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BURNISHING TREATMENT OF THE FAYING SURFACE OF THE PIPE FLANGE

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Abstract

On ships for connecting pipes in seawater installations, fire and other installations and for joining pipes to fittings or receivers, flange-type couplings are often used. It is important to ensure tightness between pipe flanges (ASME). If the system pressure does not exceed 1.6 MPa, "open" flange packing using flat gasket rings is used. Rubber, textolite, polyvinyl chloride or metals and alloys with good plastic properties (e.g. aluminum, copper, Monel alloy, Armco iron) can be used as a sealant material (depending on pressure in installation). The tightness of the joint determines the quality (geometric structure) of the surface of the flange at the contact point with the gasket. Reduced roughness ensures even distribution of surface mounting pressures on flange joint gasket. This article deals with the assessment of the use of burnishing as a finishing treatment for flange faces and the selection of rolling parameters. Samples used for the tests were made of S235J2 carbon steel. Burnishing treatment was done with the SKUV20 tool. The working element of the tool was in the shape of a roller. Burning was performed using the following parameters: the burnishing force (F_n) – 600 N, 800 N and 1000 N; Feed rate (f): 0.08 mm/rev, 0.13 mm/rev, 0.24 mm/rev; the speed of burnishing (v_n) – for a diameter of 55 mm – was 45 m/min, 65 m/min, 78 m/min. The research was carried out on the basis of trivalent plan Hartley. As the output variables (dependent variables), the roughness reduction index (K_{Ra}) and the (S_u) were adopted. Based on the multiple regression analysis, it was found that the greatest impact on reducing roughness and surface hardening of burnished material has burnishing force. The dependence between dependent variables and F_n is proportional. The effect of the burnishing speed (v_n) on the values of K_{RA} and S_u parameters is statistically insignificant. Machining of the active surface of the pipe flanges should be carried out with a burnishing force of 1 kN, a feed rate of 0.08 mm/rev and a burnishing speed of 45 m/min.

Keywords: *burnishing, pipe flange, flange face, roughness, multiple regression,*

1. Introduction

The systems of marine pipelines is made up of many components such as tanks, pipes, pumps, heat exchangers, elbows and valves etc. Pipes and fittings ensure the transport of the medium and the control of the entire process. In installations marine steel pipes are used, the non-ferrous metals and alloys, and to a lesser extent of plastics. The constructor determines the method of assembly of the individual elements of the pipeline. At the design stage, the designer takes into consideration the following elements: operating parameters and the type of material used to produce the pipeline; the absolute necessity of ensuring the integrity of the pipeline during its operation, providing access to equipment requiring repair or maintenance, assembly conditions during montage and the subsequent repairs (replacement) of its components and the frequency of these repairs [4, 5].

The Polish Register of Ships (PRS – Polski Rejestr Statków – Polish Classification Society) that closely supervises the construction of vessels from the design stage to the ship's commissioning) permits the use of the following types of pipe joints: directly welded, flanged, threaded, mechanical. Flanged connections are the most common way of connecting marine pipelines. These joints are used wherever there is a need for frequent pipeline interchanges due to the aggressiveness of the transport agent or to provide easy and quick access to its components (e.g. fittings). In addition, the use of such connections may be due to the fact that the piping is made of weldable materials (especially under mounting conditions) or non-weldable. Depending on the installation parameters slip-on or neck, pipe flanges are used. Slip-on flanges used for lower parameters are usually made as a tube (their inner diameter is slightly larger than the outer tube) and welded. Threaded flange are also encountered. Frequently used solutions are neck pipe flanges made of finished forgings. The flange of this type connects to the pipe by means of a weld between the neck of flange and the pipe. The flange element that determines the tightness of the joint is the face surface. The basic requirement for a face surface of flange it is perpendicular to the axis of the pipeline, adequate surface roughness and no transverse (transverse) defects. This is where the seal is assembled. It is important to ensure tightness between pipe flanges (ASME). If the system pressure does not exceed 1.6 MPa, "open" flange packing using flat gasket rings is used. Rubber, textolite, polyvinyl chloride or metals and alloys with good plastic properties (e.g. aluminum, copper, Monel alloy, Armco iron) can be used as a sealant material (depending on pressure in installation). The tightness of the joint determines the quality (geometric structure) of the surface of the flange at the contact point with the gasket. Reduced roughness ensures even distribution of surface mounting pressures on flange joint gasket. This article deals with the assessment of the use of burnishing as a finishing treatment for flange faces and the selection of rolling parameters. Burnishing not only reduces surface roughness but also contributes to increase corrosion resistance of materials [3, 4, 8, 9].

2. Methodology of research

The selection of the parameters of the technological process of finishing was carried out on samples in the shape of a cylinder with a diameter of 70 mm. The material to be tested was S235J2 steel used for the production of flanges for the connection of ship's pipes. The face of the shaft was treated. Roughing the surface of workpieces was carried out by turning operations. For the facing of the shaft, a cutting insert with a 80° tool included angle of CNMG 12 04 16-PM made of carbide grade GC4230 was used. The cutting insert was mounted in DCKNR 2020K 12 holder. Turning was done on a CDS 500 x 1000 universal lathe CDS 500 x 1000. Cutting parameters were as follows:

- cutting speed: v_c = 200 m/min (for shaft diameter 70 mm – 900 rpm),
- feed: f = 0.1 mm/rev,
- cutting depth a_p = 1 mm,
- number of machining passes: 1.

Surface roughness measurements were made using the HOMMEL TESTER T1000. When measuring the roughness, the evaluation length was 4 mm and the sampling length equaled 0.8 mm [1].

Hardness measurement was done using the Knoop's method using Q250M hardness meter. The 10 N load during the hardness measurement was used.

$$K_{Ra} = \frac{Ra_1}{Ra}, \tag{1}$$

where:
K_{Ra} – roughness reduction index [–],
Ra_1 – surface roughness after cutting, arithmetical mean deviation [μm],
Ra – surface roughness material after burnishing [μm].

Finishing treatment was done by burnishing with the static method with a pressure-rolling type of contact of a tool-working element with a workpiece. Springy interaction methods of the tool with the workpiece were used. The burnishing element was in the shape of a roller. The finishing was done with Yamato's SKUV 20 tool. Because pre-treatment exerts a strong influence on the quality of the burnished surface, the assessment of the impact of the burnishing parameters on the roughness and hardness of the surface is based on two parameters: roughness reduction index (1) and coefficient of relative surface hardness (2).

$$S_u = \frac{HK_2 - HK_1}{HK_1} \cdot 100\% , \tag{2}$$

where:
S_u – coefficient of relative surface hardening [%],
HK_1 – hardness before burnishing,
HK_2 – hardness after burnishing.

In order to quantify the impact of burnishing treatment parameters on the geometric structure and hardness of the surface, a three-pronged Hartley test matrix was used. This plan is built on hypercube, and the star arm for three variables is 1. The aim of the research plan was performed 11 experiments with three replicates. Hartley's plan is often used for the selection of burning treatment parameters.

The applied surface treatment parameters are shown in Tab. 1. Burning was done on a CDS 500 x 1000 universal lathe.

Tab. 1. Technological parameters of burnishing treatment

Burnishing parameter		Value
Burnishing force – F_n	[N]	600, 800, 1000
Burnishing speed – v_n	[m/min]	45, 63, 78
Burnishing feed – f_n	[mm/rev]	0.08, 0.13, 0.24

3. Results

After machining, facing, the workpieces were characterized by an average surface roughness value of Ra_1 = 1.7 µm (Tab. 2). The mean hardness value of the steel shaft face was 225 HK_1 1 (Tab. 2).

Tab. 2. Comparison of influence of emissions of different types of transport [1]

Parameter	Number of measurements	Average	Min value	Max value	Standard deviation	Standard error
Ra_1 [mm]	44	1.7	1.06	2.29	0.43	0.07
HK_1 1	44	225	185	253	13.5	2.04

The effect of burnishing parameters on the roughness reduction index value is shown in the Fig. 1 and 2. As a result of the treatment of burnishing, the value of K_{Ra}, which determines the roughness reduction index of surface, ranged from 11.26 to 26.75. The smallest value of the arithmetical mean deviation of the assessed profile Ra = 0.08 µm and the highest value of the K_{Ra} index was obtained using the following burnishing parameters: F_n = 1000 N, v_n = 45 m/min, f_n = 0.08 mm/rev. The lowest value of the K_{Ra} index can be obtained using the surface treatment parameters: F_n = 600 N, v_n = 63 m/min, f_n = 0.13 mm/rev.

Considering the obtained values of standardized multiple regression coefficients for independent variables, it can be concluded that the highest influence (BETA = 0.87) on the surface roughness reduction index K_{Ra} has the burnishing force (Tab. 3). The greater the amount of force used in burnishing operations, the value of the arithmetic average of ordinates of the roughness profile Ra is less. The other parameters of burnishing, i.e. feed rate and burnishing speed, are inversely proportional to the decrease in surface roughness index of the cylinder, and thus increase the values of these parameters, which result in higher Ra values. Taking into account the absolute values of the standard multiple regression coefficients, it can be concluded that the feed rate (BETA = –0.61) has a greater effect on the variable dependent on the burnishing speed (BETA = –0.17).

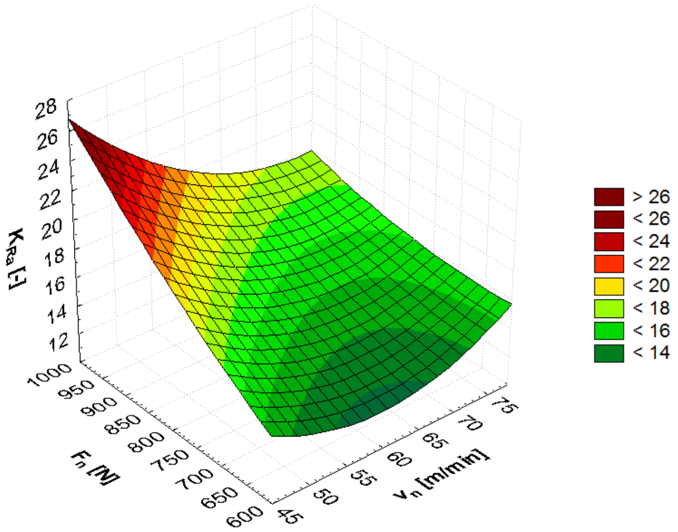

Fig. 1. Relation between burnishing parameters v_n or F_n and roughness reduction index K_{Ra} value [1]

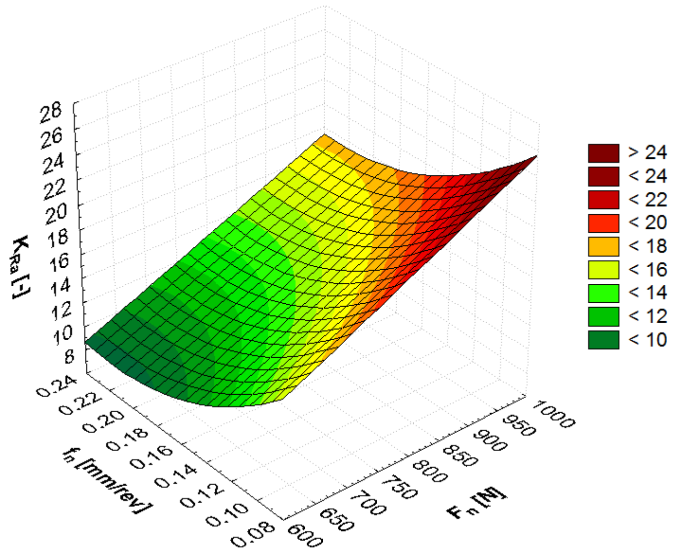

Fig. 2. Relation between burnishing parameters f_n or F_n and roughness reduction index K_{Ra} value [1]

Tab. 3. Results of multiple regression analysis for the K_{Ra} index ($F(3.7) = 13.27$, $p < 0.028$, $R = 0.92$, $R^2 = 0.85$, standard error of estimation = 1.91)

	BETA	*B*	*t*	*p*
Free term		7.68	1.72	0.13
Burnishing speed – v_n [m/min]	–0.17	–0.055	–1.06	0.33
Burnishing force – F_n [N]	0.87	0.023	5.48	0.001
Burnishing feed – f_n [mm/rev]	–0.61	–43.72	–3.61	0.01

By analysing the calculated significance levels (Student's t-test) for individual independent variables, it can be concluded that only the force and feed rate of the burnishing are significantly affected by the roughness reduction index. The independent variable F_n has the highest value (0,9) of partial correlation coefficient (Tab. 4). This variable alone explains almost 76% ($BETA^2$ x 100%) of variance of the dependent variable, excluding the impact of other dependent variables.

Tab. 4. Redundancy of independent variable or K_{Ra}

	Tolerance factor	R-squared	Partial correlation	VIF
F_n	0.86	0.14	0.9	1.16
v_n	0.85	0.15	–0.37	1.18
f_n	0.74	0.26	–0.81	1.35

The value of the calculated level of significance (t-Student's test) $p = 0.33$ for variable of burnishing speed is greater than assumed level of significance ($\alpha = 0.05$). Which may indicate on statistically little impact the value of this independent variable on K_{Ra}. Taking into account parameters of redundancy, or collinearity (i.e. Tolerance factor, VIF – variance inflation factor and R-square) (Tab. 4), it was found that there is no basis for removing the variable v_n from the statistical model. Due to the different values of the variance of the random component (residuals), a series of mathematical transformations of variables were made, aimed at obtaining a linear relationship between the dependent variable and the independent variable. Taking into account the results of the statistical analysis, the multiple regression equation for the range of burnishing parameters in Tab. 1, will be ($R^2 = 0.9$):

$$K_{Ra} = -7.45 + 0.07v_n + 0.09F_n - 258.7f_n + 0.003v_n^2 - 0.0002F_n^2 + 155.6f_n^2 + \\ + 0.5v_n f_n - 0.01v_n F_n + 0.18F_n f_n \,. \qquad (3)$$

The influence of used burnishing parameters on coefficient of relative surface hardening of treated surfaces was also evaluated. Fig. 3 and 4 show the effect of process parameters on the hardening of the end face of the specimen after burnishing treatment. As a result of surface treatment, the value of the coefficient of relative surface hardening S_u ranged from 2 to 15%. The highest average hardness of 253 HK_1 and the highest S_u value were obtained using the following burnishing parameters: $F_n = 1000$ N, $v_n = 45$ m/min, $f_n = 0.08$ mm/rev.

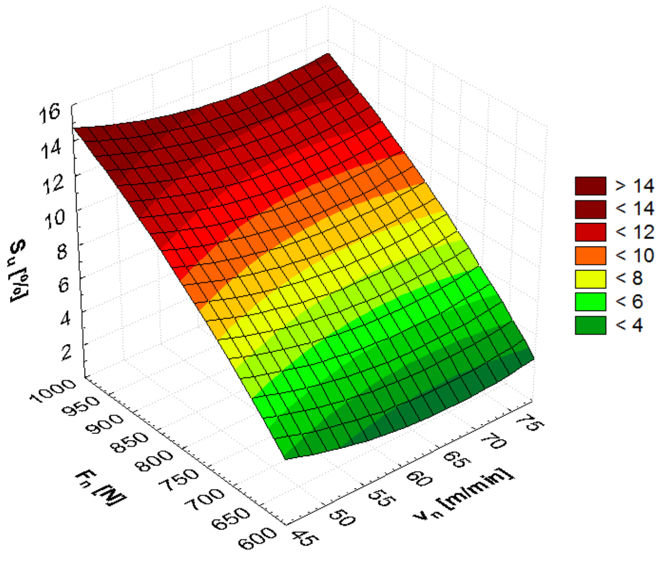

Fig. 3. Relation between burnishing parameters v_n or F_n and coefficient of relative surface hardening S_u value

By analysing the results obtained from the statistical analysis F (variance), it can be concluded from 95% ($\alpha = 0.05$) probability that all three independent variables affect the value of the dependent variable S_u (Tab. 5). The value of the multiple correlation coefficient R is 0.93. Given standardized regression coefficients, it was found that the greatest impact on the coefficient of relative surface hardening has the burnishing force (BETA = 0.95). This variable alone explains nearly 90% ($BETA^2$ x 100%) of the variance of the dependent variable, excluding the impact of

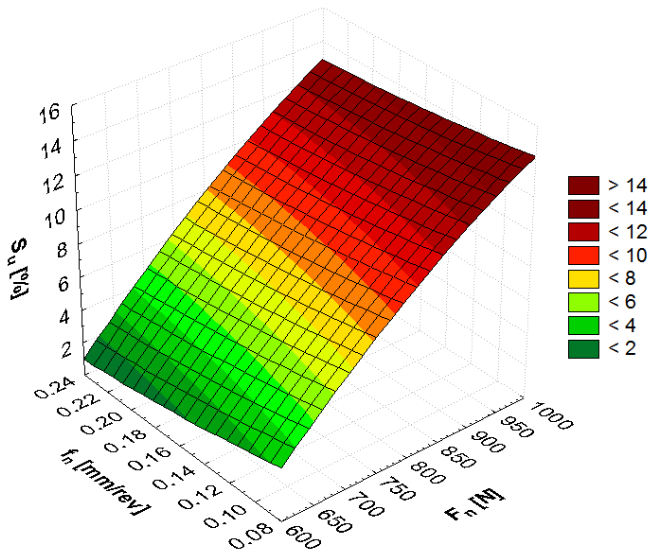

Fig. 4. Relation between burnishing parameters f_n or F_n and coefficient of relative surface hardening S_u value

Tab. 5. Results of multiple regression analysis for the Su coefficient (F(3.7) = 116.7, p < 0.001, R = 0.92, R^2 = 0.85, standard error of estimation = 0.003)

	BETA	*B*	*t*	*p*
Free term		–0.11	–6.48	3.40E–04
Burnishing speed – v_n [m/min]	–0.06	–0.035	–1.82	0.11
Burnishing force – F_n [N]	0.95	0.028	17.6	4.72E–07
Burnishing feed – f_n [mm/rev]	–0.11	–5.67	–1.2	0.25

other dependent variables. The next parameter of burnishing (BETA = –0.11), which affects the analysed property of flat surfaces, is the feed rate. This relation is inversely proportional. The speed of burnishing (BETA = –0.06) is the least affected by hardening of steel surfaces. The negative value of the standardized correlation coefficient proves inversely the proportional relationship between the burnishing speed v_n and the coefficient of relative surface hardening S_u.

Values of calculated significance levels (for t-Student test) $p = 0.11$, and $p = 0.25$ for variables: burnishing speed and feed rate are higher than the assumed significance level ($\alpha = 0.05$).

This may be due to the lack of statistically significant influence of these independent variables on the S_u value. Given the parameters of redundancy i.e. Tolerance factor, VIF – variance inflation factor and R-square) (Tab. 6), it was found that there was no reason to variables v_n and f_n removed from the statistical model.

Tab. 6. Redundancy of independent variable or S_u

	Tolerance factor	R-squared	Partial correlation	VIF
F_n	0.86	0.14	0.98	1.16
v_n	0.85	0.15	–0.56	1.17
f_n	0.74	0.25	–0.84	1.33

$$S_u = -11.17 - 0.47 v_n + 0.064 F_n - 14.29 f_n + 0.003 v_n^2 - 0.89 f_n^2 + 0.18 v_n f_n - 0.006 F_n f_n \,. \qquad (4)$$

In many publications [2, 6, 7, 10], the results of the study show the linear relationship between burnishing parameters and hardening of the workpiece. Large values of calculated significance levels may be due to the nonlinear relationship between independent variables and dependent variable. Large values of calculated significance levels may be due to the nonlinear relation between independent variables and dependent variable. Formula 4 shows a second-order polynomial for the S_u's variable prediction. The non-linear regression equation (4) can be used to predict the value of the dependent variable S_u. The value of the determination factor for this equation is 1.

4. Conclusions

1. Rolling burnishing can be successfully used as finishing work of pipe face flanges.
2. For the smoothing and strengthening of flat surfaces made of S235J2 steel with the SKUV 20 tool, use high burnishing force and low burnishing speed and feed rate.
3. The maximum values of coefficient of relative surface hardening (S_u = 15%) and roughness reduction index (K_{Ra} = 26.75) were obtained using the following burnishing parameters.
4. Burnishing force F_n = 1 kN, burnishing feed f_n = 0.08 mm/rev and burnishing speed v_n = = 45 m/min.

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