

# Fabrication of Metal Components using FDMet: Fused Deposition of Metals

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## Abstract

The Fused Deposition of Metals (FDMet) technique has been developed to directly fabricate complex functional components. The goals of this study are to successfully fabricate reasonably long filament which could be used to successfully fabricate parts using FDMet, and to optimize the build parameters in the fused deposition technology specifically for metals. In this research, two types of stainless steel powders (spherical and irregular) were investigated. The issues related to filament fabrication and FDMet were investigated. A number of parts have been successfully fabricated (FDMet) using about a foot long filament. The parts are currently being characterized and evaluated.

**Keywords:** FDMet    Layer Manufacturing    Feedstock    17-4PH Metals

## Introduction

There are many techniques available to fabricate metal components directly and indirectly. The traditional methods such as forging, drawing, welding and cutting have been used to fabricate metal parts for a long time<sup>[1]</sup>, but unfortunately these methods can only be used to fabricate simple shape components and cost is very high on low volume production.

Layered Manufacturing (LM) techniques as advanced fabrication techniques have been developed very quickly over the last 12 years due to their capability of fabricating highly complex geometric components quickly with low cost under small volume production. Currently a lot effort has been devoted to research in metal powder based fabrication: MIT has introduced metal powder into 3DP<sup>[2]</sup>, DTM has developed a new kind of Rapid Steel2.0 for SLS<sup>[3]</sup>, Laser Engineering Net Shaping(LENS) from Sandia National Laboratory<sup>[4]</sup> and Fraunhofer Institute is working on Multiphase Jet Solidification(MJS)<sup>[5]</sup>.

Fused Deposition of Ceramics has been a research focus within Center for Ceramics Research of Rutgers University in the last five years<sup>[6]</sup>. A lot of research work has been done on process development, material characterization, binder burn out (BBO) and sintering on silicon nitride and PZT. Now they are trying broaden their material list to graphite, alumina oxide.

As an initial effort to investigate the feasibility of fabricating metal components by RP method, RTV molding was developed by our research group at Rutgers University<sup>[7]</sup>. The results showed that 17-4PH stainless steel is a suitable metal powder material. During the fabrication process, we found that this molding technique could not be used to fabricate very complex geometric shape. The current efforts are directed at developing a direct metal component fabrication method: Fused Deposition of Metals (FDMet). FDMet is very similar to FDC, yet since the material is different, several alterations must be made during the feedstock preparation to satisfy the requirement of the metal powder, FDMet parameters are also different from FDC and FDM of wax or ABS polymer.

## **Methodology**

FDMet, as its name implies, is a method to fabricate metal component through deposition concept. This method combines various kinds of techniques such as advanced metal powder material, Computer Numerical Control, Rheologic characteristic and Thermal Debinding(BBO) and sintering.

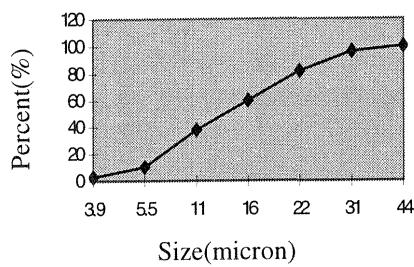
Basically this method is divided into three sections: FeedStock Preparation, FDMet (Green Fabrication), BBO and Sintering. Within the feedstock preparation process, ball milling was used to coat the metal powder with stearic acid which is dissolved in acetone before coating. Stainless steel grinding media was used this time and size is 3/8''. After the coating process, the grinding media was removed by sieving and the coated powder was dried in an oven. Sieving was introduced to remove some agglomerates inside dried powder. A Haake rehometer was used to compound the coated powder with ECG2<sup>[8]</sup> binder for 2 hours, then the compounded material was granulated process. As will be introduced later the compounded material was used to fabricate filament for FDMet. In the FDMet green fabrication process, the metal filament was used to feed into the liquifier and deposit material through a nozzle to form the part layer by layer. Since there are ECG2 binder and Stearic Acid (SA) inside the green part, Binder Burn Out (BBO) was introduced to remove the binder and SA by thermal decomposition and vaporization.

## **Feedstock Preparation**

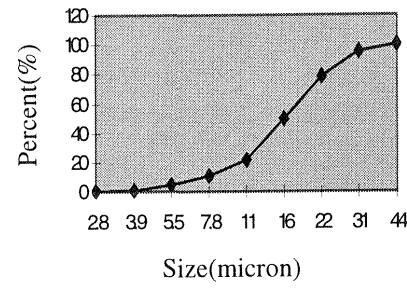
As introduced above, the feedstock preparation was used to fabricate filament needs in the following FDMet green fabrication process.

## **Powder characterization**

Two kinds of 17-4 PH stainless steel powder were used in this process. One is a spherical powder, 22 microns, and the other is irregular powder, 10 microns. The size distribution of these two kinds of powder is shown as in Fig.1. The SEM of these two kinds of powder is shown in Fig.2.

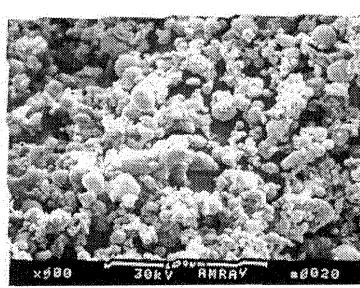


(a) Spherical powder.



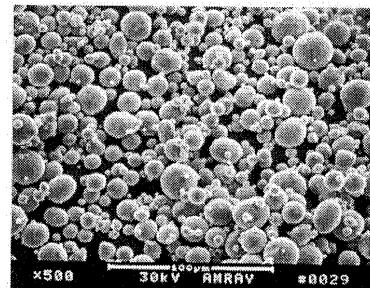
(b) Irregular powder.

**Fig. 1 Size distribution of 17-4PH stainless steel powders**



375x

Irregular Powder (-10 microns) as received



375x

Spherical Powder (-22 microns) as received

**Fig. 2 SEM of 17-4 PH stainless steel powders**

Fine powder is preferable, as we would like to use smaller possible nozzle diameters. If the powder size is too big, agglomerates will clog the nozzle, thereby ruining the fabrication process. Another requirement is the viscosity should be low enough so that the compounded material could be easily pushed out of the nozzle. Therefore spherical powder is preferred.

### Compounding

Compounding is a very critical process whose aim is to provide a homogenous mixture. A HAAKE 900 rheometer was used to mix the powder and ECG2 binder. The addition schedule of the powder was 40%, 30%, 20%, 10%. The magnitude of the torque in the process could be used to identify the viscosity of the feedstock, the variation of the torque during the process could be used to judge the homogeneity of the feedstock. Normally the process takes two hours.

## **Filament Fabrication**

Filament fabrication is the next very critical process in FDMet, because it provides filament which acts as the piston to push the melt material out of the nozzle to deposit to fabricate green parts.

Two types of processes are available now for filament fabrication, a screw extrusion process and a piston extrusion process. In the single screw extrusion process, the compounded feedstock was fed through the valve at one end into the tunnel continuously and the single screw was used to push the melt material out through a nozzle at the other end to become filament. A dimension control system was used to make sure the size of the filament is uniform.

In the piston extrusion process, the compounded material was fed into a barrel at a certain temperature 80°C-100°C, after holding for some time, a rod was used to push the molten material out through a nozzle at the bottom of barrel to fabricate the filament. This process could only produce short lengths of filament and speed is very low at the rate of 1 mm/min. The screw extrusion could produce long filaments (in many feet length) since the compounded material could be fed continuously, and speed is very fast: hundreds of feet/hour.

Our experience shows that the screw extrusion process could produce more flexible filament than the piston extrusion process.

## **FDMet**

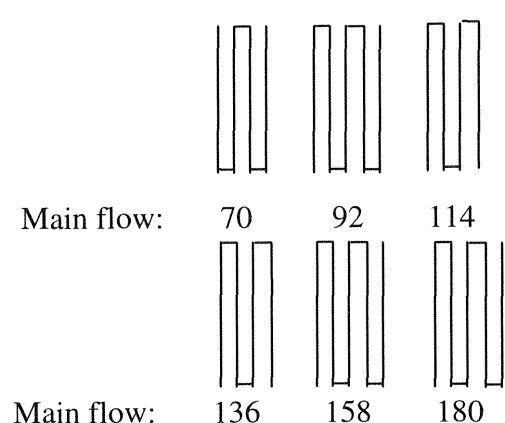
### **Parameters Determination**

In the green fabrication process of FDMet, the stainless steel filament was used to be fed into the heated liquifier and pushed through a nozzle to deposit onto a platform layer by layer to form a part.

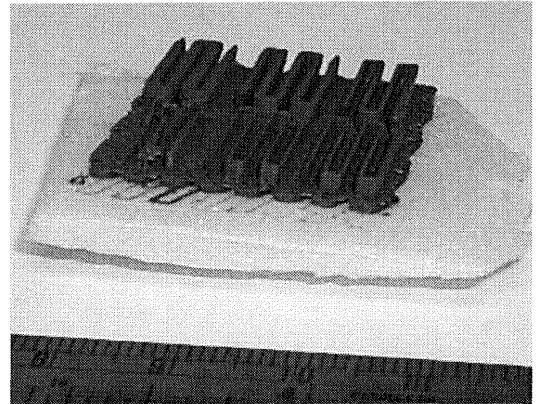
The CAD model and .STL file were created by IDEAS-5 software. The QuickSlice 2.0 software was used to slice the model and create the tool path needed in the actual fabrication process. Since stainless steel is a new kind of material used in FD technique, basic parameters such as main flow, preflow, start distance, start delay, shutoff distance, speed, acceleration and roll back had to be determined. Based on our experience with processes, we determined that the main road width is related to main flow, the start road width is related to start delay and preflow, the ending road width is related to the shut off distance and roll back. Several experiments were performed to generate workable tool path parameters for stainless steel filament.

A CAD design was created to quantify the proper main flow for a certain road width as showed in Fig. 3. This design has six sections. In each section, only main flow parameter was different. Since the range was not known, the initial experiment had a

larger range between upper & lower bounds. Based on an inspection, we can judge the material flow condition for all sections. In some sections, material flow is not enough. In some others, there is too much flow. In the next iterations, the range between upper & lower bound were reduced, and finally the lower bound (76) and upper bound of the main flow (180) were selected.

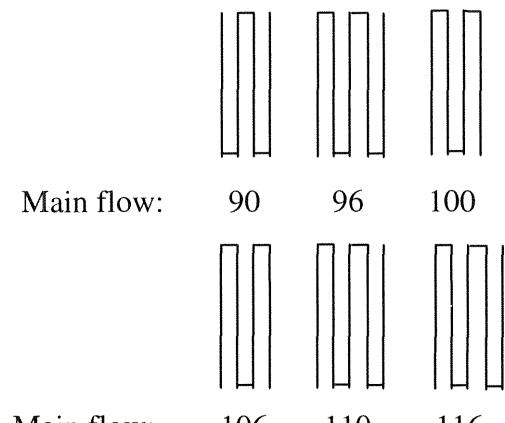


(a) CAD Design

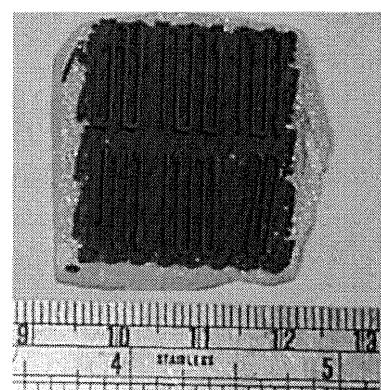


(b) Fabricated Part

**Fig. 3 CAD design and real part for main flow range determination**

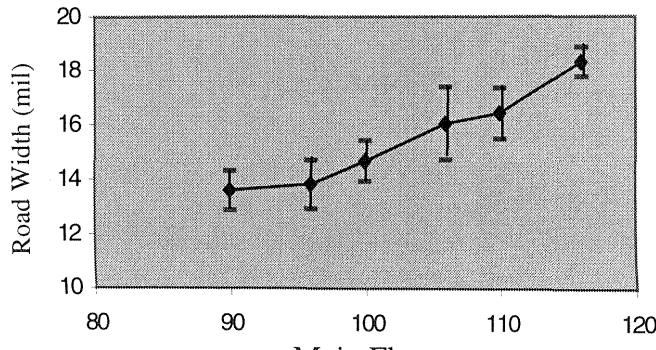


(a) CAD Design



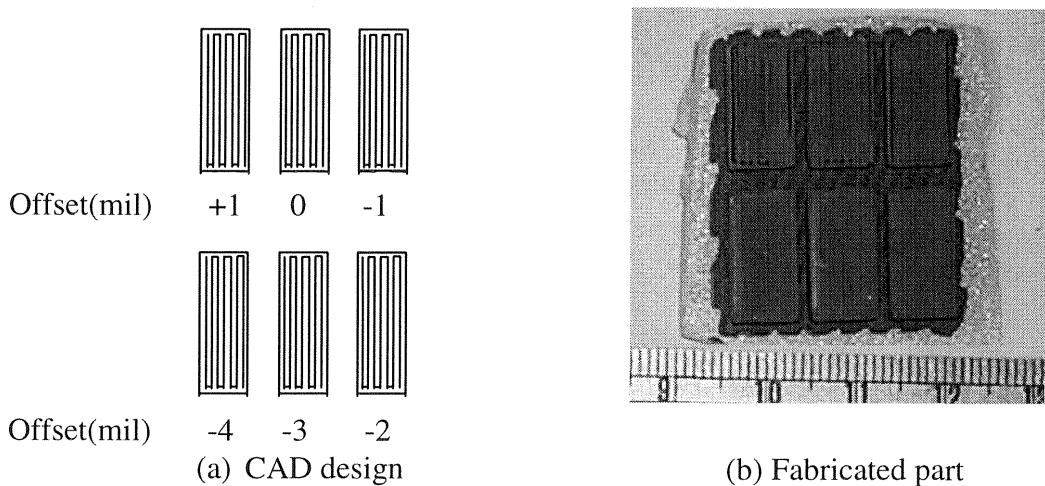
(b) Fabricated Part

**Fig.4 Relationship between main flow and road width**



Slice thickness=10mil, Nozzle size=12mil.

**Fig.5 Relation of acceptable main flow and road width**



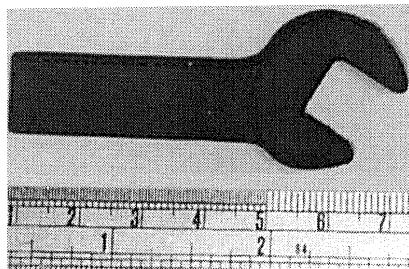
**Fig. 6 CAD design and part for proper offset of a road width**

Once the main flow range was determined, the specific relationship between the road width and main flow was determined, a similar CAD design as in Fig. 4 was created in which the main flow was confined between 90 and 116. Then three parts were created according to the design and the road width in each section was measured by video microscopy<sup>[9]</sup>. The results of the acceptable main flow are shown in Fig 5.

Since raster/raster offset is very important for making fully dense FDMet green parts, a CAD design was created to identify the acceptable offset for a certain road width. As shown in Fig.6, this design has six sections, each has only different parameter, the offset changes from +1 to -4 mil. As we can see from the images of the fabricated part, Fig. 7, the acceptable offset for road width 17 mil is -2 mil.

### Green fabrication

Several green parts including a lug fit fastner and wrench part have been made through FDMet process. A fabricated wrench part from FDMet is shown in Fig. 7. Dimensions of the part were measured and compared with RTV mold wrench shown in Fig. 8. The results (average of three measurements) shown in Table I indicate that FDMet has better accuracy compared to RTV mold.



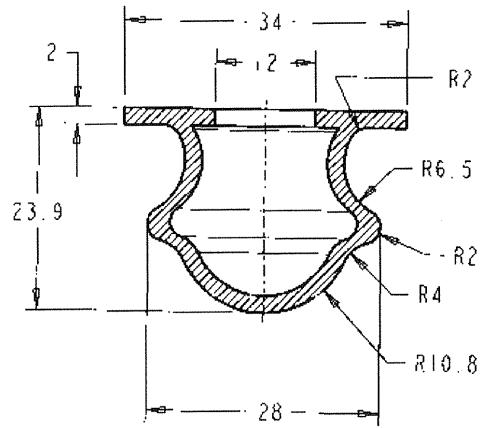
**Fig. 7 FDMet wrench part**



**Fig. 8 RTV mold wrench part**

**Table I Dimensions of wrench parts**

	CAD	RTV Molding	FDMet
Length (in.)	2.544	2.599	2.542
Height (in.)	0.195	0.217	0.210
Width (in.)	0.984	0.990	0.980



**Fig. 9 Lug fit fastner CAD design**



**Fig. 10 FDMet lug fit fastner**

**Table II Dimensions of lug fit parts**

	CAD	RTV Molding	FDMet
Inner Diameter (in.)	0.466	0.471	0.461
Middle Outside Diameter (in.)	1.053	1.059	1.050
Bottom Outside Diameter (in.)	1.353	1.368	1.336
Height (in.)	0.935	0.974	0.966

Fig. 9 shows the CAD design for the lug fit part and the fabricated lug fit part from FDMet is shown in Fig. 10. Since the internal structure is very complex and could not be fabricated by RTV molding (or by any other molding methods), the RTV mold lug fit was fabricated with simplified internal structure and the internal hole was a cylindrical shape [6] instead as shown in Fig. 9. The dimensions of the two parts were measured and compared with RTV mold lug fit, the results are shown in Table II.

## Conclusion

A novel metal component fabrication method (FDMet) has been developed. Feed stock preparation for FDMet was established and characterized. Green fabrication of several complex geometrical components has been demonstrated and the results show that FDMet has better accuracy compared to RTV mold.

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