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Automation Systems & Intelligent Solutions

Curing of Liquid Coatings on Form Parts

Robot-controlled curing by electron treatment

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Abstract

Modern surface finishing technologies enable the production of product surfaces with a high decorative and functional effect.

Increasingly, requirements for lower volatile organic compounds (VOCs), material recycling and lower energy consumption have to be taken into account while maintaining high manufacturing efficiency and throughput. The operation of compact, low-energy electron emitters on an industrial robot enables environmentally friendly non-thermal curing of liquid coatings on three-dimensional moulded parts.

Compared to the thermal process, the energy consumption and CO_2 emissions can be significantly reduced, which leads to cost reductions and increased sustainability for the user. An economical modification of three-dimensional moulded parts is possible with the use of efficient area emitters in combination with 3D-capable finger emitters.

Content

1. Standardised plants that are not standard

The ASIS GmbH, headquartered in Landshut near Munich, is a system provider for automated systems in surface technology. The internationally positioned company exports from four locations in Germany and a subsidiary near Shanghai to over 30 countries worldwide.

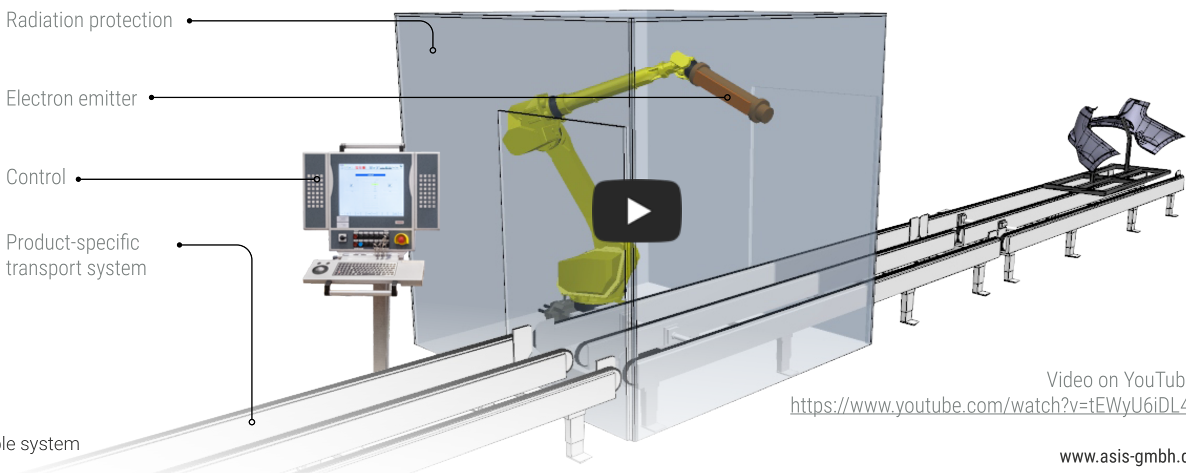
The range of services includes turnkey systems for wet paint or enamel coating, systems for quality control, surface treatment and electron treatment, wet paint application technology and process automation technology.

A dedicated digital simulation site develops material flow simulations, offline robot programming and feasibility studies.

ASIS in numbers

- Founded: 01.05.1998
- CEO: Hans-Jürgen Multhammer
- Quality assurance: ISO 9001
- Inform. assurance: TISAX
- Export countries: > 30 worldwide

Complete solutions in the area of inline electron beam technology for the non-thermal curing of liquid coatings on three-dimensional form parts are the newest business field. These industrial systems consist of compact electron emitters connected to an industrial robot as well as a product-specific transport, control and radiation protection system (see Fig. 1).



Video on YouTube:
https://www.youtube.com/watch?v=tEWyU6iDL4k

Fig. 1: Example system

2. Physical process for non-thermal curing

Liquid coatings require energy during the transformation into a solid surface ready for use, which is needed e.g. for the evaporation of the solvent or water or for the polymerisation and cross-linking (Fig. 2).

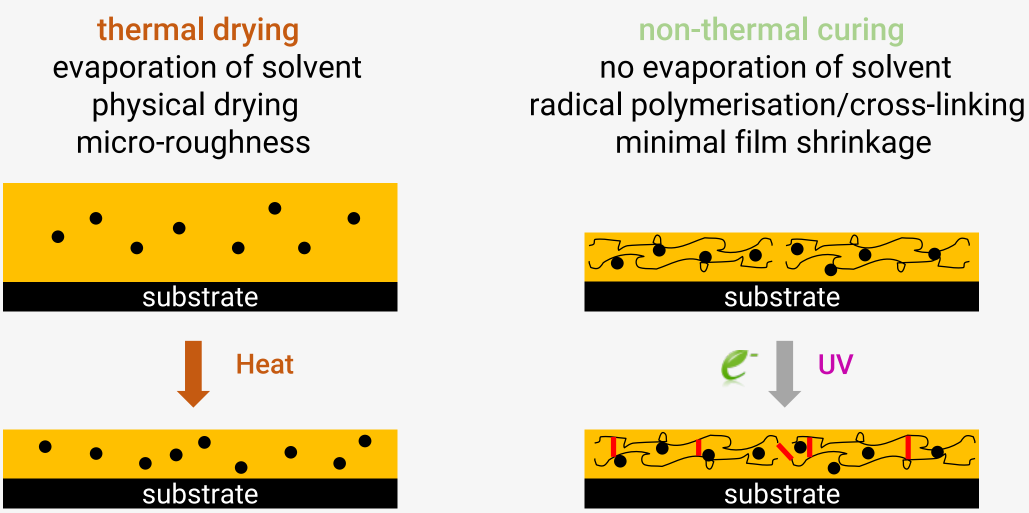


Fig. 2: Comparison of thermal drying and non-thermal curing

The industrial thermal drying of liquid coatings is associated with a high energy loss. This can be remedied, for example, by radiation drying and curing, as these enable a targeted energy input into the liquid coating.

The wavelength (λ) used (Fig. 3) not only determines the energy of the electromagnetic radiation (E_{em} [eV] = 1240/λ [nm]), but also the type of interaction with the liquid coating.

While electromagnetic radiation with wavelengths > 800 nm dries the liquid coating, electromagnetic radiation with wavelengths < 400 nm can initiate chemical reactions in the liquid coating and cure it.

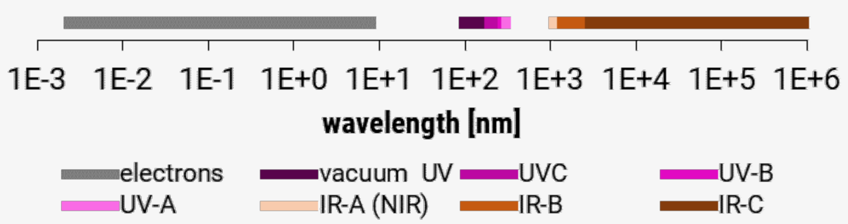


Fig. 3: Range of wavelength for radiation drying and curing

The drying and curing processes established on the market do not differ in the general composition of the liquid coating, but in terms of type of binder, solvent content and reaction speed.

The fastest process for converting a liquid coating into a solid coating is radiation curing ($\lambda < 400$ nm). Compared to thermal drying, this non-thermal process offers the advantages of solvent-free curing and immediate further processing.

UV curing (UVH) and electron beam curing (EBC) are established on the market. Compared to UVH, the latter enables:

- higher curing degrees and thus better resistance to chemicals and scratches
- higher product speeds in the curing process
- curing of pigmented, highly filled thick coatings
- the elimination of toxic photo-initiators
- lower substrate heating

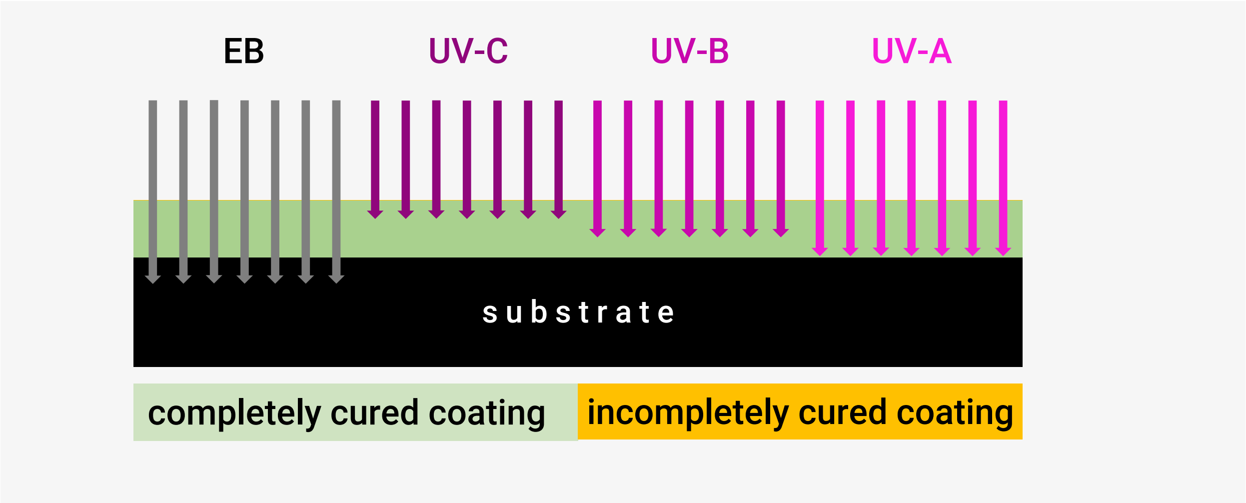


Fig. 4: Comparison of the penetration depth of UVH and EBC

This mostly unknown physical process offers a high potential for a sustainable and environmentally friendly curing of liquid coatings on different substrates with various geometries.

Compared to the thermal drying, the energy consumption and CO_2 emissions can be significantly reduced, which leads to cost reductions and increased sustainability for the user.

The first industrial applications of EBC were established in the 1970s. For example, FORD Motors Corporation used EBC to cure liquid coatings on plastic interior parts [2].

The main current applications are:

- printing inks (flexographic printing, web offset printing) [3]
- coatings (e.g. furniture decor, coil coating [4])
- coatings on panels, facade elements, doors for outdoor applications [5]
- overprint varnishes for food packaging [4]
- highly abrasion-resistant floor coverings (e.g. industrial flooring, finished parquet) [6]
- coatings on topcoat papers for the production of HPL (high-pressure laminates) and CPL (continuous-pressure laminates) [3]

Parameter	thermal	ESH
Content of solid of the liquid coating	60 %	100 %
Mass of solid coating per m²	20 g	20 g
VOC per m² at a solvent density of 0.9 g/cm³	12 g	0 g
Energy consumption	~0,091 kWh/m²	~0,028 kWh/m²
CO_2 release due to solvent combustion	37 g/m²	0 g/m²

Table 1: Energy consumption and CO_2 release for thermal drying and EBC [1]

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3. Precise process control

The sustainable and highly productive EBC does not use chemical reaction initiators (e.g. photo-initiators), as the low-energy electrons transfer their kinetic energy to the atoms and molecules of all coating components in several interactions.

At the end of the energy transfer process, covalent bonds are broken and free radicals are formed (see Fig. 5). These react with the double bonds of the oligomers/monomers and start the polymerisation.

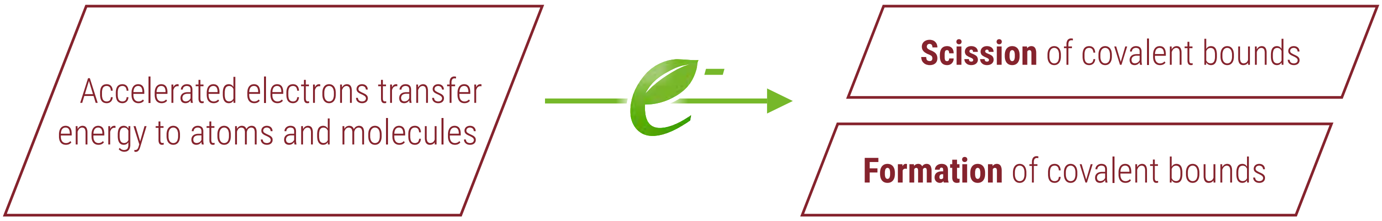


Fig. 5: Basic mechanisms of the interaction of accelerated electrons

The radicals are the starting point of complex chemical reactions leading to a change in the chemical structure as well as altered chemical (e.g. cream resistance, UV resistance), mechanical (e.g. high hardness, scratch resistance, abrasion resistance) and thermal (e.g. high thermal resistance) properties of the solid coating.

The tailored curing of liquid coatings requires the specific selection of the process parameters acceleration voltage, beam current, dose and dose rate. Furthermore, the process parameters depend on the components of the liquid coating to be cured (oligomers, monomers, pigments, fillers, additives) and the chemical environment during EBC.

The chemical environment includes the gas atmosphere, humidity, pH-value and temperature during EBC. An overview of the electron induced chemical reactions is shown in figure 6.

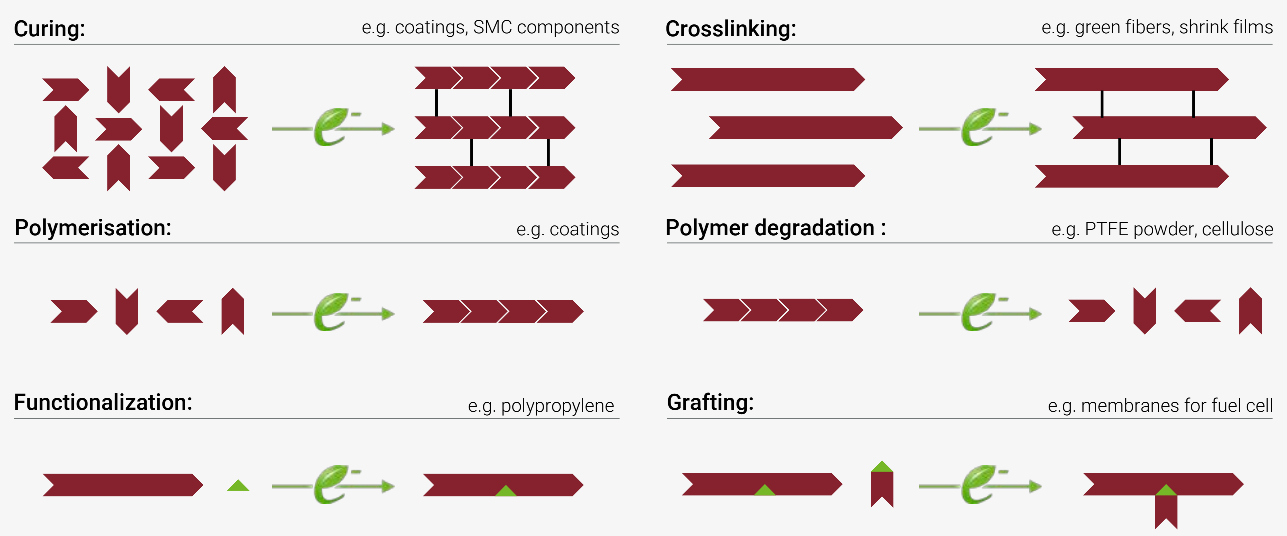


Fig. 6: Overview of electron-induced chemical reactions

The dose characterises the energy absorbed per mass and controls the number of radicals produced per polymer molecule and thus the intensity of the desired chemical reaction.

The unit of the dose is Gray (abbreviation: Gy). For the curing of liquid coatings, a dose in the range of 40 kGy to 80 kGy is required, depending on the coating formulation (Fig. 7).

The dose rate during EBC describes the dose absorbed per time.

Thus, it controls the radical generation rate and influences all time-dependent processes during the non-thermal curing, such as reaction kinetics, secondary reactions with atmospheric oxygen and the temperature increase in the coating.

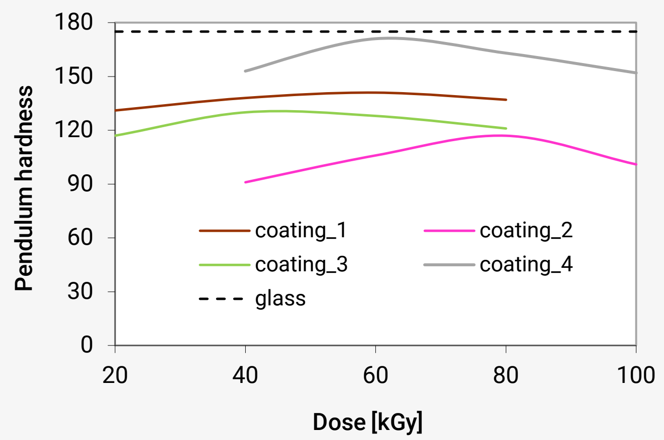


Fig. 7: Influence of dose on the pendulum hardness for different coatings

Since the presence of oxygen hinders the curing of the liquid coating, an inert gas atmosphere is required during EBC.

The dose rate during EBC influences the residual oxygen content required for the complete curing of the liquid coating (Fig. 8).

A high dose rate allows for a higher residual oxygen content (> 3000 ppm) and increased efficiency of the EBC.

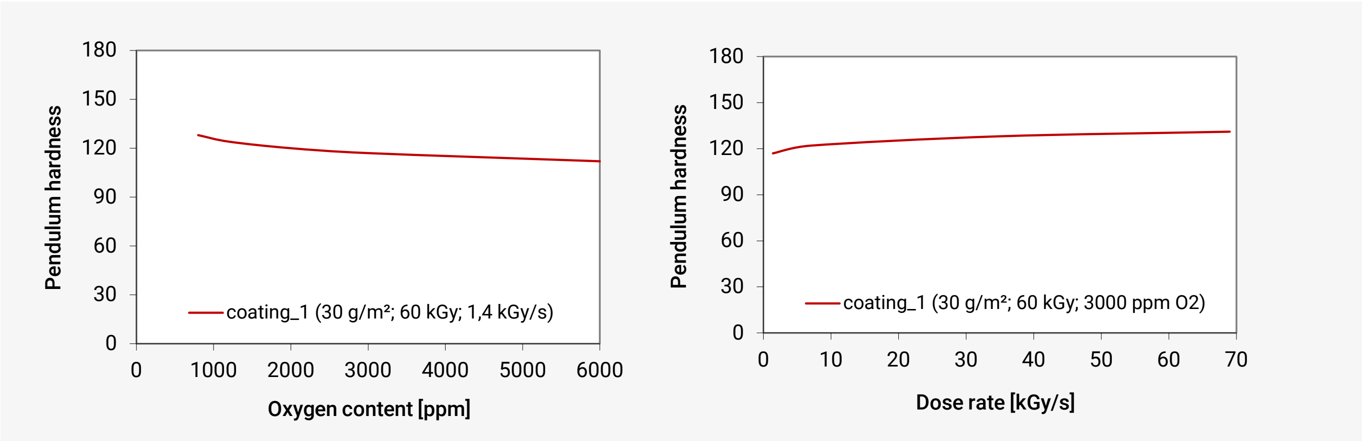
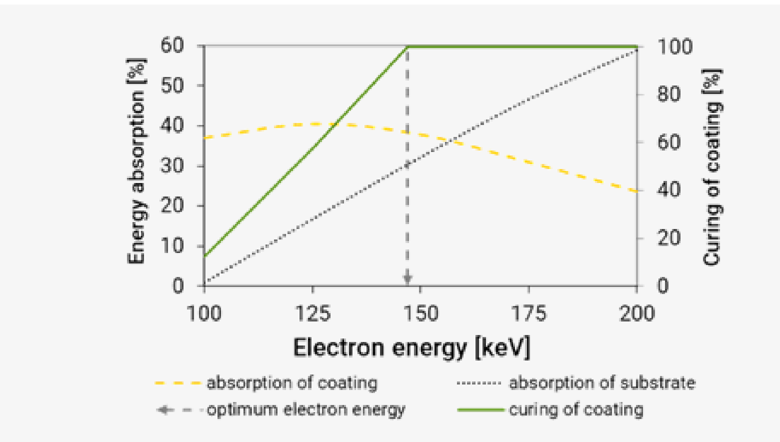


Fig. 8: Influence of residual oxygen content and dose rate on pendulum hardness

The acceleration voltage controls the spatial energy input into the liquid coating to be cured and is to be adapted to the respective coating thickness in order to minimise the energy input into the substrate and undesired substrate damage as well as to optimise the energy efficiency of the curing (Fig. 9).

The beam current controls the temporal energy input into the liquid coating and thus the dose rate or surface rate (Fig. 10).



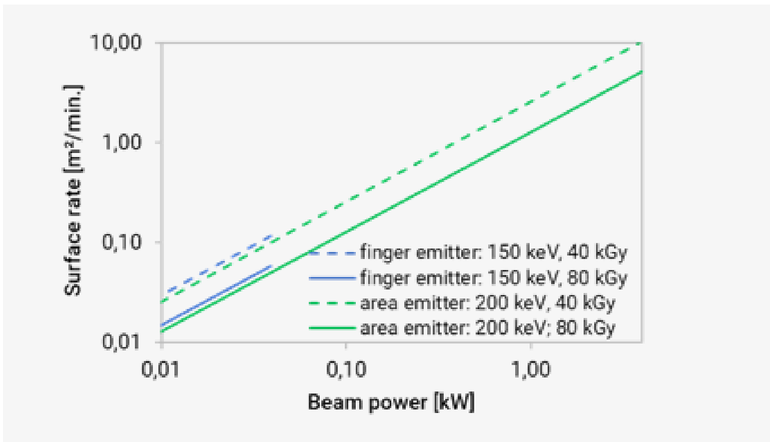


Fig. 9: Energy absorption and curing of 80 g/m² coating as function of electron energy

Fig. 10: Surface rate as function of beam power

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4. Compact facility design

The availability of maintenance-free, compact, low-energy electron emitters in the energy range from 80 keV to 200 keV enables their coupling with an industrial robot and thus the EBC of liquid coatings on three-dimensional components and their integration into the coating line (Fig. 11).

These systems are characterised by low costs and service times as well as high energy efficiency, surface rate and service life.

Coatings for outdoor applications usually require a high level of UV protection. Here, the EBC offers an energy-efficient solution. In addition, this technology can be used for surface functionalisation of three-dimensional plastic parts before a coating or bonding process.

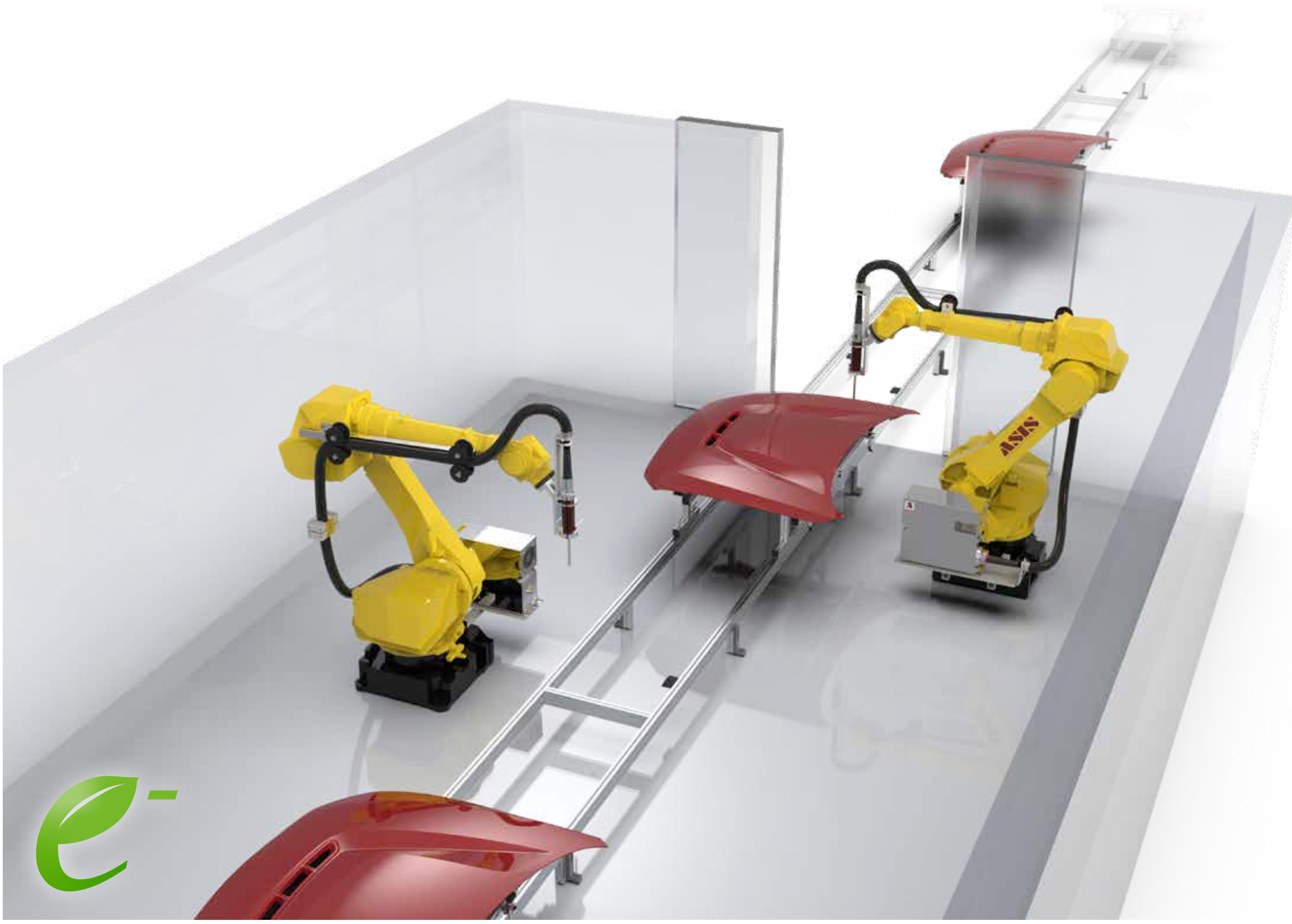

Fig. 11: Robot-controlled EBC of three-dimensional form parts

5. Electron beam curing of liquid coatings

EBC is characterised by radical polymerisation and cross-linking initiated by low-energy electrons in the absence of photoinitiators, as well as the rapid conversion of special reactive organic liquid coatings into a solid polymer network, e.g. into a ready-to-use surface.

The main important components of the coatings used are unsaturated oligomers (binders), unsaturated reactive diluents that are incorporated into the network, as well as pigments, fillers and additives.

The 100 %-, powder- and water-based coating available on the market contain almost no organic solvents (volatile organic compounds - VOC). Depending on the application, polyester acrylates (wide viscosity range), epoxy acrylates (hard, very fast curing, high gloss), urethane acrylates (hard to flexible, aliphatic: exterior applications) or amino acrylates (high curing speed) are used as binders.

Advantages:

- enhanced film properties (e.g. high hardness, scratch resistance, abrasion resistance, thermal resistance, solvent resistance as well as high gloss, low shrinkage and no ageing due to UV light)
- hardly any emission of volatile substances (VOC)
- low temperature process
- stable processing times
- significant reduction of energy consumption (by 70 - 80 %) compared to thermal drying
- lower facility dimension compared to thermal drying
- 100 % recyclability (e.g. no change of overspray)

Disadvantages:

- hardly any/no curing in the shadow area
- increased costs for coating formulations
- radiation-curable oligomers can cause skin irritation and odour nuisance
- working in atmosphere with low residual oxygen content
- higher investment costs
- additional shielding against X-rays and bremsstrahlung
- low viscosity control and limited sprayability of coating formulations

The use of water-based coatings improves the viscosity adjustment and sprayability, but requires an additional drying step, which is associated with additional energy consumption, longer application times and reduced film properties.

The robot-controlled EBC enables an energy-efficient and sustainable curing of liquid coatings on three-dimensional moulded parts.

Based on the component-specific CAD data, the calibration parameters of the electron emitter used and a programming tool, the modification paths for complex three-dimensional form parts are calculated.

The new process leads to increased film properties as well as lower energy consumption and CO_2 emissions.

Modern compact low-energy electron accelerators use linear cathodes (area emitters) and point cathodes (finger emitters) as well as a single-stage acceleration, so that no scanner is needed for the out fanning of beam.

The vacuum system required to generate free electrons is sealed off in the beam exit direction by a thin electron beam exit window (usually titanium foil). When leaving the vacuum system, the low-energy electrons release a part of their kinetic energy in the electron beam exit window and heat it up. In an 11 µm thick titanium foil, 10 % (at 200 keV) to 40 % (at 100 keV) of the electron energy is absorbed.

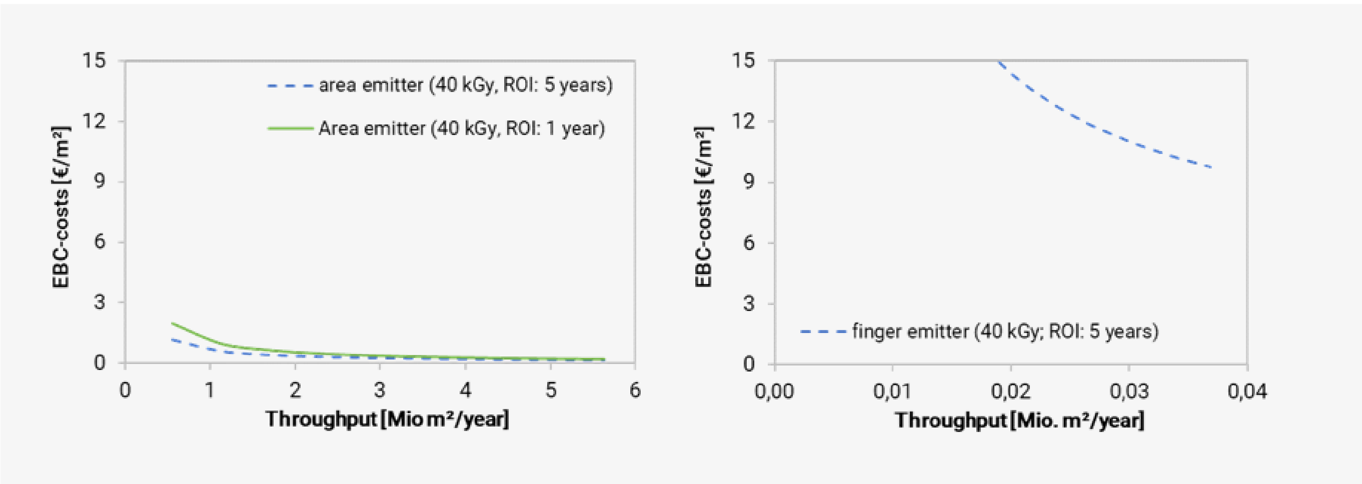

Fig. 12: ESH costs including nitrogen for curing of 80 g/m² coating (Fig. 9) with a surface emitter and finger emitter.

Excessive operating temperatures of the electron beam exit window lead to fatigue and later to mechanical failure. In the interest of long lifetimes, the area-specific beam power is limited. Thus, the maximum beam power of compact electron emitters is also dependent on the area of the electron beam exit window.

The required 3D capability of a compact electron emitter decreases with increasing area of the electron beam exit window and beam power of the electron emitter.

Thus, an economic modification of three-dimensional moulded parts requires the use of efficient area emitters in combination with a 3D-capable finger emitter (see Fig. 12).

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6. Application of coating

Three-dimensional form parts can be coated with low-viscosity, high-solids coatings using various processes such as electrostatic spraying.

EBC coatings belong to the group of high viscosity, high solids coatings and require a modification of the coating application technique in order to reduce the viscosity of the EBC coatings according to the specific requirements.

This is possible, for example, by heating the EBC paint in a paint flow heater or by using a temperature-controlled spray booth.

In cooperation with a paint manufacturer, the viscosity of the EBC paint can be adjusted to the specific application by using low-viscosity binder systems.

7. Conclusion

The coupling of compact low-energy electron emitters with an industrial robot enables the EBC of liquid coatings on three-dimensional form parts.

This non-thermal curing method promises increased coating properties as well as lower energy consumption and CO_2 emissions.

EBC requires special coating formulations, the adaptation of coating application technique and an inert atmosphere during EBC.

An economical EBC of liquid coatings on complex three-dimensional form parts requires the use of efficient area emitters in combination with a 3D-capable finger emitter.

The costs of EBC including investment (ROI: 1 year), energy, nitrogen and maintenance costs are less than 0.35 € per m^2 if the total surface area of liquid coatings to be cured annually amounts at least 4 million m^2.

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8. Contact

For further information on electron beam curing, please contact:

Dr. rer.-nat. Uwe Gohs
u.gohs@asis-gmbh.de
ASIS GmbH
Kiem-Pauli-Straße 3
84036 Landshut, GERMANY
www.asis-gmbh.de

Otto Pritscher
o.pritscher@asis-gmbh.de
ASIS GmbH
Kiem-Pauli-Straße 3
84036 Landshut, GERMANY
www.asis-gmbh.de

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