Direct Laser Sintering of Metals and Metal Melt Infiltration for Near Net Shape Fabrication of Components

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Abstract

Direct laser sintering of metal powders is a great challenge for Rapid Prototyping (RP) because of the high potential of application, for example prototype tooling for polymer extrusion.
Recent development in laser sintering of metal powders use polymer or low melting alloys as a binder phase. Postsintering to strengthen the component produces shrinkage of the part, hence the near net shape capability is limited.
The combination of direct laser sintering and infiltration with metal melts allows the production of strong near net shaped components without shrinkage.
A composite metal powder consisting of Ni, Cu, Sn and P was successfully sintered in a Selective-Laser Sintering unit in ambient atmosphere at room temperature. The influence of laser intensity on microstructure and sintering behaviour is discussed.
Infiltration experiments were done with partially sintered samples. Full density could be achieved without shrinkage. Mechanical properties and microstructural development will be discussed.

Introduction

Currently laser sintering of metal and ceramic powders to manufacture parts is in research. Indirect sintering of polymer coated powders, where the polymer acts as a low melting point binder phase, has been developed to produce metal and ceramic components. Subsequent debinding and sintering is necessary to increase strength /1/.
Direct metal sintering mostly involves the formation of a liquid through a metal phase with low melting point, e.g. Ni/Sn mixture, or by supersolidus sintering of a two phase, e.g. Cu/Sn-alloys /2/. Sintering of high temperature materials without binder phase needs high sintering temperatures. A high temperature laser sintering process (HTSLS) is under development /3/.
Porous components made by SLS need further densification, either by sintering or by infiltrating the component. Further densification by sintering produces shrinkage of the component. Infiltration with liquid metal seems to be more promising, however needs development of the technique for different powder systems. Porous

SiC bodies produced by SLS of coated powder particles have been infiltrated with liquid Al /4/. Also the infiltration of Fe-based porous components with copper alloys is very common /5/.

This paper reports on research work in laser sintering of a multiphase powder mixture in a prototype version of a laser sintering unit. In order to increase density and mechanical properties sintered samples were infiltrated with liquid metal.

Experimental

The powder material used in the experiments contains three different components, Ni and compounds of Cu, Sn and P. A micrograph of the powder is shown in Fig. 1. Laser sintering of test layers was done at ambient atmosphere with a 100 W CO_2 (CW) laser at different laser intensities and a beam scan speed of 200-800 mm/s. Complex parts were built with layer thicknesses of 200 μm. The layers were investigated by SE and optical microscopy. Bulk samples were sintered by laser sintering and for infiltration experiments by conventional sintering in Argon atmosphere.

Infiltration of the porous samples was carried out in air at 500°C, using a PbAg brazing alloy. Different infiltration times were used in order to achieve full density and improved mechanical properties. Tensile strength and hardness were measured from the as sintered and infiltrated samples.

Results and Discussions

Sintering

The thickness of the laser sintered layer was about 100 μm. Single layers were strong enough to be handled without damage. With increasing intensity of the laser beam the powder material goes from sintering to nearly completed melting. The microstructures of the sintered layers of 3 different laser intensities at the same scan rate are presented in Fig. 2 a-c and the corresponding cross sections of the individual layers in Fig. 3 a-c.

low intensity:
Sintering with low laser intensity results in partial melting of the binder phase. The layer is homogeneous over the thickness. Ni-particles, appearing bright in the SEM micrograph, are not wetted.

medium intensity:
At medium intensity wetting of all particles including Ni is observed however the top surface seems to be completely melted, while the lower part still shows individual particles.

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medium intensity:
At medium intensity wetting of all particles including Ni is observed however the top surface seems to be completely melted, while the lower part still shows individual particles.

high intensity:
At high laser intensity the powder is nearly completely remelted at the top surface. Also the lower part of the layer is melted, however individual particles are still visible.

Based on the results of the laser sintering experiments a complex shape of a small turbine, see Fig. 4, could be generated layer by layer. No curling and no distortion occurred during sintering. The component showed no shrinkage during laser sintering.

conventional sintering:
The conventionally sintered microstructure exhibits homogeneous wetting of all particles by the binder phase, as visible in Fig. 5. The material still has open porosity to allow further infiltration of the component. The as sintered density is ~ 70% of theoretical density.

Low laser intensities result in a preferred microstructure in the as sintered state, remelting occurs only at medium and high intensities. Optimisation has to be achieved in improving the bonding at low intensities, for example by altering the atmosphere. Generally remelting should be avoided, because it will cause shrinkage and curling of the sintered layer. Also the microstructure is less homogeneous.

Infiltration

Complete infiltration of the conventionally sintered components with liquid metal was achieved after 45 min total infiltration time. Fig. 6 shows the microstructure of the infiltrated sample. Partial reaction zones could be detected, however these are not generally visible in the material.
Tensile strength of the 45 min. infiltrated material is not improved as compared to the sintered material but hardness is increased. The reason for the unimproved strength lies in the presence of singular large pores in the infiltrated material, as could be observed in the fracture surface. These pores are filled very slowly, because capillary pressure is proportional to 1/r, where r is the radius of the capillary.
Prolonged infiltration time leads to an increase in strength, also hardness is sligthly reduced.

Table 1: Mechanical properties of as sintered and infiltrated material

Material	Tensile Strength (MPa)	Rockwell Hardness
as sintered material	96 - 105	25.2
45 min infiltrated material	92 - 102	89.6
90 min infiltrated material	132	69.5

Conclusions

Direct laser sintering of metal powder mixtures needs careful control of laser intensities to avoid remelting of the powder material and to achieve a homogeneous microstructure of the sintered layer. Using the described powder mixture direct sintering of more complex parts was done at room temperature.

Infiltration of the sintered porous material is practical, however, property improvement is poor at the moment. Further improvement to achieve reasonable strength values of about 200 MPa tensile strength is necessary.

References

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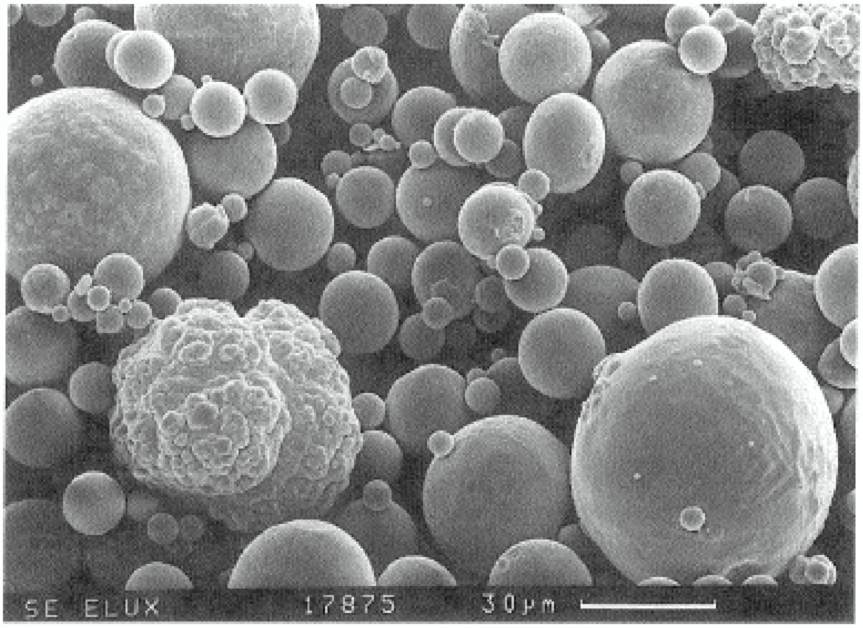
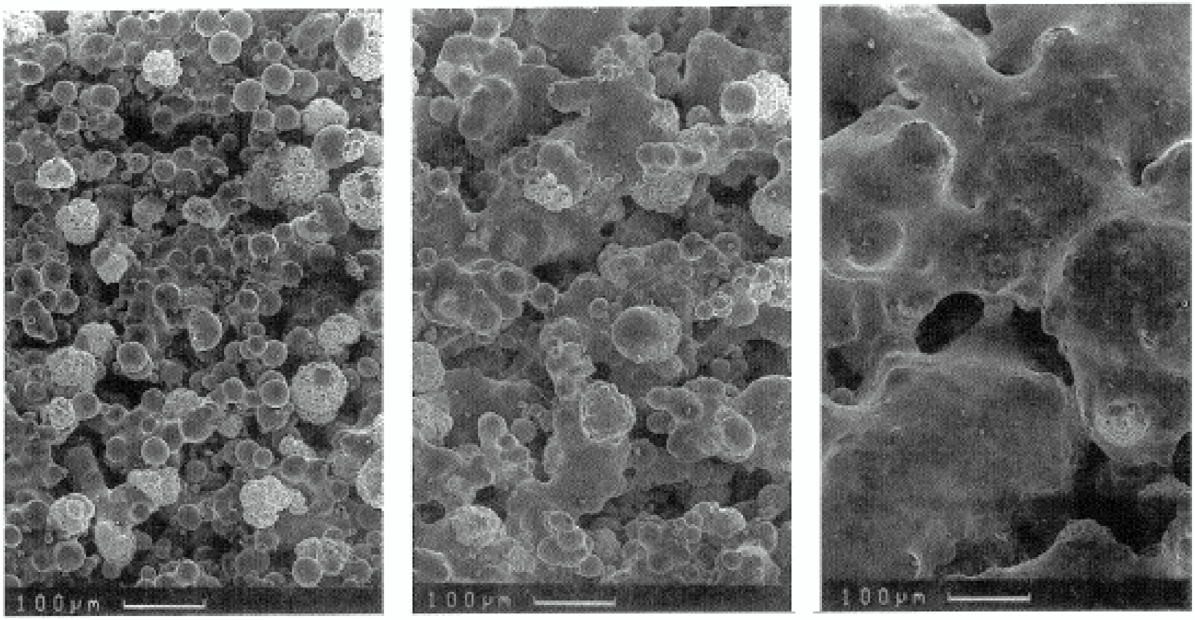
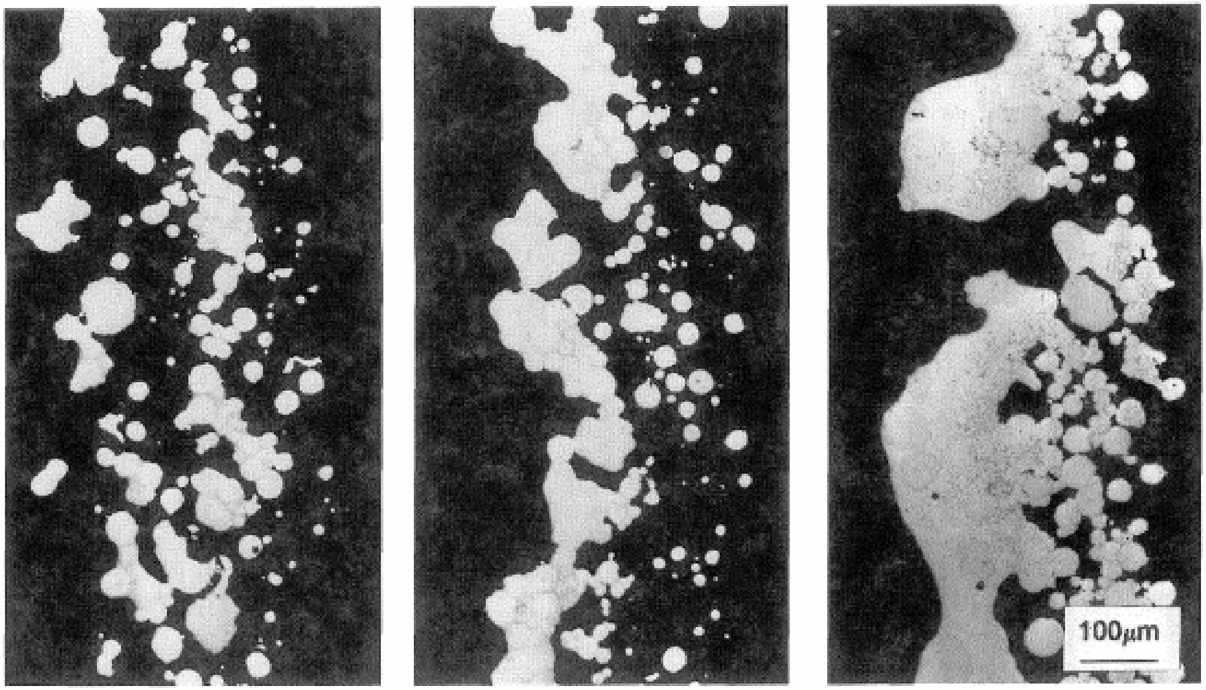


Fig. 1: SEM-micrograph of the composite metal powder used for laser sinter experiments (Ni powder appears bright in the micrograph)



a) b) c)

Fig. 2: SEM-micrographs of the as laser sintered metal powder, low (a), medium (b) and high laser intensity (c), top view



a) b) c)

Fig. 3: Optical micrograph of one individual layer of laser sintered metal material, low (a), medium (b) and high laser intensity (c), cross section (layer thicknes is 100 µm and top of the layer is to the left hand side)

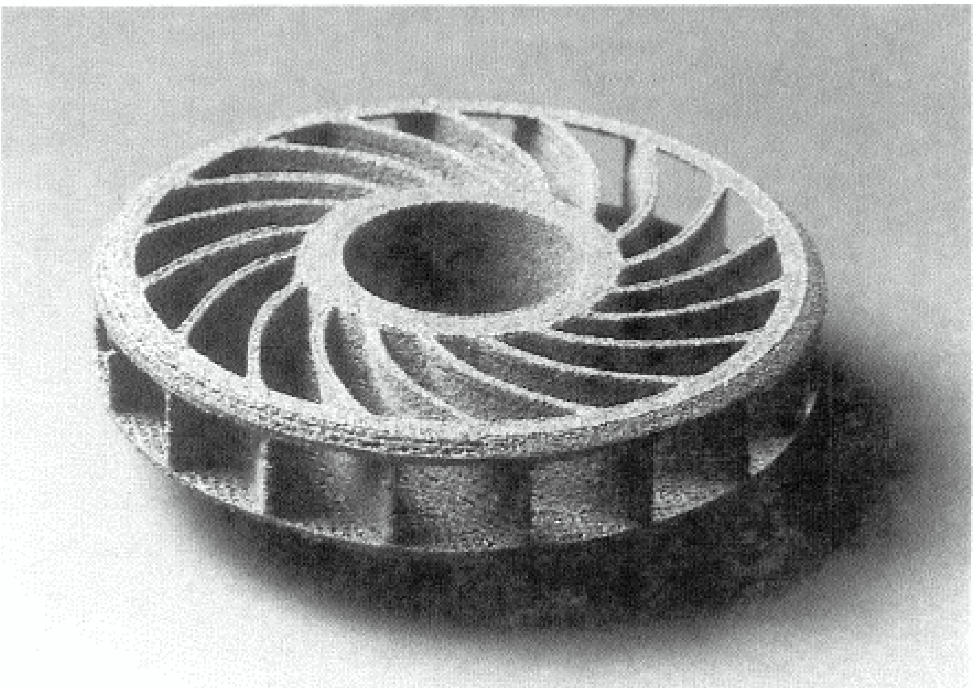


Fig. 4: Laser sintered component out of composite powder

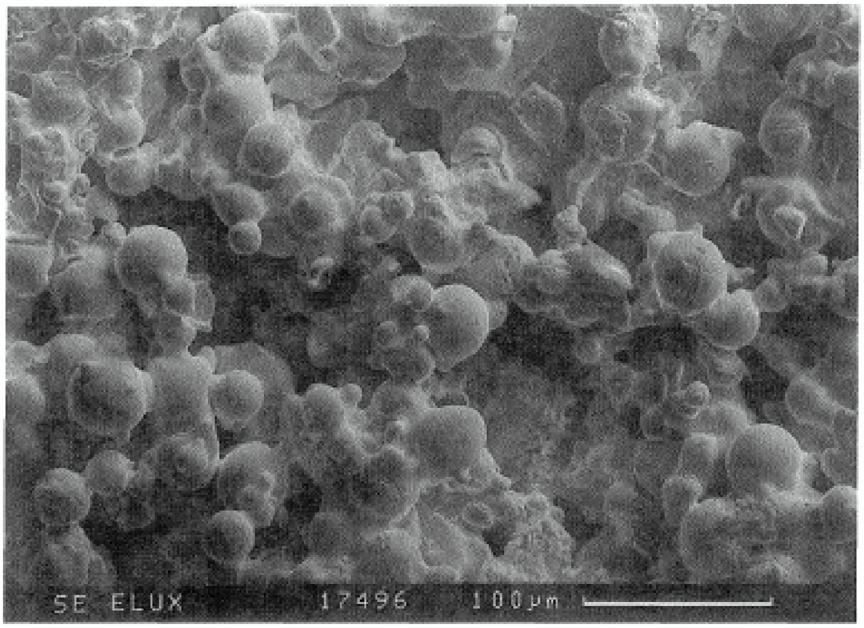


Fig. 5: Microstructure of conventionally sintered composite powder

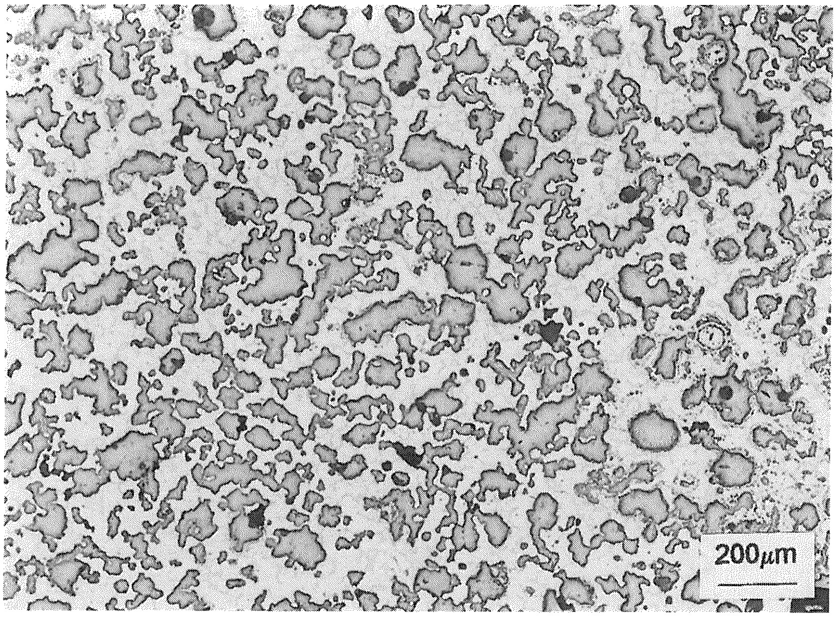


Fig. 6: Microstructure of sintered and subsequently infiltrated material