Title	The Manufacturing Of Cu-Al2O3 Composite Products: Study Of Process Parameters, Structure And Mechanical Properties
Author(s)	Pavel, Lykov; Rustam, Baitimerov; Sergei, Sapozhnikov; Dmitrii, Zherebtcov; Ruslan, Abdrakhimov; Aleksandr, Akmedianov
Citation	Pavel, L., Rustam, B., Sergei, S., Dmitrii, Z., Ruslan, A., & Aleksandr, A. (2016). The Manufacturing Of Cu-Al2O3 Composite Products: Study Of Process Parameters, Structure And Mechanical Properties. Proceedings of the 2nd International Conference on Progress in Additive Manufacturing (Pro-AM 2016), 494-499.
Date	2016
URL	http://hdl.handle.net/10220/41808
Rights	© 2016 by Pro-AM 2016 Organizers. Published by Research Publishing, Singapore

THE MANUFACTURING OF Cu-Al_2O_3 COMPOSITE PRODUCTS: STUDY OF PROCESS PARAMETERS, STRUCTURE AND MECHANICAL PROPERTIES

PAVEL, LYKOV
Aerospace Engineering Department, South Ural State University
Lenin's Prospect 76, Chelyabinsk, 454080, Russia

RUSTAM, BAITIMEROV
Laboratory «Micropowder Technologies»,
Lenin's Prospect 76, Chelyabinsk, 454080, Russia

SERGEI, SAPOZHNIKOV
Engineering-Economical Department, South Ural State University
Lenin's Prospect 76, Chelyabinsk, 454080, Russia

DMITRII, ZHEREBTCOV
Department of Physical Metallurgy, South Ural State University
Lenin's Prospect 76, Chelyabinsk, 454080, Russia

RUSLAN, ABDRAKHIMOV
Department of Physics South Ural State University
Lenin's Prospect 76, Chelyabinsk, 454080, Russia

ALEKSANDR, AKMEDIANOV
Laboratory of physical simulation of thermomechanical processes, South Ural State University
Lenin's Prospect 76, Chelyabinsk, 454080, Russia

ABSTRACT: The purpose of this work is development of a method of producing the Cu-Al_2O_3 composite product by using the selective laser melting technology. The work includes 3 stages: production of composite powder, selective laser melting, mechanical tests of the obtained material. Method of production of composite powder has 2 stages: 1) production of metal powders by atomization of the liquid melt (Cu) in the gas jet, 2) modification of the surface of the metal particles of the second phase (Al_2O_3 nanopowder) in the planetary mixer. Metal powder was produced on URM-001 gas atomizer (patented by South-Ural State University). The surface modification of metal particles is produced in a planetary mixer KURABO Mazerustar kk250 with 5 different modes. Acceptable mode of modification is selected on the basis of the analysis of composite powders on a scanning electron microscope JSM-6400LV. The roundness of powders of Cu and Cu-Al_2O_3 determined using an optical analyzer OCCHIO 500. The conclusion is made about the suitability of powders for use in selective laser melting. The specimens of Cu and Cu-Al_2O_3 were made on the SINTERSTATION® Pro DM125 SLM machine by using different modes (power output, point distance, exposure time, hatch space). Surface end volume energy densities were used for describe of SLM modes. The structure of the composite material (Cu-Al_2O_3) using the chemical mapping was investigated on scanning electron microscopy. The mechanical tests on samples of Cu and Cu-Al_2O_3 made on the GLEEBLE 3800 Thermal-Mechanical Testing system.

Proc. of the 2nd Intl. Conf. on Progress in Additive Manufacturing
Edited by Chee Kai Chua, Wai Yee Yeong, Ming Jen Tan, Erjia Liu and Shu Beng Tor

Published by Research Publishing, Singapore
ISSN: 2424-8967

KEYWORDS: Metal matrix composite, Cu-Al_2O_3, additive technologies, selective laser melting.

INTRODUCTION

Nowadays the additive technologies (Selective Laser Sintering/Melting (SLS/SLM), Electron Beam Melting (EBM), Direct Metal Deposition (DMD)) are used in high-tech industries, such as medical industry, machine manufacturing, aerospace industry, Wohlers (2005), Liu (2014). Further development of additive technologies involves the range expansion of materials used. One of the most promising directions is the creation of products from composite materials. Copper have high electrical and thermal conductivity, high corrosion resistance. Al_2O_3 is well-known hard material with high melting temperature. To combine of these physical properties in this work the method of producing the Cu-Al_2O_3 composite product by using the SLM technology is developed. The work includes 3 stages: production of composite powder, selective laser melting, mechanical tests of the obtained material.

RESEARCH METHODOLOGY

Method of production of composite powder has 2 stages: 1) production of metal powders by atomization of the liquid melt (Cu) in the gas jet, 2) modification of the surface of the metal particles of the second phase (Al_2O_3 nanopowder) in the planetary mixer.

Molten metal (copper) atomization is performed using the URM-1 (patented by South-Ural State University) apparatus (Figure 1,a), Safonov et al. (2011). Melting the metal and a subsequent superheat of the liquid melt at 200-250 °C above the melting temperature were performed using the induction melting furnace; further, as a result of excessive pressure in the sealed cavity of the induction furnace, the molten metal is supplied through the melt flow channel to the central aperture of the spray nozzle. The molten metal jet contacts with the gas jet, which results in atomization of the melt (Figure 1,b).

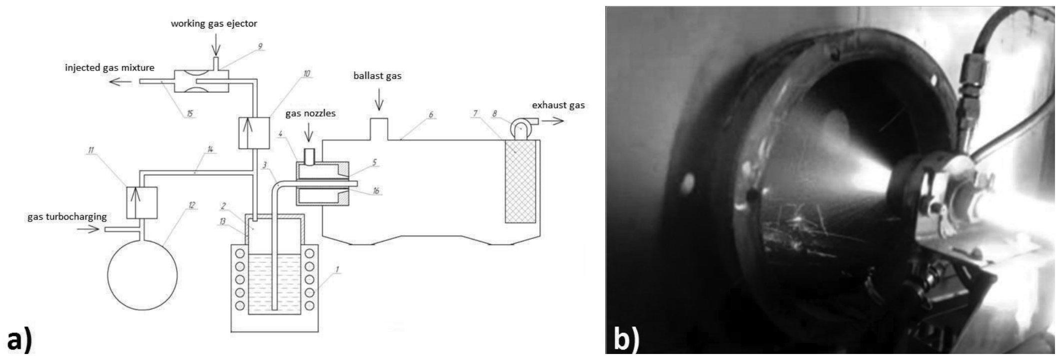

Figure 1. a - scheme of URM-1: 1 – melting furnace, 2 – working cavity, 3 – melt flow channel, 4 – spray nozzle, 5 – gas outlet channel, 6 – bunker, 7 – filter, 8 – ventilator, 9 – ejector, 10,11 – valves, 12 – tank of compressed gas, 13 – cap, 14,15 – channels inlet and outlet of the gas, 16 – central through hole; b - atomization process on URM-1

The surface modification of metal particles is produced in a planetary mixer KURABO Mazerustar kk250 with 5 different modes (Table 1). For characterization of surface modification quality scanning electron microscopy was used.

Table 1. The modes of modification

Mode	Rotation speed of platform, rpm	Rotation speed of container, rpm	Weight of the mixture, g	The proportion of the Cu powder in the mixture, %	The proportion of the Al_2O_3 powder in the mixture, %	Processing time, min
1	1350	1230	10	95	5	2
2	1350	1230	10	95	5	5
3	1350	1230	10	95	5	10
4	1350	1230	20	95	5	15
5	1350	1230	40	95	5	15

The 4x4x4 cubic specimens of Cu and Cu-Al_2O_3 was made on the SINTERSTATION® Pro DM125 SLM machine by using different modes (power output, point distance, exposure time, hatch space). Surface (eq. 1) end volume (eq. 2) energy densities were used for describe of SLM modes (Table 2,3).

$$E_V = \frac{P \cdot ET}{PD \cdot HS \cdot h} \quad (1)$$

$$E_S = \frac{P \cdot ET}{PD \cdot HS} \quad (2)$$

Where P is laser power; ET is exposure time; PD is point distance; HS is hatch space; h is layer thickness.

Structure of fabricated specimens was determined by scanning electron microscopy. JSM-6400LV electron microscope was used. Specimens were polished by using standard procedures and were etched with a $FeCl_3$, HCl and ethanol mixture.

For tensile tests three cylindrical specimens (diameter – 6 mm, length – 120 mm) was fabricated. Tensile tests were carried out on the GLEEBLE 3800 Thermal-Mechanical Testing system at 573 K temperature.

RESULTS AND DISCUSSION

Obtained copper powder is characterized by an average particle size of about 50 micron, Lykov et al. (2013). The powder was seen to be generally spherical under scanning electron microscopy, as shown in Figure 2,a.

Acceptable mode of modification is selected on the basis of the analysis of composite powders on a scanning electron microscopy (Figure 2). The most effective modification without substantially changing the shape of the particles was achieved in mode 2 (Figure 2,c). In comparison with mode 1 (Figure 2,b) Cu particles for mode 2 were covered more uniformly by Al_2O_3 nanopowder. In mode 3 (Figure 2,d) many Cu particles were mechanically deformed due to high processing duration (10 min), that may negatively influenced on powder flowability. In modes 4 and 5 (Figure 2,e and f) copper particles did not cover by ceramic nanopowder. So, mode 2 was chosen for produce of composite powder for SLM.

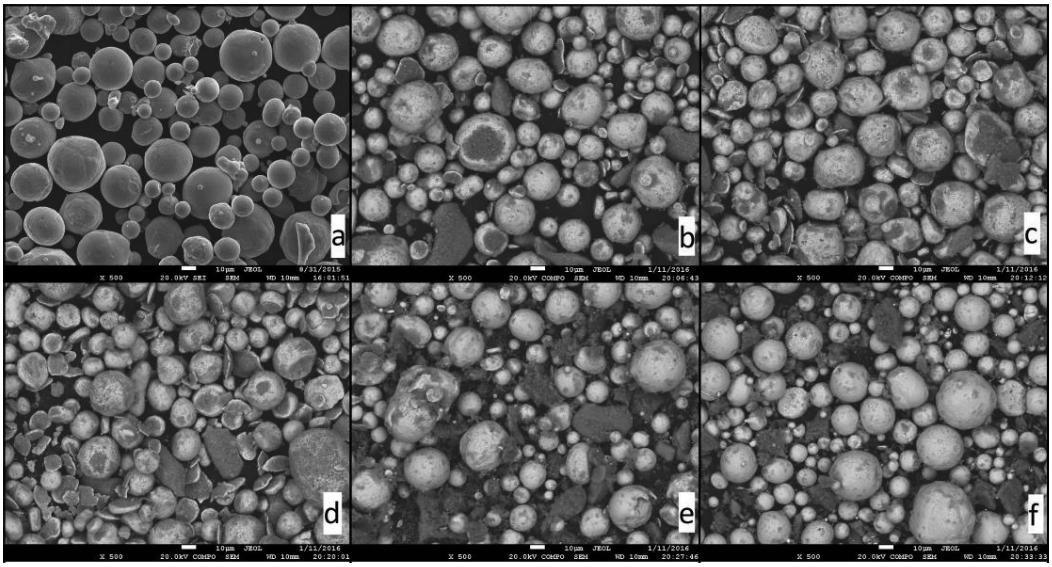

Figure 2. Images of powders (raster electron microscope JSM-6400LV): a – Cu, b – mode 1, c – mode 2, d – mode 3, e – mode 4, f – mode 5

SLM process parameters were chosen based on preliminary experiments of selective laser melting of pure copper powder. SLM process parameters presents in Table 2.

Table 2. SLM modes (Cu-Al_2O_3)

Mode	P, W	ET, μs	PD, μm	HS, μm	h, μm	Diameter of the laser spot, μm	Base plate preheating, °C	E_S, J/mm^2	E_V, J/mm^3
1	200	400	50	50	50	35	140	32	640
2	200	300	50	50	50	35	140	24	480
3	200	250	50	50	50	35	140	20	400
4	200	200	35	35	50	35	140	23	457

The structure of the SLM processed composite material structure presents in Figure 3 in chemical mapping diagrams for Cu, Al and O. Analysis of chemical maps shown that second face is distributed uniformly for all used SLM process modes. Various energy densities does not influence on second face distribution and morphology significantly.

Results of tensile tests presents in Table 3. For fabrication of tensile test specimens SLM mode 1 with highest energy density was chosen. Ultimate tensile strength of SLM fabricated composite material was 110 MPa at 573 K test temperature that less in comparison with cast pure copper. That is explained by porosity of SLM produced material due to low laser radiation absorption and high thermal conductivity of copper, Lykov et al. (2016).

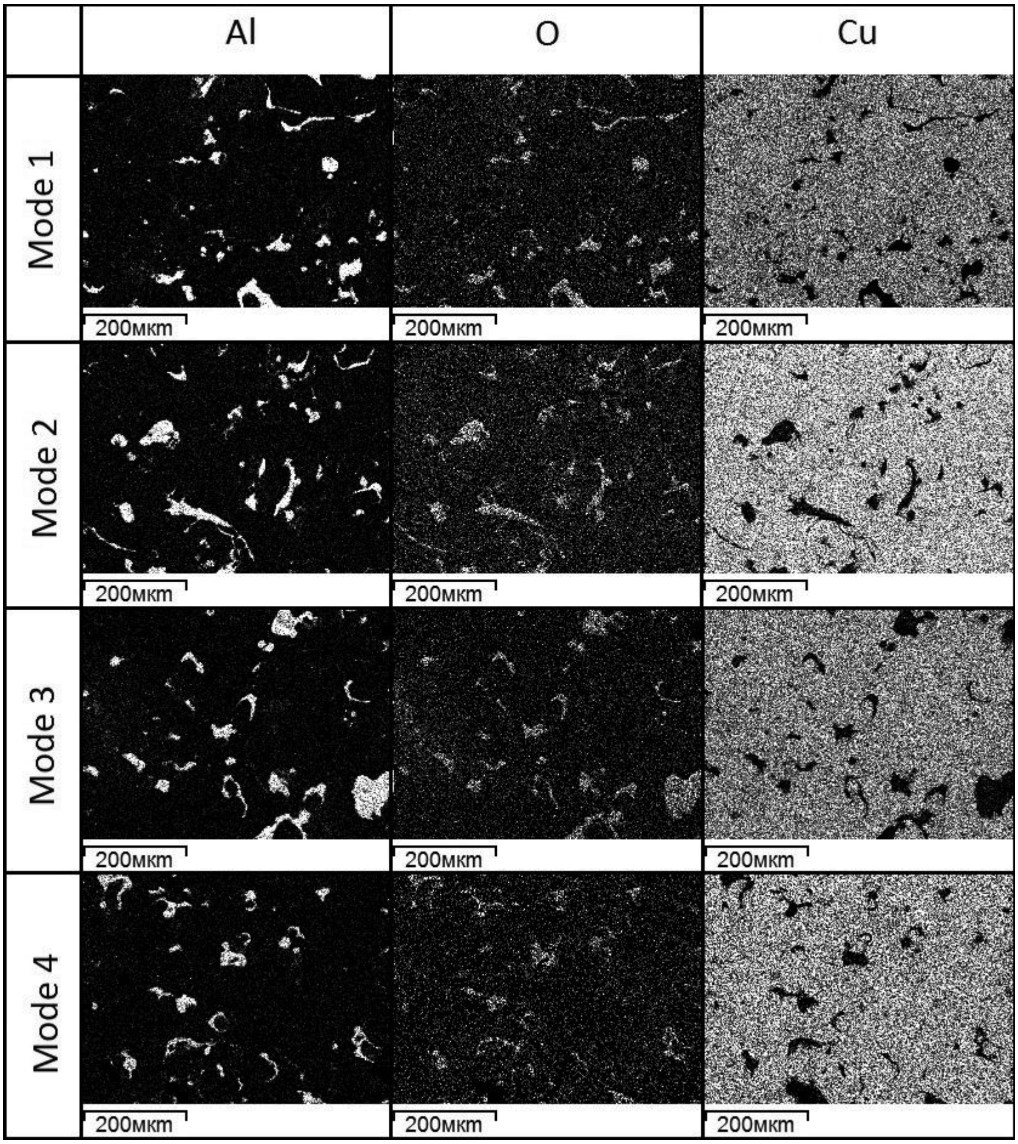

Figure 3. Chemical mapping of SLM produced $Cu\text{-}Al_2O_3$ composite material

Table 4. Ultimate tensile strength - at 573 K

Material	UTS, MPa
$Cu\text{-}Al_2O_3$ (SLM)	110
Cu (cast)	150

CONCLUSIONS

In this paper the development of a method of producing the $Cu\text{-}Al_2O_3$ composite product by using Selective Laser Melting Technology is presented. The mode for producing the composite powder by planetary mixer was determined. 4x4x4 mm specimens for analysis of composite material structure were fabricated using four SLM process modes with different energy densities. Analysis composite material structure shows, that second phase (Al_2O_3) is distributed uniformly for all used SLM process modes. Various energy densities does not influence on second face distribution and morphology significantly. Tensile tests at 573 K test temperatures show that UTS of SLM fabricated composite material (110 MPa) less in comparison with cast pure copper (150 MPa), that is explained by porosity of SLM produced material due to low laser radiation absorption and high thermal conductivity of copper.

REFERENCES

Amorim, F.L., Lohrenge, A., Neubert, V. et al. (2014) "Selective laser sintering of Mo-CuNi composite to be used as EDM electrode", *Rapid Prototyping Journal*, 20(1), 59-68.

Bai, P.K. et al. (2008) "Laser rapid prototyping process of Mo-Cu composites part", *Chinese Journal of Nonferrous Metals*, 18(6), 1094-1099.

Berti, G. et al. (2010) "Mechanical characterization of PA-Al_2O_3 composites obtained by selective laser sintering", *Rapid Prototyping Journal*, 16(2), 124-129.

Bourell, D.L. et al. (1992) "Selective Laser Sintering of Metals and Ceramics", *Int. J. of Powder Metallurgy*, 28(4), 369-381.

Conde, O. et al. (1992) "Laser chemical vapor deposition of TiN dot: a comparison of theoretical and experimental results", *Journal of Applied Physics*, 72, 754-761.

Deckers, J. et al. (2013) "Densification and geometrical assessments of alumina parts produced through indirect selective laser sintering of alumina-polystyrene composite powder", *Strojniski Vestnik – Journal of Mechanical Engineering*, 59(11), 646-661.

Kar, A. et al. (1991) "Three-dimensional transient mass transfer model for laser chemical vapor deposition of titanium on stationary finite slabs", *Journal of Applied Physics*, 69, 757-766.

Kenzari, S. et al. (2012) "Quasicrystal-polymer composites for selective laser sintering technology", *Materials and Design*, 35, 691-695.

Kumar, S. (2009) "Manufacturing of WC-Co moulds using SLS machine", *Journal of Materials Processing Technology*, 209(8), 3840-3848.

Liu, B. et al. (2009) "Study on rapid prototyping preparation process of molybdenum/copper composites", *Journal of North University of China*, 30(1), 85-89.

Liu, F.H. (2014) "Synthesis of biomedical composite scaffolds by laser sintering: Mechanical properties and in vitro bioactivity evaluation", *Applied Surface Science*, 297, 1-8.

Lykov, P.A. et al. (2013) "Powder particle formation mechanism with dispersion of different molten metals", *Metallurgist,* 57(3-4), 232-236.

Lykov, P.A. et al. (2016) "Selective Laser Melting of Copper by 200 W CO2 Laser", *SAE Technical Paper* 2016-01-0333*,* 1-4.

Safonov, E.V et al. (2011) *Russian Patent,* No.110312.

Shi, Y. et al. (2007) "Al_2O_3/SiO_2 composite ceramic parts by selective laser sintering", *Journal of Huazhong University of Science and Technology,* 35(11), 20-23.

Wang, W. et al. (2013) "Effect of SLS process parameters on sintering quality for composite $Al_2O_3/ZrO_2/SiO_2$", *Journal of North University of China*, 34(3), 417-420.

Weiss, W.L., Bourell, D.L. (1992) "Selective Laser Sintering of Intermetallics", *Metallurgical Transactions A*, 24A, 757-759.

Wohlers, T. (2005) *Wohlers Report 2005. Rapid Prototyping, Tooling & Manufacturing State of the Industry*, *Annual Worldwide Progress Report,* Wohlers Associates.