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Microstructural Evolution of Laser-Clad IN625 Powder on Rene80 Superalloy

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Abstract

Nickel-based superalloys are one of the main components of fixed and moving blades of land and air gas turbines. Susceptibility of substrate and coating during Rene80 superalloy coating with IN625 was investigated by laser cladding method. For this purpose, the substrate was selected under two conditions of casting and solution heat treatment. Microstructural studies showed that the coating, despite maintaining its hardness due to NbC carbide and Ni2(Cr,Mo) phases, did not form cracks and pores. However, in the coating-substrate interface and heat affected zone of the casting sample, cracking occurred due to the high absorption of process stresses by MC carbide (TiC) and γ´ phase as well as partial melting of these two phases. However, in the case of heat treatment, due to the dissolution of these phases and the low hardness of the substrate, the conditions of non-stress absorption and stress release further reduced the sensitivity to cracking.

Keywords: Laser Cladding, Rene80, IN625, HAZ Crack.

1. Introduction

Rene80 superalloy is one of the newest nickel-base superalloys, which has replaced IN738 superalloy due to its advantages such as resistance to corrosion, oxidation, abrasion, creep and fatigue [1]. The main precipitation phase in this superalloy is the γ´ phase Ni3(Al,Ti) which is caused by hard deposition. Since this superalloy is used in important aerospace industries such as gas turbine blades, it is necessary to maintain its properties during service through the sustenance of the inherent strength of a suitable coating created in a proper manner [2]. IN625 superalloy is a good choice for coating due to its advantages such as excellent abrasion and corrosion resistance [3]. This superalloy is not as sensitive to liquation cracks as Rene80 superalloy because it acquires its strength through the formation of a solid solution during heat treatment. In a study by Osoba et al. [4], γ´ precipitation phase was identified as the most important cause of cracking in Rene80 laser-welded superalloy in heat-affected zone (HAZ). There are several ways to coat superalloys. Solakoglu et al. [5] improved the surface quality of parts used in aerospace by applying IN718 powder through direct metal laser sintering operation. Thermal barrier coated (TBC) is another widely used coating method for superalloys used in the aerospace industry [6]. The main mechanism of these coatings (TBC) is to reduce the thermal conductivity and thus increase the resistance to hot corrosion and oxidation.

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One of the limitations of TBC coating is the entry of oxygen from the pores in the coating to the substrate and the formation of an oxide layer at the interface between the metal and ceramic coatings [7]. Among the coating methods, laser cladding (LC) is superior to other coating methods due to its advantages such as creating a uniform and dense layer, fine microstructure with minimal segregation, narrow HAZ, low distortion and fast coating time [8-10].
In addition, in the LC method, due to the strong fusion between the melted powders due to laser irradiation, a uniform coating without porosity and protection against oxygen penetration into the resulting substrate [10,11]. Laser cladding, also known as laser metal deposition, is a technique for adding one material to the surface. Laser cladding involves feeding a stream of metallic powder or wire into a melt pool generated by a laser beam as it scans across the target surface, depositing a coating of the chosen material [12]. Laser cladding technology allows materials to be deposited accurately, selectively, and with minimal heat input into the underlying substrate. The laser cladding process allows for property improvements for the surface of a part, including better wear resistance, as well as allowing for the repair of damaged or worn surfaces. Creating this mechanical bond between the base material and the layer is one of the most precise welding processes available [13]. Various studies with LC method on different superalloys have been performed to date. But few studies have examined the LC method on Rene80 superalloy. For example, Kurzynowski and et al. [14] used the LC method to coat pure rhenium on IN718 superalloy, which achieved 160% and 25%

higher hardness and abrasion resistance, respectively. Long et al. [15], with the LC method and adjusting its parameters, were able to achieve a coating with minimal separation of alloying elements, due to rapid solidification in IN718 superalloy. One of the mechanisms affecting the LC process, in addition to adjusting the LC parameters, is heat treatment. It has been reported that with proper heat treatment, a uniform, crack-free coating can be achieved [16]. In this research, by applying different heat treatment parameters, will try to cover the IN625 coating uniformly and without defects on Rene80 superalloy by LC method.

2. Materials and Methods

In this research, Rene80 superalloy was used as a substrate and IN625 superalloy powder was used as a coating material. The nominal chemical composition of Rene80 and IN625 superalloys is given in Table. 1.

Table. 1. Chemical composition of as-cast Rene80 and IN625 superalloys (wt.%).

Elements	Co	Cr	Al	Ti	Mo	W	Zr	B	Nb
Rene80	8.5	15.8	3.2	4.4	4	4	0.03	0.015	-
IN625	0.6	22	0.4	-	9.1	-	-	-	3.11

Rene80 samples were used in both casting (MT1) and heat treatment under (MT2) 1200 ℃-2 hours-air cooling conditions. Laser cladding was performed using Nd: YAG pulsed-laser device with the following parameters: power (P) 200 W, laser scanning rate (V) 5 mm/s and power feeding rate (F) 300 mg/s. Due to the close chemical composition of GTD-111 and Rene80 superalloys, the selected parameters for LC in this study were selected based on our previous study on GTD-111 [17]. For metallographic studies, specimens were cut from the cross-section of the coating by wire-cut. The specimens were etched after metallographic steps, which included sanding and polishing. Electro-etch operation was performed with 12 ml H_3PO_4+ 40 ml HNO_3+ 48 ml H_2SO_4 solution in 6V for 5s. Field-emission scanning electron microscope (FE-SEM) equipped with Energy dispersive x-ray spectroscopy (EDS) and mapping was employed to study the microstructure and composition of the CF, HAZ and BM.

3. Results and Discussion

Fig. 1.a-b shows the pool profile of the MT1 and MT2 samples. As can be seen, the MT1 sample in the interface has a crack that prevents the coating from joining to the substrate. Since the MT1 sample is coated under casting conditions, the thermal stresses resulting from the thermal gradients the main cause of cracking. One of the reasons for stress absorption in MT1 sample is the non-dissolution of γ′ phases and TiC carbides before the coating layer formed during Rene80 casting. These phases act as stress absorption centers during coating, resulting in crack formation in the HAZ as shown in Fig. 2 . As shown in Fig. 2, the crack is caused by the partial melting of the γ′ phases and TiC carbides during welding heating. The results of the EDS analysis of crack edges presented in Table 2 confirm this. Since the heating rate is very high during laser application, there is no opportunity to dissolve these phases, so during a reaction with the surrounding austenitic matrix, they cause a partial melting in their interface [18]. These places act as stress absorbers during rapid cooling of the pool, leading to crack formation in the HAZ. This is while in MT2 sample less stress absorption and stress release is more. The reason for the decrease in stress absorption is due to the dissolution of γ′ phase before coating and the reason for the release of high stress is due to the reduction of Rene80 (MT1: 400 HV, MT2: 280 HV) due to heat treatment. In fact, performing heat treatment before LC (MT2) causes the solution of the above phases in the matrix of superalloy. This ensures that during the LC these phases do not form a partial liquation and thus avoid crack formation. In separate studies, Taheri [19], Cao [17], and Chen [20] stated that reducing the hardness of the base metal is a factor to increase the release of stresses created during welding and thus reduce the sensitivity to crack. This reduced the sensitivity to crack in the HAZ of sample MT2.

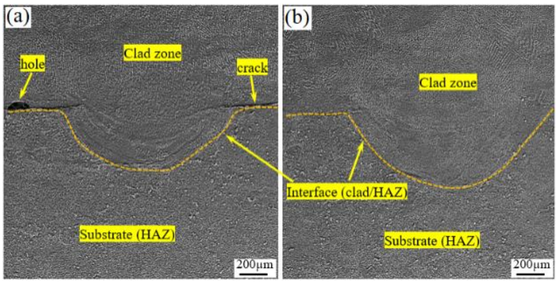

Fig. 1. Cross-section of samples (a) MT1, and (b) MT2.

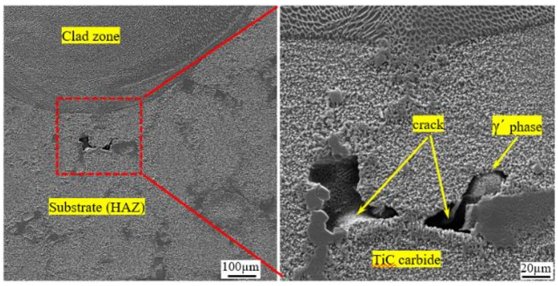

Fig. 2. Liquation crack formation in the HAZ of sample MT1.

Table. 2. Results of EDS analysis from Fig. 2 (at%).

Region	Al	Ti	Cr	Co	Ta	W	Mo	Ni	Possible phase
A	1	56	1	1	28	3	5	3	TiC carbide
B	4	15	1	8	-	2	-	70	γ´ phase

Microstructural examination of the coating shows that cracks have not formed in any of the MT1 and MT2 samples (Fig. 3). On the other hand, the presence of NbC carbide and Ni2(Cr,Mo) phase in the inter-dendritic areas has maintained the hardness of the coating (348 HV). The constituent elements of the above phases are segregated during solidification in the inter-dendritic regions. The most important reason for this is the segregation coefficient of less than 1 (K<1) element Nb [16]. This causes the element Nb to be pushed back into the melt by the solidification front during solidification. The carbon element, which has K<1, is repelled into the inter-dendritic regions like Nb [21-23]. In such conditions, due to the fact that the element Nb is a strong carbide maker, NbC carbides are formed in the inter-dendritic regions (Fig. 3) and increase the hardness and strength in these regions.

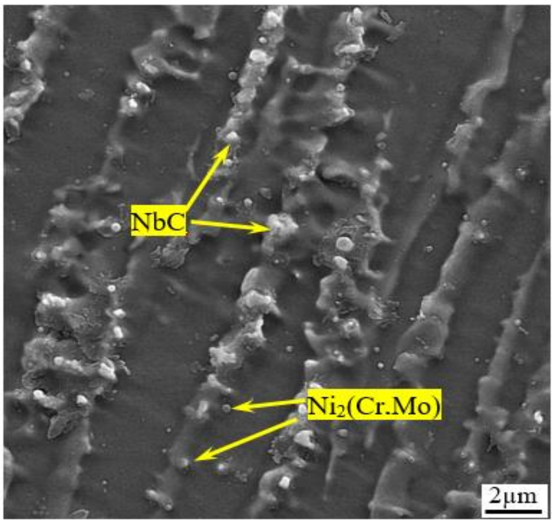

Fig. 3. Microstructure of the clad zone (MT2).

As shown in Fig. 4, no dilution has occurred in the coating, which indicates the appropriate conditions for applying the coating in the MT2 sample. Improper selection of laser parameters has been reported to increase the dilution of the coating, meaning that the components of the coating penetrate into the substrate, and the constituent elements of the substrate penetrate the coating, reducing mechanical properties. However, according to Fig. 4, the diffusion of the elements did not occur, which indicates a low dilution and therefore its suitability.

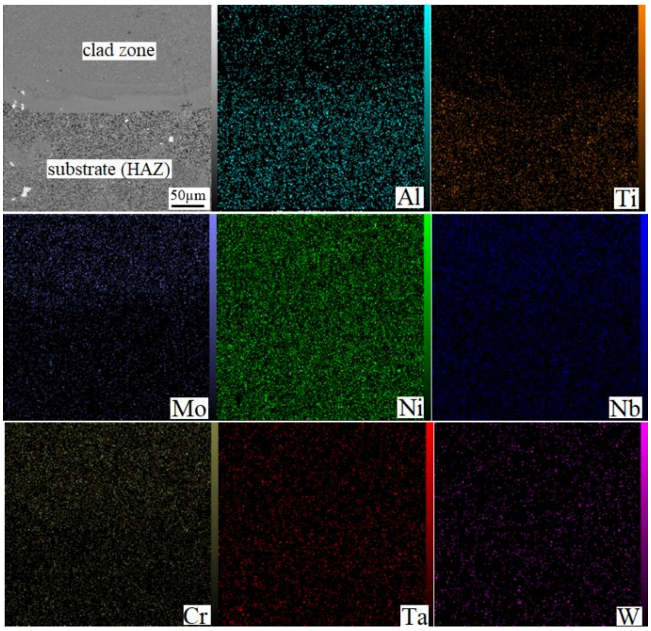

Fig. 4. EDS X-ray mapping of elements distribution in the laser cladding sample MT2.

5. Conclusion

In this research, IN 625 superalloy powder was applied by laser cladding method on Rene 80 superalloy and the following microstructural results were obtained:

1. Using suitable heat treatment of the substrate (Rene80) under solid solution conditions, a uniform coating of IN625 without any cracks in the substrate, interface and HAZ was created during the laser cladding process.
2. The NbC carbide and Ni2(Cr,Mo) phase that formed during the laser cladding in the inter-dendritic regions of the coating were responsible for the hardness and strength of the coating.
3. Suitable conditions for LC coating and solution heat treatment before LC reduced the dilution and increased the quality of the coating.

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