MATEC Web of Conferences **128**, 05005 (2017)
EITCE 2017

DOI: 10.1051/matecconf/201712805005

Investigation on Mechanical Properties' Anisotropy of Rod Units in Lattice Structures Fabricated by Selective Laser Melting

Chenchen Jing[1], Yong Zhou[1], Jiping Lu[1,a], Hongli Fan[1], Lei Ji and Penglin Li[1]

[1]*School of Mechanical Engineering, Beijing Institute of Technology, 100081 Beijing, China*

Abstract. Lattice structure with high strength and low mass using selective laser melting (SLM) has been a hot topic. However, there are some problems in the fabrication of lattice structure by SLM. Rod unit is the basic component of lattice structure and its performance affects the whole structure. It is necessary to investigate the influence of selective laser melting on rod unit's mechanical properties. A series of rod units with different inclination angle and diameter were fabricated by SLM in this research. And the mechanical properties of these units were measured by tensile test. The results show that the rod units with different diameters and inclination angles have good mechanical properties and show no difference. It is a good news for lattice structure designing for there is no necessary to consider the mechanical properties' anisotropy of rod units.

1 Introduction

In the aerospace, military, automotive, medical and other fields, the significance of the lightweight of components has become more and more important, which can help reduce the amount of spending [1,2]. Lattice structure has become a hot spot to study, as it not only provides good mechanical properties, but also greatly reduces the weight of parts [3–6]. However, complex shape of lattice structure makes the traditional way of processing very difficult. At present, proven methods of three-dimensional lattice structures' manufacturing include Investment casting [7], Deformation forming [8], Woven metal textiles [9], Non-woven metal textiles [9] and so on [10,11]. These methods are complex, costly and low in material utilization [12]. However, additive manufacturing technology can shed light on solving this problem [11].

Additive manufacturing refers to a technique that fabricates part layer by layer which can manufacture parts with any complex geometries theoretically [13]. Selective laser melting (SLM) is one of the additive manufacturing technique [14]. The SLM process begins with splitting a component into layers, and fuses the powder selectively by a laser power to make this fully melted powder combined with former layer. Finally it can get a fully dense part [15–18]. This method makes it possible to fabricate very complex lattice structures [19]. Chunze Yan et al. [3,20] have fabricated an advanced lightweight 316L stainless steel cellular lattice structures and a king of gyroid cellular lattice structures via SLM. Sajad Arabnejad et al. [21] have fabricated high-strength porous biomaterials using SLM.

However, there are some problems in the fabrication of lattice structure. The lattice structure can be seen as a series of rod elements. The SLM process can compromise the quality of these rod units. Layer-by-layer build-up makes the parts have the characteristic of anisotropy, which makes the mechanical properties of the parts inconsistent in all directions [22–24]. In addition, the SLM process also makes the portion which is close to the horizontal poor quality and rougher [25]. The influence of the angle between the rod and the build direction on the lattice structure is caused by the principle of SLM method, which arouses great research significance.

To investigate the influence of inclination angle and diameter on mechanical properties of rod unit, a group of Ti-6Al-4V rod unit structure samples were designed and manufactured by SLM with necessary support. The mechanical properties were analysed by tensile test. The results show that the rod units with different diameters and inclination angles have good mechanical properties and show no difference. It is a good news for lattice structure designing for there is no necessary to consider the mechanical properties' anisotropy of rod units.

2 Methods and Material

2.1 Sample designing

In this research, a group of rod unit structures were designed. The structure consists of two plates and a rod, and the rod is sandwiched between the two plates. Fig. 1 is an illustration of the samples with a rod length of 14mm, a plate length of 10mm, a width of 8mm, and the thickness of the plate equal to the strut diameter. The

---

[a] Corresponding author: jipinglu@bit.edu.cn

DOI: 10.1051/matecconf/201712805005

inclination of the rod is shown in Figure 1, and it is 4 mm from the substrate in the horizontal direction. It is used for tensile test in order to investigate the mechanical properties of the rod unit. In this group, 35 sets of tensile specimens with different combination of inclination angle θ (0-90 degree, in increments of 15 degree,) and strut diameter D (0.50-2.00mm, in 0.25mm increments) were set. After the tensile specimens were manufactured completely, they were cut by electrical discharge machining. The design parameters of all the samples are shown in Table 1.

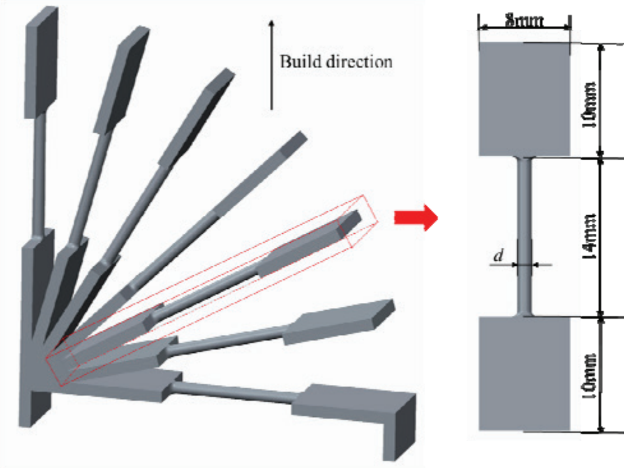

Figure 1. Detail of the sample structure

Table 1. Sample's design parameter.

Inclination angle (θ/degree)	Design diameter (*D*/mm)				
0	1.00	1.25	1.50	1.75	2.00
15	1.00	1.25	1.50	1.75	2.00
30	1.00	1.25	1.50	1.75	2.00
45	1.00	1.25	1.50	1.75	2.00
60	1.00	1.25	1.50	1.75	2.00
75	1.00	1.25	1.50	1.75	2.00
90	1.00	1.25	1.50	1.75	2.00

2.2 Sample manufacturing and tensile tests

The specimens were fabricated by EOSINT M 280 (EOS GmbH, Germany) (Figure 2) using Ti6Al4V. Titanium (Ti) alloys have high specific strength, strong resistance to creep and great corrosion resistance [26]. Due to the good mechanical characters, Ti and its alloys are becoming more important in material field, and widely used in aerospace field, military field, biomaterial field, etc. [23,27,28]. The process parameters are in optimal setup. The samples exerted the necessary support at a smaller inclination when fabricating.

The samples were cut into individual tensile specimens by electrical discharge machining after fabricated. Tensile tests were carried on INSTRON5966. Three samples were used in every group. The tensile tests were conducted with reference to ASTME-E8/E8M-15a [29].

Figure 2. The picture of EOSINT M 280

3 Results & Discussion

The fabricated samples were shown in Figure 3. In order to ensure consistent cross-sectional area of the samples, necessary support was added when printing. As can be seen from Figure 3, the rod unit diameter is uniform, and there is no significant difference. Each sample was cut into individual tensile specimens by electrical discharge machining for tensile testing. Figure 4 shows the stress-strain curves of the rod elements at each angle (0-90 degrees, in 15 degrees increments) when the design diameter of the rod is 1.50mm. It can be seen that the inclination angle of the rod elements has little influence on the mechanical properties, and so do the other rod units of the diameter. Figure 5 shows the stress-strain curves of the rod elements with different diameters (1.00-2.00mm, in 0.25mm increments) and same inclination angle (15 degree). It can be seen that the diameter of the rod element does not have a great effect on its mechanical properties and the same is true for other inclination angles.

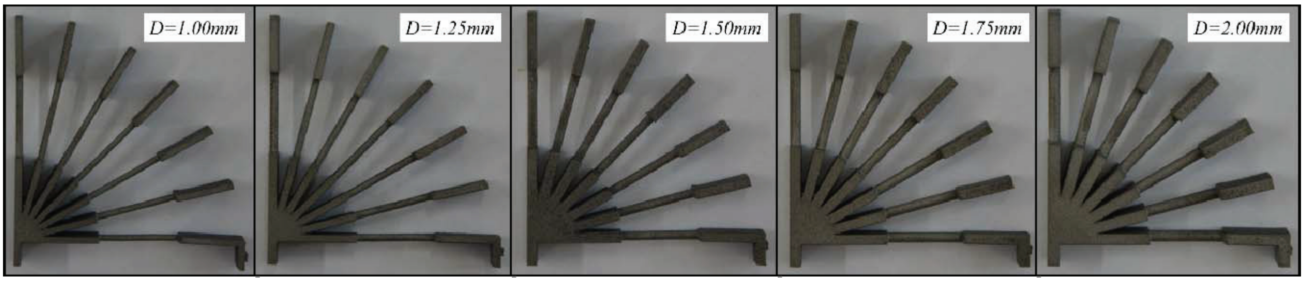

Figure 3. Ti-6Al-4V samples manufactured by SLM for rod diameter of 1.00-2.00mm in increments of 0.25mm

DOI: 10.1051/matecconf/201712805005

The yield strength (YS) and tensile strength (TS) of each rod units were summarized (Table 2) and were shown in Figure 6, where the solid line represents the tensile strength (TS) and the dash line indicates the yield strength (YS). The tensile strength and yield strength of all rod units is about 1100MPa and 1000Mpa respectively with no significant difference with the inclination angle and diameter change. It can be concluded that the inclination and diameter have no significant impacts on the mechanical properties of the rod element.

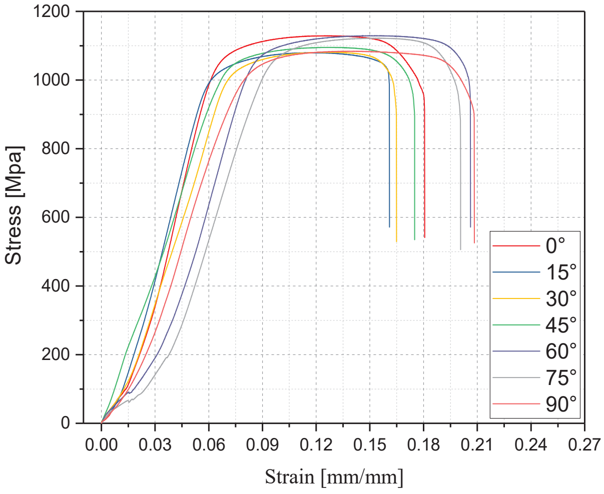

Figure 4. Stress-strain response of the Ti-6Al-4V rod units manufactured by SLM with diameter of 1.50mm

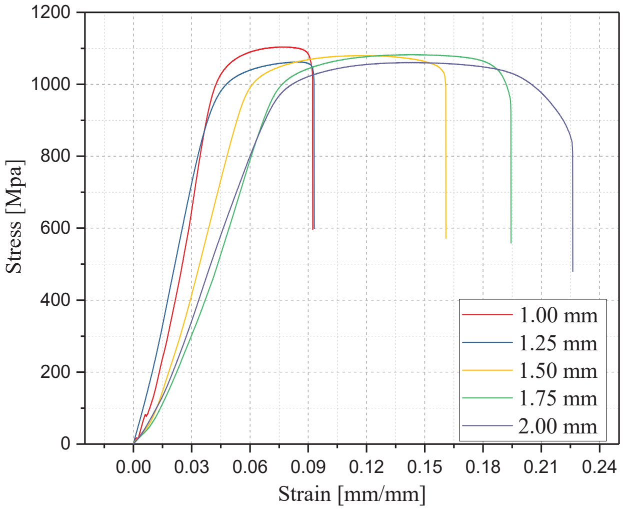

Figure 5. Stress-strain response of the Ti-6Al-4V rod units manufactured by SLM with inclination angle of 15 degree

The mechanical property of Ti-6Al-4V is directly determined by their microstructure [30-32]. There are three important factors affect the mechanical property including the size of β grains, the β grain orientation and the lamellar α microstructure. In the sample manufactured by SLM, the anisotropy of mechanical properties primarily depends on the deference of the β grain orientation [31]. For the small rod unit of lattice structure, the molten pool is very tiny, and the cooling rate is high. It leads to a small size of the β grains and the lamellar α microstructure. Thus the rod unit's tensile strength is up to 1100Mpa and yield strength is about 1000Mpa. And the effect of grain orientation is relatively weakened. Therefore, there is no obvious anisotropy of mechanical properties in rod units. The results of the experiment are meaningful to the designer, for they can ignore the anisotropy of mechanical properties when designing lattice structure.

Table 2. The tensile strength (TS/Mpa) and yield strength (YS/Mpa) of the sample

Inclination angle/degree		**Diameter/mm**				
		1.00	**1.25**	**1.5**	**1.75**	**2**
0	**TS**	1225	1109	1127	1105	1184
	YS	1113	1004	1008	1016	950
15	**TS**	1104	1062	1080	1078	1061
	YS	1011	911	980	986	919
30	**TS**	1122	1087	1079	1105	1101
	YS	1043	1034	1011	978	1012
45	**TS**	1076	1119	1102	1083	1073
	YS	1006	1020	998	997	987
60	**TS**	1094	1074	1127	1114	1062
	YS	1008	925	1037	1020	951
75	**TS**	1146	1043	1122	1107	1094
	YS	1063	934	1001	1007	987
90	**TS**	1147	1108	1076	1100	1072
	YS	1039	995	923	992	985

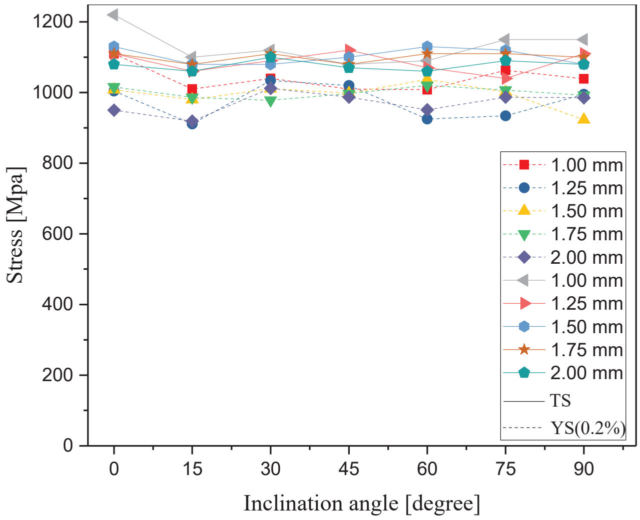

Figure 3. Influence of Inclination on Tensile Strength (TS) (Solid line) and Yield Strength (YS) (Dash line) of the rod units manufactured by SLM

4 Conclusion

To investigate the influence of selective laser melting on rod unit's mechanical properties, a group of samples with different inclination angle and diameter were manufactured. The tensile tests were carried to estimate the tensile strength (TS) and yield strength (YS). It can be concluded that the rod units fabricated by SLM exhibits good mechanical properties and the tensile strength is up to 1100Mpa and yield strength is about 1000Mpa. And there is no obviously difference with the inclination angle and diameter change. It is a good news for designer for they can ignore the mechanical properties' anisotropy of rod units when they design the lattice structure.

References

1. C. Beyer, D. Figueroa, J. Manuf. Sci. Eng. 138 (2016) 121014.
2. H. Alsalla, L. Hao, C. Smith, Materials Science & Engineering A. 669 (2016) 1–6.
3. C. Yan, L. Hao, A. Hussein, P. Young, D. Raymont, Mater. Des. 55 (2014) 533–541.
4. H. Nakajima, Fabrication, Prog. Mater. Sci. 52 (2007) 1091–1173.
5. A.G. Evans, J.W. Hutchinson, N.A. Fleck, M.F. Ashby, H.N.G. Wadley, Prog. Mater. Sci. 46 (2001) 309–327.
6. S.K. Moon, Y.E. Tan, J. Hwang, Y.J. Yoon, Int. J. Precis. Eng. Manuf. - Green Technol. 1 (2014) 223–228.
7. Wang J, Evans A G, Dharmasena K, et al. International Journal of Solids & Structures, 2003, 40(25):6981-6988.
8. G.W. Kooistra, H.N.G. Wadley, Materials & Design , 28 (2007) 507–514.
9. D.T. Queheillalt, H.N.G. Wadley, 53 (2005) 303–313.
10. H.N.G. Wadley, N.A. Fleck, A.G. Evans, 63 (2003) 2331–2343.
11. P. Li, Z. Wang, N. Petrinic, C.R. Siviour, Materials Science & Engineering A, 614 (2014) 116–121.
12. M.G. Rashed, M. Ashraf, R.A.W. Mines, P.J. Hazell, Mater. Des. 95 (2016) 518–533.
13. S.L. Sing, J. An, W.Y. Yeong, F.E. Wiria, J. Orthop. Res. 34 (2016) 369–385.
14. X. Shi, S. Ma, C. Liu, Q. Wu, Opt. Laser Technol. 90 (2017) 71–79.
15. S.L. Sing, W.Y. Yeong, F.E. Wiria, J. Alloys Compd. 660 (2016) 461–470.
16. L.E.E. Loh, Z.H.H. Liu, D.Q.Q. Zhang, M. Mapar, S.L.L. Sing, C.K.K. Chua, W.Y.Y. Yeong, Virtual Phys. Prototyp. 9 (2014) 11–16.
17. G. Casalino, S.L. Campanelli, N. Contuzzi, A.D. Ludovico, Opt. Laser Technol. 65 (2015) 151–158.
18. E. Yasa, J. Deckers, J.-P. Kruth, M. Rombouts, J. Luyten, Virtual Phys. Prototyp. 5 (2010) 89–98.
19. M. Cloots, K. Kunze, P.J. Uggowitzer, K. Wegener, Mater. Sci. Eng. A. 658 (2016) 68–76.
20. C. Yan, L. Hao, A. Hussein, D. Raymont, Int. J. Mach. Tools Manuf. 62 (2012) 32–38.
21. S. Arabnejad, R. Burnett Johnston, J.A. Pura, B. Singh, M. Tanzer, D. Pasini, Acta Biomater. 30 (2016) 345–356.
22. L. Thijs, F. Verhaeghe, T. Craeghs, J. Van Humbeeck, J.P. Kruth, Acta Mater. 58 (2010) 3303–3312.
23. L.Y. Chen, J.C. Huang, C.H. Lin, C.T. Pan, S.Y. Chen, T.L. Yang, D.Y. Lin, H.K. Lin, J.S.C. Jang, Mater. Sci. Eng. A. 682 (2017) 389–395.
24. L. Facchini, E. Magalini, P. Robotti, A. Molinari, S. Höges, K. Wissenbach, Rapid Prototyp. J. 16 (2010) 450–459.
25. M. Mazur, M. Leary, M. McMillan, S. Sun, D. Shidid, M. Brandt, Elsevier Ltd, 2017.
26. Boyer R R. Materials Science & Engineering A, 1996, 213(1–2):103-114.
27. S. Zhang, Q. Wei, L. Cheng, S. Li, Y. Shi, Mater. Des. 63 (2014) 185–193.
28. C.N. Elias, M.A. Meyers, R.Z. Valiev, S.N. Monteiro J. Mater. Res. Technol. 2 (2013) 340–350.
29. ASTM Int., Standard Test Methods for Tension Testing of Metallic Materials 1, Astm. (2015) 1–27.
30. W. Jia, L. Ma, Y. Tang, Q. Le, L. Fu, Mater. Des. 103 (2016) 171–182.
31. X. Shi, S. Ma, C. Liu, Q. Wu, J. Lu, Y. Liu, W. Shi, Mater. Sci. Eng. A. 684 (2017) 196–204.
32. Y.Z. Zhu, S.Z. Wang, B.L. Li, Z.M. Yin, Q. Wan, P. Liu, Mater. Des. 55 (2014) 456–462.