Pulsed Nd-YAG laser deposition of WC-12%Co, TiN and TiAlN

Y. P. KATHURIA*, YOSHIHISA UCHIDA, YOSHIYUKI UCHIDA
Aichi Institute of Technology, Yachigusa Yakusa-cho Toyota Japan

This paper demonstrates the feasibility of generating a thin clad coating of WC-12%Co, TiN and TiAlN on SS304 base material by using the pulsed Nd-YAG laser. In the first case, the hard metal carbide (WC) gets dissolved in the molten liquid metal (Co), acting as binder thus producing the desired matrix. In the second case TiN based composite coating was created with and without the addition of Al-powder. In the post processing, a precision grinder was employed to smoothen the top surface. Microhardness mapping was performed at various points across the surface. The results show the average microhardness value of 1910 HV for WC-12%Co coating, whereas the microhardness of the coating deposited with TiN is lower (1035 HV) than that of using Al-mixed powder (1264 HV).

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1. Introduction

In the recent past years the development in surface modification against erosion / corrosion have undertaken a new dynamic turn in laser cladding of hard materials. The unrelenting demand of low erosion, high wear resistance and increased hardness value with low thermal effects have forced the manufacturers to adopt /develop innovative techniques which could meet this demand. This led to the selective use of laser cladding of carbides and nitrides onto various base materials. For the last decade, laser cladding of cobalt /nickel based alloys such as stellite /colmonoy have successfully been used for various applications in turbine, automobile and aerospace industries. However, for improved abrasive and wear resistance, hard carbide coatings of Cr_3C_2, TiC and WC have recently been tried in various metal matrix and among them WC- 12% Co composite coating has widely been used for abrasive and wear resistance coating in die, tool and mould industries [1] - [5]. Tungsten carbide has a unique property of high melting point, high wear resistance, good thermal shock resistance, thermal conductivity and good oxidation resistance, whereas the cobalt acting as binder is introduced for densification through wetting as well as to improve the toughness so that brittle fracture among ceramic phases can be avoided. On the other hand metal nitrides such as TiN have been widely used as protective hard coatings to increase the lifetime and performance of cutting and forming tools. But the main drawback of TiN is its limited oxidation resistance, which however could be improved by the presence of elements such as Al. Therefore, the development of TiAlN coatings is considered as an alternative to TiN because of its higher oxidation resistance. Various techniques are in use for cladding of such hard carbides and nitrides onto the different base materials [6] - [12]. But the aim of this paper is to study different aspect of such clad coating specifically WC-12%Co, TiN and TiAlN using a pulsed Nd-YAG laser applicable for die and mould repairing as well as for tool industries.

2. Fabrication technology

Below, the most widely applicable technique, used in the present study for such an application, is discussed.

2.1 The cladding procedure

In this process, a molten pool of the ‘pasted’ or blown powder with a complex three-dimensional shape is formed on the substrate by the laser beam interaction with the powder material. The basic principle described elsewhere [4] could be compared to a process of layered coating. In this case the powder material such as metal matrix composite i.e. hard metal carbide WC premixed / blended with the elements Co is delivered into the laser beam thereby it is melted and deposited onto the substrate. Alternatively, this process can also be accomplished by locally melting the substrate or the alloying element with the laser beam while simultaneously adding the premixed composite powder. The coating can be achieved through layer-by-layer scanning in the horizontal direction.

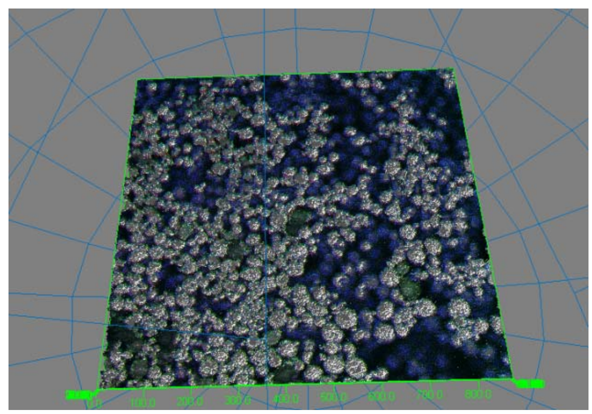
3. Experimental

The laser cladding experiments were performed with a pulsed Nd-YAG laser system (Fig. 1a) provided with beam bending optics, etc. The beam was delivered by a lens of focal length *f* = 80 mm so as to produce a defocused spot size of 300 - 400 µm on the substrate. The study was carried out in three steps. For the laser cladding of WC-12%Co powder, a commercially available premixed powder with an average particle size of approximately 10 µm was used. Appearance and distribution of spherical- shaped spherotene (WC) and Co particles in the powder is as shown in Fig. 1b. Whereas, in the second case TiN based composite coating was created with and without the addition of Al-powder. The deposition of TiAlN is performed by using a premixed TiN and Al powder as the source material. The average particle size of the TiN and Al-powder used being 75 µm and 30 µm respectively. The powder /mixture is then pasted onto the substrate surface using ethanol. The substrate was moved under the stationary laser beam by a numeric *XY*-table. The tracks were made by using the optimized process parameters (Tab. 1) so as to generate the desired clad coat on the test samples. Various types of samples were made on SS304 substrates using the line scan process with an overlap degree of 50-60%. In the post processing, a precision grinder was employed to smoothen the top surface. Fig. 2a-2b, 3a-3b and 4a-4b show the test samples fabricated in the present study. A confocal laser scanning microscope was used for surface profiling as well as the thickness measurement. An average layer thickness of about 112 µm, 7.9 µm and 18.2 µm was achieved for WC-12%Co, TiN and TiAlN clad coat after surface finish (Fig. 2c, 3c and 4c).

Table 1. Laser processing parameters

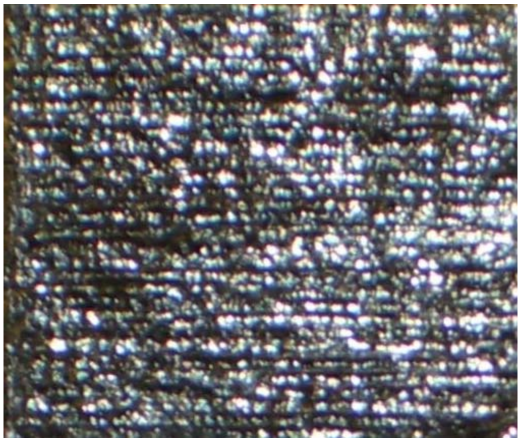
Wavelength	(λ) = 1.06 µm
Average power	(P) = 75 W
Pulse repetition rate	(PRF) = 10 Hz
Pulse width	(t_p) = 3.0 ms
Energy	(E) = 7.5 J
Assist gas	(Ar) = 6 l/min

Pulsed Nd-YAG laser system

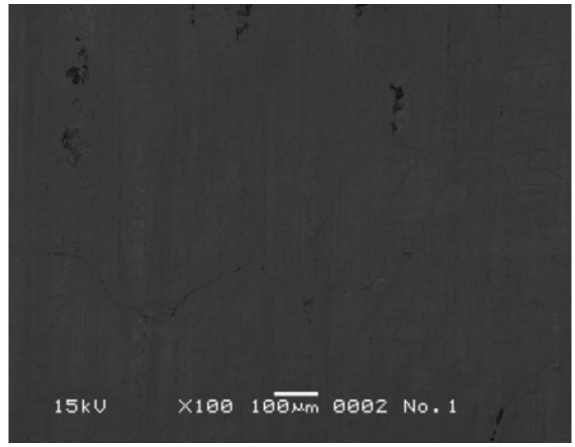


Spherotene WC-12%Co powder particles

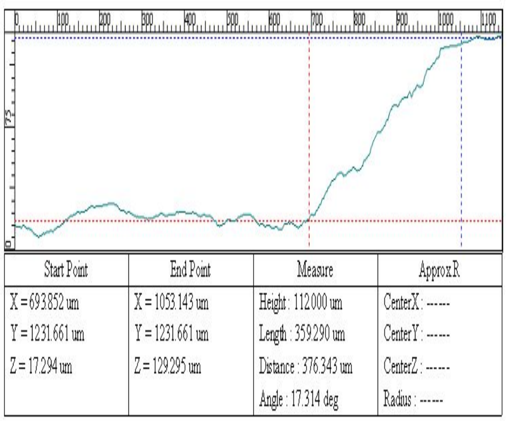
Fig. 1 Pulsed Nd-YAG laser system and WC-12%Co powder particles.



(a)



(b)



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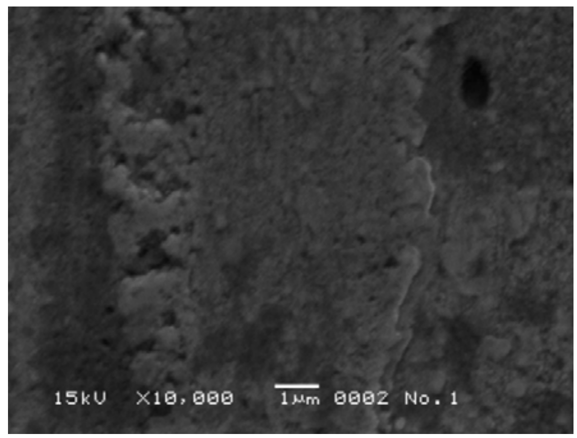
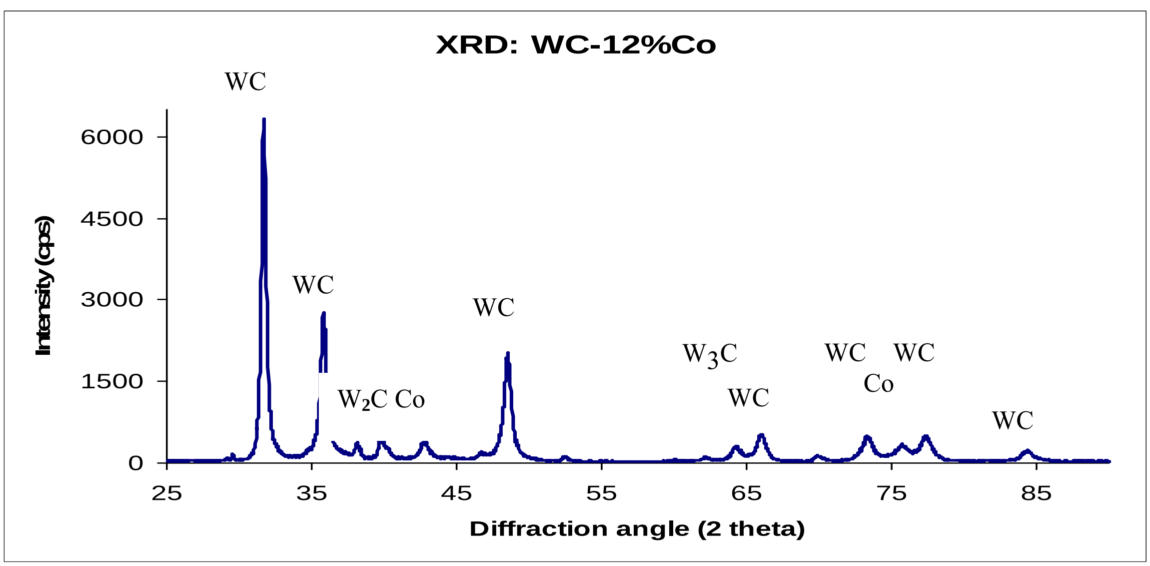
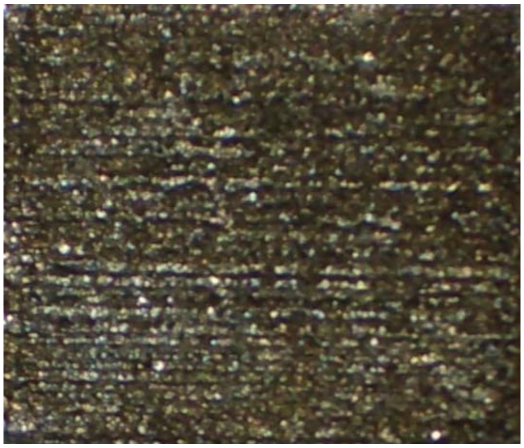


(d)



(e)

Fig. 2 (a) Bead appearance, (b) after surface grinding, (c) clad thickness profile, (d) SEM surface micrographic structure and (e) XRD spectra of WC-12%Co clad coating.



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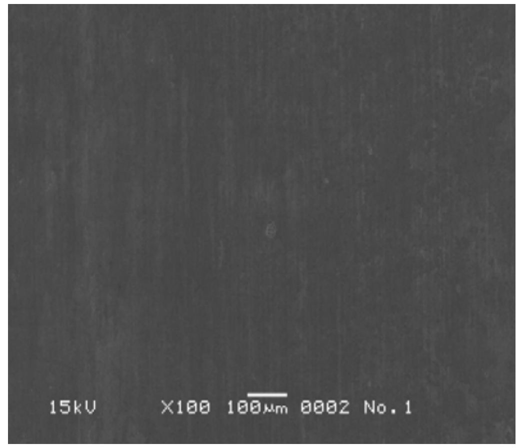

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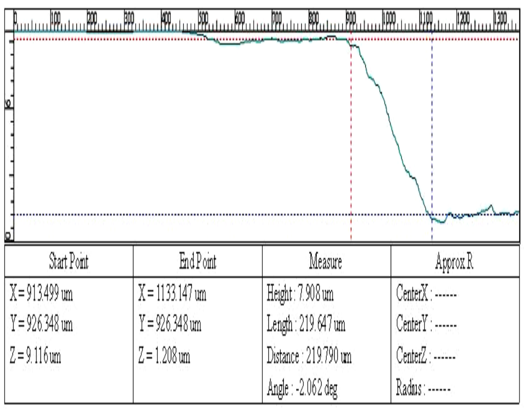

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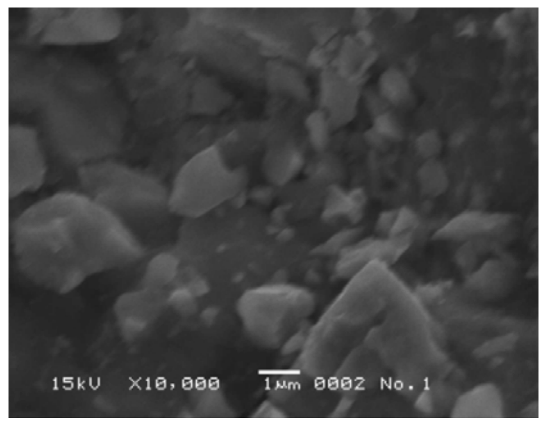

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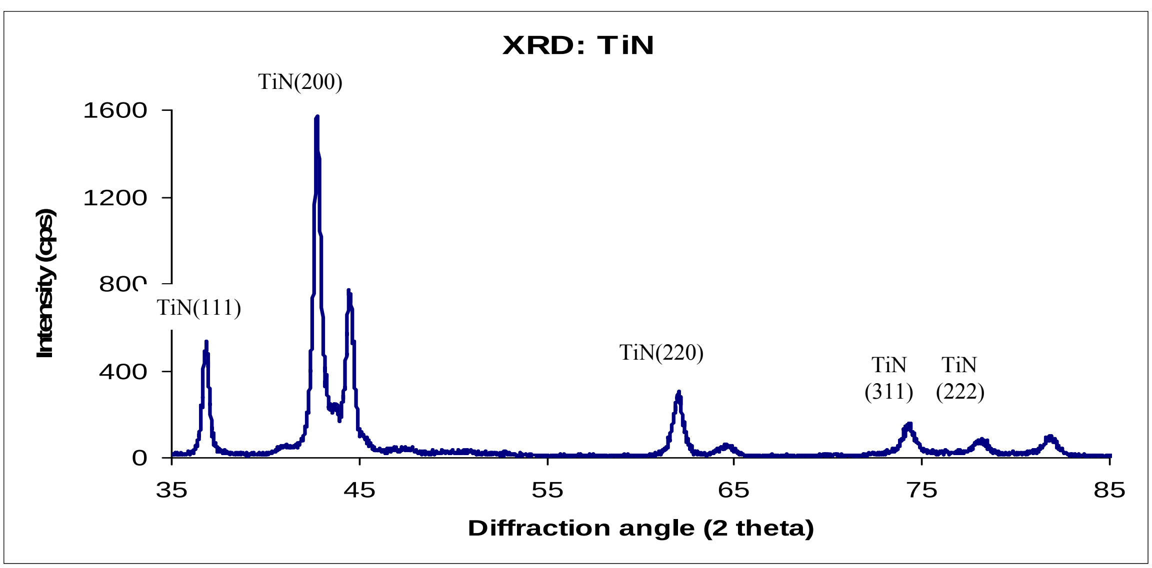
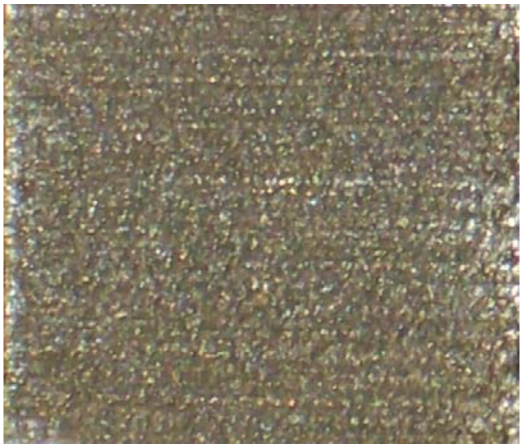
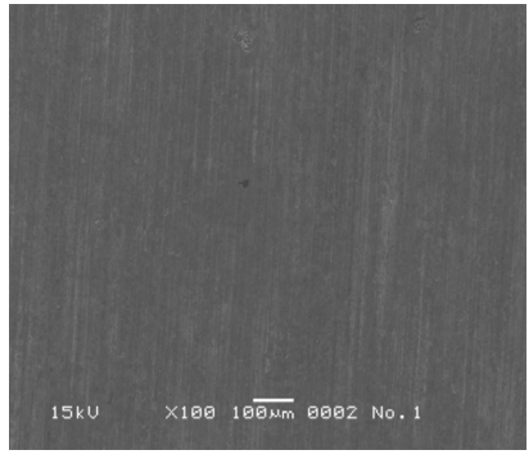


(e)

Fig. 3 (a) Bead appearance, (b) after surface grinding, (c) clad thickness profile, (d) SEM surface micrographic structure and (e) XRD spectra of TiN clad coating.



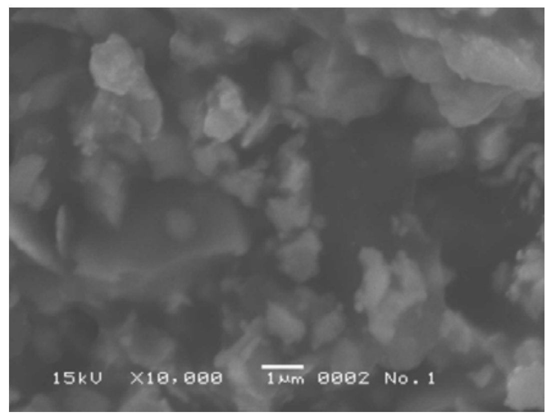
(a)



(b)

Start Point	End Point	Measure	Approx R
X = 725.854 um	X = 837.859 um	Height : 18.220 um	CenterX : ------
Y = 1044.310 um	Y = 1044.310 um	Length : 112.005 um	CenterY : ------
Z = 35.016 um	Z = 16.796 um	Distance : 113.478 um	CenterZ : ------
		Angle : -9.239 deg	Radius : ------

(c)



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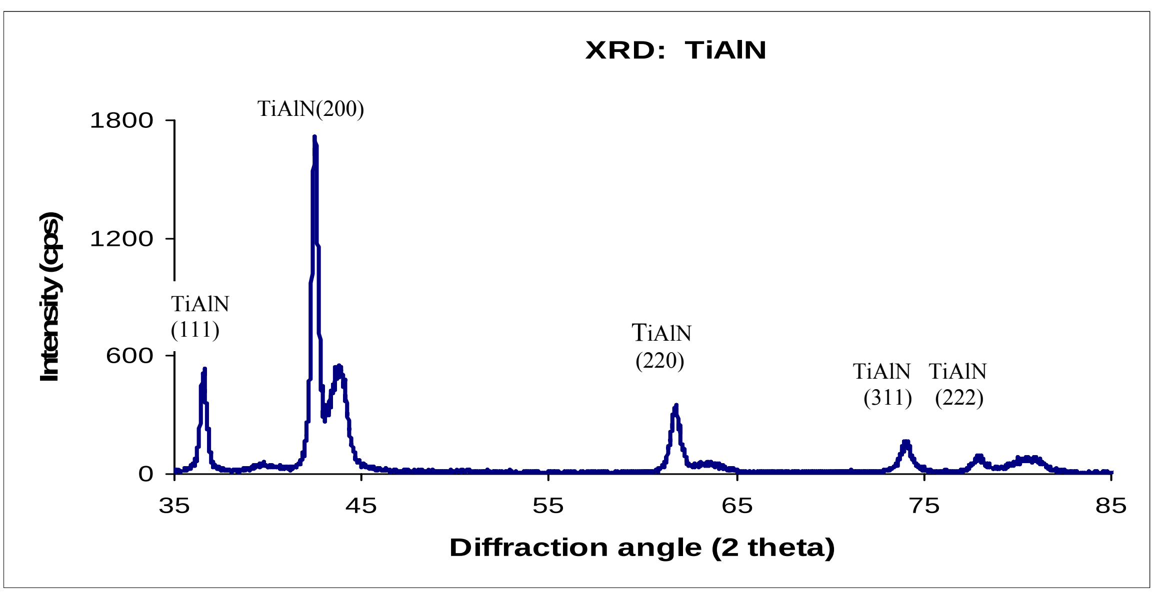

(e)

Fig. 4 (a) Bead appearance, (b) after surface grinding, (c) clad thickness profile, (d) SEM surface micrographic structure and (e) XRD spectra of TiAlN clad coating.

The X-ray diffraction (XRD) patterns of the laser clad coat of WC-12%Co, TiN and TiAlN were obtained via conventional powder diffractometry (Model: RIGAKU – ROTAFLEX) using Cu-Kα incident radiation (at a wavelength of $\lambda = 1.54056$ Å), and a take-off angle of 2°. The generator settings were 40 kV and 100 mA. The diffraction data were collected over a 2θ range of 10–100°, with a step width of 0.02° and a counting time of 5 s per step.

The microhardness measurements were done at various points on the smooth polished clad surface using a Matsuzawa microhardness tester under loading condition of 300 gf (for WC-12%Co), 100 gf (for TiN and TiAlN) and a dwell time of 10 sec., respectively [2], [11]. It results an average value of 1910 HV for WC-12%Co coating, whereas the microhardness of the coating deposited with TiN is lower (1035 HV) than that of using Al-mixed powder (1264 HV). These values are the average value of 9 measurement points across the precision grinded smooth clad surface of the samples.

4. Results and discussion

For the microscopic observations, various samples were cut, surface polished with a precision grinder. The microstructures were examined using scanning electron microscope (SEM). The results are summarized as below:

4.1 WC-12%Co

The results of laser cladding of WC-12%Co were examined by analyzing Fig. 2. The results indicate that, the clad surface appears to be good and exhibits practically no cracks. However, isolated scattered micropores were observed, which may be caused by gas trapping due to large fluid viscosity induced by WC particles [2]. Whereas, it is expected that with the higher content of the metal carbide, the hardness of the coating shall increase but it may suffer from cracks.

Since the melting points of Co is 1493 ^{o}C, therefore it melts earlier and forms a liquid phase during its interaction with the laser beam and penetrates partially only upto 10% into the WC, but mainly acts as a binder and give high temperature strength. The hard metal carbide (WC) thus gets dissolved in the molten liquid metal (Co), producing the desired matrix (Fig. 2d).

The results of the XRD spectra as shown in Fig. 2e, confirms the presence of WC and Co phases in the clad-zone. However, a few traces of the higher metallic carbide such as W_2C and W_3C are also observed.

4.2 TiN /TiAlN

The phase composition of the clad coating TiN /TiAlN as analyzed by XRD is shown in Figs. 3e and 4e respectively. From the XRD results, it can be seen that various sharp TiN and (Ti,Al)N peaks appear in the spectrum, which suggests that coating is mainly composed of these phases. Thus, TiN and TiAlN phase is the main composition in composite coating according to XRD analysis. The coating has a yellowish-brown homogeneous shining surface with SEM microstructure shown in Figs. 3d and 4d respectively. Besides that the shielding gas argon just can partially protect the powder against reaction with N_2 and O_2 in the air, but as the N_2 content is 4 times than that of O_2 in the air, therefore the TiN /TiAlN phase represents a larger fraction of the coating. As observed from the XRD spectra, diffraction peaks of both TiN and TiAlN more or less coincide. The proximity of the positions of the diffraction peaks for the TiN and TiAlN crystals (both having a face-centered cubic structure, fcc) is due to the fact that their lattice constant values are similar: 4.24173 and 4.194 Å, respectively. It is revealed that TiAlN structure is a (Ti,Al)N ternary phase, whose composition, is expressed by the formula $Ti_{35}Al_{26}N_{39}$. Infact adding aluminum to the TiN phase generally gives a polar interphase resulting in metallic or covalent bonding , thus TiAlN coatings also possesses better properties than do TiN coatings [11].

5. Conclusions

In summary, WC-12%Co, TiN and TiAlN composite coatings were successfully prepared using pulsed Nd-YAG laser deposition process. The dense and almost defect free clad coat surface is achieved after precision grinding resulting a smooth clad thickness of about 112 µm, 7.9 µm and 18.2 µm rexpectively. The X-ray diffraction results evidenced the existence of WC, Co and W_2C phases in the WC-12%Co clad region, whereas the microhardness data revealed an average value of 1910 HV. Furthermore addition of Al to TiN can improve the anticorrosion character and increase the microhardness value from TiN (1035 HV) to TiAlN (1264 HV) by some extent. Likewise, TiN and TiAlN phases are observed in the corresponding coating.

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*Corresponding author: ypkathuria@yahoo.com