Research on component preparation technology based on laser scanning modelling and additive manufacturing

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Abstract. When the artillery is damaged in the battlefield, the replacement of spare parts can quickly restore the combat capability. However, when the supply of artillery spare parts is insufficient, the technical performance and combat effectiveness of artillery will be seriously reduced. Based on the above considerations, the reverse design and selective laser melting technology are used to study the emergency manufacturing technology of artillery spare parts, to solve the problem of artillery spare parts supply and guarantee, and improve the quality and efficiency of artillery maintenance and guarantee.

Keywords: additive manufacturing, reverse design, selective laser melting, metal alloy powder.

1. Introduction
At present, artillery maintenance support is facing many difficulties, such as high cost, high difficulty and low efficiency. Therefore, the reverse design method is explored to transform the product into a three-dimensional model. Based on the three-dimensional model of components obtained by reverse design, adopting the 3D additive manufacturing process, using the selective laser melting technology [1, 2], learning from the successful experience of this technology in the fields of aerospace and warship maintenance [3, 4], emergency manufacturing of artillery spare parts can solve the practical problems of insufficient spare parts support and the difficulty of battlefield emergency repair.

In this paper, the crank arm as a typical vulnerable part of breech system in artillery is selected, and the reverse design and selective laser melting technology are studied. It is mainly divided into four steps: pretreatment, printing, post-processing and mechanical property testing. The pre-processing includes the establishment of 3D model file of workpiece, the approximate processing and slicing of 3D model file, and the transformation of STL format of model file; printing and forming is the core of 3D printing technology, including printing two-dimensional section sheet layer by layer and stacking two-dimensional sheet layer into three-dimensional parts; the post-processing is to trim the formed parts, including stripping the supporting structure from the formed parts, Strengthening and surface treatment.
of forming parts; performance test is to test the mechanical properties, assembly and application of the manufactured crank arm parts, so as to meet the actual use requirements.

2. Build component model based on reverse design

Selective laser melting technology belongs to the field of metal additive manufacturing. Additive manufacturing (3D printing) technology is based on the acquisition of three-dimensional model of components for printing and forming. Therefore, the establishment of three-dimensional model is the premise and basis of additive manufacturing [5].

There are two ways to build a 3D model. One is to use 3D modeling software to design 3D models of components, such as UG, Pro/Engineer, Solid Works, 3DMAX, MAYA, etc. STL format is the most commonly used format for 3D printers. The second is to obtain the 3D model of the parts by reverse design.

In reverse engineering, the digitization from object to CAD model includes three steps:

1. collect data of 3D objects and generate point cloud data.
2. processing the point cloud data (filtering the data to remove the noise or merging, etc.).
3. the surface reconstruction technology is used to fit the point cloud data, and generate 3D CAD model with 3D CAD software.

In this paper, the non-contact hand-held 3D laser scanning system is used to scan the crank arm parts. The system includes the hardware part of data acquisition and the software part of data processing. It is based on the principle of laser ranging, through recording a large number of dense points on the surface of the object to be measured, such as 3D coordinates, reflectivity and texture information, to quickly reconstruct the three-dimensional model of the object to be measured and various map data such as lines, surfaces and bodies. The advantage of this method is that the existing 3D objects (samples or models) can quickly measure the contour set data of the object without drawing size documents, and then construct, edit and modify the surface digital model with general output format. Figure 1 is the 3D model established by Solid Works; Figure 2 is the 3D model obtained by reverse design of laser scanning system.

![Figure 1. Forward design model (Solid Works)](image1)

![Figure 2. Reverse design model (Laser scanning)](image2)

Because the 3D model of the part has some irregular free-form surfaces, after building the 3D model, we need to approximate the model, that is to use a series of small triangle planes to approximate the free-form surface of the workpiece, and convert the 3D model of the workpiece into STL model. Then the 3D model of STL format is sliced by Magics software, which is convenient for additive manufacturing by selective laser melting process.

3. Selection of alloy powder

According to the production process requirements of the crank arm part in breech system, its mechanical property index needs to meet the requirements of Table 1. After comparative study with the current commonly used additive manufacturing alloy powder, the nickel base alloy powder IN625 with similar mechanical properties to table 1 is selected as the alloy powder manufactured by selective laser melting additive. The microstructure and mechanical properties of IN625 are analysed as follows:
### Table 1. Mechanical property requirements of crank arm part

| Mechanical property | Tensile strength $\sigma_t$ (MPa) | Yield strength $\sigma_y$ (MPa) | Reduction of area $\psi$ (%) | Impact toughness value Akv(J) |
|---------------------|-----------------------------------|---------------------------------|-----------------------------|-----------------------------|
| Numerical value     | $\geq 810$                        | $\geq 635$                      | 30                          | 47                          |

#### 3.1. SEM and EDS analysis

By means of SEM and EDS, it is found that IN625 alloy powder has uniform particle size distribution and good consistency, and the elements contained in the powder correspond to its composition table, as shown in Figure 3 and Figure 4.

![Figure 3. IN625 alloy powder particles](image)

![Figure 4. Energy spectrum analysis of IN625](image)

### Table 2. Chemical composition of IN625 alloy powder

| Composition | C   | Ni  | Cr  | Mo  | Mn  | Si  | Nb  | Cu  | Co  | Fe  | Al  | S   | Ti  |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Content     | 0.04| 52  | 19  | 3   | 0.2 | 0.2 | 3   | 0.2 | 0.5 | Bal.| 0.5 | $\leq 0.03$ | 0.8 |
3.2. Test and analysis of tensile properties

Tensile test is the most basic and widely used experiment to study the mechanical properties of materials. Uniaxial tensile test is widely used in engineering and laboratory to test the mechanical properties of materials. Mastering the characteristics of tensile and failure process is helpful to correctly and reasonably understand and select materials. SLM process is used to print IN625 alloy powder tensile test piece, and Z100 THW electronic tensile test machine produced by Zwick company of Germany is used for tensile test, as shown in Figure 5.

From the stress-strain curve of the tensile specimen in Figure 6, it can be seen that the tensile process is divided into four stages: the elastic deformation stage, the stress-strain of the material meets the positive proportion relationship; the yield flow stage, although there is no obvious yield platform in the curve in the figure, the engineering stress corresponding to the 0.2% plastic strain is taken as the yield strength of the material; the strengthening stage, after the yield stage, the material recovers when the resistance to deformation is restored, the stress curve rises gradually, and the stress corresponding to the highest point of the curve is called the strength limit; when the necking failure stage passes through the strengthening stage, the diameter of the sample suddenly decreases in a certain part, which is called necking. It can be seen from the figure that, after the strength limit is exceeded and then necking occurs, the material will appear strain softening phenomenon, that is to say, only a small stress is required for the newly increased strain, but with the increase of strain, the stress is decreasing. Since then, the axial deformation of the specimen is mainly concentrated in the necking, and the load that the specimen can bear is also rapidly reduced. Finally, the specimen is broken at the necking.

![Figure 5. Necking phenomenon in tensile test](image)

![Figure 6. Uniaxial tensile test curve](image)

| Test parameters | $R_{0.2}$ (MPa) | $R_m$ (MPa) | $F_m$ (kN) | $L_0$ (mm) | $L_u$ (mm) | $A_{manual}$ (%) | $Z$ (%) |
|-----------------|-----------------|-------------|------------|------------|------------|----------------|--------|
| Numerical value | 671.34          | 1093.94     | 86.61      | 50.00      | 64.14      | 28.28          | 35.32  |

3.3. Compression performance test analysis

The maximum compressive load divided by the cross-sectional area of the specimen at the time of specimen failure is called the compressive strength limit or compressive strength. Compression test is mainly applicable to brittle materials, such as cast iron, bearing alloy and building materials. For plastic materials, compressive strength limit can’t be measured, but elastic modulus, proportional limit and yield strength can be measured. Similar to tensile test, compression curve can be made through compression test to obtain corresponding index value, as shown in Table 4.
3.4. Impact performance test analysis
Impact experiment is a kind of experiment to study the resistance of material to dynamic load, which is different from the static load. Because of the fast-loading speed, the stress in the material suddenly increases, and the deformation speed affects the mechanical properties of the material, so the material shows another response to the dynamic load. Under impact load, it can reveal the influence of structural characteristics and working conditions on mechanical properties (such as stress concentration, internal defects of materials, chemical composition, stress state and heat treatment), which are not easy to find under static load. Therefore, it has certain significance in process analysis comparison and scientific research. Use 450J instrumented Charpy impact tester to conduct impact test on V-notch impact specimen, and obtain the data listed in Table 5.

### Table 5. Dynamic load impact test data

| Material brand | Sample number | Impact absorption (K̂v/J) | Average value(K̂v/J) |
|----------------|---------------|--------------------------|---------------------|
| IN625          | 1             | 57.70                    |                     |
|                | 2             | 69.90                    | 62.10               |
|                | 3             | 58.70                    |                     |

3.5. Material hardness test analysis
The micro vickers hardness of alloy samples were measured by HXS-1000 micro hardness tester. The applied load was 200gf and the loading time was 15s. Use R574T rockwell hardness tester of Wilson company to measure the hardness of alloy sample. The initial test force of scale is 10kgf, the total test force is 150kgf, and the holding time is 2s, rockwell hardness value is obtained. The values are shown in Table 6 and Table 7 respectively.

### Table 6. Micro Vickers hardness of test piece

| Material brand | Sample number | Micro Vickers hardness (MPa) | Average value (MPa) |
|----------------|---------------|-----------------------------|---------------------|
| IN625          | 1             | 409.20                      |                     |
|                | 2             | 528.00                      | 488.40              |
|                | 3             | 528.00                      |                     |

### Table 7. Rockwell hardness of test piece

| Material brand | Sample number | Rockwell hardness (MPa) | Average value (MPa) |
|----------------|---------------|-------------------------|---------------------|
| IN625          | 1             | 30.4                    | 30.6                |
|                | 2             | 30.3                    | 28.3                |
|                | 3             | 31.0                    | 30.6                |

4. Selective laser melting manufacturing process

4.1. SLM equipment selection
The EOS M290 equipment developed in Germany is used for selective laser melting and manufacturing of crank arm parts. The equipment has the following features: modular components, improvement of
monitoring capacity, upgrading of gas circulation system, friendly and intuitive interface software, simple and efficient operation panel. The main parameters of the equipment are shown in Table 8.

Table 8. SLM equipment (EOS M290) parameters

| Device parameters          | Numerical value       | Device parameters          | Numerical value       |
|----------------------------|-----------------------|---------------------------|-----------------------|
| Molding dimension          | 250mm x 250mm x 325mm | Powder thickness           | 20-100um (adjustable) |
| Optical scanning system    | F-theta lens, high speed scanning mirror | Scanning speed | speed 7.0m/s accuracy 6um |
| Laser type                 | Yb doped fiber laser, 400W | Manufacturing speed | 5-20cm³/h |

4.2. Slice processing of 3D model file

3D printing is to make parts according to the profile of each layer. In order to extract the profile of the section, slicing software must be used to slice the 3D model at a certain interval along the height direction of the molding. The interval of layer height is selected according to the requirements of the precision and productivity of the formed parts. The smaller the interval, the higher the precision, but the longer the molding time. The interval of layer height is generally 0.05-0.5mm, and the value in this range can get comparative light smooth shaped surface.

4.3. SLM process parameters setting

The SLM preparation process of the crank arm part includes: importing the slice model, determining the position and direction of the model on the working platform, and setting the printing parameters. SLM process parameters mainly include printing speed, layer thickness, scanning speed, etc. If the printing speed is very slow, the materials coming out of the nozzle will be cooled in the middle of the process, and it is not easy to form. If the printing speed is too fast, the size of the parts will be deformed, and manufacturing defects such as pores or cracks will appear. When the SLM is carried out, the reduction of layer thickness will significantly improve the manufacturing accuracy, but the preparation time will also increase, and the consumption of alloy powder will correspondingly increase. After comprehensive consideration of SLM equipment, alloy powder performance and processing requirements of crank arm parts, set SLM process parameters as shown in Table 9. The SLM process and the prepared crank parts are shown in Figure.7 and Figure.8.

Table 9. Process parameters of selective laser melting

| Setting thickness(mm) | Preheating temperature of base plate (℃) | Base plate leveling (mm) | Scrapper type | Number of scrapers |
|-----------------------|------------------------------------------|--------------------------|--------------|--------------------|
| 0.05                  | 80                                       | ≤0.05                    | brush        | 3                  |

| Laser power (W) | Scanning speed (mm/s) | Scanning distance (mm) | Spot diameter (um) | Protective gas |
|-----------------|-----------------------|------------------------|-------------------|----------------|
| 275             | 955                   | 0.11                   | 80                | Ar             |
5. After treatment and performance test of components

After forming the crank arm parts, professional tools are needed to remove the support. Due to the high surface roughness of the formed spare parts, especially the contact area between the support and the suspension surface, after removing the support, the working surface and the assembly position of the spare parts are treated by a grinder to make the surface accuracy meet the assembly and use requirements, without affecting its performance.

![Figure 7. SLM device printing process](image1)

![Figure 8. Crank arm parts by SLM](image2)

![Figure 9. Surface morphology of crank arm part working face](image3)

After simple surface treatment, the spare parts can be assembled and used directly. After 50 times of breech opening and locking, the spare parts are not damaged. The surface of spare parts was observed by optical microscope. The surface morphology of the crank arm part working face before and after the test is shown in Figure.9. It can be seen from the surface morphology and size measurement in Figure.9 that, the working face of the crank arm has not been deformed, nor has obvious wear and crack appeared. The crank arm can continue to be used, and the preparation process and performance index meet the use requirements.

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