SELECTION OF CUTTING PARAMETERS OF TURNING THE Ni-Al AND Ni-Al-Al_2O_3 FLAME SPRAYED COATINGS

Robert Starosta, Rafał Chabowski

Gdynia Maritime University
Faculty of Marine Engineering, Department of Marine Maintenance
Morska Street 81-87, 81-225 Gdynia, Poland
tel.: +48 58 6901249, fax: +48 58 6901399
e-mail: starosta@am.gdynia.pl, rafal@am.gdynia.pl

Abstract

The process of flame sprayed is a technology affordable and easy to implement. It does not require great skill of the operator. This method is not associated with expensive workstation equipment. It may therefore be used with success for the regeneration of machine parts by the crew of vessel engine room.

Flame sprayed coatings are characterized by porosity, oxide inclusions presence and large real area of surface. In order to obtain adequate surface roughness coatings must be applied finishing. For this purpose, the turning and grinding are used. In the paper a turning to finishing flame sprayed coatings was proposed.

Coatings of Ni-5% Al and Ni-5% Al-15% Al_2O_3, obtained by powder flame spraying, were studied. Torch of "Casto-Dyn 8000" was used. In practice, the substrate and the thermally sprayed coating are processed by the same cutting tool. For example, Messner Eutectic Castolin company offers two types of tools: "Rototool II" (square insert) and "Rototool III" with a removable cylindrical insert. Average surface roughness of coating after machined tool "Rototool II" was Ra = 3 μm. This surface often requires grinding.

The different tool geometry was suggested for better texture of coatings surface. Workpiece was machined by tool with CBN insert WNGA080408S01030A mounted in holder DWLNRL-2525M08 (cutting inserts β = 80°, approach angle κ_r = 95°, nose radius – 0.8 mm, relief angle α = 6°, rake angle γ = -6°). The influence of cutting speed, feed rate, depth of turning on the coating surface roughness was estimated. The following cutting parameters: cutting speed Vc = 45-214 m/min, feed rate f = 0.06-0.2 mm/rev, depth of cut a_p = 0.05-0.3 mm. The lowest value of the roughness of the alloy (Ra = 0.5 μm) and composite (Ra = 0.8 μm) coatings were obtained by using cutting parameters: Vc = 214 m/min, f = 0.06 mm/rev, a_p = 0.4 mm.

Keywords: *thermal spray coatings, coating turning, CBN*

1. Introduction

Modern machines now have greater operational loads. This induces the development of new construction materials or technology of surface treatment that ensures great reliability and durability of machinery parts. In cases, when the durability is determined only by the surface properties of the material (resistance to friction, corrosive wear, contact fatigue etc.), it is unreasonable to use expensive materials for production of entire elements. In such situations, one can use the technologies of surface treatment, thus improving the above operational properties. In practice, the most commonly used methods of shaping the surface layer of structural material such as surface hardening, thermal-chemical treatment (carburization, nitriding, chrome hardening), burnishing or placement of coatings with chemical, electrochemical and thermal technologies (e.g. thermal spraying or overlaying welding)

Currently the main coating material which increases the durability of the parts of the machinery is chromium. However, owing to the toxicity of chromium baths and the low efficiency of the current in the process of obtaining galvanic chromium coatings, one is looking for alternatives. One of them is the application of nickel and composite coatings with a nickel matrix, gathered by different technologies e.g. galvanically or with spraying methods [2, 8, 9].

Composite coatings with a metal matrix are: technical coatings, increasing operational durability of parts of the machinery with tribologic nodes, or protective coatings. It is believed that by appropriate selection of the matrix material and reinforcing phase (e.g. ceramics), one can obtain the coatings with optimum utility properties [11, 14].

This study, on the regeneration of shaft pivots of torque pumps, has suggested application of Ni-5% Al alloy and Ni-5% Al-15% Al_2O_3 composite coatings, applied via the method of flame spraying. The coatings with a nickel matrix are characterized by great plasticity, adhesion to the steel base, resistance to abrasion and great capacity for shifting to a passive condition. As a reinforcing phase, one used aluminum oxide with the diameter of molecules of $\prod$ = 60 μm. The method of spraying does not require great operator skills and does not necessitate the use of expensive equipment; thus, it may be used by the service personnel of a power plant or repair crews during voyages.

Owing to the structure of hot-sprayed coatings (high porosity, among other things), their surface is strongly developed and is characterized by substantial roughness [12, 13]. Cutting constitutes a traditional method of shaping the geometrical structure of coatings (turning and polishing). Considering the possibility of equipping the power plant's workshop, most preferably one should use turning of coatings or turning with burnishing afterwards.

Nadasi [6], Morel [5] and Castolin, the manufacturers of materials for thermal spraying, suggest use of the tools characterized by the following features:

- approach angle κ_r = 45°,
- zero or negative rake angle,
- relief angle*:* α = 5-8°.

And the following are the recommended parameters of cutting:

- cutting speed – V_c = 20-100 m/min,
- feed: f = 0.05-0.1 mm/rev,
- cutting depth: a_p = 0.05 (finishing treatment) - 0.8 mm (rough treatment).

Coatings Ni-Al and Ni-Al-15% Al_2O_3 cut using the tools with the above geometry and the recommended treatment parameters were characterized by roughness Ra = 3 μm [15].

Owing to the formation of chippings separated out during the turning of coatings, one uses of tools made of materials resistant to abrasion, just like in the treatment of cast irons. For this reason, the recommended tool materials are sintered carbides for cast-iron treatment (K10) or regular boron nitride (CBN). The main cause of tool wear is abrasion of the application surface. Nadasi [6] stated that the size of the particles of the obtained chips is smaller at a approach angle of 45° than 90°, which causes less wearing down of the tool and allows one to get less roughness on the turned surfaces of hot-sprayed coatings.

In the case of nickel alloys one also applies the tools which enable one to obtain a greater approach angle κ_r > 90° [4, 7]. The study [1] suggests the use of a H10 carbide tile with a blade angle of 60°, contact angle of 91° and cutting parameters – V_c = 105 m/min, f = 0.08 mm/rev, and a_p = 0.05 mm. One obtained roughness of Ni-Al coatings of approximately Ra = 2 μm of composite coating with a 45% ratio of aluminum oxide Ra = 6 μm.

2. Sample preparation

The coatings were applied on flame degreased steel rollers (steel C45), with diameter of f = 40 mm. To increase the adhesion of coatings, the thread was cut on the surface of pivots.

For spraying, one used a "Casto-Dyn 8000" burner by Castolin. During flame spraying, one used ProXon 21021 (Ni-93.45%, Al-5%, B-0.8%, Fe-0.34%, Cr-0.18%, Si-0.15%, C-0.08%) powder, as well as its mixture with powder MetaCeram 28020 (Al_2O_3-97%, TiO_2-3%). In composite coatings, the volumetric ratio of ceramic phase amounted to 15%.

The following parameters of flame spraying have been applied:

- acetylene pressure: 0.07 MPa,
- oxygen pressure: 0.4 MPa,

- air pressure: 0.1 MPa,
- spraying speed: 25 m/min,
- burner feed: 3 mm/turn,
- distance of the burner from the sprayed surface: 150 mm,
- number of applied layers: 6,
- maximum temperature of surface during spraying: 150°C,
- coating surface roughness after the spraying process amounted to Ra = 11-17 μm.

3. Methodology of research

Ni-5% Al alloy and Ni-5% Al-15% Al_2O_3 composite coatings were treated with trigonal multi-blade tiles. As a tool material, one selected borazon with catalogue symbol CB 7015 [10]. CB 7015 is a material based on regular boron nitride (CBN) with a supplement of titanium nitride, covered with a TiN coating with the PVD method. A WNGA080408S01030A plate was installed in the DWLNRL-2525M08 holder. Both the plate and the holder were from Sandvik Coromant. The geometry of the cutting tool, taking account of the geometry of the cutting tile and holder was as follows:

- cutting inserts – β = 80°,
- approach angle – k_r = -95°,
- rake angle – γ = - 6°,
- relief angle – a = 6°,
- nose radius – r = 0.8 mm,
- lack of chipping breaker.

Coating turning was carried out on a CDS – 6250 x 1000 machine. Applied turning parameters: cutting speed – V_c = 45-214 m/min, feed f = 0.06-0.2 mm/rev, cutting depth a_p = 0.05-0.3 mm.

After turning one took the measurements of the coatings' surface roughness. One used the HOMMEL TESTER T1000 profilometer. The length of the measurement section was 4.8 mm and the fundamental section was 0.8 mm.

The impact of treatment parameters on surface roughness was evaluated using the three-value Hartley's plan of research [3] including execution of eleven tests (Tab. 1). The results of surface roughness tests (arithmetic average deviation of Ra of profile roughness) have undergone statistical – regression multiple analysis, in order to determine the impact of the applied parameters of the technological process of turning on its value. The calculations were made by means of the computer software Statistica 5.5. Owing to different values of independent variables, the impact of particular parameters was analyzed on the basis of the standardized factors of multiple regression (BETA) and the calculated level of significance (p). The assumed level of significance was α = 0.05.

Tab. 1. Cutting parameters of Ni-Al coatings turning

Test No.	Layout of Hartley's plan [3] – independent variables		
	X (V_c [m/min])	X (f [mm/rev)	X (a_p [mm])
1.	-1 (45)	-1 (0.06)	-1 (0.05)
2.	+1 (214)	-1 (0.06)	-1 (0.05)
3.	-1 (45)	+1 (0.2)	-1 (0.05)
4.	+1 (214)	+1 (0.2)	+1 (0.3)
5.	-1 (45)	0 (0.1)	0 (0.15)
6.	+1 (214)	0 (0.1)	0 (0.15)
7.	0 (107)	-1 (0.06)	0 (0.15)
8.	0 (107)	+1 (0.2)	0 (0.15)
9.	0 (107)	0 (0.1)	-1 (0.05)
10.	0 (107)	0 (0.1)	+1(0.3)
11.	0 (107)	0 (0.1)	0 (0.15)

4. Results

Figure 1 and 2 present the effect of the parameters of turning on the value of the parameter Ra of roughness of the surface of Ni-5% Al alloy coatings. The largest value of parameter Ra = 4.78 µm was obtained using the lowest values of parameters of speed and cutting depth (V_c = 45 m/min, a_p = 0.05 mm) and the greatest feed (f = 0.2 mm/rev). The best surface quality (Ra = 0.82 µm) was obtained during turning, when the cutting parameters had the following values: Vc = 214 m/min, f = 0.2 mm/turn, a_p = 0.3 mm.

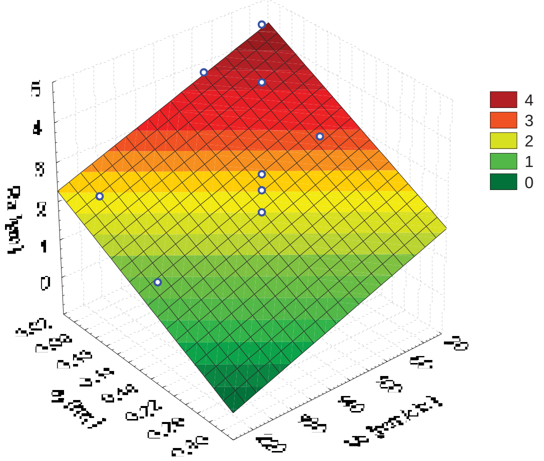

Fig. 1. Influence of depth of cut a_p and cutting speed V_c on Ni-Al coatings surface roughness (Ra)

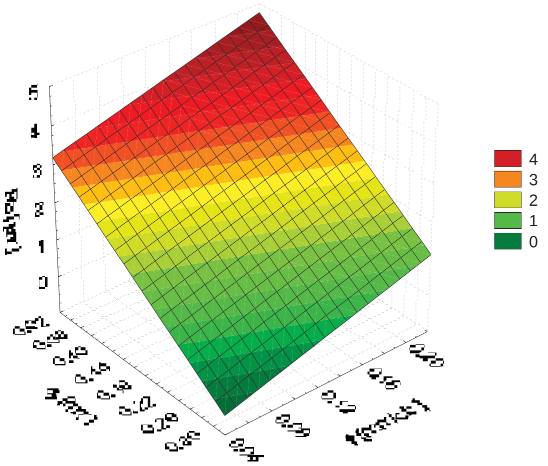

Fig. 2. Influence of depth of cut a_p and feed rate f on Ni-Al coatings surface roughness (Ra)

The result of the variance analysis F(3.7) = 19.04 on the adopted level of significance allows one to state that independent variables affect the value of a dependent variable (Tab. 2). Analysing the obtained values of the standardized factors of multiple regression for independent variables, one can state that the greatest impact (BETA = -0.71) on surface roughness, is cutting depth. The greater the cutting depth, the smaller the value of arithmetic average deviation of roughness profile Ra. The least impact on the quality of the cut surface is made by the cutting speed (BETA = -0.46). The relation between the independent variable – V_c and the dependent variable Ra is inversely proportional. The variable with the least impact on the surface roughness (BETA = 0.35), though statistically significant (p = 0.03), is feed. The greater the value of the tool feed, the worse the quality of the surface being treated.

The impact of cutting and feed speed on the roughness of the turned surface is typical. The impact of cutting depth of coatings on the quality of surfaces may be striking. It is commonly

Tab. 2. Results of multiple regression analysis for Ra parameters (R^2=0.89, F(3.7) = 19.04, p<0.001, estimation error = 0.51)

	BETA	B	level p
Free word		3.94	0.00
Cutting speed - V_c	-0.46	-0.0089	0.01
Feed - f	0.35	7.97	0.03
Cutting depth - a_p	-0.71	-10.04	0.001
BETA - standardized regression coefficient, B - regression coefficient, p - significance level			

believed that, theoretically, cutting depth has no effect on surface roughness. If, however, in workshop practice, one has observed a relation between a_p and R_a, then it is proportional. On the other hand, after treatment of hot-sprayed coatings Ni-Al, one has observed that small cutting depths quickly caused damage to the cutting knife corner and the generation of vibrations in the system tool - treated pivot. In consequence, what was obtained was not the best quality of the turned surfaces.

The value of the parameter of coatings surface roughness (Ra) can be determined through using the multiple regression equation (1):

$$Ra = -0.01V_c + 7.97f - 10.04a_p + 3.94 \pm 0.51. \quad (1)$$

The high determination coefficient value (R^2=0.89) proves almost 90% adjustment of the set regression equation to the measurement data.

The roughness of coatings obtained as a result of longitudinal turning, Ra = 0.82 μm, is often sufficient. In order to obtain an even better surface, one used a cutting treatment with a potential maximum speed of cutting (for the shaft with f = 40 mm) on a CDS lathe 6250 x 1000. The applied parameters are: V_c = 214 m/min, feed f = 0.06 mm/rev and cutting depth a_p = 0.4 mm. The values of roughness of the turned surface with an alloy coating was then Ra = 0.49 μm (Tab. 3). Under the abovementioned cutting parameters, one also treated Ni-5% Al-15% Al_2O_3 composite coatings. What was achieved then was a surface of the alloy coating with roughness Ra = 0.77 μm. Fig. 3 presents the sample profiles of roughness of the turned coatings.

Tab. 3. Arithmetic mean roughness value of coatings after turning (cutting parameters: Vc = 214 m/min, f = 0.06 mm/rev, a_p = 0,4 mm); the values of basic statistical analysis

coating [mm]	Number of measurements	Average HV 0.4	Conf.inter. –95.000%	Conf.inter. +95.000%	Minimum	Maximum	Std.dev.	Error standard
Ni-5%Al	9	0.49	0.47	0.51	0.46	0.53	0.02	0.008
Ni-5%Al-15%Al_2O_3	9	0.77	0.68	0.87	057	0.95	0.12	0.04

4. Summary

- Flame-sprayed coatings can be treated with cutting tools with a cutting tile and tool holder shaped to permit a large approach angle $\kappa_r < 90°$.
- In the case of treatment of coatings with CBN tiles, the depth of cutting cannot be too small, because the corner becomes damaged very quickly. For this reason, during the finishing treatment, one suggests the use of a greater depth of cutting than in the recommendations of the manufacturers of coating materials.
- The minimum roughness of Ni-5% Al (Ra = 0.49 μm) and Ni-5% Al-15% Al_2O_3 (Ra = 0.77 μm) coatings, treated with a tool with the plate marked WNGA080408S01030A, installed in holder DWLNRL-2525M08, was obtained using the following parameters of cutting: V_c = 214 m/min, f = 0.06 mm/rev and cutting depth a_p = 0.4 mm.

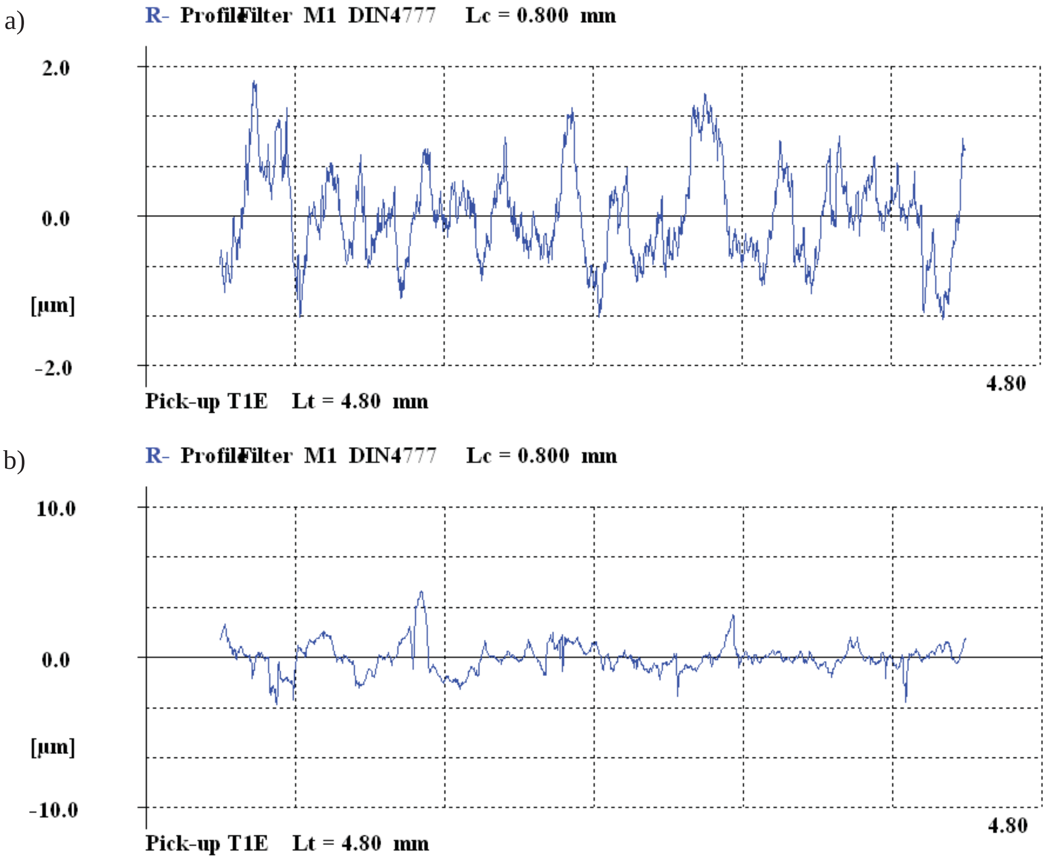

Fig. 3. The samples of roughness profile of treated coatings: a) Ni-Al, b) Ni-5%Al-15%Al_2O_3

References

[1] Dyl, T., Starosta, R., Skoblik, R., *Obróbka wykańczająca powłok MMC w aspekcie umocnienia i zmniejszenia chropowatości powierzchni*, Kompozyty, Vol. 8, pp. 147-151, 2008.

[2] Formanek, B., Szymański, K., *Natryskiwane cieplnie płomieniowo kompozytowe powłoki zawierające węgliki chromu, tytanu i wolframu*, Kompozyty, Vol. 6, pp. 52-57, 2006.

[3] Korzyński, M., *Metodyka eksperymentu – planowanie, realizacja i statystyczne opracowanie wyników eksperymentów technologicznych*, Wydawnictwo Naukowo-Techniczne, Warszawa 2006.

[4] Li, W., et al., *Residual stresses in face finish turning of high strength nickel-based superalloy*, Journal of Materials Processing Technology, Vol. 209, pp. 4896-4902, 2009.

[5] Morel, S., *Powłoki natryskiwane cieplnie*, Wydawnictwo Politechniki Częstochowskiej, Częstochowa 1997.

[6] Nadasi, E., *Nowoczesne metody metalizacji natryskowej*, Wydawnictwo Naukowo-Techniczne, Warszawa 1975.

[7] Pawade, R. S., et al., *An investigation of cutting forces and surface damage in high-speed turning of Inconel 718*, Journal of Materials Processing Technology, Vol. 192-193, pp. 139-146, 2007.

[8] Picas, J. A., Forn, A., Matthaus, G., *HVOF coatings as an alternative to hard chrome for pistons and valves*, Wear, Vol. 261, pp. 477-484, 2006.

[9] Popczyk, M., Budniok, A., *Charakterystyka struktury elektrolitycznych warstw kompozytowych na osnowie amorficznego niklu, zawierających składnik tlenkowy i metaliczny*, Kompozyty, Vol. 5, pp. 47-52, 2005.

[10] Sandvik Coromant, Katalog główny, Narzędzia skrawające firmy Sandvik Corromant, 2009.

[11] Starosta, R., Zieliński, A., *Effect of chemical composition on corrosion and wear behaviour of the composite Ni-Fe-Al2O3 coating*, Journal of Materials Processing Technology, Vol. 157-158, pp. 434-441, 2004.

[12] Starosta, R., *Properties of thermal spraying Ni-A. coatings*. Advances in Materials Science. Vol. 9, No. 1, pp. 30-40, 2009.
[13] Starosta, R., *Testing of regenerative thermal spraying Ni-Al alloy coatings*, Journal of Polish CIMAC, Diagnosis, Reliability and Safety, Vol. 3 No. 2, pp. 155-161, 2008.
[14] Szeptycka, B., Gajewska-Midziałek, A., *Investigations of the wear resistance of composite coatings Ni-SiC*, Kompozyty, Vol. 5, pp. 7-10, 2005.
[15] Wądołowki, D., *Wpływ nagniatania na wybrane właściwości powłok natryskiwanych cieplnie*, praca niepublikowana, Gdynia 2009.