Experimental Investigation on Laser Cladding process in Stainless Steel 304

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Abstract: Laser Cladding or Laser Deposition is a processing technique used for adding one material to the surface of another in a controlled manner. A stream of a desired powder is fed into a focused laser beam as it is scanned across the target surface, leaving behind a deposited coating of the chosen material. This enables the applied material to be deposited selectively just where it is required. Grade 304 has excellent corrosion resistance when exposed to a range of corrosive environments and media. It is usually regarded as "marine grade" stainless steel but is not resistant to warm sea water. Warm chloride environments can cause pitting and crevice corrosion. Grade 304 is also subject to stress corrosion cracking above around 60°C. In this research, they provide excellent pitting resistance and good resistance to most chemicals involved in the paper, textile and photographic industries. Using Zr-Al-Ni-Cr-Mo amorphous alloy as a coating material for stainless steel will increase the corrosion resistant even in warm sea water and also it increases micro hardness and friction resistance.

Index Terms – Laser Claddding, Stainless steel 304, Al-Zn-Ni-Cr, SEM Test.

I. INTRODUCTION

To improve the surface properties of metallic mechanical parts, such as the resistance against wear and corrosion, several thermal surface treatments are available for instance flame spraying, plasma spraying and arc welding are established techniques. Characteristic for these techniques is the application of a surface layer with the required properties on top of a cheap material without those properties. Depending on the applied technique common problems are a combination of a poor bonding of the applied surface layer to the base material. The occurrence of porosity, the thermal distortion of the work piece, the mixing of the surface layer with the base material and the inability of a very local treatment. One of the techniques that overcome these problems is laser cladding.

Laser Cladding has been defined as a process which is used to fuse with a laser beam another material which has different metallurgical properties on a substrate where by only a very thin layer of the substrate has to be melted in order to achieve metallurgical bonding with minimal dilution of added material and substrate in order to maintain the original properties of the coating material. Laser cladding has established itself in practice. Well known applications include the improvement of the wear resistance of diesel engine exhaust valves, the enhancement of the corrosion resistance of gas turbine blades and the repair of dies.

As the laser cladding technique was virtually unknown in the local industry, they sponsored a project that should introduce this technology into the Dutch industry. This was followed by some series of experiments which contributed to a better understanding of the process and gave insight in the mechanisms that rule laser cladding. It was clear then that a successful introduction of laser cladding into industry could only be achieved by making the process less empirical and by developing industrial applications that can serve as an example. Therefore, more experiments had to be performed. Some tools had to be employed to enhance the process knowledge and to support the development of new industrial applications. These tools included mathematical tools that can describe some essential parts of the process, as well as dedicated equipment that allows an easy transfer of results between laboratories and improves the clad quality. This thesis is a result of this project. The lack of models contributes to the necessity to perform expensive series of experiments and feasibility tests for new applications.

II. LITERATURE REVIEW

Cunshan Wang et al., (2009), Ni–Zr–Al alloy used as coating on the AZ91HP magnesium alloy by laser cladding. Results show that the coating mainly consists of an amorphous, two ternary inter metallic phases with Ni10Zr7 and Ni21Zr8 type structures resulting in high hardness, good wear resistance and corrosion resistance. The interface between the clad layer and the substrate has good metallurgical bond. Ni-based alloy with the optimum composition was coated on a AZ91HP magnesium alloy by laser cladding. The coating layer mainly consists of amorphous, two ternary intermetallic phases with Ni10Zr7 and Ni21Zr8 type structures, and is well bonded to the substrate. The formation of the amorphous and intermetallics phases in the cladding layer makes the coating exhibit high hardness, good wear resistance and corrosion resistance.

Goswami et al., (2003) deposited (Ni–20Cr)–10Cr3C2 and (Ni–20Cr)– 40Cr3C2tracks over a 0.15% C steel substrate using a CO2 laser operating in continuous wave (CW) mode. The microstructure presented the original carbides in small amounts together with acicular reprecipitated carbides. The latter were larger in size towards the surface of the clad, whilst the surviving Cr3C2 carbide particles were larger (up to 50_m in size) and more numerous closer to the interface. A lower proportion of

reprecipitated carbides near the interface could be explained by the greater number of surviving particles, as well as the high solidification rate in this region, which might not have been favourable to reprecipitation.
G.F. Sun et al., (2014), Alloyed layers on 304 SS blades with Cr–CrB2 powders werefabricated by laser surface alloying. Microstructure evolution, element and phase distribution, micro hardness and corrosion performance of the alloyed layers were investigated. Corrosion potentials of all alloyed layers are higher than that of 304 SS. Specimens fabricated at 2.5 kW exhibit higher micro hardness, higher wear resistance and higher corrosion resistance compared with those at 3.0 kW. The improvement of the wear resistance of 304 SS is significant (maximum 19 times that of 304 SS) while the improvement of corrosion resistance is mild (maximum 1.85 times that of 304 SS). Laser surface alloying 304 SS with Cr–CrB2 can improve both wear and corrosion resistance of it with proper processing parameters (laser power 2.5 kW, scanning speed in the range of 10–20 mm/s in this investigation).

J.D. Majumdar et al., (2014), Wear is a surface-dependent degradation that may beimproved by a suitable modification of the microstructure and/or composition of the near surface region. Therefore, instead of the bulk reinforcement, if a wear resistant composite layer is developed on the near surface region, it would enhance the wear resistance significantly without affecting the toughness. And improve the wear and corrosion resistance of the mixer blades by laser surface alloying with pre-placed CrCrB2 powders based on the above discussions.

Theiler et al., (1998), Deposited Cr3C2-reinforced NiCrBSi, NiBSi and NiCr50 in aninvestigation on the fabrication of graded composition free form parts. The Cr3C2 content was varied between 0% and M 90% by volume. The authors identified undissolved and reprecipitated carbides in the shape of needles embedded in the matrix when the proportion by volume of Cr3C2 exceeded 30 vol %. Increasing the volume further resulted in more undisclosed particles and longer reprecipitated needles. Reprecipitation of the carbides occurred mainly in the Cr3C2 phase, with a lower proportion of Cr7C3 and no undesirable M23C6

III. MATERIALS REQUIRED

3.1. Zirconium

Zirconium is a strong, ductile and malleable metal where their physical and chemical properties are similar to that of titanium. It has good corrosion and heat resistance. At elevated temperatures, the finely divided metal is capable of igniting spontaneously in air. It cannot be dissolved in acids or alkalis. Zirconium is used in oxide or zirconia form. Zirconium oxide has low thermal conductivity.

3.2. Molybdenum

Molybdenum, a refractory metal is widely used as an alloying element. Due to its good thermal and electrical conductivity, high melting point and excellent strength at elevated temperatures, molybdenum can be used for various applications in its pure form. In addition, molybdenum has low thermal expansion coefficient.

3.3. Aluminium

Pure aluminium is soft, ductile, and corrosion resistant and has a high electrical conductivity. It is widely used for foil and conductor cables, but alloying with other elements is necessary to provide the higher strengths needed for other applications. Aluminium is one of the lightest engineering metals, having strength to weight ratio superior to steel.

3.4. STAINLESS STEEL 304 PROPERTIES

These steels exhibit excellent resistance to a wide range of atmospheric, chemical, textile, and petroleum and food industry exposures. The maximum temperature to which Types 304 and 304L can be exposed continuously without appreciable scaling is about 1650°F (899°C). For intermittent exposure, the maximum exposure temperature is about 1500°F (816°C). Type 304 is non-hardenable by heat treatment. Annealing: Heat to 1900 - 2050°F (1038 - 1121°C), then cool rapidly. Thin strip sections may be air cooled, but heavy sections should be water quenched to minimize exposure in the carbide precipitation region. Stress Relief Annealing: Cold worked parts should be stress relieved at 750°F (399°C) for 1/2 to 2 hours. Types 304 and 304L have very good draw ability. Their combination of low yield strength and high elongation permits successful forming of complex shapes. However, these grades work harden rapidly. To relieve stresses produced in severe forming or spinning, parts should be full annealed or stress relief annealed as soon as possible after forming.

Table.1. Mechanical Properties of 304 SS

PROPERTY	VALUE
Proof Stress	200 Min MPa
Tensile Strength	500 to 700 MPa
Elongation	A50 mm 40 Min %
Hardness Brinell	215 Max HB

IV. EXPERIMENTAL PROCEDURE

The specimens of 304 stainless steel rod size of 10mm×30mm were used as substrates. This surface was machined to a uniform finish using surface grinding machine, and then cleaned by acetone and alcohol just before the laser-cladding. The Zr-based amorphous powder was selected for the foundation cladding materials. The nominal composition of the alloy was Zr_{63}-Al_6-Ni_8-Cr_{15}-Mo_8.The powders were pre-placed onto the specimen surfaces homogeneously. The thicknesses of the pre-placed coatings were about l mm. The coating was cladding by DL-HL-T5000, 3.5kW continuous CO2 laser processing equipment. The values of laser power3.5 kW, scanning speed 400 mm/min, the laser beam size and 1 mm×10 mm, respectively. Argon was served as a protective gas to avoid the oxidation of alloy powder during the cladding. It is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image.

SEM can achieve resolution better than 1nanometer. Specimens can be observed in high vacuum, in low vacuum, in wet conditions (in environmental SEM), and at a wide range of cryogenic or elevated temperatures. The most common mode of detection is by secondary electrons emitted by atoms excited by the electron beam. The types of signals produced by a SEM include secondary electrons (SE), backscattered electrons (BSE), characteristic X-rays, light (cathodoluminescence) (CL), specimen current and transmitted electrons. Secondary electron detectors are standard equipment in all SEMs, but it is rare that a single machine would have detectors for all possible signals. The signals result from interactions of the electron beam with atoms at or near the surface of the sample. Exponent’s laboratory facilities related to corrosion testing and evaluation include electrochemical cells, potentiostats, metallographic equipment, optical and scanning electron microscopes, and tensile test equipment. These capabilities are used to help our clients solve a variety of problems associated with materials selection, degradation mechanisms, and failure analysis in a range of industries, including construction, biomedical, manufacturing, utilities, chemical and petrochemical, and electronics.

IV. EXPERIMENTAL RESULTS

The Test specimen is fine polished and prepared to examine with Scanning Electron Microscopy (SEM) for different magnification and scale. The SEM image of the microstructure of the pure aluminum with x100 magnification in 100µm scale is presented. The microstructure of laser cladding specimen of $Zr_{63}Al_6$-Ni_8-Cr_{15}-Mo_8 with magnification 1.00K.X and scale 20µm is mentioned in Fig B. The image reveals the better quality of specimen with absence of cracks, voids and porosity. The alloy element of Cr appears in snow white colour and similarly Al , Zr are appears in dark grey colour.

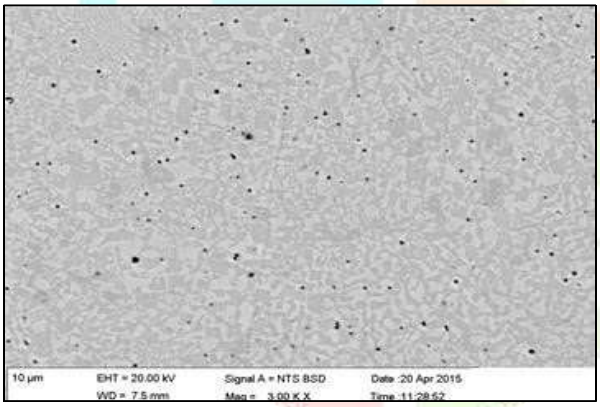

Fig.1 (a) SEM ImageMAG 500X, Scale 10µm

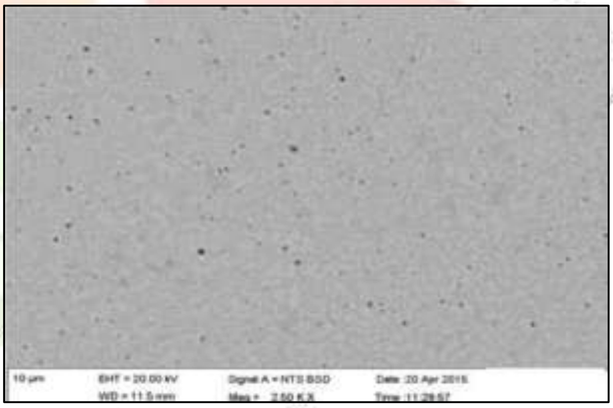

Fig.1 (b) SEM Image MAG 250X, Scale 10µm

The corrosion behaviour of cladding specimen is tested by electro chemical etchant measurements. In this test, cladding specimen of Zr_{63}-Al_6-Ni_8-Cr_{15}-Mo_8 and SS304 substrate were immersed in 3.5 % NaCl solutions. The applied voltage, current, surface area, test duration and calculated corrosion are listed in Table 7.2. The specimen weight is obtained in grams to calculate corrosion loss and cladding specimen has minimum corrosion loss of 0.1023 gram. The Corrosion surface images with magnification of 500 X and 20µm scale is shown in Fig 7.2. The presence of Cr in cladding specimen has improved corrosion resistance and attained

Table 2. Corrosion test

Sample	Test Solution	Surface Area (cm^2)	Ampere (A)	Applied Voltage (mV)	Duration (Hour)	Corrosion (gram)
304 Stainless Steel	NaCl (3.5%)	0.78	0.10	0.25	5	0.134
Coating	NaCl (3.5%)	0.78	0.10	0.25	5	0.0319

Table 3. Micro Vickers Hardness Test

Sample	Location 1	Location 2	Location 3	Location 4	Location 5	Average value (HV)

304 SS	129	131	129	130	129	129
Cladding	464	469	470	468	466	467

V. CONCLUSION

The Zr-Al-Ni-Cr-Mo alloy powders have used to laser cladding on 304 SS substrates. The coating specimen has the mixture of Cr, Ni, this provide good microstructure improvement hardness, corrosion and wear properties. The cladding surface has achieved the micro hardness of $HV_{0.2}$ as 767HV and corrosion test for 5 h duration has found the material saving improvement of 23.80% by the cladding process. The Zr type cladding coatings provide higher micro hardness better corrosion resistance compared to that of 304 SS substrate. Hence the hardness is increased from 129HV to 767HV. So the combination of ZrAl-Cr-Ni-Mo amorphous coating on stainless steel 304 will be increase the hardness and corrosion resistance compare to 304 SS.

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