminants and can be used in a broader fields of application. Our current focus on the improvement of resolution using novel mechanisms for inhibitor powder delivery.

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[6] Atlanta, GA. Also, abstract for the following peer reviewed conference paper has been accepted and the full paper is under writing process: Asiabanpour, B., Cano, R., Van Wagner, L., McCormick, T., Wasik, F., Jayapal, V., "New Design for Conserving Polymer Powder for the SIS Rapid Prototyping Process",

[7] 16 International th Solid Freeform Fabrication (SFF) Symposium, August 1-3 2005, Austin, TX. In addition, it is planned a journal paper (in Journal of Rapid Prototyping) to be submitted by the end of summer.2005.

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