ELSEVIER

Applied Surface Science 201 (2002) 154–160

applied surface science

www.elsevier.com/locate/apsusc

High temperature behaviour of plasma transferred arc and laser Co-based alloy coatings

A.S.C.M. d'Oliveira[a,*], R. Vilar[b], C.G. Feder[a]

[a]*LaMaTS, Mechanical Engineering Department, Universidade Federal do Paraná, Centro Politécnico Cx Postal 19011, 81 531 990 Curitiba/PR, Brazil*

[b]*Materials Engineering Department, Instituto Superior Técnico, Lisboa, Portugal*

Received 10 May 2002; received in revised form 17 June 2002; accepted 17 June 2002

Abstract

Surface engineering is a topic of great relevance on today's engineering. Surface features can be improved from the point of view of the material being deposited or from the point of view of the depositing process. The present work characterises coatings of a cobalt-based alloy, deposited by PTA welding on an AISI 304 stainless steel substrate. Samples were subjected to temperature cycling at 1050 °C. As-deposited features and their stability to high temperature were study, results are presented and compared with similar samples obtained by laser cladding. The performance of hardfaced material was evaluated by microstructure, chemical analysis and microhardness measurements. For the processing conditions tested, results showed that, for operating conditions that do not require elevated temperature, laser hardfacing shows the bests results, due to the refine solidification structure produced. However, for the high temperature tested, PTA deposits exhibited superior microstructural stability whereas laser deposits undergo significant changes.

© 2002 Published by Elsevier Science B.V.

PACS: 61.82.Bg (metals and alloys)

Keywords: Co-based alloys; Microstructure; High temperature stability; Plasma transferred arc; Laser cladding

1. Introduction

Special alloys are commonly used for coatings components so their service life can be increased. Significant efforts have been made to develop a variety of Co-based alloys (containing carbides or Laves phases) that show an enhanced wear and corrosion resistance [1,2]. Recent improvements on their performance have been obtained through the optimisation of the deposition process. Among these, according to the literature, plasma transferred arc (PTA) welding represents a very good alternative to other surface welding processes, such as conventional techniques or more recent ones such as laser cladding. It is important to bear in mind that hardfacing process selection is as determinant to the surface properties as the alloy selection, both being dictated by service performance requirements [3,4].

In this work two known hardfacing processes [5–12], PTA welding and laser cladding, are used to deposit a Co-based alloy (strengthened by carbides), used in petroleum refinery equipment. A common feature to these processes is that both use powdered

* Corresponding author. Tel.: +55-41-361-3119; fax: +55-41-361-3129.
E-mail address: sofmat@demec.ufpr.br (A.S.C.M. d'Oliveira).

0169-4332/02/$ – see front matter © 2002 Published by Elsevier Science B.V.
PII: S0169-4332(02)00621-9

hardfacing material and one of the main differences are the solidification rates expected. Although Co-based alloys are heat resistant materials not much has been done to evaluate their microstructural stability as a function of the coating process. In this work extreme temperatures are used to evaluate high temperature microstructural stability. Experimental conditions used were obtained from a refinery plant interested in extreme temperature conditions. As equipment are submitted to stop-overs for maintenance purposes, cycling and soaking procedures were used to test the coatings produced.

Modification on wear behaviour can be expected from changes in size and amount of hard phases [8,13], an evaluation of the metallurgical changes contributes to a better prediction of service life, and as consequence, maintenance operations schedule.

2. Experimental procedures

Cobalt-based alloy hard coatings (Co–Cr–W–C)—Stellite 6, single and two consecutive layers were deposited on stainless steel AISI 304 plate (120 mm × 15 mm × 12 mm), with PTA welding and laser cladding. As-received chemical composition of substrate and coating materials are presented in Table 1.

Processing conditions for PTA and laser deposits were as follows:

- *PTA*
  - plasma gas flux: Ar 2.33 l/min,
  - protective gas flux: Ar/H_2 4.72/7.08 l/min,
  - feeding gas flux: Ar 2.36 l/min,
  - main arc intensity: 53–70 A (first layer) and 90–93 A (second layer and single layer specimen),
  - voltage: 20.6–23 V,
  - powder feeding rate: 26.5 g/min,
  - arc oscillation: thickness, 16 mm; frequency, 1.3–1.5 Hz,
  - welding speed: 200 mm/min.
- *Laser cladding*
  - equipment: CO_2 CW maximum power 3.0 kW,
  - applied power: 2.2 kW,
  - focus distance: 25 cm,
  - welding speed: 480 mm/min,
  - powder feeding rate: 1.2 g/min,
  - overlapping: 33.3%.

Structure stability was evaluated submitting samples to thermal cycles. A thermal cycle consisting of a soaking period at 1050 °C followed by water quenching. Three different conditions were used: a short cycle (30 min soaking time), a long cycle (2 h and 30 min soaking time) and five consecutive short cycles.

Coating features on the as-deposited and heat-treated condition were characterised by optical and scanning electronic microscopy of the transverse cross-section, near the interface on the one layer specimens and at 100 μm from the external surface on the two layers specimens. Vickers microhardness was done with 500 g to determine hardness profile and 25 g load to characterise dendritic and interdendritric regions at 100 μm from the external surface on the two layers specimens. Semi-quantitative chemical analysis was done by EDS. Dilution, as the amount of the base material participating on the coating, was determined by quantitative metalography on single layer deposits.

3. Results and discussion

3.1. General features

Hardfacing done by both processes exhibit a good surface appearance, without the presence of porosities or cracks. The higher deposition efficiency of the PTA process can be evaluated by the thicker deposits produced both on single pass and multilayer deposits when compared to laser processing (Table 2).

Table 1
Chemical composition of the as-received materials

	C	Si	Mn	P	S	Cr	Ni	Fe	W	Mo	Co
AISI 304	0.08 (Maximum)	1.0 (Maximum)	2.0 (Maximum)	0.045 (Maximum)	0.03 (Maximum)	18.00/20.0	8.00/10.5	Balance	–	–	–
Stellite 6	1.1	2.0	2.0	–	–	30.0	3.0	3.0	4.5	1.5	Balance

Table 2
Coating thickness for single layer and multiplayer deposits obtained with the processing techniques used

	Single layer (mm)	Multilayer (mm)
PTA welding	2.5	4.5
Laser cladding	1.0	1.6

Table 3
Interdendritic arm spacing measured on the as-deposited coatings

Hardfacing process	λ (μm)	Standard deviation (μm)
PTA	6.65	1.63
Laser	1.68	0.31

Table 4
Dilution levels on PTA and laser deposits

Hardfacing process	Measured dilution (%)	Reference dilution [3] (%)
PTA	6.9	5–15
Laser	9.4	1–10

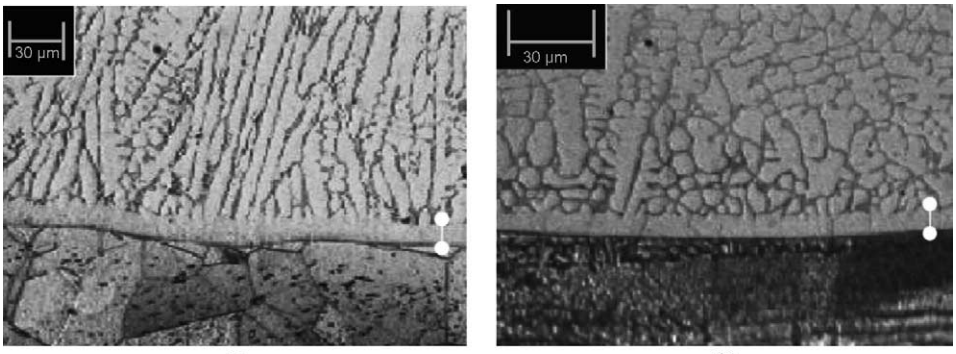
A general view of the as-deposited coatings is shown in Figs. 1 and 2a, where the microstructures of the interface and near surface regions are presented, respectively. Typical solidification structures are recognized. The observed fine structure of the laser deposits, confirmed by secondary dendritic arm spacing measurements (Table 3) results from the faster solidification rate involved [14,15].

Solidification structure near the interface with the substrate reveals the influence of the solidification and cooling rates of each process. In the case of laser cladding, a planar region is followed by a cellular and a dendritic structure. The slower cooling rates of PTA [16] process eliminates the cellular region, therefore near the interface one observes a planar region followed by a dendritic structure.

Solidification and cooling rates are also affected by the specimen dimensions. Being the substrate plates used for both processes of the same dimensions and the coatings produced of different thickness, the larger volume ratio (coating/substrate) contributes to slower the solidification rate, leading to a less efficient heat flow through the substrate obtained on PTA deposits.

As-deposited hardness is higher for laser, (510 HV), than PTA (470 HV) coatings. Although wear resistance has been related to hardness, this information is not sufficient to predict which surface will present a better performance as it depends on the operative wear mechanism (abrasion, erosion, etc.) and therefore on the microstructure [1,16]. As-deposited microstructures can be described as a Co rich matrix with a network of carbides in the interdendritic regions [3,17]. The measured differences on hardness can be attributed to the morphology of the carbides, consequence of the different cooling rates experimented on each hardfacing process.

Dilution levels as the participation of the substrate on the final coating are presented in Table 4. Both



(a) (b)

Fig. 1. General view of the interface between the Co-based alloy coating and the substrate for the processing techniques used: (a) PTA; and (b) laser.

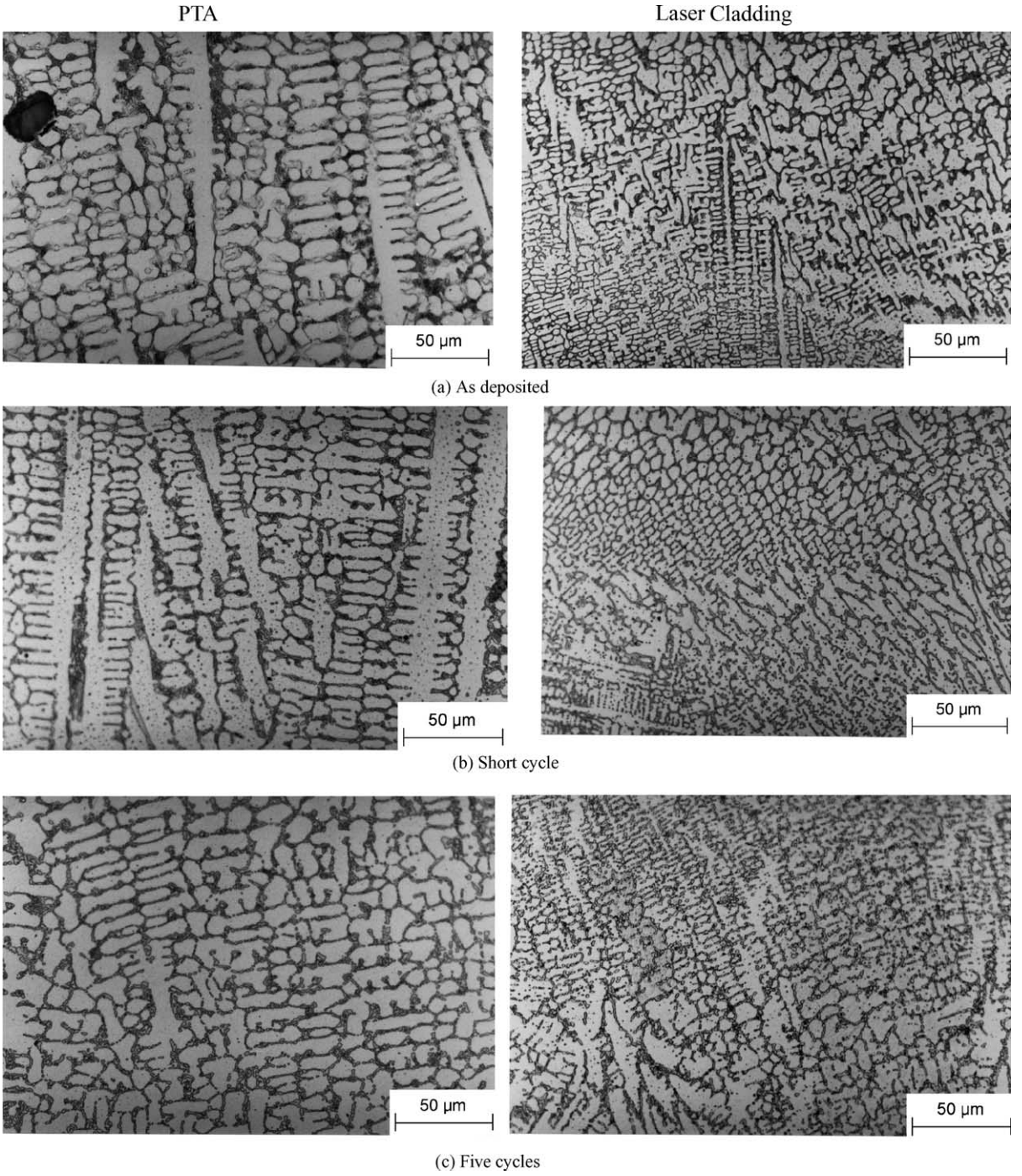


Fig. 2. Effect of temperature cycling on the PTA and laser coatings microstructures: (a) as-deposited; (b) single cycle (30 min); and (c) five cycles.

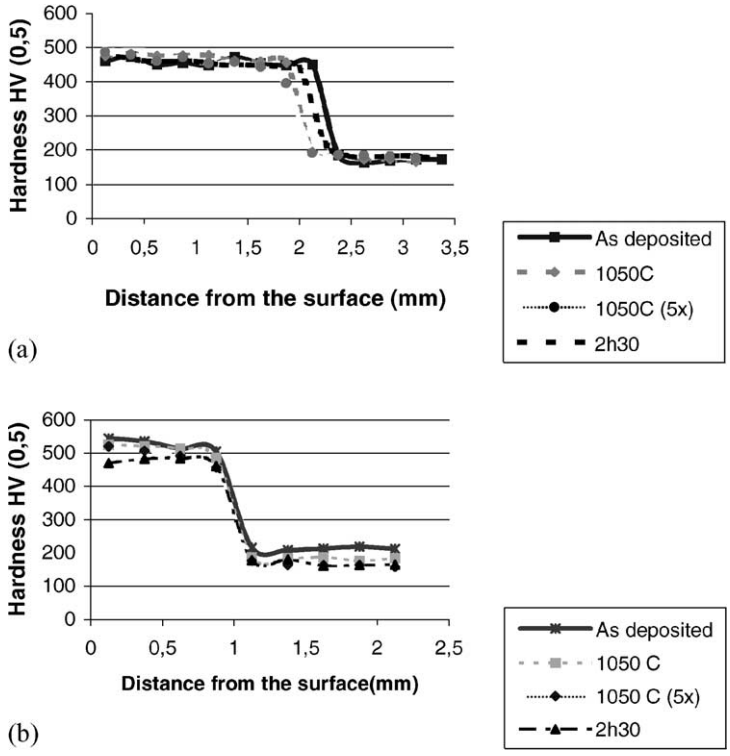


Fig. 3. Microhardness profiles of the transverse section of: PTA (a); and laser (b) deposits, before and after high temperature treatment.

procedures produced lower dilution levels than observed for coatings produced with conventional welding techniques but well in the range mentioned in the literature. PTA coatings exhibit dilution levels close to the reported lower bound whereas laser coatings dilution is close to the reported upper bound.

3.2. High temperature structure stability

The response of the coatings to the extreme temperature used is illustrated by the microstructural changes (Fig. 2) and microhardness profiles of the transverse section of single layer specimens are presented in Fig. 3.

Hardness gradient between coating and substrate confirms the lower dilution levels measured on the as-deposited specimen. After high temperature treatment hardness gradients are reduced for both specimen as diffusion of elements from the substrate can occur. Surprising on a first analysis is the fact that heat treatment does not affect hardness of PTA deposits whereas laser coatings exhibit a decrease on hardness reaching PTA hardness levels. This behaviour is observed both on cycled and soaked specimen at 1050 °C.

Microstructural analysis confirms the different response to high temperature treatment of the coatings. PTA structures exhibit alterations on the carbides morphology; besides the change on morphology laser coatings show an apparent increase on carbides volume fraction as they precipitate in the matrix. The increase on carbides volume fraction on laser deposits is confirmed by scanning electronic microscopy (Fig. 4).

Materials response to heat treatment can be understood considering the high temperature used. Being lower than the solubilization temperature (T >1095 °C), carbides are not expected to dissolve. The explanation for the observed behaviour is on the precipitation sequence of the alloy, experienced by each of the deposits. As the cooling rates of PTA deposits are slow, precipitates on the as-deposited are relatively stable therefore further heat treatment (ageing) is ineffective. On the other hand, the faster solidification rates of laser cladding process keep elements, like Cr, in solution, as

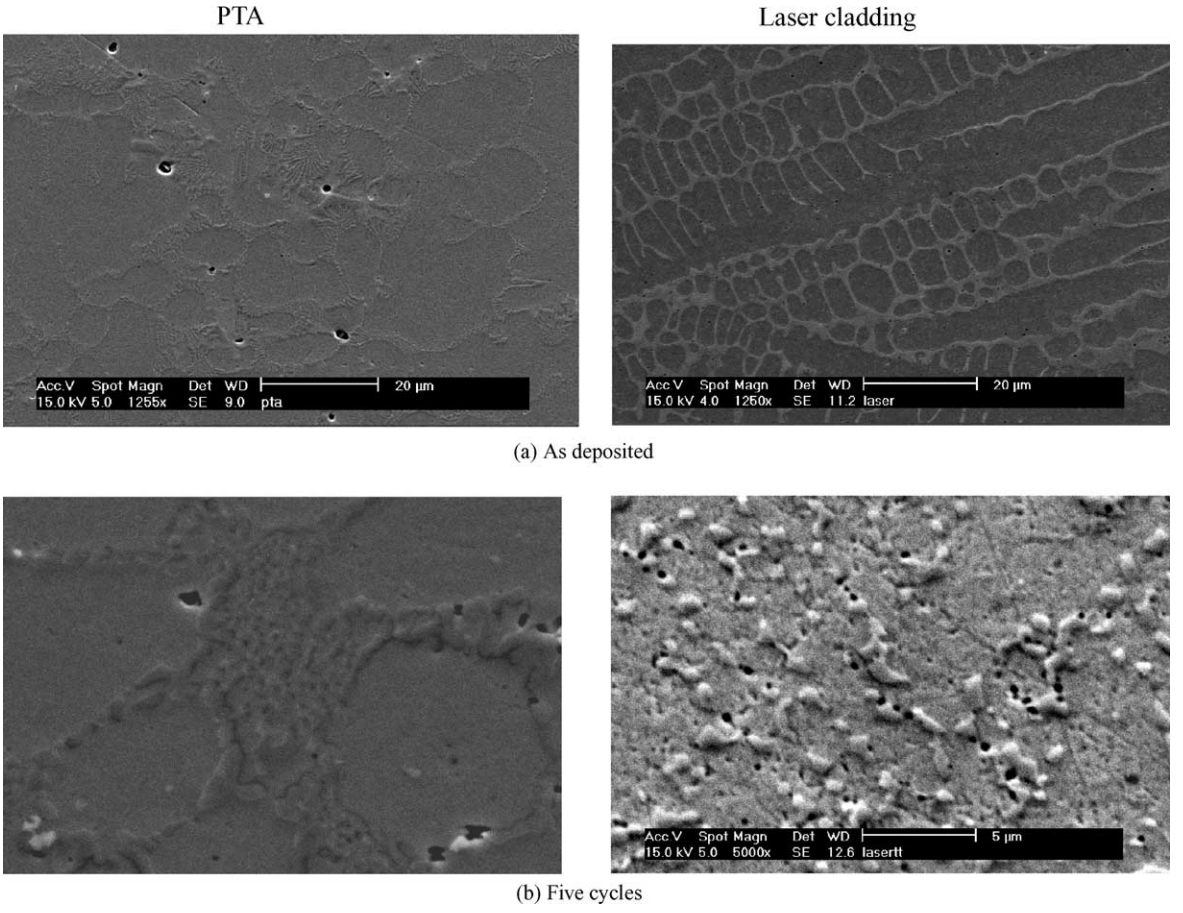


Fig. 4. PTA and laser microstructures as observed on scanning electronic microscope before and after high temperature exposure: (a) as-deposited; and (b) after five cycles at 1050 °C.

specimen are subjected to ageing at 1050 °C carbides tend to precipitate leading to changes on properties. The high temperature used results on over-ageing and is responsible for the decrease on hardness.

Semi-quantitative chemical analysis (Fig. 5) confirms this behaviour as higher Cr contents were measured in the as-deposited matrix. After ageing treatment at high temperature Cr levels on dendritic

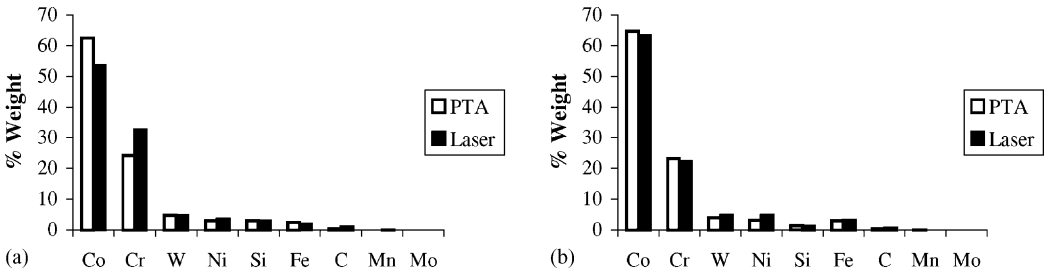


Fig. 5. Semi-quantitative chemical analysis (EDS) of the dendritic regions of PTA and laser coatings: (a) before; and (b) after high temperature treatment.

Table 5
Vickers microhardness (25 g) of the dendritic regions of PTA and laser coatings

	As-deposited (HV)	Five cycles (HV)
PTA	483	480
Laser	572	434

regions of both coatings are similar. Localised microhardness measurements, 25 g load, on the dendritic regions (Table 5) contribute to the above explanation that PTA specimen in the as-deposited condition exhibit stable carbides, which account for the observed microstructural stability.

According to the present results hardfaced components subjected to high service temperatures, should be processed so that stable structure are produced, either by choosing the adequate coating process or by applying an appropriate heat treatment after surface welding. As one reduces the alterations on carbides, morphology, volume fraction, etc. minimal changes on high temperature wear behaviour are expected, and accelerate degradation of surfaces are minimised.

4. Conclusions

- As-deposited laser hardfacing result on finer solidification structures with higher hardness than PTA coatings.
- PTA coatings exhibit hardness stability after high temperature exposure whereas laser deposits present a decrease on hardness.
- High-temperature treatment leads to changes on carbides morphology and also to precipitation, in the case of laser deposits.

Acknowledgements

Authors would like to thank Universidade Federal do Paraná (UFPR), Agencia Nacional do Petróleo (ANP), Conselho Nacional de Pesquisa e Desenvolvimento (CNPq) for funding the present work. Special thanks are due to Professor Paulo Sergio C.P. da Silva for enlightening discussions and to Adaildo L. Vieira Jr. for his help on editing the present paper.

References

[1] P. Crook, H.N. Farmer, Friction and wear of hardfacing alloys, in: ASM Handbook—Friction, Lubrification and Wear Technology, Vol. 18, 1st Edition, ASM Metals Park, Ohio, 1992, pp. 758–765.
[2] D. Raghu, Y.B.C. Wu, Recent development in wear and corrosion-resistant alloys for the oil industry, Mater. Perform. 36 (1997) 27.
[3] J.R. Davis, Hardfacing, Weld cladding and dissimilar metal joining, in: ASM Handbook—Welding, Brazing and Soldering, Vol. 6, 10th Edition, ASM Metals Park, Ohio, 1993, pp. 699–828.
[4] R.J. Dawson, C.B. Thompson, Applications for hardfacing in the pulp and paper industry, in: Corrosion, Nace International, 1989.
[5] T.M. Chen, T.S. Lui, L.H. Chen, Overlaying of Stellite 6 superalloy on austenitic manganese steel by PTA method, in: Proceedings of the Sixth Conference on Surface Modification Technologies, Chicago, USA, 1992, pp. 2–5.
[6] B. de B. Foltran, E.Y. Kuwabara, A.S.C.M. d'Oliveira, Congresso Brasileiro de Engenharia Mecânica, Sao Paulo, Brazil, 1999.
[7] E. Lugscheider, U. Morkramer, A. Ait-Mekideche, Advances in PTA surfacing, in: Proceedings of the Fourth National Conference on Thermal Spray, Pittsburgh, PA, USA, 1991, pp. 529–535.
[8] D. Raghu, R. Webber, PTA proves its work in high-volume hardfacing jobs, Welding J. 75 (1996) 34–40.
[9] H. Kim, Y.J. Kim, Microstructural evaluations of the plasma transferred arc coated layers on the hardness wear resistance and corrosion for the hardfacing of Ni- and Co-based alloys, in: Proceedings of the 15th International Conference on Thermal Spray, 1998, p. 217.
[10] A. Belmondo, M. Castagna, Wear-resistance coatings by laser processing, Thin solid films 64 (1979) 310–317.
[11] R. Colaço, T. Carvalho, R. Vilar, Laser cladding of Stellite 6 on steel substrates, High Temp. Chem. Proc. 3 (1994) 21–29.
[12] Singh, Laser: The leading technology for surface treatments, in: Proceedings of the International Conference on Beam Processing of Advanced Materials, The Minerals, Metals and Processing Materials Society, 1993.
[13] D. Raghu, B. Mckee, C. Sheriff, J.B.C. Wu, High temperature erosion resistant materials for petroleum refinery equipment, in: Corrosion, Nace International, 2001.
[14] A. Frenk, N. Henchoz, W. Kurz, Laser cladding of cobalt-based alloy: processing parameters and microstructure, Zeitschrift fuer Metallkunde 84 (12) (1993) 886–892.
[15] J.L. de Mol Van Otterloo, J.Th.M. de Hosson, Microstructural features and mechanical properties of a cobalt-based laser coating, Acta Mater. 45 (1997) 1225.
[16] E. Lugscheider, B.C. Oberlander, A comparison of the properties of coatings produced by laser cladding and conventional methods, The Institute of Materials, 1 Carlton House Terrace, London SW1Y 5DB, UK, 1992, pp. 383–400.
[17] C.P. Sullivan, M.J. Donache Jr., F.R. Morral, Cobalt-based Superalloys, Centre d'information du Cobalt, 1970, 72 p.