Available online at www.sciencedirect.com
ScienceDirect
Physics Procedia 83 (2016) 891 – 898
Physics Procedia

9th International Conference on Photonic Technologies - LANE 2016

New approach to multi-material processing in selective laser melting

Yuri Chivel[a,]*

MerPhotonics, 3 rue Alphonse Merrheim, 42100 Saint Etienne, France

Abstract

New method and SLM machine for 3D multi-material parts production has been elaborated. SLM machine concept and concept of the build platform cleaning system is presented and discussed. New optical monitoring system has been elaborate. Results of test applying for powder feeding to test object are presented. Special metodology of the multi-material object sintering is proposed for better accuracy of 3D object production having regards to shrinkage and dissolution.

Peer-review under responsibility of the Bayerisches Laserzentrum GmbH

Keywords: multi-material parts; selective laser melting; cleaning system; dissimilar material; particles diameter

1. Introduction

The use of multi-materials may be viewed as a technically challenging and economically favorable manufacturing method [1].Single material additive tecnnology systems cannot fulfil the requirements of some applications that require multiple material objects from one machine, such as compliant mechanisms, embedded components, 3D circuits, human tissues, medical compatible implants. By utilizing multi-material components, economic and lightweight designs may be achieved via the reduction of required assembly processes and parts. Multi-material systems will enable the manufacturing of functional structures within products, such as conductive tracks or optical pathways, resulting in radically novel products with unprecedented degrees of functional density.The industry has already begun taking advantage of multi-material designs in numerous applications including coating of internal surfaces ,the embedding of functional structures in electronics [2],components with compliant hinges in automative industry [3].

* Corresponding author. Tel.: +33-0477-3313-82 .
E-mail address: yuri.chivel@gmail.com

Peer-review under responsibility of the Bayerisches Laserzentrum GmbH
doi:10.1016/j.phpro.2016.08.093

A great deal of effort is going into elaboration of the multi-material fabrication systems . Stereolithography has been adapted to support multiple materials [4]. This is accomplished by using multiple vats with UV-curable polymers. These systems can provide high resolution, but changing materials for each layer makes the printing process very complicated and slow. Also efforts have been to use selective laser sintering with multiple powders [5]. Multi-material inkjet-based systems have also been developed [6]. There are machines for selective laser cladding, which can produce a 3D multi-material product, but the production precision does not exceed 100-200 microns and the product requires significant improvement, such as milling.

The selective laser sintering/melting (SLS/SLM) process is well- suited to the incorporation of multiple powdered materials [7]. But all presented on the market methods and a machines for production 3D objects by selective laser sintering/melting are focused on the use of a single powder. Machines for production of multi-material products by selective laser sintering/melting (SLS/SLM) process which makes it possible to obtain accuracy up to 10 microns are absent.

Different approaches were made for multi-material parts production by selective laser melting/sintering A one dimensional parts can be produced using standard SLM machine equipment. For fully three dimensional multi-material parts production new recoating methods and mechanisms have been elaborated, one of which based on electrostatic [8] and second one is nozzle mechanism [9, 10]. The SLS/SLM process presently uses a roller or blade device to sweep thin layers of a single powdered material across the build area. It was concluded that it impossible to deliver multiple materials with roller or blade without cross-contamination [11]. It has been proposed to replace this roller device by an array of hopper-nozzles that can directly patterned regions of multiple powdered materials [12]. Also the method which combine roller and nozzle delivery and vacuum removal has been proposed [13].

These methods don't yeld a required spatial resolution, rate of powder delivery, as the nozzle diameters smaller than 110, 200 micron is not possible to use [14] and moving speeds above 20 mm/s cannot create complete printed lines [14]. Moreover these methods are very sophisticated for industrial promotion.

So far, at the present time there are no technical solutions to be implemented in the framework of the industrial production process of manufacturing multi-material objects from metal, ceramics and engineering plastics by SLS/SLM.

New method and SLM machine for 3D multi-material parts production has been elaborated [15], where standard recoating systems with roller or blade can be used.The main idea consists in using a narrow fraction of powders of various materials with different medium particle size and special algorithm of powder layer recoating. This not only makes possible three dimensional multi-material parts , but this method enables to separate the overflow powders of a various materials for reuse.

2. Method of the multi-material parts processing

A method involves the selection of powders of various materials according to diameter, the successive application of layers of powder of a given thickness during the vertical displacement of a piston of bild chamber with an object to be sintered, and the programmed selective sintering/melting of a given area in the plane of each layer. After sintering the piston is raised through a height of layer, unsintered powder is removed from a layer. The piston is then returned, and a layer of powder having a different diameter and being of a different material is applied and selectively sintered. The process is repeated the requisite number of times depending on the number of materials applied in a layer, producing sintered areas from powders of dissimilar materials in a single layer. When the object-sintering process is finished, the unsintered powder is removed from the build chamber, and the powders are separated according to diameter, thus separating the powders of dissimilar materials. The separated powders are returned to feed containers and are re-used. The technical result consists in the possibility of producing objects having prescribed properties using powders of dissimilar materials located in a single horizontal plane in a single layer. The principle of the method is illustrated in Fig. 1, 2.

By sieve the powders of dissimilar material with different appointed diameter of the particles for each material are selected (Fig.1). As this takes place, particles diameters of the dissimilar powders are related as multiple.

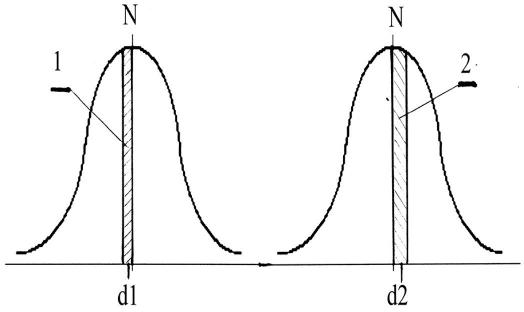


Fig.1. Powders distributions.

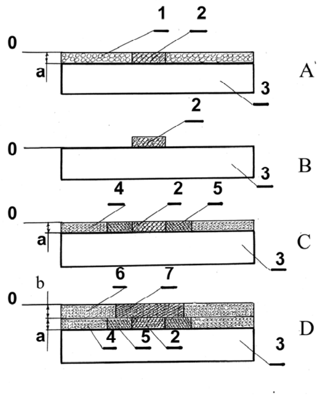


Fig.2. Stages of multi-material sintering.

On the build piston 3 of the build chamber (Fig. 2A) the layer **a** μm thick of powder 1 is applied. After sintering the area 2 the build piston is raised through a height **a** of the layer and unsintering powder is removed (Fig. 1B).

Thereafter piston returns to its previous position (Fig. 2C), the layer **a** μm thick of powder 4 other material and other particles diameter is applied. Selective laser melting is carried out at the area 5. The process is repeated the requisite number of times.

After the sintering of this layer the build piston is lowered through a height **b** of the next layer (Fig. 2D). The new powder layer 6 is applied and the above – listed operations are carried out at new layer, as an example, sintering the area 7.

After completion of the 3D object sintering, unsintering powder is removed from build chamber and separation of the powders according their diameters by sieving is conducted and in so doing, powders of dissimilar materials are separated.

From time to time ups and downs of the build piston at different height and depth in accordance with the layers composition allow to obtain sintered areas from powders of dissimilar materials in a single layer,to obtain spatial curve interface between the areas from dissimilar materials, to produce fully three dimensional multi-material object. The harnessing of distinction in particle diameters of a powders from dissimilar materials for its separation make it possible to achive high efficiency of the powder re-use.

3. SLM machine concept

For realization of the new method of multi-material processing the concept of SLM machine has been elaborated. SLM machine is made up of laser, laser scanner with F-teta lens, processing chamber, build chamber with build piston, which moves powder layer and 3D –object in vertical direction, several feeding containers , re-coater powder feeding system which consists of several identical modules, build platform, cleaning system for removing unsintered powder, sieving station for unsintered powder gathering, separation and vacuum transportation to powder feeding containers for re-use.

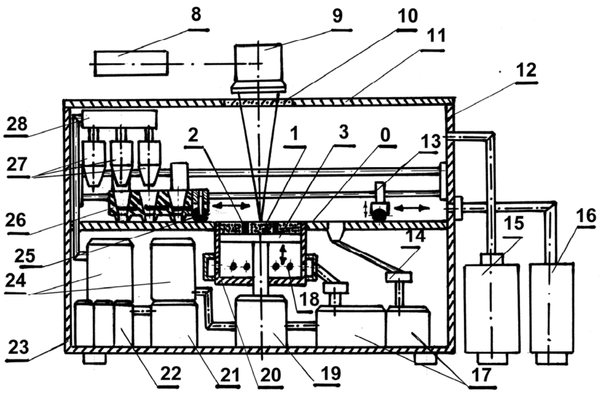


Fig. 3. Selective laser melting machine design.

The essence of the conception is illustrated in Fig. 3. where:
8- laser, 9- laser scanner with lens, 0 – build platform, 1- powder layer, 2- 3D object, 12- processing chamber, 13- surface cleaning system, 14- shut off valve, 10- window, 20- build chamber, 15- gas system, 16- vacuum system, 17 – powder container, 18 – openings for removing the unsintered powder, 19 – motor of vertical transport, 21- system for powder separation by sieving, 22- containers of separated powders, 23- sieving station, 24- vacuum transport system, 25- roller, 26- re-coater powder feeding system, 27- powder feeding container, 28- distributer.

After finishing the sintering of the 3D-object build piston is lowered down and unsintered powder is removed through a openings in build chamber. In sieving station the powder is separated into powders of dissimilar materials and re-used.

This SLM machine offers essential dissimilarites and advantages over the known machines. There is possibility to sintering several powders in the same layer sequentially, instead of parallel.Owing to that, technological regime of sintering of the dissimilar materials, with different melting temperature and thermal conductivity, simplify because within the every step of sintering powder is fed on the compact material. As well as the build platform cleaning system and system for material separation according the size of a particles has no analoques.

4. Concept of build platform cleaning system design

Removal of the unsintered powder at the process of the multi-material 3D-object production has been the object of much attention in the realzation of the new method. The estimation shows that height of powder bead during the process of removing a powder layers with thickness 20-100 µm at a distance 500 mm range up to 4-10 mm. High quality cleaning is not possible exclusively mechanically. Because of this, an original combination of mechanical and vacuum cleaning has been elaborated. From the powder bead surplus powder is drawn off by a vacuum cleaner. The brush cleaning is achived by the gas supply through axis of the roller and vacuum cleaner.

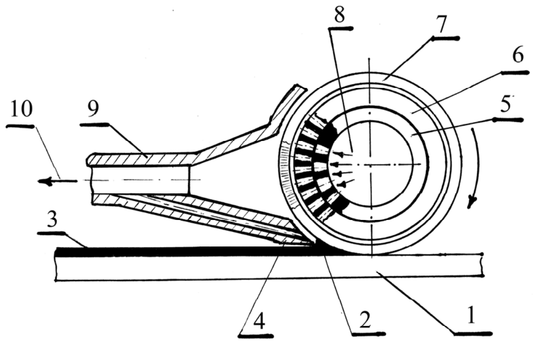


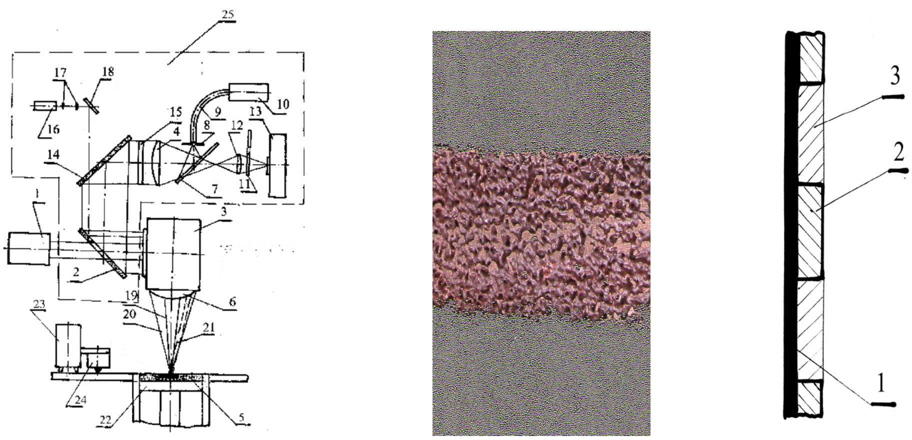
Fig. 4. Build platform cleaning system design.

The essence of the concept is illustrated in fig.4 where:
1- build platform, 2- powder beard,3- powder payer, 4- channel of vacuum removing of the beard, 5- axis of the cleaning roller, 6- shaft of the cleaning roller, 7- brush, 8- gas supply,9- brush cleaning device.

5. Elaboration of the monitoring system

Fabrication of the multi-material 3D-object with high accuracy particularly in the contact area between dissimilar materials requires precision monitoring both process of the powder layer re-coating and process of sintering.
For precise control of dimensions and quality of the 3D – object in the process of selective laser melting the new method and apparatus have been elaborated [16, 17]. The process of melting is monitoring by measurements temperature distribution in laser irradiation zone using a high speed digital CCD – camera and maximum temperature in laser spot by pyrometer.

For monitoring of dimensions and quality the 2D scanner head is housed on re-coater powder feeding system (Fig. 5a). After sintering of each layer of the 3D object, when applying the next layer of powder, the image of the sintered layer is registered by scanner with a resolution of up to several microns. The image is compared with the program-specified section and the exposure parameters (laser power, speed and the laser spot scanning software) can be adjusted before sintering the following layer. Also a quality of applied powder layer is controlled when re- coater moves back. Using 2D image scanner it is possible to obtain spatial resolution up to 10000 dpi, which is unattainable by other devices.



a. b c

Fig. 5. Optical monitoring system – (a), test of powder feeding-(b), test object –(c). 1- Inox powder, 2- sintered layer of Cu-powder, thickness-400 μm. Scan resolution – 600 dpi.

The essence of the conception is illustrated in Fig. 5. where:
1 - laser, 2, 18 - rotary mirror, 3 – galvanometer scanner, 4 – lens, 5 - the surface being treated, 6 - F-teta lens, dichroic mirror -7, 8 - the diaphragm of pyrometer, 9 - fiber, 10 – pyrometer, 11 – filters, 12 – lens, 13 – videocamera, 14 – dichroic mirror, 15- filter, 16 –illumination laser,17- telescope, 19 – housing, 22- piston, 23- re-coater, 24 – 2D image scanner.

An illumination source 16 for backlight of the surface whose radiation using a telescope 17 and rotating mirror 18 and mirror 2 is introduced into galvanometer scanner and focuses in the treatment area. The surface image at source wavelength is constructed using the F-teta lens and lens 4 in the plane 12 of the matrix of videocamera 13 through the filters 11 which allocates either illumination laser radiation or thermal radiation of the surface.
Results of test applying for powder feeding on test object (Fig. 5. b, c) are sutisfactory. Minor amounth of powder fall on surface of previously sintered area 2 has no effect on the sintering of the powder in area 3.

6. Metodology of the multi-material object sintering

When sintering the multimaterial object with high accuracy, particular attention has been given to shrinkage and dissolution.

When solid phase and melt are in contact a process of dissolution of a solid phase in melt occurs. At an unidimensional approximation, the position of solid surface is defined as [18]:

$$\Delta X = 2\, b\, (\alpha\, t)^{0.5} \tag{1}$$

where α – diffusivity b – factor dependent on material,for steel b = 0.75.

Nominal diffusivity of solid elements in melt steel, for example, are assumed to be $\alpha = 1 \times 10^{-9}$ m^2/s for all the elements [19]. The calculations also considered the effect of enhanced diffusion of solid elements due to melt flow by increasing the diffusivity arbitrarily to a value of $\alpha = 1 \times 10^{-6}$ m^2/s. The results of calculations are presented in Fig. 6.

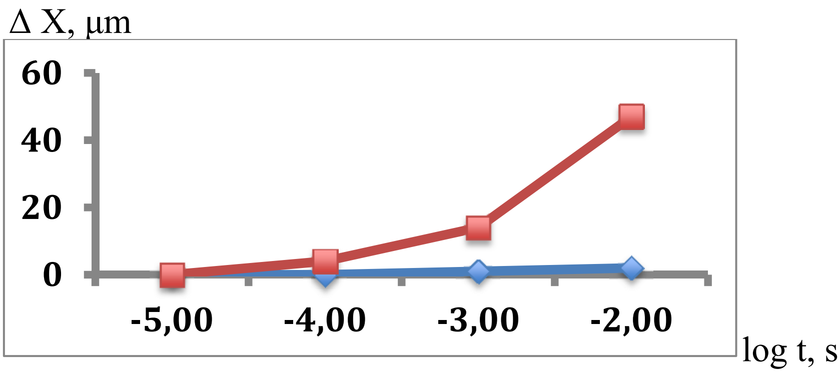


Fig. 6. Dissolution of solid in melt versus time: ■ - $\alpha = 1 \times 10^{-6}$ m^2/s, ◆ - $\alpha = 1 \times 10^{-9}$ m^2/s.

To avoid wash –out of interface the time of solid-melt contact must be reduced. Special strategy of scanning must be applied for this. Also special strategy of scanning must be applied when sintering/melting under high shrinkage (Fig. 7). A possible solution to avoid overheating near the sides and to equilibrate the temperature gradient is to use spiral scanning (Fig. 7). If the scan speed is high enough, the spiral scanning leads to better results than the standard parallel line strategy.

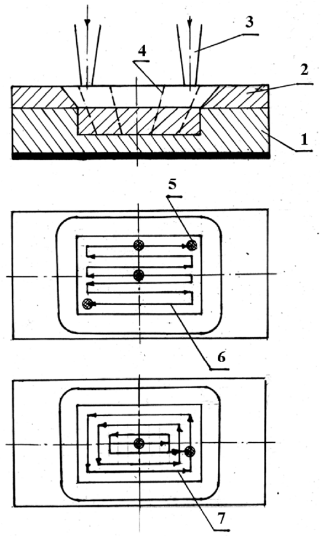


Fig. 7. Strategy of scanning at high shrinkage:1- sintered powder **1**; 2 – powder **2**; 3- laser beam; 4- melt front; 5- laser spot; 6, 7 – scan track.

According to proposed strategy (Fig. 7), for closing the recess in the sintered powder 1 by melting the layer of the powder **2** scanning must be carried out from the centre of the recess to interface. Melt front is moving to the interface and melted powder **2** is lowered into recess, filling it. The time of solid-melt contact is minimum.

Conclusion

New method and SLM machine for 3D multi-material parts production has been elaborated, where standard recoating systems with roller or blade can be used. The main idea consists in using a narrow fraction of powders of various materials with different medium particle size and special algorithm of powder layer recoating. This not only makes possible three dimensional multi-material parts, but this method enables to separate the overflow powders of a various materials for reuse.

For precise control of dimensions and quality of the 3D – object in the process of selective laser melting the new method and apparatus have been elaborated, which allow not only monitor the temperature and dimension of melt but also allow monitor a dimensions of the 3D object with micron accuracy.

When sintering of the multimaterial object with high accuracy, particular attention has been given to shrinkage and dissolution. Special metodology of the multi-material object sintering is proposed for better accuracy of 3D object production having regards to shrinkage and dissolution.

References

1. Bourell David L., Rosen David W., and Leu Ming C. 2014 .The Roadmap for Additive Manufacturing and Its Impact. 3D Printing and Additive Manufacturing. 1(1), 6.
2. Espalin, D., Muse, D. W., Macdonald, E., Wicker, R. B., 2014. 3D Printing multifunctionality: structures with electronics, International Journal of Advanced Manufacturing Technology, 72(1), 963.
3. Solinitis K., Pandremenos, J., Paralikis, F., Chryssolouris, G. 2009. Multifunction materials used in automotive industry: A critical review. Engineering Against Fracture 1, 59.
4. Choi, J.-W., Kim, H.-C., Wicker, R. 2011. Multi-material stereolithography. Journal of Materials Processing Technology, 211, 3, 318.
5. Kumar, P., Santosa, J. K., Beck, E., Das, S. 2004. Direct-write deposition of fine powders through miniature hopper- nozzles for multi-material solid freeform fabrication. Rapid Prototyping Journal ,10, 1, 14.
6. T. C. Burg, C. P. Cass, R. Groff, M. E. Pepper, K. J. L. Burg.2010. Building off-the-shelf tissue-engineered
7. composites, Philos. T. R. Soc A, 368, 1839.
8. Jepson L., Beaman J., Bourell D., Wood K .1997. SLS processing of functionally gradient materials. Proc SFF Symposium , University of Texas, Austin ,67.
9. C.van der Eijk,T. Mugaas, R. Karlsen, 2004.Metal printing process development of a new rapid manufacturing process for metal parts. Proceedings World PM 2004 Conference, Vienna, Austria, 294.
10. T. Laumer, M.Karg, M. Schmidt. 2012. Laser Beam Melting of Multi-material Component. Physics Procedia, 39,518.
11. M.Ott, M.F.Zaeh. 2014. Multi-material processing in additive manufacturing. Proc SFF Symposium , University of Texas, Austin, 220.
12. Lappo K.,Wood K.,Bourell D., BeamanJ. 2003.Discrete multiple material selective laser sintering (M2SLS):nozzle design for powder delivery. Proc SFF Symposium , University of Texas, Austin, 93.
13. Santosa J., Jing D., and Das S., 2002. Proc SFF Symposium , University of Texas, Austin, 620.
14. Lappo K.,Wood K.,Bourell D., BeamanJ. 2003 , Discrete multiple material selective laser sintering (M2SLS): Experimental study of part processing. Proc SFF Symposium , University of Texas, Austin, 109.
15. Chianrabuta S., Mellor B., Yang S. 2014. Dry Powder Material Delivery Device for Multiple Material Additive Manufacturing. Proc SFF Symposium , University of Texas, Austin, 36.
16. Yu.Chivel . Patent RU № 2580145 , WO 201507539. 11.11.2014, US Patent Appl. 15/038,036.
17. Yu.Chivel. On-line temperature monitoring of the selective laser melting ,2013. Physics Procedia, 41, 897
18. Yu.Chivel. Patent RU № 2640030, WO 2015121730. 06.02.2015.
19. N.Rykalin,A.Uglov,I.Zuev,A.Kokora.1985. Laser and electron beam material processing. Handbook. Mir Publisher, Moscow, 580 p.
20. K. Hsien, K. Bobu, S. Vitek . 1996. Solid solution database. Material Sci. and Eng. , A215, 84.