

SELECTIVE LASER SINTERING OF Cu-Pb/Sn SOLDER POWDERS

J. A. Manriquez-Frayre and D. L. Bourell
Center for Materials Science and Engineering
The University of Texas at Austin, Austin Tx., 78712

ABSTRACT:

Solid Freeform Fabrication (SFF) as an overall approach in the manufacturing field has been applied to very different areas and on different materials systems including polymers, ceramics, metals and vapor phase. Even though it is clear that polymers have enjoyed a rapid and successful advance in terms of applications, research in the other areas have shown potential applications as well.

In this paper, Cu-Sn/Pb solder and Cu-Sn blends have been used as starting material for the Selective Laser Sintering (SLS) manufacture of SFF objects. The general properties of the objects thus produced are presented. In particular, density and microstructural characterizations results are discussed..

INTRODUCTION:

Selective Laser Sintering (SLS) as an alternative in the fabrication of complex parts using the Solid Freeform Fabrication (SFF) approach is becoming a reality in the industry of today. Although SLS of metals has been in the mind of many since this technique first showed its potential [1], it has not had the same development as its partners the SLS of polymers and ceramics. The main reason for this difference has been that SLS of metals has two aspects that make it difficult to deal with: first, it requires a laser with high output-power and second, a workstation with a high temperature capability as well as the proper design to control the processing atmosphere during the SLS experiment. All these requirements are necessary if the fabrication of metal parts with acceptable integral quality is an objective. These two requirements are not present in the

SLS of polymers, and in the actual application of SLS of ceramics neither of these requirements is as strong as in the case of metals.

We have overcome this problem in principle by using a starting material which consists of a mixture of high melting point and low melting point powders [2,3]. This type of mixture would allow the use of a low output-power laser and at the same time would allow to test the capability of the SLS technique to handle the fabrication of metal parts. At the same time, however, efforts have been made to build up a workstation capable of handling high temperature and controlled atmospheres as well as the use of a high power laser [4].

In this work, some of the results in our attempt to develop the SLS of metals are presented.

EXPERIMENTAL:

A complete description of the SLS technique and its associated workstation has been reported already [5]. In this work, the selective laser sintering was carried out using a workstation with a Nd:YAG laser ($\lambda=1.06 \mu\text{m}$). The main parameters of the laser as used in this work are listed in Table I:

Table I.- Laser parameters for the SLS experiments

Laser	Nd:YAG ; $\lambda=1.06 \mu\text{m}$
Beam Diameter	0.5 mm
Surface scanning speed	3-5 cm/sec

All experiments were carried out in an air atmosphere. The powder to be sintered was always preheated up to 150 C before the laser scanning to diminish the introduction of thermal stresses across the boundaries of the selectively lased layer. These thermal stresses have been shown to create curling on the layers being laser processed.

The powder blends used for these experiments were mixtures of Cu and 30Sn/70Pb solder as well as Cu and Sn powders. Series of different composition were made to allow the construction of density vs. composition curves for each system.

The characteristics of the powder used to prepare the mixtures were: Cu; spherical with a maximum particle size of about 150 μm ,

30Sn/70Pb solder; elongated with the largest axis about 100 μm and Sn; spherical with a maximum particle size of about 45 μm .

All powder blends contained approximately 5% by weight of ZnCl_2 . This wetting agent was added by dissolution to the metal mixture before the SLS experiments were carried out. After dissolution and drying, this agent forms a film around all the metal particles in the mixture. The effect of this ZnCl_2 addition was previously shown to be beneficial to the wetting characteristics of the powder blend during the SLS process [3].

RESULTS:

Fig 1 shows a longitudinal cross section plane of some of the parts that have been fabricated from Cu-Sn/Pb solder and Cu-Sn powder blends by the SLS technique. The superposition in a proper way of many layers like those shown in the figure leads to the build up of parts with a functional use.

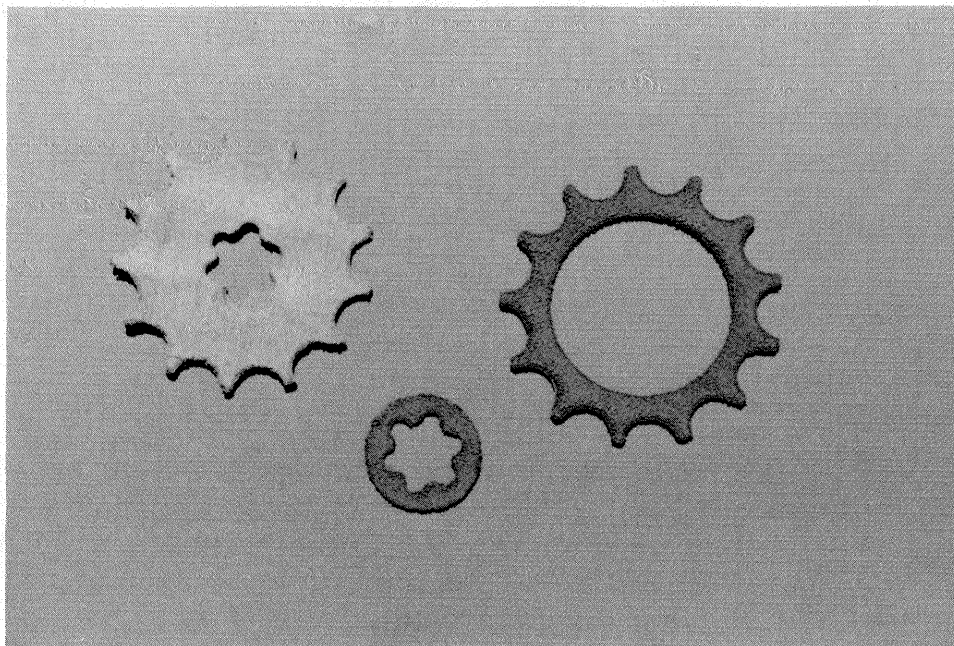


Fig. 1.- An example of the present capability of the SLS technique to fabricate metal parts. The powder used to fabricate these parts was a mixture of Cu and Sn/Pb solder. Each part consists of several layers that were individually processed by selective laser sintering of loose powder. The largest two parts have an outside diameter of about 3 in each.

Fig. 2 shows the microstructure of the top surface of a sample processed from a powder mixture with composition 95% (50 Cu-50 solder) + 5% ZnCl₂ as observed under the Electron Scanning Microscope (SEM). As it is visible in the micrograph, the porosity of the microstructure is interconnected. Also, it is noted that the structure solidified with a cluster type pattern. The strength of the part comes from a weak interbonding between clusters. This weak type of bonding was also observed when transverse cross section of the part was analyzed under the SEM, Fig. 3. This picture also shows a better view of the cluster type arrangement developed upon solidification of the material. The type of microstructure showed in Figures 2 and 3 is the same observed for all the samples of the Cu-Sn/Pb solder system when different compositions were used.

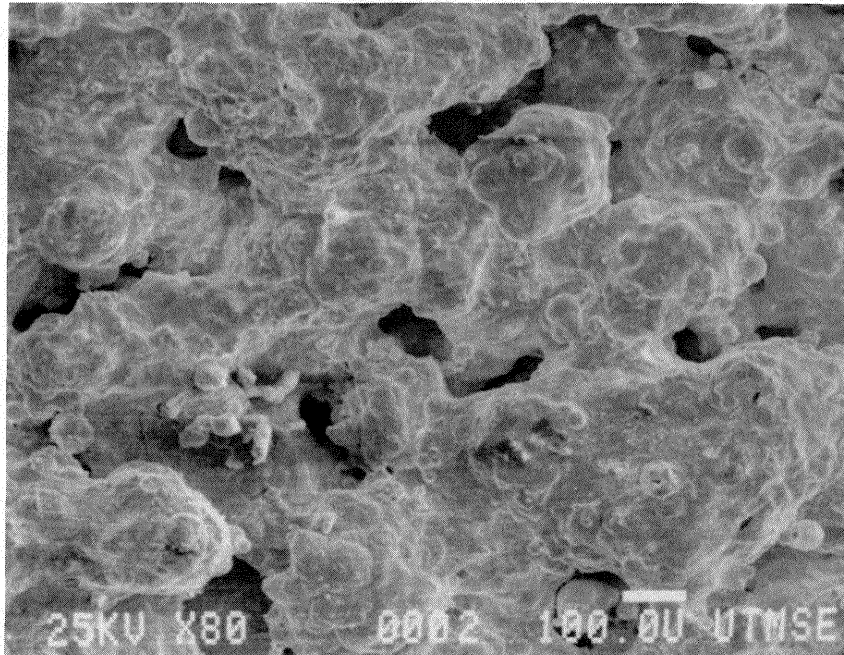


Fig. 2.- Microstructure of a sample processed with a composition 95% (50Cu-50Sn/Pb solder) + 5% ZnCl₂. A laser power of 25 W and a scanning speed of 4.1 cm/sec were the parameters used in the SLS process.

In Fig. 4 we show the top surface of a sample processed from a powder mixture with composition 95% (50 Cu-50 Sn) + 5% ZnCl₂. As can be seen, the structure of the solidified surface is still high in porosity, but there is not visible clustering. Fig. 5 is a micrograph of the transverse cross section surface of the same sample shown in Fig. 4. The most notorious feature is the layered-type structure of the sample along the longitudinal axis. This type of microstructure was present in all different compositions of the Cu-Sn system. This is in clear contrast with the cluster-type structure of the Cu-Sn/Pb solder system.

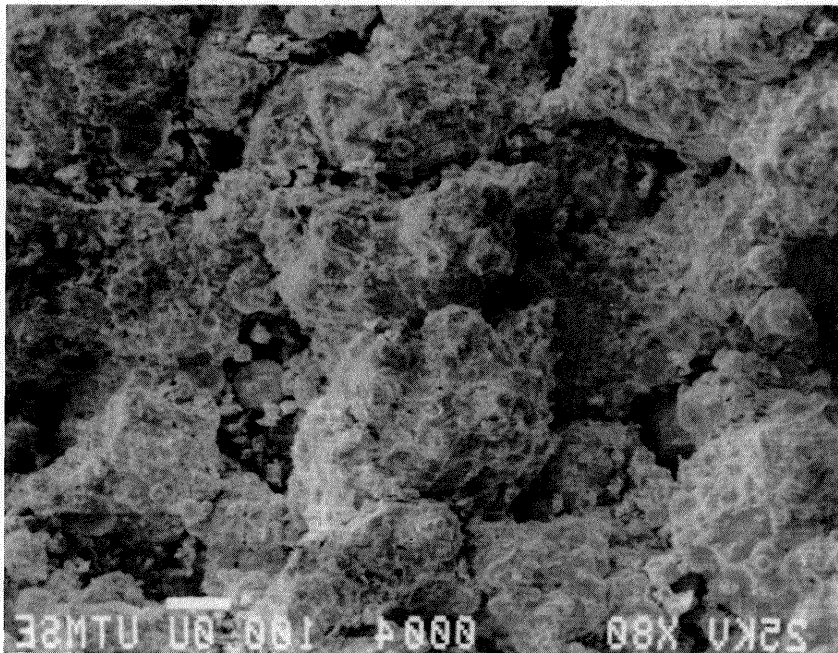


Fig. 3.- Cross section view of the same sample shown in Fig. 2. The cluster-type pattern observed in this sample is characteristic of all other compositions.

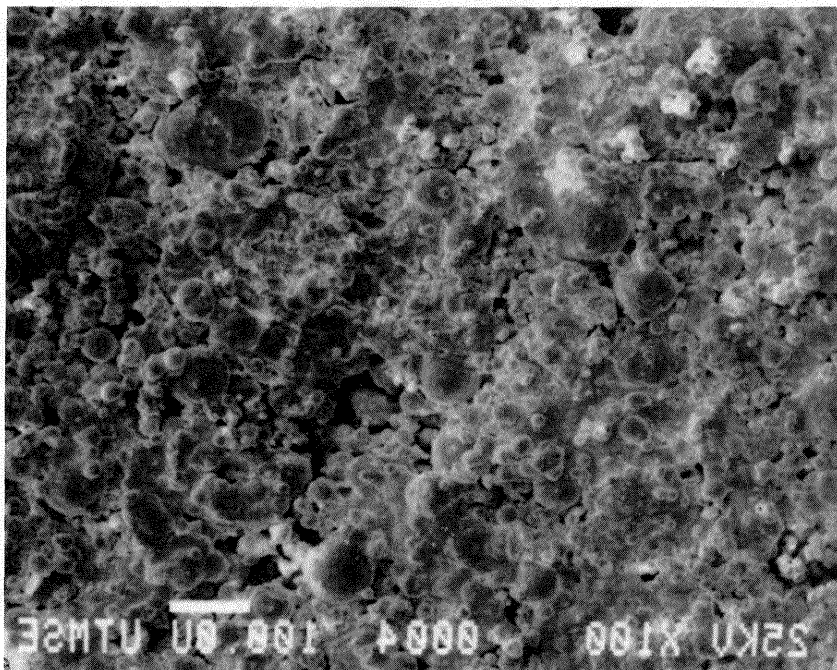


Fig. 4.- Microstructure of a sample (top surface) processed with a composition 95% (50Cu-50Sn) + 5% ZnCl₂. A laser power of 20 W and a scanning speed of 3.5 cm/sec were used to fabricate this sample.

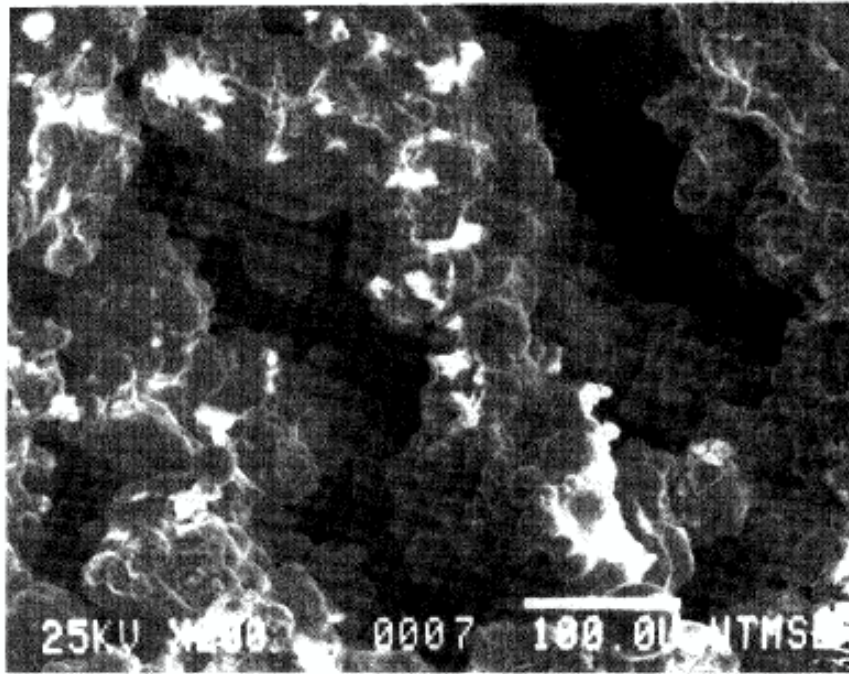


Fig. 5.- The solidified microstructure of the Cu-Sn system was different from the Cu-Sn/Pb solder system. In this micrograph the layered-type structure of the same sample shown in Fig. 4 is revealed by looking at the cross section surface under the SEM.

As expected, the density of these samples turned out to be low. The density increased with the volume fraction of the lower melting point phase. Fig. 6 shows the density of the as processed parts for both systems as a function of the composition.

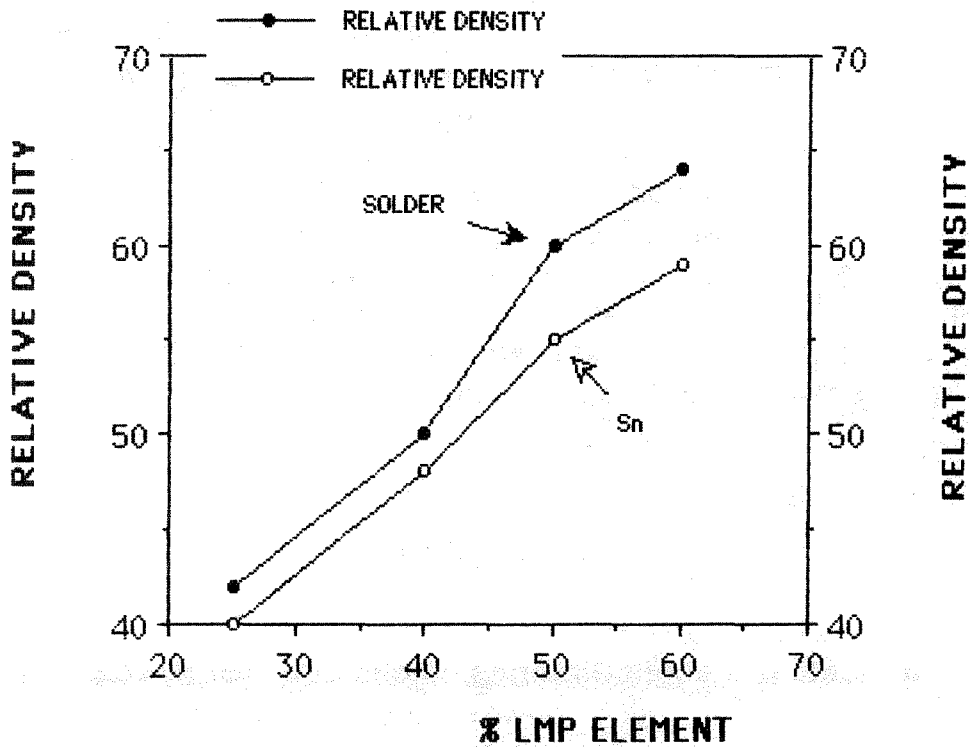


Fig. 6.- Density vs. composition curves for the Cu-Sn/Pb solder and the Cu-Sn systems.

DISCUSSION:

From the results of the structural analysis it is clear that even though wetting occurred it was not sufficient to drive the whole system into a complete liquid-phase sintering during the SLS process. This was evident as we observed that the powder layers did not collapse under the action of the laser sintering. The consequence of this lack of collapse of the structure under the action of the laser is the occurrence of the high interconnected porosity.

The difference in the type of solidified structure for the two material systems was in agreement with the slightly higher density of the Cu-Sn/Pb solder system as compared with the Cu-Sn system. The structure of the latter did not shrink at all under the laser sintering.

As expected from the microstructure observed, the density of the samples turned out to be low. Fig. 6 shows the density of the as processed parts for both systems as a function of the composition. Both limits on the composition scale were dictated by the loss of the structural integrity of the parts: the lower limit occurred because no bonding at all develops when the volume percent of the low melting point component is too low, and the upper limit occurred because an excessive volume percent of the low melting point component causes the laser molten material to ball up upon solidification instead of forming a flat surface [6].

The density vs. composition curve is explained as we realize that in order to increase the density we need to fill the voids present from the initial packing density of the powder mixture. This can occur either by filling those initial voids completely with the low melting point component (no movement of the high melting point particles) or by having the low melting point component act as the wetting phase in a liquid phase sintering process. It seems clear that in this work liquid phase sintering was not the dominant process during the SLS of the powder mixtures since very limited densification took place.

CONCLUSIONS:

The Selective Laser Sintering technique (SLS) can be used to fabricate metal objects using powder blends that contain a mixture of high and low melting point materials.

The density of the SLS samples fabricated in this work was low. Densities of about 65% were achieved in cases where a high content of low melting point material was present.

The analysis of the microstructure of the two material systems studied in this work (Cu-Sn/Pb solder and Cu-Sn) shows that the solidification process occurred in different ways in the two systems. In the Cu-Sn/Pb solder system the solidification process lead to a cluster-type structure, while in the Cu-Sn system a layered-type structure was always observed.

The low values associated to the density of the samples seems to be related to the fact that the processing atmosphere (air in this case) strongly limited the densification process even in the case where wetting agents had been added to the powder blends.

Although the density and mechanical properties of the samples prepared in this work were low in values, the potential use of the SLS technique in the manufacture of operational metal parts still looks very attractive.

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