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Economic corrosion protection – Powder on powder in a single stoving process

Introduction

Due to being solvent-free powder coatings play an increasing role in industrial coating. In 2010, an increase of 12,8 % of the coating powder production volume was determined compared to 2009. [1] The starting point for the work carried out so far is the partially still insufficient corrosion protection of powder coatings on edges.

Figure 1: Cutting-edge corrosion on a powder-coated exhauster cap edge thinning of the coating [2]

One possibility for improving the corrosion protection of powder coatings on cutting edges is the application of powder coatings with good edge-covering properties. Smoothly levelling powder coatings with high gloss degrees (degree of gloss 60° > 70) basically have low and textured powder coatings have good edge-covering properties, see Figure 2 and Figure 3.

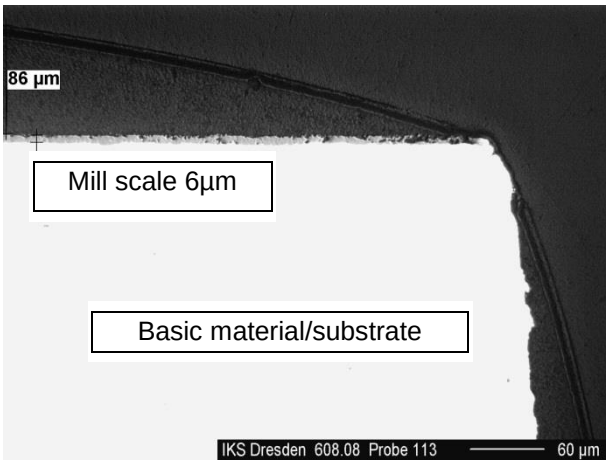

Figure 2: Film thickness of a polyester resin powder coating on cutting edge on unprepared steel sheet, gloss degree of the powder coating (60°) > 80

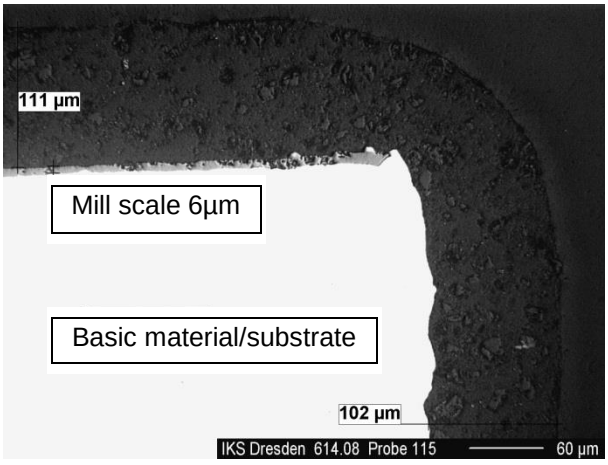

Figure 3: Film thickness of a polyester resin powder coating on cutting edge on unprepared steel sheet, fine-texture powder

Certain applications, however, require smoothly levelling powder coatings with high gloss degree and simultaneously good edge covering. This is in opposition to the material properties of smooth powder coatings. The high gloss degree of powder coatings after stoving is achieved by the low viscosity and the levelling during melting and film formation when the powder is exposed to temperature during stoving. This leads to the heavy edge thinning of the coating, resulting in problems in regard to corrosion protection.

The problem of the partially insufficient edge-covering properties of smooth powder coatings has been known for several years. The examination results published by *Pietschmann, J. E. et al* in 1990 showed that the relevant variables regarding edge thinning are the surface tension and the melting viscosity of the liquid coating, see Figure 4. [5]

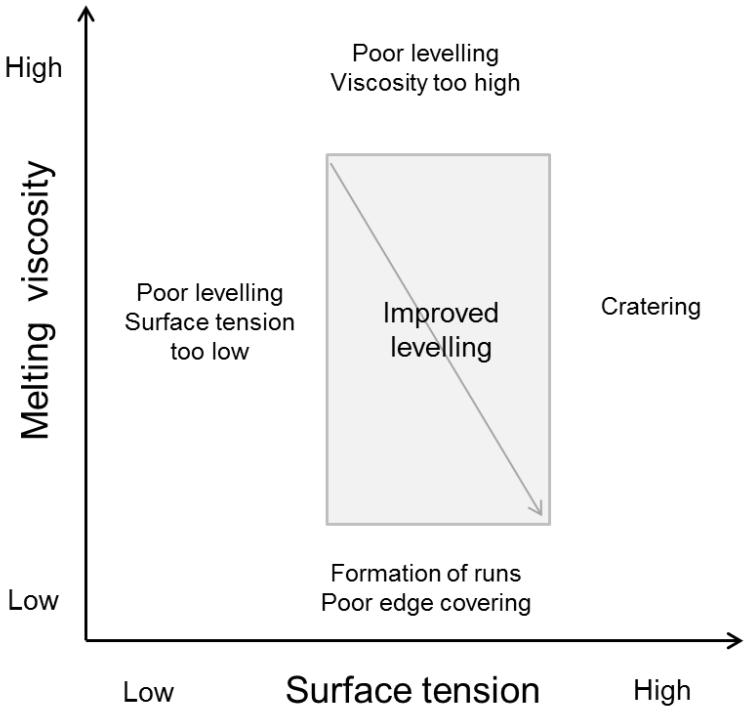

Figure 4: The surface quality of a powder coating as a function of surface tension and melting viscosity [3, 5]

A possible starting point could be the application of an additional edge-protection powder or of a primer powder. In practice, this variation is known and state-of-the-art. For increased corrosion protection requirements, corrosivity categories C3, high durability, and higher, two-layer powder coatings are recommended, see Figure 5.

Nr	Oberflächen-vorbereitungs-grad[a]	Grundbeschichtung(en)			Deckbeschichtung(en)			Beschichtungssystem		Schutzdauer nach DIN EN ISO 12944-1 Korrosivitätskategorie													
		Binde-mittel	Anzahl der Schichten	NDFT µm	Binde-mittel	Anzahl der Schichten	NDFT µm	Anzahl der Schichten	NDFT gesamt µm	C2			C3			C4			C5-I			C5-M		
										L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
P1.1	Sa 2 ½	EP	1	80	—	—	—	1	80														
P1.2	Sa 2 ½	—	—	—	EP/SP, SP, PUR	1	80	1	80														
P1.3	Sa 2 ½		—	—		2	60	2	120														
P1.4	Sa 2 ½	EP	1	60		1	60	2	120														
P1.5	Sa 2 ½		1	80		1	80	2	160														
P1.6	Sa 2 ½		1 bis 2	100		1	80	2 bis 3	180														

[A] Alternative, in gleicher Weise geeignete Vorbereitungs- und Vorbehandlungsverfahren sind zulässig.

Figure 5: Table A.1 Examples for powder coating systems on unalloyed and low-alloy steel [4]

Deficits of conventional two-layer powder coatings

The production of two-layer powder coatings is a serial or successive process. That means, that stoving, often referred to as pre-gelling, follows the application of the primer powder, subsequently the same working steps are carried out for the top powder. In regard to discontinuous stoving of the powder layers by means of a box furnace as well as regarding continuous stoving of the powder layers in a continuous furnace the building component must go through the stoving process of the powder coating twice, which is uneconomical (cost-intensive).

Additionally, in regard to the usual procedure for two-layer application including two stoving processes it is not always secured that good edge covering is achieved with the powder coating, see Figure 6.

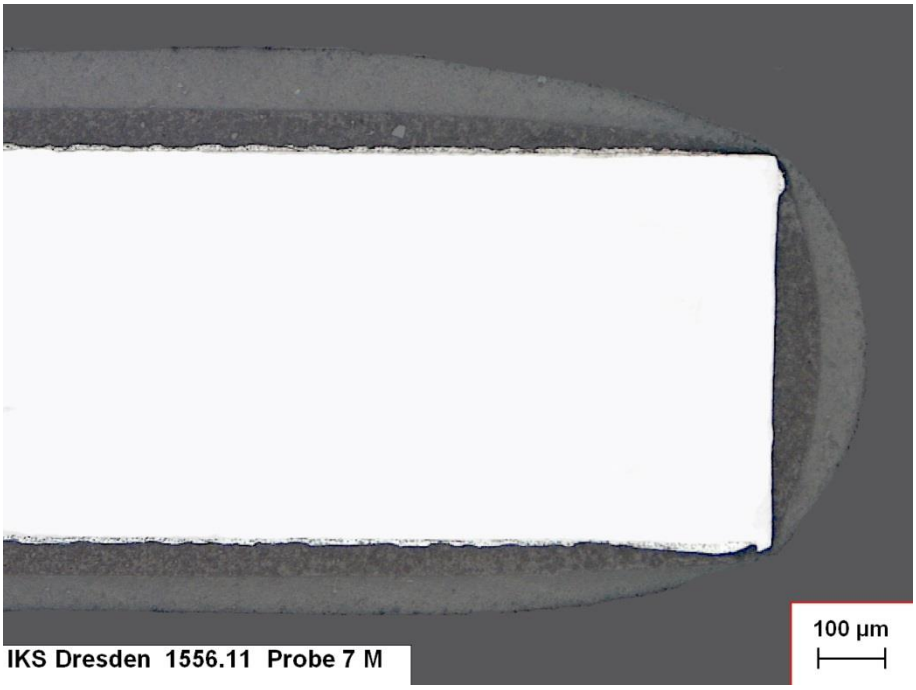

Figure 6: Low edge covering of a two-layer powder coating on galvanized steel sheet (epoxy resin primer powder + polyester resin top powder)

The new product and process technology shall require only one stoving process, in which two powder layers (powder on powder) are applied successively, which have different properties. The primer powder shall have good edge-covering properties, the top powder shall be glossy having a gloss degree, if required, of above 70 units (60°), see Figure 7.

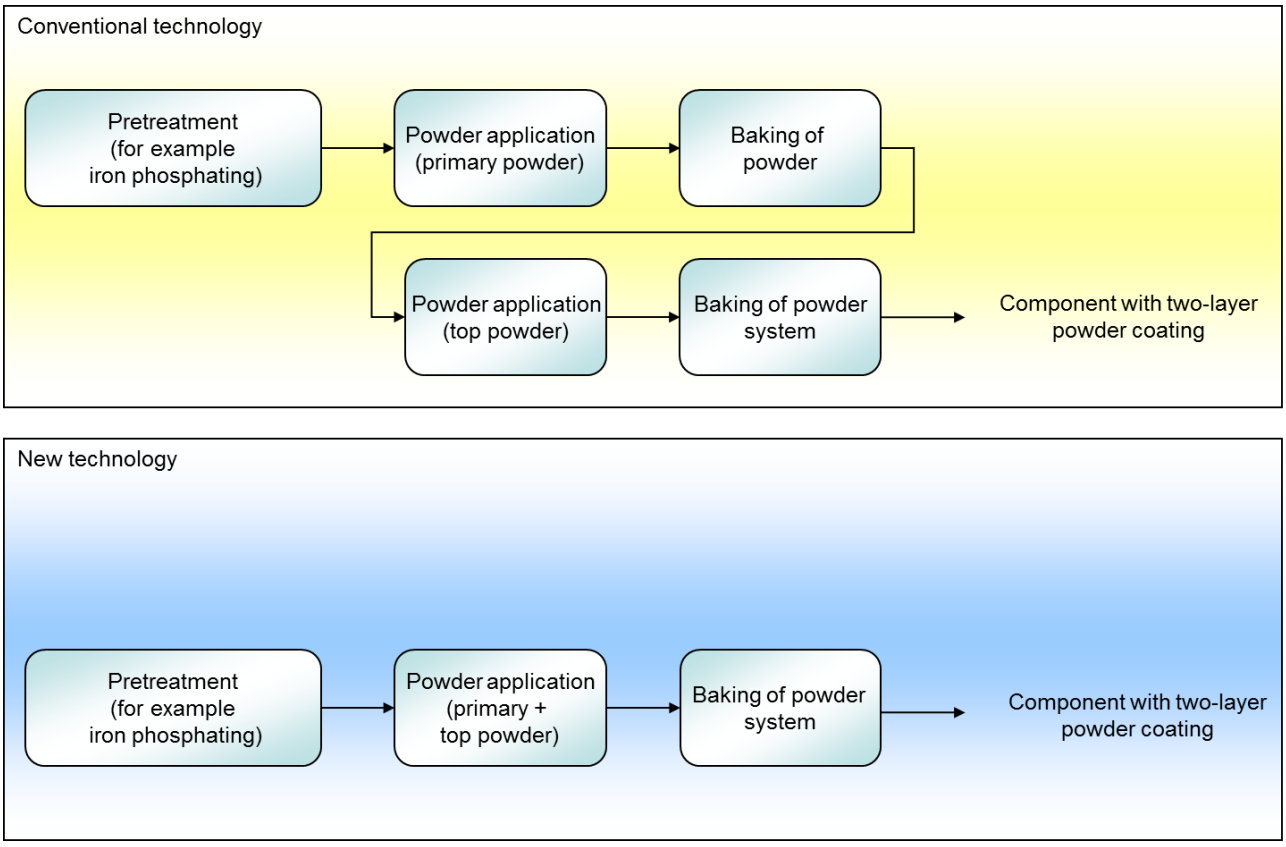

Figure 7: Process steps during powder coating, top: conventional technology, bottom: new technology

Necessity for the process variation powder on powder

Solely the increase of the powder film thickness is – at least in regard to a glossy powder coating – not sufficient in order to achieve sufficient edge covering, especially on sharp cutting edges. Therefore, the glossy powder coating must be “lined” by using a suitable primer powder so that the edge thinning of the glossy top powder is inhibited.

Opposed to the conventional technology of producing two-layer powder coatings by means of the doubled process of application and hardening the objective behind the method to be developed is to profit from the advantages of a two-layer powder coating with only a single stoving process by means of the application of powder on powder with a single, downstream stoving zone. This procedure variation is highly cost-effective.

(Pre)conditions for the powder-on-powder technology

In order to solve the problem, generally, primer powder and top powder have to be compatible; in detail, the following shall apply:

1. The primer powder and the top powder shall be successively applicable in sufficient film thickness in the procedure variation powder on powder. In automatic powder application plants, so-called powder centres, problems can occur due to powder contamination.
2. During hardening or during film formation in the furnace both of the powder layers shall not mix too intensely so that the colour and the weather-resistant properties of the top coating are not impaired.
3. No misses, due to wetting interferences or caused by water separation when using HAA cross-linking polyester resins, shall be detectable in the coating film of the top powder.
4. Sufficient adhesion shall exist between primer powder and top powder after stoving (no adhesion failure).
5. The edge thinning of the coating in the context of the new method combination shall be low. The edge-covering property shall be significantly better than for the standard variation.

Consideration of different application methods

Extensive application tests for the selection of suitable methods or method combinations for the powder application have been carried out in the laboratory. A combination of electrostatic charging for the primer powder and Tribo-charging for the top powder emerged as being particularly suitable.

Results of application tests

For a selected powder combination of primer powder and top powder plane steel-sheet test specimens have been powder-coated in consideration of the application methods mentioned above and, subsequently, have been stoved once, as described. For the selected powder combination it appeared that the following single layers shall be complied with:

- Primer powder: 40-60µm
- Top powder: 100-120µm

After stoving, these film thicknesses can be measured, for example destructively by means of wedge-cut tests. For the exact determination of the single film thicknesses for the primer powder as well as for the top powder metallographic cross-sections were prepared, see Figure 8.

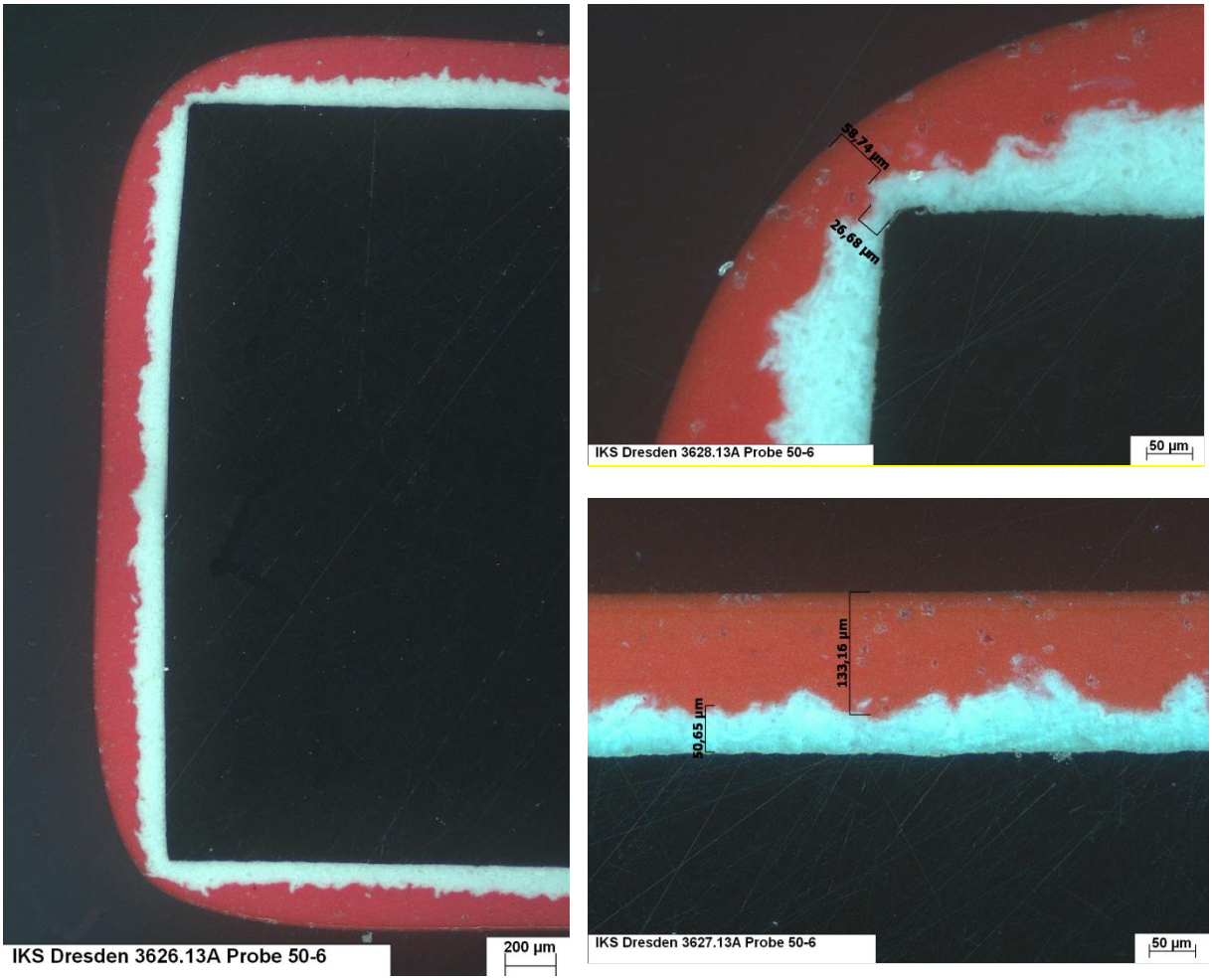

Figure 8: Metallographic cross-section of test specimen 50-6

Beside the single layers of the primer powder and the top powder a certain mixing zone of both of the powder coating layers is detectable on the cross-section images illustrated above. This mixing zone significantly differs from the exactly confined interface between primer powder and top powder in the context of conventional application.

During comparative infrared-spectroscopic examinations on the top powder, however, no contamination due to priming-coat matter was detectable. Simple mixing tests and application tests showed, however, that even the slightest amounts of primer powder (0,1 mass%) are visible in the top powder after stoving.

In regard to the powder-on-powder test specimens a slight surface imperfection/matting of the top powder appeared in the top view at certain angles. This matting is most likely to be measured by means of gloss measurements at an angle of 20°, see Table 1.

Table 1: Results of gloss and colour measurements

Test specimen	**Characterization**	**Gloss measurement**		**Colour measurement**		
		20°	***60°***	***L***	***a***	***b***
E1	Reference (single-layer)	59,8	89,6	40,5	41,3	23,4
E10	Powder-on-powder test specimen	45,9	85,2	41,0	43,5	24,0

Corrosion protection properties of two-layer powder coatings

For the assessment of the corrosion protection properties of two-layer powder coatings in accordance with the conventional as well as “powder-on-powder” application methods stress tests in accordance with DIN 55633 and DIN EN ISO 12944-6 have been carried out. Due to the applied film thicknesses the stress application conditions of corrosivity category C4, high durability, have been selected as follows:

- Neutral salt spray in accordance with DIN EN ISO 9227 NSS, duration of stress application: 720h (with scratch)
- Water-vapour condensation in accordance with DIN EN ISO 6270, duration of stress application: 480h

A two-layer powder coating consisting of epoxy resin primer powder plus polyester resin top powder was used as conventional powder coating variation. Both of the powder films have been successively applied and stoved. For the “powder-on-powder” variation a powder coating variation, optimized by extensive tests, was selected, consisting of an epoxy-resin polyester mixed powder as primer powder and a polyester resin top powder. Due to the different binder basis of the primer powders of both variations no direct comparison of the test results is possible, however, the results of the stress tests can be neutrally evaluated. In order to determine the direct influence of the preparation method on the stress test results, currently stress tests are still carried out using the epoxy-resin polyester mixed powder as primer powder plus polyester resin top powder, however, conventionally applied and stoved successively, see Table 2.

Table 2: Distribution of the test specimens for stress application and testing

Application	Samples	Substrate	Primer powder		Top powder		Stress application	tests before stress application	tests after stress application
			Method of application	Stoving conditions	Method of application	Stoving conditions			
conventional	E3	DC01 blasted	GR-7035-GL410 Corona	180°C / 20min	FA-3478-GL422 Corona	180°C / 20min	Reference sample	Gloss measurement 20° / 60°, Cross-cut, Pull-off adhesion test	x
	E4, E5, E6						DIN EN ISO 9227 NSS (C4 high, 720h)	visually	visually, Cross-cut (immediately, 24h), corrosion and delamination at the scribe, Pull-off adhesion test
	E7, E8, E9						DIN EN ISO 6270 condensation of water vapour (C4 high, 480h)	visually	visually, Cross-cut (immediately, 24h), Pull-off adhesion test
Powder on Powder	E28	DC01 blasted	ML-7032-MA315 Corona	-	FA-3478-GL422 Tribo	180°C / 20min	Reference sample	Gloss measurement 20° / 60°, Cross-cut, Pull-off adhesion test	x
	E29, E33, E38						DIN EN ISO 9227 NSS (C4 high, 720h	visually	visually, Cross-cut (immediately, 24h), corrosion and delamination at the scribe, Pull-off adhesion test
	E39, E40, E42						DIN EN ISO 6270 condensation of water vapour (C4 high, 480h)	visually	visually, Cross-cut (immediately, 24h), Pull-off adhesion test

The powder coatings of the unstressed reference test specimens showed good adhesion values for both variations. After stress application no abnormalities in the form of cracking, rust breakthroughs of the coating, and blistering were found on the examined powder coatings. Also the cross-cut test resulted in the cross-cut value Gt 0 (very good), with one exception (Gt 3 for a powder-on-powder test specimen after water-vapour condensation). In comparison to corrosion protection coatings, on powder coatings mostly very high adhesion values are achieved during pull-off tests when selecting a

suitable adhesive (two-component epoxy-resin adhesive) and a good surface preparation of the metal surface prior to powder coating. The adhesion values range from approx. 17 to 25 MPa, with mostly minor differences in regard to the failure pattern. Only after the continuous stress application “water-vapour condensation” the “powder-on-powder” variation significantly decreases in the moisture level, adhesion failure for 90%, which is to be evaluated as negative, see Figure 9.

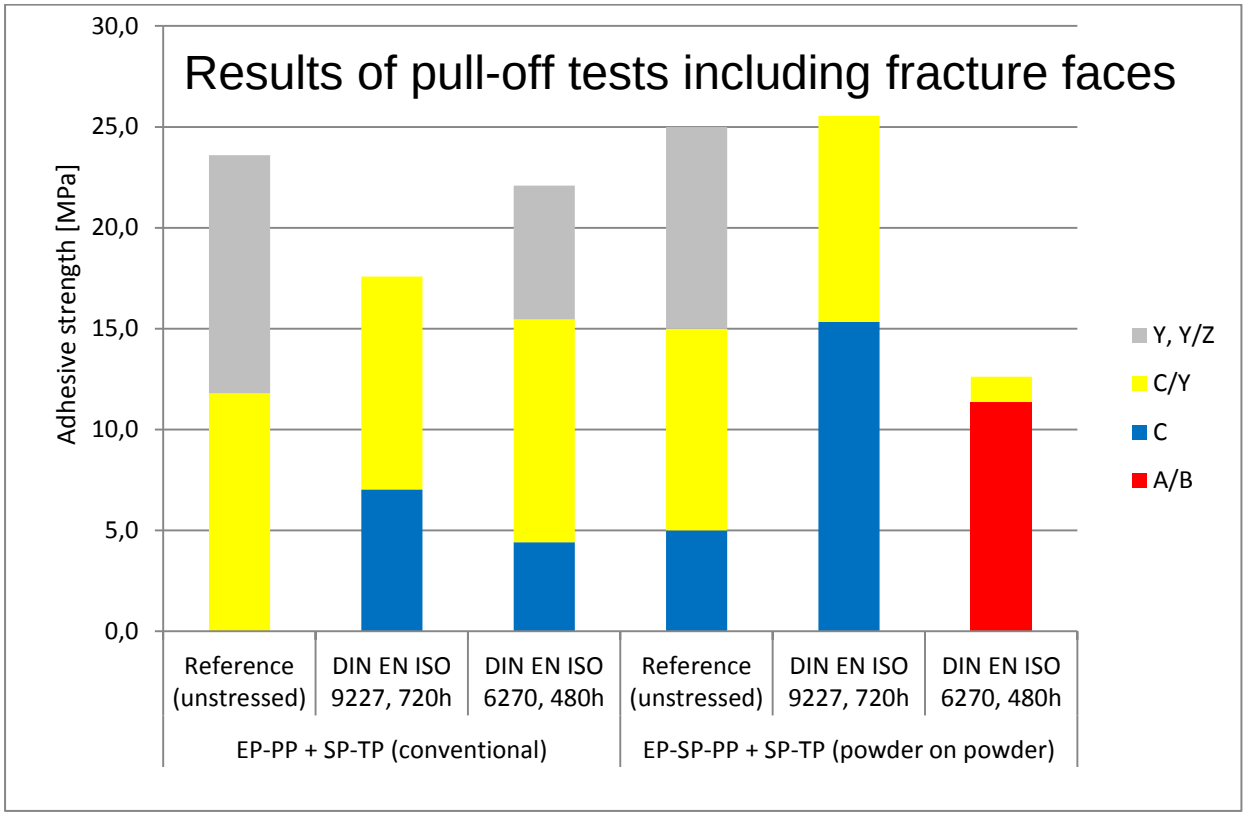

Figure 9: Results of pull-off tests on both of the powder coating systems prior to and after stress application

At this point the results for corrosion and delamination around the scratch after exposure to neutral salt spray should be mentioned. For both variations comparable values were measured, see visual appearance of the test specimens in Figure 10, which had been exposed to neutral salt spray. However, the total film thickness of the “powder-on-powder” test specimens of approx. 270µm was significantly above the film thickness of the conventional variation of approx. 150µm. As already mentioned, these tests are repeated.

Conventional variation (EP primer powder + SP top powder)

“Powder-on-powder” variation (EP-SP mixed powder (primer powder) + SP top powder)

Figure 10: Visual appearance of both powder variations after exposure to neutral salt spray

Summary

For increased corrosion protection requirements of corrosivity category C3 medium, high durability, and higher, normally two-layer powder coatings are recommended. Under certain conditions better corrosion protection on cutting edges can be achieved, which increases the quality of building components altogether. Improved edge-covering properties for two-layer powder coatings, however, cannot always be achieved, especially when smooth, glossy surfaces are required. In the context of a preceding project it was found, amongst others, that textured powder coatings have advantageous edge-covering properties as opposed to glossy powder coatings. However, textured powder coatings have special additives which may interfere with the intercoat adhesion of the primer powder and top powder.

On the one hand, the work presented in this context is done in order to develop the powder-on-powder technology for the production of two-layer powder coatings in only a single stoving process. At the same time, on the other hand, an improved edge covering should be achieved using the powder coatings by combining two powder coatings with different properties/functions.

First examination results in the laboratory as well as under conditions close to production showed that a powder-on-powder application with the developed combination of primer powder and top powder with a successive single stoving process works. Yet, further detailed work regarding the powder coating of building components with complicated geometries as well as the powder coating under large-scale production conditions will have to be done. A respective report may possibly be prepared at a later time.

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Sources

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