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SELECTIVE LASER MELTING IN MICRO MANUFACTURING

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Abstract: *Currently, one of increasingly important purposes in industry (from aerospace and automotive to biomedical and chemical) is to decrease component size and produce small-sized devices with high functionality. Selective laser melting makes it possible to create fully functional micro parts directly from metal powders without using any intermediate binders or any additional processing steps. Consolidation of powder by local laser melting is a promising manufacturing technique because of easy control over powder deposition and laser radiation. In present study the SLM technology was applied for fabrication of several models that could be used in micro cooling systems, the objects with highly developed surface and small-sized Kenics® element to direct mixing of fluid flows.*
Key words:*Selective laser melting; Metallic powders; Micro manufacturing*

1. INTRODUCTION

At present,the micro manufacturing (MM) industry (MEMS, micro medical applications, micro engine and so on)rapidly expanding and strongly needs a wide range of new products and new approaches (Kennedy, 2009).Selective laser melting (SLM) is known as a unique technology to produce objects from metal or ceramic powders with complex geometry and mechanical properties comparable to those of bulk materials. Also, it is a promising method for fabrication of functionally graded multi-material parts. The SLM technology can be used at all the stages of the product development – from design concept to low volume production (Chuaet al., 2010; Wohlers, 2010; Worldwide guide to rapid prototyping, 2010).One of the principal criteria is the accuracy of fabrication with respect to the desired dimensions of the final product.

At present time the SLM machines able to produce parts in the range from several millimeters up to 250 mm. The contemporary needs of the market pose new challenges as to increase the size of the manufactured parts (>250 mm, scale up) and to minimize them (<1 mm, scale down).In this study the possibility of using the SLM technology for fabrication of micro-sized parts was analyzed.

2. EXPERIMENTAL PROCEDURE

Stainless steel (SS) grade 904L is an austenitic nickel-chromium steel which is widely used to produce parts by SLM technology. The pre-alloyed gas-atomized SS grade 904L (–16 µm) and (–7 µm) powders from Sandvik Osprey Ltd. were used in our study. The chemical composition (% wt.) of powders was the following: Fe (balance), Ni (23-28%),Cr (19-23%), Mo (4-5%), Cu (1-2%), Si (2% max),Mn (0.55%), C (0.02% max), P (0.045% max), S (0.035% max).

Granulomorphological analysis of the particles was carried out by an optical granulomorphometer ALPAGA 500 NANO which is a real-time optical sieving system (OCCHIO s.a.). The powders were dried by heating up to +80°C during 12 hours, and then cooled in a cooling chamber. Apparent and tappeddensities were measured at room temperature and relative air humidity of 50-55%.The equivalent diameters (weight by volume), tapped and apparent densities of the employed metal powders are present in Table 1. For all the powders, most of the particles had a high sphericity and a smooth surface with a negligible quantity of satellites (Fig. 1).

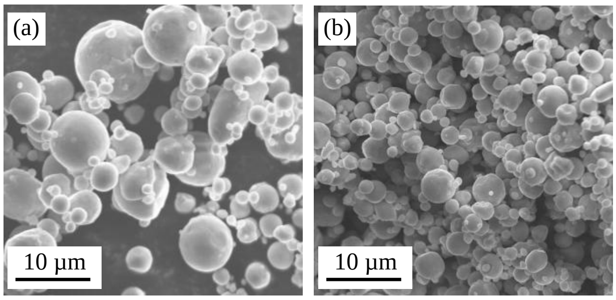


Fig. 1. The SEM micrographs of SS grade 904L –16 µm (a) and –7 µm (b) powders

The experiments were carried out on SLM machine PM 100 (Phenix Systems). The source of radiation isYLR-50 cw Ytterbium fiber laser by IPG Photonics operating at the wavelength of 1075 nm. The main characteristics of the PM 100 machine are as follows: the maximum laser power is *P*=50 W, the maximum laser scanning speed is *V*=3 m/s, the laser spot size is 70 µm, the minimum layer thickness is 5 µm (for fine powders). The furnace of the machine provides a temperature up to 900°C and has a closed environment filled by nitrogen or argon as a protective gas.

Materials / Powder characteristics		904L (–7 µm)	904L (–16 µm)
Equivalent diameter (weight by volume), µm	p_{10}	3.0	5.1
	p_{50}	5.0	11.2
	p_{90}	7.5	18.5
Apparent density, %		34±3	44±1
Tapped density, %		44±5	52±1

* p_{10}–p_{50}–p_{90} are 10th, 50th and 90th percentiles of studied indexes. 10–50–90 percentiles are the values below which 10–50–90% of the observations may be found.
Tab. 1. Powder characteristics *

3. RESULTS AND DISCUSSION

3.1 Manufacturing parts with micro-sized elements

A series of experiments on the manufacturing of objects with developed surface and fine micro-sized structure (thin platewith vertical cylinders) were carried out. Such objectscan be used as substrates to support catalysts in chemical reactions.

In Fig. 2 is shown sample with developed surfaceconsisting of a set of pins with 400 µm diameters and 1 mm heights.

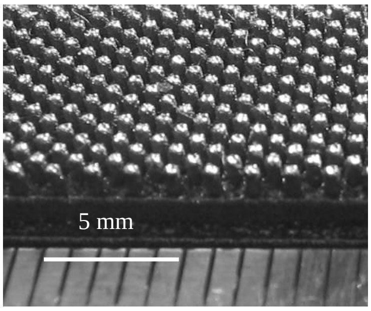
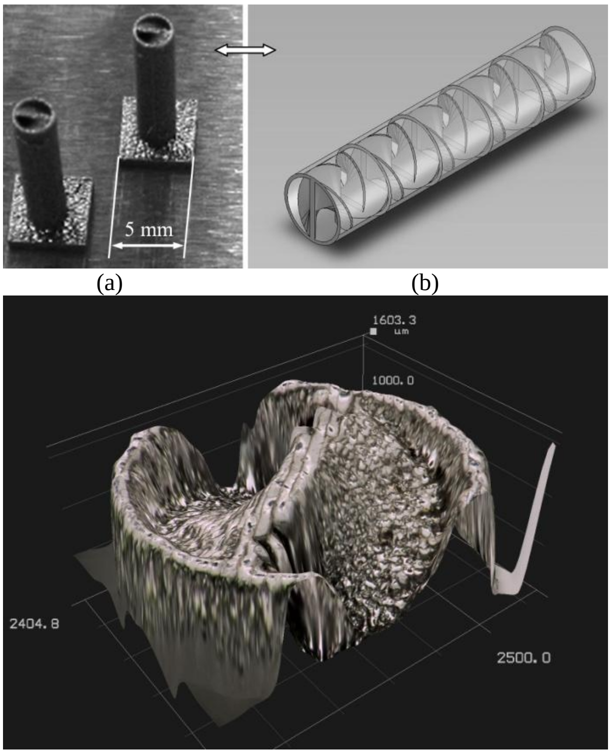


Fig. 2. Sample from SS grade 904L (–16 µm) powder with developed structure. The number of pins per unit area is 175 pins/cm^2

A further decrease of pin diameter and increase of the number of pins per unit area resulted in considerable difficulties: pinshave an irregular shape and contacts with the plate are deteriorated.

For manufacturing of small size Kenics SLM technology was applied (Fig. 3). To mixing element directs the flow of material radially toward the pipe walls and back to the center it was developed Kenics® KM Series Static Mixers. Additional velocity reversal and flow division results from combining alternating right- and left-hand elements, thus increasing mixing efficiency. Kenics Mixers are used in numerous industries for a variety of blending, dispersion, heat transfer and residence time control applications.



(a) (b) (c)

Fig. 3. Mixing element Kenics from SS grade 904L (–7 µm) powder: diameter is 3 mm and height is 15 mm (a), internal structure (b), top wiew (c)

3.2Future trends for SLM in MM industry

Further reduction size of the structural elements and fully functional objects lead to considerable difficulties (Bartolo et al., 2008),it is complicated to reproduce the shape of the sample corresponding CAD model.As shown by Yadroitsev et al. (2009), a minimal regular gap ~60 µm between 140 µm-wide parallel walls was achieved at the hatch distance 200 µm (at a smaller hatch distance the walls were often connected between them and thus a regular through-porosity was not observed).An important role begins played the size of the laser focal spot, size of powder particles, powder layering, thickness and packing density of a deposited layer and the processes of heat transfer in laser-powder interaction zone (Kingskog et al., 2000; Simchi, 2004; Gusarov et al., 2009). To obtain positive results in the miniaturization process is necessary to construct new specialized SLM machines.

For manufacturing functional parts for MM industry (e.g. engine parts of microrobots from titanium or piezoceramics) is enough a small working area of 1x1 cm. Therefore, it is possible to use compact laser of low power (~1÷5 W) with high stable and quality laser radiation (TEM_{00} mode). A small working area allows to apply the short-focal-length optics. At the focal spot diameter 10 µm, the laser power density is about $1{\div}5{\times}10^6$ W/cm^2 for this type of lasers, which is sufficient for melting metal and ceramic powders. Using a fine powder (–5 µm)and thin powder layers (~10 µm) will be able to produce the structural elements with the size about 20 µm and fully functional parts ~100÷500 µm.Today, one of the main problems in the micro manufacturing by SLM is the development of innovative systemsfor deposition thin layers of fine powders with high homogeneity and high packing density.

4. CONCLUSION

New approachespermit to develop low-cost (reduce the price by 5–10 times), compact, functional, easy to use SLM machines. This will enable the wide dissemination of this class of machines in the research centers and enterprises engaged in the field of micro manufacturing. New technical solutions can be implemented much faster in production.

These innovative SLM machines will open a new page in the field of micro manufacturing and enable the produce of smaller and smaller components and functional parts with incredible size and accuracy.

5. REFERENCES

Bartolo, P. J. et al. (eds.) (2008). *Virtual and rapid manufacturing*, Taylor & Francis Group, ISBN: 978-0-415-41602-3, London

Chua, C. K.; Leong,K. F.& Lim,C. S. (2010). *Rapid prototyping. Principles and applications*, 3rd Ed. World Scientific, ISBN: 978-9812778987

Gusarov A. V.; Yadroitsev, I.; Bertrand, Ph.; Smurov I. (2009). Model of radiation and heat transfer in laser-powder interaction zone at selective laser melting. *Journal of Heat Transfer*, Vol. 131, No. 7, 072101-1 – 072101-10.

Kennedy, B. (2009). Scaled for Micro, *Available from:* http://www.micromanufacturing.com *Accessed:*2009-05-06

Kingskog, T.; Kulkarni, K.; Mossner, W.; Whychell, D. (2000). Influence of powder prticle size on properties of MIM parts.*Proceedings of Advances in powder metallurgy and particulate materials*, Princeton, NJ, MPIF, Vol. 4, 185–193.

Simchi, A. (2004). The role of particle size on the laser sintering of iron powder. *Metallurgical and Materials Transactions B*, Vol. 35, No. 5, 937-948.

Worldwide guide to rapid prototyping (2010): http://www.additive3d.com

WohlersT. (2010).*Additive Manufacturing: State of the Industry*, Wohlers Associates, Inc., ISBN: 0-9754429-6-1

Yadroitsev, I.;Shishkovsky, I.; Bertrand, Ph.& Smurov, I. (2009). Manufacturing of fine-structured 3D porous filter elements by selectivelaser melting. *Applied Surface Science*, Vol. 255, No. 10, 5523–5527