WEAR ENHANCEMENT OF HIGH YIELD STEELS USING LASER CLADDING

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ABSTRACT

Laser cladding is a process that uses laser beam as a heat source to melt metallic powder, generating a layer that improves or produces a new surface. The current study aims to improve the base material surface by applying a layer of high alloy nickel via the coaxial laser cladding procedure. The experimental tests were conducted utilizing S700MC steel as base material, owing to its widespread industrial application in agriculture for various components. The cladding tests were performed with a Trumpf TruPulse 556 pulsed laser and a PRECITEC coaxial cladding module. To determine mechanical behaviour, the samples were analysed using optical and electronic microscopy, EDS, microhardness, and wear resistance. The results show that NiCrBSi powder is a suitable material for repairing the S700MC steel and increase the lifespan of components.

KEYWORDS: Laser cladding, NiCrBSi, hardness

1. INTRODUCTION

Laser cladding has become an essential technology for reconditioning worn components or fabricating new functional surfaces, especially in high-demand sectors that require precise solutions for components refurbishing. The cladding process use the laser radiation as heat source to melt a filler material, in the form of powder, which solidifies and bonds to form a cladded / coatings layer on a substrate [1]. It is a multidisciplinary process that involves laser physics, computational design (CAD/CAM), robotic automation, sensor integration, and metallurgy—each contributing to the optimization of layer deposition. Such multidisciplinary integration has enabled laser cladding to meet a wide range of requirements in various industries, including aerospace, automotive, and increasingly, agriculture [1],[2],[3].

Agriculture, the primary source of global food, is experiencing an increasing level of importance alongside the decline of natural resources as industries deal with this transforming journey. However, as agricultural demands grow, especially in the context of natural resource constraints, the concept of "Agriculture 4.0"—or "smart agriculture"—has emerged as an advanced, technology-intensive paradigm for sustainable agricultural practices.

In literature there are emphasized three key agricultural concepts, highlighting how "precision agriculture" is evolving in the context of modern farming practices [4].

The concept of "Agriculture 4.0" brings a range of advantages, including increased crop yields, reduced production costs, and greater accuracy in agricultural practices. By implementing advanced technologies, the agricultural sector could play a significant role in addressing the current food crisis.

While developed nations are gradually embracing the innovations of the fourth agricultural revolution, adoption in developing countries remains limited.

Barriers such as insufficient funding, lack of access to advanced technologies, skill shortages, and inadequate policy support hinder widespread implementation. Gaining a deeper understanding of these challenges and their evolving nature is crucial to formulating effective strategies that can maximize the benefits of Agriculture 4.0.[5].

A main component in enhancing the efficiency and longevity of agricultural machinery is the selection of high-performance materials that can withstand the rigorous demands of modern farming or to recondition the active part of components (eg. Plough strengthening by welding [6]). In this context, the choice of materials used in agricultural machinery becomes particularly important as it directly affects the equipment's performance, durability, and efficiency. Traditional agricultural equipment often relies on conventional steel, which may lack the strength, durability and weight-saving characteristics needed to meet the demands of modern farming practices [7]. S700MC steel is a high-strength steel with exceptional

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mechanical properties, including high tensile strength and good weldability. The superior strength-to-weight ratio of S700MC steel enables the design of lighter yet robust equipment, leading to increased fuel efficiency, reduced soil compaction and improved overall performance. The S700MC steel is also successfully used for roads safety barriers or RRS [8]. However, even high -strength materials like S700MC are susceptible to wear in abrasive agricultural environments (plough, subsoilers etc), necessitating additional treatments to improve surface wear resistance. Various high alloyed powders can be used for increasing the wear resistance of high yield strength steel designated for agricultural tools. To increase the durability, Shan et al. [9] proposed a new method to determine the optimal composition of alloyed powder for increasing the corrosion resistance.

The results indicate that the Fe-based alloy composition 50Cr12Ni3Mo2W6Co5BSiTi3CeO2 is the best option for achieving high wear resistance, with a cladded layer hardness of 567 HV0.2. In a recent study, Singh, S. [10] revealed the advancement of the laser cladding process for preventing slurry erosion of surfaces. The MMC/Hybrid coatings can provide one of the best resistances against slurry erosion. Listauskas et. al [11] highlight that wear and tear of the plough is due to the abrasive particles in the soil that are harder compared with the steel and one solution is to increase the harness of the steel. The performance of high-yield steels can be affected by the intense heating involved in conventional heat treatment or reconditioning processes.

This study presents a novel approach to enhancing the wear resistance of S700MC high-strength steel through laser cladding using Ni-based powders. The primary objective is to produce defect-free cladded layers using NiCrBSi. This method addresses the limitations of traditional surface reconditioning techniques, which often compromise the steels mechanical properties. By using the laser cladding process, the study aims to improve surface performance while preserving the substrate proprieties.

2. MATERIALS AND METHODS

The deposited material used in this study is a Ni-based hard alloy powder (Oerlikon NiCrBSi) and 100x100x5 mm S700MC high strength steel as substrate. S700MC is a high-strength, low-alloy steel with a minimum yield strength of 700 MPa, excellent tensile strength, and good weldability. The hardens of 245 HV and its high strength-to-weight ratio suits demanding applications, but its abrasive wear resistance can benefit from surface treatments like laser cladding. The NiCrBSi filler material, in the form of powder, is spheroidal with 20 – 60 µm and favors the freely-flowing material feed during the process. The chemical composition of materials is summarized in table 1 and table 2.

2.1. Experimental set-up

The cladding process was conducted using a pulsed Nd laser (Trumpf TruPulse 556) with a peak pulse power of 10 kW, combined with a PRECITEC YC 50 coaxial cladding head at a focal length of 200 mm. A Termach AT-1200HPHV feeding system was employed to deliver the filler material, utilizing argon as both the transport and shielding gas.

The powder was introduced into the cladding module via four nozzle outlets, ensuring even distribution around the laser beam. The experimental parameters are detailed in table 3, and these settings were identified as optimal based on our previous research (Cuculea et. al [12]) and of preliminary test trials.

2.2. Methods

The cladded layers were examined and characterized by optical microscopy with a LEICA DML inverted microscope, as well as by scanning electron microscopy (SEM) (Quanta FEG 250, FEI, Netherlands) utilizing a back-scattered electron detector (BSD).

The elemental composition analysis was carried out using energy dispersive X-ray spectroscopy (EDS) with an Apolo SSD detector from EDAX Inc., USA. Microhardness testing was made using a Falcon 600G2 fully automated Vickers hardness tester, with a load range of 0.1 g to 62.5 kgf. For wear testing, a ball-on-disk tribometer from CSM Instruments was used, with a maximum rotational speed of 500 revolutions per minute and a load capacity of up to 10 N.

3. RESULTS AND DISCUSSIONS

The optical microscopy images (figure 1) of the cladded layer reveal that it is relatively thin, with a thickness ranging from approximately 260 to 300 microns. A key advantage of the laser cladding process is its versatility; if a thicker coating is required, additional layers can be deposited, with each subsequent layer fully overlapping the previous one to increase the overall thickness.

The cladded layer exhibits a high-quality surface, free of pores, cracks, or other structural defects.

Table 1. Chemical composition of the NiCrBSi metallic powder

C [%]	Si [%]	Fe [%]	B [%]	Cr [%]	Ni [%]
0.5	3.7	2.75	2.2	11	balance

Table 2. Chemical composition of S700MC steel

C [%]	Mn [%]	Si [%]	P [%]	S [%]	Al [%]	Nb [%]	V [%]	Ti [%]	Mo [%]	B [%]
0.12	2.10	0.16	0.025	0.015	0.015	0.09	0.20	0.225	0.50	0.005

Table 3. Process parameters

Power [W]	Pulse duration [ms]	Frequency [Hz]	Deposition rate [cm/min]	Feed rate [g/min]	Spot diameter [mm]	Energy [J]	Overlapping [%]
2000	5	40	23	6	1.5	10.07	55

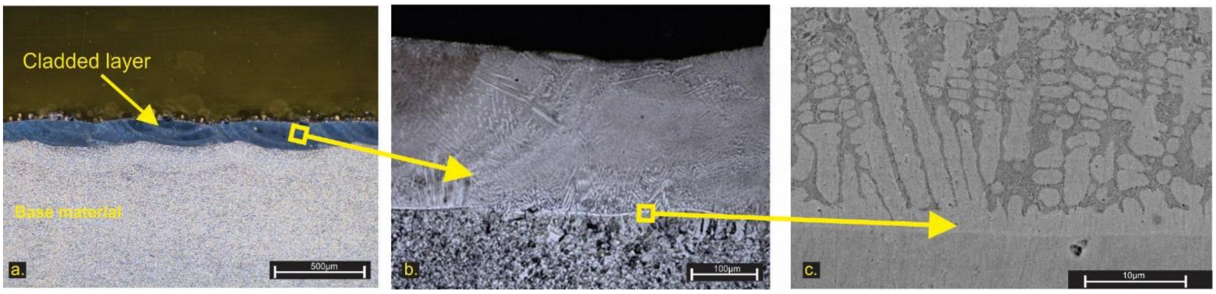


Fig. 1. Cross section of the cladded layer realised with Ni-based powder

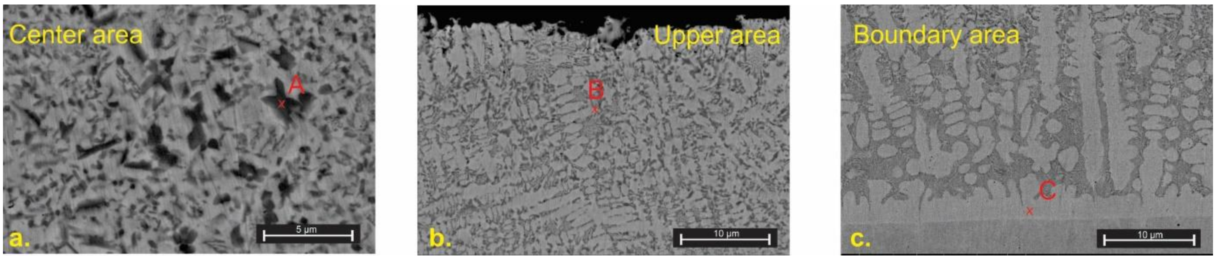


Fig. 2. SEM micrographs and EDS microchemical analyses map. a) central area of the cladded layer, b) upper area of the layer and c) boundary zone with the substrate

Table 4. EDS analyses according to microzones from figure 2

Wt [%]						
Microzone	**Ni**	**Cr**	**Si**	**Fe**	**C**	**O**
A	36.1	18.2	3.7	16.9	14.0	11.1
B	63.3	8.5	3.1	15.0	4.4	5.7
C	21.5	5.2	2.6	59.2	3.1	8.4

The SEM analyses reveal a typical microstructure of the Ni superalloys composed from a Ni-rich matrix with formations of hard phases. Fig. (2a) highlights one of these hard phases, which EDS analysis from table 4, microzone A, confirms as having a high chromium content. The presence of these hard phases significantly contributes to the increased hardness of the coating. Additionally, EDS analysis shows the relative abundances of Fe, Cr, and Ni in the upper region of the deposited layer, each present in high concentrations, which further supports the enhanced hardness and wear resistance of the cladded layer. In contrast, Fig. (2c), corresponding to point C from table 4 localised at the boundary with the base material, indicates a high concentration of Fe with lower quantity of Ni and Cr.

Analysing the EDS data from table 4 it is visible that the iron diffusion from the base material increase from 16.9 % at the top of the layer up to 59.2 at the interface with the substrate. The EDS analysis was conducted without measuring the boron content, as the results could be unreliable due to interference from carbon signals.

4. HARDNESS AND WEAR RESISTANCE

The NiCrBSi cladded layer demonstrates significantly higher hardness compared to the base material;

however, due to thermal gradients, hardness may vary across the coated area. Utilizing a pulsed laser further enhances hardness, as its low thermal input minimizes excessive heat transfer during powder melting. Compared to studies using continuous a laser radiation, our approach achieved a visible increase in hardness, reaching up to 643 HV01.

Figure 3 illustrates the hardness distribution from the upper region of the cladded layer to the boundary zone, where hardness decreases due to dilution effects with the base material. Energy-dispersive X-ray spectroscopy (EDS) analysis shows an increased Fe content in this transition area, significantly impacting the hardness profile. The base material is characterised by a 245 HV01 hardness.

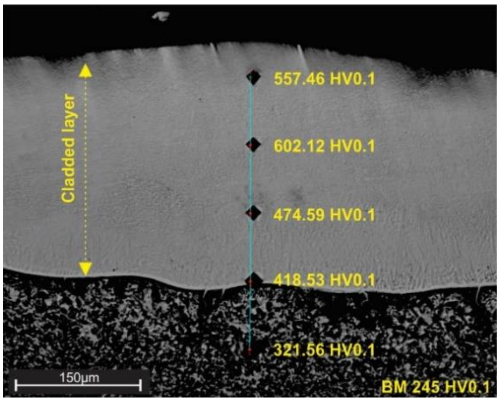


Fig. 3. Harness distribution on the cross-section of the cladded layer

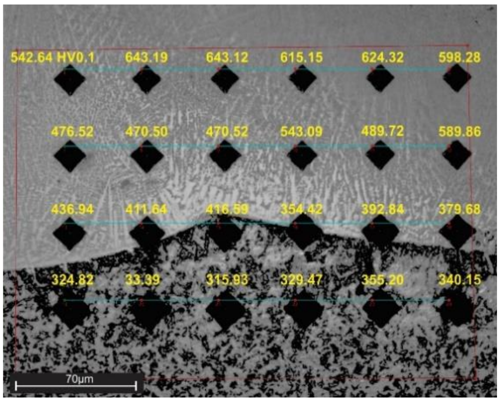
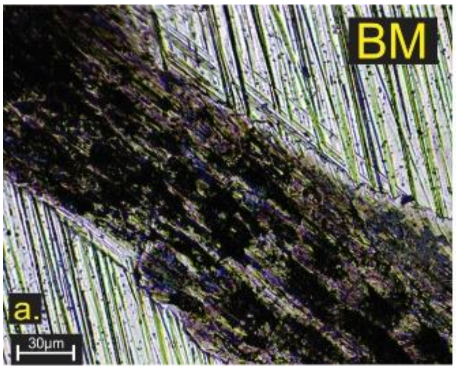


Fig. 4. Hardness map at the interface area between the cladded layer and the substrate

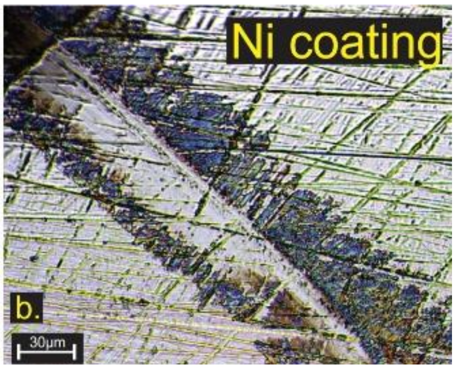
The boundary region of the cladded layer is very important to the cladding layer overall mechanical behaviour, as diffusion phenomena in this area can have a major influence on its properties. Figure 4 presents a hardness map at the boundary area, highlighting the distribution of hardness values across the interface. The map indicates that the highest hardness is concentrated in the central area of the cladded layer, where values exceed 600 HV, showing good fusion with formation of hard phases and low iron content. In contrast, hardness values decrease toward the interface, revealing the influence of dilution with the base material.

The hardness gradient illustrates how the laser cladding process can preserve the filler material proprieties in the upper and middle area of the coating, while the boundary zone, affected by diffusion from the substrate, shows reduced hardness.

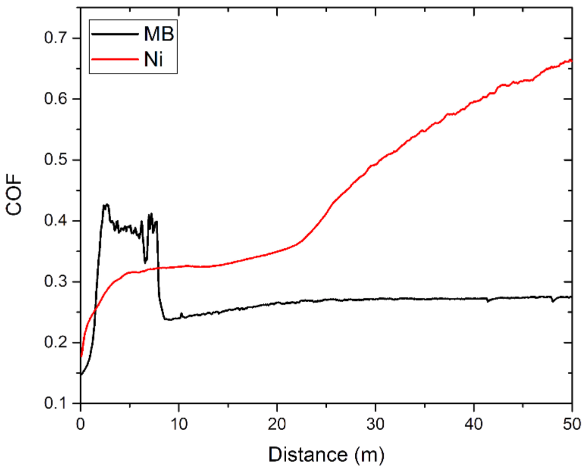
The hardness of the cladded layer outperforms the base material with min. 200%, as an increasing from 245 HV01 on the substrate to a max. of 643 HV01 was determined. Furthermore, the wear behaviour resulted in an interesting result.



a)



b)



c)
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Fig. 5. Wear mark on the surface of MB; a) and cladded layer; b) and c) coefficient of friction (COF) as a function of distance for both materials

Figure 5 a and b show the marks obtained after the ball on disc test on the base material surface and on the cladded layer one. This graph from figure 5 c, illustrates the coefficient of friction (COF) as a function of distance for the BM and cladded layer surface. In this case, the cladded layer, despite its high hardness, exhibits a higher and less stable COF compared to the base material. This elevated COF may be attributed to the presence of hard phases or abrasive particles on the cladded surface. These particles can be exposed during wear, increasing the frictional force but not necessarily leading to higher wear rates. On the contrary, these hard phases can enhance the wear resistance by resisting material removal, even as they increase surface friction. Conversely, the base material, with a lower hardness, shows a lower and more stable COF, but it does not imply superior overall wear performance, as the base material may still experience more significant material removal due to its lower hardness and limited ability to resist wear-inducing forces.

The observed high COF for the cladded layer reflects the friction dynamics and interaction of surface asperities, rather than directly representing the wear resistance, which remains excellent due to the high hardness and proprieties of the cladded layer.

5. CONCLUSIONS

The Ni based cladded layer have been successfully fabricated by pulsed laser cladding, resulting in defect free cladding. The cladded layer is characterised by a dendritic microstructure, with coarse dendrite arms aligned along the direction of the thermal gradient. Additionally, a well-defined metallurgical interface is present between the cladded layer and the substrate.

The cladded layer shows significantly enhanced hardness, with a peak value of 643 HV0.1 compared to 245 HV0.1 for the base material. Energy Dispersive Spectroscopy (EDS) revealed notable diffusion phenomena, particularly the migration of iron from the substrate into the cladded layer (59.2 % iron at the boundary zone). This diffusion caused a localized reduction in hardness up to 418.53 HV01 near the substrate interface. Additionally, hardness measurements showed also lower value of 557.46 HV0.1 in the upper part of the cladded layer attributed to uneven melting and distribution of the powder during cladding process.

The fabricated Ni-based cladded layer demonstrates high wear resistance and increased hardness, primary due the presence of hard phases identified through EDS analysis. These hard phases, particularly those rich in chromium, contribute to the hardness of the coating and enhance its resistance to material removal, as indicated by the minimal wear mark observed. However, the increased hardness and the non-uniform distribution of hard phases also contribute to the increasing of the coefficient of friction (COF).

Laser cladding with NiCrBSi superalloy is a viable method for enhancing or reconditioning of worn parts made of high yield steels. Agriculture is one of the industries that can directly benefit from the development of this technology.

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