VOL. 13, NO. 4, FEBRUARY 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ANALYSIS OF COAXIAL LASER MICRO CLADDING PROCESSING CONDITIONS

Tarasova Tatiana V.[1], Gvozdeva Galina O.[1], Stefen Nowotny[2], Ableyeva Riana R.[1] and Dolzhikova Evgenia Yu.[1]
[1]Moscow State University of Technology Stankin, Moscow, Russia
[2]Fraunhofer Institute for Material and Beam Technology (Fraunhofer IWS), Russia
E-Mail: tarasova952@mail.ru

ABSTRACT

The laser build-up cladding is a well-known technique for repair, coatings and additive manufacturing tasks. Modern equipment for the laser cladding enables material to be deposited with the lateral resolution of about 100 µm and to manufacture miniature precise parts. However, the micro cladding regimes are unknown. Determination of these regimes is an expensive task as a well-known relation between laser cladding parameters and melt pool dimensions are changing by technology micro-miniaturization. These relations cannot be more used for the laser micro cladding parameters determination. In this paper the formation of single clad track on a Al-alloy substrate by coaxial laser micro cladding using Yb: YAG continuous laser was studied both from a theoretical and experimental point of view. The theoretical analysis concentrated on the laser beam energy transfer using a simple model of heat transfer to the substrate. This approach provides laser micro cladding parameter values required for the formation of desired width clad track to be predicted. For an appropriate experimental analysis of the main process parameters involved, a method based on a gradual change of a single processing parameter was examined. Correlations between the main micro cladding parameters and geometrical characteristics of a single clad track have been found.

Keywords: laser micro cladding, additive manufacturing, aluminium alloys, coaxial.

INTRODUCTION

The laser cladding is a widely used technique for repair, surface protection and additive manufacturing tasks [1]. As an additive manufacturing method the laser cladding has a lot of significant advantages compared with such well-known technique like selective laser melting and electron beam melting: independence of a working space dimension, cladding possibility on a free-form surface. However, precision level of this method is high not enough to manufacture miniature precise parts where application of this method looks like the most cost-effective. Demand for the precise parts increases continuously with the modern trends of techniques micro-miniaturization.

Modern equipment for the laser cladding enables material to be deposited with the lateral resolution of about 100 µm [2-6]. However, the micro cladding regimes are unknown. Determination of these regimes is an expensive task as a well-known relation between laser cladding parameters and melt pool dimensions are changing by technology micro-miniaturization. These relations cannot be more used for the laser micro cladding parameters determination.

The aim of present work is a complex theoretical and experimental investigation on the single track formation on an Al-alloy substrate by coaxial laser micro cladding to determine the relations between the main micro cladding parameters and geometrical characteristics of an single clad track. The data on these relations is necessary to provide a steady manufacturing process using the new laser micro cladding technology.

Experimental

Laser micro cladding experiments were conducted using especially developed experimental equipment. A detailed description of the equipment is presented in [7]. The equipment is composed of:

- Disk laser TrumpfTruDISK 1000 as a laser beam source
- 5-axis machining center Hermle C800U as a positioning system
- Coaxial powder nozzle COAXpowerline
- Powder feeder Twin-system10-C

The investigated materials were gas atomized powders of a AlSi30 alloy. Results of a granulometrical/ granulomorphological analysis of these powders are presented in [7].

After the laser micro cladding experiments were done the occurred samples were investigated first visually, than with an optical microscope and finally by the cross-section preparing. The symbol system used for geometrical characteristics evaluation is presented in [8]. Value of clad track width and depth of penetration are used as melt pool dimensions.

The regimes of the AlSi30 alloy micro cladding were established by analysis supported by several tests.
The available data on dynamic of the laser cladding regimes caused by technology micro-miniaturization was reviewed and analyzed. Thereupon the assumption on laser micro cladding regimes (laser power, scanning velocity, powder feed) for the Al alloys was made.

The influence of the micro cladding parameters (for the selected value regions) on the melt pool size was

investigated first theoretically. This investigations were based on the temperature field calculation occurred at the treatment zone. The obtained temperature distribution was used to determine the melt pool size.

The temperature field calculation was conducted using both conventional N.N. Rykalin equations for a moving Gaussian distributed heat source and the heat transfer numerical model of the Dr. Gussarov where latent heat of melting in the system balance was taken in account. The heat transfer numerical model of the Dr. Gussarov is detailed descripted in the [9]. The results of the conducted computations is a set of data on melt pool size depending on cladding parameters.

With the aim of founding of the correlations between the main micro cladding parameters and geometrical characteristics of a single clad track tests on the single track cladding for the selected regimes were conducted.

RESULTS AND DISCUSSIONS

The excepted dynamic of laser cladding parameters involving by the melt pool size scale from 2…3.5 mm down to 0.1 mm is presented in Figure-1.

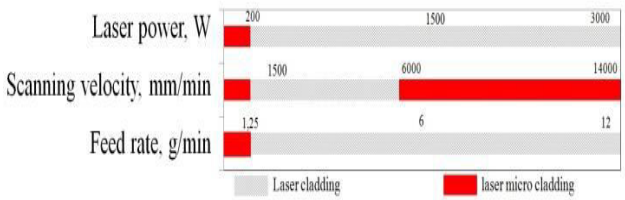
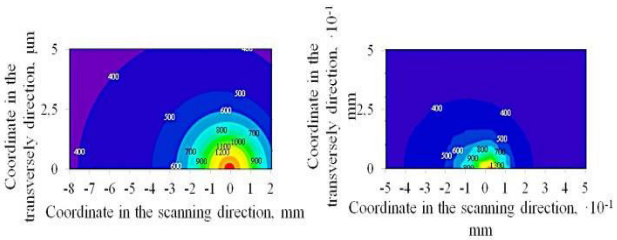


Figure-1. The excepted dynamic of laser cladding parameters involving by the melt pool size scale from 2…3.5 mm down to 0.1 mm.

Results of the comparative calculation of the temperature fields in the melt pool in the case of laser cladding process (by the melt pool size of 2…3.5 mm) and in the case of laser micro cladding process (by the melt pool size of 0.1 mm) are presented in Figure-2. It was shown that there is an extreme increase of the cooling rate and maximal temperature of the melt pool by technology downscale. The maximal temperature in the melt pool by micro cladding (T_{pool} = 1400 K) is significant higher than the AlSi30 alloy melting point (T_{melt} = 2200 K). It means that for the melt pool size prediction in the case of micro cladding latent heat of melting in the system balance should be taken in account.



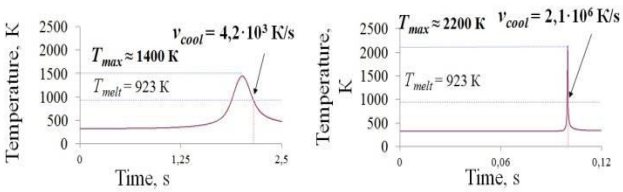


Figure-2. Results of the comparative calculation of the temperature fields in the melt pool for the laser cladding process (left side) and for the laser micro cladding process (right side): temperature distribution on the surface (top), thermal cycle at the point on the surface (bottom).

For this reason a computation of the temperature fields in the melt pool using the heat transfer numerical model of the Dr. Gussarov was conducted. Set of the thermophysical properties used for the computation is given in Table-1. From the temperature distribution analysis obtained as result of the computation (see figure. 3) melt pool profiles were reconstructed (see figure. 4) and a set of data on melt pool size depending on cladding parameters was obtained.

Table-1. Thermophysical properties of the AlSi0, 5Mg alloy.

Parameter	
Melting temperature, K	928
Heat of melting, J/m^3	1,053·10^9
Boiling temperature, K	2792
Evaporation heat, J/m^3	2,84·10^{10}
Heat capacity (solid state), J/(K·m^3)	2,484·10^6
Heat capacity (liquid state), J/(K·m^3)	2,943·10^6
Thermal conductivity (solid state), W/(K·m)	209
Thermal conductivity (liquid state), W/(K·m)	100
Molecular mass	26,98
Density, kg/m^3	2700
Absorption coefficient (λ = 1,03 мкм)	0,43

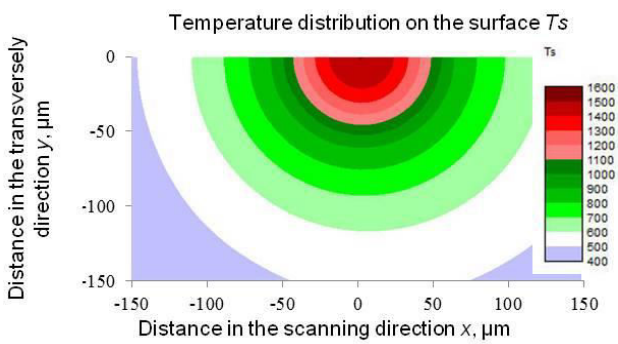


Figure-3. Example of a temperature distribution on the surface Ts, obtained using heat transfer numerical model [9] and used for the melt pool profile reconstruction.

VOL. 13, NO. 4, FEBRUARY 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

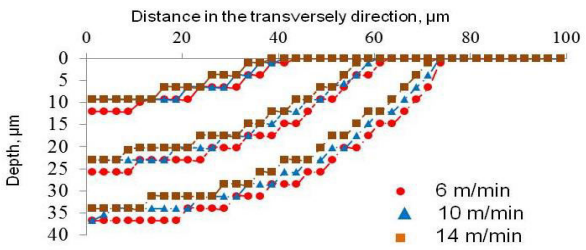


Figure-4. Set of the melt pool profiles obtained as a result of the computation using heat transfer numerical model [9].

A regression analysis of this data set was conducted. The relationships between geometrical characteristics of the treatment zone sizes and laser micro cladding parameters (laser power, scanning velocity) were found:

$$b = 116{,}94 + 33{,}33P - 4{,}17v + 1{,}25P \cdot v - 6{,}67P^2 + 0{,}83v^2 \quad (1)$$

$$t = 23{,}61 + 12{,}83P - 1{,}38 - 0{,}92P^2 + 0{,}46v^2 \quad (2)$$

Based on (1), (2) relationships theoretical technological maps of laser micro cladding were drawn (see Figure-5).

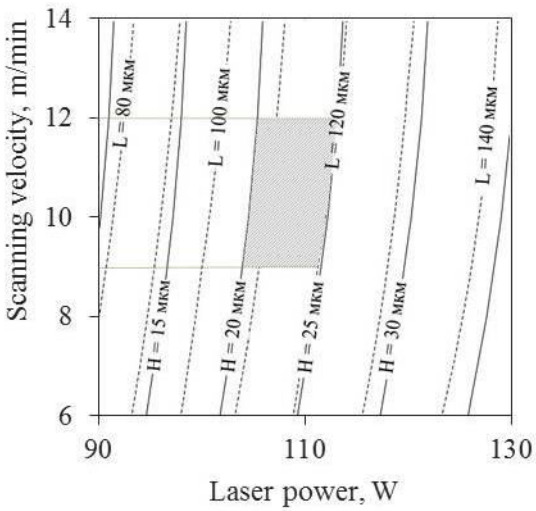


Figure-5. Technological maps of laser micro cladding derived by the computation.

From these technological maps analysis the predicted micro cladding regime to manufacture melt pool of the required size 100 μm were established. This prediction was made without the influence of feed powder to consider, but it can be used as an initial point of an experiment with a minimal powder feed rate. The powder feed rate was continuous increased up to value of 1, 25 g/min. The parameters region used for single track creation is given in Table-2.

Table-2. Parameters region used for single track micro cladding.

Parameter	Value				
Laser power, W	105	110	115	-	-
Scanning velocity, m/min	9	10	11	12	-
Feed rate, g/min	0,125	0,6	1,05	1,15	1,25

The different laser treatment regime (alloying/heat treatment, cladding, debonding) were observed in the investigated regions of parameters value (Figure-6).

Inside area I (the powder feed rate is minimal - see Figure-6) no cladding occurs. By cross section analysis treatment zone can be seen because of structure change comparing to the initial structure of the sample (Figure-7).

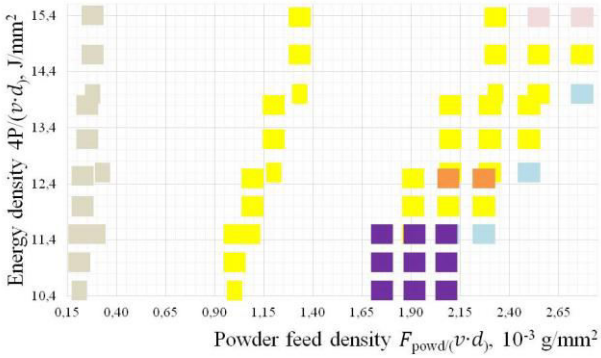


Figure-6. Energy diagram of the laser micro cladding.

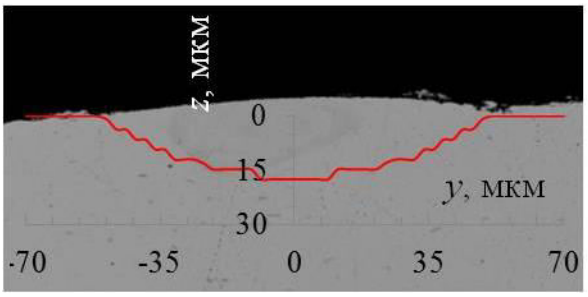


Figure-7. Single track cross-section produced with parameters set from the area I of the energy diagram.

At the same time no clad layer formation on the sample surface was observed both in cross section and by visual regarding. It can be proposed that by the feed rate lower 0, 6 g/min incoming powder plays no significant part in thermal balance. On that ground the data on the melt pool size from this area were used for the verification of relationships (1), (2) derived from the computation. A high value of the determination coefficient confirmed the correlation between calculated and experimental values of geometrical characteristics of a treatment zone (see Figures 8-9).

VOL. 13, NO. 4, FEBRUARY 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

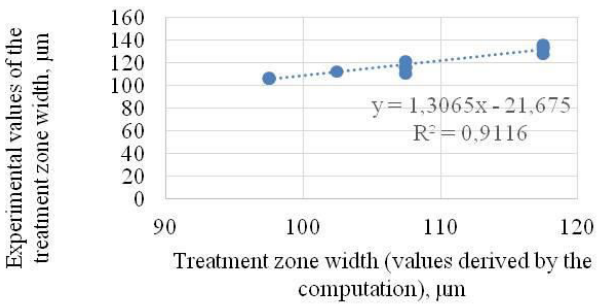


Figure-8. Regression of the experimental and computational values of the treatment zone width from the area I of energy diagram.

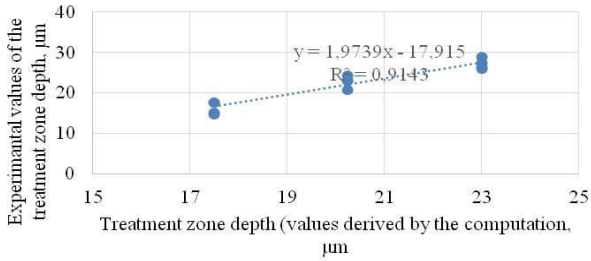


Figure-9. Regression of the experimental and computational values of the treatment zone depth from the area I of energy diagram.

Inside area II, the clad track can be formed but the substrate is not melted and therefore no good metallurgical bond is formed between the laser track and the substrate. Laser cladding is not successful in this area.

Somewhere inside the area III the laser cladding process lies in an optimal zone. The clad track cross section produced using the parameters set from the area III of the energy diagram is presented in the Figure-10.

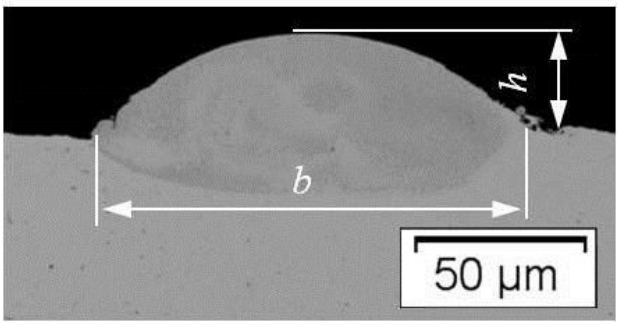


Figure-10. Clad track cross section produced using the parameters set from the area III of the energy diagram (h - track height, b - track width).

Data on melt pool size from this area was used to the relation development between main laser micro cladding parameters and geometrical characteristics of the clad track (equations (3), (4), Figure-11.

$$b = 138{,}4 + 9{,}1P - 5{,}3v + 21{,}9F_{ПОР} + 1{,}5P \cdot v + 1{,}6P \cdot F_{ПОР} - 2{,}1P \cdot v \cdot F_{ПОР} - 1{,}6P^2 - 0{,}7v^2 - 14{,}9F_{ПОР}^2 \quad (3)$$

$$h = 14{,}3 + 3{,}1P - 2{,}6v + 3{,}4F_{ПОР} - 0{,}3P \cdot v - 0{,}4v \cdot F_{ПОР} + 0{,}5P \cdot F_{ПОР} - 0{,}4P^2 + 0{,}5v^2 - 2{,}1F_{ПОР}^2 \quad (4)$$

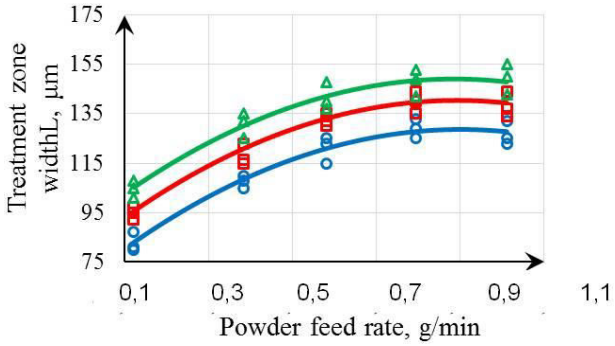


Figure-11. Relationships between treatment zone width and powder feed rate for the laser micro cladding derived by experimental data regression analysis.

Obtained relationships enable to calculate clad track dimension depending on treatment parameters. Using these relationships the technological map of the laser micro cladding was developed (Figures 12-13).

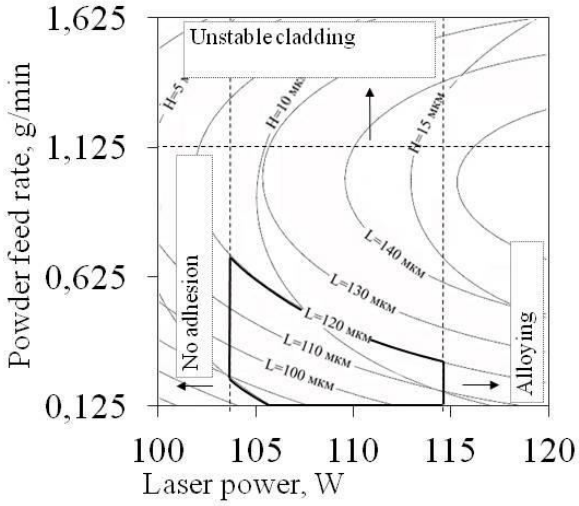


Figure-12. Technological maps of AlSi30 laser micro cladding (scanning velocity fixed at the level 12 m/min).

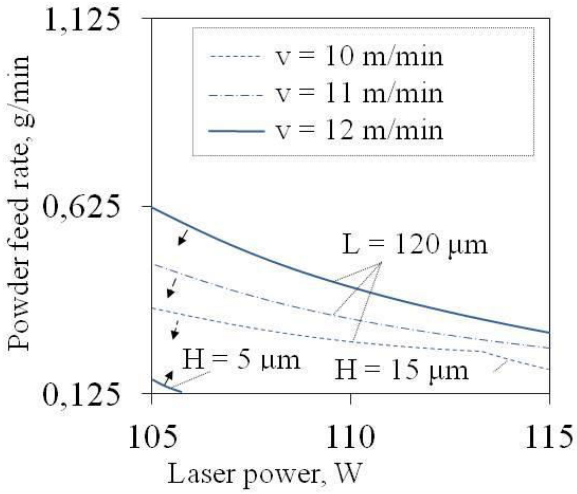


Figure-13. Dynamic of laser cladding regimes by scanning velocity variation parameters set for the clad track formation with a width 100…120 µm was found.

CONCLUSIONS

The complex theoretical and experimental investigation on the single track formation on an Al-alloy substrate by coaxial laser micro cladding was conducted.

The experimental relations between the mainmicro cladding parameters and geometrical characteristics of a single clad track on an Al-alloy substrate were obtained.

Theoretical approach used by Al-alloy laser micro cladding process investigation was verified.

It was demonstrated that single clad tracks with the width of about 100 µm could be produced using parameters set predicted by the developed relationships.

ACKNOWLEDGEMENTS

The work is performed with financial support of the Ministry of Education and Science of Russian Federation within the framework of state assignment №11.1267.2017 /4.6.

The work is carried out on the equipment of the Center of collective use of MSTU "STANKIN" in collaboration with Fraunhofer Institute for Material and Beam Technology.

REFERENCES

[1] St. Nowotny, S. Scharek, E. Beyer, K.-H. Richter. 2007. Laser Build-Up Welding: Precision in Repair, Surface cladding, and Direct 3D Metal Deposition. J. Thermal Spray Technol. 16: 344-348.

[2] F. Br¨uckner, St. Nowotny, M. Riede, F. Kubisch, Ch. Leyens, E. Beyer. 2013. Surface Functionalization by Highprecision Laser Cladding. Laser Technik J. 10: 29–31.

[3] J. Del Val, R. Comesana, F. Lusquinos, A. Riveiro, F. Quinter, J. Pou. 2010. Downscaling of conventional laser cladding technique to microengineering. Phys. Proc. 5: 341-348.

[4] C. Meacock, A. Crespo, R. Vilar. 2007. Laser powder microdeposition of Ti6Al4V for the rapid manufacture of dental implants, in. P. J. Bartolo *et al*. (ed.). Proceedings of the 3rd international conference on advanced research in virtual and rapid prototyping, Leiria, Portugal. 107-113.

[5] S. Sankaré. 2007. Development of a rapid manufacturing process of titanium alloy mechanical parts by micro-laser cladding. Thèse, Université Strasbourg.

[6] J. Del Val, R. Comesaña, F. Lusquiños, M. Boutinguiza, A. Riveiro, F. Quintero, J. Pou. 2010. Laser cladding of Cobasedsuperalloy coatings: Comparative study between Nd:YAG laser and fibre laser. Surf. Coat. Technol. 204: 1957-1961.

[7] Y. A. Melnik, T. V. Tarasova, G.O. Gvozdeva, S. Nowotny. 2016. High precision surface protection of Al-based alloy parts using laser micro cladding. Mechanics and Industry. 17: 710. 1-7.

[8] S.N. Grigoriev, T. V. Tarasova, G.O. Gvozdeva, S. Nowotny. 2014. Microcladding of hypereutectic Al-Si alloys: technological aspects and structure features. International journal of cast metals research. 27(6): 357-361.

[9] A.V. Gusarov, *et al*. 2009. Model of radiation and heat transfer in laser powder interaction zone at selective laser melting. Journal of Heat Transfer. 131(7): 1-10.