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Comparative study of Co-based alloys in repairing low Cr-Mo steel components by laser cladding

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Abstract

Refurbishment of damaged components is nowadays a useful solution to save maintenance costs. Laser cladding is one of the most advantageous solutions to fulfill this kind of repair. With the aim of reusing deteriorated steam circuit parts of thermal power stations, a laser cladding process has been developed. Different Co-based alloys of Stellite[®] and Tribaloy[®] families, which offer good resistance against impact, corrosion and erosive wear at high temperatures, were used as coating materials to improve the durability of this repair. A comparative study of morphology, structure and hardness of the deposited layers with optimized parameters has been carried out.

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Keywords: Laser cladding; Stellite[®]; Tribaloy[®]; low alloy steels

1. Motivation

Conventional welding processes are commonly used to generate more resistant surfaces in the repair of components belonging to steam circuits in thermal power stations. These methods have several disadvantages comparing with laser cladding technology, like great thermal strains, extensive heat affected zones (HAZ) and large dilution between coating and base material, understanding dilution as the relative amount of base material melted during the process and mixed with the coating material. Laser cladding process can reduce these problems and preserve the individual properties of each material by a precise control of the transferred energy [1].

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Coating materials for this application have to offer good hot hardness behavior and resistance against impact, corrosion and erosive wear even at high temperatures. Stellite[®] as well as Tribaloy[®] families of Co-based alloys fit adequately in these requirements. Stellites[®] mainly consist of Cr-rich carbides in a solid solution dominated by Co, while Triballoys[®] are integrated by hard intermetallic Laves phases dispersed in a cobalt alloy matrix, which gives these materials their outstanding properties of wear and corrosion resistance as well as mechanical strength.

For this study, three Stellites[®] and two Triballoys[®] were chosen. Stellite[®]6 is the one most commonly used in the conventional welding industry because of its well behavior in more coating processes. M_7C_3 carbides can be found in the Co-rich solid solution, where M represents W a hardening and strengthening element, as well as the intermetallic phases Co_7W_6 , Co_3W and $M_{23}C_6$ carbides in less quantity. Another Co-based alloy, Stellite[®]21, was used in this analysis, which has better properties against corrosion due to its content of Mo, forming the intermetallic phases Co_3Mo and Co_7Mo_6 . Apart from that, Stellite[®]21 has less content of C than Stellite[®]6 resulting in the formation of less $M_{23}C_6$ carbides, where M represents Mo in this case. Among Stellites[®] the one which presents more problems for conventional welding is the Stellite[®]12 alloy due to its higher content of W which makes it the hardest one of them [2]. Because of that, it is interesting to know its behavior with a non-conventional process as laser cladding. Commercial Triballoys[®] T-800 and T-900 were also selected. An intermetallic Laves phase compound of Co, Mo and Si (as Co_3Mo_2Si and/or $CoMoSi$) immersed in a tough matrix of eutectic or solid solution of Co is what makes Triballoys[®] an effective coating for machine parts subjected to high requirements. The main difference between them is the Ni content that gives T-900 less hardness but higher strength than T-800 alloy [3].

2. Experimental

A high power diode-pumped Nd:YAG laser (DY022 by ROFIN) with maximum power of 2200W was used in the process. Laser beam is transmitted by a 600 μ m optical fiber to the laser head (YC50 by PRECITEC), which movement is controlled by a 6-axis robot (IRB 2400 by ABB). A powder feeder Twin 10-c by SULZER-METCO was employed to carry the coating Co-based alloys in powder shape to the nozzle. Powder injection is made coaxially with the laser beam. An inert gas, N_2 , was used as shielding and powder carrier gas. All processed samples were cut across, polished and chemically etched for their metallographic study. A scanning electron microscope (JSM 6400 by JEOL) was used to study microstructures.

3. Results and Discussion

The base material selected for the experiments was ASTM A182 F11. This Cr-Mo low alloy steel is one of the most used materials to make steam circuit components with considerable dimensions. Chemical compositions of this material as well as Stellites[®] and Triballoys[®] are shown in Table 1.

Table 1. Chemical composition of ASTM A182 F11 steel, Stellite® and Tribaloy® alloys

(wt.%)	Fe	Co	C	Cr	W	Ni	Mo	Si	Mn	P	S	B
Stellite®6	Max.3	Bal	1.2	28	4.5	Max.3	-	1.1	1	-	-	-
Stellite®12	2.34	Bal	1.42	30.6	8.7	2.1	0.32	1.39	0.44	0.008	0.007	-
Stellite®21	1.49	Bal	0.26	27.4	0.1	2.58	5.3	1.6	0.43	0.1	0.009	0.001
T-800	-	Bal	0.080	17.5	-	1	28	3.4	-	-	-	-
T-900		Bal	0.080	18	-	16	23	2.70	-	-	-	-
ASTM A182 F11	Bal	-	0.05- 0.15	1.00- 1.50	-	-	0.44- 0.65	0.50- 1.00	0.30- 0.60	0.03	0.03	-

For the optimization of process parameters, single cladding beads of 30mm length were made by varying laser power P , process speed V and powder feeding rate Q . Taking into account the clad morphology, it was found that the amount of coating material per unit of length must be in the range between 15 mg/mm and 20 mg/mm to ensure a value of geometric ratio (width/height) higher than 3. In this way, porosity between layers can be avoided when overlapping is performed.

Metallurgical union between coating and substrate can be seen by means of a SEM micrograph that reveals a planar solidification front as well as the growth of coating dendrites in the perpendicular direction of this front, Fig. 1. This growth direction corresponds in laser cladding to the main heat transfer direction during solidification [4].

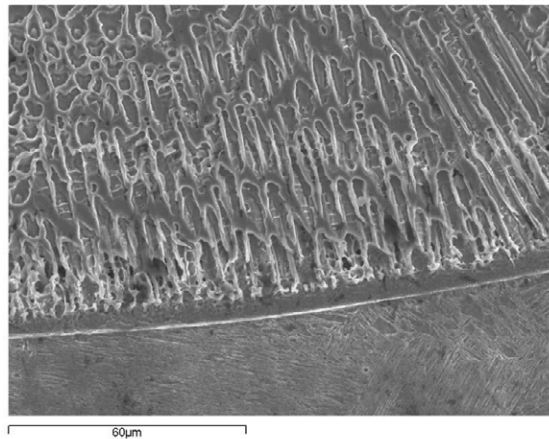


Fig. 1. Planar solidification front and dendrites orientation near the boundary between ASTM A182 F11 and Stellite® 21

Working with a polished and cleaned surface of ASTM A182 F11 substrate and laser speeds between 3 and 5 mm/s, laser energy densities must be roughly between 100 and 140 J/mm² to ensure union between this Co-based coatings and base material. If higher values of energy density are delivered, higher will be the materials dilution and the HAZ, limiting its maximum value to 20 % in order to avoid an excessive mixing of both materials and as a consequence the loss of their original properties. For every sample, dilution D has been calculated by means of the Ec 1, being A_d the coating area that penetrates in the

substrate and A_c the coating area above the substrate line.

$$D = \frac{A_d}{A_c + A_d} \quad (1)$$

Concerning Stellites[®], all obtained coatings have a dendritic microstructure and no cracks or porosity were observed. To compare shape and size of dendrites, samples with same process parameters were chosen. These samples can be seen in Fig. 2, in which process parameters are: $V = 5 \text{ mm/s}$, $P = 1925 \text{ W}$, $Q = 0.1 \text{ g/s}$. Dendrites formed by Stellite[®] 12 are the smallest ones. This fact together with the higher content of C and W and therefore the formation of more carbures, makes Stellite[®] 12 the hardest one between them. Stellite[®] 21 has the higher size of dendrites and the lower content of carbures so its value of hardness the lowest one.

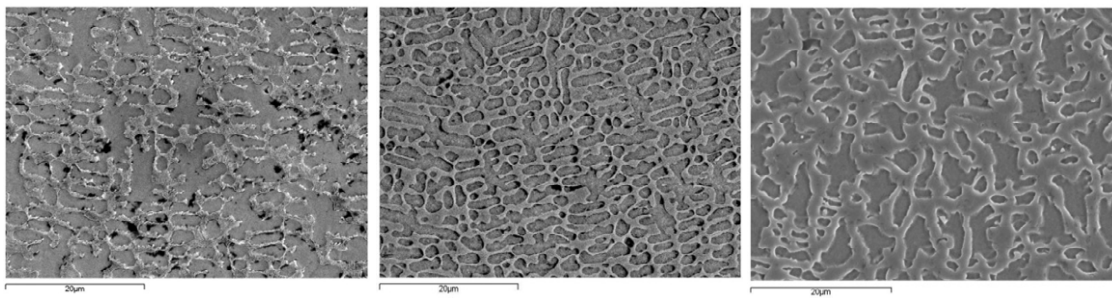


Fig. 2. (a) Stellite[®] 6 dendrites; (b) Stellite[®] 12 dendrites; (c) Stellite[®] 21 dendrites

Composition of Stellite[®] laser cladding coatings is homogeneous, although a little variation of composition between dendritic and interdendritic zones can be observed. In case of Stellites[®] 6 and 12 the content of W and Cr is higher in the interdendritic zone whereas in Stellite[®] 21 are the elements Mo and Cr, Fig. 3.

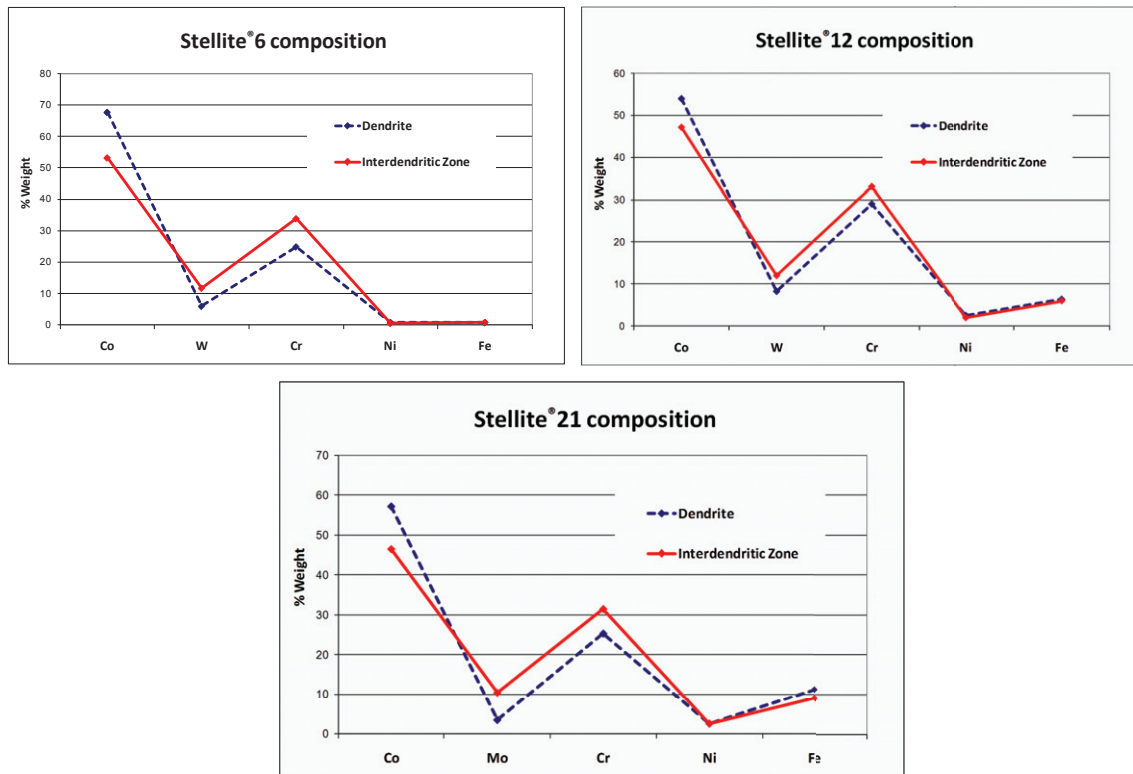


Fig. 3. Composition of main elements in Stellite® 6, Stellite® 12 and Stellite® 21 laser cladding coatings

In case of Triballoys® T-800 and T-900, samples with same process parameters as Stellites® were chosen. Dendritic microstructure of Tribaloy® T-900 is similar to them, Fig. 4, but Tribaloy® T-800, presents two different microstructures in its composition depending on the Fe content, Fig. 5, a lamellar and a dendritic microstructure. In this way, when higher is the Fe content higher will be the presence of dendritic microstructure in T-800 coating.

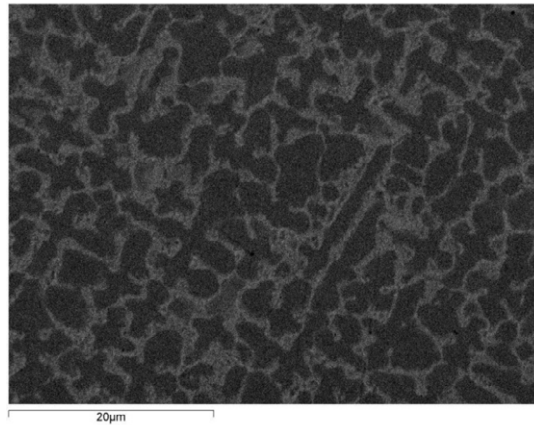


Fig. 4. Back-scattered electron image of T-900 dendrites

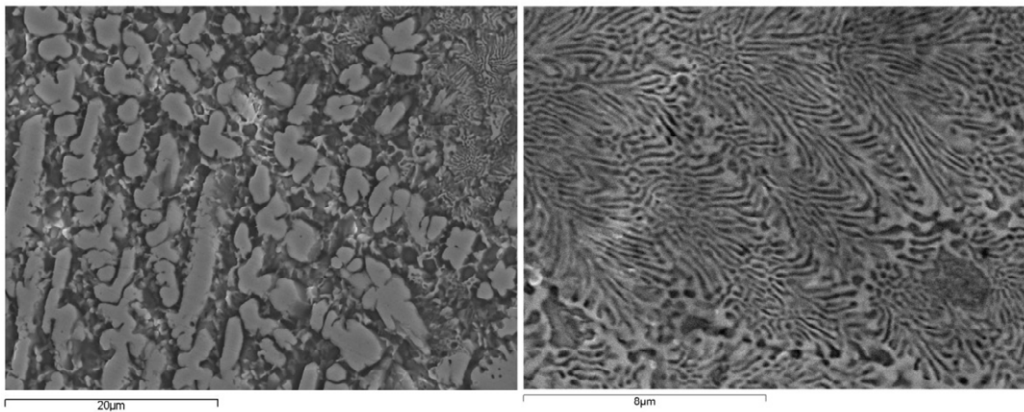


Fig. 5. SEM images of Lamellar and dendritic microstructures of T-800

Regarding hardness, every one of the used Co-based coating materials improves this property with respect to ASTM A182 F11, see Fig. 6 and 7. The one with higher values of hardness is Tribaloy® T-800 which can achieve values of about 1200HV causing cracking in all deposited single beads. This inclination of crack forming can be decrease by applying preheating to the work piece. Process characteristics make also that all obtained samples present an increase in the nominal hardness value. Due to the high cooling rates of laser cladding process, a hard martensitic phase appears in the HAZ. In some cases like Stellite 21 and Tribaloy 900 this phase can be even harder than the values achieve in the coating area. By applying a tempering heat treatment after the process this hardness can be reduced.

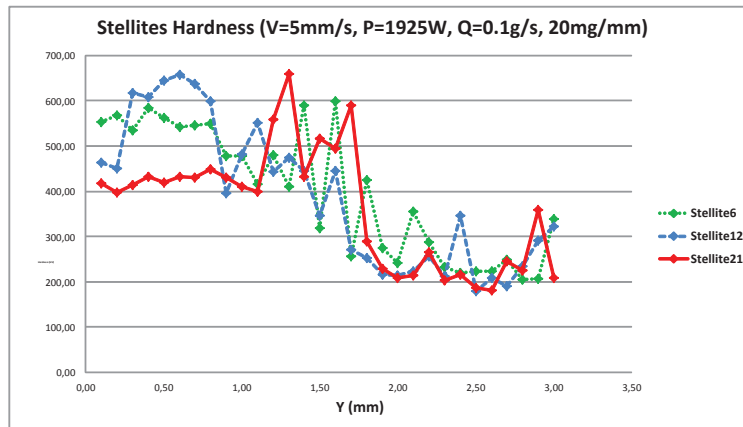


Fig. 6. Hardness of Stellite® 6, Stellite® 12 and Stellite® 21, with same process parameters

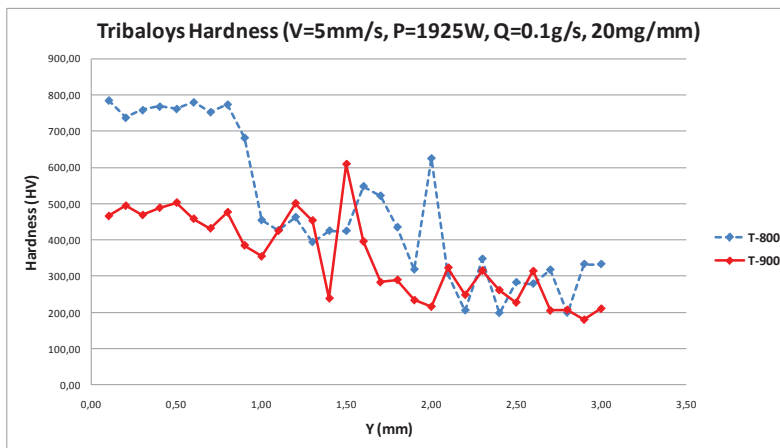


Fig. 7. Hardness of Triballoy® T-800 and Triballoy® T-900, with same process parameters

4. Conclusions

This study has proved not only the possibility of performing coatings to repair or improve the properties of the Cr-Mo ASTM A182 F11 steel, but also the fact that these layers can be obtained by means of the laser cladding process. Dendritic microstructures and free crack and porosity coatings were achieved in the case of Stellite[®] and Tribaloy[®] T-900, keeping original properties of coating and substrate. Only Tribaloy[®] T-800 presents crack formation. Preheating of substrate can reduce this tendency of cracking but not completely remove its formation. Further steps in this research will be the deposition of an intermediate Stellite[®] 6 layer between the ASTM A182 substrate and the T-800 coating to analyze if cracks can be eliminated in this way.

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