METALOGRAPHIC ANALYSIS OF DURABLE LAYERS MADE BY LASER CLADDING FOR EXPOSED PARTS

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Abstract

The main objective of this research is to design and analyse laser cladding with different additive materials and variable cladding parameters. Coatings were produced to increase the corrosion and mechanical resistance of highly stressed rotating parts. Metallographic analysis of the coatings was carried out using optical microscopy, surface hardness measurements and hardness profiles. The coatings were also subjected to wear tests. The laser coatings were made of materials ROCKIT-401, AISI M2 and 410L. All coatings were of high quality with no significant defects. ROCKIT-401 is a suitable material for cladding of wear and corrosion resistant parts due to its chemical composition, high hardness and wear resistance.

Keywords: Laser cladding, metallographic analysis, hardness profiles, wear resistance

1. INTRODUCTION

Laser Metal Deposition or Laser Cladding stands as one of the most relevant processes in development [1] and, thanks to its versatility as an Additive Manufacturing process [2], Laser Cladding technology has become an interesting process for designing and generating parts with complex structures in the industry [3]. In addition to the latter, when dealing with already manufactured parts, Laser Cladding is often used to enhance the wear or corrosion resistance of diverse surfaces and as a way of repairing damaged surfaces. Elements such as tools and dies are able to achieve longer life-times thanks to the addition of functional layers on their surface [4], by coating cheaper bulk materials with more expensive and mechanically better materials, and thus achieving enhanced surface properties.

Protective coatings play a vital role in extending component durability by providing enhanced wear resistance [5]. From a materials perspective, coatings of tungsten carbide (WC)-cobalt (Co) and electrolytic hard chrome are used in a vast majority of engineering applications due to their exceptional wear resistance and good corrosion resistance [6, 7]. However, 'Co'-containing and hexavalent 'Cr'-containing materials are categorized as 'carcinogenic', which compromises the health and safety of operators and end-users [8]. Therefore, identifying non-toxic and sustainable alternatives without compromising the primary functionalities of wear and corrosion resistance is desirable. Alternatives are Fe-based wear resistant coatings, which comprise a metallic Fe-matrix and an intermetallic carbide-strengthening phase [9-12]. Recently, a crystalline Fe-based coating i.e. Rockit-401, processed by laser cladding demonstrated excellent wear and corrosion resistance, which can be an environmentally friendly alternative to the hard-chrome plating due to its low 'Cr' content.

Laser coatings were produced from ROCKIT-401 and alternative materials M2 and 410L. Wear tests, hardness measurements and microstructural analysis were carried out on the coatings to compare them and assess their suitability for high wear and corrosion resistant parts.

2. PREPARATION OF TEST SAMPLES

The laser cladding process was applied to produce the coatings in company LaserTherm on a 60 mm diameter bar made of C45 steel. The coatings were applied in single and double layered. A direct diode laser with a

LASERLINE LDF 6000-40 source and a LaserTherm process laser head - LT-EHSLC90 were used. The coatings were made of ROCKIT-401, AISI M2 and 410L. The cladding materials were from supplier Höganäs AB, a manufacturer of metal powders for powder metallurgy. Rockit 401 is an alloy featuring both good wear properties and corrosion resistance. Rockit-401 is a highly alloyed ferritic-martensitic steel with a high chromium content and it is characterized by good wear and corrosion resistance. The wear resistance of ROCKIT-401 was compared with AISI M2 tool steel, which is a molybdenum based medium alloyed high speed steel Due to its chemical composition, M2 steel offers a balanced combination of properties, i.e. toughness, wear resistance and high hardness. Another cladding material was 410L steel, a chromium martensitic steel that should have good corrosion resistance combined with sufficient hardness and strength.

The chemical composition of the additive materials according to the supplier's certificate is given in **Table 1**.

Table 1 The chemical composition of the additive materials (wt. %)

Material	C	Cr	Ni	P	S	Mo	W	Mn	Si	V	Fe
ROCKIT-401	0.15	18.39	2.40	0.014	0.004	-	-	-	-	-	balance
AISI M2	0.91	3.99	-	-	-	5.0	6.0	0.3	0.2	1.9	balance
410L	0.01	12.6	0.1	-	0.01	-	-	-	0.5	-	balance

3. COMPARISON OF WEAR RESISTANCE BY PIN-ON-DISK METHOD

The principle of the test is to push an indenter with a spherical canopy of a specified radius with a defined force into the test area of the sample, which is rotating at a specified speed. The indenter is pressed against the sample with a predefined force. For the purposes of the test, the samples were ground into a flat surface to the required depth and surface quality. The wear of the material is determined from the indentor mark left in the test material after the test. This is both the volume of own wear (loss) and the indentation (deformation) of the test sample. Wear resistance is expressed by the so-called wear rate. The wear rate is calculated from the parameters of the wear volume, the load and the total distance travelled by the indenter against the sample - see equation (1). The pin-on-disk test was performed on each of the tested samples under the following conditions: room temperature; 15 N load; 6 mm diameter indenter made of Al_2O_3; track radius 1.5 mm; number of cycles 30,000; total travel distance 282.74 m; rotational speed 240 rpm; duration of each test - 2 hours; two tests performed on each sample, from which the average value was calculated.

$$\text{Wear rate} = \frac{\text{Wear track volume (mm}^3\text{)}}{\text{Load (N) x Path travelled by ball indenter (m)}} \ (\text{mm}^3/\text{Nm}) \tag{1}$$

The results measured on the test samples are shown in **Figure 1**. The highest wear resistance was measured for the M2 double-layer coating. The single-layer coating M2 had only slightly worse results. The trend for ROCKIT-401 was similar, with the two-layer coating reaching better results than the single-layer coating. ROCKIT-401 was only slightly worse than M2 tool steel. Coatings with cladding material 410L achieved the worst results. Here, the two-layer sample achieved significantly worse results than the single-layer sample.

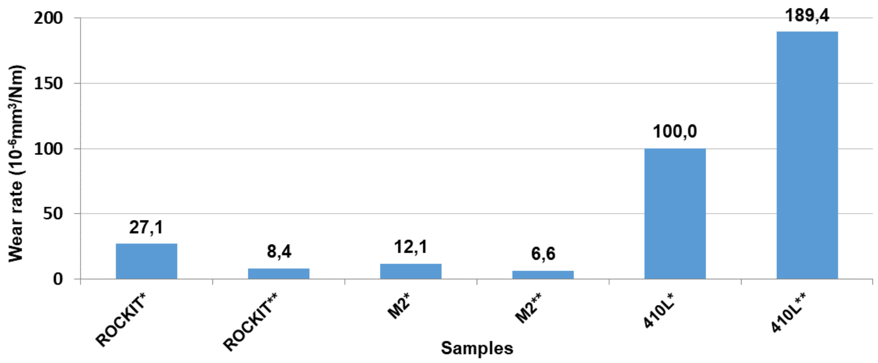

Figure 1 Graphical comparison of wear rates (*single-layer coating, **double-layer coating)

4. SURFACE HARDNESS

Hardness was measured on a STRUERS DuraScan 50 laboratory hardness tester. HV 1 load was chosen for this test. Due to the high surface roughness, the hardness measured 0.3 mm below the surface of the coating was taken as the surface hardness. Coatings made of M2 steel achieve the highest surface hardness of around 800 HV 1. ROCKIT-401 coatings have a lower hardness over 600 HV 1. Double-layer coatings have higher hardness than single-layer coatings. They thus correspond with the measured wear resistance. However, the single-layer coating of M2 steel has a higher hardness than the double-layer coating of ROCKIT-401 and yet has a lower level of wear resistance. 410L steel has a much lower hardness than ROCKIT-401 and M2, mainly the two-layer coating has a surface hardness of only over 200 HV 1. The values shown in **Table 2** are average values calculated from five measured indents.

Table 2 Surface hardness measurement results (HV 1)

ROCKIT-401		AISI M2		410L	
single layer	double layer	single layer	double layer	single layer	double layer
616.2	631.8	785.8	803.6	416.4	215.6

5. HARDNESS PROFILES

The hardness of the single-layer and double-layer coatings is similar for ROCKIT-401 and is around 600 HV 1. The hardness of the single-layer coating near the transition zone is lower. In the heat-affected zone, the hardness is around 400 HV 1. Then it drops relatively quickly to the level of the base material, which has a hardness above 200 HV 1. The hardness of the two-layer coating in the heat-affected zone is below the level of 400 HV 1. Then it drops to the level of the base material. The hardness in the heat-affected zone is lower in a two-layer coating than in a single-layer one, and the drop to the base material hardness level is much more gradual. These differences are caused by higher thermal effects of the base material, see **Figure 2A**.

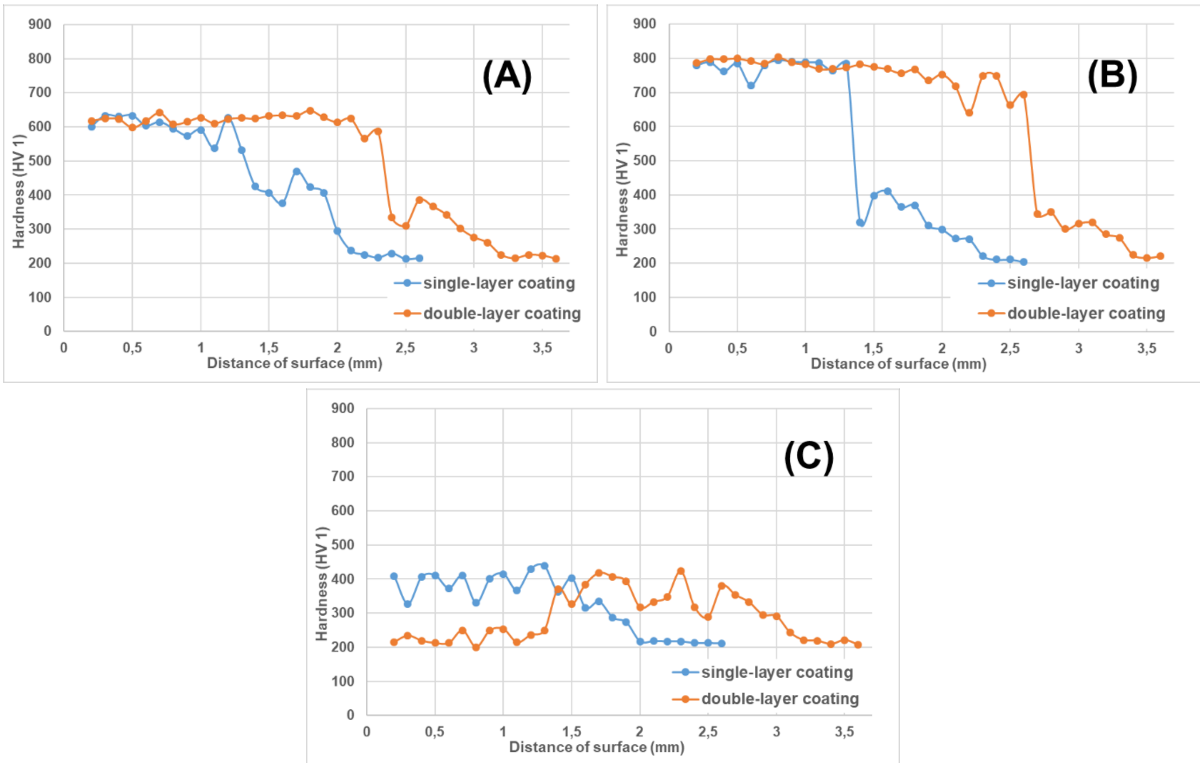

Figure 2 Hardness profiles, (A) - ROCKIT-401, (B) - AISI M2, (C) - 410L

The shape of the hardness profiles of the M2 coatings is similar to ROCKIT-401. Only the hardness of the coatings is much higher and is mostly just below 800 HV 1, see **Figure 2B**.

The hardness profiles of the 410L coatings are different compared to the previous ones. The hardness of the single-layer coating of 410L fluctuates quite strongly around the value of 400 HV 1. The hardness of the outer layer of the double-layer coating is low, only over 200 HV 1. The hardness of the inner layer is higher, fluctuating strongly around 400 HV 1 and is thus similar to the hardness of the single-layer coating. The hardness in the heat-affected zone decreases from 400 HV 1 to the level of the hardness of the base material, see **Figure 2C**.

6. METALLOGRAPHIC ANALYSIS

The height of the single-layer coatings exceeds 1 mm, the height of the double-layer coatings exceeds 2 mm for all cladding materials. All coatings had good metallurgical bonding between the layers and between the coatings and the base material.

No significant defects were observed in the structure of the ROCKIT-401 coatings, only a few small pores. The microstructure of the coatings consists of a martensitic matrix with eutectic hard phases (**Figure 3A**).

In the case of the single layer coating, no significant defects were observed, only a few small pores. Pores up to 1 mm were observed in the double-layer coating. The microstructure of the coatings consists of martensite (**Figure 3B**).

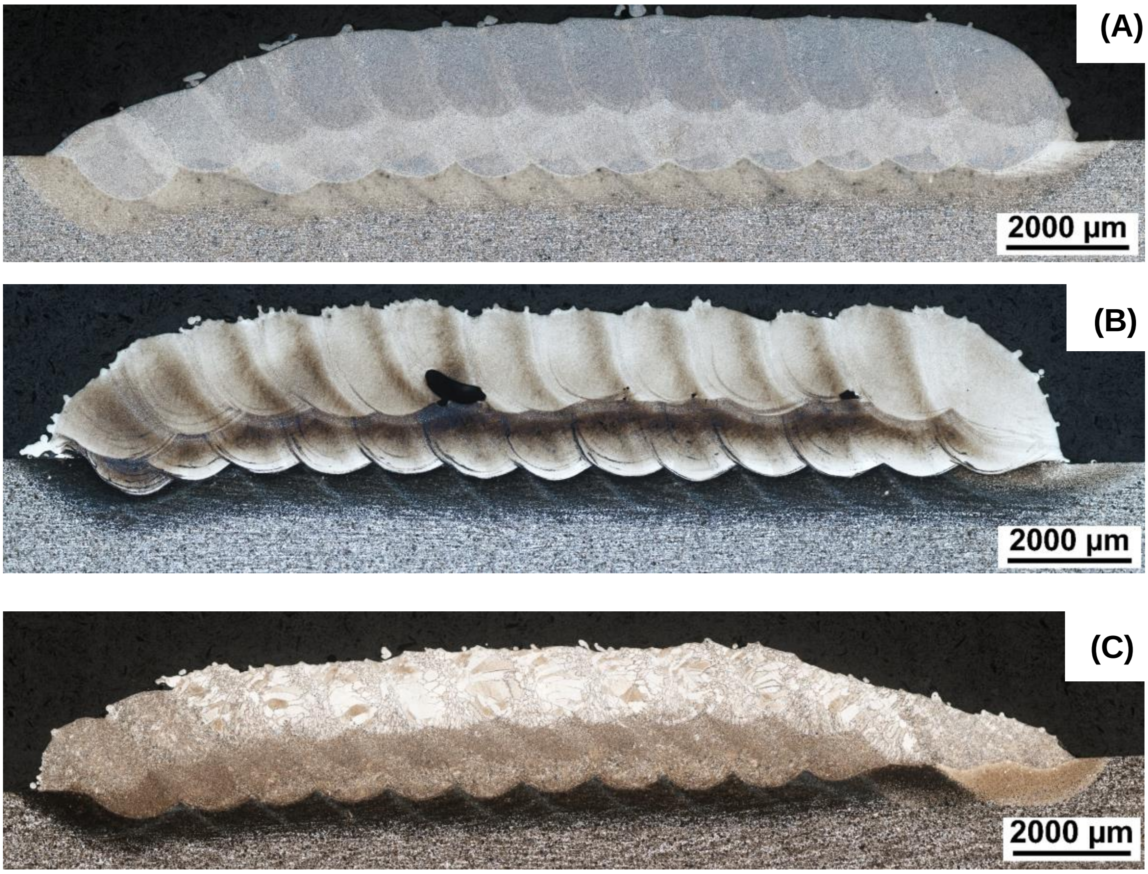

Figure 3 Structure of double-layer coating, (A) - ROCKIT-401, (B) - AISI M2, (C) - 410L

No significant defects were observed in the 410L coatings, only a few small pores, see **Figure 3C**. The microstructure of a single-layer coating consists of martensite, in which a number of small precipitates (probably carbides) are excluded, and their distribution is not uniform. The structure of the double-layer coating is inhomogeneous, with large differences in appearance between the outer and inner layer, see **Figure 4A**. The microstructure of the outer layer is composed of relatively coarse ferrite grains. There are formations of martensite at the boundaries of the primary grains, see **Figure 4B**. These formations are mostly needle-like morphology. Small precipitates (probably carbides) with a globular shape appear in both ferrite and martensite and their distribution is not uniform. The microstructure of the inner layer consists of martensite. There are many small globular precipitates in the martensitic matrix, but they are unevenly distributed in the martensitic matrix. There are large differences in coarseness between the different regions of the inner layer. The microstructure of the material adjacent to the outer layer, which has been affected in the cladding of this layer, is much finer grained than the microstructure of the material adjacent to the base material, which has not been affected in the cladding of the outer layer, see **Figure 4C**.

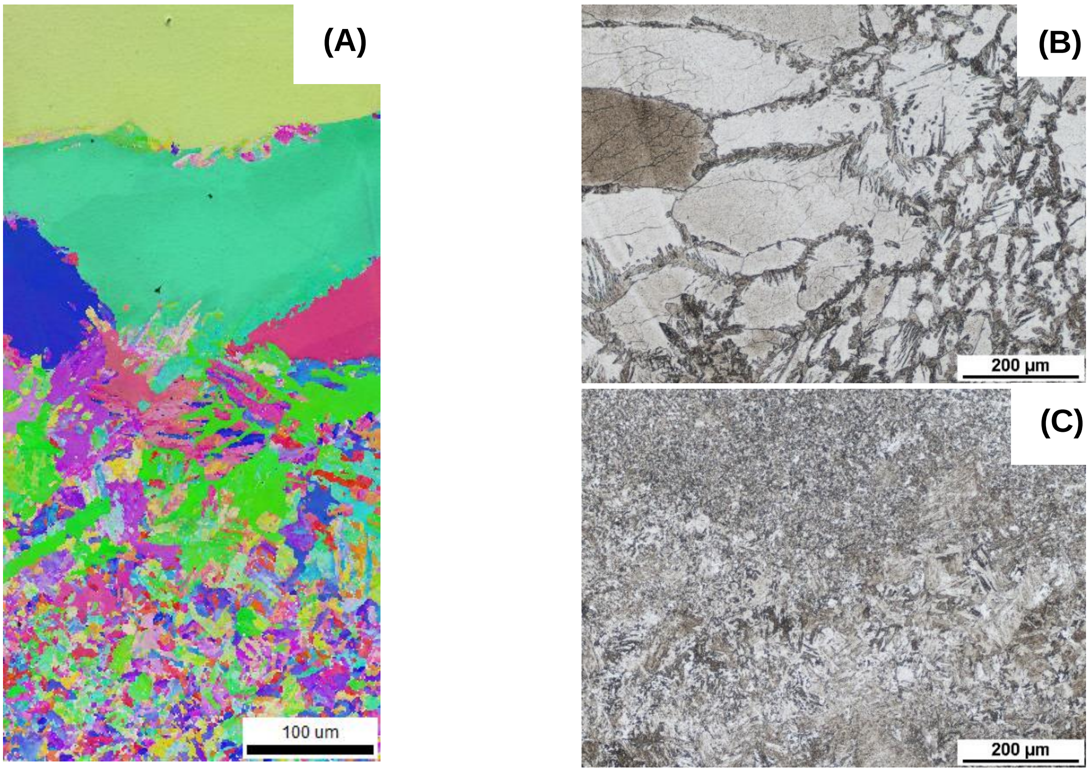

Figure 4 Microstructure of 410L double-layer coating, (A) - EBSD, transition area between layers, (B) - outer layer, (C) - inner layer

7. CONCLUSION

The laser coatings were made from ROCKIT-401, AISI M2 and 410L materials. All coatings were produced with high quality and no significant defects. Only the AISI M2 double-layered coating had pores up to more than 1 mm. The ROCKIT-401 coating showed high wear resistance almost at the level of the AISI M2 tool steel. ROCKIT-401's chemical composition, high hardness and wear resistance suggest it as a suitable material for cladding of wear and corrosion resistant parts. 410L coatings have lower wear resistance and lower hardness, particularly the double-layered coating, which consists of a ferritic-martensitic structure. The single-layer coatings 410L is suitable for parts with less abrasion resistance.

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