MONITORING INFLUENCE OF SELECTED PARAMETERS ON SURFACE QUALITY AFTER POLYMER POWDER COATING

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Presented article is aimed to powder coating and monitoring surface quality. Powder coating is considered as one layer surface treatment to protect against environment. Thickness of layer is several micrometers (depend on powder type) and meets high requirements and demand on surface protection against scratches, abrasion and other material specifications. Presented article is focused on experimental study of surface roughness influence on surface quality after polymer powder coating (surface roughness and coat thickness). Last part of article is aimed to statistical verify individual parameters by chi test.

KEYWORDS

powder coating, surface roughness, milling, surface

1 INTRODUCTION

Surface treatments are one of the base final operations in manufacturing industry. Surface treatment is used to obtain required quality of the surface to protect internal layers of components against effects of environments to achieve long time functionality. The most required attributes on surface treatments are [Feco 2015, Harnicarova 2012]:

- abrasion resistance,
- change in electrical conductivity,
- heat resistance,
- hardness,
- corrosion resistance.

Powder coatings belong to protective single layer surface treatment. Layer of applied powder coating is several micrometers thick (depend on type of powder) and fulfills high standards and requirements on surface protections against scratches, abrasion and other functional requirements. Powder coating has good ability to protect surface against weather and corrosion. Huge amount of powder coatings is characterized by high level of chemical resistance. Nowadays modern technologies of powder coatings are able to create 50 shades of grey and others colors and wide range of external design. Powder coatings are used in different industries [Hutyrova 2014, Schweizer 1991].

Principle of powder coating technology is based on electrostatic charge of insulator moving in electrostatic field with high intensity. Required potential is obtained from additional supply of electrostatic field. Transition of the powder through ionized air is free ions attached on powder particles, which diffuse and create negative charge. Charging of powder particles is characterized on the top of powder gun, where intensity of electrostatic field is on the highest value because of position of electrodes. Created electrostatic voltage is in the range from 20 to 100 kV [Orlovsky 2014, Michalik 2014].

Structure of layer made by powder coating is regulated by shape of nozzle (Fig. 1), velocity of particles, which goes from the edge of the gun in electrostatic field between electrode and component. Advantage of presented way of approach is high productivity, less powder consumption and simple possibility of automation. Disadvantage of technology is in its higher purchase price and in necessary to absolutely ground painted components [Misey 1991, George-Andrei 2014].

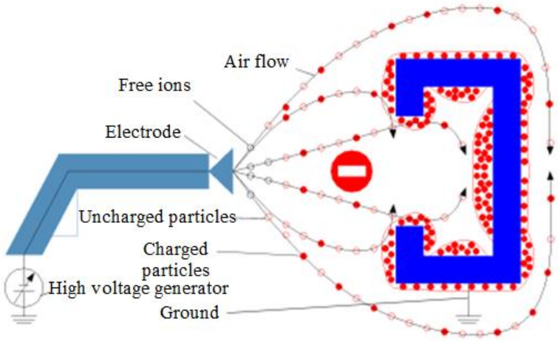

Figure 1. Schematic of electrostatic charging

2 EXPERIMENTAL PART

Experimental samples are made of steel C45E, which is non-alloy steel often used in machinery industry of less strained components. Optimal mechanical properties with toughness are obtained by hardening and subsequent tempering. Semi product used in experiment was square rod dimension 100 x 100 x 1500 mm, which was cut to 4 samples with following dimensions:

- first sample – 100 x 100 x 17 mm,
- second sample – 100 x 100 x 21 mm,
- third sample – 100 x 100 x 19 mm,
- fourth sample – 100 x 100 x 20 mm.

Addition for machining was 2 mm. Samples were cut by band saw Bomar type Ergonomic 275.230DG. Subsequently samples were milled on vertical CNC milling center Pinnacle VMC 650 S to achieve required testing dimension of experimental samples:

- first sample – 100 x 100 x 15 mm,
- second sample – 100 x 100 x 19 mm,
- third sample – 100 x 100 x 17 mm,
- fourth sample – 100 x 100 x 18 mm.

Milling was done using 6 teeth end mill FMPCM 3063S with diameter D=63mm (Fig. 2).

Figure 2. End mill FMPCM 3063S

Cutting conditions of the experiment are shown in following table, where were variable spindle speed, feed rate and depth of cut (Tab. 1).

Table 1. Table of cutting conditions

No. Sample	Spindle speed *n* [rpm]	Feed rate v_f[mm.min^{-1}]	Depth of cut *ap* [mm]
1.	1000	500	1
2.	2500		
3.	2000	600	1
4.	2000	800	

Roughness of the surface was measured using roughness meter Mitutoyo SJ400 (Fig. 3), which is able to measure roughness, waviness and primary profile. Measured values of roughness before powder coating are shown in table follows (Tab. 2).

Figure 3. Roughness meter Mitutoyo SJ 400

Table 2. Table of cutting conditions

		Roughness *Ra* [µm]	Roughness *Rz* [µm]
Sam. 1	**Top - milled surface**	0.51	3.1
	Bottom - cut surface	6.16	28.6
Sam. 2	**Top - milled surface**	1.28	9.3
	Bottom - cut surface	5.41	30.6
Sam. 3	**Top - milled surface**	0.46	3.4
	Bottom - cut surface	7.21	34.2
Sam. 4	**Top - milled surface**	0.76	4.2
	Bottom - cut surface	7.83	39.4
	Milled groove	0.58	3.2

Process of powder coating was realized on painting line from producer Ideal line (Fig. 4), where sequences of technological steps are [Ragan 2012]:

- chamber pretreatment of the samples, where is treatment realized in three subsequent steps:
- ferric phosphate with concentration 10- 15 g/l, temperature 30 – 50°C for 3 minutes,
- rinsing with service water for 3 minutes,
- rising with service water with decreased conductivity (low ionic water)
- second chamber is determined to dry components after previous operation for 6 min in 130 °C warm air,
- powder coating chamber using manual powder gun from producer ITW Gema AG,
- final process of powder coating was bake at temperature 180°C.

Figure 4. Powder coating chamber and powder gun label

For experimental test was used powder Teodur AP type Ral 9005 Jet black in shade matt smooth.

Subsequent was measured values of surface roughness to define dependence between surface roughness before powder coating, after powder coating and thickness of the coat. Measuring was realized on roughness meter Mitutoyo SJ 400 (Fig. 5) to maintain conditions the same accuracy of measuring. Values of measure roughness Ra and Rz are shown in following table (Tab. 3).

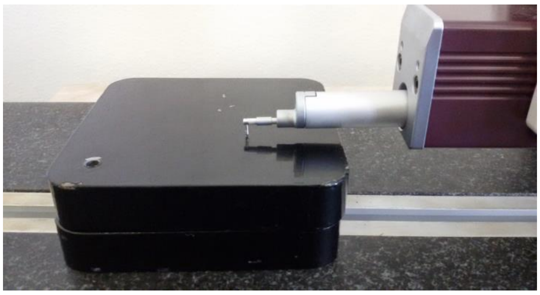

Figure 5. Measuring of surface roughness

Table 3. Values of measured surface roughness Ra and Rz

		Roughness *Ra* [µm]	Roughness *Rz* [µm]
Sam. 1	**Top - milled surface**	0.08	0.5
	Bottom - cut surface	0.08	0.5
Sam. 2	**Top - milled surface**	0.09	0.5
	Bottom - cut surface	0.52	1.7
Sam. 3	**Top - milled surface**	0.15	0.9
	Bottom - cut surface	0.16	0.9
Sam. 4	**Top - milled surface**	0.12	0.7
	Bottom - cut surface	0.62	2.4
	Milled groove	0.2	0.9

Roughness as one of parameter surface topography after machining is able to influence by several conditions. First primary way of approach to machining, then cutting conditions such as spindle speed, feed rate and depth of cut. From the experimental result can be state, that surface roughness directly influences quality and thickness of implicated coating. Measuring the coat thickness was realized by coating thickness gauge mark PhynixSurfix (Fig. 6)[9].

Figure 6. Thickness meter PhynixSurfix

Measuring device PhynixSurfix is used in industry to fast identification coat thickness, where is not necessary to work with wide range of values to save into internal memory. Device offer to measure different materials and to calibrate probe to individual accuracy depend on measured coating materials. Sample were oriented by drilled hole to hang in the process of powder coating, which was set into left upper corner to ensure axial direction of milled surface for transparent measuring (Fig. 7).

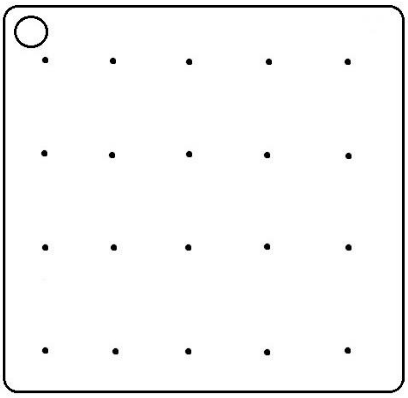

Figure 7. Orientation sample and define of measuring points for all samples

Measured values of thickness were measured with probe on top side of sample after milling in direction perpendicular to mill direction. Subsequently were measured values of roughness on opposite side of samples on the surface after cutting by band saw in perpendicular direction to saw moving.
Graphical dependences such as analyzing of experiment was done by software Mathcad 14.0, which is industry used software with special application for engineering calculations. Average values were calculated to define general course of selected monitored parameters for individual comparing and also for interpolation of measured values (Tab. 4).
Presented graphical dependence give information about correlation of both courses, where is possible to calculate ratio coefficient between monitored parameters. Ration between roughnesses is on average values 21,88, what confirm initial hypothesis about more qualitative surface after coating, when coating overlays convex and concaves of surface profile (Fig. 9).

Table 4. Measured values of coat thickness

	Thickness [µm]						
	Pos.	1	2	3	4	5	
Sam. 1 - after milling	1	101.6	104.8	114.8	108	111.2	
	2	101	88.6	88.9	89.3	93.1	
	3	112.6	87.9	74.6	73.4	76.1	
	4	123.4	97.5	72.4	65.9	69.5	
	Thickness [µm]						
	Pos.	1	2	3	4	5	
Sam. 1 - after saw	1	123	111.4	105	125	128.8	
	2	81.1	80.8	93.1	112.8	137.4	
	3	68.3	68.4	90.5	119.6	134.2	
	4	49.2	53.4	80.4	111.2	128.6	
	Thickness [µm]						
	Pos.	1	2	3	4	5	
Sam. 2 - after milling	1	79	82.5	84.6	100.4	98	
	2	88.9	76.9	70.5	72.3	75.6	
	3	101	80.2	68.4	60.6	63.4	
	4	118.2	90.6	69	57	58.6	
	Thickness [µm]						
	Pos.	1	2	3	4	5	
Sam. 2 - after saw	1	144.4	146.6	131.6	114.8	119.2	
	2	124.6	117	100.2	108.6	122.8	
	3	88.9	87.1	89.3	98.5	120.2	
	4	71.8	67	75.4	84.4	126.2	
	Thickness [µm]						
	Pos.	1	2	3	4	5	
Sam. 3 - after milling	1	111	110	115	105	123.6	
	2	109.4	102.6	112.4	102	112.4	
	3	117.6	106.8	103	97.3	91.8	
	4	134	110.2	105	96.3	83.4	
	Thickness [µm]						
	Pos.	1	2	3	4	5	
Sam. 3 - after saw	1	143	126	113.6	115.4	115	
	2	116.6	109.6	104.2	103	142	
	3	77.4	71	77.4	100.6	148	
	4	55.2	63.1	68.9	102.6	141	
	Thickness [µm]						
	Pos.	1	2	3	4	5	
Sam. 4 - after milling	1	110.8	94.2	89.1	89.4	93.2	
	2	92.7	78.2	95.1	83.5	90.2	
	3	76	75.1	77	85	90.8	
	4	57.6	59.5	65.6	79.5	93.3	
	Thickness [µm]						
	Pos.	1	2	3	4	5	6
Sam. 4 - after saw	1	92.7	85.5	82.9	91.7	78.6	98.5
	2	79	71.5	48.6	60.5	61.7	81.9
	3	70.1	60.1	47	51.3	48.6	65.5
	4	75.1	54.8	46.9	44.5	35	52.1

Maximal differences among surface roughness values are monitored in sample 2 and 4 after saw, where also measured highest values of surface roughness before coating were, and during firing process the powder incompletely fill surface unevenness.

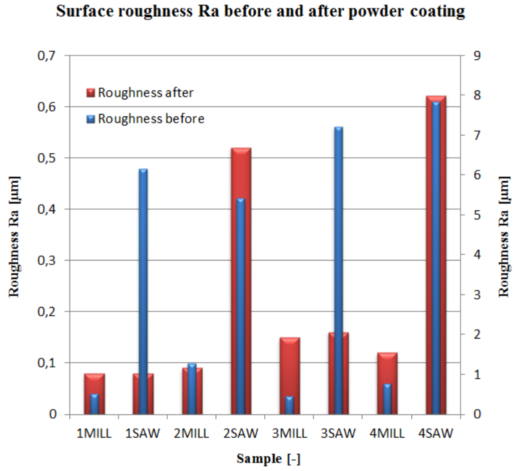

Figure 9. Graphical dependence of surface roughness Ra before and after powder coating

Course of coating thickness oscillating around average values 0,088 micrometers and can be state, that maximal values of thickness is observed on sample 2 after saw and 3 after milling, where was average values of surface roughness before coating. From presented graphical dependence (Fig. 10) can be state, that thickness is not dependent on surface roughness and thickness is from the range 0,06 to 0,1 micrometer and powder in firing process overlays surface unevenness.

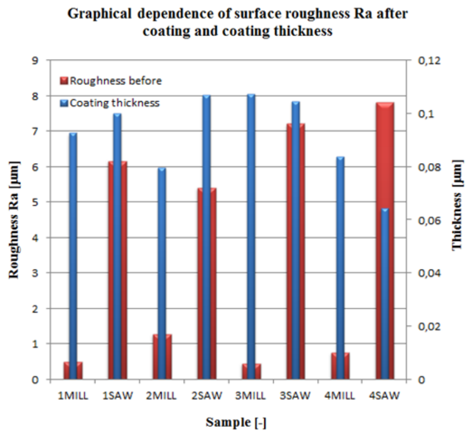

Figure 10. Graphical dependence of surface roughness Ra before coating and coat thickness

Analytical part also contains evaluation of basic statistical indicators, which are shown in table follows (Tab. 5).

Table 5: Statistical indicators

Statistical sign	Roughness before coating	Roughness after coating	Coat thickness
Standard deviation	2.528	0.201	13.216
Dispersion	6.391	0.041	174.65

Testing of conformity between two parameters (1) was realized by statistical function x^2 (Chi- square). Testing criteria was gradually chosen depend on evaluated parameters surface roughness before and after coating, and subsequently coat thickness on various surface roughnesses.

$$x^2 = \sum_{i=1}^{k} \frac{(x_i - N_{pi})^2}{N_{pi}} \qquad (1)$$

Where:
χ chi test
X real values
N expected values

Number of independent data is determinate by degrees of freedom, while independent data are in experiment considered as base for statistical estimation. Calculating is by following mathematical equation (2):

$$k = (m-1).(n-1) \qquad (2)$$

Where:
m numbers of rows
n number of columns

Null hypothesis is set to confirm dependence between monitored statistical signs, specifically:

- H01: Monitored of surface roughness after coating is dependent on coat thickness.
- H11: Monitored parameters are independent.
- H02: Monitored coat thickness is dependent on surface roughness before coating
- H12: Monitored parameters are independent.
- H03: Monitored of surface roughness after coating is dependent on surface roughness before coating.
- H13: Monitored parameters are independent.

Null hypothesis H0 represent investigated phenomenon, what is main testing criteria. Alternative hypothesis H1 confirm opposite phenomenon, what mean independence of monitored parameters, but by calculating can be occurred faults as follows (Tab. 6):

Table 6: Fault distribution in hypothesis testing H0

	Refuse H0	Confirm H0
H0 valid	Fault I. type	right
H0 not valid	right	Fault II. type

Calculated values give possibility to state, that coat thickness is dependent on surface roughness after machining, but (Tab. 7) surface roughness after powder coating is independent on coat thickness. Surface roughness before and after process of powder coating is mutual dependent.

Table 7: Result values of Chi test

Dependence	CHI-TEST	
Coat thickness and surface roughness after coating	0,98634957	**98,63 %**
Surface roughness before coating and coat thickness	0,012938373	**1,29 %**
Surface roughness before and after powder coating	0,982368614	**98,23 %**

3 CONCLUSIONS

Topic of presented article is process of surface treatment methods of materials, where the objective is pointed on dependence of surface roughness on final quality of surface quality after polymer powder coating. Is necessary to state to achieve the maximal quality of the surface is required to set conditions from the range for chosen material (temperature, time of deposition, powder type and voltage). Presented article is aimed to measurement of coat thickness depend on surface quality before surface treatment to monitor general quality of the process. Result of the experiment is that, coat thickness is depend on surface roughness after milling, but on other side is not dependent on surface roughness before machining. Surface roughness before and after machining is initial dependent and coat thickness is independent parameter, which is directly influenced by technological process of surface treatment specifically polymer powder coating.

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