

Rapid Manufacturing of Metal Parts^{*}

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Abstract: As a key technology of rapid prototyping and manufacturing (RP&M), rapid manufacturing of metal parts is a target of RP&M. Introducing selective laser sintering (SLS), an important branch of RP&M, this paper gives a new method oriented on low-power SLS system to fabricate metal parts. With this kind of technology, the mixture of metal and polymer powder is sintered first to get green part, then, after debinding and metal infiltration, dense parts are gotten. In the end, influencing factors of this technology are analyzed. At the same time, some applications are given.

Key words: SLS, metal parts, rapid manufacturing

The rapid manufacturing (RM) of metal parts, one of major destinations of rapid prototyping (RP), is cared widely in recent years^[1-3]. Up to now, kinds of technology have been developed to fulfill the target. Using selective laser sintering (SLS), a branch of RP, metallic parts can be fabricated in three different ways. The first involves direct sintering of metallic powder (e.g. copper) to manufacture metallic parts or components. In this case, RP system with high-power laser generator works under sheltering gas. With the second method, mixture of two kinds different metal powder is used. During the machining, powder with low melting point is used as binder and melted, at the same time, the other material with higher melting point, structure material, is left unchanged. Powder mixture is also used in the third way, but this time, binder is not low melting point metal, but polymer. At a lower temperature, polymer in the mixture is sintered to form green parts first, which are not strong enough to be used in practice. After debinding and metal infiltrating, metal parts are manufactured^[4,5].

Among all these RM techniques mentioned above, there is no high power laser or sheltering gas needed in the third technology, the production and device expense are decreased greatly. But the post-treatment of it is more complicated than that of the other two methods. Based on the low power selective laser sintering system, RAP-I, this paper introduces the third way of RM in detail. At the same time, the effects of processing parameters are analyzed.

1 SLS System

1.1 Process principle

Unlike other RP technologys, SLS sinters powder material with laser layer by layer to form 3-D part, its principle is shown in Fig.1.

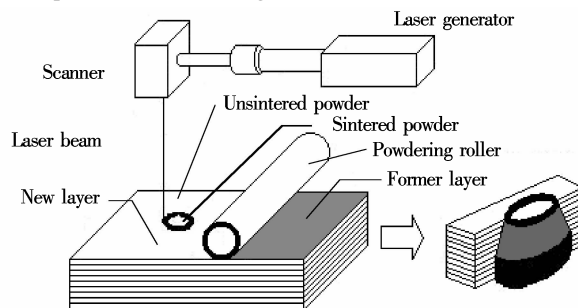


Fig.1 SLS process schematic diagram

During machining, the software of an SLS system first receives the CAD model of a part and converts it to NC code. Then, under the instruction of the NC code, SLS system selectively sinter powder material, that is, where the laser beam is, where powder there is melted, other place where there is unscanned by the laser beam, material there is left unmelted. Little by little, layer by layer, 3-D CAD model is converted to 3-D part^[6].

1.2 RAP-I

Generally, an SLS system consists of four parts, powdering apparatus, laser power, laser generator and CNC unit which includes industrial PC, software and servo system etc. The software of the CNC unit is in charge of receiving CAD model of a part, slicing

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according to the geometric information of a CAD model, creating two dimension scanning track of laser and controlling each movement to ensure the well going of machining. Powdering apparatus, whose responsibility is ensuring the uniformity and the density of a layer, influence the sintering process and quality directly. Fig.2 is a typical SLS system, RAP-I, developed by RP Center, Nanjing University of Aeronautics and Astronautics.



Fig.2 SLS system RAP- I

2 Process Procedure

The process procedure is shown in Fig.3. In

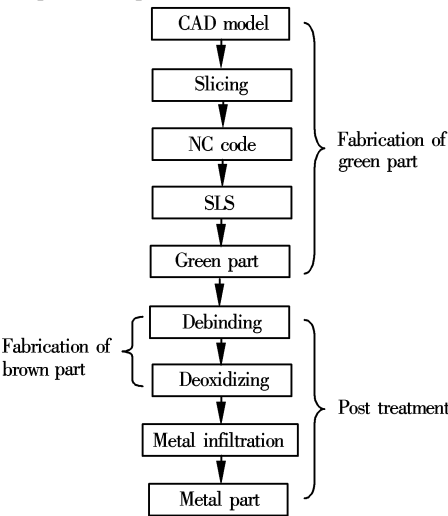


Fig.3 Process procedure

summary, there are three steps in the rapid manufacturing technique of metallic parts. First, receiving STL file that represents the CAD model of a part with its special slicing software, an SLS system divides the model into a series of two dimension layers. Then, NC code is generated according to the geometry shape of all these layers. Under the controlling of these codes, powder mixture is sintered selectively to form a layer. Thus, layer by layer, the green part is manufactured. The second step is mainly about the

forming of brown part, here, a green part is first heated to the temperature about 800 °C in a general furnace to remove the binder. After that, at about 1 080 °C, impurity in the green part is deoxidized in a powder metallurgy furnace to get brown part which has an interconnect microstructure. It is just because the interconnect microstructure that makes the following metal infiltration possible. The next step following the fabrication of brown part is metal infiltration, in this step, brown part is kept in the powder metallurgy furnace at 1 120 °C so that metal can be infiltrated into the brown part to reach the final density.

3 Applications

After the introduction to RM technology based on SLS, we take a nonstandard gear as an example to introduce the whole factual machining. Fig.4 is the CAD model of this gear. According to the process principle mentioned above, the procedure can be divided into two steps, fabrication of green part and post-treatment.

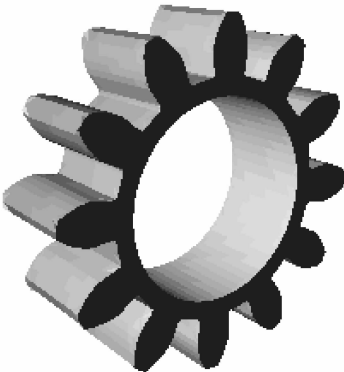


Fig.4 CAD model of a nonstandard gear

3.1 Fabrication of green part

Just as what we mentioned above, among kinds of different CAD models, an SLS system generally receives its STL format which uses a series of triangle facets to represent 3-D surface of a part. And each triangle is represented with its three vertex coordinate (x, y, z) and normal vectors. Factually, the prototype to be manufactured is the approximator of the STL model of the part. The more the number of triangle facets is, the higher the fabrication accuracy is. The following is a typical STL file:

```
Solid < name >
  Facet normal  $n_i$   $n_j$   $n_k$ 
    outer loop
      vertex  $v_{1x}$   $v_{1y}$   $v_{1z}$ 
      vertex  $v_{2x}$   $v_{2y}$   $v_{2z}$ 
      vertex  $v_{3x}$   $v_{3y}$   $v_{3z}$ 
```

```
endloop
endfacet
endsolid <name>
```

Compared to other format of CAD model, the using of STL file simplifies the data process of RP. Today, most of RP systems take STL as one of its main inputs. Much famous CAD software also offers STL module as one main interface of CAD/CAM. All these make STL files the defacto industrial standard of data transition from CAD system to RP system^[7].

Receiving the STL model of a 3-D part, an SLS system gets the geometric information of all layers which compose the part to be fabricated with its own slicing software. Then, through adequate processing, the geometric information gotten above is converted to NC code which can be used by an SLS Machine to make the desired part. The whole slicing process is shown in Fig.5.

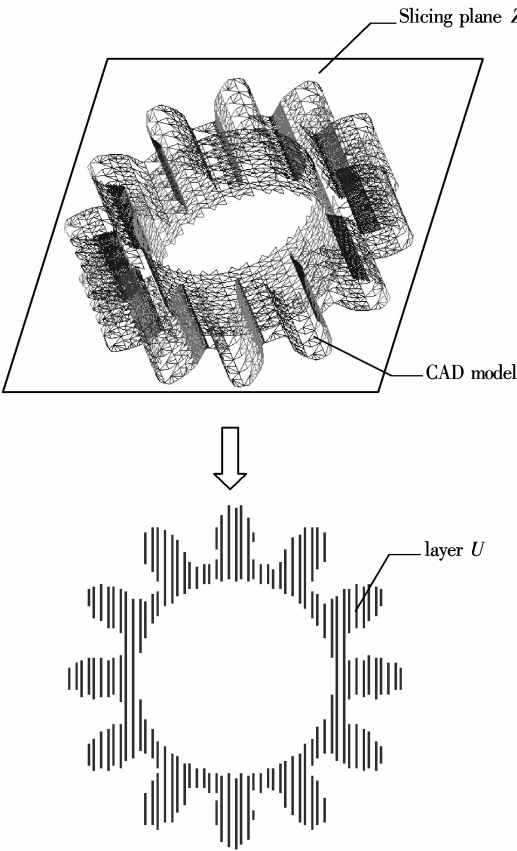


Fig.5 Slicing process

During the slicing process shown in Fig.5, an SLS system first gets all cross lines between each triangle facet and Z, a plane at a certain height, all these lines construct the boarder of one layer of the desired part. Then, with a group of adequate parallel lines, filling the district bordered by the lines gotten above, a layer of the part is gotten, these lines used to fill the closed district are scanning lines in NC code.

After slicing process, under the control of

computer, laser beam of an SLS machine sintered mixture of ferrous and polymer to get a layer of the gear mentioned above. Finishing a layer, the work table of the SLS system is lowered a layer thickness and the fabrication of new layer begin. Fig.6 is the green part we have got.



Fig.6 Green part of a nonstandard metal

The SLS system used here is RAP-I, and parameters in this machining is shown in Tab.1.

Tab.1 Machining parameters

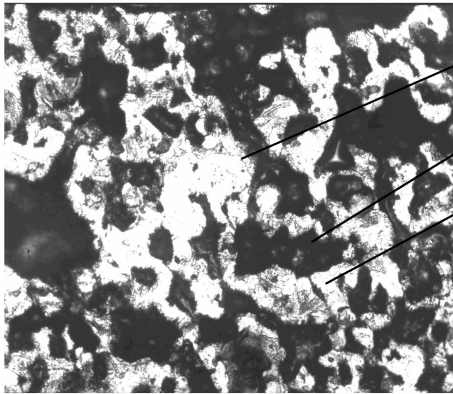
Laser power	40 W
Scanning speed	170 mm/s
Scanning interval	0.13 mm
Layer thickness	0.13 mm

3.2 Post-treatment

After the fabrication of green part, there must be some post-treatments to get the final density and strength. Parameters employed in the post-treatment are shown in Tab.2. Under the sheltering of nitrogen, green part is debinded so that oxide in the prototype is much less than it is when there is no sheltering gas. Even so, the deoxidizing is necessary to improve the purity of the final part. After all these steps, a desired brown part is gotten, Fig.7 shows the microstructure of a brown part. Here, the mixture used for the green part making has a polymer content of 16%, we can see that part clearly. Finally, there is only one step left, that is metal infiltration. Placing a piece of copper plate on the top surface of brown part, at the melting point of copper, the plate is melted and liquid copper is infiltrated to the part to get final density in a metallurgy furnace. Fig.8 is the microstructure of the part we get, it is clear that the natty interconnect structure disappeared and the density of the part is improved greatly, but there are still some little pores left. Fig.9 is the nonstandard gear manufactured with this kind of technique.

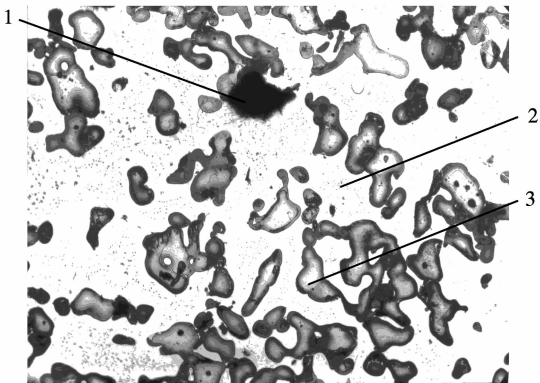
Tab.2 Post-treatment parameters

Treatment	Temperature	Time	Sheltering gas
Debinding	800 ℃	60 min	N ₂
Deoxidizing	1 080 ℃	> 40 min	NH ₃
Infiltrating	1 120 ℃	55 min	NH ₃



1—Pealite; 2—Pore; 3—Ferrous

Fig.7 Microstructure of a brown part (200 ×)



1—Pore; 2—Copper; 3—Isolate ferrous particle

Fig.8 Microstructure of a metal part (200 ×)



Fig.9 A nonstandard metal gear

4 Analysis and Discussion

4.1 Polymer in the powder-binder mixture

For its excellent sintering character, polymer

plays an important role in the fabrication of green part. Used as binder, it must be removed from the prototype to get the desired density and strength, thus the Green Part is converted to a real part. At the beginning of the technique, the higher the polymer content is, the easier the sintering would be. But too much polymer binder in the powder-binder mixture can lead to the ferrous particle’s disconnecting with each other. After debinding, almost all the binder in the prototype is removed, the part is kept in shape for the connection between iron particles, and the insufficient disconnection would affect the metal infiltration directly or even lead to the collapsing of the brown part. In the factual machining, the polymer content is controlled from 16% to 50% .

4.2 Machining parameters

The machining parameters of SLS including laser power, scanning speed, scanning interval and layer thickness affect the accuracy and the quality directly. For low power SLS system, effects of laser power on the process can be realized through the changing of scanning speed. Thus, generally, the quality or process control of the machining is realized through adequate scanning speed, adequate scanning interval and suitable layer thickness. The higher the scanning speed, the sooner the green part is made. But, too high a speed will result in insufficient sintering during the process. On the contrary, too low the speed is, powder material in the machining layer would get a high temperature in a short time or even evaporated, carbonized. The greater the scanning interval and the layer thickness, the more obvious the step domino effect is. But, too less the scanning interval and layer thickness can also result in evaporation and carbonization of material in current layer. In practice, for RAP-I which has a 40W CO₂ laser generator, a scanning speed about 170 mm/s, a scanning interval under 0.2 mm and a layer thickness lower 0.25 mm, are often selected to get high quality green parts.

5 Conclusion

Based on the introduction of RM, this paper describes the RM technology oriented on low power SLS system systematically, such as operating principle, SLS system, material and post-treatment. Finally, a factual part fabricated with this technology is given.

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金属零件的快速成型

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摘 要 金属零件的快速制造是当前快速成型领域的一大研究热点. 在介绍快速成型技术的一个重要分支——选区激光烧结与快速成形烧结系统 RAP- I 基础上, 本文提出了一种基于小功率激光快速成型系统的金属零件成型新工艺. 这种方法首先烧结金属与有机粘结剂的混合粉末, 生成“绿件”, 然后除粘、熔渗金属, 得到致密的金属件. 文中给出了加工实例, 并对这种工艺的影响因素进行了详细的分析与讨论.

关键词 选区激光烧结, 金属零件, 快速制造

中图分类号 TH16; TG665