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POTENTIALITY OF HIGH-SPEED LASER CLADDING (HSLC) PROCESS FOR METAL DEPOSITION IN THE BRAZILIAN SCENARIO

POTENCIALIDADE DO PROCESSO EXTREME HIGH SPEED LASER CLADDING (HSLC) PARA DEPOSIÇÃO DE METAIS NO CENÁRIO BRASILEIRO

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ABSTRACT

This study explores the potential of High-Speed Laser Cladding (HSLC) within the Brazilian context. Given the nascent stage of HSLC technology in Brazil, preliminary experiments were conducted to assess its technical feasibility. AISI 316L tubes served as substrates for AISI 316L steel coatings, with the thickness of the deposited layers thoroughly analyzed. Results showed consistently continuous and adherent coatings without delamination. The findings suggest that HSLC is well-suited for high-quality, efficient applications in Brazil's oil, mining, and automotive industries, highlighting its potential to meet the demands of these sectors for innovation and precision.
Keywords: cladding; EHLA; HSLC; laser technology; metallization.

1 INTRODUCTION

Metal coatings are fundamental in protecting industrial components against wear, corrosion, and other types of deterioration, extending their useful life and ensuring operational efficiency (FOTOVVATI; NAMDARI; DEHGHANGHADIKOLAEI, 2019). Hard chrome plating, commonly done by electroplating with chromium chloride, offers durability and hardness but poses environmental and safety concerns due to hexavalent chromium's toxicity. De Araújo (2006) found effluent chromium levels in Recife's electroplating companies exceeded limits by over 36,000 times, causing severe environmental impact. Other coating processes include weld deposition, thermal spraying, Chemical Vapor Deposition (CVD), and Physical Vapor Deposition (PVD), but they have limitations in terms of the quality of the resulting coating, including low adhesion, limited corrosion resistance, and defects in the protective layer (FOTOVVATI; NAMDARI; DEHGHANGHADIKOLAEI, 2019).

Laser cladding, including Laser Cladding (LC) and High-Speed Laser Cladding (HSLC), is gaining industrial acceptance for its low heat input, high precision, and automation. These advanced techniques use a laser to deposit metal onto substrates, with methods such as powder injection, pre-placed powder, or wire feeding. Among these, metal powder injection is particularly effective (TOYSERKANI; KHAJEPOUR; CORBIN, 2004). The key difference between laser cladding and HSLC lies in the interaction point between the additional material and the laser beam. HSLC uses a nozzle to direct powder above the melt pool, melting the particles before they reach the substrate. (SCHOPPHOVEN; GASSER; BACKES, 2017). This difference can be seen in Figure 1.

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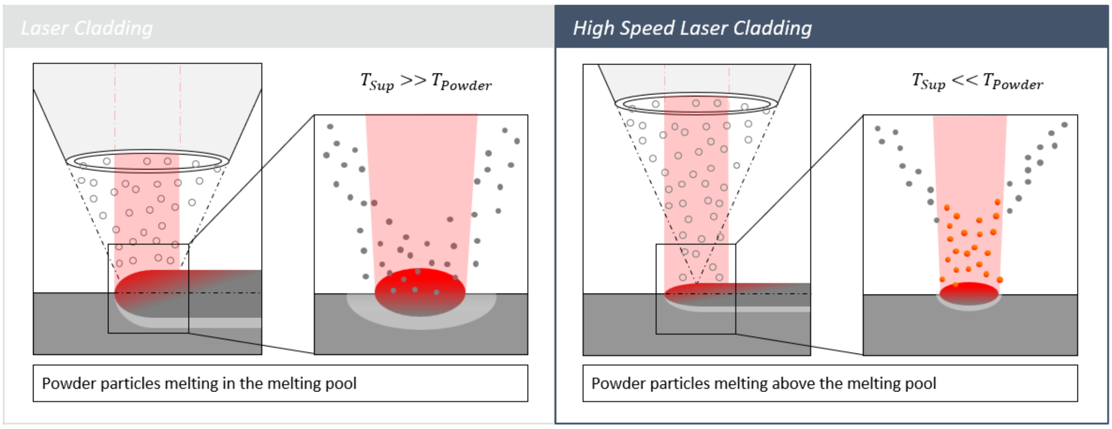
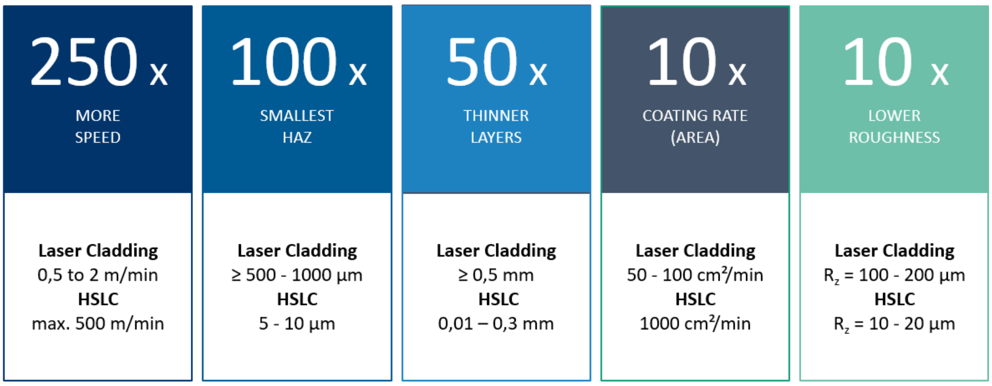
Figure 1 - LC and HSLC comparison



Source: SCHOPPHOVEN (2019)

Both LC and HSLC offer substantial advantages over conventional processes, including coatings with low dilution, refined microstructures, reduced distortion and Heat Affected Zone (HAZ), and superior surface quality (SCHOPPHOVEN et al.,2019). These technologies are versatile, accommodating a wide array of materials and alloys through the use of metal powder as an additional material (LIANG et al., 2023). Figure 2 illustrates the key advantages of HSLC compared to LC.

Figure 2 - Advantages of HSLC over Laser Cladding



Source: SCHOPPHOVEN (2019)

HSLC, developed and patented at the Fraunhofer Institute for Laser Technology ILT in Aachen, Germany (FECHT, 2020), has been adopted in Europe and Asia, exemplified by Dutch

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company IHC Vremac Cylinders BV using it for coating hydraulic cylinders in offshore applications. Hornet Laser Cladding BV, a Dutch company closely associated with Fraunhofer ILT spin-off ACunity GmbH, planned to supply China's first HSLC system in 2017 (SCHOPPHOVEN; GASSER; BACKES, 2017).

Given the limitations of traditional coating techniques, HSLC emerges as a promising alternative. Its chemical-free application makes it environmentally friendly, while the resulting low-porosity layers provide durable protection against wear and corrosion. The dense deposition layer offers effective protection with a single application, and its strong adhesion to the substrate eliminates the need for complex pre-treatment. HSLC addresses concerns about coating thickness, allowing for layers ranging from 10 to 300 µm, and it produces surfaces with low roughness, ensuring high quality and minimizing thermal affected areas, dilution, and part distortions (SCHOPPHOVEN; GASSER; BACKES, 2017). For further details, refer to Table 1 for a comparison of key technology characteristics.

Table 1 – Comparison of the main coating technologies

Characteristic	**Laser Cladding**	**HSLC**	**Welding**	**Thermal Spray**	**CVD**	**PVD**	**Hard Chrome Plating**
Bonding strenght	High	High	High	Moderate	Low	Low	Moderate
Dilution	Medium	Low	High	Nil	Nil	Nil	Nil
Coating materials	Metals and composites	Metals and composites	Metals	Metals and ceramics	Metals and ceramics	Metals and ceramics	Metal
Coating thickness	50 to 2000 µm	10 to 300 µm	1 to few mm	50µm to few mm	0.05 to 20 µm	0.05 to 10 µm	1 to 1000 µm
Repeatability	Moderate to high	Moderate to high	Moderate	Moderate	High	High	High
Heat Affected Zone (HAZ)	Low	Very Low	High	High	Very Low	Very Low	Very Low
Controllability	Moderate to high	High	Low	Moderate	Moderate to high	Moderate to high	High
Cost	High	High	Moderate	Moderate	High	High	Low

Source: The authors (2024)

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HSLC holds vast potential, extending from coating technology to additive manufacturing. In 2015, the global market for hard chrome plating was valued at $13.64 billion, and the thermal spray market at $7.56 billion. A conservative 10% share of the surface refinishing market by HSLC could amount to an annual volume of €2 billion. Another advantage lies in its capability to coat previously uncoated components at scale, enabling the production of innovative parts with enhanced resistance to wear and corrosion over their lifecycle. Moreover, HSLC shows promising applications in additive manufacturing, a sector that has grown by approximately 30% annually since 2011, particularly for manufacturing large components (SCHOPPHOVEN; GASSER; BACKES, 2017).

While these technologies offer numerous benefits, their high initial investment costs have limited their adoption. Nevertheless, advancements in laser source efficiency, cost reduction, and the evolution of new generations like high-power diode and fiber lasers, indicate significant potential for widespread adoption of laser cladding in critical sectors for coating applications (TOYSERKANI; KHAJEPOUR; CORBIN, 2004). Despite Brazil's burgeoning scientific community and technological advancements, there remains a lack of studies focusing on HSLC applications within the country. Although the potential benefits such technology could offer across various sectors, the research in Brazil has yet to fully explore this area. The absence of specialized facilities and expertise could hinder the initiation and progression of studies in this domain. Addressing this gap and fostering interdisciplinary collaborations could unlock significant potential for Brazil to leverage HSLC technology for innovation and economic growth.

This study aims to investigate the potential of HSLC in the Brazilian scenario. Hence, preliminary tests of the HSLC technology were carried out to assess the feasibility and advantages of the technique. To the best of the authors' knowledge, these are the first tests of HSLC conducted in Brazil. The coatings deposited by HSLC were analyzed to understand the potentiality of this technology in the key industrial sectors in Brazil. This work is the result of the international project HIP-LMD (High Productive Laser Metal Deposition), an innovative initiative that aims to develop and improve laser metal additive manufacturing technology in Brazil and Germany.

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2 EXPERIMENTAL

To demonstrate the feasibility of the HSLC process, experiments were conducted on 4” AISI 316L tubes in customized HSLC equipment constructed in the SENAI Institute of Laser Innovation in Joinville (Santa Catarina). The thickness of the coating in the deposited regions was evaluated using an optical microscope Zeiss SUPRA 55 VP FEG-SEM. The experiments were divided into three series, maintaining constant conditions while varying the overlap parameter, defined as the percentage of overlap of each weld bead. AISI 316L powder was used as the additional material. Details of the experimental conditions are provided in Table 2.

Table 2 – Tests and experimental conditions

Tests	Laser Power [W]	Powder Feed [g/min]	Stand Off [mm]	Carrier Gas [l/min]	Deposition Speed [m/min]
1	5000	30	11	5	46
2	5000	30	11	5	75
3	5000	30	11	5	92
4	5000	30	11	5	107
5	5000	30	11	5	127
6	4000	30	11	5	46
7	4000	30	11	5	75
8	4000	30	11	5	92
9	4000	30	11	5	107
10	4000	30	11	5	127

Source: The authors (2024)

3 RESULTS AND DISCUSSION

The results of coating thickness according to overlap values in the HSLC process are summarized in Table 3. Overall, all deposition conditions yielded surfaces of high quality, showing no signs of delamination.

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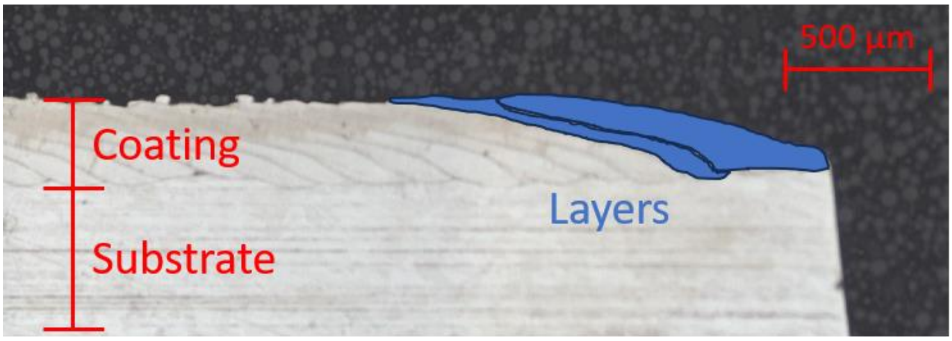
Table 3 – Tests with thickness results and their overlap values

Tests	Laser Power [W]	Deposition Speed [m/min]	Thickness [mm]		
			40%	60%	80%
1	5000	46	0.3	0.33	0.47
2	5000	75	0.3	0.18	0.36
3	5000	92	0.3	0.12	0.22
4	5000	107	0.3	0.17	0.25
5	5000	127	0.3	0.12	0.2
6	4000	46	0.21	0.25	0.45
7	4000	75	0.12	0.21	0.25
8	4000	92	0.09	0.19	0.29
9	4000	107	0.13	0.17	0.22
10	4000	127	0.07	0.11	0.23

Source: The authors (2024)

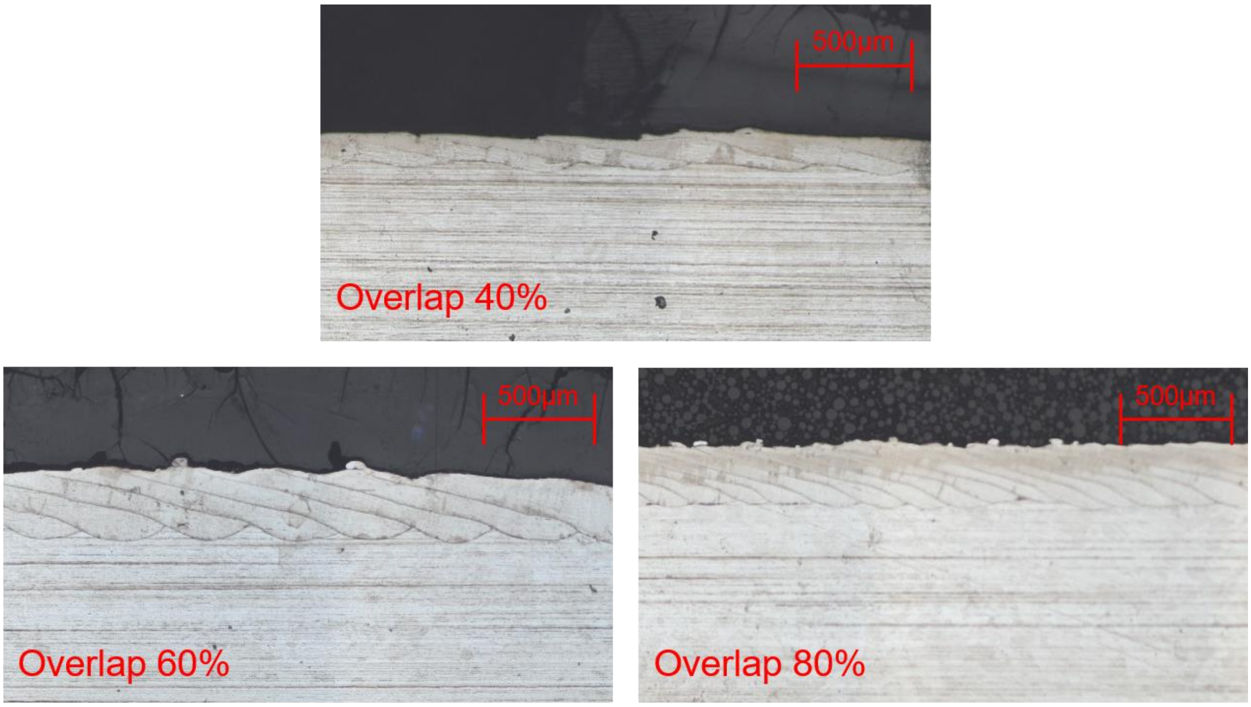
The results from Figure 3 illustrate that HSLC technology produces uniform coatings with minimal waviness and defects such as porosity or cracks. This uniformity and the thin layer thickness facilitate subsequent post-processing steps like machining, and minimizing material removal. Furthermore, the coatings exhibit low dilution, attributed to a small HAZ, which underscores HSLC's effectiveness in preserving the base material's properties. Figure 4 analysis reveals trends in the process: decreasing overlap correlates with thinner layers, reduced spattering, and smoother surfaces.

Figure 3 – HSLC coating



Source: The authors (2024)

Figure 4 – Wave and spatter analysis for different overlap values



Source: The authors (2024)

Brazil, like other regions of the world, is facing a significant opportunity when considering the implementation of HSLC technology. This process is not yet applied on an industrial scale, but several national industrial sectors could benefit substantially, not only in economic terms but also in the environmental context, especially considering that many industries still use hard chrome, a process known for its toxicity, as the predominant coating method.

In the automotive industry, for example, vehicle manufacturers have the possibility of applying coatings to critical engine components such as pistons and cylinders. This application not only aims to improve the efficiency of these components, but also to strengthen their resistance to wear, contributing to overall fuel efficiency. Another component suited for HSLC in this branch is the brake disc. HSLC provides wear and corrosion protection for the component, reducing the particle emissions created by the braking operation. The Brazilian oil sector is also susceptible to benefiting from the HSLC process. Companies operating in offshore environments can adopt coatings on hydraulic cylinder rods, offering more efficient protection against corrosion and wear in adverse

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conditions. In the mining industry, where abrasive wear is a constant concern, applying coatings to equipment such as shovels, drills and grinding hammers can significantly extend their service life, improving operational efficiency. Many companies are investing time and resources in the development of this research, such as Vale S.A., the world's second-largest mining company, which is performing a significant role as the project's financier. The results of this project will benefit not only Vale S.A., but also the smaller mining companies that are part of the project's user committee. This collaboration demonstrates how collective research can have a positive impact on Brazilian industry, promoting sustainable development and innovation.

In addition to these industries, sectors such as energy, food and chemicals can also benefit from the HSLC process. The results indicate that HSLC is highly suitable for meeting the rigorous demands of Brazil's oil, mining, and automotive sectors, demonstrating its capability to deliver innovation and precision in these industries. Therefore, the introduction of HSLC in the Brazilian industrial scenario not only represents an advance in terms of efficiency but also a transition towards more sustainable practices, reducing dependence on environmentally damaging methods such as hard chrome plating.

5 CONCLUSIONS

The HSLC tests proved the viability of this technique as a promising alternative to conventional coating methods, highlighting its significant potential for application in Brazilian industry. Analysis of the coatings deposited by HSLC revealed low roughness and reduced dilution, without the presence of pores. All processing conditions resulted in coatings that were continuous and well adhered to the substrate, without the occurrence of delamination. The lower layer thickness of the process ensures greater precision, reducing the need for post-processing, while the lower HAZ reduces distortions in the piece, making it suitable for the recovery of high-value components. Despite the high investment cost, technological advances are likely to make the process more accessible in the future.

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