

Selective Laser Sintering and Fused Deposition Modeling Processes For Functional Ceramic Parts

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Introduction

A variety of solid freeform fabrication (SFF) techniques have been developed to produce prototype parts directly from a computer-aided drawing (CAD) without any hard tooling, dies or molds [1]. Most of these techniques use polymer, wax, or paper materials to produce the parts.

These techniques, with some modifications, can be used to rapidly prototype functional ceramic parts. Once developed, these techniques could also be used to manufacture small quantities of ceramic parts on a just-in-time basis. Fabrication using conventional techniques is a costly, time-consuming, and inflexible process when a few ceramic prototypes or when small quantities of parts are needed.

Solid freeform fabrication of ceramic parts offers numerous advantages over conventional processing. Prototypes can be prepared rapidly and cost-effectively. Design changes can be made easily and inexpensively. Larger number of design options can be investigated. Parts can be designed and engineered to take advantage of the stronger properties of ceramics, while minimizing the weaker ones. Typically, ceramic parts are made using an existing design, regardless of the material used for the original part. The ability to rapidly prototype a ceramic component will contribute to concurrent engineering, a popular design process being used today.

Lone Peak Engineering (LPE) is developing three SFF processes for ceramics based on:

1. Selective Laser Sintering (SLS)
2. Fused Deposition Modeling (FDM)
3. Laminated Object Manufacturing (LOM™)

™LOM is a registered trademark of Helisys, Inc. Torrance, CA

This paper discusses preliminary results with the SLS and FDM processes. LPE's ceramic LOM based process has been reported at this symposium [2] as well as at other meetings and in different publications [3].

Procedure

A three-step procedure was used to fabricate ceramic components by the SLS and FDM processes: Material Preparation, Green Part(s) Formation, and Heat Treatment. A flowsheet is shown in Figure 1.

Material Preparation

The same procedure was used to prepare the materials for both the SLS and FDM processes. The ceramic powder^a was mixed with a binder system that contained various binders, plasticizers, and dispersants. The mixing was performed in a sigma blade mixer, which is jacketed, so the mixture can be heated. These mixtures contained between 45 and 55% ceramic powder on a volume basis.

Green Part(s) Formation

The green, unsintered parts were formed using conventional SLS and FDM equipment. The ceramic-binder mixture was first processed into the proper feed stock for each SFF process. The feed stock was then used to prepare the green parts. Specific procedures used for the SLS and FDM processes are discussed below.

SLS Process

The ceramic-binder mixture was ground into a powder using conventional milling techniques. The ground powder consisted of larger particles containing the fine ceramic powder particles in the binder matrix. The average particle size of the ground powder was between 50 and 100 μm .

The green parts were fabricated in a conventional SLS machine^b. The ceramic-binder powder was substituted for the normal powders used in the SLS machine. The green SLS parts are shown in Figure 2. Multiple parts were produced in each run.

^a A-16SG alumina, ALCOA, Pittsburgh, PA

^b SLS 125, DTM, Austin, TX

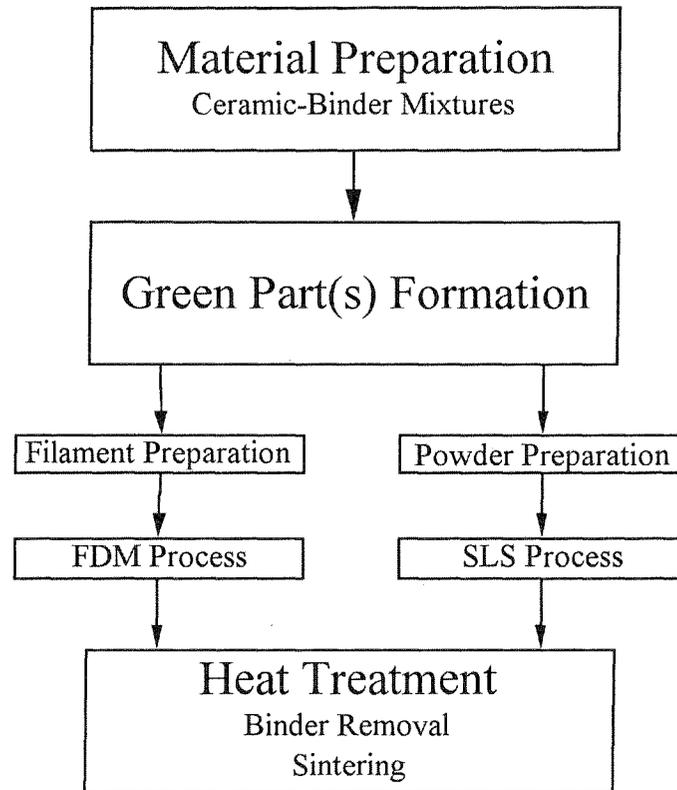


Figure 1. Flowsheet for ceramic-based SLS- and FDM-process.

FDM Process

The ceramic-binder mixture was extruded into filaments for the FDM process. The filaments were approximately 0.070" in diameter. The filaments were used to fabricate the green parts shown in Figure 3 using a conventional FDM Machine[°]. The parts in Figure 3 were produced using short discontinuous filaments 6 to 8" long. A single part was produced in each run.

Heat Treatment

The SLS- and FDM-produced parts under went similar heat treatments. The first heat treatment removed the binder by slowly heating the part in air up to 600°C. After the binder was removed, the parts were sintered in air at 1550°C for two hours.

[°] 3D MODELER, Stratasys, Inc., Minneapolis, MN

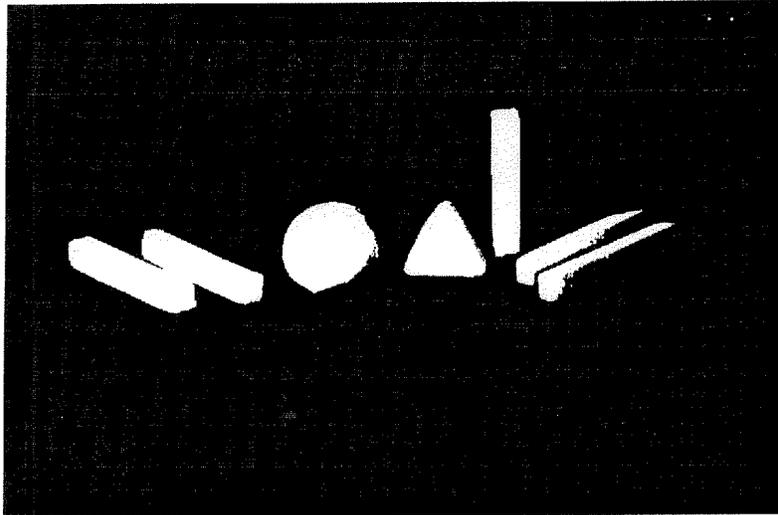


Figure 2. Green ceramic parts made by the SLS process.

Results and Discussion

Both the SLS- and FDM-produced parts were sintered without any obvious degradation or distortion to the parts. The green and sintered properties are shown in Table 1. The results for each process are discussed below.

SLS Parts

The sintered density of the SLS parts ranged from 53 to 65 % of theoretical density^d (%TD) with 36 to 47 % open porosity. The green density will have to be increased to achieve a higher sintered density. The green densities shown in Table 1 are between 30 and 35 %TD. The green density will have to be increased to more than 45 %TD to obtain sintered densities above 90 %TD.

The variation in green density of the SLS parts may be due to the different shapes of the parts made. Generally, sintered density increases with green density, but this trend was not observed for the SLS parts shown in Table 1. This may also indicate a dependence on part shape.

The porous nature of the sintered SLS parts indicates that this process may be an ideal process to produce ceramic cores for investment casting. For structural applications the density of the SLS parts will have to be increased.

^dFor this grade of alumina, a theoretical density of 3.90 g/cm³ was used.

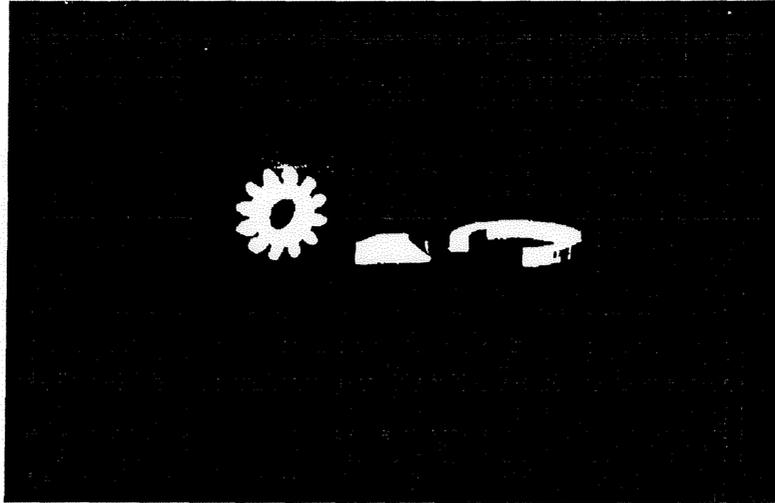


Figure 3. Green ceramic parts produced by the FDM process.

FDM Parts

The FDM process resulted in parts with sintered densities above 96 %TD. These high densities are a direct result of the high green densities of the FDMed parts. Ceramic components with high densities above 90 %TD such as the FDMed parts could be used in structural applications.

The ceramic-binder system used in the FDM process can also be used in an injection molding process. By using the same ceramic-binder system, the FDMed prototype parts will be very similar to the injection molded parts. As the volume of parts outgrows the capacity of the FDM process, production can be easily transferred to an injection molding process.

Conclusions and Challenges

Based on the preliminary work performed, the feasibility of the SLS and FDM processes to produce ceramic components has been demonstrated. The challenge for the SLS process will be to increase the sintered density, if the SLS parts are to be used in structural applications. The challenge with the FDM process for ceramics will be to develop a ceramic-binder mixture that has all of the characteristics necessary to be used in FDM equipment.

Acknowledgments

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Table 1. Green and Sintered Properties of SLS- and FDM-Produced Parts.

<u>Process</u>	<u>Shape</u>	<u>Green</u>	<u>Wt Loss, %</u>	<u>Sintered Properties</u>		
		<u>Density, g/cm³</u>		<u>Density, g/cm³</u>	<u>%TD</u>	<u>Porosity, %</u>
SLS	Bar	1.16	16	2.10	53.8	46.7
	Triangle	1.37	16	2.07	53.1	47.0
	Sphere	1.21	16	2.54	65.1	36.0
FDM	Gear	2.47	15	3.81	97.6	3.1
	C-part	2.49	15	3.79	97.3	3.7
	Pyramid	nm ^a	15	3.75	96.2	5.1

^a nm = not measured

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References

1. Marcus, H. and D. Bourell. 1993. "Solid Freeform Fabrication", in Advanced Materials and Process, pp. 28-32, September, 1993.
2. Griffin, Curtis, JoDee Daufenbach, and Scott McMillin. "Solid Freeform Fabrication of Functional Ceramic Components Using a Laminated Object Manufacturing Technique", Solid Freeform Fabrication Proceedings, September, 1994, H.L. Marcus et al eds., pp. 17-25, University of Texas Press, 1994.
3. Griffin, C.W., J. Daufenbach, and S. McMillin, "Desktop Manufacturing: LOM Versus Pressing", Bulletin of the American Ceramic Society, 73[8]:109-113, August 1994.