Analysis of mechanical properties and performances of laser melting forming of H13 mold steel in selected areas

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Abstract. When preparing H13 molds by laser melting in selected areas, due to the complex force direction of the mold during use, it is necessary to analyze the mechanical properties of the specimens at different forming angles. By preparing specimens with different forming angles (0°, 30°, 45°, 60°, 90°), tensile specimens of different forming angle specimens were made and the results were analyzed. The results show that there are many defects between layers, resulting in anisotropy of the mechanical properties of the sample. The 0° sample has the highest mechanical performance, with a tensile strength of 1933.1 MPa and an elongation of 11.1%. As the forming angle increases, the resistance Tensile strength and elongation showed a downward trend. The 90° sample had the lowest tensile strength, with a tensile strength of 1552.8 MPa and an elongation of 6.42%.

1. Introduction

H13 steel is a C-Cr-Mo-Si-V steel with high carbon content, high alloying element content, and good hardenability. It is usually used to make injection molds with high working temperature and thermal fatigue [1-2]. Selective area laser melting technology (SLM) is the main method of metal material manufacturing in additive manufacturing. It uses high-energy heat source to quickly melt and solidify metal powder materials to form solid parts [3-4].

There have been related researches on the printing process parameters and mechanical properties of H13 die steel, but there are some researches on the directionality of mechanical properties for some parts, but the research results in this regard are somewhat insufficient [5-6]. Based on the research of R.Casati [7] on defects, in SLM parts, the defects produced by horizontal manufacturing are less than those produced by vertical manufacturing. The reason is that the bonding performance between layers is related. The mechanical properties of H13 mold steel in different forming directions are prepared by the selective laser melting method, and the influence of SLM forming direction on the mechanical properties is emphasized. The mechanical properties and forming angles of the formed samples are summarized.

2. Experiment

This experiment uses imported H13 metal powder and performs quality inspection on the metal powder. The manufacturing process parameters are laser power 250W, scanning speed 950mm/s, powder spreading thickness 30mm, overlap distance 0.1mm, and the forming angle of the substrate. They are 0°, 30°, 45°, 60°, and 90°. SLM Solutions Group AG 280 equipment was used for manufacturing, LEICA DM1750M optical microscope was used for observation and organization, and Hitachi S-3400N scanning electron microscope was used for fracture analysis.

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2.1. Materials and equipment
The particle size of H13 die steel metal powder obeys Gaussian distribution. D10, D50 and D90 are respectively 21.737μm, 34.581μm and 54.902μm. Figure 1 shows the microscopic appearance of the powder with high sphericity.

![Figure 1 The micro morphology of H13 die steel powder](image)

The laser metal powder melting equipment used in the experiment is SLM Solutions Group AG 280 equipment. The laser spot diameter is 80-115μm, the laser power is 200W~500W, the minimum spreading thickness is 0.02mm, the maximum scanning speed is 10000mm/s, and the maximum forming range is 250mm*250mm*365mm. The molding process is carried out in argon protective gas, and the thickness of each powder spread is 0.35mm. The scanning power is 400W, the scanning speed is 800mm/s, and the overlap distance between adjacent melt channels is 0.11mm. After laser forming one layer, the laser scanning angle of the next layer is rotated 67° counterclockwise, and each layer is formed into a priority scanning contour, and then the inside is scanned for forming.

2.2. Materials and equipment
The process parameters of forming H13 die steel used in the test are laser power 250W, scanning speed 950mm/s, spreading thickness of 30mm, overlap distance of 0.1mm, and tensile specimens in 5 directions (0°, 30°, 45°, 60°, 90°) for manufacturing, as shown in Figure 2.

![Figure 2 Schematic diagram of selected area laser melting](image)

3. Results and discussion

3.1. Micro morphology
The microstructure analysis of the H13 mold steel SLM molding sample shows that it is found that the defect is easy to occur between the layers, and it has nothing to do with the molding angle. Figure 4 is the microscopic morphology of the SLM molding H13 mold steel. Defects between layers cause cracks to easily grow at the defects (pores, microcracks, etc.) in the tensile test, resulting in a decrease in
mechanical properties. It can be seen from Fig. 3 that the cracks between the layers may affect the tensile specimens with different forming angles.

3.2. Mechanical properties

The H13 die steel SLM molded sample was machined, and the processing drawing is shown in Figure 4, and the sample was tested for tensile properties at room temperature to study the anisotropy of the molding. During the stretching process, the stress-strain behavior of SLM forming H13 die steel is different from that of conventional die steel. All tensile specimens suddenly fractured without necking. The stress-strain of the specimens formed at different angles is shown in Figure 4. The H13 die steel SLM molding without heat treatment has high tensile strength, and the tensile strength of the manufacturing direction at 0° to the base plate reaches 1933.3 MPa, and the total elongation at break is 11.1%, the tensile strength of 90° formed with the substrate is the lowest, the tensile strength is 1552.8MPa, and the total elongation at break is 6.42%. However, it can be seen from the table that the tensile properties of the samples formed in the horizontal direction are significantly higher than those in the vertical direction, the tensile strength is 1.2 times that of the vertical direction, and the elongation at break is 1.6 times that of the vertical direction. Bo [7] research shows that the tensile strength of the sample made by FST (forging, specialized annealing, thermal refining) is 1762MPa, and the total elongation at break is 4.1%. The tensile strength of SLM specimens is similar to that of FST specimens, but the elongation is greater than that of FST specimens.
3.3. Differential analysis of forming angle

The slicing method of the tensile specimen of the H13 die steel formed by SLM is shown in Figure 6. As the manufacturing angle gradually increases, the angle between the force direction and the slicing direction gradually increases during the stretching process. According to the literature [8], the fracture failure mode of SLM molded parts is the positional relationship between the position of external force and the internal defects (pores, cracks). Since the SLM molding technology is a layer-by-layer stacking technology, defects are easily formed at the junction of layers, as shown in Figure 5, cracks are easy to appear between layers. For the 0° sample, the tensile direction is parallel to the crack direction, and the fracture failure mode is "shear type". As the forming angle increases, the angle between the tensile direction and the crack direction increases until the 90° sample is stretched. The direction is perpendicular to the crack direction, and the fracture failure mode is "open type" [9-10]. As a result, as the forming angle increases, the tensile strength and elongation tend to decrease.

![Figure 5 Schematic diagram of SLM forming H13 die steel tensile specimen slice](image)

3.4. Fracture analysis

Fracture analysis is performed on samples with different forming angles at room temperature, as shown in Figure 6. The tensile fracture morphology of SLM molding H13 presents typical brittle fracture characteristics, with two different areas of shear lip area and fiber area. A cleavage step can be observed in the figure, indicating that the fracture mechanism is a quasi-cleavage fracture. During the stretching process, cracks mainly appeared in small shallow pits and deformation pits, and scattered holes became the source of these cracks. At the same time, the interface defects between lath martensite and retained austenite are also the cause of cracks. The martensite grains of the SLM sample are finer, and the second phase grains are not precipitated, so fracture occurs along the grain boundary. The micropores propagate along the strain crack direction to retain austenite or spread along the martensite grain boundary. There are almost no dents on all fracture surfaces, and the cleavage surfaces are dense and there is no obvious river pattern [11-12]. As the manufacturing angle increases, the angle between the crack and the fracture surface is gradually reduced in the SEM, which is consistent with the analysis of the forming angle, which is the cause of the anisotropy of the mechanical properties of the H13 die steel formed by SLM.

![Fracture analysis images](image)
Figure 6 Fracture morphology of different forming angles
(a) 0° sample; (b) 30° sample; (c) 45° sample; (d) 60° sample; (e) 90° sample.

4. Conclusion

(1) SLM formed H13 die steel forms 0° with base plate the tensile strength in manufacturing direction reaches 1933.3MPa, the total elongation at break is 11.1%, and 90° is formed with the base plate the tensile strength is the lowest, the tensile strength is 1552.8MPa and the total elongation at break is 6.42%. The tensile strength is greater than or equal to that of FST manufactured samples (1762MPa), and the elongation index is greater than that of FST manufactured samples (4.1%).

(2) Defects of H13 die steel formed by SLM mainly lie in porosity and cracks between layers. With the change of tensile direction, the direction of defects and defects changes from shear to open, which leads to anisotropy of SLM parts.

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