Influence of layer-by-layer laser sintering conditions on the quality of sintered surface layer of products

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Abstract. The influence of technological modes of sintering: the displacement velocity of laser beam V, laser power P, scanning step S and preheating temperature of powder material t on the quality of sintered surface layer of aluminum powder PA-4, copper powder PMS-1 and cobalt-chromium-molybdenum powder DSK-F75 were studied.

1. Introduction
Nowadays the most innovative direction in modern industry is additive technologies allowing manufacturing complex functional products from powder materials based on 3D-CAD model [1]. These technologies vary from the other by the way of obtaining ready components – not by removal of material layer from rough materials but by using layer-by-layer building-up of materials at the same time obtaining the required shape and size of product [2, 3]. Using this technology brings reduction in raw materials consumption by 75 %. The main problems of using considered technologies in Russia are connected with application of imported equipment and materials [4, 5, 6]. Production by means of layer-by-layer laser sintering from domestic powder materials requires conducting experimental studies to define sintering modes and find out their influence on the quality of sintered surface layer.

2. Result and Discussion
The present work describes influence of technological modes of sintering: the displacement velocity of laser beam V, laser power P, scanning step S and preheating temperature of powder material t on the quality of sintered surface layer of domestic powder materials with different melting temperature. Experimental studies were held on technology laser complex consisting of ytterbium fiber laser LK-100-V, three-axis table, computer numerical control (CNC) and original program software [7].

Powder materials of different size and different melting temperature were selected for processing to analyze behavior of powder materials under laser sintering.

- Aluminum powder PA-4 is manufactured from primary aluminum by means of pulverization. Percentage of active aluminum: 98 %. Powder melting temperature: 660 °C. Bulk density: 0.96 g/sm³. Powder size: 0.07 mm. At the present moment aluminum and its alloys are used in many fields of industry and engineering. Primarily aluminum and its compounds find application in aviation and automobile industries. Aircraft structures, engines, blocks, cylinder heads, crankcases, pumps and other components are manufactured from aluminum and its alloys.

- Copper stabilized powder PMS-1, with copper content of 99.5 %. Range of powder melting temperature: 1030-1070 °C. Bulk density: 1.25-1.9 g/sm³. Powder size: 0.07 mm. Powder is used in powder metallurgy for production of sintered products, and in instrument engineering [8].
- Cobalt-chromium-molybdenum powder DSK-F75, with cobalt content of 66.4 %, chromium of 28 %, molybdenum of 3 %. Range of powder melting temperature: 1350-1450 °C, bulk density: 8.4 g/sm³. Powder size: 0.1 mm. Powder is used in machinery engineering for manufacturing components operating under high temperatures.

In order to provide quality of sintered surface layer from powder materials with different range of melting temperature, alteration in the level of deformations and thickness of sintering depending on sintering modes were studied [9].

Samples of sintered single layer (20 mm long, 5 and 10 mm wide) were obtained during experimental studies. The areas of technological modes of layer-by-layer laser sintering were distinguished resulting from exploratory studies. For obtaining sample from powder PA-4, with some mechanical strength the rational mode is: P=(10-20) W, V=(1000-3000) mm/min, S=(0.1-0.2) mm, t=(26-200) °C. For copper powder PMS-1 P=(14-30) W, V=(200-3000) mm/min, S= (0.1-0.3) mm, t=(26-200)°C. Rational mode for powder DSK-F75 is: P=(10-20) W, V=(100-300) mm/min, S= (0.1-0.15) mm, t=(26-200)°C. Power of laser radiation is varied depending on the melting temperature of powder material and temperature conductivity coefficient, particles shape and size. Hard-melting powder material DSK-F75 (powder size 0.1 mm) is marked by increase in power of laser radiation and decrease in beam displacement velocity. Geometric state of the sintered surface was carried out by specially developed methodology with applying instrumental digital microscope [10].

Figures 1-6 demonstrate influence of power of laser radiation on the quality of sintered surface layer. Lack of power while sample sintering leads to their diffusion; power excess, on the contrary, leads to deformation, appearance of longitudinal and transversal cracks and powder inflammation.

Figures 1-2 shows samples made from aluminum powder PA-4. Power alteration: from 10 to 20 W, at the constant velocity V=1000 mm/min, sintering temperature t=26 °C and scanning step S=0.2 mm result in increase in thickness of sintered layer from 0.765 to 1.55 mm. Sample presented at Figures 1-2 has low mechanical strength and diffuses when contacting with it.

Figure 1. Appearance of the sintered surface PA-4 (x2), Sintering modes V=1000 mm/min, t=26 °C, S=0.2 mm, P=10 W.

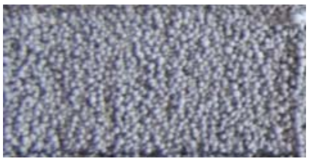

Figure 2. Appearance of the sintered surface PA-4 (x2), Sintering modes V=1000 mm/min, t=26 °C, S=0.2 mm, P=20 W.

Figures 3-4 demonstrates influence of power on appearance of the sintered surface from copper powder PMS-1. Power alteration from 15 to 30 W while V=200 mm/min, t=200 °C, S=0.3 mm leads to alteration of Rz from 475 to 975 µm. Samples resulted to be strong, but with formation of longitudinal and transverse cracks. As the power increases, cracks start to grow due to increase in thermal stresses and high thermal conductivity of powder PMS-1.

Figure 3. Appearance of the sintered surface of PMS-1 (x2), Sintering modes V=200 mm/min, t=200 °C, S=0.3 mm, P=15 W.

Figure 4. Appearance of the sintered surface of PMS-1 (x2), Sintering modes V=200 mm/min, t=200 °C, S=0.3 mm, P=30 W.

Figures 5-6 demonstrates influence of power on the appearance of sintered surface DSK-F75. While sintering this powder coagulation was observed. Coagulation is combining of small particles of dispersed systems into larger ones under the action of adhesion power. Power alteration from 10 to 20 W, while V=300 mm/min, t=26 °C, S=0.1 mm leads to increased coarseness of surface layer from 425 to 625 μm, diameter of coagulated particles from 175 to 325 μm and thickness of sintered layer from 0.65 to 1.0 mm. Sample presented in Fig. 3a is not characterized by large mechanical strength.

Figure 5. Appearance of the sintered surface DSK-F75 (x2), sintering modes V=300 mm/min, t=26 °C, S=0.1 mm P=10 W.

Figure 6. Appearance of the sintered surface DSK-F75 (x2), sintering modes V=300 mm/min, t=26 °C, S=0.1 mm P=20 W.

Figures 7-16 show photographs of appearance of the studied powder materials depending on the displacement velocity of laser beam. Figures 7-8 shows photographs of appearance alteration of the sintered surface of powder PA-4 depending on the displacement velocity of laser beam. Increasing displacement velocity of laser beam from 1000 to 3000 mm/min, while P=20 W, t=26 °C, S=0.2 mm has lead to decrease in the thickness of sintered layer from 1.55 to 1.33 mm.

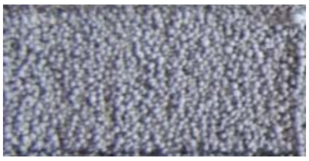

Figure 7. Appearance of the sintered surface PA-4 (x2), sintering modes P=20 W, t=26 °C, S=0.2 mm, V=1000 mm/min.

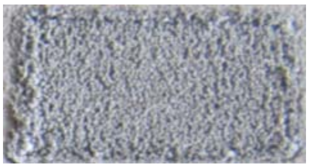

Figure 8. Appearance of the sintered surface PA-4 (x2), sintering modes P=20 W, t=26 °C, S=0.2 mm, V=3000 mm/min.

Figures 9-10 shows samples from copper powder PMS-1, obtained while P=15 W, t=200 °C, S=0.3 mm. When V=200 mm/min defects along and across cracks formation appear on the sample. When V=3000 mm/min, powder does not have time to sinter. When velocity increases the thickness of sintered layer decreases from 1.700 to 0.7 mm. Defects are conditioned by high heat conductivity of powder material, and sharp temperature gradient during and after sintering. Sample given in Figures 10 has low mechanical strength and diffuses when contacting with it.

Figure 9. Appearance of sintered surface PMS-1 (x2), sintering modes P=30 W, t=200 °C, S=0.3 mm, V=200 mm/min.

Figure 10. Appearance of sintered surface PMS-1 (x2), sintering modes P=30 W, t=200 °C, S=0.3 mm, V=3000 mm/min.

Sintering while V=200 mm/min and P=15 W, t=200 °C, S=0.1 mm leads to combustion of powder material (Figures 11-12). Defects placed along and across the cracks formation are observed. While velocity of 3000 mm/min the obtained sample has high strength, and it has no defects. The thickness of sintered layer decreases with velocity increase from 1.0 to 0.7 mm, coarseness 590 to 225 µm.

Figure 11. Appearance of the sintered surface PMS-1 (x2), sintering modes V=200 mm/min и P=30 W, t=200 °C, S=0.1 mm, V=200 mm/min.

Figure 12. Appearance of the sintered surface PMS-1 (x2), sintering modes V=200 mm/min и P=30 W, t=200 °C, S=0.1 mm, V=3000 mm/min.

Samples obtained while modes P=22 W, t=114 °C, S=0.2 mm, when V=200 mm/min and 3000 mm/min form strong sintered surface (Figures 13-14). Increase of velocity leads to alteration of sintered layer thickness from 0.9 to 0.41 mm, Rz from 930 to 550 µm. Sample given in Figures 13-14 has structure of molten metal and is black in color due to formation of copper oxide.

Figure 13. Appearance of sintered surface PMS-1 (x2), sintering modes P=22 W, t=114 °C, S=0.2 mm, V=200 mm/min.

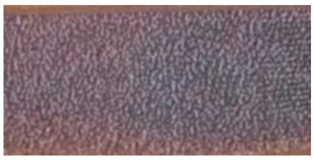

Figure 14. Appearance of sintered surface PMS-1 (x2), sintering modes P=22 W, t=114 °C, S=0.2 mm**,** V=3000 mm/min.

While velocity increase from 100 to 300 mm/min, when P=10 W, t=26 °C, S=0.1 mm, coarseness of surface decreases from 560 to 425 µm, thickness of sintered layer from 0.88 to 0.65 mm (Figures 15-16).

Significant influence of laser beam on the quality of surface layer should be taken into account when setting displacement velocity of laser beam. Velocity increase results in decrease of layer thickness and coarseness; in some cases it is large for formation of sintered surface. Velocity decrease in some cases results in combustion of powder material and appearing of defects due to overheating higher than boiling point.

Figure 15. Appearance of sintered surface DSK-F75 (x2), sintering modes P=10 W, t=26 °C, S=0.1 mm, V=100 mm/min.

Figure 16. Appearance of sintered surface DSK-F75 (x2), sintering modes P=10 W, t=26 °C, S=0.1 mm, V=300 mm/min.

Figures 17-22 present comparison of appearance of sintered surface PA-4 when changing the scanning step. By increase of the scanning step from 0.1 to 0.2 mm, while sintering modes P=10 W, t=26 °C, V=1000 mm/min (Fig. 9) it results in increased thickness of sintered layer from 0.74 to 0.765 mm.

Figure 17. Appearance of sintered surface PA-4 (x2), sintering modes P=10 W, t=26 °C, V=1000 mm/min, S=0.1 mm.

Figure 18. Appearance of sintered surface PA-4 (x2), sintering modes P=10 W, t=26 °C, V=1000 mm/min, S=0.2 mm.

Figures 19-20 shows sintered surface with some strength (scanning step S=0.1 mm and P=15 W, t=200 °C, V=3000 mm/min). Changing scanning step from 0.1 to 0.3 mm decreases thickness of sintered layer from 0.7 to 0.66 mm, increasing Rz from 225 to 425 µm.

Figure 19. Appearance of sintered surface PMS-1 (x2), sintering modes P=30 W, t=200 °C, V=3000 mm/min, S=0.1 mm.

Figure 20. Appearance of sintered surface PMS-1 (x2), sintering modes P=30 W, t=200 °C, V=3000 mm/min S=0.15 mm.

While increasing scanning step from 0.1 to 0.15 mm, sintering modes P=10 W, t=26 °C, V=300 mm/min, Figures 21-22 shows decrease of surface coarseness from 425 to 300 µm, thickness of sintered layer decreases from 0.65 to 0.4 mm, diameter of coagulated particles decreases from 175 to 150 µm.

Scanning step influences quality of surface layer not that significantly. Its influence on powder materials differ. During sintering of powder PA-4 increase of scanning step results in increase of thickness of sintered layer. During sintering of cobalt-chromium-molybdenum composition increase of scanning step results in decrease of thickness of sintered layer, Rz and diameter of coagulated particles. During sintering of copper powder PMS-1 thickness of sintered layer decreases, coarseness increases.

Figure 21. Appearance of sintered surface DSK-F75 (x2), sintering modes P=10 W, t=26 °C, V=300 mm/min, S=0.1 mm.

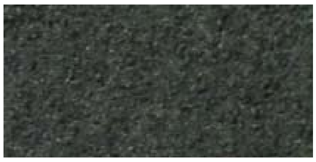

Figure 22. Appearance of sintered surface DSK-F75 (x2), sintering modes P=10 W, t=26 °C, V=300 mm/min S=0.15 mm.

Figures 23-26 demonstrate comparison of appearance of sintered surface DSK-F75 according to preheat temperature of powder material. Preheat temperature of powder material being increased from 26 to 200 °C, while sintering modes P=10 W, S=0.15 mm, V=300 mm/min, coarseness of surface decreases from 300 to 280 µm, thickness of sintered layer increases from 0.4 to 0.65 mm, diameter of coagulated particles decreases from 150 to 115 µm.

Figure 23. Appearance of sintered surface DSK-F75 (x2), sintering modes P=10 W, S=0.15 mm, V=300 mm/min, t=26 °C.

Figure 24. Appearance of sintered surface DSK-F75 (x2), sintering modes P=10 W, S=0.15 mm, V=300 mm/min, t=200 °C.

Comparison of appearance of sintered surface PMS-1 according to preheating temperature of powder material is given in Figures 25, 26. Increased preheating temperature of powder material from 26 to 200 °C leads to decrease of defects size, while the following sintering modes P=30 W, S=0.3 mm, V=200 mm/min. Thickness of sintered layer increases from 1.4 to 1.67 mm.

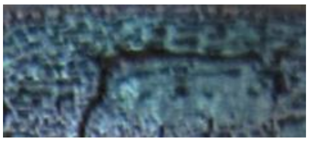

Figure 25. Appearance of sintered surface PMS-1 (x2), sintering modes P=30 W, S=0.3 mm, V=200 mm/min, t=26 °C.

Figure 26. Appearance of sintered surface PMS-1 (x2), sintering modes P=30 W, S=0.3 mm, V=200 mm/min, t=200 °C.

Conclusion

Studies that have been carried out enable to conclude that power has significant influence on the quality of sintered surface layer. Inappropriate setting of power can result in either diffusing from contact or deforming, or combustion of powder so that the process goes out of control. Another significant factor is influence of displacement velocity of laser beam on the quality of surface layer. Increase of displacement velocity results in decrease of thickness and coarseness of sintered layer, in some cases it is insufficient for surface formation. Velocity decrease in some cases leads to combustion of powder material and appearing of defects. Scanning step influences the quality of sintered surface layer insignificantly. During sintering of cobalt-chromium-molybdenum composition increase of scanning step results in decrease of sintered layer thickness, Rz and diameter of coagulated particles. Alteration of preheating temperature of powder material leads to insignificant increase of sintered layer thickness, decrease diameter of coagulated particles and coarseness and increase of strength properties. The present study will be useful for setting the sintering modes for new powder compositions.

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