Title : Free Form Fabrication of High Strength Metal Components and Dies

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Abstract :

A two-stage method has been devised for free form fabrication of nickel, iron and copper based alloy parts with shape and property control equal or superior to investment castings in the same base alloys. A major advantage of the approach is the ability to utilise commercially available selective laser sintering systems with virtually no modification from their standard configurations for plastic model generation. We have demonstrated the essential feasibility of shape, dimension and property control for complex, low production volume rocket engine components and for tools and dies in higher volume commercial production situations. This presentation is limited in scope to a brief overview of our recent progress.

Introduction:

Direct Selective Laser Sintering(SLS) of metals has not met with much success in the past due to thermal management problems, adequate control of the atmospheric environment within the SLS chamber, rough surface finish, and low density of the finished part (30-40% of theoretical). This has had the effect of producing low strength, low ductility metal parts. All of these associated problems have prevented the manufacture of components and dies using SLS technology up till now.

The purpose of this paper is to introduce an approach which allows intricate and complex, high strength, ductile metal components and dies to be fabricated using SLS technology in a two stage process. This method may be utilized with a number of alloy systems.

Technical Approach :

Our method involves two main stages - selective laser sintering (SLS) for the green product and pressureless densification for the net shaped part. The overall method may be better described, however, under five processing steps :

Results :

The alloys which have been successfully processed to net shaped parts are : (1) Inconel 718; (2) Haynes alloy 230; (3) Inconel 600; (4) NARloyZ (Cu-Ag-Zr); (5) mild steel. Dimensional repeatability of fully dense parts is within 25 μm.

Tensile property data is shown in Table 1 for Haynes 230 from test coupons fabricated directly by the new SLS method and compared with equivalent typical data from test specimens machined from conventional wrought and investment cast products in the same base alloy.

Table 1

Process	**Tensile Strength MPa (ksi)**	**Yield Strength MPa (ksi)**	**Elongation (%)**
SLS	800 (116)	386 (56)	16
Hot rolled & annealed	862 (125)	414 (60)	50
Investment cast	552 (80)	276 (40)	35

The SLS microstructure in the Haynes 230 tensile coupons had fairly equiaxed, fine cellular grains (estimated at ASTM 8-10).

Conclusion & Recommendations :

Our new method, based on SLS has been shown to be a viable process to manufacture components and dies direct from a CAD model.

The mechanical property data is very encouraging, but has not been optimized. Further work is required in order to improve ductility while increasing the ultimate strength to match the wrought product. Fatigue data needs to be developed. Other alloy systems, which have shown promise with the SLS technology, also need to be developed.

The second stage for part densification requires significant further effort to develop the accuracy and consistent quality required for commercial implementation. Process modelling will be a key factor in this development.

A larger sinterstation needs to be developed to make full scale parts (larger than the 305mm dia. X 380mm high build space currently available).

Step 1. The metal powders of the desired alloy composition and a suitable binder are blended.

Step 2. A preform shape of a desired part (green part) is then built by SLS with the binder constituent of the powder blend acting to bind the metal powder after localized SLS melting of the binder and resolidification as connecting necks or bridges between the metal particles. The binder powder / alloy powder mix is designed to impart the following attributes to the SLS parts being made : (1) excellent flow characteristics in a SLS machine; (2) excellent sintering behavior with less thermal distortion and higher repeatability between builds than the standard 100% polymer powders typically used in the SLS machines (due to the higher thermal conductivity of the metal/binder powder blend); (3) high metal volume fraction in the green part; (4) high dimensional tolerance, repeatability, surface finish and robustness of the green parts due to the strong bridging behavior of the liquid binder between metal particle contacts under natural surface tension forces.

Step 3. Binder removal from the SLS preform is achieved at elevated temperature and low atmospheric pressure. The use of a low volume fraction of high purity binder has the following benefits : (1) very low contamination of the parent metal from binder residue; (2) relatively rapid out gassing with negligible physical damage to the porous preform due to the low volume fraction of binder and its preferential location as bridges around the metal particle points of contact. This polymer-sintered powder morphology provides open, connected pores for easy flow of the binder vapor to the preform surface during the vacuum furnace debinding process without build up of local pockets of vapor pressure which may damage the preform part.

Step 4. Sintering and densification of the preform is next achieved by controlled heat up in the same vacuum furnace as used for step 3. It has been shown that specific heat up rates and isothermal hold times within a narrow temperature range can cause sintering of the preform to near full density with sufficiently controlled and repeatable shrinkage to provide net-shape parts with desirable shape and dimensional tolerances.

Step 5. Although Step 4 may be designed to provide fully dense parts, it may still be desirable to incorporate a final stage of hot isostatic pressing (HIP) treatment. HIP treatment may be necessary to simultaneously close residual porosity in the part and to complete the chemical homogenization of the part. Removal of residual porosity may be important to improve fatigue properties.

In addition to the obvious application of rapid prototyping, this new SLS method may be economically attractive for manufacturing small lots of complex components, which are difficult or even impossible to manufacture using conventional routes.

SLS gives designers the flexibility to design for performance without having to consider the manufacturing process of the end components. This makes for faster design times and more innovative designs.