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DETERMINING THE SUITABILITY OF VARIOUS SURFACE TREATMENT METHODS WITH THE CONTROL OF BLASTING TIME WITH RESPECT TO THE QUALITY OF POWDER COATING

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The paper is focused on steel surface processing to ensure an improved adhesion of applied powder layer. Mechanical pre-treatment, chemical pre-treatment and their combination were used to compare their results with each other and to find out the pre-treatment that affected the final outcome the most. The final score was determined by the grid method. The outcome displayed a huge mutual dependency between the result and a kind of various surface treatments. The method with no pre-treatment was by far the worst, followed by the mechanical pre-treatment only, followed by the chemical pre-treatment only, and finally by their combination. The time of blasting affects the final outcome. Through the grid method, coating thickness, and aesthetic test it was confirmed that an optimal blasting time of 5 min provides the best outcome.

Keywords: mechanical pre-treatment; chemical pre-treatment; surface; blasting; curing; grid method

The electrostatic application of plastics, in other words powder coating, represents an extended method of surface treatment consisting of different kind of metals. Powder coating has several key advantages over liquid coating, and fine powder coating makes the surface finish quality comparable with liquid coating (Shah et al., 2006).

This technology has spread to the whole world. With its environmentally friendly production of metal parts, it is an appropriate solution especially in the environment of agricultural and forestry activities (Bulgakov et al., 2018; Zastempowski and Bochat, 2020). Among other protective material treatments, powder coating is one of the leading and most innovative segments of paints and coatings (Rustico et al., 2015). The main advantages of powder coating include its 100% recyclability, but it is very hard to reach in reality (Fu et al., 2011). Powder coating is mainly used for steel components that are exposed to corrosive or otherwise degrading environments (Badila et al., 2014; Frey et al., 2015; Prendi et al., 2015). Powder coatings are valued not only for their final aesthetic appearance but also for their protective properties, which increase the life of products, affect their functionality, and extend their applicability up to extreme conditions (Bajat et al., 2010; Pérez et al., 2002; Puig et al., 2015). There are various methods of powder coating. Clear powder coating is produced by the suspension method, which consists of a 10 µm particle size and narrow particle size distribution. This method has the advantage of excellent powder flowability and higher transfer efficiency compared to conventionally produced powder coatings (Satoh et al., 1998). In terms of corrosion, resistance needs to be enhanced by structural applications of corrosive environments (Bochon et al., 2015; Carboneras et al., 2010; Catarina et al., 2017). There are various kinds of formulations, and most of nano-zirconia coating formulations are based on hexafluorozirconic acid solutions that may contain

hexafluorosilicic acid indispensably (Ramanathan and Balasubramanian, 2016). The trajectories of smaller particles can be managed by low airflow setting so that gas flow is narrow and therefore more focused (Golgoon et al., 2018; Scrinzi and Rossi, 2010; Shah et al., 2006). A very important part of powder coating that influences the final result is the quality of powder together with coating conditions that affect film thickness and efficiency (Lothongkum et al., 2007). In terms of powder coating for the required final outcome, proper pre-treatment is absolutely important. The usage of fine powder ensures the improved surface quality at the finish (Shah et al., 2006). Adhesion measurements from the cross hatch cut and the tape test indicated that plasma surface activation definitely enhanced adhesion irrespective of the type of plastic selected, though the rank varied depending on the substrate material (Gururaj et al., 2011; Iuga et al., 2001). There are also other metals widely used in powder coating. Titanium and its alloys, which are used for healthcare such as dental or orthopaedic material, and the proper surface can be achieved by chemical treatments (Ágreda et al., 2012; Kozakiewicz et al., 2015; Mojtaba Mirabedini et al., 2002).

The common doping method is rather less suitable for direct element doping of the surface Mg alloy due to its financial demand and complexity (Cai et al., 2020; Feng et al., 2021). To support the expected outcome, it is suitable to use an adhesion promoter. The use of the adhesion promoter significantly affects the strength of both uncoated EN AW-5754 aluminium alloy adhesive joints and the adhesive joints subjected to powder coating. However, the use of the adhesion promoter has a less significant effect on cathodic-coated samples or surface sensitive analytical methods (Louati et al., 2020; Rudawska and Wahab, 2019). The failure mode was determined using surface-sensitive analytical methods. Surface treatments

using plasma-sprayed LaRC-type polyimides result in good durability, as evidenced by minimal crack growth for wedge specimens and by failure in the adhesive, which can be labelled as a cohesive failure (Dillard et al., 2006). Another approach is Taguchi method, which was used to investigate the effects of process parameters on the response and reduced number of parameters. The response surface methodology (RSM) was used for modelling the mathematical relationship between the process parameters and response, namely dry film thickness (DFT) (Barcova et al., 2006; Karaoglan and Ozden, 2021).

Blasting, also known as sandblasting, is a technological surface treatment of materials with a stream of fine particles (Puig et al., 2014; Trabelsi et al., 2006). Chemical pre-treatment has various forms such as degreasing, phosphating, or chromating. In case of chemically untreated steel, EMPA (The Swiss Federal Laboratories for Materials Science and Technology) revealed a sharp phase boundary, rimmed again by Fe-based metallic particles (Barcova et al., 2006; Louati et al., 2021).

The aim of this article is to determine the influence of surface treatment on the quality of powder coating, which is used not only in the conditions of primary production. The quality of powder coating will be determined based on measurements from the grid method, depending on the surface finish. Novelty is represented by the specific results by which the pre-treatment method has more influenced the final result in terms of surface adhesion. Furthermore, the described dependency between blasting time and final result could provide economic savings with shortening of blasting time in exchange for a little bit lower quality that can still meet specific requirements.

Material and methods

The steel rods of type h11 EN10278 that tend to be preferably used in agricultural equipment were utilized. The objective is to show a mutual dependency between the result and various surface treatments. The powder IGP-Korroprimer 30 produced from epoxy resins is an anti-corrosion powder with grain less than 100 μm , density according to shade approx. 1.5–1.6 $\text{kg}\cdot\text{dm}^{-3}$, and impact penetration less than 50.8 cm. Chemical pre-processing is made up of ferric phosphate Duridin and lasts for about 20 min. Four levels of pre-treatment methods were used. Namely, no treatment, mechanical only, chemical only, and their combination.

In terms of the grind method, final quality was evaluated in accordance with respective standard (ČSN EN ISO 2409, 2021). With a toothed hand machine, there are 6 linear furrows made and another 6 perpendicular, which lead up to 25 squares (Fig. 1). Then, the amount of adherent squares out of 25 is counted and finally associated with groups 0–5. The lower the score, the better the final outcome.

Thickness was measured using a special thickness meter POWDERTAG manufactured by TQCSheen, Ltd. (USA). Aesthetic test was made by visually and ranked from the 0 (best) to 5 (worst).

Four different blasting times of 0, 2, 5, and 15 min were used to compare the final effect. These times were chosen to create a larger variety of blasting periods that were

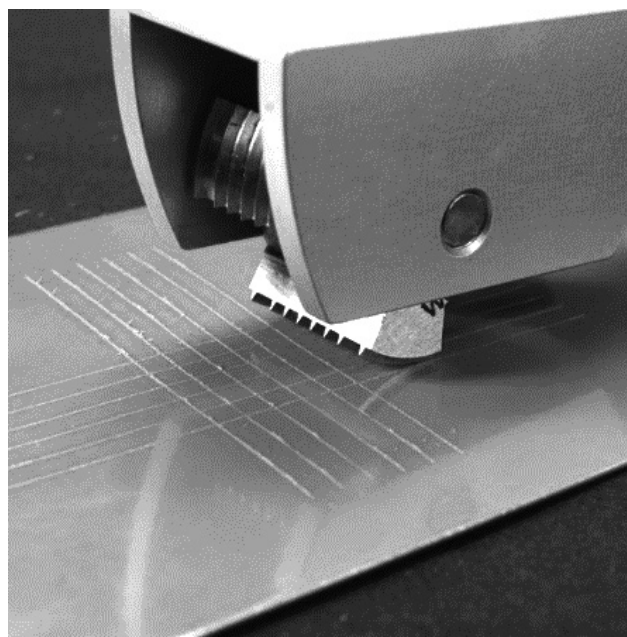


Fig. 1 Grid method

different from 5 min recommended by the manufacturer and therefore were able to compare the results properly.

Mechanical pre-treatment

The treatment responsible for this area is blasting. Within this procedure, tiny pieces of abrasive are handled towards steel rods. This process eliminates minor grime on the surface, e.g., powder residue, corrosion, etc. The blasting machine Optima New delivered by OTECO CZ, spol. s r.o. (Czech Republic) was used for measurement. The machine has 3 throwing wheels with 6 blades and an input power of 27 kW. Steel granulate S230 with a hardness of 390–530 HV was used as an abrasive.

Chemical pre-treatment

The treatment responsible for this area is degreasing. On the top of steel rods, there are oil layers that serve as a shield and prevent from corrosion. This procedure ensures the required condition of the material. The chemical pre-treatment line called the Ideal line was made by Kovofiniš, a.s. (Czech Republic) and represents a width of 1700 mm, height of 2350 mm, and length of 15000 mm, with a maximum speed of 1.6 $\text{m}\cdot\text{s}^{-1}$. In terms of powder coating purposes, any oily or dirty superficies of steel materials represents strictly inappropriate way since there is no option to ensure a powder layer. The system of chemical pre-treatment is based on warming the material of roughly 120 °C. The intended chemical medium starts to affect the steel surface after that. After the above-mentioned procedure, the selected material is without any obstacles and ready for application. The fourth technique is represented by mechanical and chemical procedure.

The application of powder coating to a pre-treated steel part is carried out in a MAJKA 1161-PDM cabin by the DATEL, s.r.o. manufacturer (Czech Republic). It is a walk-through cabin for two manual plastic application systems from both sides that are used simultaneously. In the cabin, there is air

extraction integrated with a capacity of $2.6 \text{ m}^3 \cdot \text{s}^{-1}$. Subsequently, the air returns back through the filter. Opti Flex 2B created by ITW Gema, GmbH (Switzerland) is an electrostatic manual powder coating device consisting of two integral parts – the powder coating gun Opti Flex 2GM03 and the powder coating gun control Opti Flex 2CG09.

The powder plastic MPBT FAST RED RAL 3000 by the INVER, SPA manufacturer (Italy) was used. For the optimal application of powder coating, the following parameters are necessary:

1. Total amount of air: $2.5 \text{ Nm}^3 \cdot \text{h}^{-1}$.
2. Amount of floating powder: 50%, i.e., $180 \text{ g} \cdot \text{min}^{-1}$.
3. For applying the powder to flat surfaces: voltage 80 kV, electric current 40 μA .
4. For applying the powder to inner corners: voltage 40 kV, electric current 20 μA .

The powdered part requires subsequent curing in a firing oven with a temperature of 165°C for 20 min.

The statistical calculation of the means and standard deviations of the measured parameters together with the analysis of variance (ANOVA) was carried out. ANOVA compares test variants at a significance level of $\alpha = 0.05$. The multi-criteria analysis is based on weighted arithmetic average in three different specific tests with the weights of Grid method 0.3,

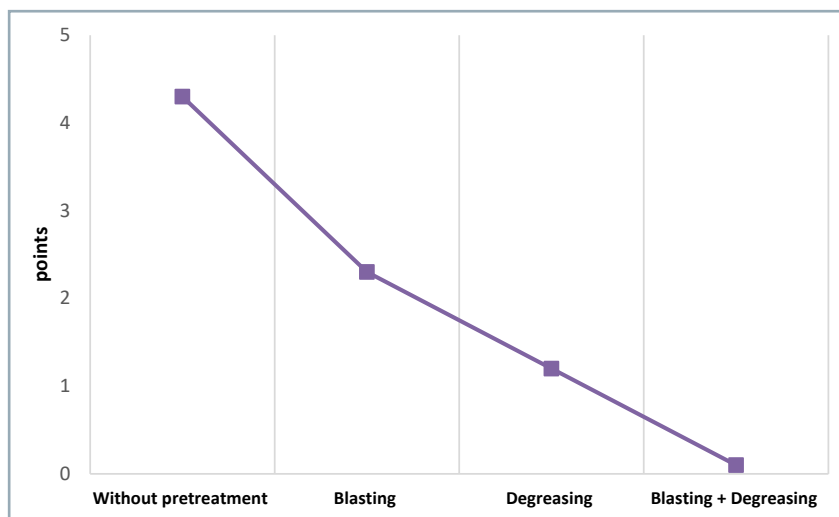


Fig. 2 Effect of the surface preparation method on the result of the grid test

Coating thickness 0.5, and Aesthetic test 0.2.

Results and discussion

Forty final outcomes (10 per each category of pre-treatment) were processed to determine the mutual dependency between the result and various surface treatments.

The evaluation of observed figures was carried out in accordance with ČSN EN ISO 2409 (2021), and points in are shown in Table 1. The lower the score, the better the final outcome. The scope is from 0 to 5.

Table 1 shows that the worst result is with no pre-treatment and average around 4.3 points. Mechanical pre-treatment reached an average around 2.3 point – still far away from acceptance. Chemical pre-treatment showed another improvement to 1.2 point. Blasting is obviously a procedure with worse results than degreasing. The final set of steel material processed by both procedures showed an average of 0.10. The fourth measurement also represents the most stable figures in terms of standard deviation of 0.32. To reach the required level of satisfaction, other parameters out of the pre-treatment surface area must also be met (Fig. 2).

Table 1 Results of significance of pre-treatment

Number of measurement	Without pre-treatment	Blasting	Degreasing	Blasting + degreasing
1	4	3	1	0
2	4	2	2	0
3	4	2	1	1
4	4	2	1	0
5	5	2	1	0
6	4	2	1	0
7	5	3	1	0
8	4	2	2	0
9	4	3	1	0
10	5	2	1	0
Average	4.3	2.3	1.2	0.1
St. deviation	0.48	0.48	0.42	0.32

Table 2 Different tests dependent on blasting time of 0, 2, 5, and 15 min

Blasting time	0 min			2 min		
Measurement number	grid method	coating thickness	aesthetic test	grid method	coating thickness	aesthetic test
1	5	90	4	1	87	0
2	5	70	4	1	79	0
3	5	89	3	2	88	0
4	5	89	3	1	87	0
5	5	73	4	2	80	0
6	5	81	3	1	75	0
7	5	81	4	1	70	0
8	5	84	3	1	77	0
9	5	74	4	1	87	0
10	5	80	3	1	70	0
Average	5	81.1	3.5	1.3	80	0
St. deviation	0	6.73	0.5	0.4	6.68	0
Variance	0	45.3	0.25	0.16	44.6	0
Blasting time	5 min			15 min		
Measurement number	grid method	coating thickness	aesthetic test	grid method	coating thickness	aesthetic test
1	0	79	0	1	86	4
2	0	70	0	1	79	3
3	0	79	0	1	89	3
4	0	70	0	1	76	3
5	0	83	0	1	75	3
6	0	73	0	1	82	4
7	0	84	0	1	88	3
8	0	80	0	2	83	4
9	0	84	0	1	73	4
10	0	75	0	1	77	4
Average	0	77.7	0	1.1	80.8	3.5
St. deviation	0	5.14	0	0.3	5.36	0.5
Variance	0	26.4	0	0.1	28.7	0.25

Sand blasting

The key factor of a sand blasting procedure is blasting time that affects the final result. The evaluation of 4 different times (0, 2, 5, and 15 min) of blasting was carried out with a focus on 3 evaluation tests. The grid method is connected with adhesion and shows a recalculated amount of square badly burnt out on the scale from 0 (the best) to 5. The second criterion is coating thickness that must be between 70 μm and 90 μm . An aesthetic test reports an appearance of powder with a scale from 0 (the best) to 5. Find below Tables 2, 3 and Figs 3, 4, 5.

The comparison of thicknesses by the ANOVA method shows no significant differences between the files.

The multi-criteria analysis carried out with weighted averages in three different tests with the weights of grid method 0.3, coating thickness 0.5, and aesthetic test 0.2 showed that the blasting time 5 min provided the best

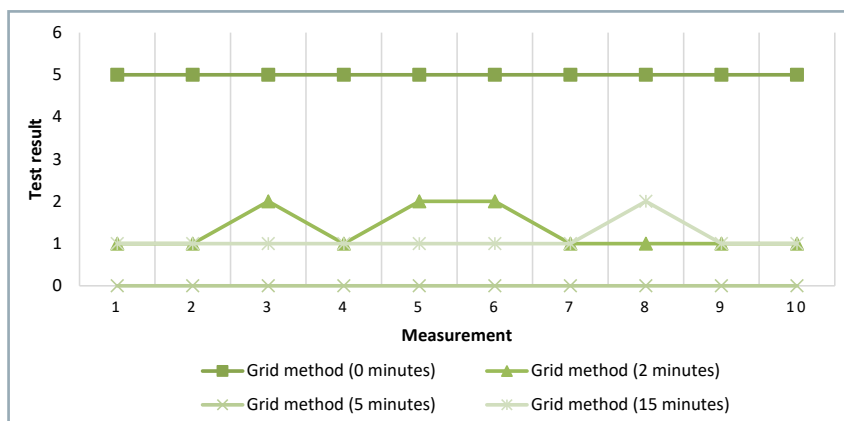
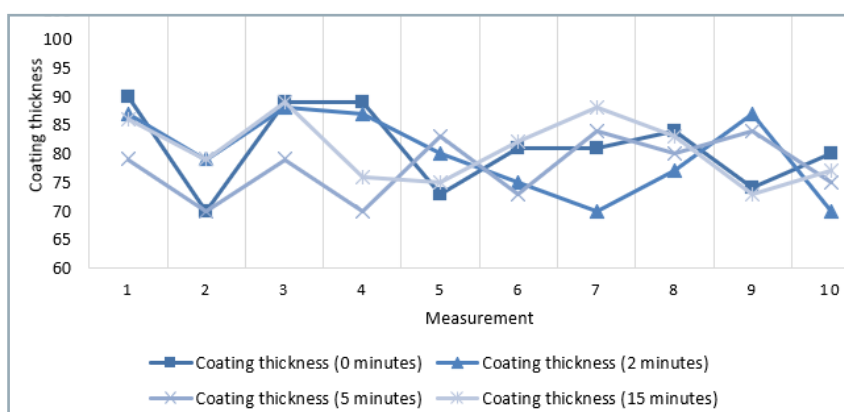
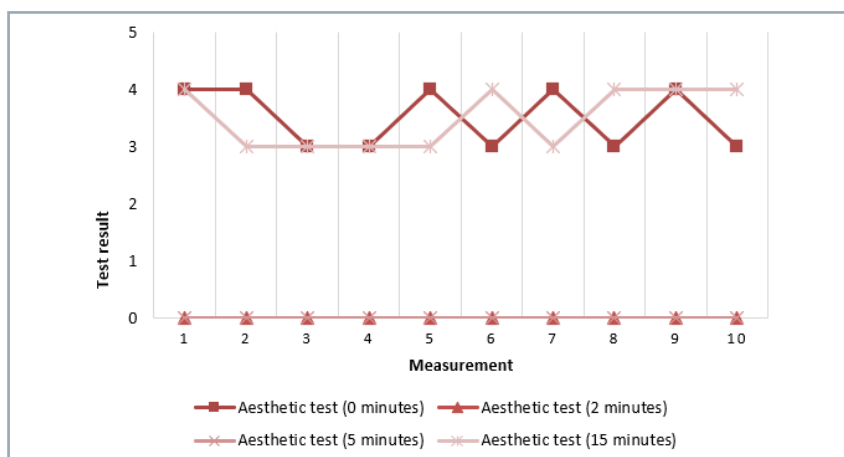
results. The points range from the best 0 to the worst 5 in all the three specific tests. Coating thickness was divided into 3 categories 70–73, 87–90; 74–77, 84–86, and 78–83 μm sorted by proximity to an ideal of 80 μm .

Blasting time has obviously an influence especially in terms of the grid method. There is an insufficient result (5 points) without blasting. The results have significantly improved towards point 1 when the time period rose to 2 or 15 min. The best result with point 0 was achieved with 5 min of blasting. Blasting period did not affect the powder width. Regarding the aesthetic test, the blasting time of 15 or 0 min led to the worse result of 3.5 points, whilst the blasting time of 2 or 5 min reached point 0. The key assumption for a well-managed process of powder coating is a high quality of pre-treatment.

Surfaces intended for the application of plastics are often contaminated due to previous technological operations.

Table 3 Multi-criteria analysis calculated based on weighted average (the lower the points the better)

Blasting time	0 min	2 min	5 min	15 min
	weighted average points	weighted average points	weighted average points	weighted average points
Grid method	1.50	0.36	0	0.33
Coating thickness	0.60	0.7	0.45	0.50
Aesthetic test	0.70	0	0	0.70
Sum	2.80	1.06	0.45	1.53

**Fig. 3** Effect of the blasting period on the grid test result**Fig. 4** Effect of the blasting period on the coating thickness result**Fig. 5** Effect of the surface preparation method on the aesthetic test result

Only an appropriately chosen form of pre-treatment guarantees the removal of these unwanted impurities from the surface of the material. Insufficient pre-treatment is a cause of low adhesion, the formation of blisters, and early under-corrosion of coating (Cong and Fellner, 1993; Karaoglan and Ozden, 2021; Mirabedini et al., 2002). Mechanical pre-treatment improves adhesion conditions (Blažek, 2009). According to Klimeš (2003), blasting leads to impurity removal. Depending on the nature of the material and the degree of contamination, a suitable abrasive is selected. Most often, metal granulate with a grain size of 0.4 mm to 0.8 mm is selected (Mohyla, 2006). Chemical pre-treatment is a suitable medium in relation to the nature of the material much more complicated than the mechanical one. One of the most utilized methods is degreasing (Withy et al., 2006).

Conclusion

Based on the measurement, a robust dependency between the pre-treatment type and the final quality of the steel material is visible. Without any pre-treatment, the grid method (the lower the number the better) showed by far worse results represented by an average of 4.3 points. With mechanical pre-treatment, the average improved to 2.3 points only, however, still far away from the required figures. Chemical pre-treatment represented even better results with an average of 1.2. Finally, their combination revealed the best way with an average of 0.1 and provided nearly flawless results.

The best option is thus a combination of both pre-treatments, followed by chemical pre-treatment, then mechanical pre-treatment, and finally with no pre-treatment.

In terms of blasting, the grid method confirmed the best blasting

time of 5 min, averaged by 0. As for the aesthetic test (the lower the number the better), the optimal time of blasting is also 5 min, but 0 and 15 min showed very bad figures averaging around 3.5.

However, coating thickness is not affected by the time of blasting, oscillating between targeted 70 µm and 90 µm. Thus, it is not confirmed that longer blasting time leads to better final result.

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References

- ÁGREDA, C. G. – MENDES, M. W. D. – BRESSIANI, J. C. – BRESSIANI, A. H. A. 2012. Apatite coating on titanium samples obtained by powder metallurgy. In *Advances in Science and Technology*, vol. 86, pp. 28–33. DOI: <https://doi.org/10.4028/WWW.SCIENTIFIC.NET/AST.86.28>
- BADILA, M. – JOCHAM, C. – ZHANG, W. – SCHMIDT, T. – WUZELLA, G. – MÜLLER, U. – KANDELBAUER, A. 2014. Powder coating of veneered particle board surfaces by hot pressing. In *Progress in Organic Coatings*, vol. 77, no. 10, pp. 1547–1553. DOI: <https://doi.org/10.1016/j.porgcoat.2013.09.018>
- BAJAT, J. B. – POPIĆ, J. P. – MIŠKOVIĆ-STANKOVIĆ, V. B. 2010. The influence of aluminium surface pretreatment on the corrosion stability and adhesion of powder polyester coating. In *Progress in Organic Coatings*, vol. 69, no. 4, pp. 316–321. DOI: <https://doi.org/10.1016/j.porgcoat.2010.07.004>
- BARCOVA, K. – MASHLAN, M. – ZBORIL, R. – FILIP, J. – PODJUKLOVA, J. – HRABOVSKA, K. – SCHAAF, P. 2006. Phase composition of steel-enamel interfaces: Effects of chemical pre-treatment. In *Surface and Coatings Technology*, vol. 201, no. 3–4, pp. 1836–1844. DOI: <https://doi.org/10.1016/J.SURFCOAT.2006.03.015>
- BLAŽEK, J. 2009. Optimization of Curing Temperature in Powder Coating. 68 pp. Diploma thesis. Brno University of Technology. Available at: <http://dspace.vutbr.cz/handle/11012/5233> (In Czech: Optimalizace teploty vytvrzování při práškovém lakování)
- BOCHON, I. – KARETH, S. – KILZER, A. – PETERMANN, M. 2015. Synthesis and powder generation of powder coatings using supercritical carbon dioxide. In *The Journal of Supercritical Fluids*, vol. 96, pp. 324–333. DOI: <https://doi.org/10.1016/j.supflu.2014.09.042>
- BULGAKOV, V. – FINDURA, P. – KROČKO, V. – NOZDROVICKÝ, L. – KORENKO, M. – KUVACHOV, V. 2018. Experimental study of operational properties of two-machine drilling aggregate. In *Acta Technologica Agriculturae*, vol. 21, no. 2, pp. 81–86. DOI: <https://doi.org/10.2478/ATA-2018-0015>
- CAI, Y. – WANG, X. – WAN, L. – YANG, J. – GAO, Y. 2020. Preparation of antimony-doped stannate chemical conversion coating on AZ31B Mg alloy. In *Transactions of the Indian Institute of Metals*, vol. 73, pp. 1891–1898. DOI: <https://doi.org/10.1007/s12666-020-01996-8>
- CARBONERAS, M. – HERNÁNDEZ, L. S. – DEL VALLE, J. A. – GARCÍA-ALONSO, M. C. – ESCUDERO, M. L. 2010. Corrosion protection of different environmentally friendly coatings on powder metallurgy magnesium. In *Journal of Alloys and Compounds*, vol. 496, no. 1–2, pp. 442–448. DOI: <https://doi.org/10.1016/J.JALLCOM.2010.02.043>
- CATARINA, G. A. S. – BORSOI, C. – ROMANZINI, D. – PIAZZA, D. – KUNST, S. R. – SCIENZA, L. C. – ZATTERA, A. J. 2017. Development of acrylic-based powder coatings with incorporation of montmorillonite clays. In *Journal of Applied Polymer Science*, vol. 134, no. 27, article no. 45031. DOI: <https://doi.org/10.1002/APP.45031>
- CONG, P. K. – FELLNER, P. 1993. Influence of the Pretreatment of Silicon Powder by Electroless Nickel Coating on Its Codeposition with Nickel. In *Chemical Papers*, vol. 48, no. 5, pp. 326–329. Available at: https://chempap.org/file_access.php?file=485a326.pdf
- ČSN EN ISO 2409: 2021. Coating materials – Grid test. (In Czech: Nátěrové hmoty – Mřížková zkouška)
- DILLARD, J. G. – JACKSON, F. R. – HOLMES, B. L. – AARTUN, L. – PARVATAREDDY, H. – DILLARD, D. A. – ZATORSKI, R. 2006. The durability of adhesively-bonded titanium: performance of plasma-sprayed polymeric coating pretreatments. In *The Journal of Adhesion*, vol. 65, no. 1–4, pp. 217–238. DOI: <https://doi.org/10.1080/00218469808012247>
- FENG, Y. – YANG, H. – YANG, Z. – HU, C. – WU, C. – WU, L. 2021. A review of the design, properties, applications, and prospects of Ni-based composite powders. In *Materials & Design*, vol. 208, article no. 109945. DOI: <https://doi.org/10.1016/J.MATDES.2021.109945>
- FREY, M. – ÉDOUARD, D. – ROGER, A. C. 2015. Optimization of structured cellular foam-based catalysts for low-temperature carbon dioxide methanation in a platelet milli-reactor. In *Comptes Rendus Chimie*, vol. 18, no. 3, pp. 283–292. DOI: <https://doi.org/10.1016/J.CRCI.2015.01.002>
- FU, J. – KRANTZ, M. – ZHANG, H. – ZHU, J. – KUO, H. – WANG, Y. M. – LIS, K. 2011. Investigation of the recyclability of powder coatings. In *Powder Technology*, vol. 211, no. 1, pp. 38–45. DOI: <https://doi.org/10.1016/J.POWTEC.2011.03.016>
- GOLGOON, A. – ALIOFKHAZRAE, M. – TOORANI, M. 2018. Nanocomposite protective coatings fabricated by electrostatic spray method. In *Protection of Metals and Physical Chemistry of Surfaces*, vol. 54, pp. 192–221. DOI: <https://doi.org/10.1134/S207020511802017X>
- GURURAJ, T. – SUBASRI, R. – RAJU, K. R. C. S. – PADMANABHAM, G. 2011. Effect of plasma pretreatment on adhesion and mechanical properties of UV-curable coatings on plastics. In *Applied Surface Science*, vol. 257, no. 9, pp. 4360–4364. DOI: <https://doi.org/10.1016/J.APSUSC.2010.12.060>
- IUGA, A. – MORAR, R. – SAMUILA, A. – DASCALESCU, L. 2001. Electrostatic separation of metals and plastics from granular industrial wastes. In *IEE Proceedings: Science, Measurement and Technology*, vol. 148, no. 2, pp. 47–54. DOI: <https://doi.org/10.1049/IP-SMT:20010356>
- KARAOGLAN, A. D. – OZDEN, E. 2021. Electrostatic powder coating process optimisation by implementing design of experiments. In *Transactions of the IMF*, vol. 99, no. 1, pp. 46–52. DOI: <https://doi.org/10.1080/00202967.2020.1846349>
- KOZAKIEWICZ, J. – OFAT, I. – TRZASKOWSKA, J. – KUCZYŃSKA, H. 2015. Studies on silicone-acrylic hybrid aqueous dispersions and corresponding silicone-acrylic nanopowders designed for modification of powder coatings and plastics: Part II – Effect of modification with silicone-acrylic nanopowders and of composition of silicone resin contained in those nanopowders on properties of epoxy-polyester and polyester powder coatings. In *Progress in Organic Coatings*, vol. 78, pp. 419–428. DOI: <https://doi.org/10.1016/j.porgcoat.2014.01.010>
- KLIMEŠ, L. 2003. About the history and production of powdered plastics. In *Surface Coatings*, vol. 2003, no. 3, pp. 18–19. (In Czech: O historii a výrobě práškových plastů)
- LOTHONGKUM, A. W. – NONTAPONE, R. – SEANGKIATYUTH, K. – TANTHAPANICHKOON, W. 2007. Powder characteristics and coating conditions of fresh and reused polyester resins for electrostatic powder coating: powder recycling and loss prevention. In *Advanced Powder Technology*, vol. 18, no. 2, pp. 175–186. DOI: <https://doi.org/10.1163/156855207780208664>
- LOUATI, H. – TILMATINE, A. – OUIDDIR, R. – ALIBIDA, A. – ZOULOZOU, N. 2020. New separation technique of metal/polymer granular

- materials using an electrostatic sorting device. In *Journal of Electrostatics*, vol. 103, article no. 103410. DOI: <https://doi.org/10.1016/j.elstat.2019.103410>
- LOUATI, H. – ZOUZOU, N. – TILMATINE, A. – ZOUAGHI, A. – OUIDDIR, R. 2021. Experimental investigation of an electrostatic adhesion device used for metal/polymer granular mixture sorting. In *Powder Technology*, vol. 391, pp. 301–310. DOI: <https://doi.org/10.1016/j.powtec.2021.06.019>
- MOHYLA, M. 2006. *Technology of Surface Treatment of Metals*. 3rd ed. Ostrava : VSB – Technical University of Ostrava, 150 pp. ISBN 80-248-1217-7. (In Czech: *Technologie povrchových úprav kovů*)
- MIRABEDINI, S. M. – MORADIAN, S. – SCANTLEBURY, J. D. – THOMPSON, G. E. 2002. The role of interfacial layers on the performance of an epoxy/polyester powder coated aluminium alloy. In *Iranian Polymer Journal*. In *Iranian Polymer Journal*, vol. 11, pp. 167–176.
- PÉREZ, C. – COLLAZO, A. – IZQUIERDO, M. – MERINO, P. – NÓVOA, X. R. 2002. Comparative study between galvanised steel and three duplex systems submitted to a weathering cyclic test. In *Corrosion Science*, vol. 44, no. 3, pp. 481–500. DOI: [https://doi.org/10.1016/S0010-938X\(01\)00070-1](https://doi.org/10.1016/S0010-938X(01)00070-1)
- PRENDI, L. – MILLS, M. – BASTIEN, J. – HENSHAW, P. 2015. Thermosetting powder coatings: Finish appearance and durability at cure window corner points. In *Progress in Organic Coatings*, vol. 78, pp. 411–418. DOI: <https://doi.org/10.1016/j.PORGCOAT.2014.01.025>
- PUIG, M. – CABEDO, L. – GRACENEA, J. J. – JIMÉNEZ-MORALES, A. – GÁMEZ-PÉREZ, J. – SUAY, J. J. 2014. Adhesion enhancement of powder coatings on galvanised steel by addition of organo-modified silica particles. In *Progress in Organic Coatings*, vol. 77, no. 8, pp. 1309–1315. DOI: <https://doi.org/10.1016/j.porgcoat.2014.03.017>
- PUIG, M. – CABEDO, L. – GRACENEA, J. J. – SUAY, J. J. 2015. The combined role of inhibitive pigment and organo-modified silica particles on powder coatings: Mechanical and electrochemical investigation. In *Progress in Organic Coatings*, vol. 80, pp. 11–19. DOI: <https://doi.org/10.1016/j.PORGCOAT.2014.11.014>
- RAMANATHAN, E. – BALASUBRAMANIAN, S. 2016. Synthesis and characterization of hexafluorozirconic acid powder and its application in nanoceramic coating. In *Surface and Coatings Technology*, vol. 304, pp. 228–236. DOI: <https://doi.org/10.1016/j.SURFCOAT.2016.07.009>
- RUDAWSKA, A. – WAHAB, M. A. 2019. The effect of cataphoretic and powder coatings on the strength and failure modes of EN AW-5754 aluminium alloy adhesive joints. In *International Journal of Adhesion and Adhesives*, vol. 89, pp. 40–50. DOI: <https://doi.org/10.1016/j.IJADHADH.2018.11.005>
- RUSTICO, E. Z. – MATIAS, A. C. – GREPO, L. C. 2015. Manpower utilization in the powder coating production of a powder coating company. In *Procedia Manufacturing*, vol. 3, pp. 332–339. DOI: <https://doi.org/10.1016/J.PROMFG.2015.07.166>
- SATOH, H. – HARADA, Y. – LIBKE, S. 1998. Spherical particles for automotive powder coatings. In *Progress in Organic Coatings*, vol. 34, no. 1–4, pp. 193–199. DOI: [https://doi.org/10.1016/S0300-9440\(97\)00116-1](https://doi.org/10.1016/S0300-9440(97)00116-1)
- SCRINZI, E. – ROSSI, S. 2010. The aesthetic and functional properties of enamel coatings on steel. In *Materials & Design*, vol. 31, no. 9, pp. 4138–4146. DOI: <https://doi.org/10.1016/j.matdes.2010.04.030>
- SHAH, U. – ZHANG, C. – ZHU, J. 2006. Comparison of electrostatic fine powder coating and coarse powder coating by numerical simulations. In *Journal of Electrostatics*, vol. 64, no. 6, pp. 345–354. DOI: <https://doi.org/10.1016/J.ELSTAT.2005.09.001>
- TRABELSI, W. – TRIKI, E. – DHOUIBI, L. – FERREIRA, M. G. S. – ZHELUDKEVICH, M. L. – MONTEMOR, M. F. 2006. The use of pre-treatments based on doped silane solutions for improved corrosion resistance of galvanised steel substrates. In *Surface and Coatings Technology*, vol. 200, no. 14–15, pp. 4240–4250. DOI: <https://doi.org/10.1016/j.surfcoat.2005.01.044>
- WITHY, B. – HYLAND, M. – JAMES, B. 2006. Pretreatment effects on the surface chemistry and morphology of aluminium. In *International Journal of Modern Physics B*, vol. 20, no. 25–27, pp. 3611–3616. DOI: <https://doi.org/10.1142/S0217979206040076>
- ZASTEMPOWSKI, M. – BOCHAT, A. 2020. Gyroscopic effect in machine working assemblies. In *Acta Technologica Agriculturae*, vol. 23, no. 1, pp. 24–29. DOI: <https://doi.org/10.2478/ATA-2020-0005>

