PAPER • **OPEN ACCESS**

Application of 316L stainless steel coating by Directed Energy Deposition process

To cite this article: G A Barragan *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1154** 012014

View the article online for updates and enhancements.

You may also like

- Measurement, modelling and optimization of the average temperature at the tool work interface for turning of AISI 1040 steel using ANN-GA methodology
Vishal Kumar Singh, Chandan Kumar, Govinda Besra et al.

- Tribological characterization of TiN coating fabricated by duplex surface treatment of pack-titanizing and plasma-nitriding
Ali Habibolahzadeh and Farahnaz Haftlang

- Study on microstructure and mechanical properties of Ni60 + WC/Ni35/AISI1040 functional surface gradient structure of remanufacturing chute plate for the mining scraper by a low cost high power CO_2 laser cladding technique
J Luo, J J Gao, S W Gou et al.

The Electrochemical Society
Advancing solid state & electrochemical science & technology
242nd ECS Meeting
Oct 9 – 13, 2022 • Atlanta, GA, US
Submit your abstract
Extended abstract submission deadline: April 22, 2022
Connect. Engage. Champion. Empower. Accelerate.
MOVE SCIENCE FORWARD

This content was downloaded from IP address 143.107.227.95 on 11/04/2022 at 13:55

Application of 316L stainless steel coating by Directed Energy Deposition process

G A Barragan[1,2], F Mariani[2] and R T Coelho[2]

[1]Grupo de investigación en Ingeniería Aeroespacial, Universidad Pontificia Bolivariana, Circular 1 # 70 -01, Medellín - Colombia.
[2]Laboratory for Advanced Process and Sustainability - LAPRAS, Engineering School of Sao Carlos, University of Sao Paulo, 400 Trabalhador Sao Carlense ave, Sao Carlos, Brazil.

E-mail: german.barragan@upb.edu.co

Abstract. The corrosion problem faces a challenge for components in different industries. This research project aims to produce AISI 316L coatings in AISI 1045 plates of steel through additive manufacturing (AM) using a laser powder-fed system Direct Energy Deposition (DED) method. The coatings produced will be characterized using microstructural techniques (SEM/EDX and laser confocal), as well as microhardness Vickers. The average hardness value of the coating surface was 220 HV. The use of DED process for the coat of AISI 1045 material with AISI 316L has been proved as an efficient and viable operation.

1. Introduction

The materials employed during the build of a process plant or petrochemical equipment require different properties, among which are mechanical performance, resistance to corrosion, fabricability, and availability stand out due to the characteristics of its operation (highly corrosive and abrasive media) [1]. In many cases, the application itself dictates what materials are needed. Commonly employed materials include, between others, cast iron, alloyed steels, aluminium, titanium alloys, ceramics, and polymers.

The corrosion problem will be given more priority concerning materials for chemical process industries, than in other industries [2]. Carbon steels are widely used for either structural purposes or process equipment purposes [3]. Nevertheless, corrosion is its primary cause of failure [4], [5] with a substantial economic and environmental impact [6].

Directed Energy Deposition (DED), defined as "a category of additive manufacturing (AM) processes in which material is deposited onto a substrate employing the fusion and formation of a melt pool caused by a focused energy source" [7]. It is also used for coating metals with a variety of corrosion resistant or refractory materials [8]. The utilization of such technique in coating and repairing has many advantages, such as a reduced heat-affected zone and part distortion [9], [10].

AISI 316L manufactured by AM methods have been the focus of multiple studies covering aspects such the mechanical properties [11], [12], [13], [14], [15] and corrosion behaviour [16], [17] founding properties comparable with the cast and annealed wrought materials [18], [19], [20], [21].

During this research, a 316L stainless steel powder was deposited over a substrate of AISI 1045 steel employing the DED technique with laser as an energy source. The coating quality and the viability

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

IOP Conf. Series: Materials Science and Engineering 1154 (2021) 012014 doi:10.1088/1757-899X/1154/1/012014

of its utilization for the corrosion improvement method for carbon steels in different applications such as the petrochemical industry was explored.

2. Materials, Equipment, and Methods

2.1. Materials

AISI 1045 drawn bar was selected as a substrate on the presented tests. As feedstock material, LPW 316, an atomized AISI 316L stainless steel powder, was employed with a normal distribution of the particle sizes, varying from 47.9 µm to 108µm. The materials were selected because the coating of carbon steels with stainless steels is a potential application of the DED process to improve its corrosion behaviour. Figure 1 shows an image of the powder used obtained by a laser confocal microscope Olympus LEXT OLS4100. It is possible to notice that spherical is the predominant particle geometry.

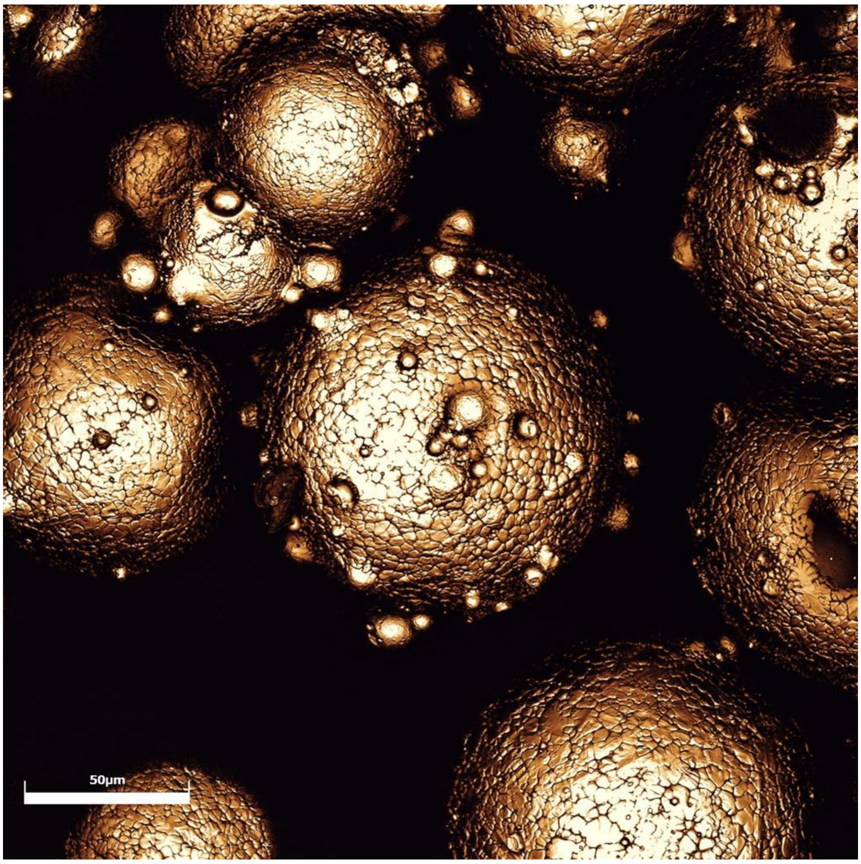

Figure 1. 316 L Stainless steel powder

Table 1 describes a typical chemical composition of the materials used in the here presented research.

Table 1. Material composition (wt.%) [22].

	Fe	C	Cr	MN	Ni	Cu	Mo	Si	S	P	N
AISI 1045	Bal.	0,43 – 0,5		0,06 – 0,09							
AISI 316L	Bal.	0,03	18 - 19	1,0 – 2,0	0,1	1,0	2,25 – 2,5	0,20 -0,75	0,02	0,04	0,1

2.2. Equipment
For the deposition of the coating, the ROMI DCM 620-5X Hybrid was used. It is a typical machining center, capable of metal cutting and equipped with an AMBIT metal deposition head, supplied by Hybrid Manufacturing Technologies, installed besides the regular machine spindle. The laser head is powered by a 500 W Nd: YAG continuous laser operating with 1.070 nm of wavelength. The material was delivered by a powder feeder Metco Twin 150. Powder feed rate was controlled by a rotation metering disk. Additional technical information available in [23], [24].

Figure 2. Deposition head - ROMI DCM 620-5X Hybrid [24]

2.3. Methods
The substrate material was face milled by the machine to obtain a flat surface and remove any existing corrosion film, avoiding possible interference on the coating results. Next, using the deposition head, the focused laser beam produced the melt pool of the carbon steel material at the surface of the workpiece. Then, stainless steel powder coating material is added simultaneously and melted by the laser to form a deposition track.

The deposition experiments consisted of a square surface coating of 225 mm2 employing multiple tracks to obtain a 316L thickness material of 1,5 mm over the substrate. At the present experiments, zigzag strategy was used to cover the entire area, with 90° rotations for each successive layer deposition. A similar strategy was employed by Gong et al, [25]. Using the experience of preceding experiments; the process parameters were selected to obtain an adequate track geometry for the coating procedure. Feed speed 350 mm/min, the feedstock material delivery rate of 5,5 g/min and laser power 300 W, they were not altered during layer stacking. The process was carried with a protective argon flux delivered by the deposition head in ambient atmospheric conditions.

Microhardness test, optical and scanning electron microscopy evaluation were carried out on the samples. The metallographic workpiece was mechanically polished and etched with Aqua Regia reagent.

3. Results and discussions
The sample analysed to assess the quality of the coating and the viability of its utilization for the corrosion improvement method on carbon steels in different applications such as the petrochemical industry. Figure 3 shows an SEM image of a sample cross-section. Three distinctive regions were observed: the substrate, HAZ zone and the coating. The coating tracks seems to be well attached to each other and with the substrate material in a metallurgical way. No significant defects or porosity could be found.

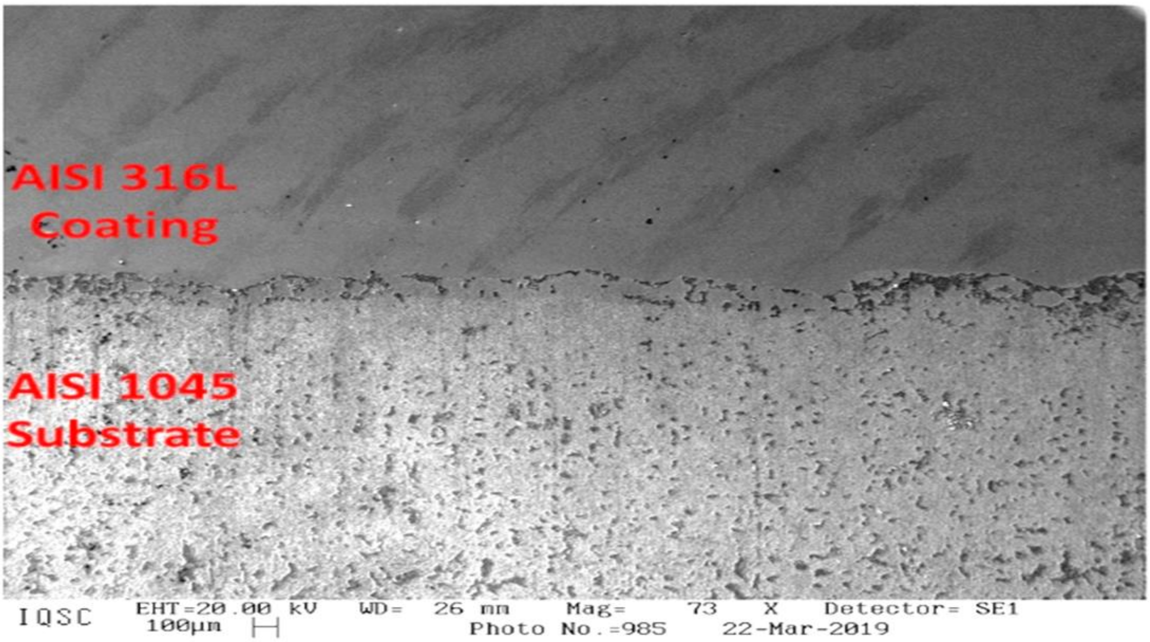

Figure 3. SEM image sample cross-section

An X-ray energy dispersive spectroscopy (EDX) equipment attached to the SEM enabled the chemical analysis quantification of the coating (Figure 4). The objective of such analysis was to check if there were any chemical element lost or diffusion during the deposition process that can reduce the corrosion resistance of the coating material. A stable condition of Cr and Ni was found as an important situation when consider that they are responsible to provide the good corrosion behavior of the 316L stainless steel. Lost, or dilution, of those elements must be avoided.

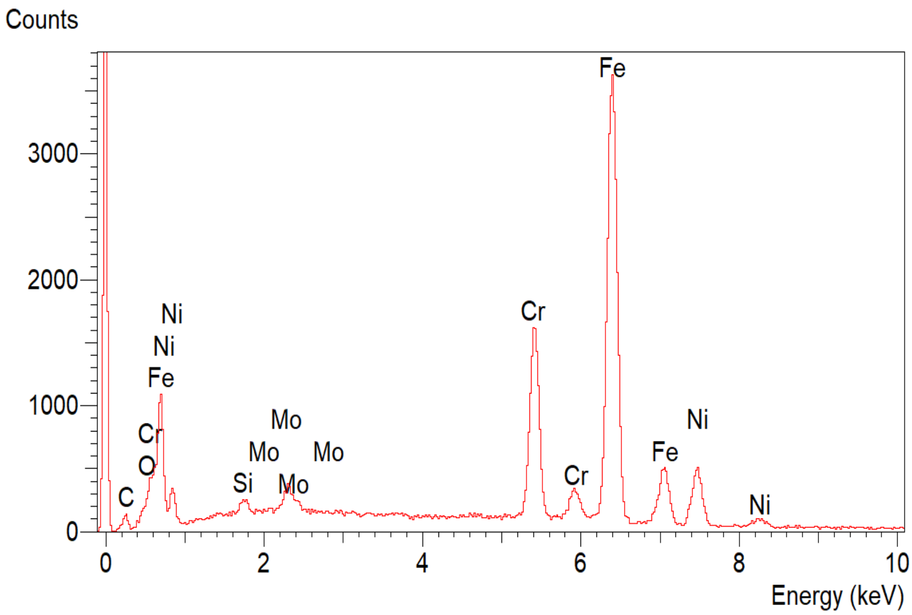

Figure 4. AISI 316L coating chemical analysis

The grain size and microstructure features show a direct relationship with the thermal history occurred during the deposition process under the DED technique. The laser-material interaction time is very short and high cooling/solidification rates are to be expected. Figure 5 shows a typical microstructure optical image of the deposited coating. The observed solidification is the type A. The microstructure is totally austenite, exhibiting cells and dendrites solidification structures.

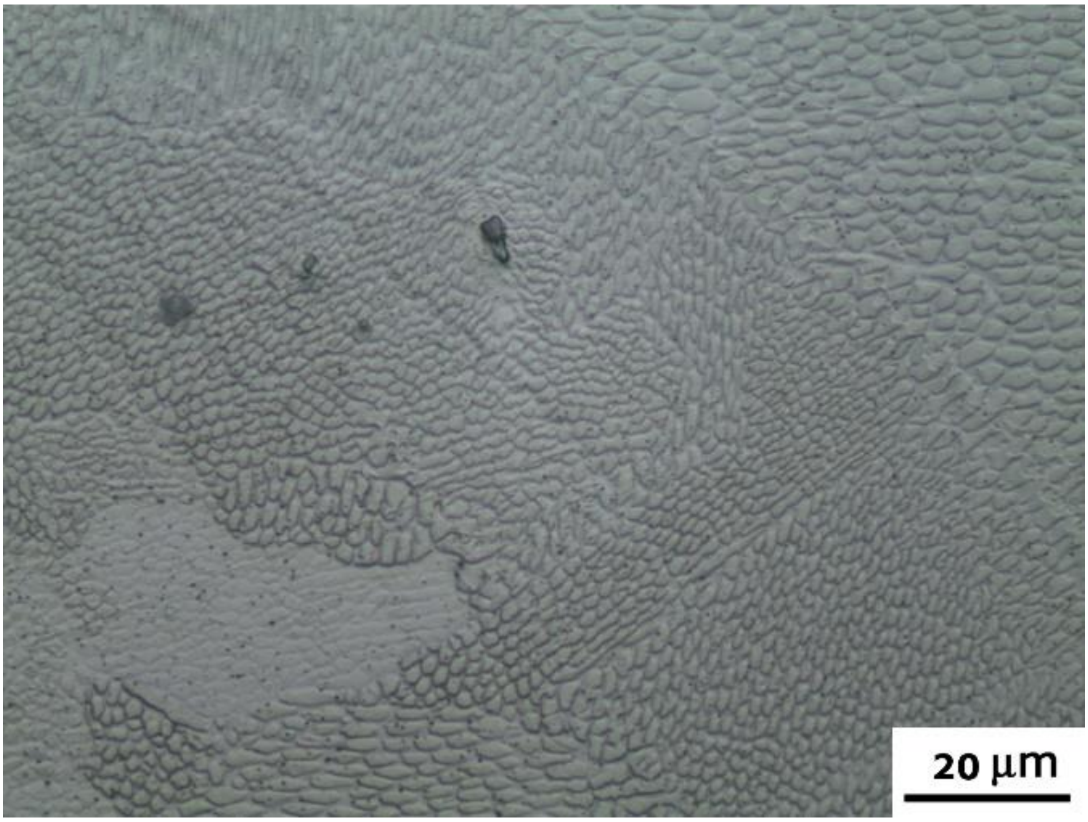

Figure 5. Typical microstructure image of the 316L coating

Microhardness Vickers is an essential mechanical performance indicator. The average workpiece hardness was 220 HV, acquired through averaging 10 measurements at different locations of the coating cross-section. Ahsan, et al. [26] reported a similar hardness value for AISI 316L laser deposited material. A substantial increase of hardness value was evidenced in the HAZ reaching 240 HV. Due to the high cooling rate, in this region, it is plausible to find a hard-martensitic microstructure.

4. Conclusions

The AISI 316L coating was mainly motivated to find a method that offers corrosion protection to the AISI 1045 metal substrate when come into contact with harmful agents, aiming at improvements in workpiece useful life.

The use of Directed Energy deposition process for coating of AISI 1045 material with AISI 316L has been proved to be a viable and feasible process. No considerable defects or changes in coating chemical composition was found, specifically on Cr and Ni contents.

The coating presented a typical microstructure containing austenite and the hardness values show a slight increase, compared with the traditional manufactured 316L.

Low porosity rates presented in the coating could be considered as a good indication of the protective capacity provided by the applied application method.

Acknowledgments
This study was partially financed by the São Paulo Research Foundation - (FAPESP) – grants 2016/11309-0; 2019/26362-2; Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) - Finance Code 001; UPB training agreement - CDG 19.

References

[1] B. Raj, U. K. Mudali, T. Jayakumar, K. V. Kasiviswanathan and R. Natarajan, "Meeting the challenges related to material issues in chemical industries," *Journal of the Indian Academy of Sciences, SADHANA*, vol. **25**, no. 6, p. 519 – 559, 2000.

[2] L. Garverick, Corrosion in the petrochemical industry, ASM international, 1994.

[3] K. Elayaperumal and V. S. Raja, "Materials of Construction for Chemical Process Industries," in *Corrosion Failures: Theory, Case Studies, and Solutions*, John Wiley & Sons, Inc, 2015, pp. 75 - 110.

[4] K. Kidam and M. Hurme, "Analysis of equipment failures as contributors to chemical process accidents," *Process Safety and Environmental Protection,* vol. **91**, no. 1 - 2, pp. 61-78, 2013.

[5] A. S. Makhlouf and M. Aliofkhazraei, Handbook of Materials Failure Analysis with Case Studies from the Chemicals, Concrete and Power Industrie, Butterworth-Heinemann, 2015.

[6] G. Schmitt, "Global needs for knowledge dissemination, research, and development in materials deterioration and corrosion control," World Corrosion Organization, 2009.

[7] ASTM, "ASTM F2792-12a, Standard Terminology for Additive Manufacturing Technologie," 2015.

[8] W. Li and M. Soshi, "Modeling analysis of grain morphologies in Directed energy deposition (DED) coating with different laser scanning patterns," *Materials Letters,* vol. **251**, no. 15, pp. 8 - 12, 2019.

[9] X. Zhang, W. Cui, W. Li and F. Liou, "Effects of tool path in remanufacturing cylindrical components by laser metal deposition," *The International Journal of Advanced Manufacturing Technology,* pp. 1 - 11, 2018.

[10] X. Zhang, W. Li, K. M. Adkison and F. Liou, "Damage reconstruction from tri-dexel data for laser-aided repairing of metallic components," *The International Journal of Advanced Manufacturing Technology,* vol. **96**, p. 3377–3390, 2018.

[11] I. Tolosa, F. Garciandía, F. Zubiri, F. Zapirain and A. Esnaola , "Study of mechanical properties of AISI 316 stainless steel processed by “selective laser melting”, following different manufacturing strategies," *The International Journal of Advanced Manufacturing Technology,* vol. **51**, p. 639–647, 2010.

[12] A. Zhukov, A. Deev and P. Kuznetsov, "Effect of Alloying on the 316L and 321 Steels Samples Obtained by Selective Laser Melting," *Physics Procedia,* vol. **89**, pp. 172 - 178, 2017.

[13] P. A. Kuznetsov, A. Zisman, S. Petrov and I. Goncharov , "Structure and mechanical properties of austenitic 316L steel produced by selective laser melting," *Russian Metallurgy (Metally),* p. 930 – 934, 2017.

[14] C. Wang, X. Tan, E. Liu and S. B. Tor, "Process parameter optimization and mechanical properties for additively manufactured stainless steel 316L parts by selective electron beam melting," *Materials & Design,* vol. **147**, pp. 157-166, 2018.

[15] M. Mukherjee, "Effect of build geometry and orientation on microstructure and properties of additively manufactured 316L stainless steel by laser metal deposition," *Materialia,* vol. **7**, 2019.

[16] M. Lodhi, K. M. Deen and W. Haider, "Corrosion behavior of additively manufactured 316L stainless steel in acidic media," *Materialia,* vol. **2**, pp. 111 - 121, 2018.

[17] M. Lodhi, M. Deen, M. C. Greenlee-Wacker and W. Haider, "Additively manufactured 316L stainless steel with improved corrosion resistance and biological response for biomedical applications," *Additive Manufacturing,* vol. **27**, pp. 8 -19, 2019.

[18] J. Yu, M. Rombouts and G. Maes, "Cracking behavior and mechanical properties of austenitic stainless steel parts produced by laser metal deposition," *Materials & Design,* vol. **45**, pp. 228 - 235, 2013.

[19] T. Amine, J. W. Newkirk and F. Liou, "An Investigation of the Effect of Direct Metal Deposition Parameters on the Characteristics of the Deposited Layers," *Case Studies in Thermal Engineering,* vol. 3, pp. 21-34, 2014.

[20] P. Guo, B. Zou, C. Huang and H. Gao, "Study on microstructure, mechanical properties and machinability of efficiently additive manufactured AISI 316L stainless steel by high-power direct laser deposition," *Journal of Materials Processing Technology,* vol. **240**, pp. 12 - 22, 2017.

[21] M. Akbari and R. Kovacevic, "An investigation on mechanical and microstructural properties of 316LSi parts fabricated by a robotized laser/wire direct metal deposition system," *Additive Manufacturing,* vol. **23**, pp. 487-497, 2018.

[22] ASM , ASM Handbook, Volume 1, Properties and Selection: Irons, Steels, and High Performance Alloys, ASM International Handbook Committee, 1990.

[23] OERLIKON METCO, "Product Data Sheet Metco Twin 150 Powder Feeder," 2017.

[24] ROMI, "ROMI DCM 620-5X HYBR D Catalogue," 2019.

[25] Y. Gong, Y. Yang, S. Qu, P. Li, C. Liang and H. Zhang , "Laser energy density dependence of performance in additive/subtractive hybrid manufacturing of 316L stainless steel," *The International Journal of Advanced Manufacturing Technology volume,* vol. **105**, p. 1585–1596, 2019.