Title	Direct Metal Tool Fabrication of AISI 420 Tool Steel by Selective Laser Melting
Author(s)	Zhao, Xiao; Wei, Qingsong; Liu, Jie; Shi, Yusheng; Li, Zhongwei
Citation	Zhao, X., Wei, Q., Liu, J., Shi, Y., & Li, Z. (2014). Direct Metal Tool Fabrication of AISI 420 Tool Steel by Selective Laser Melting. Proceedings of the 1st International Conference on Progress in Additive Manufacturing (Pro-AM 2014), 121-126.
Date	2014
URL	http://hdl.handle.net/10220/41682
Rights	© 2014 by Research Publishing Services.

DIRECT METAL TOOL FABRICATION OF AISI 420 TOOL STEEL BY SELECTIVE LASER MELTING

XIAO ZHAO
State Key Lab of Materials Processing and Die&Mould Technology, Huazhong University of Science and Technology, No. 1037, Luoyu Road, Hongshan District, Wuhan, China

QINGSONG WEI
State Key Lab of Materials Processing and Die&Mould Technology, Huazhong University of Science and Technology, No. 1037, Luoyu Road, Hongshan District, Wuhan, China

JIE LIU (CORRESPONDING AUTHOR)
State Key Lab of Materials Processing and Die&Mould Technology, Huazhong University of Science and Technology, No. 1037, Luoyu Road, Hongshan District, Wuhan, China

YUSHENG SHI
State Key Lab of Materials Processing and Die&Mould Technology, Huazhong University of Science and Technology, No. 1037, Luoyu Road, Hongshan District, Wuhan, China

ZHONGWEI LI
State Key Lab of Materials Processing and Die&Mould Technology, Huazhong University of Science and Technology, No. 1037, Luoyu Road, Hongshan District, Wuhan, China

ABSTRACT: Recently, the improvement of Additive Manufacturing systems and processes promise the fabrication of nearly full density metal tools and moulds for long-term use. However, only a few kinds of tool steel were processed by SLM successfully. The AISI 420 tool steel is introduced as the processing material for its good corrosion resistance and excellent polishability as the injection mould. The scanning speed and laser power were optimized to fabricate the samples. The maximum density achieved with AISI 420 tool steel was about 99.955%, and defects of small pores were found. The samples had a maximum hardness of HRC 50.74, showing a great potential to fabricate the real injection mould.

1 INTRODUCTION

Direct metal RT techniques can fabricate high performance tools, greatly shortening the “time to market” (Levy et al., 2003) and improving the product competitiveness. Recently, various metal RT techniques, including direct metal laser sintering (DMLS), selective laser melting (SLM), direct laser fabrication (DLF), laser engineered net shaping (LENS), direct metal deposition (DMD), laser-aided direct metal tooling (DMT), etc., have been developed to fabricate a true tool (Ahn, 2011). Among these techniques, SLM technique has a higher dimensional accuracy by using small layer thickness and laser beam diameter, offering a high potential for the fabrication of complex metal tools with inner structures.

A signification amount of work has been carried out on Fe based alloys (Kruth et al., 2004; Yadroitsev et al., 2012; Song et al., 2014),. However, very limited kinds of commercial tool steels were processed by SLM, and the obtained density generally cannot reach a full density (Wright et al., 2006; Xie et al., 2005). The elements of tool steels are very active to oxygen, leading to the

Proc. of the Intl. Conf. on Progress in Additive Manufacturing
Edited by Chua Chee Kai, Yeong Wai Yee, Tan Ming Jen and Liu Erjia

ISBN: 978-981-09-0446-3 :: doi:10.3850/978-981-09-0446-3_048

poor densification response (Gu et al., 2012). Therefore, the tool steel and processing parameters should be carefully chosen to achieve the high density parts. In this paper, AISI 420 tool steel was processed on the self-developed HRPM-II SLM equipment. Single track and samples were fabricated to achieve the high density parts. The sample structure and Rockwell hardness were studied. The results showed AISI 420 is a promising tool steel to fabricate injection mould by SLM.

2 EXPERIMENTAL DETAILS

The HRPM-II SLM equipment mainly consists of a continuous fiber laser (maximum output of 200 W), an automatic powder delivery system, a building chamber, and a computer system. The SLM process is undertaken in the Ar2 atmosphere to avoid the oxidation of the metallic powder. The gas-atomized AISI 420 tool steel powder is supplied by Changsha Hualiu Metallurgy Powder Co, Ltd, China (Fig. 1a) and has a size distribution of d10-d50-d90: 8-20-38μm (Fig.1b). The scanning speed is between 400mm/s and 800mm/s and the laser power is between 110W and 150W.

Table 1. The nominal chemical composition of the AISI 420 alloy powder

Element	C	Cr	Mn	Si	V	P, S	Fe
Wt%	0.2-0.45	12-14	< 1	< 1	0.15-0.4	< 0.03	Balance

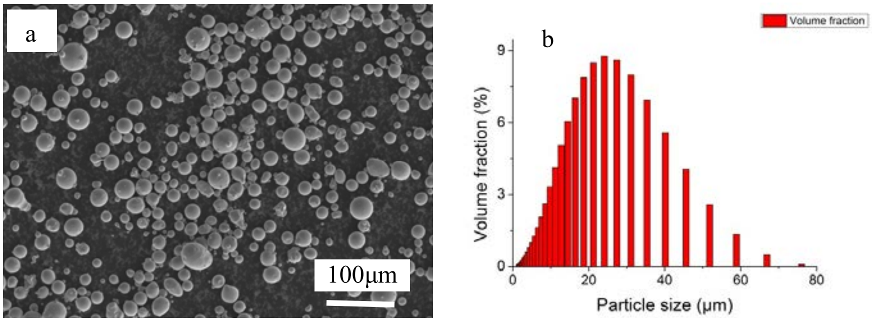

Figure1. (a) SEM image of the powder, (b) The size distribution of the powder

3 RESULT AND DISCUSSION

3.1 SLM processing parameters' optimization

The process map of AISI 420 tool steel (Fig.2) was found similar to SS 316L (Yadroitsev et al., 2010). AISI 420 tool steel powder has a good consolidation with the laser energy input of about 0.18-0.28 J/mm. As is shown in Fig.3 (a), small balls were found in Zone 1 similar to the droplet zone in Yadroitsev's work, but the droplets were smaller without merging to big drops. Continuous tracks were found in Zone 2 (Fig.3 (b)), while the tracks were occasionally broken in Zone 3 (Fig.3 (c)). Compared with 316L, 420 tool steel has higher thermal diffusivity and similar melting point (The Engineering ToolBox, 2005). Heat moves more rapidly in 420 tool steel, improving the scanning speed. With a low scanning speed, the liquid metal solidified in a longer time and the track became disturbed as a result of the capillary (Yadroitsev et al., 2010; Rombouts et al., 2006).

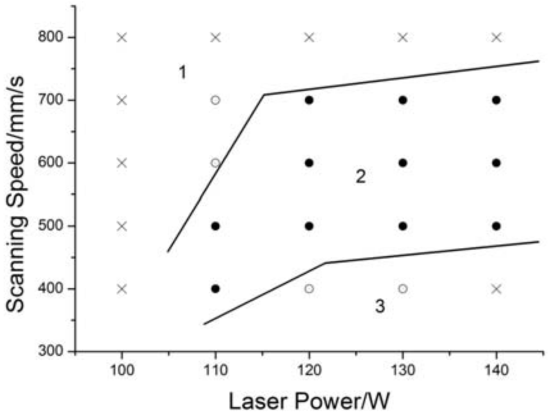

Figure 2. The single track process map. × means the relatively poor tracks, ● means the best tracks, and ○ means the better tracks.

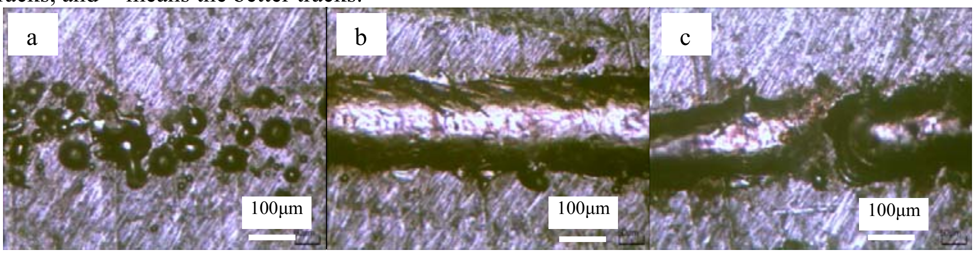

Figure 3. Single track on the steel substrate. (a) P=100W, V=800mm/s; (b) P=140W, V=600mm/s; (c) P=140W, V=400mm/s

The widths of single tracks were measured five times with a Caikon 4XCE Optical Microscope. As is shown in Fig.4, the average width of the single line varied from 120μm to 154μm. The width increased with the laser power except 140W. The better standard deviation was found with the scanning speed of 500mm/s and 600mm/s. As a result, samples were fabricated by SLM with the scanning speed of 550mm/s. The smaller layer thickness is helpful to increase the density of the final samples. The layer thickness of 0.02mm was used in this study. The laser power was 110W-150W, the scanning speed is 550mm/s, and the scanning space is 0.07mm. Four cylinders (φ15mm ×10mm) were fabricated. The relative results are listed in Table 2. The density increased with the laser power before 140W, and decreased with 150W. All the samples showed a much better density than SLM H13 (Xie et al., 2005) and M2 (Simichi et al., 2004) alloy tool steel. It was demonstrated that the high alloy steels has a greater sensitivity to the process conditions (Simichi et al., 2004). An Ellingham diagram (Gaskell, 1995) shows Mo, V and W has better stability in high temperature, may leading to the MoO_3, V_2O_3 and WO_3 of H13 and M2 tool steel during the SLM. The contamination of oxide was thought to be a severe impediment to interlayer bonding and cause defects such as balling (Das, 2003). Though Fe and Cr are also very active to oxygen, the relative oxides are easier to decomposition in the high temperature. As a result, 420 tool steel is easier to process by SLM.

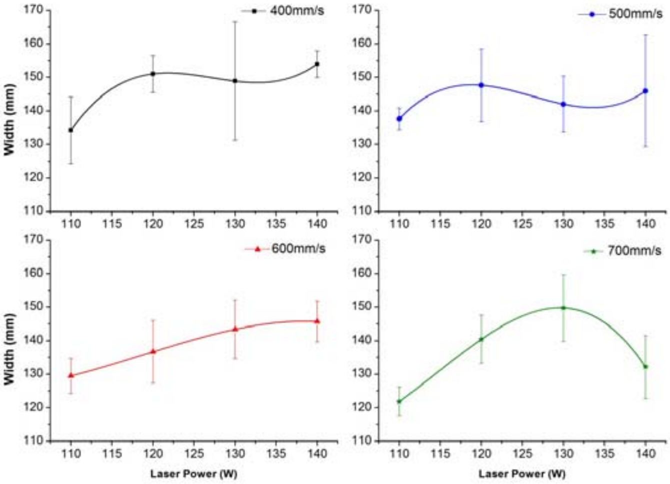

Fig.4 The width of the single track with different laser power and scanning speed

Table 2. The density of samples by using different laser powers

Laser power/ W	Relative density			Average
120	98.976	99.062	99.086	99.041
130	99.887	99.966	99.976	99.943
140	99.947	99.966	99.976	99.955
150	99.911	99.865	99.983	99.920

3.2 Sample structure analysis

Fig.4 shows the pore structure present in the sample produced by SLM (140W). It can be seen that spherical and irregular pores exist. The spherical holes may be caused by gas entrapped in the liquid metal during the SLM process or the atomization process, and the irregular pores maybe caused by lack of fusion (Bi et al., 2010). All the pores observed by OM had a size blow 10µm, which is much smaller than pores of H13 tool steel (Xie et al., 2005). No micro-cracks were observed in the 420 steel samples, while numerous and large cracks were observed in the M2 sample (Simichi et al., 2004). The crack was caused by the high residual internal stress with the high laser energy and low scanning speed (Simichi et al., 2004). The process parameters used in this study help to reduce the residual stress. A tempering process is still need to remove residual stress due to the rapid melting and cooling of deposited material (Ahn, 2011).

3.3 Hardness analysis

Fig.5 shows the measurement of Rockwell hardness of the cross-section perpendicular to the laser scanning direction. The hardness increases with the laser power. The average values of the hardness are 46.65 HRC, 47.86 HRC, 47.92 HRC and 50.74 HRC of 120W, 130W, 140W and 150W, respectively. The hardness is lower than the commercial AISI 420 steel with heat treatment (≥HRC 50) because of the decarbonization.

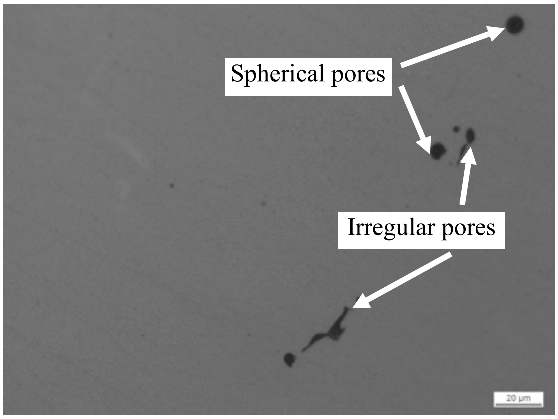

Figure 4. Sample structure of AISI 420 tool steel. Scanning speed=550mm/s, laser power=140W, scanning space=0.07mm, layer thickness=0.02mm.

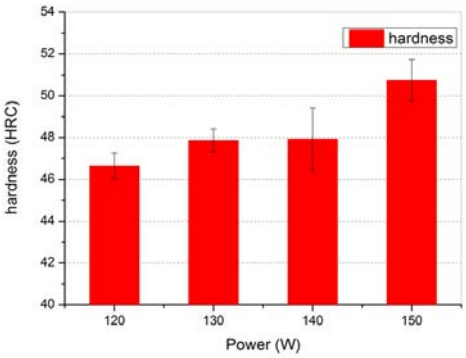

Figure 5. Rockwell hardness results for SLM samples

4 CONCLUSIONS

In this study, the feasibility of SLM of AISI 420 to fabricate injection mould was investigated. The processing optimization, sample structure and hardness were discussed in detail. With optimized process parameters, crack-free sample was fabricated. The maximum density reached 99.955%. Spherical and irregular pores were observed with small size. Though the hardness was found a little lower than the commercial AISI 420 tool steel, AISI 420 showed a potential to fabricate the real injection mould.

ACKNOWLEDGMENTS

The authors gratefully appreciate the financial support from the National Key Technology Support Program (No 2012BAF08B03), the National Natural Science Foundation of China (51375188, 51375189), the independent R&D subjects of Huazhong University of Science and Technology and the State Key Laboratory of Materials Processing and Die & Mould Technology (0225110098). Some measurements were conducted in the Analysis and Testing Center of Huazhong University of Science and Technology.

REFERENCES

Ahn, D. G. (2011). "Applications of laser assisted metal rapid tooling process to manufacture of molding & forming tools—state of the art", *International Journal of Precision Engineering and Manufacturing*, 12(5), 925-938.

Bi, G., Ng, G. K. L., Teh, K. M., & Jarfors, A. E. (2010). "Feasibility study on the Laser Aided Additive Manufacturing of die inserts for liquid forging", *Materials & Design*, 31, S112-S116.

Das, S. (2003). "Physical aspects of process control in selective laser sintering of metals", *Advanced Engineering Materials*, 5(10), 701-711.

Gaskell, D. R. (2008). "Introduction to the Thermodynamics of Materials (Vol. 2) ". CRC Press.

Gu, D. D., Meiners, W., Wissenbach, K. & Poprawe, R. (2012). "Laser additive manufacturing of metallic components: materials, processes and mechanisms", *International Materials Reviews*, 57(3), 133-164.

Kruth, J. P., Froyen, L., Van Griethuysen, J., Mercelis, P., Rombous, M. & Lauwers, B. (2004). "Selective laser melting of iron-based powder", *Journal of Materials Processing Technology*, 149, 616-622.

Levy, G. N., Schindel, R. & Kruth, J. P. (2003). "Rapid manufacturing and rapid tooling with layer manufacturing (LM) technologies, state of the art and future perspectives", *CIRP Annals-Manufacturing Technology*, 52(2), 589-609.

Rombouts, M., Kruth, J. P., Froyen, L. & Mercelis, P. (2006). "Fundamentals of selective laser melting of alloyed steel powders". *CIRP Annals-Manufacturing Technology*, 55(1), 187-192.

Song, B., Dong, S. J., Deng, S. H., Liao, H. L. & Coddet, C. (2014). "Microstructure and tensile properties of iron parts fabricated by selective laser melting", *Optics & Laser Technology*, 56, 451-460.

Simchi, A., & Asgharzadeh, H. (2004). "Densification and microstructural evaluation during laser sintering of M2 high speed steel powder". *Materials science and technology*, 20(11), 1462-1468.

The Engineering ToolBox, 2005. www.engineeringtoolbox.com.

Wright, C. S., Youseffi, M., Akhtar, S. P., Childs, T. H. C., Hauser, C., Fox, P. & Xie, J. (2006). "Selective laser melting of prealloyed high alloy steel powder beds", *Materials science forum*, 514, 516-523.

Xie, J. W., Fox, P., O'Neill, W., & Sutcliffe, C. J. (2005). "Effect of direct laser re-melting processing parameters and scanning strategies on the densification of tool steels", *Journal of materials processing technology*, 170(3), 516-523.

Yadroistev, I., Yadroitsava, I., Bertrand, P. & Smurov, I. (2012). "Factor analysis of selective laser melting process parameters and geometrical characteristics of synthesized single tracks", Rapid Prototyping Journal, 18(3), 201-208.

Yadroitsev, I., Gusarov, A., Yadroitsava, I. & Smurov, I. (2010). "Single track formation in selective laser melting of metal powders", *Journal of Materials Processing Technology*, 210(12), 1624-1631.