Innovative Technology for Highly Productive Powder Coating of Coils and Blanks

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1 Introduction

The coating of coils and blanks with powder combines the material-specific benefit of the solvent free and high-quality powder coating process with the procedural advantages of coating sheet metal before forming it into three dimensional parts ("precoating"). However, so far only a very small percentage of the steel and aluminum coil and blank production volume is coated with powder. Most of it is processed in the architecture and buildings sector. Typical products are facade systems, cassettes, cladding and sandwich panels, being produced by simple bending and folding operations. Today's coil and blank powder coating lines are working with conventional powder spray guns, requiring voluminous spray booths and powder recovery systems. Furthermore their line speed is limited to about 20 m/min, since for a higher speed an excessive number of spray guns would be needed impeding a reliable coating process.

In order to overcome the present limitations of powder coating in the coil and blank sector, a publically funded R&D project has been carried out jointly by the *Leibniz Institute of Polymer Research IPF (Dresden), the Institute of Industrial Manufacturing and Management IFF (University of Stuttgart), the Fraunhofer Institute for Manufacturing Engineering and Automation IPA (Stuttgart), and the Fraunhofer Institute for Machine Tools and Forming Technology IWU (Chemnitz).* The project has been supported by 15 companies (mostly SMEs), representing the complete scope of the involved industries: manufacturers of powder coatings, auxiliary materials, sheet metal, powder application and curing techniques, forming tools as well as end users. The project work has resulted in an innovative technology for highly productive powder coating of coils and blanks. This technology includes the coating powder system, the powder application technique, the curing process, and the sheet metal forming process. The main features of this technology are:

1. Highly flexible and fast curing coating powder systems allowing complex deep draw and stretch forming operations for producing three dimensional parts, e.g., for the automotive, the mechanical engineering, the furniture, and the packaging sector
2. Space, energy, and material saving powder application techniques without spray guns, allowing extremely compact coil / blank coating zones and line speeds of more than 100 m/min
3. Highly efficient infrared curing technologies allowing heating up of the coil / blank substrate within seconds in a compact curing zone
4. New plastic based forming tool systems producing complex true-to-form and true-to-size parts, avoiding abrasion and scratches in the powder coating layer, as well as needing minimal amount of lubricants

The following chapters give an overview of the project results. A detailed description of the complete R&D work is given in the project report [1].

2 Highly flexible powder coatings based on uretdione crosslinker

The innovative powder coating system is based on a two-step crosslinking mechanism originally developed by the Institute of Polymer Research (IPF) for curing in convection ovens [2][3]. At oven temperatures below 160 °C, in a first step a polyallophanate network is generated. At temperatures above 160 °C this network can be transferred via a second step into a urethane network (Fig. 1).

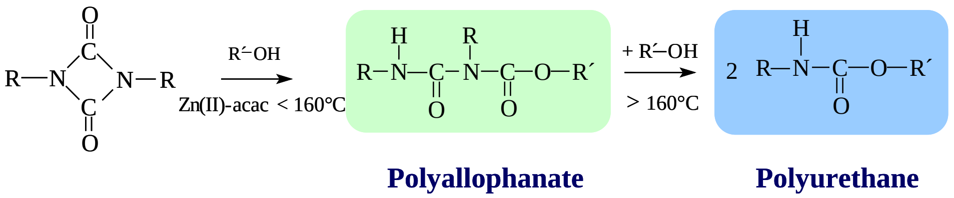


Fig. 1: Two-step curing mechanism of uretdiones and OH-functionalized resins in polymer melts.

Within the scope of the R&D project, the powder coating composition had to be adapted to the completely different infrared curing conditions, particularly with regard to the higher maximum temperature achieved on the metal substrate ("peak metal temperature") during the infrared irradiation in combination with the much shorter curing process. For this purpose, several parameters have been optimized by the Institute of Polymer Research (Fig. 2). The new formulation had to meet all the requirements, both with regard to the coating quality, particularly leveling, formability, adhesion, gloss retention, the absence of microcracks, and with regard to the energy efficiency of the infrared curing process (amount of energy needed for a complete crosslinking process).

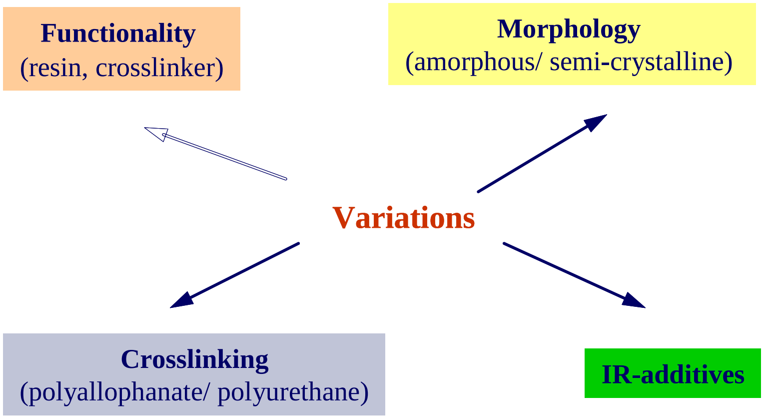


Fig. 2: Parameters of coating powder that were optimized within the scope of the R&D project with regard to formability, adhesion, gloss retention, and microcracks as well as with regard to the energy efficiency of the infrared curing process.

Rheological studies have clearly shown the advantages of semi-crystalline powder coatings with regard to film leveling during the fast infrared curing process. Semi-crystalline powder coatings are characterized by a very fast drop of melting viscosity when exceeding the melting temperature (Fig. 3). This allows for a better film leveling. Amorphous powder coatings are characterized by a less abrupt decrease of the melting viscosity when the temperature is increased. Compared to amorphous systems, semi-crystalline powder coatings reach the minimal melting viscosity at lower temperatures, and the minimum viscosity value is lower.

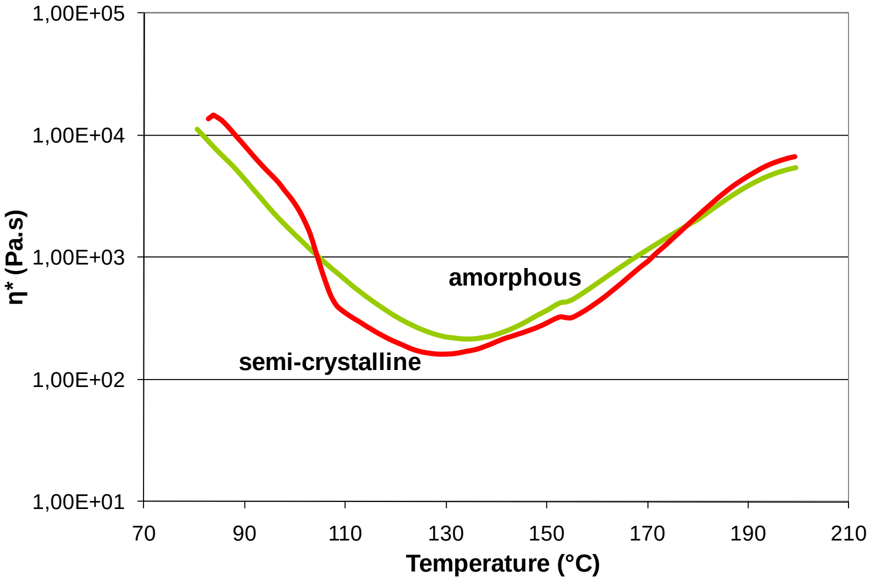


Fig. 3: Melting viscosity of uretdione powder coatings according to morphology (heating rate 5 K/min).

Several infrared additives – among others products that are used in powder coatings for the first time [4] – have been tested with regard to increase the infrared irradiation efficiency in white pigmented powder formulations. White coating powders are particularly critical due to their high reflection coefficient.

Depending on the emission spectrum of the infrared radiator, savings of energy and irradiation time of more than 20 % could be realized by using infrared additives with a well adapted absorption spectrum.

3 High-speed powder application without spray guns

In order to overcome the technical limitations of today’s coil and blank powder coating lines, Fraunhofer IPA and the IFF have further developed their patented electrostatic TransApp® powder coating technique [5] based on the electrostatic fluidized bed process (Fig. 4). Compared to the conventional powder spray gun and spray booth techniques, electrostatic fluidized bed modules are capable of applying the powder at line speeds of more than 100 m/min, nevertheless having a much lower space requirement. In addition, the consumption of compressed air and of electric power for exhaustion is less than one third of the consumption of a comparable conventional powder coating line. These advantages result from the following fundamental technical features:

- the electrostatic fluidized bed powder application module works without spray guns,
- the extremely high powder transfer rate from the electrostatic fluidized bed to the substrate enables coating in a matter of seconds,
- compressed air is needed only for fluidizing the powder, not for spray guns,
- due to the powder transfer to the substrate solely via electric forces, only marginal amounts of overspray have to be sucked off, needing only small exhaust air volume flow to comply with the safety requirements (EN 12981) and, as a consequence, enabling small-sized powder recovery systems.

Important innovations realized within the scope of the R&D project are in the new techniques of adapting the electric field in order to improve film thickness uniformity, paying particular attention to the coil/blank edge. For these purposes, in addition to experimental work, the electrostatic and aerodynamic forces have been numerically simulated, and particle trajectories have been calculated.

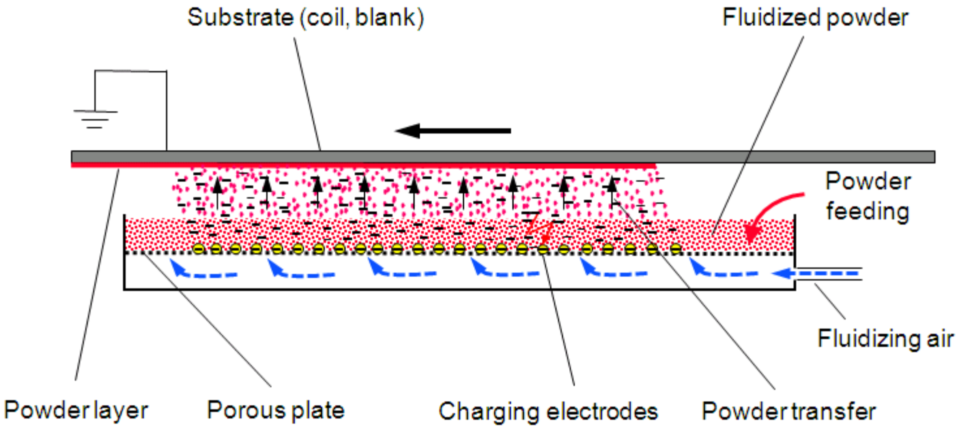


Fig. 4: **Principle of the electrostatic fluidized bed technique being further developed for powder coating of coils and blanks without spray guns.**

As a result of the experimental work and the numerical simulations, special charging electrodes and additional passive electrodes have been built. In addition, pulsed corona charging instead of D.C. high-voltage charging has turned out to be very successful regarding film thickness uniformity and film leveling. In particular, back ionization in the form of locally high ionic wind velocities and thus insufficient edge coating can be minimized by the use of pulsed corona charging (Fig. 5).

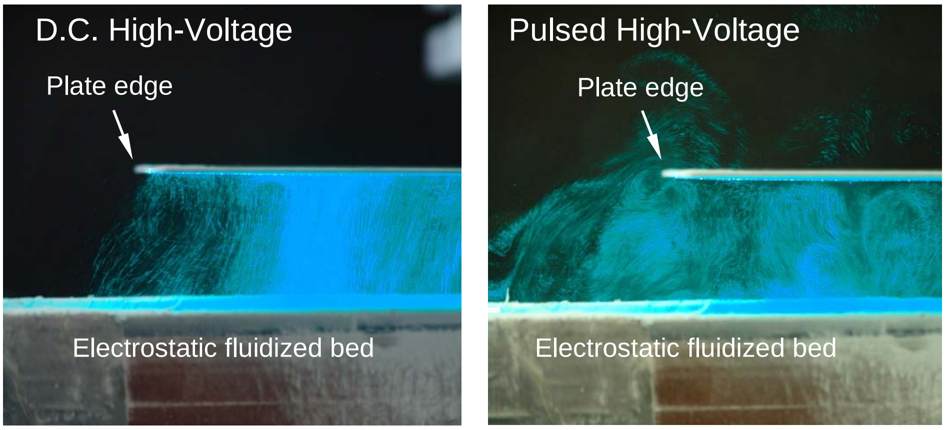


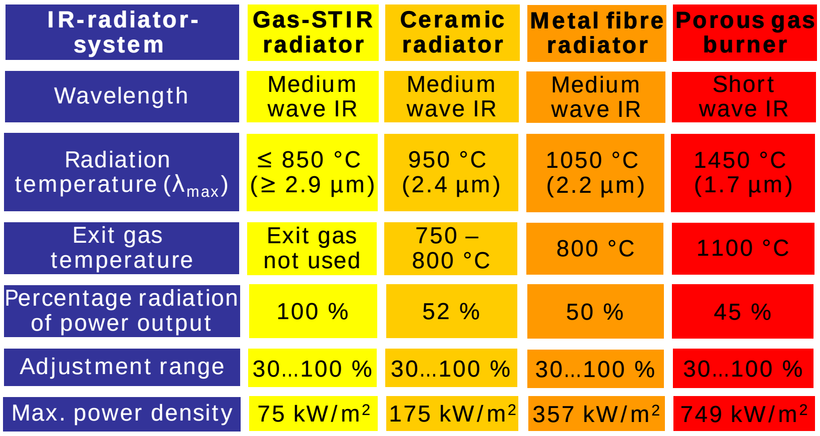
Fig. 5: **Pulsed corona charging in the electrostatic fluidized bed improves the film thickness uniformity on the plate edges (laser light sheet technique).**

Unlike in conventional powder coating lines with several spray guns, the electrostatic fluidized bed process produces no overlapping of single powder brushes. This is another feature for achieving more uniform coatings.

During the numerous coating tests with different kinds of coating powders the electrostatic fluidized bed has proven to be highly flexible with regard to the powder characteristics like, e.g., particle size distribution. For example, thin film powder coatings with their fine particle size distributions can be processed without additional measures.

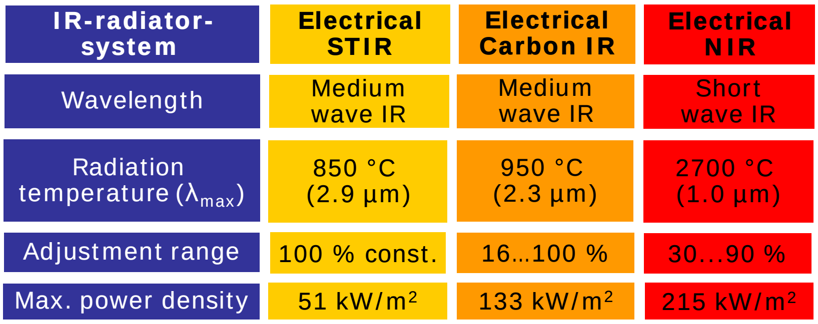
4 Fast curing processes using high-power infrared radiators

With regard to the compactness of powder coating line dimensions, the fast powder application process requires a fast melting and cross-linking of the applied powder layer. Conventional convection ovens are only suitable for low line speeds due to the long curing times in the range of several minutes. Highly productive powder coating of coils and blanks requires short curing process times down to below 20 seconds. This can be realized by using high-power infrared radiators in combination with powder coating mixtures adapted to the non-steady temperature – time curve of infrared heating processes.



IR-radiator-system	Gas-STIR radiator	Ceramic radiator	Metal fibre radiator	Porous gas burner
Wavelength	Medium wave IR	Medium wave IR	Medium wave IR	Short wave IR
Radiation temperature (λ_{max})	≤ 850 °C (≥ 2.9 µm)	950 °C (2.4 µm)	1050 °C (2.2 µm)	1450 °C (1.7 µm)
Exit gas temperature	Exit gas not used	750 – 800 °C	800 °C	1100 °C
Percentage radiation of power output	100 %	52 %	50 %	45 %
Adjustment range	30...100 %	30...100 %	30...100 %	30...100 %
Max. power density	75 kW/m²	175 kW/m²	357 kW/m²	749 kW/m²

Fig. 6: Gas-powered infrared radiators tested within the scope of the R&D project.



IR-radiator-system	Electrical STIR	Electrical Carbon IR	Electrical NIR
Wavelength	Medium wave IR	Medium wave IR	Short wave IR
Radiation temperature (λ_{max})	850 °C (2.9 µm)	950 °C (2.3 µm)	2700 °C (1.0 µm)
Adjustment range	100 % const.	16...100 %	30...90 %
Max. power density	51 kW/m²	133 kW/m²	215 kW/m²

Fig. 7: Electrically operated infrared radiators tested within the scope of the R&D project.

As part of the R&D project, four different types of gas-powered and three different types of electrically operated infrared radiators have been tested, including an electrically operated Near Infra Red (NIR) radiator system, as well as a gas-powered and an electrical radiator system using the new Selective Transformed Infra Red (STIR) technique [6] (Fig. 6, Fig. 7). The radiators vary in wavelength, radiation temperature, exit gas temperature (gas-powered IR), and power density. For comparing the different types of infrared radiators, an experimental setup has been designed (Fig. 8). The setup allows a quick change of the infrared radiator system as well as a freely programmable and repeatable movement of the powder coated sheet panel underneath the radiator.

By the experimental setup the infrared curing process has been optimized with regard to the minimum curing process time needed to meet all the requirements concerning the coating quality. The impact test according to ISO 6272 has turned out to be the best practice regarding a meaningful quality pre-test. The criterion was to reach an impact and reverse impact value of >160 inch x lb.

The complete curing process consists of the IR exposure phase and of the postcuring phase after the sheet panel has left the IR zone. The postcuring phase ends with the cooling-down of the sheet panels in a basin with cold water. Figure 9 shows the temperature measured on the back side of the 1 mm aluminum sheet panels during the curing tests carried out with the 7 different IR radiator systems. The rhombical marks in the temperature-time curves show the end of the IR exposure phase (IR irradiation on the powder coated top side of the sheet panels). The post-curing phase is characterized by a further rise in the panel backside temperature to a maximum, followed by a decline until the cooling down in the water basin, which is marked by the end of the curves. Except for the electrically operated NIR system with its two radiator units separated by a gap of 210 mm, the IR irradiation phase took place in each case underneath exactly one radiator unit.

The porous gas burner shows the highest power density of all the tested infrared radiator systems and therefore allows for the shortest IR exposure time. Figure 9 in combination with Fig. 10 shows that power density and energy efficiency both have an effect on the infrared curing process time. It has to be mentioned that the gas-powered STIR radiator is a prototype produced especially for the R&D project. Due to the high heat losses via the hot exhaust gas, the energy efficiency of this energetically not optimized gas-powered STIR radiator is very low. However, the motivation for designing this prototype was to realize an infrared radiator system enabling ideal curing processes for powder coatings. The previous curing tests carried out in the R&D project have shown that an optimal coating quality regarding leveling, formability, adhesion, gloss retention, absence of microcracks, etc. requires a specific control of the individual phases of the melting and crosslinking process. For this purpose, a multi-zone infrared radiator system is necessary, as illustrated in Fig. 11. The gas-powered STIR prototype represents a first approach to this concept.

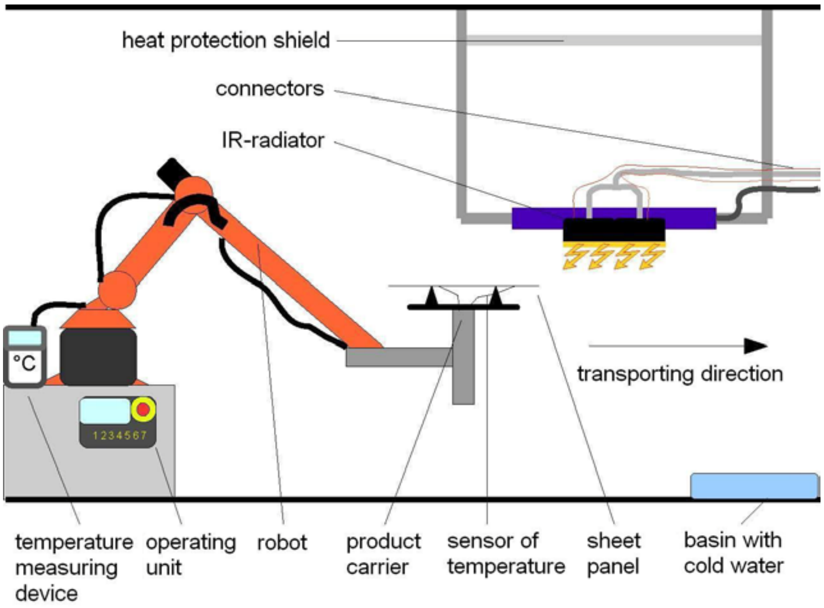


Fig. 8: Experimental setup for testing the different types of gas-powered and electrically operated infrared radiators.

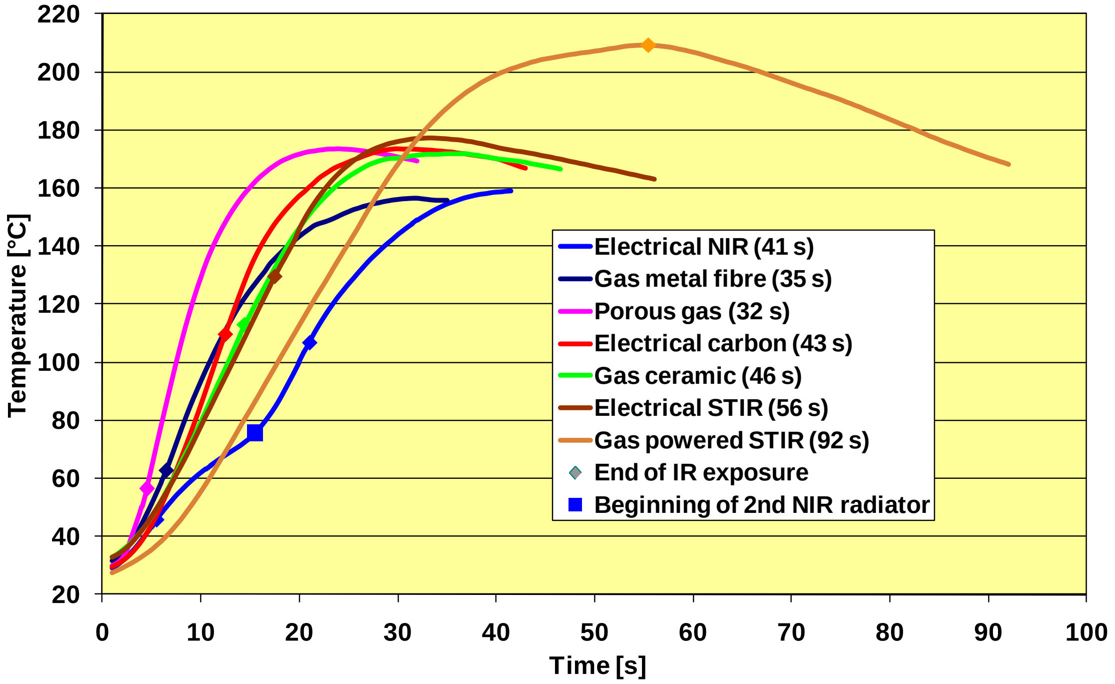


Fig. 9: Temperature measured on the back side of the sheet panels during the movement underneath the different types of infrared radiators; aluminum (AA 6016 T4) sheet panels size 200 x 500 mm², thickness 1 mm; powder coating film thickness 60 ± 10 µm. Impact / reverse impact value > 160 inchxlb.

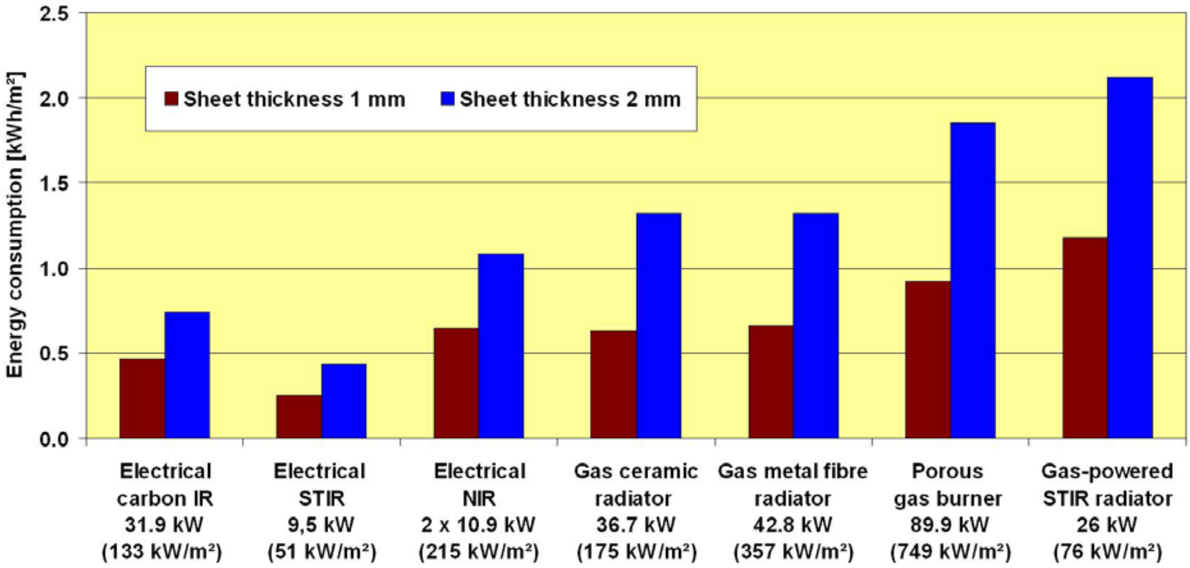


Fig. 10: Specific energy consumption of the different types of infrared radiators in relation to 1 m² of substrate surface; aluminum sheet panels size 200 x 500 mm², thickness 1 mm (AA 6016 T4) and 2 mm (AA 5754); powder coating film thickness 60 ± 10 µm. Impact / reverse impact value > 160 inchxlb.

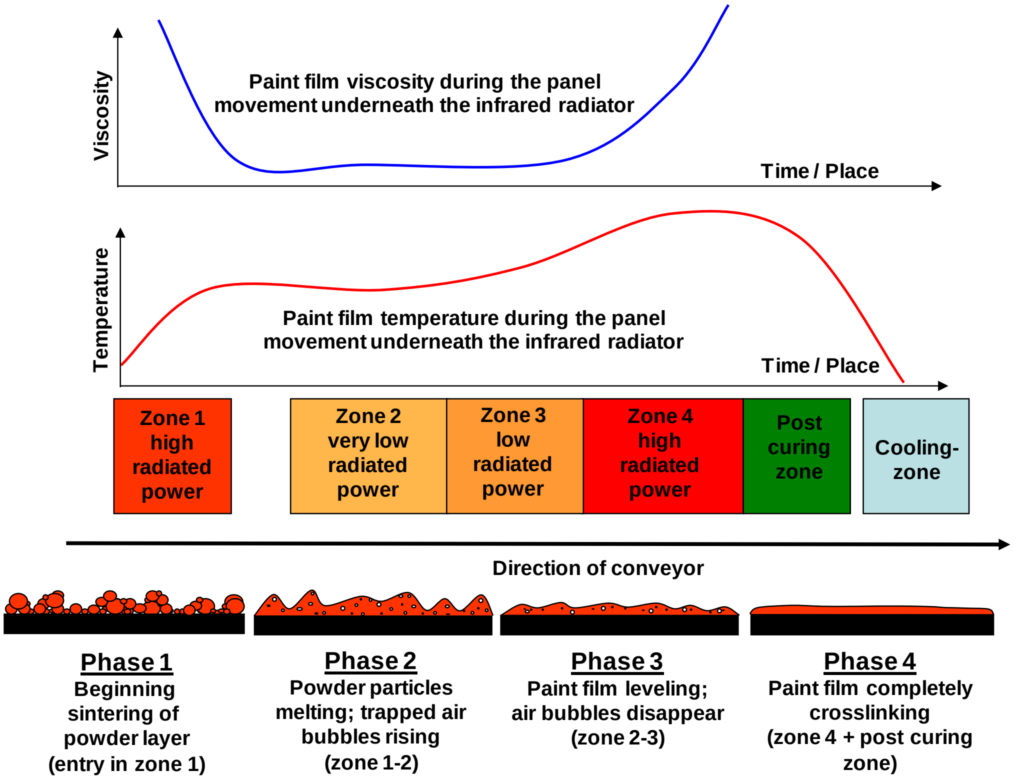


Fig. 11: Concept of a multi-zone infrared radiator system enabling ideal curing processes for powder coatings with regard to high coating quality.

5 Conceptual design of highly productive powder coating lines for coils and blanks

The results of the R&D project show that, based on the combination of the electrostatic fluidized bed technique with the fast infrared curing technique, both versatile coating lines for blanks and high-speed coating lines, in particular for coils, can be designed. Figure 12 shows a (simplified) concept for a versatile powder coating line for blanks. The blanks are preprimed, and therefore no pretreatment zone is needed.

The infrared curing zone has a length of 40 m. This allows for a high throughput with line speeds up to 1 m/s or, at lower line speeds, curing processes on blanks with a thickness of up to 3 mm, as well as curing of sensitive powder coatings with reduced IR power.

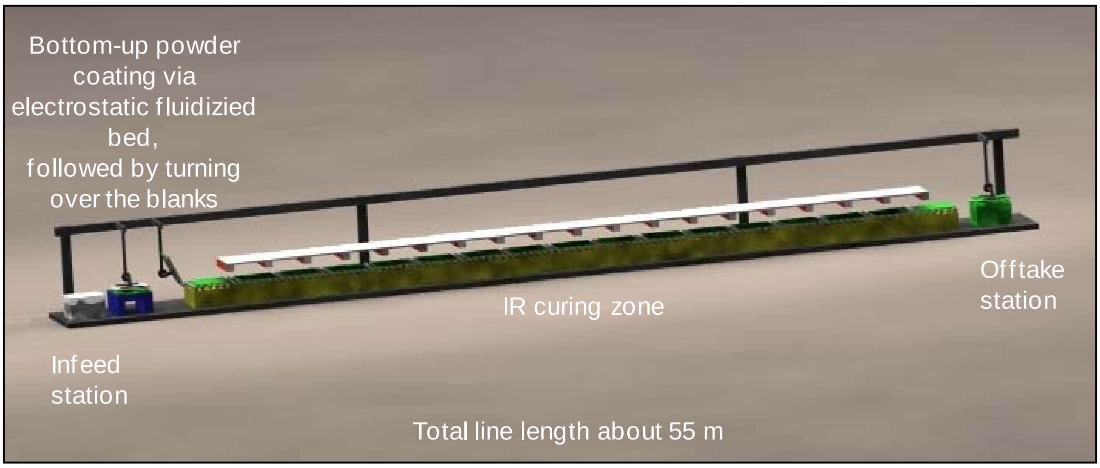


Fig. 12: Simplified concept for a versatile powder coating line for preprimed blanks.

The versatile concept enables quick color changes by providing several fluidized bed modules which can be interchanged easily.

6 Forming precoated blanks to real parts

The basic studies carried out by IWU have shown that applying the innovative coating powder systems, developed by IPF, in combination with the optimised IR curing conditions, developed by IPA/IFF, result in powder coating layers on aluminium panels passing the basic tests like form limited curve test (Erichsen test) and deep drawing test (tension/compression) without any restriction regarding formability, adhesion, gloss retention, and micro cracking.

During the next step, powder precoated blanks have been formed at IWU to complex industrial parts by using new plastic based forming tool systems producing true-to-form and true-to-size parts. Figures 13 and 14 show examples of parts for the automotive and the furniture sector produced by hydroforming techniques. The plastic based forming tool systems avoid abrasion and scratches in the powder coating layer, and need minimal amount of lubricants.

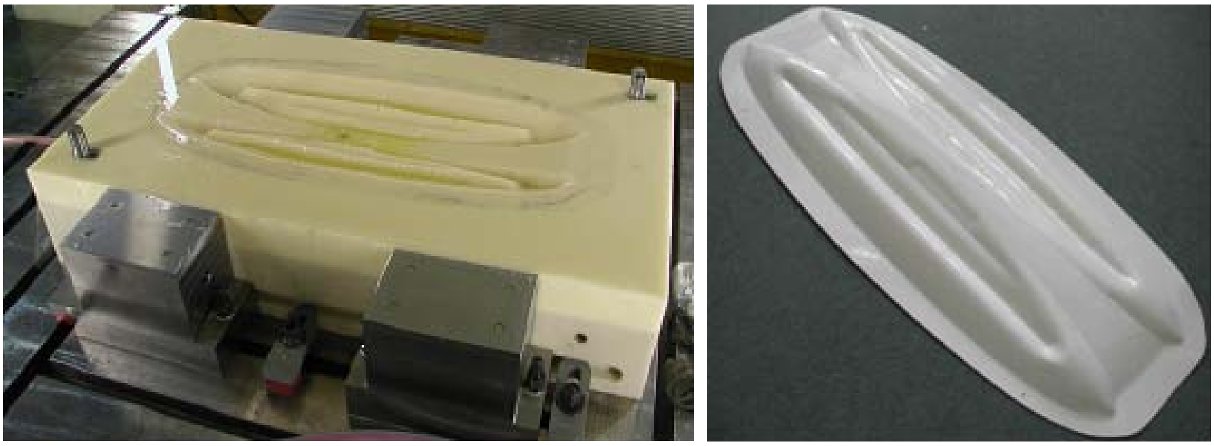


Fig. 13: Powder precoated aluminum blank formed into an automotive part (right) in a plastic based hydroforming tool (left).

Source: IWU

Fig. 14: Powder precoated aluminum blanks formed into parts (right) for a chair (left) by hydroforming.

Source: IWU

References

[1] Project report „*Hocheffizientes Aluminium-Precoating mit pistolenloser Pulverapplikation und schnellem Einbrennen in Verbindung mit umformstabilen Pulverlacken“.* Joint project (271 ZBG) within the German ZUTECH programme, funded by the *Bundesministerium für Wirtschaft und Technologie (BMWi)* through the *Arbeitsgemeinschaft industrieller Forschungsvereinigungen „Otto von Guericke“ e.V. (AiF)*, published 2010.

[2] Gedan-Smolka, M., Lehmann, D., Lehmann, F., Edelmann, M.: Low temperature curing uretdione powder coatings form the basis of innovative processing lines”; Fatipec 2004, Tagungsband Vol. 1, S. 291-301

[3] M. Gedan-Smolka, F. Lehmann, D. Lehmann, International J. of Coating Science, 2001, 1

[4] R. Knischka, U. Lehmann, J. Benkhoff: Infrarotabsorber verbessern Energieeffizienz der NIR-Trocknung, Farbe + Lack, 12/2008 S. 35-39

[5] Patentschrift DE 10 2004 010 177 B4: Elektrostatische Fluidisiervorrichtung und elektrostatisches Wirbelbadverfahren zur Beschichtung von Substraten mit Beschichtungspulver

[6] http://www.infrabiotech.de/