Lasers in Manufacturing Conference 2017

Selective laser sintering/melting of multi-material parts

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Abstract

New method for 3D multi-material parts production has been elaborated. SLM machine concept and concept of the build platform cleaning system is presented and discussed. Metodology of the multi-material object sintering is proposed for better accuracy of 3D object production having regards to shrinkage and dissolution . Results of experimental investigations of material cross - contamination are presented.

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].

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

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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. Multi-material 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 .

On the build piston 3 of the build chamber (Fig.2 A) 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.

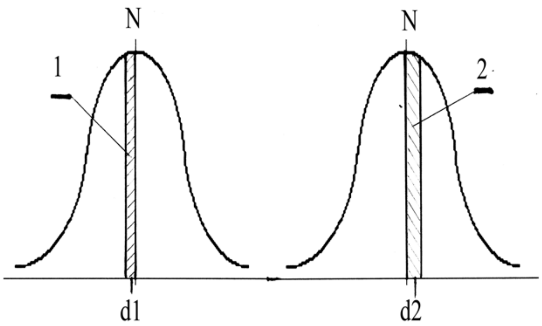


Fig. 1. Powders distributions

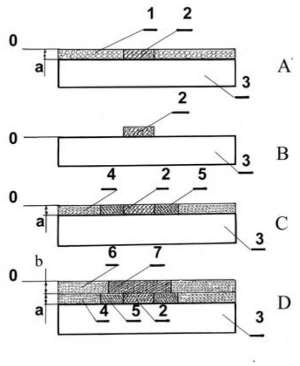


Fig. 2. Stages of multi-material sintering

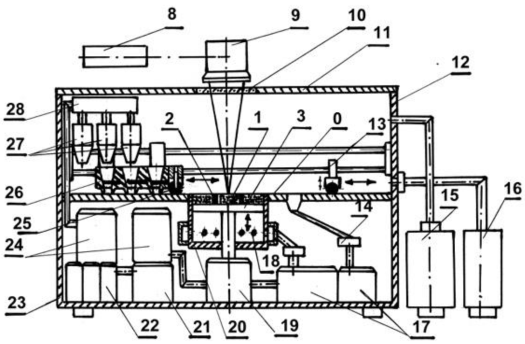
After the sintering of this layer the build piston is lowered through a height **b** of the next layer (Fig.2D) . The new powder layer 6 is applied and the above – listed operations are carried out at new layer, as an example, sintering the area 7.

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. Concept of SLM machine

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. The essence of the conception is illustrated in fig.3. where:



(a) (b)

Fig. 3. (a) Selective laser melting machine design.(b)- sketch project
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. Now the project is under construction (fig.3b).

4. Buid 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, a 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

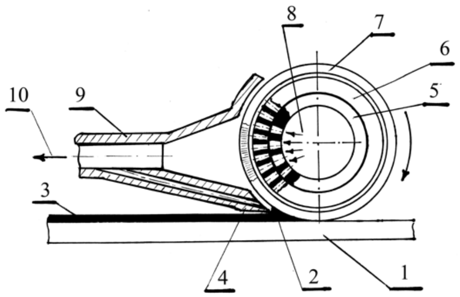


Fig. 4. Build platform cleaning system design
1- build platform, 2- powder beard,3- powder payer, 4- channel of vacuum removing of the beard, 5- axis of the cleaning roller, 6- shaft of the cleaning roller, 7- brush, 8- gas supply,9- brush cleaning device

5. Investigation of material cross - contamination

One of the main problem in multi-material processing is material cross- contamination [ ] . The cross-contamination effect in our designed system has been studied experimentally. Special experimental procedure has been conducted (fig.5,6).

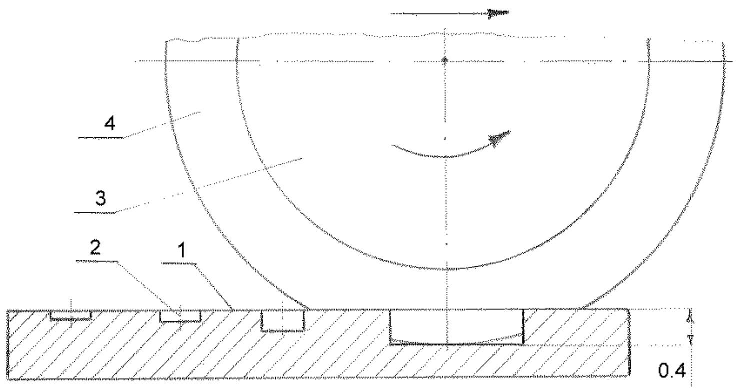


Fig. 5. Scheme of experimental procedure. 1- plate, 2- grooves,3- roller,4- pile coating.

Grooves 2 in a steel plate of depth 50,100,200,400 micron were filled with steel powder 30 µm in diameter. Cleaning roller 3 with the special high – temperature (T > 1500 K) silica pile coating 4 was moved with rotation and removed the powder from the grooves (fig.6)

a

b

c

Fig. 6. Stages of the experimental procedure.

Experiments showed that the pile coating absorbs and removes the powder perfectly, leaving less than 0.1% (experimental limit) of the powder (fig.6c). During operation of the cleaning system roller moves to the dock station and is cleaned by a vacuum cleaner.

6. Sintering methodology

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 a unidimensional approximation , the position of solid surface is defined as [19]:

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

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 [20]. 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. 7.

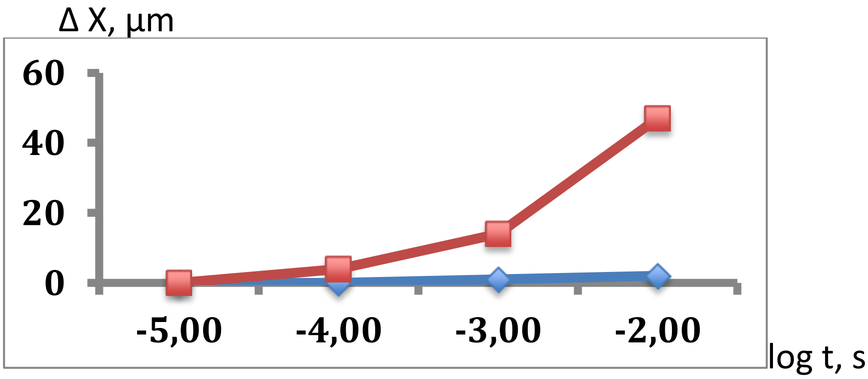


Fig. 7. Dissolution of solid in melt versus time : - $\alpha = 1 \times 10^{-6}$ m^2/s , - $\alpha = 1 \times 10^{-9}$ m^2/s.

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.

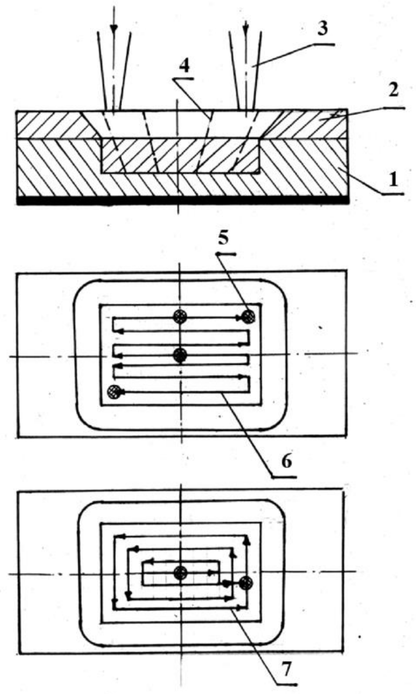


Fig. 8. Strategy of scanning at high shrinkage:1- sintered powder **1**; 2 – powder **2**; 3- laser beam ; 4- melt front; 5- laser spot; 6,7 – scan track.

According to proposed strategy (Fig. 8), 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.

7. 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.

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 .

The cross-contamination effect has been studied experimentally. Not more then 0.1% cross-contamination are fixed. Multimaterial technology has the potential to become an important manufacturing resource for the next generation of AM technology. This is because single material AM 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 etc.

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