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

G A Barragan¹,², F Mariani² and R T Coelho²

¹Grupo de investigación en Ingeniería Aeroespacial, Universidad Pontificia Bolivariana, Circular 1 # 70 -01, Medellin - Colombia.
²Laboratory for Advanced Process and Sustainability - LPRAS, 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
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 \( \mu \text{m} \) to 108\( \mu \text{m} \). 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](image)

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

|         | 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].

![Deposition head - ROMI DCM 620-5X Hybrid](image)

**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 mm$^2$ 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.
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 3.** SEM image sample cross-section

**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](image)

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.
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