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Pulsed Laser Cladding of Ni Based Powder

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Abstract. The aim of this paper is to optimize the operational parameters and quality of one step Metco Inconel 718 atomized powder laser cladded tracks, deposited on AISI 316 stainless steel substrate by means of a 1064 nm high power pulsed laser, together with a Precitec cladding head manipulated by a CLOOS 7 axes robot. The optimization of parameters and cladding quality has been assessed through Taguchi interaction matrix and graphical output. The study demonstrates that very good cladded layers with low dilution and increased mechanical proprieties could be fabricated using low laser energy density by involving a pulsed laser.

1. Introduction

Up to date, there are many technologies available to fabricate coatings layers on different types of steel substrates, among which laser cladding is one of the most used technique for improving the properties of new surfaces or to recondition the worn components [1,2]. A higher compactness of the coatings high precision and superior mechanical proprieties are only several advantages of laser cladding over the conventional coatings methods (plasma coating, flame coating or welding) The main goal in the laser cladding technology is to not overheat the base material and to obtain a low dilution, typically (< 5%) and in the same time to have an increased adhesion between the coating and base material [3,4].

Usually for laser cladding a continuous wave laser is used that can provide a high and constant power for the process [5,6,7]. CO_2, Nd:YAG and diode are the most common continuous lasers involved in laser cladding processes. In contrast, a pulsed laser is able to provide the laser energy in plusses meaning that the power density can be tuned by setting the pulse duration and the number of pulses per time unit. In a complex study, Sun at el. [8] investigated the influence of pulse energy, frequency and powder feed rate on the Stellite 6 cladding on stainless steel and concluded that dilution has a major influence on the hardness of the cladded layer and that an 89% pulses overlap is the optimal values in order to prevent the occurrence of small cracks in the cladded layer. A similar study was carried out by Farnia et al. [10] which analyse and optimize the melting ratio as the key factor for the process design. It was determined that pulse duration and overlapping factor have different effects at low and high values. Moreover, the melting ratio increases at low values of pulse duration and decrease at longer pulse duration that mean there is more interaction time between the laser pulse and the coating in case of short pulses.

A comparison between continuous and pulsed laser was made by Zhang et al [9] using preplaced powder method to coat titanium–vanadium carbides reinforced in a Fe-based matrix. They report advantages like nanoscale carbides formation, finer grain structure and improved hardness in case of using the pulsed laser.

Pulsed laser cladding of WC carbide in overlapped geometry was successfully realized by C.P. Paul [11]. Full dense and crack free coating were fabricated using different parameters for pulse width, frequency and laser power.

Muwala et al. [12] uses a modulated Yb-fibre laser to investigate the preplaced cladding of Inconel 718 powder on AISI 304 steel substrate. Using PVA as binder to deposit the powder was determined that stacks of columnar dendrites are formed predominately in case of using the pulsed laser due to the repeated melting solidifications cycles.

The aim of this study is to further investigate the influence of laser pulse width and frequency on the geometry profile and hardness of Ni based powders. Using the design of experiments method is determined what parameters have the most influence on the cladded tracks and what is the interaction between the process parameters.

2. Materials and methods

2.1. Materials

Stainless steel was used as substrate for the laser cladding tests, respectively AISI 304 grade plates with nominal dimensions of 60x60x6 mm. Currently 304 stainless steel in used for manufacturing of a large number of components in marine equipment, automotive industry, petro-chemical industry and for applications that require moderate to high corrosion resistance,

Nickel based Inconel 718 atomized powder has been used for laser cladding through different process parameters. This type of powder is characterized by a very good behavior for laser cladding and can be used for various reconditioning applications of worn stainless steel components.

The Inconel coatings are dense, pore free and exhibit excellent creep and stress rupture coupled with a good corrosion resistance at high temperatures (up to 700°C).

Table 1. Chemical composition of the powder.

Material	Element (%)											Powder dimension
	Ni	Cr	Fe	Mo	Cu	Nb	Ti	Si	Mn	C	B	
MetcoClad 718	Bal	19	18	3	-	5	1	0.2	0.08	0.05	0.005	44…90 µm
AISI 304*	9.6	19.2	Bal	-	-	-	-	0.80	1.61	0.053	-	

* analysed by SPECTROMAXx M spectrometer

2.2. Cladding obtaining

The experimental tests have been carried out using a TRUMPH Trupulse 552 pulsed laser with an average power of 552 W and a Precitech YC50 coaxial cladding head manipulated by a CLOOS 7 axes welding robot (figure 1). The powder was dosed using a AT-1200HPHV Termach (Thermach Inc. USA) powder feeder and argon with 99.99% purity was used as carrier gas.

The cladding module consists in a conical powder injection system having the laser beam positioned coaxially with the powder jet.

A stand-off distance of 10 mm was used between the cladding head and the substrate and a 5˙ tilting angle in the cladding direction was necessary to protect optical system of the laser. To investigate the effects of the cladding parameters on the clad profile and mechanical proprieties, experiments consisting in coaxial laser cladding of a single track was performed.

Altogether nine individual track of 40 mm length were fabricated with a specific set of parameters and the optimum ones have been determined through the DOE analysis method.

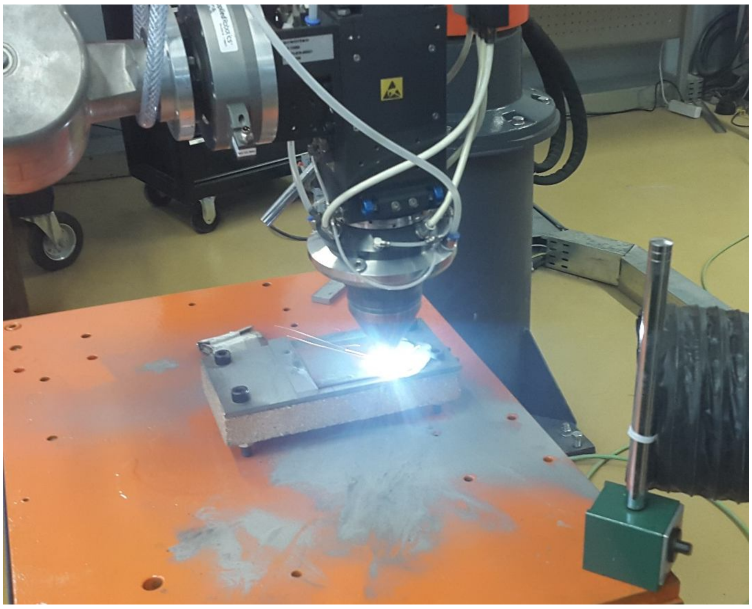

Figure 1. The experimental frame used for the laser cladding of Inconel 718.

Table 2 summarizes the process parameters and the main geometrical and mechanical characteristics of the laser cladded tracks. All the claddings have been performed using a 2 mm pulsed laser spot diameter with rectangular shaped profile and a powder feed rate of 4 g/min.

Table 2. Laser cladding parameters.

Sample	Power [W]	Pulse duration [ms]	Frequency [Hz]	Width [mm]	Hight [mm]	Clad Area [mm^2]	Melt Area [mm^2]	Melt depth [mm]	Wet angle [·]	Dilution [%]	Micro Hardness [HV_{02}]
1.1	2000	0.8	130	1.35	0.20	1.49	0	0	152	0	182
1.2	2300	1	130	1.83	0.33	0.39	0	0.03	150	0	200
1.3	2600	1.2	130	2.19	0.45	0.60	0.15	0.22	146	20	214
2.1	2000	1	150	1.73	0.36	0.42	0	0.04	145	0	215
2.2	2300	1.2	150	1.93	0.45	0.57	0.18	0.23	142	24	223
2.3	2600	0.8	150	1.66	0.35	0.40	0	0	144	0	203
3.1	2000	1.2	170	1.65	0.44	0.52	0.09	0.12	132	14.75	228
3.2	2300	0.8	170	1.66	0.32	0.38	0	0	150	0	208
3.3	2600	1	170	2.07	0.52	0.72	0.12	0.20	125	14.28	220

The laser cladded tracks have been cut and prepared by grinding, polishing and electrochemical etching in 10% wt. oxalic acid solution using continuous current (5 V and 400 mA). An inversed Leica DM IL optical microscope was used for the cross-section analysis of the single tracks. The micro-hardness analyses were realised using a Shimadzu HMV 2T micro-hardness tester. Five HV_{02} were made on each sample using the following set-up: load 200gf and dwell time of 15 sec

3. Results and discussions

Figure 2 illustrates the geometrical appearance of the obtained samples cross-section.

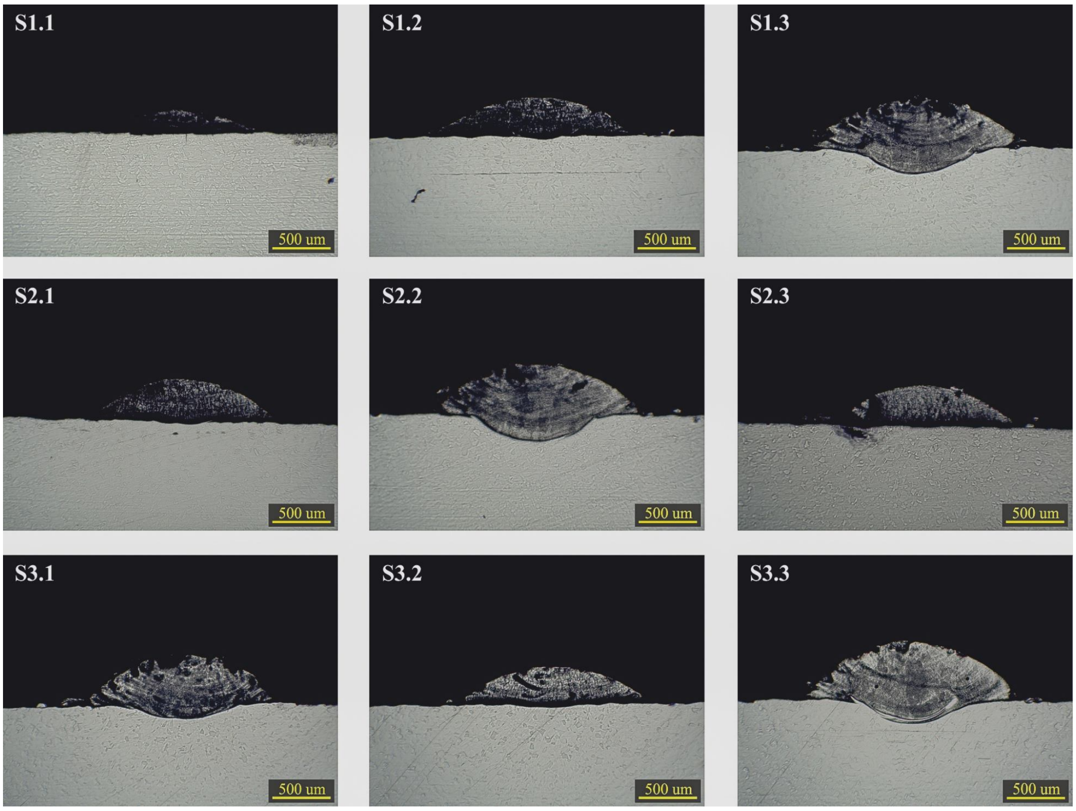

Figure 2. Low magnification microscopy of the single tracks laser claddings.

Compared with the continuous wave laser cladding presented in our previous works [13,14,15], the pulsed laser deposition bears more specific parameters regarding pulse frequency, duration, energy, and so forth which have a pronounced influence on the quality of the coatings. It can be clearly observed from figure 1 that the process parameters have a major influence on the geometrical profile of the laser cladded tracks. The pulse duration and pulse frequency of the laser have a direct influence on the amount of energy that is transferred into the cladding process per unit of time and area. As the general aim of the laser cladding process is to use low amounts of energy to avoid overheating the substrate. In the same time, it is also necessary to have enough power density to melt the powder and to create a strong bonding with the substrate. This fine tuning of the laser energy could be obtained by using a pulsed laser that allows controlling the pulse length and the number of pulses employed per unit area. Using the Taguchi design of experiments matrix, the influence of the power, pulse duration and frequency on the properties of the coatings (clad area, melt depth, dilution, micro-hardness) has been assessed. The nine tracks presented in the figure 2 shows that all process parameters have a

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significant influence on the tracks profile, as determined from the interaction plots depicted in figures 3 a and b. As a general rule for interpreting this type of graphs, the highest mean value (clad area, hardness) or the lowest (dilution, melt depth) represents the optimum value for the respective parameter. Also, the value of the slope dictates the intensity of the influence for the chosen variables. A higher variation slope means a significant interaction/dependency.

The most obvious influence of the operational parameters is on the clad area that represent the area of the material coated on the surface of the base material. Using the Taguchi three step optimization design approach, the dependence between the process parameters (power, pulse and frequency) and the clad area has been assessed (figure 2).

The cladded area is mainly influenced by the first two parameters variation, respectively from 2000 to 2300 W for laser power, 0.8 to 1 ms for laser pulse width and from 130 to 150 Hz for laser frequency. The optimal values for laser power is 2000W, 0.8 ms pulse width and 130 Hz frequency.

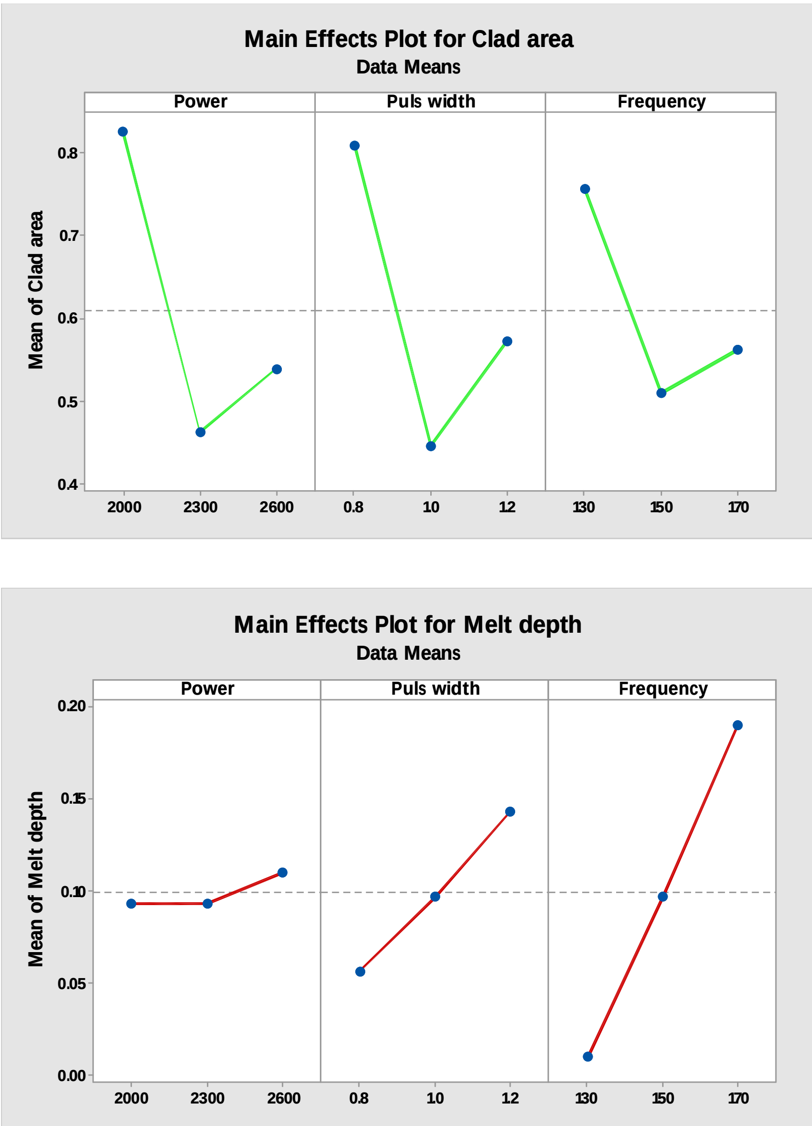

Figure 3. Main effect plot of clad area and melt depth as function of laser power, pulse width and frequency.

The process parameters have a different effect on the melt depth of the cladding tracks. Figure 1 suggests that laser power has no significant influence on the melt depth compared with the laser frequency that can drastically modify the melt depth form 0 up to 0.20 mm with direct consequence on the dilution and mechanical proprieties of the coating. It results that even if the laser energy is influenced by the power and pulse duration, the increasing of the number of pulses on the same unit of area will produce an increase of the melt depth of the substrate.

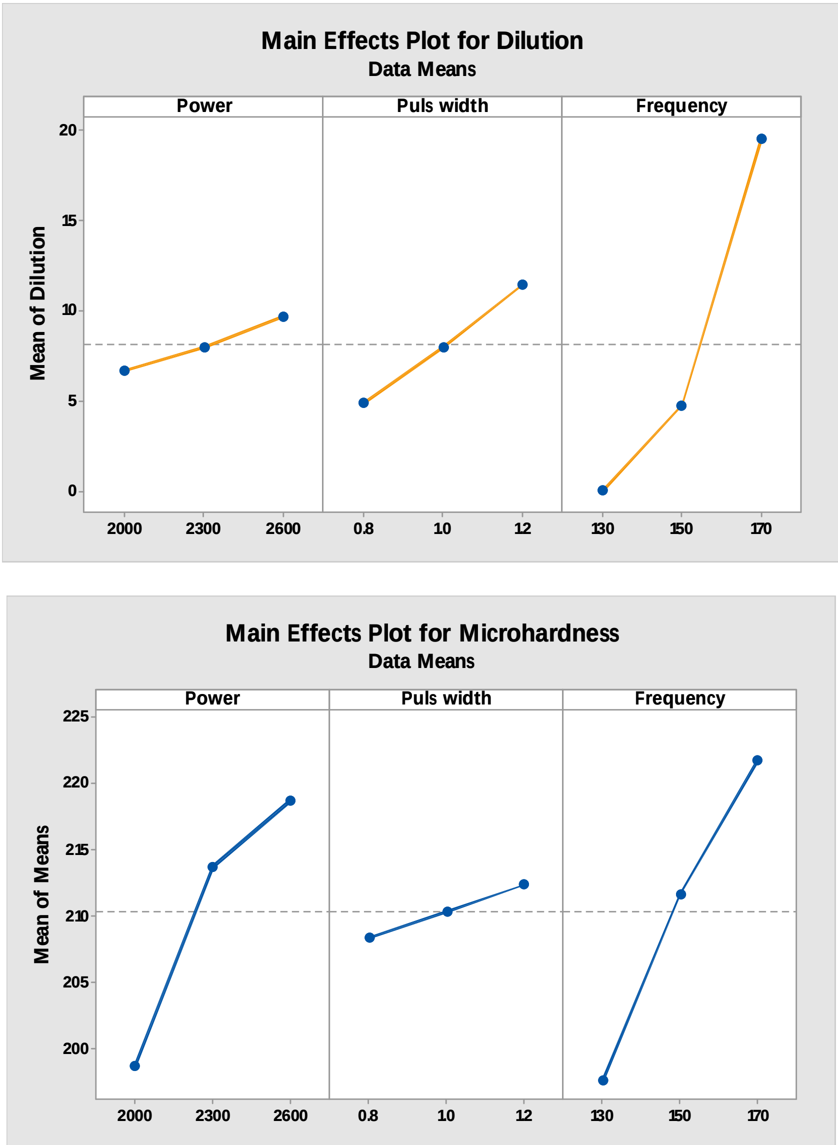

Figure 4. Main effect plot of dilution and microhardness as function of laser power, pulse width and frequency.

By analyzing the main effect plot for dilution, it has been determined that dilution is influenced by the melt depth of the cladded tracks the similarity between the two plots being obvious (figure 4 a and b). The frequency can produce the most visible effect on the melt depth and microhardness as resulted from figure 3b.

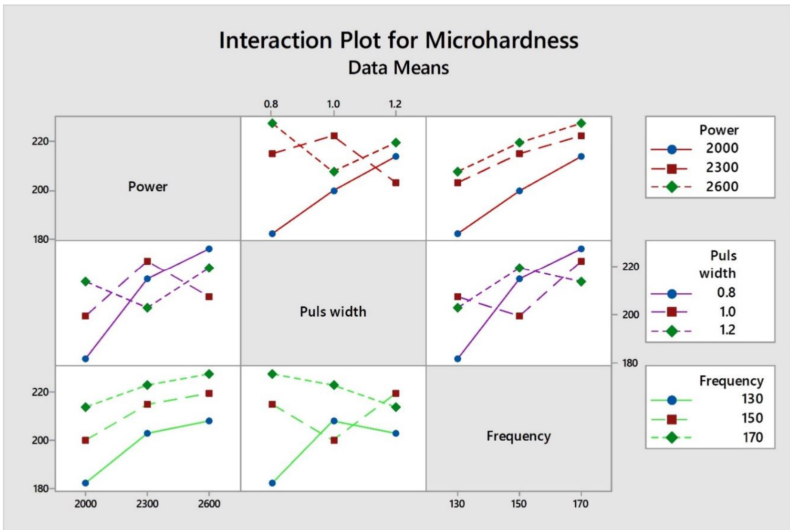

Figure 5. Interaction plot between power, pulse width and laser frequency.

Finally, all the effect plot for clad area, melt depth, dilution and microhardness must be considered as been related and interacted with-other.

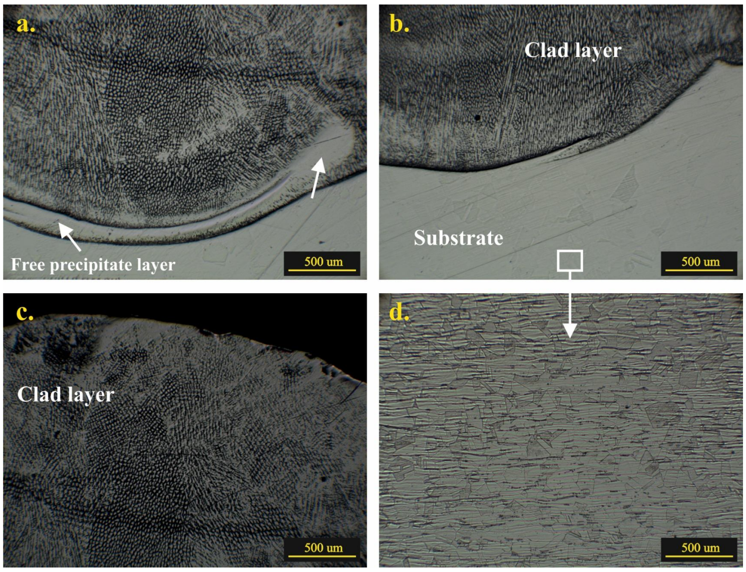

Figure 6. Microstructure of the Inconel 718 cladded tracks.

The process parameters can interact with-other and create a particular mean effect. The interaction plot presented in figure 5 highlights the interaction between the power, pulse width and frequency related to the clad micro-hardness. By analyzing the interaction slopes is clearly that only in case of power and frequency combination there is no significant interaction so the main effect, respectively the hardness increasing can be predictable. The interaction is severe in case of pulse with combination settings with power or laser frequency. It results that for a predictable result in case of laser cladding using a pulsed laser the best way to obtain the desired clad geometry profile is to set the power and frequency and to maintain the pulse with constant. The cladding microstructure is composed from coarse dendrite near the interface with the base material and more fine dendrite structure in the upper area of the coating. A noninterference line or a free precipitate layer as it could be seen in figure 6 a is the interface zone between the materials. No visible or microstructural modifications have been noted in the heat affected zone due to the low heat input of the pulsed laser. The cross-section profile and microstructure are modified depending on experimental parameters set-up. Therefore, a threshold temperature must be ensured to promote the nucleation of the dendrites and the formation of a dense and compact structure. This threshold temperature was not reached on samples 1.1 2.3 and 32 where large islands of unmelted powder are present in the coating surface.

4. Conclusions

In this study, a nickel based Inconel 718 atomized powder has been cladded on AISI 304 steel substrates by means of a pulsed laser. In order to find the optimal parameters of the laser which have an increased influence on the cladding quality, namely laser power, pulse width and frequency, a DOE approach has been used, by using a Taguchi design. The results, which express the interrelationship between laser cladding parameters and the characteristics of the clad produced, can be used to find optimum laser parameters, to predict the responses, and to contribute to a better understanding of the laser cladding process.

References

[1] Zhang P and Liu Z 2016 *Materials & Design* **100** 254–262
[2] Hemmati I, Ocelı´k V and Hosson J Th M 2015 *Electronic and Optical Materials* pp.137-162
[3] Hemmati I, Ocelı´k n V and DeHosson J Th M 2012 *Materials Letters* **84** 69–72
[4] Song T B, Hussain K and Voisey T 2016 *Physics Procedia* **83** 706-715
[5] Luo X, Li J and Li G J 2015 *Journal of Alloys and Compounds* **626** 102–111
[6] Damian Janicki 2017 *Optics & Laser Technology* **94** 6–14
[7] Hemmati I, Ocelı´k V and De Hosson J.Th.M 2013 *Physics Procedia* **41** pp. 302 – 311
[8] Sun S, Durandet Y and Brandt M 2005 *Surface and Coatings Technology* **194** pp. 225–231
[9] Zhang H, Zoun Y, Zou Z and Zhao W 2015 *Materials Letters* **139** pp. 255 – 257
[10] Amirreza F, Farshid M G and Sabbaghzadeh J 2013 *Optics and Lasers in Engineering* **51** 69–76
[11] Paul C P, Alemohammad H, Toyserkani E, Khajepour A and Corbin S 2007 *Materials Science and Engineering* A **464** 170–176
[12] Muvvala G, Karmakar D P and Nath A K 2017 *Optics and Lasers in Engineering* **88** 139–152
[13] Stanciu E M, Pascu A, Tierean M H, Voiculescu I, Roata I C, Croitoru C and Hulka I 2016 *Materials and Manufacturing Processes* **31** 1556-1564
[14] Iosif H, Serban V A, Utu D, Duteanu N M, Pascu A, Roată I C and Maior I 2016 *Romanian Journal of Materials* **46**(1) 49 – 54
[15] Pascu A, Stanciu E M, Roata I, Croitoru C, Baltes L and Tierean M 2016 *Bulletin of the Transilvania University of Brasov* **9**(58) 9-16

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