DOI: 0.2478/adms-2014-0024

T. Dyl

Gdynia Maritime University, Faculty of Marine Engineering, Department of Marine Materials and Technology, Gdynia, Poland

dylu@am.gdynia.pl

ANALYSIS OF THE POSSIBILITY OF APPLYING OF ALLOY AND COMPOSITE COATINGS AFTER PLASTIC WORKING IN SHIPBUILDING

ABSTRACT

Alloy and composite coatings are widely used in engineering, automotive and shipbuilding because of the possibility of improving the operational characteristics of the surface layer (mechanical, tribological, corrosion and decorative). The welding technology of applying alloy and composite coatings is widely used. The technology of infrasound thermal spraying of metal matrix composite coatings was presented. It is a simple technology and a very useful one in ship machinery regeneration during the cruise craft (e.g. internal combustion engines, torque pumps, separators). The metal matrix composite coatings must undergo finishing due to high surface roughness after application. Coatings obtained by thermal spraying have a large surface roughness, it is therefore necessary to make finishing coatings. Due to economic and technological developments it is essential that the coating was thin, abrasion-resistant, high smoothness, and the finishing was of chip that is not cause material loss. In order to ensure quality of technology offered the elements of the of machines used in shipbuilding of cold working by rolling, with small values of strain ratio, ultimately as a finishing alloy and composite coating is planned to use surface plastic forming of machine parts.

Key words: *alloy and composite coatings, plastic working, corrosion resistance*

INTRODUCTION

The technology of production and regeneration of the applied alloy and composite coating are recognized among engineers, technologists, because of the possibility of increasing the performance characteristics of the surface layer (strength, tribological, corrosion and decorative). Composite and alloy coatings of metal matrix dispersion inclusions of non-metallic phase is characterized by high resistance to tribological wear and corrosion. Metal matrix composite are used in such fields of technology, such as: aerospace, electronics, energy, industry, defense, automotive, aviation, shipbuilding, and more.

Composite coatings of ceramic - metals is used primarily to enhance the durability of machine parts. Therefore, new materials are permanently looked for, what has resulted in the past in development of composite materials. The coatings dispersed are consisting of metallic matrix (metals and their alloys) and small non-metallic particles. The deposition of ceramic

particles simultaneously with metallic matrix leads often to composite coatings possessing properties much better than those of metallic coating. The nickel and, less often, other iron group elements are usually used as a matrix and Al_2O_3 as tough particles [1]. Flame spraying is widely used to deposit coatings in the production and regeneration of machine elements (drive shaft, crankshaft, pump rotors and casings, valve inserts and internal combustion engine cylinders) [2,3].

This article presents the findings of the research into the possibility of using the cold plastic working (cold rolling and cold pressing) to obtain the selected properties of the flame sprayed Ni-Al alloy coatings and Ni-Al- Al_2O_3 composite coatings. The alloy coatings had a single-phase structure, of the maximum 10% aluminium solubility in the crystal lattice of nickel, whereas in the composite coatings the volume fraction of non-metallic material Al_2O_3 was 15% and 30 %.

The article has been aimed to preliminary analyse the possibility of replacement of the traditional finishing methods, by surface plastic working. Samples with steel C45 and coating were subjected to cold rolling and pressing to obtain the following values of actual draft: $\varepsilon_h = 12\%$. Flame-sprayed coatings were characterised by a considerable value of parameter Ra. The surface roughness obtained by flame spraying is not satisfactory in respect to the service qualities because as large values unclear as $Ra = 13\ \mu\text{m}$ are obtained [4,5]. Therefore the coatings should be subjected to finishing in order achieving the required surface quality. The plastic working caused decrease surface roughness. Minimum value of Ra parameter was observed after hot rolling. It was found that maximal roughness was presented after pressing. The corrosion tests were performed in 0.01 M H_2SO_4 solution by potentiokinetic technique. The corrosion rate was dependent on method of plastic working. The increasing drafts resulted in rise corrosion current density and decrease in value of corrosion potential [6, 7, 8, 9]. In the papers [10, 11] presented numeric analysis of the rolling process of bimetal plates (C45 steel with Ni-Al alloy coating). Model research of rolling it was stated that there is a possibility of plastic working by means of finishing flame spray coating. Therefore the experiments were performed to test the processes of rolling and pressing of steel specimens coated with alloy and composite coatings with ceramic dispersed phase and corrosion properties after plastic working.

RESEARCH METHOD

The research was carried out coatings of nickel-base alloy and nickel-matrix composite were applied on the base of C45 steel by subsonic flame spraying using in the Department of Marine Maintenance, Faculty of Mechanical Engineering, Gdynia Maritime University. Coatings were made with such materials as powder ProXon 21021 (Ni-94%, Al-5%, B-1%) and its mixture with powder MetaCeram 28020 (Al_2O_3 -97.7%, TiO_2 -2.2%, SiO_2 -0.1%) [4], the powders were produced by Castolin. Volume concentrations of non-metallic compound Al_2O_3 in the obtained coatings: 15% and 30 %. The process of flame spraying of the alloy coatings can be characterised by the following parameters [5,7]: acetylene pressure: 0.07 MPa, oxygen pressure: 0.4 MPa, distance between the burner and sprayed surface: 150 mm, number of layers applied: 6, obtained coating thicknesses $h_p = 0.6\ \text{mm}$. Rolling and pressing of alloy and composite coatings was performed in the Laboratory of Plastic Working of the Faculty of Mechanical Engineering, Gdańsk University of Technology. Specimens were upended in the cold process on a hydraulic press ZD20, at real draft $\varepsilon_h = 12\%$, unit pressure

900 MPa. Cold rolling was performed at the ambient temperature using the laboratory two-high mill with the cylinder diameter ϕ 200 mm and drum length 250 mm, at draft $\varepsilon_h = 12\%$. As a result of the laboratory tests focused on rolling and pressing of coated flat specimens it was found that volume content of non-metallic compound Al_2O_3 has a considerable effect on the change of Ra parameter, which characterises surface roughness, and also on the change of the composite coating hardness. Assessment of the strain effect on the coating structure was performed with the use of optical microscope Axiovert 25 at $200\times$ magnification. Adhesion of the alloy and composite coatings was assessed in accordance with standard using the following two qualitative methods: scratch method and temperature change method. The assessment was made by viewing the surface with stereoscopic microscope MBC-9 at fivefold magnification. The coating adhesion was considered as good if no lamination, bubbles or exfoliation had been observed.

Microhardness was measured with the use of Vickers Hardness Tester FM-800. The load of 0.49 N was applied for 10 seconds at the ambient temperature. To assess the effect of the technological process on microhardness of the processed coatings, relative hardening of the superficial layer was determined in accordance with the following formula :

$$S_u = \frac{\mu HV_1 - \mu HV_0}{\mu HV_0} \cdot 100\% \quad (1)$$

where:

S_u – coating relative hardening,

μHV_0 – microhardness before plastic working,

μHV_1 – microhardness after plastic working.

Surface roughness after plastic working was measured with a profilometer Hommel - Etamic T8000 in the Faculty of Marine Engineering Gdynia Maritime University. The assumed measurement section length of test sample was 4.8 mm and 0.8 mm for the elementary section. The measurements were performed according to the principles contained in ISO standards. According to the measurement of the arithmetical mean deviation of the roughness profile (Ra), the surface roughness reduction ratio was determined using the formula below:

$$K_{Ra} = \frac{Ra'}{Ra} \quad (2)$$

where:

K_{Ra} – surface roughness reduction,

Ra – material surface roughness before plastic working,

Ra' – material surface roughness after plastic working.

Measurement of corrosion resistance of the coatings was performed using electrochemical test in a three-electrode system. A specimen of the surface area of 0.75 cm^2 was degreased with acetone and then placed in a vessel containing 500 cm^3 of $0.01\text{ M H}_2\text{SO}_4$ at the ambient temperature together with an auxiliary (polarising) electrode made of platinum-coated titanium and the reference electrode (saturated calomel electrode). Before the measurements were taken, the specimens had been exposed to an electrolyte for one hour to enable

stabilisation of corrosion potential. The whole time the measurement the electrolyte was constantly stirred. For the duration of the experiments, polarisation curves $i = f(E)$ were recorded in the range ± 150 mV from the corrosion potential. Cathodic curve was recorded first, and then the anodic one. In all cases, the potential change rate was 10mV/min. Electrochemical studies were performed ATLAS device 053 EU & IA.

RESULTS

The experimental research allowed for determination, based on the measurements of microhardness and roughness profile after flame spraying and after plastic working, that the dispersed phase content in the composite coating has a significant effect on strengthening and smoothness of the coating surface.

Another important remark is that after rolling and also after pressing, the specimens with nickel alloy coating gain much greater microhardness as compared to the specimens with composite coating. Therefore lower content of dispersed phase results in greater strengthening of the coating base. Introduction of ceramic dispersed phase itself increases hardness of the coatings' base. Hence plastic working as the strengthening finish treatment is advisable mainly for alloy coatings. After pressing, an increase in alloy coatings hardness even up to 80% is observed, whereas for composite coatings with 15% content of Al_2O_3 the coatings base hardness rises by 50%. In the case of cold rolling, even greater hardening ratios for both alloy and composite coatings (93 % for Ni-Al coating and 66% for coating Ni-Al-15% Al_2O_3) are attainable.

Draft and unit pressure applied in plastic working of the steel specimens with alloy and composite coatings caused only plastic strain of the coating material. In the base steel, no structure change testifying to its plastic strain was observed. Metallographic study showed reduction in the porousness of the alloy and composite coatings subjected to plastic working (refer with: Fig. 1). Application of plastic working finish for flame-sprayed coatings results in a significant improvement of the surface quality. After plastic working, the average arithmetical roughness profile is to twenty times as lesser as the average arithmetical roughness profile of the coating before to plastic working. As a result of rolling, parameter Ra reaches much lower values comparing to the roughness profile deviation after pressing. Flame-sprayed alloy coatings were characterised by greatly developed real surface. The average arithmetical roughness (Ra) was around 13 μm . The applied methods of plastic working as coatings finishing allowed for significant reduction of the value of considered the parameter. The minimum value of $Ra = 0.44 \mu m$ for $\epsilon_h = 12$ % was achieved for cold rolled coatings, whereas the pressing process allowed for obtaining the surface roughness of the order of $Ra = 1.23 \mu m$. Loads applied within plastic working of the steel specimens with alloy and composite coatings caused only plastic strain of the coating material.

Table 1 shows corrosion study results for coatings of nickel-base alloy and nickel-matrix composite with ceramic dispersed phase (*volume fraction ceramic dispersed phase* - $D_{ph} = 0\%, 15\%, 30\% Al_2O_3$).

The applied qualitative methods of the coatings adhesion testing did not show any adverse effect of plastic working finish on their adhesion to the steel base.

Table 1. The results of the corrosion testing for alloy and composite coatings with volume fraction ceramic dispersed phase

Manufacturing Technology	D_{ph} [%]	ε_h [%]	j_{corr} [$\mu A/cm^2$]	E_{corr} [mV]
after flame sprayed	0	-	257	-173
after pressing	0	12	319	-199
after rolling	0	12	249	-205
after flame sprayed	15	-	139	-172
after pressing	15	12	127	-397
after rolling	15	12	114	-399
after flame sprayed	30	-	103	-179
after pressing	30	12	221	-435
after rolling	30	12	189	-489

Fig. 1. Microstructure of alloy and composite coatings, for different volume fraction ceramic dispersed phase, after rolling: a) $D_{ph} = 0\%$ Al_2O_3 ; b) $D_{ph} = 15\%$ Al_2O_3 ; c) $D_{ph} = 30\%$ Al_2O_3 ; and after pressing: d) $D_{ph} = 0\%$ Al_2O_3 ; e) $D_{ph} = 15\%$ Al_2O_3 ; f) $D_{ph} = 30\%$ Al_2O_3

The influence of the ceramic dispersion in the nickel matrix composite coatings on corrosion current density after flame-sprayed and after plastic working is presented in Fig. 2. Corrosion current density for the composite coatings after plastic working is twice lower compared to the alloy coatings. This may prove that a lower rate of electrochemical corrosion of conduct (refer with: Fig. 2). The figure 3 shows influence of the ceramic dispersion in the composite coatings on corrosion potential after sprayed and after plastic working. The corrosion potential for composite coatings have been treated with plastic working is two to three times smaller than for the alloy and composite coatings after spraying. Increased content of ceramic dispersion reduces the corrosion potential, and therefore increases the capacity of electrochemical corrosion.

Electrochemical corrosion tests proved that the proposed finishing methods aiming to reduce roughness of flame-sprayed coatings resulted in the corrosion potential value shift towards the anodic values. Application of pressing increased the coating corrosion rate j_{corr} and potential corrosion E_{corr} compared to that before plastic working. (Table 1). The figure 4 shows potentiostatic polarization curves on the nickel matrix composite coatings for 15 % Al_2O_3 ceramic dispersion after plastic working. The smaller the value of corrosion current density can provide a lower rate of electrochemical corrosion in the case of alloy and composite coatings treated plastic working. The smaller the value of the corrosion potential may be characterized by a greater ability to act electrochemical corrosion. Corrosion investigation made in 0.01 M H_2SO_4 showed that in most cases of plastic working operations, there was an increase in the corrosive current density accompanied by the drop in the corrosion potential.

Fig. 2. The influence of the ceramic dispersion in the nickel matrix composite coatings on corrosion current density after pressing, rolling, flame sprayed

Fig. 3. The influence of the ceramic dispersion in the nickel matrix composite coatings on corrosion potential after pressing, rolling, flame sprayed

Fig. 4. The potentiostatic polarization curves for composite coatings with volume fraction ceramic dispersed phase $D_{ph} = 15\% \text{ Al}_2\text{O}_3$ after plastic working pressing and rolling

The experiments allowed for determination – based on the measurements of microhardness and roughness profile after flame spraying and after plastic working – that the dispersion phase content in the composite coating has a significant effect on strengthening and smoothness of the coating surface.

The dependency of the ratio of relative strengthening of the composite coating – on the nickel base – on the volume content of non-metallic material Al_2O_3 is shown in Fig. 5. It shows that an increase in the percentage content of aluminium oxide is accompanied by a decrease in the coating strengthening ratio after plastic working. Another important thing is that after rolling and also after pressing, the specimens with Ni–Al alloy coating gain much greater microhardness compared to the specimens with composite coating. Therefore lower content of dispersion phase results in greater strengthening of the coating base. Introduction of Al_2O_3 dispersion phase itself increases hardness of the coatings' base. Hence plastic working as the strengthening finish is advisable mainly for Ni–Al alloy coatings. After pressing, an increase in Ni–Al alloy coatings' hardness by up to even 80% is observed, whereas for composite coatings with 15% content of Al_2O_3 the coating's base hardness rises by 50%. In the case of cold rolling, even greater hardening ratios for both alloy and composite coatings ($S_u = 93\%$ for Ni–Al coating and $S_u = 66\%$ for coating Ni–Al–15% Al_2O_3) are attainable.

The obtained results of hardness measurements showed that all the proposed methods of plastic working finish caused strengthening of the investigated coatings. The greatest ratio of coating strengthening occurred in the cold rolled and cold pressed specimens, whereas in hot rolled specimens the strengthening ratio was the least.

Fig. 5. Effect of volume fraction ceramic dispersed phase D_{ph} in obtained composite coatings on relative strengthening ratio after cold plastic working, 1 – after pressing, 2 – after cold rolling

The data presented in Fig. 6 indicate that the greater content of dispersion phase in composite coatings, the greater roughness is achieved. Also, the surface roughness reduction ratio reaches its greatest values for Ni–Al alloy coatings. The lowest values of the roughness reduction ratio occur for composite coatings with 30% content of Al_2O_3 (Fig. 6).

Fig. 6. Effect of volume fraction ceramic dispersed phase D_{ph} in obtained composite coatings on surface roughness reduction ratio after cold plastic working, 1 – after pressing, 2 – after cold rolling

Flame-sprayed alloy coatings were characterised by greatly developed actual surface. The applied methods of plastic working as coatings finishing allowed for significant reduction of the value of the parameter in question. The minimum value of $R_a = 0.38\mu m$ was achieved for

hot rolled coatings at actual draft $\varepsilon_h = 12\%$, whereas the pressing process allowed for obtaining the surface roughness of the order of $R_a = 1.23\ \mu\text{m}$.

CONCLUSIONS

After experimental studies it can be concluded that there is a possibility of nickel-based coatings in shipbuilding. These coatings are applied by thermal spraying followed by plastic working has a very good resistance to corrosion in the environment being tested. Alloy and composite coatings after rolling and pressing have low roughness and high hardness.

The based on experimental data states that the ceramic dispersion content in the composite coating has a significant effect on strengthening and quality of the coating subjected to plastic working.

The following conclusions were also reached:

- application of plastic working as a strengthening method of finishing is advisable mainly for Ni-Al alloy coatings, where significant strengthening occurs, and the ratios of coating strengthening are 80 % – after pressing, and 93 % – after rolling;
- application of plastic working as a strengthening finish method is also advisable for composite coatings with 15% content of Al_2O_3 where hardness of the coating base increases by 50% – after pressing and by 66% – after rolling; minimum values of the surface roughness is obtained after rolling;
- the coating subjected to cold plastic working gained a more homogeneous structure as most of the pores, which had occurred after flame spraying, were closed;
- the lower value of corrosion potential in coating plastic working composite treated shows that the increase of ceramic dispersion Al_2O_3 can affect the ability to increase the occurrence of electrochemical corrosion in the nickel matrix composite coatings;
- the smaller the value of corrosion current density can provide a lower rate of electrochemical corrosion in the case of composite coatings after plastic working;
- the lowest corrosion current density occurs in the composite coatings containing 15% Al_2O_3 ceramic dispersion after rolling and after pressing.

REFERENCES

1. Starosta R., Zieliński A.: Effect of chemical composition on corrosion and wear behaviour of the composite Ni-Fe- Al_2O_3 coating, *Journal of Materials Processing Technology*, 157–158 (2004), 434.
2. Adamiec P., Dziubiński J.: Regeneration and production of surface layers of transport machinery elements, [in Polish] WPS, Gliwice 1999.
3. Klimpel A.: Welding and thermal spraying: Technologies, [in Polish], WNT, Warszawa 2000.
4. Specification of application and processing technology of powder coatings ProXon 21021, Castolin - Eutectic 2003.
5. Starosta R.: Properties of Thermal Spraying Ni-Al Alloy Coatings, *Advances in Materials Science*, Vol. 9, 1 (19) (2009) 30.

6. Dyl T.: Microstructure, microhardness and corrosion resistance of steel tubes after the piercing - spreading process, *Advances in Materials Science* Vol. 6, 1-2 (9-10) (2006) 5.
7. Dyl T., Skoblik R., Starosta R.: The Effect of the Ceramic Dispersion on the Nickel Matrix Composite Coating Properties after Plastic Working, *Solid State Phenomena*, 147-149 (2009) 813.
8. Starosta R.: Potentiodynamic tests flame sprayed composite coatings, dispersion of nickel matrix, *Composite*, 2 (2008) p.195.
9. Dyl T., Starosta R.: Effect of the Ceramic Dispersion in the Nickel Matrix Composite Coatings on Corrosion Properties after Plastic Working, *Solid State Phenomena*, 183 (2012) 43.
10. Dyl T., Starosta R.: The influence of rolling on the distribution of stress and strain in nickel – aluminum alloy coatings, *Materials Engineering*, 3-4 (2007) 524.
11. Dyl T., Starosta R.: Numerical and experimental research of flat rolling of alloy coatings Ni-Al, *Periodical of Mechanical*, (2012) 36.