

Selective Laser Sintering of a Copper-PMMA System

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Abstract

The Selective Laser Sintering process was used to manufacture green copper parts from a copper-polymer mixture. PMMA was used as the polymer binder for the metal. The green part was fired in a furnace under reducing conditions to obtain a pure metal part. The metal-polymer system and the conditions used to make parts are described in this paper. The effect of laser parameters and particle sizes on part density are also discussed. Keywords : laser sintering, copper, polymer, part density, dwell time, shrinkage.

Introduction

Selective Laser Sintering (SLS) is a novel technique for production of three dimensional parts directly from a computer model without part specific tooling or human intervention by sintering powder together with a computer controlled laser. A detailed description of the SLS process is available in literature(Deckard and Beaman,1989 and Marcus et al, 1990). In this paper we investigate the use of SLS to manufacture metal parts by fusing a low molecular weight polymer binder mixed with metal powder. We examine the effect of the laser dwell time on green part strength and the part shrinkage upon firing for different values of green density. Effect of particle size on green strength is also discussed. The density of the fired part is found to correlate with the green part density.

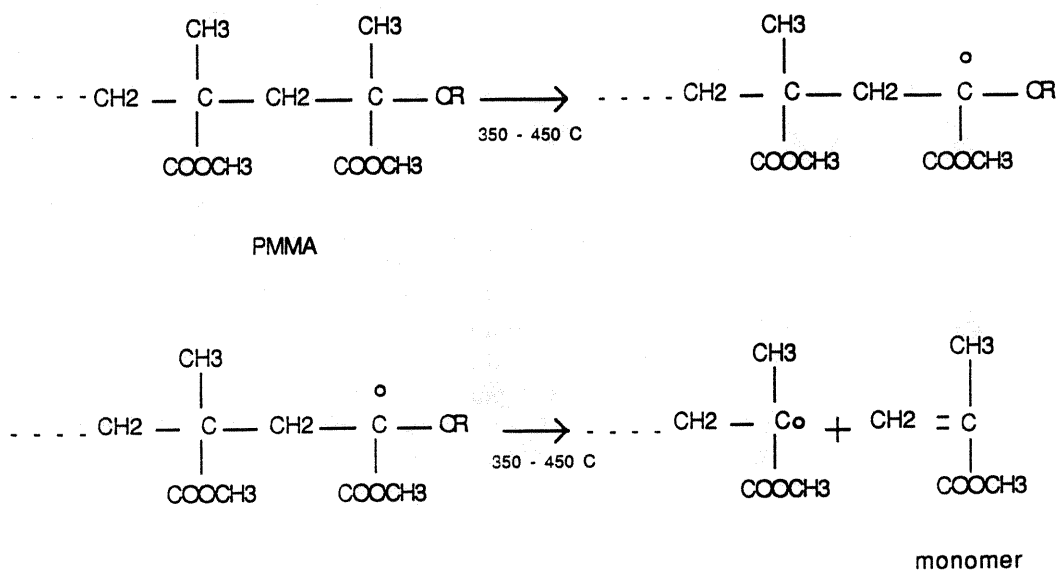
Process Description

The raw materials used in the SLS metal part manufacture consist of copper powder and PMMA, a polymer that acts as the binder for the copper powder. The size of copper powder was 7 - 14 μm and the polymer size was less than 53 μm . The melt index of the PMMA binder was 4.97 gms/10 min under a load of 3.7 Kgs at a temperature of 200 C in the Melt Index machine.

Melt index of the polymer is a very important parameter that determines the flow and hence the sinterability of the polymer binder as well as the green strength of the metal-polymer composite. A mixture of copper and PMMA in the ratio of 60-40% by volume (8 wt% polymer) was run in the SLS machine to produce green metal parts. The processing conditions for the powder mixture are shown below :

(1)	Layer thickness	5 mils
(2)	Bed temperature	28 - 30 C
(3)	Beam speed	9 - 51 inch/sec
(4)	Laser Power	25 W and 23 W
(5)	Beam diameter	20 mils

These parts were subsequently packed in alumina and fired in a muffle furnace under reducing conditions. The furnace is initially flushed with nitrogen for an hour and the temperature is then raised to 600 C and held there for an hour. The PMMA is decomposed completely under these conditions. Hydrogen is then admitted into the furnace and the temperature is raised to 950 C. Copper is sintered under hydrogen for 8 hours at the elevated temperature. A Hydrogen flowrate of 50-90 cc/min is normally used in the furnace. An important factor to be taken into account in the material system selection is the decomposition of the polymer binder. Ideally we would need a polymer that burns off completely without leaving any residue or ash. Depolymerization of PMMA occurs by breakdown of the polymer backbone at elevated temperatures (350-450 °C). The presence of a tertiary carbon atom in the polymer chain causes the PMMA polymer to unzip and the primary product of this thermal degradation process is the monomer. Shown below is the mechanism of depolymerization :



Results and Discussion

The Thermal Gravimetric Analysis (TGA) was performed on PMMA to determine the residue content. The weight loss curve is shown in figure 1. The PMMA powder was found to leave a residue of 5-6 wt% under nitrogen atmosphere in the TGA. PMMA is not supposed to leave any residue on thermal decomposition but the presence of additives in the polymer as well as impurities accumulated during the grinding of the PMMA pellets could explain the presence of residue. The residue in the sintered copper part is estimated to be 0.4 wt%. The presence of residue did not however prevent the sintering of the copper powder on firing. The effect of residue on mechanical properties of sintered parts has yet to be determined.

TGA File Name: parh1
Sample Weight: 11.552 mg
Mon: May 08 14:10:22 1991
parh1

PERKIN-ELMER
7 Series Thermal Analysis System

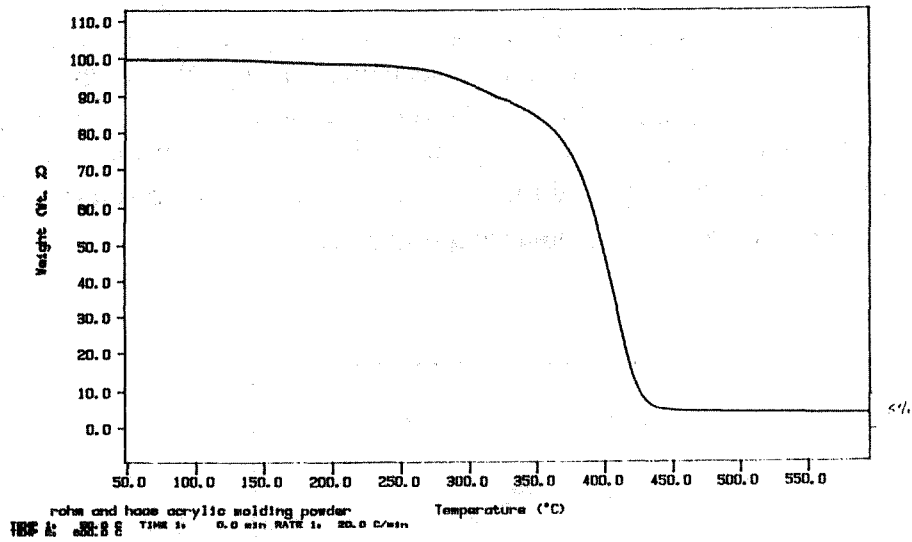


Fig1. Weight loss curve for polymethylmethacrylate

Figure 2 shows sample green parts made in the SLS machine. These parts show that this process can be applied to make prototype parts with various complex features.

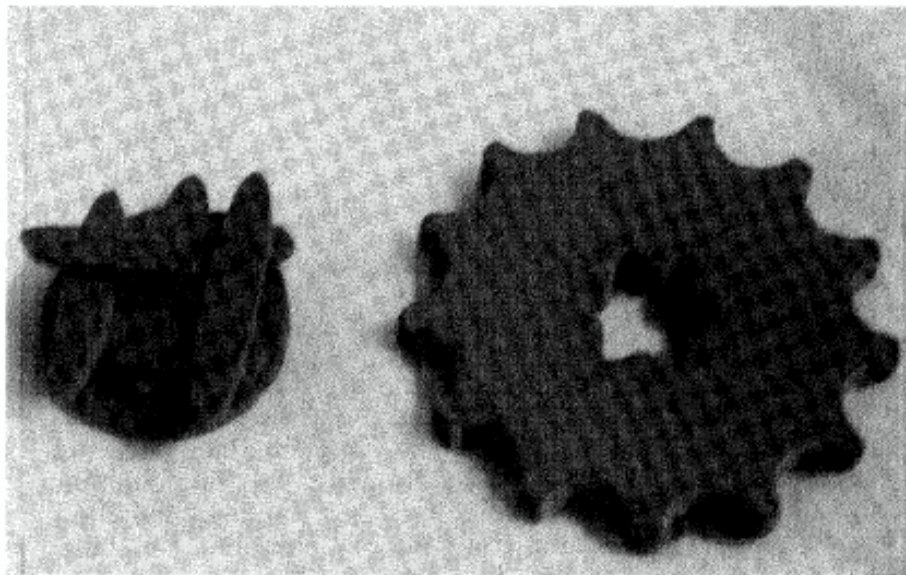


Fig2. Sample green parts from the SLS process

The effect of laser dwell time on green part density is shown in figure 3. The dwell time of the laser beam is the ratio of beam diameter to the scanning velocity. We see that the green density of the part increases with dwell time. At very low dwell times (< 350 μ sec) there is not enough sintering for the part to hold together and at very high dwell times (>2000 μ sec) the polymer starts to decompose during laser sintering. A laser dwell time around 1500 μ sec seems to be the optimal condition for this material system.

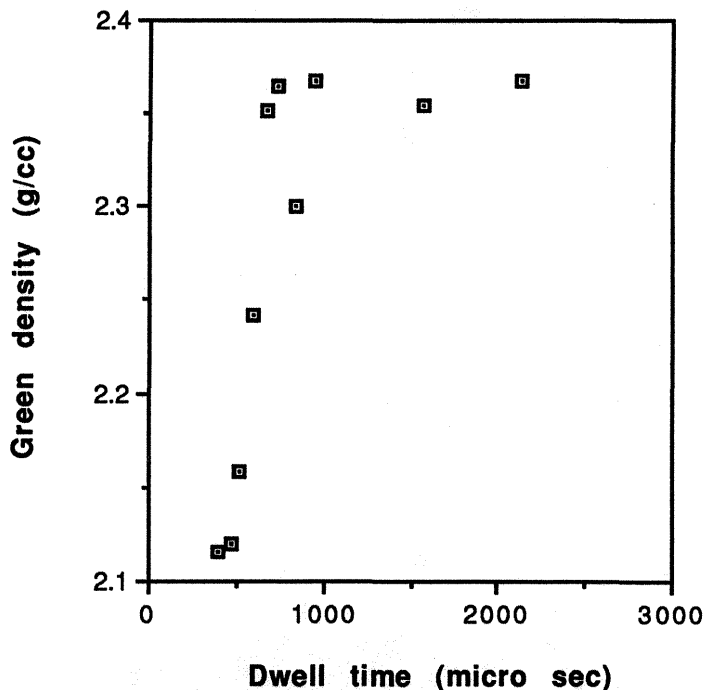


Fig3. Effect of Laser dwell time on Green density
[23 W CO2 Laser]

Figure 4 shows the plot of fired density of the copper part as a function of the green part density. The fired part density increases linearly with increase in green density. The part shrinkages in the x, y, and z directions are shown in figure 5 as functions of green density. We find that the shrinkage in the z-direction (the direction of gravity) is consistently larger than that in the x or y directions suggesting that gravity is playing an important role in the metal sintering process. One of the methods to reduce part shrinkage would be to start off with a higher green density. Green density of the part can be enhanced by increasing the density of the powder bed. The use of mixtures of particle sizes increases the bulk density of the powder compact because the smaller particles can fit into the interstices between larger particles. Bimodal particle size distribution appears to satisfy most of the criteria for optimal sintering (Liniger and Raj, 1988). Complete densification requires a high coordination number, a high green density and a uniform packing density. We plan to study the influence of the particle size distributions of the metal and polymer powder on the green part density.

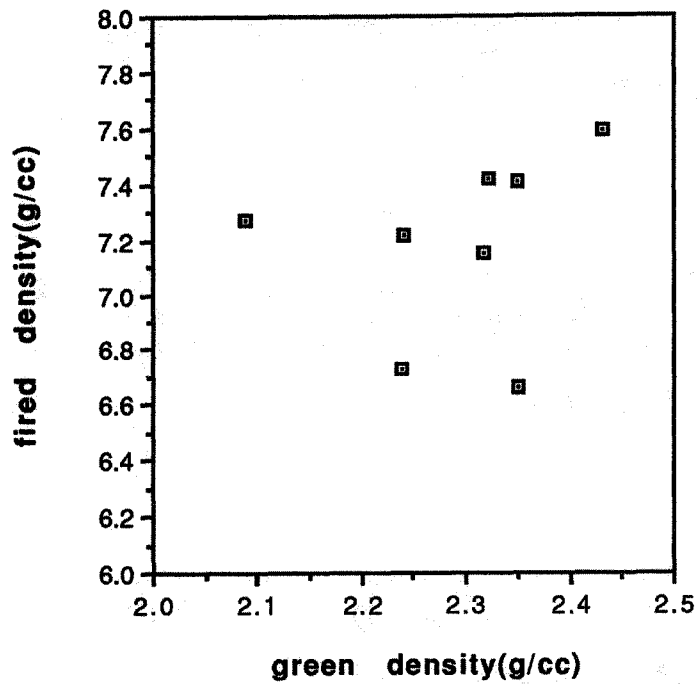


Fig4. Plot of fired density versus green density

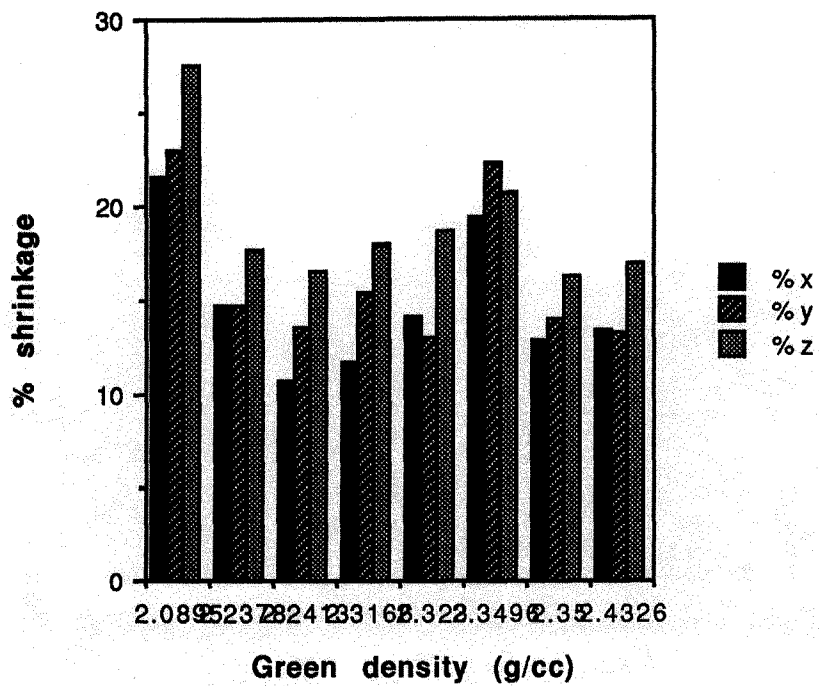


Fig5. Percent Shrinkage versus green density

Conclusion

We have demonstrated the feasibility of manufacturing metal parts using the metal-polymer system. Future work entails the optimization of material properties and process parameters that influence the part density and surface definition. We also plan to coat the metal powder with a polymer and use the same for part production.

References

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3. Eric G. Liniger and Rishi Raj, *J. Am. Ceram. Soc.*, 71 [9] C-408 - C-410 (1988)