Accuracy and Mechanical Behavior of Metal Parts Produced by Lasersintering

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ABSTRACT

The work shows the mechanical properties of direct laser-sintered metal parts. The parts were tested after sintering and after an infiltration. Furthermore the accuracy of the parts was measured. Micrographs of the parts show the microstructure of the copper-nickel-tin alloy. The achievable complexity of parts is demonstrated by examples. An overview of future activities is given.

INTRODUCTION

The direct laser-sintering of metals was published last year describing a bronze powder in a EOSINT M system /1/. This work shows the development of the process as well as the development of the postprocessing by infiltration. Different infiltrants have been used to increase the strength and hardness of the prototypes. Furthermore the improvement of the surface quality by electrodeposition is shown. The surface quality is necessary for the use of prototypes as injection molds. The first polymer parts produced by injection molding are shown.

MATERIAL

The material used is a mixture of nickel with copper, tin and phosphorus. Mixtures of this type are very common to get a low melting binder phase /2/. In Figure 1 the sum analysis measured by EDX (energy-dispersive-analysis-of-X-rays) of the powder is shown. The grain size is between 20 and 50 microns (Fig. 2). The parts were built with a layer thickness of 200 microns. Figure 3 shows a SEM (scanning-electron-microscope) image of the surface after the sintering process. The sintering process works in ambient atmosphere at room temperature.

POST-PROCESSING

The post-processing of the prototypes can be separated into two steps. The first is an infiltration to obtain dense parts and to achieve a first smoothing of the surface /3/. The second step is an electrochemical smoothing of the surface for the use as molds. Without this smoothing the microscopic undercuts prevents part removal or cause the destruction of the part during the removal. The infiltration was done with different infiltrants shown in table 1. The infiltration processes was varied in time, atmosphere and use of fluxing agents (Table 2). The best results could be achieved with the PbAg2Sn2 infiltrant. The specimen infiltrated with the other materials had a high porosity. The infiltration is possible with all of the tested materials except Zamak.

Tab.1: Infiltrants

Alloy	Meltingtemp.	Infiltrationtemp	Chemical composition
Zamak	386 °C	500 °C	Zn: 92 - 93 %, Al: 3,9 - 4,3 % Cu: 2,5 - 3,2 %, Mg: 0,03 - 0,06 %
L-Ag40Sn	690 °C	710 °C	Ag: 40 %, Cu: 30 %, Zn: 28 %, Sn: 2 %
L-Ag40Cd	650 °C	660 °C	Ag: 40 %, Cu: 19 % Zn: 21 %, Cd: 20 %
PbAg2Sn2	340 - 395 °C	500 °C	Pb: 96 %, Ag: 2 %, Sn: 2 %

The alloys PbAg2Sn2 (Fig. 4) and Zamak were infiltrated with a water based fluxing agent (F-SW12). The higher melting materials (Ag40Sn (Fig. 5), Ag40Cd (Fig. 6)) were infiltrated with a pasty fluxing agent (F-SH1). The surface was smoothed by a nickel coating.

Tab.2: Infiltration, experiments

Alloy	Time [min.]	Atmosphere Ar/H	Fluxing Agents	Result
Zamak	30, 60	x	none	-
-"-	30, 60	-	F-SW 12	-
L-Ag40Sn	5, 45, 90	-	F-SH 1	++
L-Ag40Cd	5, 45, 90	-	F-SH 1	0
PbAg2Sn2	30, 60	x	none	+
-"-	30, 60	-	F-SW 12	+

MECHANICAL BEHAVIOR

The mechanical behavior is shown in table 3. Last year we presented the first results using a lead based infiltrant. The result was an increase in tensile strength of about 60 % compared with the uninfiltrated sintered powder. The transition to silver based infiltrants led to much better results. The tensile strength could be increased from 132 MPa using the lead based infiltrant to 250 MPa by using a silver based one.

Table 3: Mechanical behavior of the infiltrated specimen

Alloy	Tensile Strength [MPa]
without infiltration	81
L-Ag40Sn	250
L-Ag40Cd	130
PbAg2Sn2	132

ACCURACY AND APPLICATIONS

Of the various production processes used for plastic components (extrusion, blow molding, etc.) injection molding is by far the most widely used for complex shaped parts of the type typically built by layer manufacturing techniques.

A number of process chains and hybrid techniques have been used to produce injection molding toolings from stereolithography models, sometimes involving multiple stages of replication using both flexible silicone and rigid epoxy or similar castings. The total achievable accuracy tends to decrease as a number of replication processes increases, and the number of prototypes which can be produced depends on both the final mold material and the material being injected, but hard tooling suitable for small series of prototype parts can be made.

Hard tooling suitable for injection molding of a wider range of materials and larger series can be built directly in metal using EOSINT M.

For dimensions up to 100 mm a building accuracy of approximately 0.1 mm can be achieved, for larger dimensions 0.1-0.2 %. The layer thickness is typically 0.1 mm. Figure 7 shows three stages in the production of a metal injection mold. On the left is a laser-sintered mold insert without any further post-processing. Next to it is the other half of the mold, after being infiltrated with tin. The infiltration fills in the pores between the sintered particles to produce almost full density and a much smoother surface, but has negligible effect on the part accuracy. On the right is an identical infiltrated mold insert after finishing the molding surfaces by hand. These finished molds were used for injection molding at the CRIF institute in Liège, Belgium. First the parting surfaces were machined by EDM, then the molds were embedded in a mother mold and runners and ejectors were machined. Subsequently several hundred parts were injection molded in polypropylene, polyethylen and ABS at a nozzle pressure of 600 bar and injection temperatures of up to 225°C. 35%-glass-filled nylon parts have also been injected at 280°C and up to 850 bar. After 300 shots with ABS there was no visible wear of the molding surfaces. Figure 8 shows the mold and some parts produced by injection molding. Tests of the durability of the molds are continuing at EOS and a number of beta-sites.

EOSINT M enables Rapid Prototyping directly in metal for the first time and thereby provides a much shorter process chain for technical prototypes in plastic than was previously possible. Further work is necessary to establish the technical and economic limits of these technologies, and intense development work and investigations of applications will continue for some time.

FUTURE DEVELOPMENT

In future steel based powders will be used. First experiments have been done with coated 316L powders with good results. Powders with higher melting points and therefore other infiltrants with higher strength can be used.

CONCLUSIONS

Parts directly laser-sintered from metal powders are suitable for many applications. It has been proved that the infiltrated material can be used as molds for injection molding. The strength of the infiltrated specimen has been increased from 132 MPa to 250 MPa by using other infiltrants during post-processing. It has been shown that the results are sufficient for the production of prototype molds for injection molding.

REFERENCES

/1/ M. Sindel, T. Pintat, M. Greul, O. Nyrhilä, C. Wilkening, „Direct Laser Sintering of Metals and Metal Melt Infiltration for Near Net Shape Fabrication of Components", Proc. of the SFF Symp. 1994, p. 94-101

/2/ Bourell, D.L., Marcus, H.L., Barlow, J.W., Beaman, J.J., „Selective Laser Sintering of Metals and Ceramics", International Journal of Powder Metallurgy (Oct. 1992) 28, (4), 369-381

/3/ Michaels et al., „Metal Parts Generation by Three Dimensional Printing", Proc. of the fourth international Conference on Rapid Prototyping 1993, p. 25

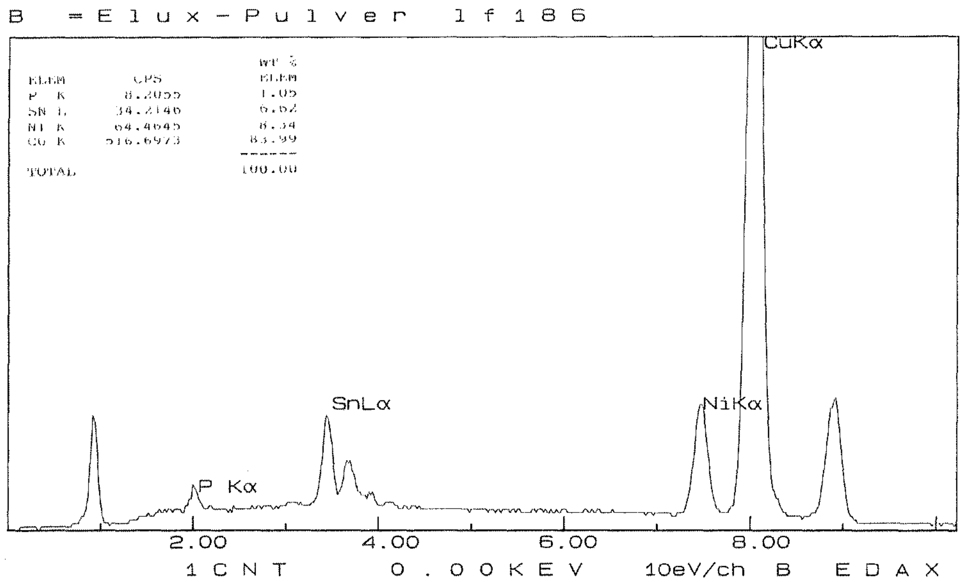

Fig. 1: EDX-Analysis of the powder

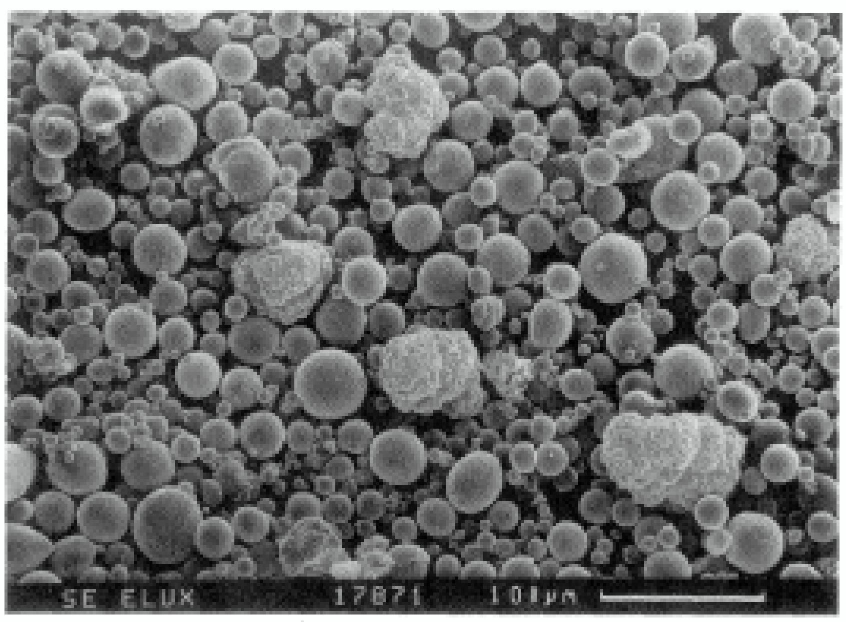

Fig. 2: SEM Image of the powder

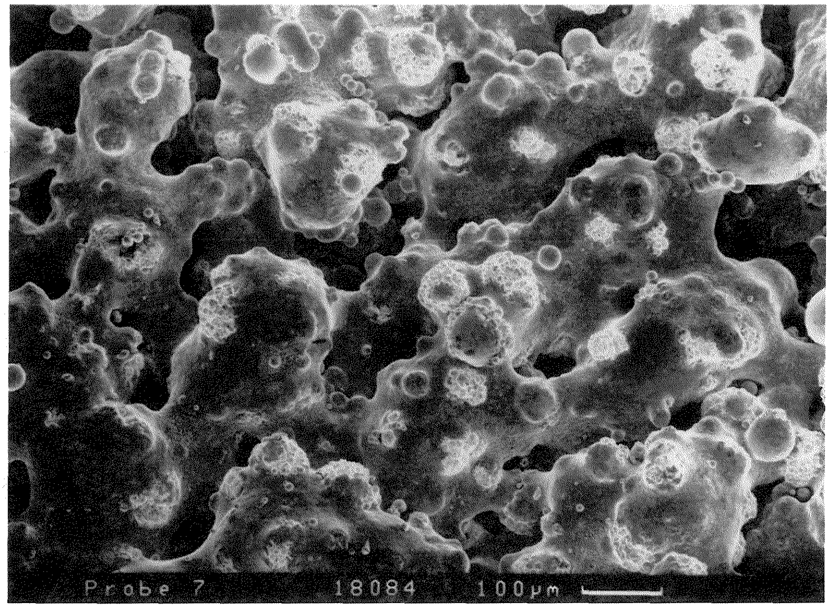

Fig. 3: SEM image of the surface after sintering

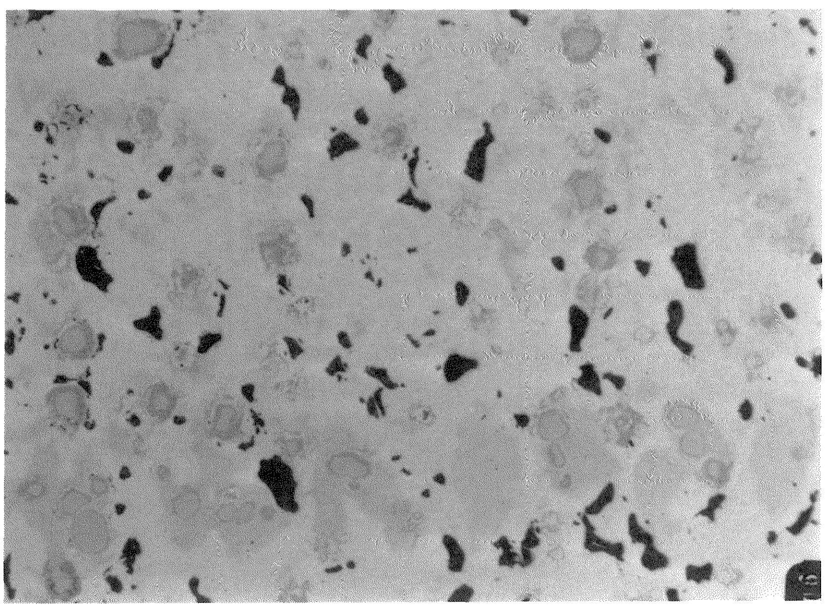

Fig. 4: Micrograph of the powder infiltrated with PbAg2Sn2 50:1

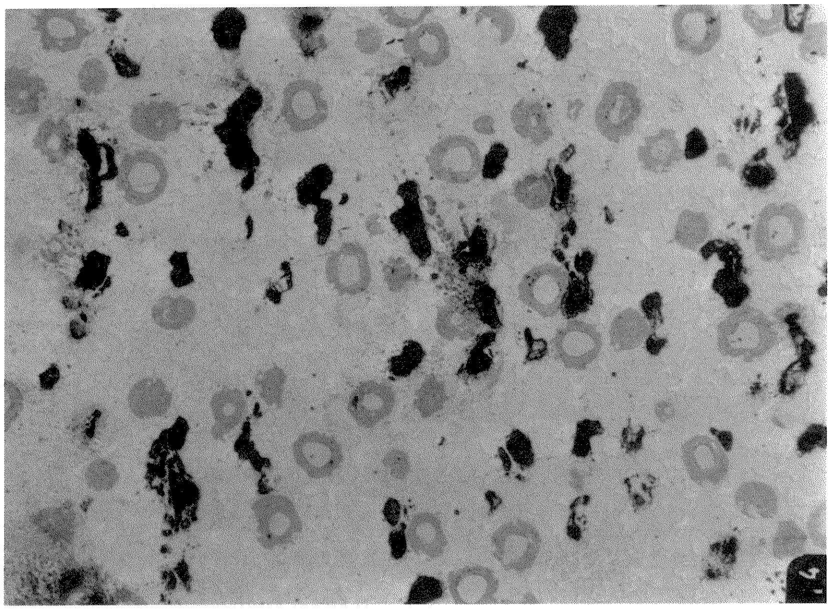

Fig. 5: Micrograph of the powder infiltrated with Ag40Sn 50:1

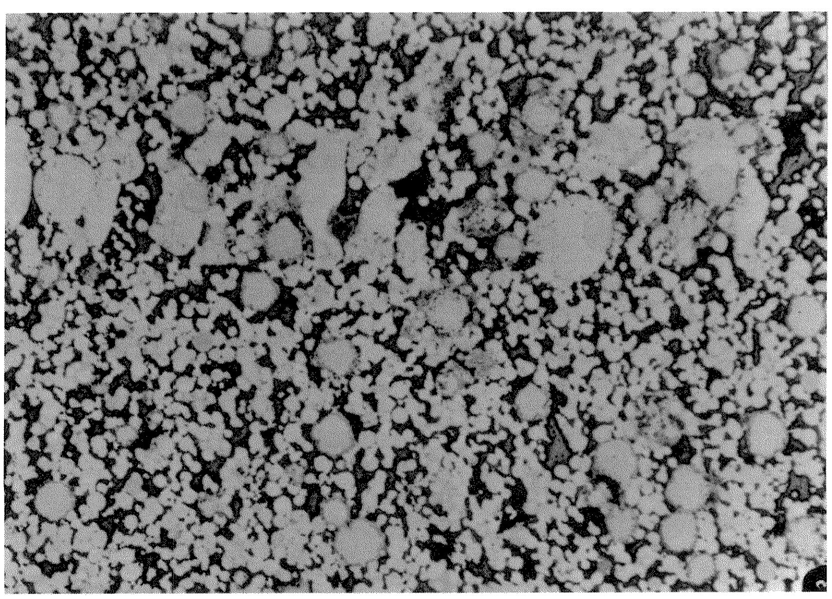

Fig. 6: Micrograph of the powder infiltrated with Ag40Cd 50:1

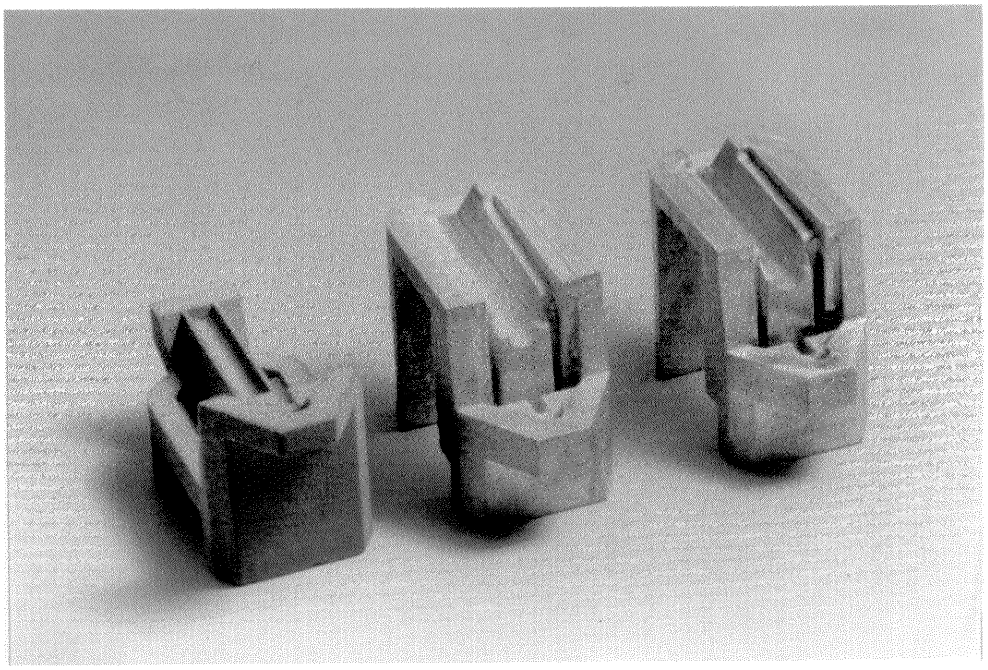

Fig. 7: Three stages in the production of a metal injection mold (left: laser-sintered, middle: infiltrated with tin, right: finished by hand)

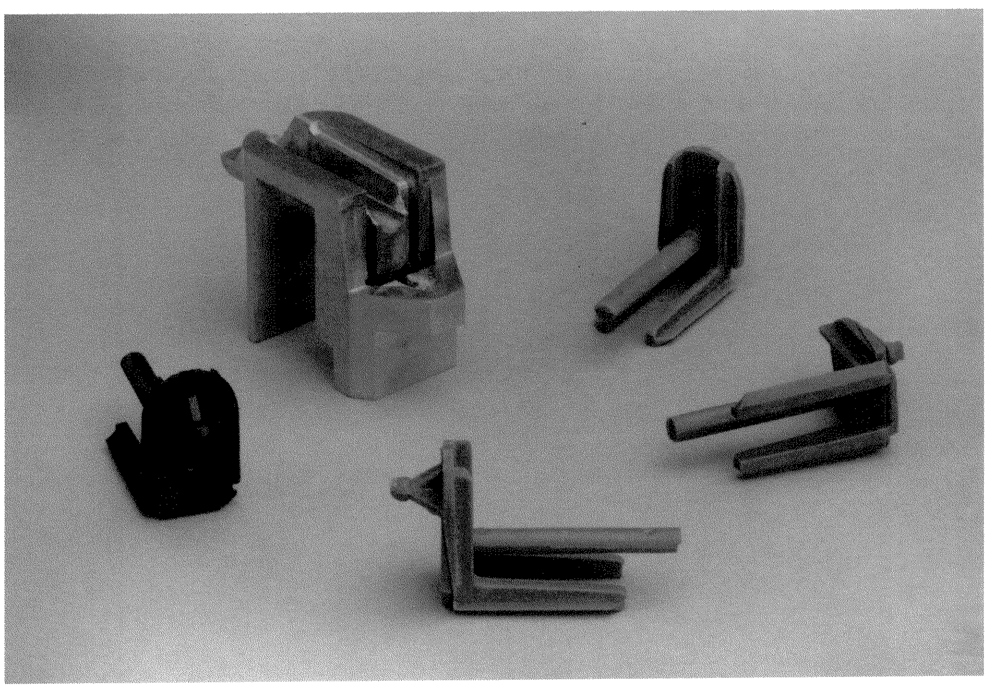

Fig. 8: Mold and the resulting molded parts