Research on the strength of selective laser sintering core

JIURU LI, JIUHE QU, JUHUI CHEN, Haitian ZHOU, Yongguo SUN, Lin Fu

1 Harbin University of Science and Technology, Harbin 150080, China
2 The No. 703 Research Institute of China Shipbuilding Industry Corporation, Harbin 150078, China

*hrblijuru@sina.com, b**1359914383@qq.com, c*chenjuhui@hrbust.edu.cn,
d*345593499@qq.com, e*sunyongguo@hrbust.edu.cn, f*fulin703@sina.com

Abstract—Taking the tensile strength as the inspection index, the single-factor influence experiment was carried out on the addition of phenolic resin and the four factors of laser power, laser scanning rate and sand thickness in the sintering process, and the optimal level combination of each factor was obtained: the addition of phenolic resin 5%, laser power 38W, laser scanning rate 3400mm/s, sand thickness 0.25mm.

1. Introduction
In the performance of selective laser sintering parts, the strength has always been the focus of researchers. For the coated sand core, its strength directly determines the quality of the cast metal parts. Strength measurement indicators include flexural strength and tensile strength, and the most widely used is the tensile strength of the sample[1]. G.Casalino[2,3] used the response surface analysis of variance to study the interaction of laser power, scanning speed and scanning distance in phenolic resin-coated quartz sand SLS sintering. KKBHJ Gill et al.[4] used the binder content and sintering process parameters as variables at the same time, and used the full factorial experimental method to investigate the strength of the coated silica sand SLS molded parts. A Celardi[5] used finite element analysis to study the mechanical behavior of SLS specimens. Stichel TL[6] et al. added X-ray comprehensive microstructure analysis on the basis of tensile test. P Kholpanov et al.[7] studied the interaction effect of laser rate and sand thickness on strength. G.V. Salmoria[8] et al. studied the influence of laser power, scanning speed and powder particle size on the mechanical properties of sintered parts. Therefore, this paper focuses on the research of strength, and uses the tensile strength value as the strength inspection index. Through the single-factor experiment of controlled variables, the effect of phenolic resin addition, laser power, laser scanning rate and sand laying thickness on the core strength is explored. Affect the law.

2. Experimental materials and equipment
The sintering equipment used in the experiment is the HKS1200P rapid prototyping laser sintering printer, and its specific parameters are shown in Table 1. The material used is the original sand with a particle size distribution of 140/70 mesh orb-coated sand, the binder is thermoplastic phenolic resin, the curing agent is urotropine, accounting for 12% of the resin added, and the lubricant is calcium stearate. Production by lamination method. Other process parameters are selected according to production experience, namely: preheating temperature of 70°C, spot diameter of 0.4mm, laser beam scanning spacing of 0.25mm, and molding room temperature of 50°C.
Table 1 Parameters of hks1200p rapid prototyping laser sintering printer

| category                              | parameter                                   |
|---------------------------------------|---------------------------------------------|
| Laser Sintering Printer Models        | HKS1200P                                    |
| Laser type                            | CO2                                         |
| Appearance dimensions of the host     | 2500mm×2500mm×3300mm                         |
| (length × width × height)             |                                             |
| Molding chamber size (length × width  | 1200mm×1200mm×550mm                         |
| × height)                             |                                             |
| Molding material                      | coated sand                                 |
| Maximum scan power                    | 40W                                         |
| Scanning distance                     | 0.25mm                                      |
| Layer thickness                       | 0.3mm                                       |
| Sand laying method                    | Funnel-type layered sand laying             |

The tensile strength test adopts WDW-200 computer-controlled floor-standing electronic universal testing machine. The standard "8" sintered block was selected as the tensile specimen.

3. Test Results and Discussions

3.1. Effect of phenolic resin addition on tensile strength

Using the process parameters of laser power of 38W, laser scan rate of 3400mm/s, and sand thickness of 0.25mm, changing the amount of phenolic resin added, the change trend of the experimental results is shown in Figure 1.

![Fig. 1 Variation curve of tensile strength with phenolic resin addition](image)

It can be seen from Figure 1 that with the increase of the amount of phenolic resin added, the strength of the sample shows an upward trend, and the strength is the highest when the phenolic resin content is 5%. When the resin content is 4%, the strength is increased by about 54% compared with 3%, but the strength at 5% resin content is only about 11% higher than that at 4% resin content. When the resin content is too high, due to the limited total amount of input energy, the heat transfer effect is limited, and all the resins cannot be reacted. The presence of gas between the coated sands will reduce the density of the molded part and reduce part of the strength, so the strength cannot be strictly related to the amount of phenolic resin added, proportional increase.

Therefore, although theoretically the higher the content of phenolic resin, the higher the tensile strength of the sintered sample, but considering the amount of gas and the actual tensile strength
requirements of production, the addition amount of phenolic resin should not be too high, 4%-5% is relatively high. Good range of options.

3.2. Effect of Laser Scanning Power on Tensile Strength

Using the process parameters of phenolic resin addition of 5%, laser scanning rate of 3400 mm/s, and sand thickness of 0.25 mm, changing the laser scanning power, the experimental results are shown in Table 2.

| Laser scanning power (W) | Sample tensile strength (MPa) |
|--------------------------|------------------------------|
| 30                       | 0.98                         |
| 32                       | 1.03                         |
| 34                       | 1.11                         |
| 36                       | 1.21                         |
| 38                       | 1.28                         |
| 40                       | 1.23                         |

The change trend of the experimental results is shown in Fig. 2.

![Graph showing variation in tensile strength with laser scanning power](image)

Fig. 2 Variation curve of tensile strength with laser scanning power

According to the analysis in Fig. 2, the tensile strength of the sintered samples first showed a relatively large upward trend with the increase of the laser power, and then began to decrease after the power reached 38W. This is because the laser first imparts more energy to the surface sand layer through radiation heat transfer on the surface of the sand layer. After the surface sand layer absorbs energy, a temperature gradient is formed with the lower sand layer. The temperature increases, so in general, the higher the laser power, the higher the total energy, the more thorough the heat transfer to the sand layer, and the more solidified and sintered parts, the higher the strength. However, when the total power is too high, the energy density at the center of the laser beam will increase significantly, resulting in too much heat is transferred to the surface of the sand layer. It causes carbonization and overburning of the phenolic resin and loses its bonding ability. Ultimately, the strength of the sintered specimen decreases.

3.3. Effect of Laser Scanning Rate on Tensile Strength

The process parameters of phenolic resin addition of 5%, laser power of 38W, and sand thickness of 0.25mm were used to change the laser scanning rate. The experimental data are shown in Table 3.

| Laser scan rate (mm/s) | Sample tensile strength (MPa) |
|------------------------|-------------------------------|
| 3000                   | 1.18                          |
| 3200                   | 1.25                          |
| 3400                   | 1.28                          |
| 3600                   | 1.24                          |
| 3800                   | 1.17                          |
| 4000                   | 1.14                          |
The variation trend of the experimental results is shown in Figure 3.

![Figure 3](image_url)

**Fig. 3 Variation curve of tensile strength with laser scanning rate**

It can be seen from the figure that with the increase of the laser scanning rate, the intensity of the sample first increases and then decreases. This is because if the laser scanning rate is too slow, due to the Gaussian distribution of the laser beam energy, the surface obtained tends to absorb more energy, resulting in higher temperature, which can cause an overburn condition. On the other hand, the total energy transferred to the inside of the sand layer is also more, which is easy to cause the direct decomposition of the internal resin. If the laser scan rate is too fast, less energy is input, and the temperature of the inner sand layer will be lower. This results in the inability to form more solidified sintered sintered bonds, and finally its strength will be lower.

To sum up, the scanning rate of the laser should be combined with the power of the laser to select an appropriate value, and a reasonable combination of the two is extremely important to improve the strength of the sample.

### 3.4. The effect of sand thickness on strength

The addition of phenolic resin is 5%, the laser power is 38W, and the laser scanning rate is 3400mm/s. The thickness of sand topping is changed. The experimental results are shown in Table 4.

| Sand thickness (mm/s) | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 |
|----------------------|------|------|------|------|------|
| Sample tensile strength (MPa) | 1.33 | 1.35 | 1.32 | 1.28 | 1.21 |

The variation trend of the experimental results is shown in Figure 4.
It can be seen from the figure that with the increase of sand thickness, the tensile strength of the sample shows a downward trend, but the sand thickness is not as low as possible. For example, the strength at 0.10mm is lower than that at 0.15mm. This is because too low sand laying thickness may cause the sand layer to be directly burned through, and the sand laying roller will directly push the formed part away during the layer-by-layer sand laying process, which directly affects the forming quality. On the other hand, a decrease in the thickness of the sand laying also means an increase in the number of sand layings and scans, which slows down the production rate. Therefore, 0.25mm is still selected as the best level.

4. Conclusion
In this paper, the single factor experiment method was used to analyze the influence of different thermoplastic phenolic resin additions and process parameters in the sintering process on the strength of the sintered samples. The conclusions are as follows:

Under the premise of higher requirements for sintering speed, when sintering thermoplastic phenolic resin-coated sand, the best process for its strength is as follows: the addition of phenolic resin is 5%, the laser power is 38W, the scanning speed is 3400mm/s, The thickness of the sand layer is 0.25mm, and the tensile strength of the standard sample sintered by the best process is 1.28MPa.

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References
[1]. Sofia D, Macri D, Barletta D, et al. Use of titania powders in the laser sintering process: Link between process conditions and product mechanical properties[J]. Powder Technology, 2021, 381: 181-188.
[2]. Casalino G, De Filippis L A C, Ludovico A D, et al. Preliminary experience with sand casting applications of rapid prototyping by selective laser sintering (SLS)[C]//International Congress on Applications of Lasers & Electro-Optics. Laser Institute of America, 2000, 2000(1): D263-D272.
[3]. Casalino G, De Filippis L A C, Ludovico A D, et al. An investigation of rapid prototyping of sand casting molds by selective laser sintering[J]. Journal of Laser Applications, 2002, 14(2): 100-
106.

[4]. Hon K K B, Gill T J. Selective laser sintering of SiC/polyamide composites[J]. CIRP Annals, 2003, 52(1): 173-176.

[5]. Cerardi A, Caneri M, Meneghello R, et al. Mechanical characterization of polyamide cellular structures fabricated using selective laser sintering technologies[J]. Materials & Design, 2013, 46: 910-915.

[6]. Stichel T, Frick T, Laumer T, et al. A Round Robin study for Selective Laser Sintering of polyamide 12: Microstructural origin of the mechanical properties[J]. Optics & Laser Technology, 2017, 89: 31-40.

[7]. Kholpanov L P, Zakiev S E, Shishkovskii I V. Modeling of thermal processes in laser sintering of reactive powder compositions[J]. Journal of Engineering Physics and Thermophysics, 2005, 78(6): 1088-1095.

[8]. Salmoria G V, Leite J L, Paggi R A, et al. Selective laser sintering of PA12/HDPE blends: Effect of components on elastic/plastic behavior[J]. Polymer Testing, 2008, 27(6): 654-659.