



THE INFLUENCE OF TREATMENT PARAMETERS ON THE QUALITY OF MMC COATINGS SURFACES APPLIED TO RECONDITION PARTS OF SHIP MACHINERY

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Abstract

During voyage lots of repairs are carried out onboard vessels. It is quite frequent to recondition cylindrical surfaces (for example torque pump shaft neck). The welding technology of applying alloy and composite coatings is very common. In this paper the technology of infrasound thermal spraying of composite metal-ceramic coatings was presented. It is a simple technology and a very useful one in ship machinery repairs during voyage (e.g. internal combustion engines, torque pumps, separators). The MMC coatings must undergo finishing treatment due to high surface roughness after application. The most popular is machining (e.g. lathing or grinding). The authors also propose the application of plastic treatment. In the paper the influence of treatment parameters as well as plastic treatment on the treated surface quality of cylinders made of C45 steel with Ni-Al alloy coating and Ni-Al-Al₂O₃ was defined.

Key words: *composite MMC coatings, roughness reduction, strain hardening, finishing of coating.*

1. Introduction

Materials of new or improved qualities are widely used in such fields of technology as for example cosmonautics, electronics, energetics, armaments industry, automotive industry, aviation, shipping etc. Composite materials are divided according to the matrix: metal, polymer or ceramic. The choice of matrix for composite material depends on the required output qualities, whose aim is for instance to decrease material weight, to achieve appropriate thermal expansion or lubricating ability, rigidity, proper thermal conductivity, hardness, resistance to abrasion, radiation, raised temperature, chemical media, corrosion etc [1]. Composite materials of metal MMC matrix are often used for coatings. Composite coatings of metal matrix with disperse intrusions of non-metal phase are characterised by high resistance to tribologic wear. Technologies used to obtain disperse coatings are the following: galvanic methods, plasma and infrasound spraying HVOF. However, they require high financial support and special skills for equipment operation. Therefore they can not be utilised on board ships for reconditioning parts of machinery during voyage [2,3,4]. The determination of the influence of disperse phase Al₂O₃ on the potential properties of composite coatings of nickel matrix, applied by the use of infrasound flame thermal spraying, enables preliminary examination of the usefulness of this method in acquiring composite coatings. When choosing this technology the following factors were taken into account: simplicity of technology, usefulness for ship torque pumps repair during voyage, low costs of material and equipment. Composite coatings on nickel matrix obtained by thermal spraying have high values of surface roughness [5]. That is why the coatings must undergo finishing machining treatment. However, in spite of machining treatment, alloy coatings flame sprayed were very rough depending on the

method of application and the speed of machining, and the R_a parameter was ranging from 2,55 to 7,79 μm [6]. In order to determine the technology of finishing treatment that would improve the surface quality of composite coatings – the usage of proper treatment parameters for grinding and machining were suggested together with proper machining tools of a negative clearance angle, made of sintered carbides which are recommended for heat-resistant super alloy and titanium alloys treatment. These alloys have high resistance to thermal and mechanical stresses during continuous or interrupted treatment. After carrying out experimental research, the influence of lathing and grinding on the roughness of composite Ni-Al- Al_2O_3 coatings thermally sprayed was defined. Then the cold rolling trials of composite MMC coatings were performed to estimate the possibility of applying plastic treatment to shape stereometric structure of composite Ni-Al- Al_2O_3 coatings sprayed thermally.

2. Research method

Experimental research was carried out in the Department of Marine Maintenance, at the Faculty of Marine Engineering at Gdynia Maritime University. In order to define the influence of finishing treatment parameters on the treated surface quality of shaft neck in torque pumps, the following range of research was determined: two types of coatings Ni-Al alloy and composite Ni-Al- Al_2O_3 were sprayed and subjected to machine treatment (lathing and grinding) as well as plastic treatment.

Lathing was performed at three machining speeds. Grinding alloy and composite surfaces were operated for constant machining parameters. Rolling was carried out at two real deformations $\phi_h = 0,06; 0,12$. The surface that was covered with alloy and composite coatings was prepared in an appropriate way by rough lathing, then prime layers were applied, and finally it was degreased and cleaned of the oxidation products.

Infrasound flame powder spraying of alloy and composite coatings was performed at the assumed parameters: flame gas pressure - acetylene : 0,7MPa, oxygen pressure : 0,4 MPa, burner distance from the sprayed surface: 150 mm, the number of layers sprayed : 12, achieved thickness of coatings : $h_p = 0,6 \div 1,2$ mm [5, 6]. Prior to applying Ni-Al and Ni-Al- Al_2O_3 layers by “cold” infrasound flame powder coating (where the base was preheated to the temperature of about 100°C, and after spraying the sample temperature did not exceed 250°C) and by “hot” coating (where the base was heated to about 250°C, and then the coating was performed while the object temperature reached 500-600°C) – the roughness measurements were taken on the rollers surface. Rollers surface roughness R_a before spraying coatings was 8 to 16 μm , whereas average arithmetic roughness profile for the layer obtained by “cold” and “hot” thermal spraying was about 13 μm .

The finishing lathing treatment of alloy and composite sprayed coatings was performed on a universal lathe TU 1000. During treatment of both types of coatings the following machining parameters were applied: rate of feed $f_n = 0,08$ mm/turn; depth of machining $a_p = 0,05$ mm; machining speed $V_{c1} = 21$ m/min, $V_{c2} = 66$ m/min, $V_{c3} = 105$ m/min. Multi blade plates TNMG 16 04 08-23 H10F of a negative angle made by Sandvik Coromant and consisting of sintered carbides were utilised. Such plates are recommended for super alloys and titanium alloys treatment at low machining speeds, as they are characterised by good resistance to thermal and mechanical shocks during continuous as well as interrupted treatment which do not require greasing. A regular T-Max P handle with a fixed plate clamp, symbol DTG NR 2020 K16 was used for securing the plate in a tool post. Abrasive treatment of alloy and composite coatings was carried out on a centre-type grinder for rollers. The rotational speed of the grinding wheel was $V = 42$ m/s.

3. Experiments results

The finishing treatment of Ni-Al alloy and composite Ni-Al-Al₂O₃ coatings was performed by means of chip, grind and plastic treatment.

The ‘cold’ thermally sprayed Ni-Al alloy coating was lathed without cooling-greasing medium. While treating the ‘cold’ thermally sprayed Ni-Al coating, the multiblade plate was behaving properly. The coating showed good machining quality. No visible defects or damages appeared on the plate.

The ‘hot’ thermally sprayed Ni-Al coating underwent the same finishing treatment as the ‘cold’ thermally sprayed Ni-Al coating at the same machining parameters. The latter coating showed similar good machining quality and sustained no damage.

The process of lathing the composite ‘hot’ sprayed Ni-Al-Al₂O₃ coating was performed without cooling-greasing medium. At the lowest assumed machining speed $V_{c1} = 21$ m/min the plate underwent damage and quick wear appeared on the surface of application, while the coating was slightly lathed with a low quality lathing surface. Then the coating was lathed at the speed of

$V_{c2} = 66$ m/min but this attempt showed the increase of the previous result and finally the plate was completely damaged, having thermal cracks perpendicular to the machining edge.

For the next finishing treatment test of ‘hot’ sprayed composite Ni-Al-Al₂O₃ coating, a cooling-greasing solution in the form of emulsifying oil Emulgol ES-12 was utilized which improved the machining process. However, in spite of using the greasing oil, the plate surface of application was worn. The lowest roughness values (Tab.1.) were achieved at the highest machining speed $V_{c3} = 105$ m/min.

After machining treatment the treated surface of the alloy Ni-Al coating was perfectly smooth and showed metallic lustre. Composite Ni-Al-Al₂O₃ coating showed poorer grinding quality. The treated surface had visible surface defects which could have resulted from tearing particles of a coating surface. Moreover, while treating the composite coating, the grinding wheel showed signs of bluntness and it had to be sharpened frequently.

The process of rolling alloy and composite coatings was carried out in the Laboratory of Plastic Treatment at the Department of Machine Materials Technology and Welding at the University of Technology in Gdańsk [7]. ‘Cold’ rolling was performed at the ambient temperature in the laboratory rolling mill duo with the rollers diameter of $\phi 200$ mm and the roll face length 250 mm for the real rolling reduction $\phi_h = 0,06; 0,12$. It was estimated that the surface of alloy and composite coatings possesses considerably better quality in comparison with the coatings that were chip treated. The lowest values for roughness parameters after rolling with real rolling reduction $\phi_h = 0,12$ are shown in Table 1.

The assessment of adherence of alloy and composite coatings to the base was carried out before and after the chip, abrasive and plastic treatment, according to norm PN-79/H-04607. Two methods were used: scratch method and temperature changes method. The coating was examined under the stereoscopic microscope MBC-9 being magnified five times. The coating adherence was considered good if no shells, no blow holes or exfoliations were observed. The quality assessment methods applied for evaluating coating properties did not show negative influence of the finishing treatment on the coating adherence to steel base.

Surface roughness was measured after the finishing treatment by a profile meter HOMMEL TESTER T1000.

The measuring length was 4.8 mm, and the sampling length was 0.8 mm. On the basis of average arithmetic roughness profile (parameter R_a) - the surface roughness decrease factor was determined:

$$K_{Ra} = \frac{R'_a}{R_a} \quad (1)$$

where: R'_a – average arithmetic roughness profile before finishing treatment,
 R_a – average arithmetic roughness profile after finishing treatment

Figure 1 presents examples of composite MMC coatings surface profilogram that underwent finishing treatment for the lowest value of average arithmetic roughness profile.

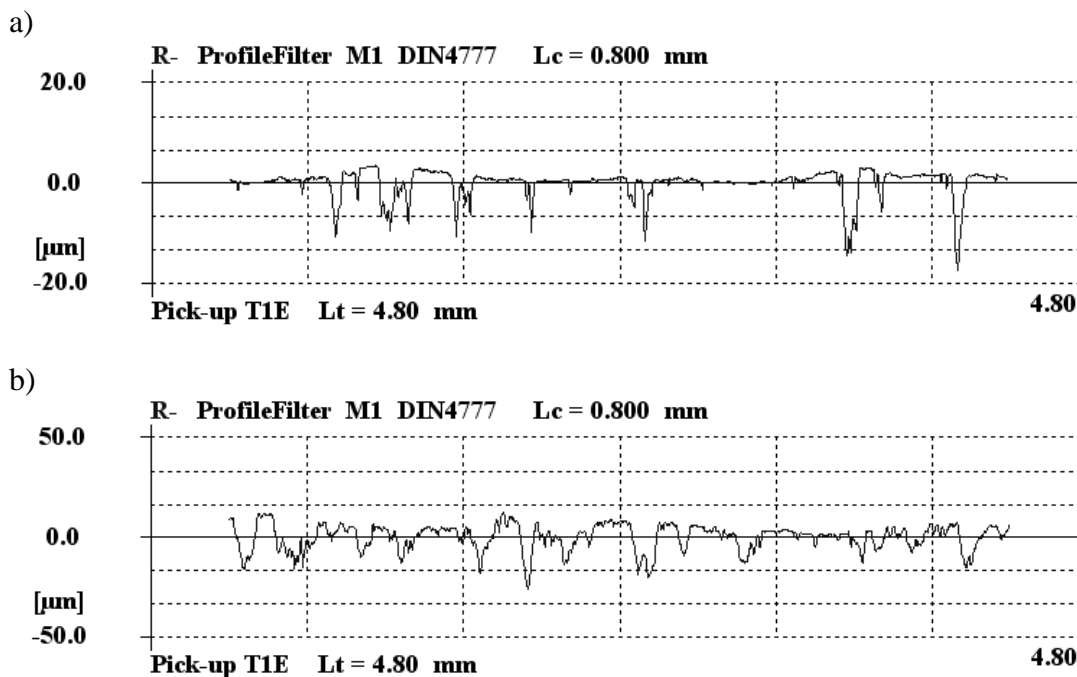


Fig.1. Roughness profilogram after finishing treatment:
a) after grinding, $R_a = 1,72 \mu\text{m}$, b) after rolling, $R_a = 5,23 \mu\text{m}$

Figure 2 presents surface roughness decrease factor after application of finishing treatment by means of lathing, grinding and rolling of alloy and composite coatings on metal matrix MMC.

Surface roughness has decreased most after grinding and the least after lathing. After rolling, composite layers gained surface roughness that was comparable to that after grinding, but the surface roughness decreased after rolling. Moreover, the plastic treatment being a chipless treatment does not cause surface material decrement. The technological process of plastic formation of composite MMC coatings, both “cold” and “hot” sprayed went well and without any significant difficulties, however during abrasive treatment particles of layer material were torn out and it was necessary to sharpen the grinding wheel quite often. That is why, from the technological and economical points of view, it seems appropriate to utilize plastic treatment to form stereometric properties of composite coatings. In order to obtain better quality of treated composite MMC coatings surface – another type of treatment that is burnishing treatment, based on surface plastic deformation has been put forward.

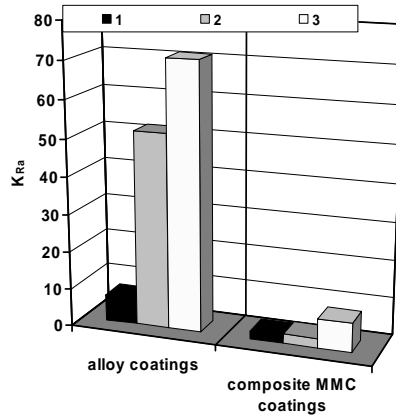


Fig.2. Roughness decrease factor (K_{Ra}) of alloy and composite MMC coatings: 1- after lathing, 2- after rolling, 3- after grinding.

Table 1 shows the measurements results related to load curve of the alloy and composite roughness profile that underwent finishing treatment.

Tab.1. Parameters measurements results related to load curve of the roughness profile

Treatment type	coating type	R_a , μm	R_k , μm	R_{pk} , μm	R_{vk} , μm
lathing	composite	6,20	20,07	5,36	13,27
	alloy	1,95	6,12	1,38	3,27
grinding	composite	1,72	1,14	0,83	9,42
	alloy	0,19	0,56	0,36	0,28
rolling	composite	5,23	10,38	2,92	12,21
	alloy	0,26	0,53	0,20	0,98

On the basis of the data included in table 1 it is possible to state that the reduced depth of valleys (R_{vk}) defined for composite coatings reaches high values after grinding and rolling, compared to parameters values : depth of roughness core (R_k) and reduced height of elevations (R_{pk}).

This may reflect high load share of composite coatings undergoing finishing treatment by grinding and rolling.

Figures 3 and 4 present load curves of the roughness profile of composite and alloy coatings subjected to finishing treatment by finishing lathing, grinding and rolling. It can be observed (Fig.3.) that the highest load share is characteristic for composite coatings after grinding and rolling.

So the most favourable finishing treatment for composite Ni-Al- Al_2O_3 coatings would be grinding and rolling, due to the possibility of obtaining proper tribological properties of the reconditioned parts of ship machinery. It can also be noticed (Fig.4) that in case of alloy coatings , the highest load share occurs for the coatings subjected to plastic treatment by means of rolling. That is why plastic treatment seems to be the best finishing treatment for alloy coatings Ni-Al, taking into account the fact that the squeezing self stress condition is achieved in the coatings which in turn may affect the increase of the durability of ship machinery components.

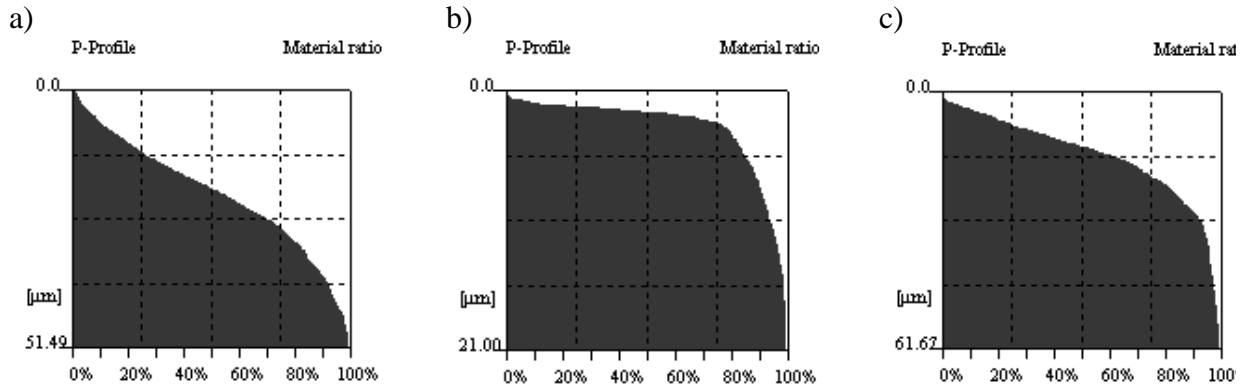


Fig.3. Load curve of the composite coating roughness profile after finishing treatment: a) after lathing, B) after grinding, c) after rolling

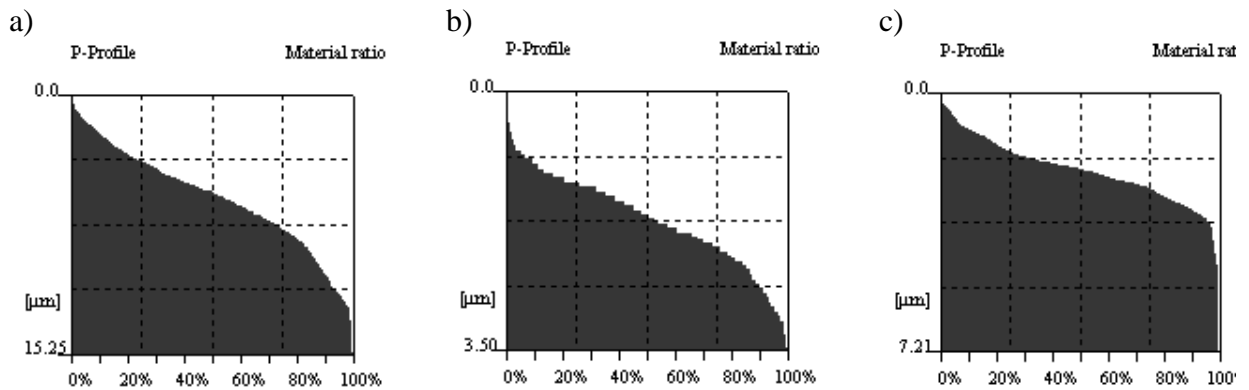


Fig.4. Load curve of the alloy coating roughness profile after finishing treatment: a) after lathing, B) after grinding, c) after rolling

The micro hardness measurement was carried out by means of hardness meter Vickers type with the use of a H type device secured to the handle of metallographic microscope Vertival at the load of 0,4N. To evaluate the influence of the technological process parameters on the micro hardness of the coating treated, the rate of relative consolidation of the surface treated was determined from the following formula:

$$S_u = \frac{\mu HV_2 - \mu HV_1}{\mu HV_1} \cdot 100\% \quad (2)$$

where: μHV_1 – micro hardness of coating matrix before finishing treatment,
 μHV_2 – micro hardness of coating matrix after finishing treatment.

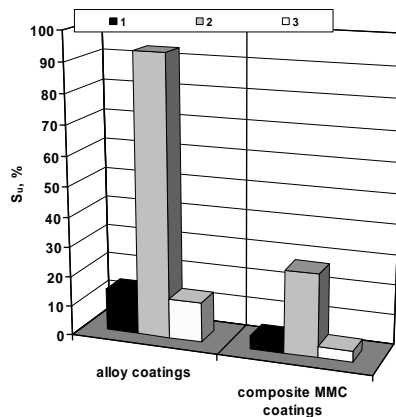


Fig.5. The rate of relative surface consolidation (S_u) of alloy and composite MMC coatings: 1- after lathing, 2- after rolling, 3-after grinding

Figure 5 presents the rate of relative surface consolidation of the treated surface after lathing, grinding and plastic treatment of Ni-Al alloy and composite Ni-Al-Al₂O₃ coatings. It can be observed that the consolidation of composite and alloy coatings as a result of machining treatment was quite insignificant. However, considerable increase of alloy and composite coatings consolidation occurred after plastic treatment by means of rolling. Therefore the squeezing self stress condition was achieved in the coatings which will undoubtedly affect the durability increase of the reconditioned and generated machinery parts.

The process of lathing alloy coatings that were “hot” or “cold” sprayed went well and the machining plate did not undergo any damage, but the Ni-Al coating itself, showed great smoothness. When lathing Ni-Al-Al₂O₃ coatings that were “hot” sprayed, the plate used was damaged. After lathing it was observed that the coating showed signs of “tearing” particles out of the coating stereometric structure. The Ni-Al-Al₂O₃ coating that was “cold” sprayed, was greased with emulsifying oil Emulgol ES-12, and in spite of that showed low susceptibility to lathing treatment. During that process the plates also got damaged. The grinding treatment of alloy and composite coatings sprayed in both methods was performed at fixed machining parameters. The Ni-Al coating showed metallic lustre after the treatment and high smoothness which could indicate a considerable improvement of R_a parameter compared to the condition before treatment. The coating had no signs of tearing particles out of coating stereometric structure. The Ni-Al-Al₂O₃ coatings were ground, however the grinding wheel got blunt and it was necessary to sharpen the wheel during the treatment.

4. Summary

On the basis of the results obtained from experimental research it is possible to state the following:

- the decrease of surface roughness of composite MMC coatings can be observed after machining treatment (lathing and grinding) as well as after plastic treatment,,
- Ni-Al alloy coatings showed lower roughness than composite Ni-Al-Al₂O₃ coatings after machining treatment and plastic treatment,,
- , considerable decrease of surface roughness occurred at higher speeds of lathing,
- for alloy coatings thermally sprayed, the average arithmetic roughness profile showed low values ($R_a= 0,26 \mu\text{m}$ for $\varphi_h= 0,12$, $R_a = 0,33 \mu\text{m}$ for $\varphi_h= 0,06$) after rolling, compared to surface roughness profile after lathing,
- Ni-Al and Ni-Al-Al₂O₃ coatings that were “hot” sprayed demonstrated lower roughness R_a after grinding, compared to Ni-Al and Ni-Al-Al₂O₃ coatings that were “cold” sprayed,
- the highest load share is characteristic for composite coatings after grinding and rolling, and that is why it seems that the most appropriate finishing treatment for composite Ni-Al-Al₂O₃ coatings would be grinding or plastic treatment, due to the possibility of achieving proper tribologic properties of the reconditioned ship machinery parts,
- composite MMC coatings were characterised by low surface roughness, considerable consolidation, more uniform structure (most pores created after thermal spraying were closed) after plastic treatment compared to coatings that were ground.

Composite coating underwent a finishing treatment by means of lathing and grinding. However the technology developed did not come up to the expectations, which can be proved by the difficulties that occurred during machining treatment (quick wear of grinding tools) or tearing particles out of the stereometric coating structure. As a result it seems advisable to improve the technology of finishing treatment for Ni-Al-Al₂O₃ coatings. Composite coatings

that were rolled showed roughness values similar to those after grinding, however the rate of relative consolidation gained much higher values. So, taking into consideration technological as well as economical factors, the plastic treatment seems to be appropriate for shaping stereometric properties of composite coatings. Consequently, the surface plastic treatment is suggested as an alternative finishing treatment, in order to achieve better quality of the treated surface in composite MMC coatings thermally sprayed.

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