INFLUENCE OF THE CURING PROCESS ON THE QUALITY OF POWDER COATING

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The article describes the types of the curing process and its influence on the quality of lacquer powder coating. The curing process will be analyzed on two different materials, aluminum and steel, and in three technically different kilns, followed by the comparison of the burning effect.

KEYWORDS

technology, surface treatments, Powder Coating, powder coatings, sample, curing process, testing coatings

1 INTRODUCTION

The method of surfacing material with powder coatings is currently rapidly growing method expanding worldwide. This boom caused mainly by the excellent qualities of the powder coating, a very small percentage of powder paint waste, frugal technology and environmental friendliness. Thanks to the continuous development of new powder coating chemical composition, the method of burning, now called curing. This process is the final phase of powder coating production therefore it has a crucial influence on the final quality of the entire coating. It is also the slowest and most expensive part of the powder coating process, hence selecting a suitable curing apparatus must be paid great attention to. Powder coating is an advanced modern technology used in the field of metal surface treatment in particular, but also other materials such as plastic, glass or wood. In addition to the visual requirements, powder coated surface also complies with the mechanical and chemical requirements. Process of powder coating consists of a surface pre-treatment, a powder coating and subsequent curing in an oven. This method of surfacing is very environmentally friendly. Since nowadays a great emphasis is placed on this attribute it is also why it is widespread throughout the world. [Sedlacek 1992], [Aclak 2015], [Technolak 2009]

2 EXPERIMENT PROPOSAL

The experiment was designed for two types of basic metal material - steel and aluminum - see Fig.1. Degreasing with industrial alcohol was selected as sole part of the pre-treatment phase. In accordance with the technical and safety instructions for powder coating, hand pistols will be used for spraying the powder coating. The paint will be the same for all samples and the spraying device always properly cleansed, to avoid mixing with the previously used paint. Spraying will be carried out only by trained personnel in all three cases. Curing of the powder coatings made in three different kilns. The first kiln - hot air pass-through with direct gas heating, the second kiln - hot air chamber with electric heating, third kiln – pass-through with an infrared catalytic kiln.

The kilns will be set in accordance with the technical powder coating requirements for proper burning. During curing it will be ensured that a temperature profile throughout the curing is obtained in order to observe the curve of the temperature rising to the burning level as well as the total burning time. Various tests and measuring will be carried out on the samples. Thickness of the coating will be measured according to ISO 2808 norm, changes of the color deviations ΔE in the CIE Lab color space and the gloss level according to ISO 2813. Among the tests there will be mandrel bending test according to ISO 1520, coating adhesion grid test according to DIN EN ISO 2409 and pull-off test according to DIN EN ISO 4,624.
[Svacina 2015]

2.1 Powder paint application

EUROPOLIVERY company powder coating material type: DURPOL EE BIANCO was used. It is a white color paint with a smooth gloss finish on a epoxy-polyester base. Powder coating was carried out on three sections with two different application devices and three separate spray booths. In the first of the cases, the application equipment SAMES E-Jet 2 with a vibrating base for the paint box and a plastic double sided spray booth. In the next case the application equipment GEMA Optiflex, also equipped with a vibrating base for the paint box, was used and the coating was carried out in a smaller one-sided polished stainless steel spray booth. The last coating application equipment was the same as in the second case, but the spray booth was two-sided MAJKA type, also made from polished stainless steel. All three devices are electrostatic and employing manual coat application. Thus enabling the same value settings for the coat application and comply with the settings selected as per particular color technical sheet - the value of voltage of 75 kV and a current value of 65 mA.

Figure 1: Examples of samples - left steel, aluminum, right

2.2 Test samples curing

a) In a hot air pass-through kiln with direct gas heating. This method does not allow the discharge of exhaust gases from the kiln. The length of the kiln is 36 m, and it is a U shaped type of kiln, therefore 2x18 meters divided by partition. At the beginning and the end there are air screens preventing the heat from escaping out of the kiln. The conveyor speed was set at 1.8 m / min.

b) In the hot air chamber kiln with electric heating. The internal dimensions are at 1900 mm in height, width and depth. After the paint spraying the samples were hung onto a mobile framework and backfilled into the kiln.

c) Last curing was carried out in a pass-through catalytic infrared oven - see Fig.2. Its length is 5500 mm, width 1400 mm and height 3200 mm. The kiln has 36 infrared panels in three rows of 12 panels around the circumference of the kiln. Samples were hung on a simple overhead conveyor. Two different performance settings were tested, as well as three various conveyor speeds of 0.6, 0.8 and 1 m / min. The initial test showed the 1m / min speed of the conveyer as the most suitable option.

Figure 2: Catalytic infrared kiln

2.3 Color variation measuring

Spectrophotometer X-Rite SP60 type was used for measuring the color variation. The system can adjust the values of L, a and b, which the color should reach after curing. The instrument will measure the actual value of L, a, b, that the sample reaches and recalculates itself the values of ΔL, Δa, Δb and subsequently the overall deviation ΔE. Measuring is performed according to ISO 7724 and the color deviation is measured in CIE Lab color space. [Okcolour 2015]

2.4 Gloss measurement

Gloss Sheen type GLOSS master 60˚, which measured gloss at an angle of 60˚ was used for the gloss measurement. Part of gloss-meter was a black calibration tile with gloss value was 95.4 gloss units. During calibration a level of 95.3 gloss units was achieved. This result was within tolerable variance value. Gloss-meter is approved for ISO standard 2813. [Okcolour 2015]

2.5 Coating thickness measurement

The coating thickness was measured by the device Elcometer 456. The device itself evaluates an average value of the coating after cross-measuring determined points, and automatically switches between ferromagnetic and non-ferromagnetic measuring. The coating thickness of a single layer coating is between 50 microns to 150 microns. The thickness is different for each color, and it must be respected according to the particular color technical data sheet for subsequently ensure chemical and mechanical qualities. Curing should not influence the coating thickness, but its value is important for subsequent measuring of pull-off, bending and grid test. Measuring was carried out in accordance with ISO 2808.

2.6 Grid test

Grid test is used to measure the quality of the adhesion to the base material. Elcometer 107 set, which consists of a cutting tool, magnifying glass, adhesive tapes, and a paintbrush which was used instead of a scrubbing brush. Further it consists of a set of cutting knives, usage of which vary according to the material and thickness of the coating. Measuring was carried out in accordance with DIN EN ISO 2409. [Czech Standards Institute 2007]

2.7 Pull-off test

Pull-off test is used to measure the quality of grip. For measuring Elcometer 108 with digital display was used in accordance with DIN EN ISO 4,624. Instrument kit consists of a device for measuring adhesion and a test sample piece made of stainless steel and glue. [Czech Standards Institute 2007]

2.8 Bending over a cylindrical mandrel

The bend test was conducted on a bending device TQC. This durable device is used for determining the resistance of paint, varnish and similar coatings to cracking or plucking of the coating after the test sample had been bent the around the cylindrical mandrel. [Proinex 2015]

2.9 Records of kiln temperature

For the first two records of the temperature in curing ovens a set CURVE-X2 USB was used. This set measured the temperature in a hot air kiln as well as in a gas kiln with direct heating and in electric kiln. The kit includes the measuring device, sensor probe, the protective isolating box and a software.

The measuring device tracks the course of the powder paint curing process in the kilns. It collects data about the operating temperature of the product and its surroundings, and shows the data on a display. The probes have a small difference of shape and material, thus ensuring the correct qualities of continuous heat flow. Guiding cables have an outer coat that prevents their destruction. The protective box is made of high quality stainless steel and provides thermal protection with a high coefficient of thermal resistance. Three types of probes were used for measuring. Probe with magnet for scanning iron, clamp probe for scanning aluminum and a probe for the air temperature monitoring. The third temperature measuring was done using thermos camera Fluke Ti200. The camera was set to capture the image in an interval of one second and with the help the automatic focus it was aimed at the test sample during the curing process. After assembling frames with heat values and times of their creation it was possible to create a graph of the temperature level progress.

[Proinex 2015], [Thermal imagers 2015]

3 MEASURING AND TEST EVALUATION

[Svacina 2015]

3.1 Evaluation of color deviations

Each shade has clearly defined values L, a, b, which should be as equal as possible after the paint curing.

Basic hue values according to the technical data sheet DURPOL EE BIANCO:

L = 93,22

a = -0,7

b = 2,52

Sample No.	L	a	b	ΔL	Δa	Δb	ΔE
1	94,91	-0,77	+0,96	+1,69	-0,07	-1,56	2,3
2	94,97	-0,83	+0,83	+1,75	-0,13	-1,69	2,43
3	94,32	-0,91	+0,58	+1,6	-0,21	-1,94	2,52

Table 1: The measured values for aluminum in a hot air electric furnace

L = value of gloss
a+ = value of red
a- = value of green
b+ = value of yellow
b- = value of blue
ΔE = color deviation

Convection electric - see Tab. 1 and gas kiln with direct heating achieved similar results of deviations ΔE and according the evaluation table of ISO 7724 they would be classified as clearly recognizable values for ΔE 1.5 - 3. For catalytic infrared kiln the samples with the setting 2 / speed of 1 m / min were selected for the next measuring and according to the evaluation table were categorized in recognizable value ΔE 1 to 2. According to the table these values can be considered as unsatisfactory, but the visual inspection showed no signs of color variations from white gloss, except when set to 1 / speed of 0.5 m / min in

infrared catalytic kiln where the samples of both materials were slightly yellowish and dull due to over burning. It is interesting that when using catalytic infrared kiln and aluminum sample while the settings were 1 / speed of 0.5 m / min the deviation was E = 1.53. This deviation was the smallest of the three settings but the sample was slightly yellowish and dull.

3.2 Evaluation of gloss measuring

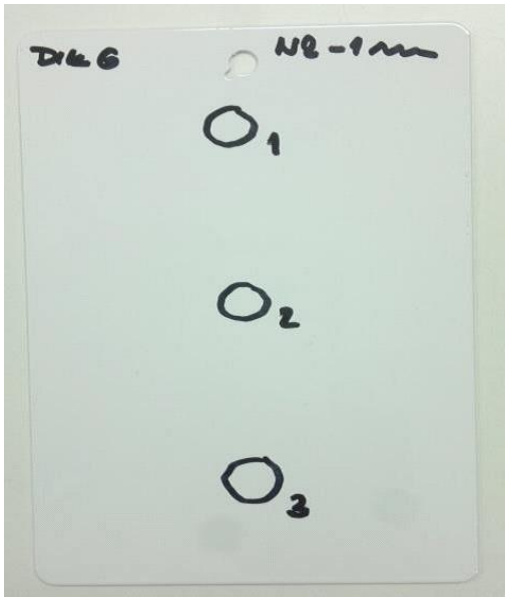

Figure 3: Areas of measurement

Sample No.	Area 1	Area 2	Area 3	diameter
1	90,1	88,1	90,1	89,4
2	90,8	87,6	93,0	90,5
3	92,1	91,2	93,5	92,3

Table 2: The measured gloss values for aluminum in a hot air electric kiln

The gloss values of all samples fit into the tolerance range of gloss values of the technical data sheet, which is 80 to 100 units. Between the kilns the range of differences are of whole units from the smallest of 88.8 and the largest of 93.2 gloss units. Among the materials the average gloss values of steel sample are 2 units greater than that of aluminum - see Fig.3 and Tab. 2.

Over burnt sample visual gloss loss was confirmed, in case of steel it is about 5 units and for aluminum about 9 gloss units below the lower limit.

3.3 Coating thickness measuring evaluation

Measuring of coating thickness was made on three samples and divided into three areas in 9 points. Each area consists of three points of measuring. The three areas are divided into upper, central and lower. The results of measuring it mostly influenced by paint application, but they are important with respect to subsequent mechanical testing. For proper and exact evaluation of tests it must be ensure the paint layer respects the manufacturer's recommendation. The coated surface on all samples conforms to the requirements of the technical sheet. To reach the mechanical qualities alleged by the manufacturer, the thickness of the paint should be in the range of 70-80 microns. The results show that no kiln causes curtaining or colors on one of the materials.

3.4 Grid test evaluation

The results of the tests are captured on the detailed photos of the grids - see Fig.4. They are used to determine suffered damage.

Figure 4: Detail of grid tests for aluminum in a hot air electric kiln

Detailed photos that all 6 samples reached the level of 0 for grid test evaluation. Sticking the technical conditions for curing required by the manufacturer which is 180 ° C for 15 minutes, the grid test failed to confirm the different influences caused by either different kilns or material.

3.5 Pull-off test evaluation

Due to the time reasons the pull-off test was carried out only once on each sample. For this reason, the test cannot be considered fully valid. In order to conform to the standards more measuring should take place. I can, however, be taken as a informational. Same as during the grid test, also during this test detailed photos of the test results were captured - see Fig. 5,6, and the result values of the adhesion strength in MPa were filled in the table - see Tab. 3.

Figure 5: Aluminum - hot gas oven with direct heating

Figure 6: Steel - hot-air gas oven with direct heating

Adhesion strength [MPa]	Convection electric furnace	Hot-air gas furnace	Infrared catalytic kiln
Aluminum	3,02	3,06	3,43
Steel	3,52	3,79	3,63

Table 3: The adhesion strength in MPa

Adhesion strength varies between different materials and the kilns. Aluminum samples in the catalytic infrared kiln with stood for approximately 0.4 MPa more than hot air oven. The samples of steel to with stood the most in the gas kiln. In comparison between materials, the steel has with the exception of the aluminum sample from catalytic infrared kiln, the values of more than 0.5 MPa better than aluminum.

The disruption of the coating occurred in three cases. In one case about 70% of A / B and two below 10% A / B. The remaining samples are reached 100% Y / Z. In kiln comparison the best results were obtained with electric kiln, which produced two samples without coating disruption. The steel material achieved better results with a single disruption of less than 10%.

3.6 Evaluation of the course record in the oven

It is apparent in the graph that the electric closed chamber kiln did not record temperature fluctuation and the temperature rise was steadier see Fig. 7 than in the gas kiln. Curing times at these ovens were identical and kept solid 180 ° C / 15 min. Catalytic infrared oven had more aggressive temperature rise and curing time was about one-fifth shorter. The test results did not show inferior qualities during fast burning.

4 CONCLUSION

The article compares the effect of the curing process on the quality of powder coating compositions. Three curing kilns and two kinds of materials were selected. Curing was performed in a hot air electric chamber kiln, hot gas passable with direct heating and past trough catalytic infrared kiln. The test materials were steel and aluminum.

Used paint and pretreatment were on all samples same. 6 tests were carried out for evaluation. After measuring the color deviation it was discovered that the smallest influence had the catalytic infrared kiln, that reached a deviation value between 1 - 1.5, while the hot air kiln values ranged from 2.3 to 2.8. Even at high value variations visually the paint kept its shade. Different material did not affect the resulting color deviation the differences are in decimal points. The gloss values of all samples are in the middle of the range stated in the technical sheet. Among the kilns the differences are in units of gloss between 89 and 93. Steel showed an average of 2 units of gloss values higher than aluminum. Over burnt test sample reached value of 10 units below the lower limit.

The coating thickness meets the requirement of the paint manufacturer, which guarantees unaffected results of mechanical tests. Measuring showed that no method of curing causes curtaining of the paint on the product, and only over burnt sample showed paint thickness loss due to burning of the powder prior to curing.

Adhesion grid test did not prove the curing process method influence. All samples have reached the level 0. This also eliminates the influence of the different materials. Adhesion pull-off test measuring did not confirm these results. The best result was reached with electric convection kiln, both of the samples reached only adhesive failure between the surface of the paint and glue.

Second best results was achieved with catalytic infrared kiln where the aluminum sample paint coat disruption was less than 10%The worst result was a hot-air gas kiln, where the aluminum sample reached paint coat disruption of 70% and the steel sample reached less than 10%.

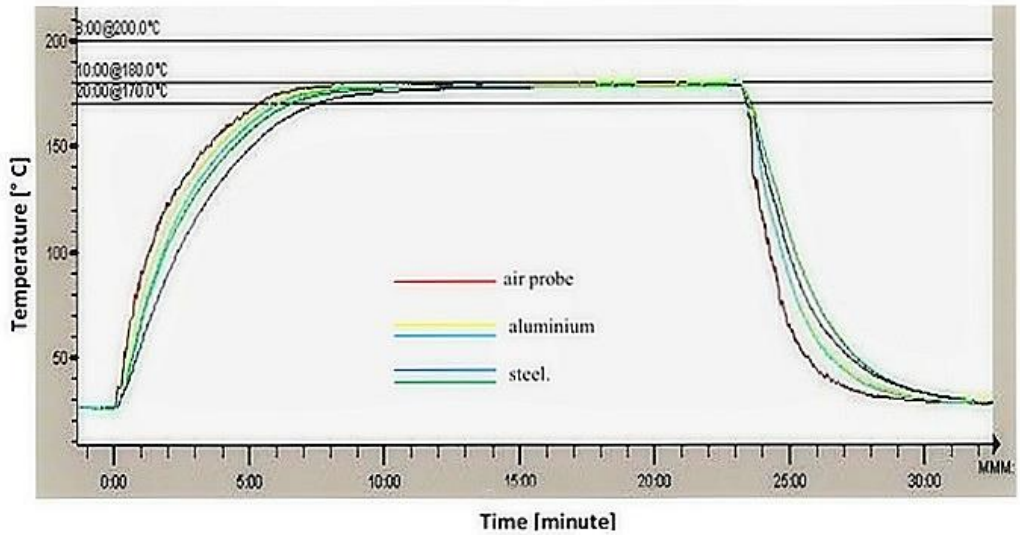

Figure 7: Convection electric kiln - temperature curve

Rive force differed among the kilns only when using aluminum sample in infrared kiln, where the value was 0.4 MPa more than in the remaining kilns. In comparison, steel material achieved better results both in paint disruption test and the pull-off test where it reached 0.5 MPa higher values than that of aluminum.

Bending test confirms the results of the pull-off test. All kilns achieved the bending guaranteed by the technical sheet. Convection electric kiln results were satisfactory in all tests with steel material. The last test with aluminum material showed slight cracks when using mandrel of 2mm in diameter. In infrared catalytic kiln the slight cracking was visible already during the second measuring. Cracking occurred also during the second measuring in the gas kiln.

The results confirmed a greater grip on samples of steel.

Temperature curves show a rapid temperature rise in the case of infrared ovens and a short curing time. The temperature curve of electric kiln keeps a temperature value thanks to the enclosed inside space.

The results clearly show the apparent influence of the kiln setting together with the conveyor. Best results were achieved with the convection chamber kiln which has a the simplest settings.

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