Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 12 (2011) 313–322

Physics Procedia

LiM 2011

Laser Cladding of TiC for Better Titanium Components

J.Sampedro[a]*, I. Pérez[a], B.Carcel[a], J.A. Ramos[a], V. Amigó[b]

[a]AIDO, C/ Nicolás Copérnico, 7. Paterna 46980. Spain
[b]ITM of Politechinical University of Valencia, Camí de la Vera s/n, Valencia 46022. Spain.

Abstract

Pure commercial titanium is widely used because of its high corrosion resistance and lower cost compared with other titanium alloys, in particular when there is no high wear requirements. Nevertheless, the wear resistance is poor and surface damage usually occurs in areas under contact loadings. Laser cladding is a suitable technique for manufacturing precise and defect free coatings of a dissimilar material with higher wear and corrosion resistance. In this work a good understanding of laser metal deposition mechanisms allowed to obtain defect free coatings of Ti6Al4V and TiC metal matrix composite (MMC) using a flash lamp pumped Nd:YAG laser of 1 kW. A complete investigation of the process parameters is discussed and resultant wear properties are shown. The results show the feasibility to apply the process for manufacturing, improving or repairing high added value components for a wide range of industrial sectors.

Keywords: Laser cladding; Titanium; Carbides; Wear.

1. Introduction

Composite material offer many advantages over other materials and particle reinforced metal matrix composites (MMC) have high hardness, respectable strength and fracture toughness, are widely used in high wear resistance applications [1, 2, 3].

To date, WC-based composites are the most known because of their excellent wear resistance-strength combination. However, poor corrosion resistance of WC-Co hard metals and their improper reliability at high temperatures restrict applications of these materials within quite narrow limits [4].

A suitable alternative material has to possess a high hardness and wear resistance combined with sufficient corrosion resistance.

Titanium carbide reinforced composites can serve as a good candidate to replace WC-Co hard metals [2, 3].

Titanium and its alloys are extensively used in aeronautical, marine and chemical industries owing to their specific properties such as high strength, excellent corrosion and high temperature resistance. Nevertheless, the application of titanium alloys under severe wear and friction condition is restricted due to their poor tribological properties [5–7].

* Corresponding author. Tel.: +34961318051.
E-mail address: jsampedro@aido.es.

doi:10.1016/j.phpro.2011.03.040

Wear is a phenomenon primarily determined by the surface properties of the material rather than by bulk properties. In this respect, surface modification techniques offer a solution to the problem. The capabilities of laser cladding of low thermal input, full density of added material and metallurgical bonding allow carrying out several strategies to increase the wear and corrosion resistance of titanium.

High power lasers are potential tools in material processing applications, cutting, welding and marking are the most common processing techniques used in industry since the laser became an industrial tool. In the last years additive manufacturing techniques emerged strongly because of industry demands. The main fields of applications are prototyping, direct manufacturing, repairing of high added value components and improvement of surfaces properties [8]. Main advantages of laser are the flexibility, low thermal input, full density of added material and metallurgical bonding.

There is a large diversity of materials suitable to process by laser cladding. The majority of applications are focused in steel processing for repairing and cobalt base alloys for increasing the wear resistant. Most of the materials are commercial materials formulated for thermal spray. The nature of the process led to a natural increment of the hardness in the majority of materials because of the high cooling rates and the resulting grain refinement.

The objective of this investigation is to evaluate strategies to improve the mechanical properties of Titanium Grade 2 and the alloy Ti6Al4V. In particular to investigate and understand the effects of laser cladding of alloy Ti6Al4V on cheaper base material such Titanium Grade 2 to improve wear resistance and friction coefficient.

In the other side, to investigate the mixture Ti6Al4V reinforced with TiC particles to improve the surface properties of Ti6Al4V samples. A critical variable will be to consider the influence of different weight ratio of TiC particles.

2. Experimental

The experimental investigation was carried out by means of a Nd:YAG laser (wavelength 1064 nm) of TRUMPF (HL1006D) with maximum output power of 1KW. The light is guided through an optical fibre of 0.6mm core. The laser head contains the optical system with a focusing lens of 200mm. The optical system is assembled to the cladding coaxial nozzle. For this investigation the laser beam diameter was set to 2mm and the distance from the nozzle to the sample was set to 12 mm (Figure 1).

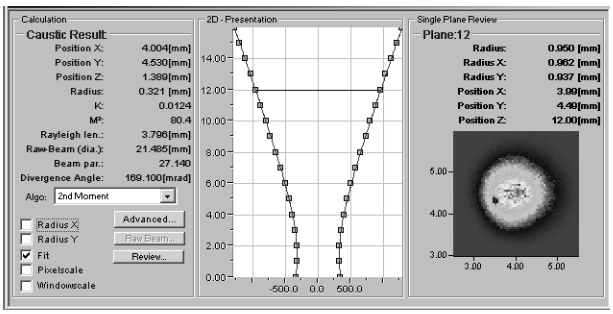


Figure 1. Beam laser characterization at the working plane. Beam diameter of 2 mm.

In this work two strategies have been studied: laser cladding of Ti6Al4V over Ti pure of grade 2 samples and laser cladding of Ti6Al4V + TiC with different concentrations of TiC on Ti6Al4V samples, , therefore the objectives have been to evaluate the influence of process parameters regarding clad geometry and wear resistance.

Table 1 and Table 2 show the range of parameters investigated. In all cases the shielding gas was helium.

For feeding the additive material a dispensing system Sulzer Twin 10C was used. The motion system consist of 4 stages XYZC commanded by a digital CNC of Siemens.

All samples were cut transversally, mechanically grounded, polished in diamond paste and etched using Kroll's etchant. Cross-sections of resulting claddings were examined by optical and scanning electron microscopy. Microhardness measurements were performed along cladding cross-section from substrate to interface with a Struers Duramin-1 tester. Wear test were performed using a microtest MT4002 tribometer with a pin-on -disk set up.

Table 1. Range of parameters investigated for laser cladding of Ti6Al4V.

	Power (W)	Velocity (mm/min)	Powder flow (g/min)
Range	500 – 1000	300, 480, 720	2 – 5
Increment	100	-	1

Table 2. Range of parameters investigated for laser cladding of the mixture Ti6Al4V + TiC.

	Power (W)	Velocity (mm/min)	Powder flow (g/min)	TiC (%)
Range	400 – 1000	480, 720	3 , 5	30, 60
Increment	100	-	-	-

Table 3 and Table 4 show the composition of additive and base materials used in this investigation. The mixture Ti6Al4V + TiC was mechanically mixed in planetary ball mill during 2 hours according to ratios 30% and 60% in weight of TiC, the final grain size of the mixture was 30-75 μm. By other side, Ti6Al4V was a commercial available powder.

The base materials were grounded with SiC paper and degreased using acetone and ethanol before deposition.

Table 3. Composition and grain size of additive materials.

Additive material	*Grain size (μm)*	*Ti*	*Al*	*V*	*Fe*	*C*	*Other*
TiC	10-30	bal.	-	-	-	19,2	0.5
Ti6Al4V	45-100	bal.	6,40	4,10	0,12	0,01	0,16

Table 4. Composition of base materials: hot rolled Ti6Al4V and Ti Grade 2.

Base material	Thickness (mm)	Ti	Al	V	Fe	C	Other
Ti6Al4V	Φ=50x5	bal.	6,40	4,10	0,12	0,01	0,16
Ti Gr2	3	bal.	-	-	0,039	0,012	0,40

3. Results and discussion

3.1. Laser cladding of Ti6Al4V

The clads obtained showed good quality in general, mainly because the range of parameters was set based on previous experiences. In this way the majority of clads showed optimal results with low dilution, and were free of pores and cracks.

Table 5. Single clads of Ti6Al4V obtained with the range of parameters of Table 1 at 3 g/min.. In general de the results showed no appreciable defects. A dimensional analysis is shown in Figure 3.

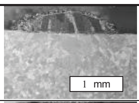
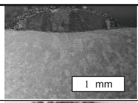
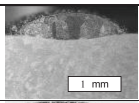
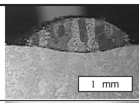
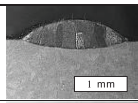
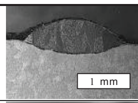
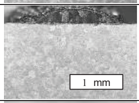
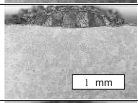
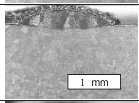
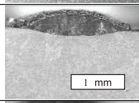
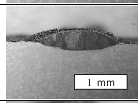
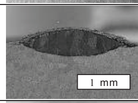
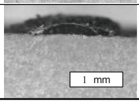
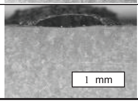
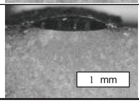
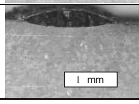
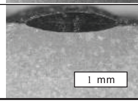
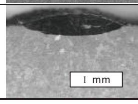
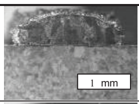
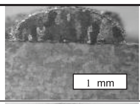
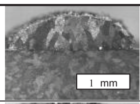
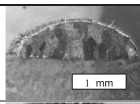
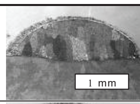
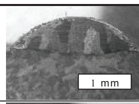
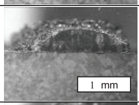
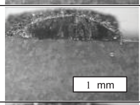
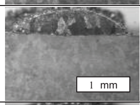
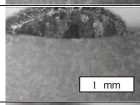
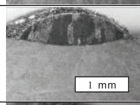
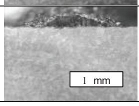
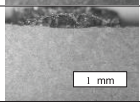
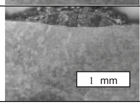
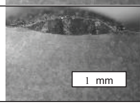
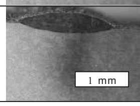
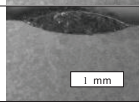
3g/min	Laser power (W)					
Velocity (mm/s)	500	600	700	800	900	1000
5						
8						
12						

Table 6. Single clads of Ti6Al4V obtained with the range of parameters of Table 1 at 5 g/min.. In general de the results showed no appreciable defects. A dimensional analysis is shown in Figure 4.

5g/min	Laser power (W)					
Velocity (mm/s)	500	600	700	800	900	1000
5						
8						
12						

An exhaustive study of the parameters and a dimensional analysis (see Figure 2) of the resulting clads is showed in next charts (see Figures 3 and Figure 4).

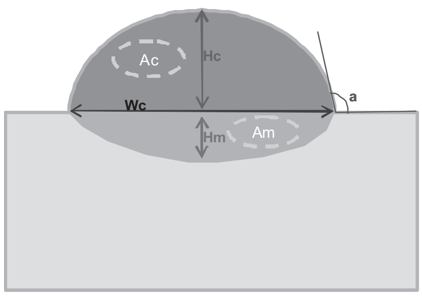


Figure 2. Dimensional analysis of single clads. Parameters measured. Wc: width of clad, Hc: height of clad, Hm: deep of dilution of clad material on substrate material, Ac: area of clad, Am: area of dilution, a: angle of clad.

As predicted, the width of each single clad (Wc) increase with the increment of the specific laser energy, although the high of the clads (Hc) does not experiment a significant change.

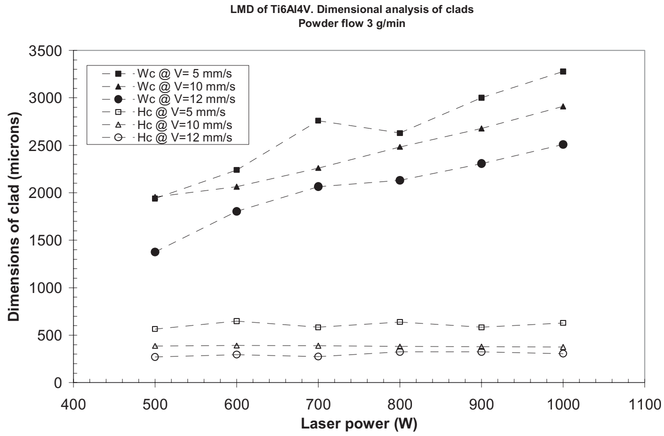


Figure 3. Dimensional analysis of single clads of Ti6Al4V with powder rate 3g/min. Wc: Width of a single clad. Hc: Height of single clad from

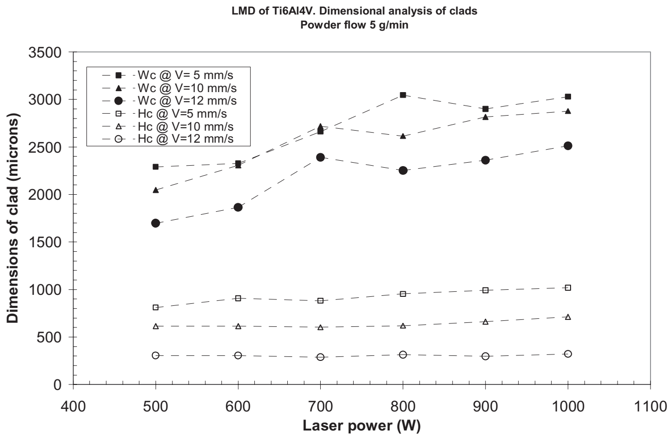


Figure 4. Dimensional analysis of single clads of Ti6Al4V with powder rate 5g/min.

Three parameters were selected for a powder rate of 3g/min to perform large coatings (30mmx30mm) in order to perform the wear tests. Table 7 shows the selection parameters in a range of specific energy.

Table 7. Selection of single clads parameters for wear analysis.

Clad nº	Power (W)	Velocity (mm/s)	Powder flow (g/min)	PV/D (kJ/cm2)
9	700	8	3	4.6
14	600	12	3	2.5
17	900	12	3	3.7

The hardness results are showed in Figure 5, in all cases the hardness of the coating is higher than for the base material (135 Hard Vickers), but the heat affected zone (HAZ) has lower hardness due to a lower cooling rate. By other side, the hardness of the coating increases as the cooling rate is higher that corresponds to a lower specific energy.

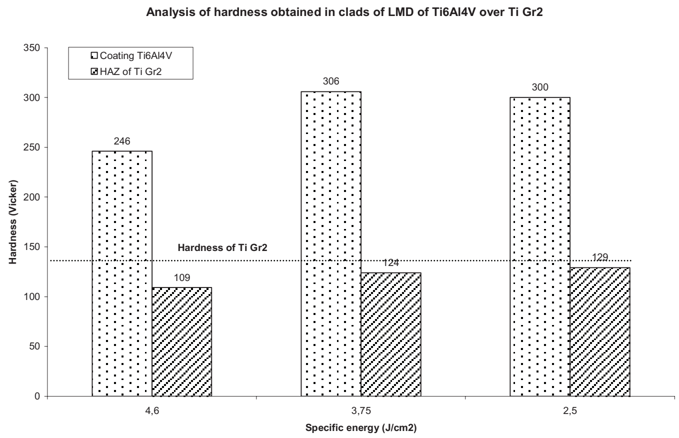


Figure 5. Analysis of hardness of clads number 17, 9 and 14 with process parameters of Table 7.

Nevertheless, the main problem for the large coating is a lack of adhesion in the edges of the coating. This can be explained as the beam profile is not homogeneous in the edges and the temperature gradients generate stress in the interface. Controlling the energy density it can control the thermal gradient and reduce the stress (Figure 6).

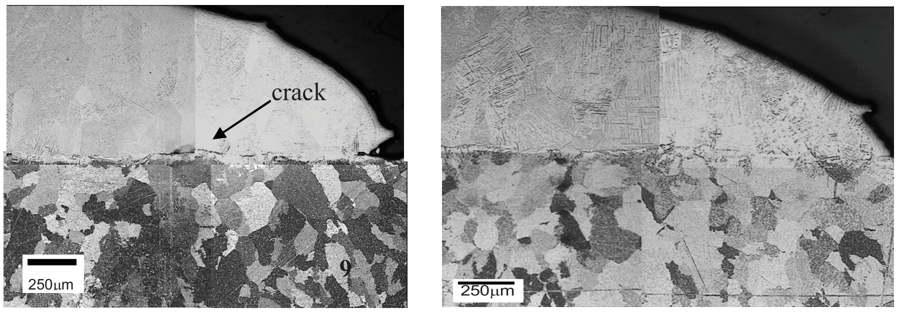


Figure 6. (Left) Inspection of defects in the edges of the coating. Sample 9 with cracks near the interface. (Right) Samples 17 with no observable defects.

The wear resistant test, performed using microtest MT4002 tribometer, showed good results. In all cases tested, the wear resistance was improved in contrast with the base material (Ti Gr.2) (Figure 7).

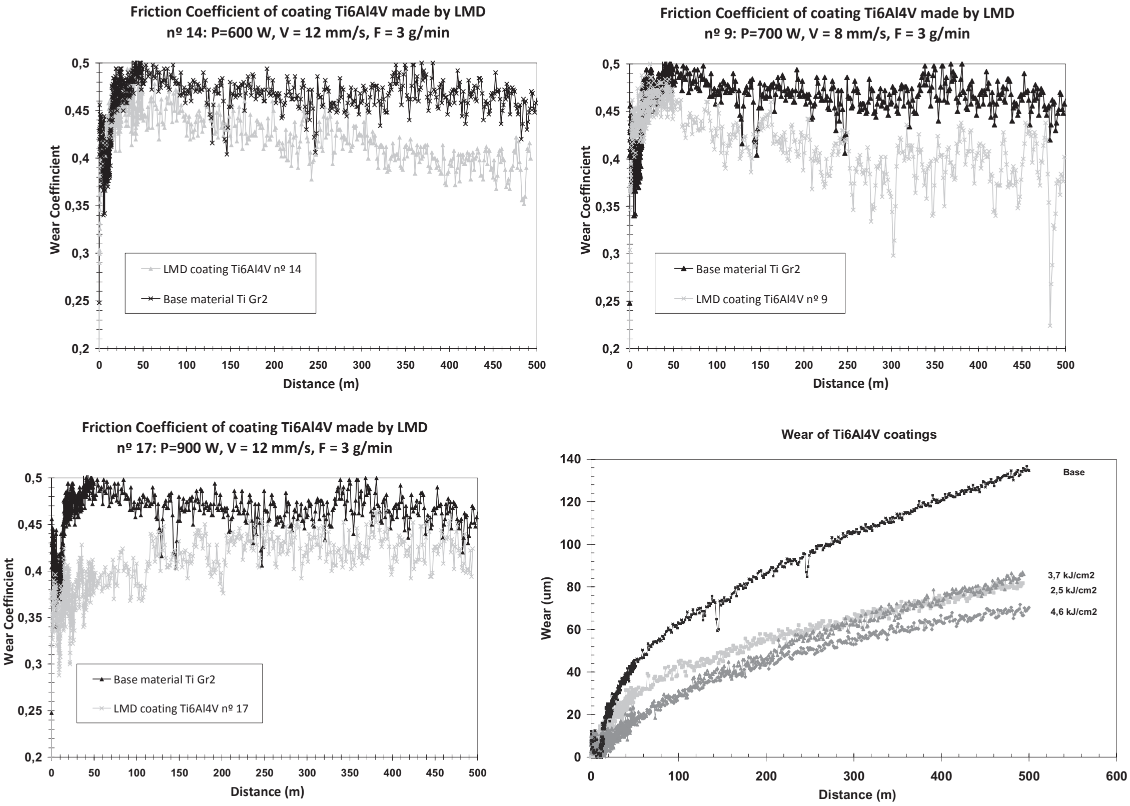


Figure 7. Friction coefficient test and wear test obtained using a microtest MT4002 tribometer with a pin-on -disk set up. The results of each coating are compared with the base material. In all cases Ti6Al4V coating improves wear resistant ans reduces the friction coefficient.

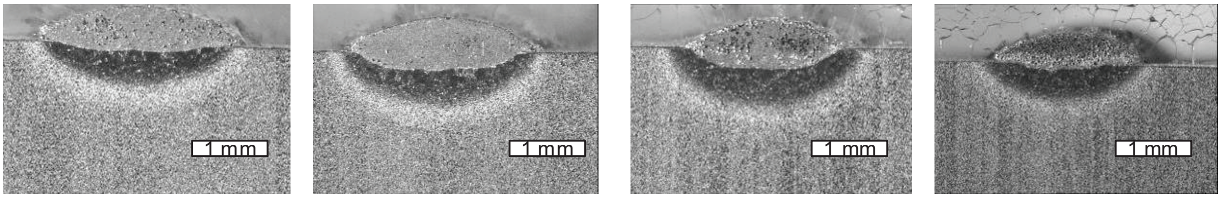
3.2. *Laser cladding of Ti6Al4V reinforced with TiC particles*

In the first stage, a wide range of processing parameter has been tested, according to Table 2, in order to determinate a set of parameters with the best results. Table 8 shows the selected parameters as a function of the specific laser energy and the concentration of TiC powder in the powder. The criteria for determining the optimum quality for the coating were based on a compromise of low dilution, best homogeneity and lowest occurrence of pores and cracks.

Table 8. Selection of process parameters.

Clad number	Power (W)	Velocity (mm/s)	Powder flow (g/min)	TiC (weight %)
30%TiC_5	600	12	3	30
30%TiC_7	800	12	3	30
60%TiC_5	600	12	3	60
60%TiC_1	400	8	3	60

The metallographic analysis of the selected deposited single clads show coatings free of cracks and porosity.



(a) (b) (c) (d)

Figure 8. Ti6Al4V + TiC single clad layers free of crack and pores. (a) 30% weight ratio of TiC, 600 W, 12 mm/s, 3 g/min. (b) 30% weight ratio of TiC, 6¡800 W, 12 mm/s, 3 g/min. (c) 60% weight ratio of TiC, 600 W, 12 mm/s, 3 g/min., (d) 60% weight ratio of TiC, 400 W, 8 mm/s, 3 g/min.

TiC particles used have an irregular form, when carbides are irradiated with the laser the particles loss their original size. The material lost is dissolved in the matrix (see Figure 8). As the process become more intense the carbides tend to a complete dissolution. In Figure 8, this fact can be observed in more detail.

Regarding TiC arrangement in clad volume, the particles distribution varies also with clad parameters, for instance clad number 60%TiC_1 has a homogeneous arrangement of carbides, and in the opposite 30% TiC_7 shows a complete dissolution of carbides in the matrix. This fact is obvious since the power of 30%TiC_7 is 800W and for a double concentration of carbides the power is 400W (see Figure 9).

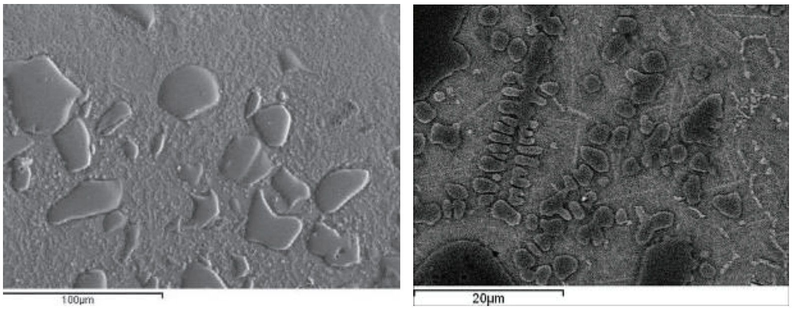


Figure 9. At low specific laser energy, most TiC particles have edges angles and an irregular form. With an augment of specific laser energy, the size of the TiC particles is reduced and their edges become smooth, implying that TiC particles are partially dissolved into the Ti6Al4V-matrix.. When the specific laser energy is further increased, TiC particles are completely dissolved and many fine dendrites appear during cooling [13]. (Left) TiC particles with irregular form. (Right) Dendrites of TiC in matrix of Ti6Al4V, due to a partial dissolution in the matrix.

When obtaining large coatings, TiC particles dissolution become more visible in simple inspections. In Figure 10 it sees large coatings free of defects, but with different TiC particles distribution because overlapped areas have reheat treatment. With a laser power of 800 W (corresponding to 30%TiC_7 of Table 8), it observes only TiC particles in the centre of each single layer. The distribution becomes homogeneous when the laser power is decreased.

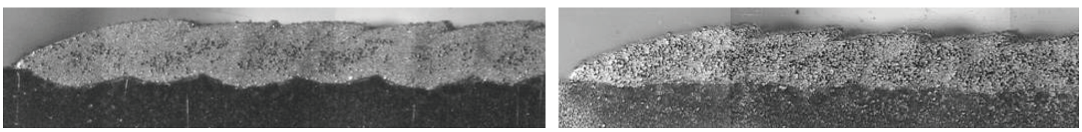


Figure 10. Large coating obtained by laser cladding of Ti6Al4V + 30%TiC with 3 g/min of powder flow, velocity of 12 mm/s, and 800 W (left) and 600 W (right) of CW Nd:YAG laser.

Hardness test have been performed in single layers (see results in Table 9). As it can be observed the microhardness of the clad layer decrease as the specific laser energy is increased due to the massive dilution of primary TiC particles in the clad.

Table 9. Hardness measurements (HV 0.5).

Clad number	Hardness in the coating (Vickers)	Power (W)
30%TiC_5	1032	600
30%TiC_7	480	800
60%TiC_5	1120	600
Base material Ti6Al4V	360	-

Cladding layers obtained were compared with untreated substrate using dry sliding wear tests. The selection of the right combination of process parameters leads to an improvement of the wear resistance and an increase of the friction coefficient (Figure 11).

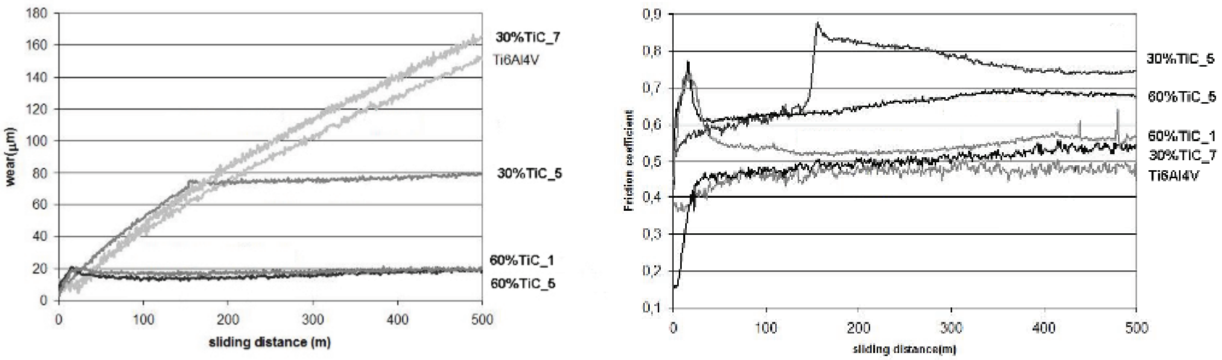


Figure 11. Friction coefficient and wear ratios versus sliding resistance

4. Conclusions

The objective of this investigation was to improve the mechanical properties of Ti Gr2 and Ti6Al4V surfaces by depositing defect free coatings of Ti6Al4V and the mixture Ti6Al4V + TiC respectively using laser cladding process.

The results obtained within this investigation shows suitability to improve titanium components by two strategies. Laser cladding of commercial powder Ti6Al4V on TiGr 2 samples increases the hardness of base material from 120 HV to 300 HV, also the wear test showed improved wear resistance of the coatings.

By other side laser cladding of Ti6Al4V reinforced with TiC required to determine the percentage of TiC in the mixture. Weight ratios between 30% and 60 % of TiC show good results in general but the influence of the energy of the process must be considered in order to control the dissolution of TiC particles. The investigation of the influence of process parameters allow to obtain defect free coatings with homogeneous distribution using a 30% of weight in the mixtures.

But in general, the hardness of samples surface of Ti6Al4V was increased, also the wear resistance and the friction coefficient from 0,5 to 0,7.

Therefore the results obtained shows suitability of laser cladding to repair and to manufactured titanium components with improved mechanical properties.

Acknowledgements

This work is financially supported by Spanish Minister of Science (Grant nº DPI2005-09244-C04-01) under National Industrial Production Programme.

References

[1] Candel J., Amigó V., Ramos de Campos, J.A, Busquets, D. “ Sliding wear resistance of TiCp reinforced composite coating produced by laser cladding” Surface and Coating, Vol 204 (20), 3161-3166.

[2] I. Hussainova. Wear 225 (2003) 121.

[3] I. Hussainova, Wear 258 (2005) 357.

[4] J. Kübarsepp, H. Reshetnyak, Wear 177 (1994) 185.

[5] Y.S. Tian, C.Z. Chen, S.T. Li, Q.H. Huo, Appl. Surf. Sci. 242 (2005) 177.

[6] R.L. Sun, D.Z. Yang, L.X. Guo, S.L. Dong, Surf. Coat. Technol. 132 (2000) 251.

[7] L. Cai, Y. Zhang, L. Shi, Rare Metals 26 (2007) 342.

[8] Gasser A., Backes, G., Kelbassa I.,Wissenbach, K. “Laser metal deposition (LMD) and selective laser melting (SLM) in turbo-engine applications” Laser Technik Journal, 2010 (2), 58 – 63.