This State-of-the-Art Report "Conductive Coatings for Industrial Floors" was prepared by Deutsche Bauchemie e.V.'s same-named Study Group 5.9, discussed and released by Special Committee 5, "Plastics in Concrete Construction", with the intention of providing information to member companies and the interested public on conductive floors in rooms and spaces where there is a risk of electrostatic charging.

All information, technical documentation, reports and experience provided by the producers of conductive coating products that were received by March 2003 have been integrated into this report.

Deutsche Bauchemie e.V. Frankfurt am Main would be very pleased if you would share your experience or give us your opinion regarding this State-of-the-Art Report.
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General Information on Reactive Resin Floors

When constructing new halls for industrial purposes but also when maintaining and repairing such objects or modifying them for new uses, suitable floor systems must be planned and executed for each specific object.

The requirements placed on industrial floors have changed dramatically in the past years, different usage requires special surfaces.

The producers of synthetic products for the building industry offer corresponding solutions for all of these requirements.

The owner of the building must, of course, fulfil legal requirements but on the other hand, placing a reactive resin cover on a floor opens up whole new options.

Depending on requirements and composition, coatings made of reactive resins have the following properties:

- resistant to chemicals
- decorative
- electrically conductive
- liquid tight
- seamless
- easy to clean and maintain
- mechanically loadable, also with vehicles
- crack-bridging
- non-slip
- weather and age resistant

The following product groups of reactive resins are predominately used:

1. Polyaddition resins
   - Epoxy resins (EP) [1]
   - Polyurethane resins (PUR) [2]

2. Polymerisation resins
   - Polymethyl methacrylate (PMMA) [3]
   - Unsaturated polyester (UP)
   - Vinyl ester resins (VE)

For many floor surfaces normal use means heavier loads, e.g. traffic loads. By selecting a proper coating system, the service life and durability of a floor surface can be extended.
These properties alone justify the use of preventive measures to protect concrete surfaces.

A coating is therefore a measure that helps to maintain the building and is planned by responsible architects right from the beginning.

**Mechanically loaded floors**
Dust is the enemy in many production technologies because it can cause malfunctions and errors in production sequences.

Sealants, coatings and covers on floors prevent dust. They are applied in a layer 0.5 – 6 mm thick and, due to the fact that they are relatively easy to apply or place, their use is widespread. Coated surfaces are highly resistant, have little tendency to wear through abrasion and increase service life.

**Chemically loaded floors**
Floors coated with reactive resins are liquid tight and resistant when subjected to chemical loads.

These properties have been proved by the many Building Inspectorate test certificates and approvals that testify to their use in water protection systems.

**Decorative floors**
Decorative floor covers can be produced with reactive resins. These systems provide a wide range of possibilities for design, using colour.

Coating systems can be applied in a solid colour but highly decorative covers can also be created with, e.g. colour chips or flakes.

Architects and planners have the possibility of creating highly individual floor designs with these coating systems.

**Conductive coatings**
Not only legislation but also many industries require the use of conductive floors in certain areas.

These floor systems have the task of quickly and reliably leading off any charges on personnel and objects through the floor to earth potential.

**Summary**
All of these floors with coatings made of reactive resins fulfil the requirements that are placed on industrial floors.

Strength, wear resistance, resistance to chemicals, a decorative appearance, conductivity and good cleaning qualities are all proof of their benefit.
Electrostatic Principles

2.1 Requirements

Electrical charges are a decisive variable in the field of electrical engineering. All objects and humans have positive and negative electrical charges which are normally in equilibrium, i.e. they are electrically neutral. Carriers that are negatively or positively charged emanate an electrical field. Humans and objects can become charged through movement or through electrostatic induction. Electrostatic induction is the separation of mobile electrical charges in an initially neutral body that takes place when it is approached by an electrically charged object.

Through mechanical separation, e.g. by lifting, friction, crushing processes, pouring of solid objects and substances, or the flow, pouring and spraying of liquids as well as the flow of gasses and vapours that contain slight quantities of finely distributed solids, a charge is usually transferred at the common interfaces of the respective charge carriers, causing a difference in potential. The charge carriers are electrostatically charged.

Under certain circumstances, the result of such spontaneous discharges may cause a spark to form. This potential risk must be avoided not only when combustible liquids, explosive substances and combustible dust are concerned, but also in the case of electronic devices and electronic components that are sensitive to electrostatic charges.

Electrically conductive floors are an important element in safety requirements to protect humans and operating facilities since the build-up of voltage cannot be reduced while walking on an insulated floor. Only when a body with a different potential is touched does the built-up charge flow off spontaneously.

Materials for conductive floor covers are qualified on the basis of their measured resistance.

2.1 Requirements

**Combustible liquids (BetrSichV)**

(German regulations on operational safety) When storing flammable and highly flammable liquids (formerly hazard classes A I, A II and B in VbF, German regulations on combustible liquids), the following resistance may not be exceeded:

- Resistance to earth \(1 \cdot 10^8 \ \Omega\)
- Surface resistance \(1 \cdot 10^9 \ \Omega\)

**Gasses, vapours or mist**

For areas in which there is a risk of explosion through gasses, vapours or mist, the following limit values apply (according to BGR 132) (Professional Association Rules):

- **Zone 0:** areas in which a dangerous, explosive atmosphere caused by gasses, vapour or mist is continuously present or present on a long-term basis
  - Resistance to earth \(\leq 10^6 \ \Omega\)
Zone 1: areas in which the occasional occurrence of dangerous, explosive atmospheres caused by gasses, vapours or mist can be expected.
Resistance to earth $\leq 10^8$ $\Omega$

Zone 2: areas in which explosive atmospheres caused by gasses, vapours or mist are only rarely expected and then only for a short period. There are no requirements on resistance to earth in this zone.

Combustible dusts
The following limit values apply to areas which are at risk because of combustible dusts.

Zone 20: areas in which dangerous explosive atmospheres caused by dust are long-term or frequent.
Resistance to earth $\leq 10^8$ $\Omega$

Zone 21: areas in which occasional, short-term, dangerous explosive atmospheres caused by whirled deposited dust can be expected. There are no requirements on resistance to earth in this zone.

Explosive materials
Explosive materials are materials that are listed in laws on explosives as well as materials that are deemed explosive according to the tests specified by these laws. Resistance to earth $\leq 10^6$ $\Omega$

Areas in which there are components sensitive to electrostatic discharges
The requirements for these areas are regulated in standards. The limit value specified in the standard represents a standard value. In practice, however, limit values are often set by the building owner or his ESD coordinator specifically for the object.
When testing electrostatic conductivity, resistance to earth is normally measured. Regardless of which standard is used, an electrode is placed on the coating to be tested and resistance to earth is measured with a standardized measuring device to earth potential.

In case of specific ESD requirements, the "person-footwear-floor" system test can also be executed.

### 3.1 Measuring with a 1 kg Probe

(An illustration of the probe is found in photograph 1, A, page 11)

This measuring technique is used in areas where there is a risk of explosion. It is described in the following guidelines/standards:

1. **BGR 132**: German professional association rules for avoiding the risk of ignition resulting from electrostatic charges issued by the Main Association of Professional Trade Associations. The requirements are described in 2.1. [4]

2. **DIN 28052 – part 6**: Surface protection using non-metallic materials for building elements made of concrete in processing facilities; proof of suitability and tests. In facilities for handling combustible liquids according to BetrSichV, coatings may not lead to a risk of ignition caused by electrostatic charges. The requirement is fulfilled if leakage resistance equals $R_E < 1 \cdot 10^8 \Omega$ [5]

3. Principles for the approval of coating systems used on concrete in storage, filling and handling facilities issued by the German Institute of Building Technology (DIBt); requirements for the storage of water-endangering and combustible liquids according to BetrSichV: [6]
   - up to 50% relative humidity $R_E < 1 \cdot 10^6 \Omega$
   - 50% to 70% relative humidity $R_E < 1 \cdot 10^7 \Omega$
   - greater than 70% relative humidity $R_E < 1 \cdot 10^6 \Omega$


### 3.2 DIN EN 1081

(An illustration of the probe is found in photograph 1, B, page 11)

In April 1998, this standard replaced DIN 51953. The new standard describes measurement with a 3-point electrode; limit values are not given. [8]

### 3.3 ESD-S 7.1-1994

(An illustration of the probe is found in photograph 1, E, page 11)

This is a standard issued by the ESD Association, USA. It describes measurement techniques for testing the electrical resistance of floors in a range of $2.5 \cdot 10^4 < R_E < 1.0 \cdot 10^{11} \Omega$, to classify their electrostatic behaviour. Measurement is carried out with a probe that weighs 2.27 kg (5 pounds) with a diameter of 6.35 cm (2.5 inches) Ø. [12]
This standard issued by the American Society for Testing and Material (ASTM) describes procedures for classifying resilient floor covers in the form of tiles or sheet flooring in regard to their electrostatic behaviour. The floor covers are divided into the following groups:

- **Conductive floors**
  \[ 2.5 \cdot 10^4 \, \Omega < R_E < 10^6 \, \Omega \]

- **Static-dissipative floors**
  \[ 1.0 \cdot 10^6 \, \Omega < R_E < 1.0 \cdot 10^9 \, \Omega \]

Measurement is carried out with a probe weighing 2.27 kg (5 pounds) with a diameter of 6.35 cm (2.5 inches). Individual values may lie beyond this range as long as the mean values fulfil the requirements. [13]

### 3.4 ASTM F 150-98

(An illustration of the probe is found in photograph 1, E, page 11)

This standard issued by the American Society for Testing and Material (ASTM) describes procedures for classifying resilient floor covers in the form of tiles or sheet flooring in regard to their electrostatic behaviour. The floor covers are divided into the following groups:

- **Conductive floors**
  \[ 2.5 \cdot 10^4 \, \Omega < R_E < 10^6 \, \Omega \]

- **Static-dissipative floors**
  \[ 1.0 \cdot 10^6 \, \Omega < R_E < 1.0 \cdot 10^9 \, \Omega \]

Measurement is carried out with a probe weighing 2.27 kg (5 pounds) with a diameter of 6.35 cm (2.5 inches). Individual values may lie beyond this range as long as the mean values fulfil the requirements. [13]

### 3.5 DIN IEC 61340-4-1 (VDE 0300 part 4-1)

(An illustration of the probe is found in photograph 1, C, page 11)

This standard stipulates the testing techniques for determining electrical resistance on all types of floor covers and laid floors. Up until 2002, the standard classified floors into three areas: [9]

- **Electrically conductive floors** (ECF)
  \[ R_E < 1 \cdot 10^6 \, \Omega \]

- **Dissipative floors** (DIF)
  \[ 1 \cdot 10^6 \, \Omega < R_E < 1 \cdot 10^9 \, \Omega \]

- **Astatic floors** (ASF)
  \[ \text{charge} < 2 \, \text{kV} \]

Measurement is carried out with a probe weighing 5 kg with a diameter of 5 cm. The latest version of this standard does not classify types of floors; only the actual testing technique is described. The probe must weigh 2.5 kg and have a contact surface of 65 mm in diameter on hard, unyielding surfaces.

### 3.6 DIN EN 61340-5-1 und -2

(An illustration of the probe is found in photograph 1, C, page 11)

In 2002 this standard replaced DIN EN 100015. Measurement takes place according to DIN IEC 61340-4-1. The requirement for floors is \( R_E < 1 \cdot 10^9 \, \Omega \). If a floor-footwear system is used as the main means for grounding personnel, the resistance for this combination must be determined by an ESD coordinator. Values between \( 0.75 \cdot 10^6 \) and \( 35 \cdot 10^6 \, \Omega \) are recommended.

For safety reasons, a minimum value for the specific object may be stated. [10]
3.7 ESD STM 97.1 and 97.2 - 1999

Floor Materials and Footwear Resistance Measurements in Combination with a Person.

Both of these standards have been issued by the American "ESD Association".

ESD STM 97.1 is solely a measuring standard and does not specify any limit values. It describes the measuring technique for determining the leakage resistance of the "person-footwear-floor" system. The measured voltages used for testing are 10 volt and 100 volt. In general, observance of the recommendation for system resistance in DIN EN 61340-5-1 is required.

ESD STM 97.2 does not use resistance to earth as the measured quantity but the charge of the person in volt. This "walking test" is solely a measuring standard and does not specify limit values. Normally, the walking test is passed if the charge of the person is less than 100 volt.

3.8 DIN VDE 0100

(An illustration of the probe is found in photograph 1, D, page 11)

As a further requirement, the observance of DIN VDE 0100 may be required for the protection of personnel. In this case, the position transition resistance of insulating floors and insulating walls is measured. Measurement is carried out with a 25 cm x 25 cm metal plate and a damp cloth and resistance may not be less than $5 \times 10^4 \, \Omega$ in any one place. [11]
According to the experience of member companies, the results that are achieved by the measuring techniques described in 3.1 to 3.4 using different probes are comparable. What is important is that there is little contact resistance between the coating and the measuring probe. The use of soft, highly conductive rubber or moist blotter paper serves well for this purpose.

The techniques described in 3.5 and 3.6 do not provide reproducible results in many cases because of the contact problems between the measuring probe and the floor.

In conformity with DIN 28052-6, surfaces that can be subjected to foot traffic should only be measured after 7 days at the earliest. It is recommended to select the number of measurements according to Table 1:

<table>
<thead>
<tr>
<th>Area of the placed coating system</th>
<th>Number of measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>less than 10 m²</td>
<td>1 measurement / 1 m²</td>
</tr>
<tr>
<td>10 to 100 m²</td>
<td>10 to 20 measurements</td>
</tr>
<tr>
<td>more than 100 m²</td>
<td>10 measurements / 100 m²</td>
</tr>
</tbody>
</table>

If the required measured value is not achieved once at one of the measuring points, further measurements within a radius of approx. 50 to 70 cm should be executed.

A: 1 kg probe according to BGR 132, DIN 28052 - part 6, Principles for approving coating systems on concrete in storage, filling and handling facilities issued by DIBt and Worksheet S 30 "Electrically Conductive Floor Covers" issued by Arbeitsgemeinschaft Industriebau e.V. (AGI).

B: 3-point electrode according to DIN EN 1081

C: Measuring probe according to DIN IEC 61340-4-1 and DIN EN 61340-5-1 and -2

D: Probe according to DIN VDE 0100

E: Probe according to ESD-S 7.1-1994 and ASTM F 150-98
4.1 Resistance to Earth Potential

To determine the resistance to a point that can be earthed, the electrical resistance that exists between a measuring probe on the measuring device and an earthed point (earth potential) is measured.

With this system, the resistance between the hand of a person who is wearing ESD footwear and standing on the testing device and earth potential is measured. Experience in practice has shown, for example, that the resistance of the system is highly dependent on the transition resistance between person-footwear and footwear-floor.

4.2 “Person-Footwear-Floor” System Resistance

With this system, the resistance between the hand of a person who is wearing ESD footwear and standing on the testing device and earth potential is measured. Experience in practice has shown, for example, that the resistance of the system is highly dependent on the transition resistance between person-footwear and footwear-floor.

4.3 Walking Tests

In ESD STM 97.2, a measuring technique to determine the charge of a moving person in combination with the floor is described. This technique provides a dynamic measurement of the complete system “walking person”, footwear and floor system. This means that the voltage that builds up on the person moving on the floor in volt and the time of compensation of voltage through the floor are measured (Chapter 3.7).

The following minimum conditions should be fulfilled by the “person-footwear-floor” system:

- The maximum charge of persons walking on the floor system should not exceed 100 V
- Compensation of voltage between the charged person and the floor should take place quickly (optimal < 0.3 seconds)

Therefore, when this measuring technique is used, the requirements that are placed are highly dependent on the measuring conditions and on the person, footwear and floor system as a whole.
The following illustration shows how conventional conductive coatings on a reactive resin base are usually constructed:

Photograph 4: Standard construction of a conductive floor coating

Priming and, if the substrate needs to be smoothed, a levelling filler create a pore-free, smooth surface for the subsequent coatings.

The actual conductive coating consists of a thin conductive layer which is covered by a thicker finishing layer. The conductive layer is electrically connected to the building’s earth through a copper conductor.

The charge is transported from the surface of the finishing coat in a vertical direction down through the finishing coat to the conductive layer. From here the charge is then transported within the conductive layer to the building’s earth. By dividing the task of transporting the charge, coating manufacturers can make use of light as well as coloured top coatings since this layer only needs to conduct electrical charges from its surface to the conductive layer below. A relatively low content of conductive aggregates (e.g. carbon fibres) suffices for this task and these have little influence on the optical appearance of the coating. The transport of the charge to the building’s earth is carried out through a highly conductive black layer which contains, e.g. carbon black or graphite.

5.2 Conductive Floors for Avoiding the Risk of Ignition and in ESD Areas

Conductive floors with the construction described above have a resistance to earth in a range between $10^4 \, \Omega$ and $10^9 \, \Omega$. These values reliably and permanently fulfil conventional requirements for the conductivity of floors in areas in which combustible or explosive materials are stored or handled.
For facilities and work places in ESD areas, conductive floors are only one component in the complete system to prevent hazardous electrostatic charges. In these areas, not only the floor but also desks, chairs and work clothes must be made conductive by suitable means.

Different standards concerning the design of ESD areas place different requirements on the conductivity of the different components. Among others, the following conditions are stipulated:

1. **System test person-footwear-metal plate according to ESD STM 97.1**
   \[500-2000 \cdot 10^3 \, \Omega\]

2. **Test with 5 kg electrode according to DIN IEC 61320-4-1**
   \[R = < 1 \cdot 10^6\]
   Optimal \[10^4-10^5\]

3. **System test person-footwear-floor**
   Set value \[7.5 \cdot 10^5-3.5 \cdot 10^7 \, \Omega\]

4. **Measurement of decay time according to DIN EN 61340-5-1**
   From 1000 V to 50 V \(< 2s\)

5. **Charge voltage according to DIN EN 61340-5-1 and IEC 61340-5-2**
   \[U = < 100 \, V\]

**5.3 Notes on Placing Conductive Reactive Resin Floors in ESD Areas**

Individual solutions should be the goal for each individual case and the following items should be discussed with the client:

- Establishment of requirements concerning resistance to earth and resistance to personnel as well as the necessity of a walking test
- Establishment of the measuring techniques and conditions
- Establishment of the number of measured values for resistance to earth and resistance to personnel (see Chapter 3)
- Establishment of the materials to be used for constructing the system and the layer thickness of the individual components to be achieved in the system
- Determination of the characteristic values stated above based on a sample system on site by the client’s ESD coordinator or outside expert
- Working conditions for the respective system components
- Notes on regular maintenance of the complete ESD system to be carried out by the user

Even a carefully placed and well maintained "person-footwear-floor" system does not provide 100% protection from damage caused by electrostatic charges.
In general: The technical documentation provided by the member companies represented in Study Group 5.9 was used as the basis for preparing this State-of-the-Art Report.


Standards and Guidelines Named in this Report


[6] Principles for Approval: Coating systems for concrete in storage, filling and handling facilities, coating systems for collection basins, collection rooms and surfaces made of concrete in facilities for the storage, filling and handling of water-endangering liquids, September 2000 [D]


Sources of the Standards

[A] Jedermann-Verlag, Postfach 103140, 69021 Heidelberg, Germany
[B] Beuth Verlag GmbH, Burggrafenstraße 6, 10787 Berlin, Germany
[C] VDE-Verlag GmbH, Bismarkstraße 33, 10625 Berlin, Germany
[D] Deutsches Institut für Bautechnik, Kolonnenstr. 30 L, 10829 Berlin, Germany
[E] Electrostatic Discharge Association, 7900 Turin Road, Bldg 3, Ste 2, Rome, New York, USA
[F] ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA
[G] Callwey Verlag Leser Service, Heuriedweg 19, 88131 Lindau, Germany
**Terminology**

**Ω**
Ohm: unit of electrical resistance named after the German physicist, Georg Simon Ohm (1778 to 1854):

\[ 1 \text{ } \Omega = 1 \text{ } \text{Volt} / 1 \text{ } \text{ampere} = 1 \text{ } \text{m}^2\text{kg}\text{s}^{-3}\text{A}^{-2} \]

**kΩ**
Kiloohm: 1,000 Ohm.

**MΩ**
Megaohm: 1,000 Kiloohm or 1,000,000 Ohm.

**Leakage resistance**
The leakage resistance of an object is the electrical resistance that is measured between an electrode placed on the object and earth.

**Astatic**
Materials are astatic or anti-static if they disperse or inhibit electrostatic charge through friction or through surface contact separation towards other materials (triboelectrical charging).

**BetrSichV**
German operational safety regulations which have replaced VbF (German regulations on combustible liquids)

**Electrostatic charges**
Electrostatic charges are electric charges that accumulate through mechanical separation of same or different materials at the separated surfaces or occur on other conductive objects or persons caused by electrostatic induction. The lifting of feet (footwear) from a surface is a separation process which, when walking, can cause a person to become charged. The charging capacity of a person is approx. 100 pF (Pikofarat, ein pF = 1·10^{-12} F).

**Resistance to earth**
The resistance to earth of an object is the electrical resistance that is measured between an electrode placed on an object and earth.

**Earth potential**
Reference earth (neutral earth) according to DIN VDE 0141 is that part of the surface of the earth in which no measurable voltage occurs between two points from earth current.

**ESD**
ESD (ElectroStatic Discharge) is the discharge of static electricity. It leads to the equalisation of electric charges between two bodies with different potentials and is affected by the discharge of a spark or direct galvanic contact when an electrostatic field is discharged.

**ESDS**
Electrostatic discharge sensitive device: a component or device which may be damaged by electrostatic discharges.
EPA
ESD protected area: an area in which components or devices are protected from damage caused by electrostatic discharges by practical means.

Hazard classes
Combustible liquids within the sense of (German) regulations governing facilities for storing, filling and transporting combustible liquids on land (VbF 53) are materials with a flash point which at 35°C are neither solid or unctuous, have a vapour pressure of 3 bar or less at 50°C and belong to one of the following hazard classes:

- Hazard class A I: flash point below 21°C
- Hazard class A II: flash point from 21°C bis 55°C
- Hazard class A III: flash point over 55°C bis 100°C
- Hazard class B: flash point below 21°C however, as opposed to Hazard class A I it is soluble at 15°C

Corresponding designations according to VbF / BetrSichV

<table>
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<tr>
<th>Formerly (VbF)</th>
<th>New (BetrSichV)</th>
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<tr>
<td>A I or B</td>
<td>Highly flammable</td>
</tr>
<tr>
<td>A II</td>
<td>Flammable</td>
</tr>
<tr>
<td>A III</td>
<td>***</td>
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</table>

According to the new BetrSichV rules, facilities formerly classed A III no longer need to be monitored.

Charge
An (electric) charge designates a certain quantity of electricity on a body or object.

Conductive layer
A layer connected to earth which bleeds off charges.

Surface resistance
Surface resistance is the electrical resistance between two electrodes placed on the surface of a coating.

Potential difference
Potential difference is the difference between the potentials of two points in an electric field.

Position transition resistance
Position transition resistance is required according to DIN VDE 0100, part 410 and part 600 to avoid hazardous leakage currents in order to protect employees at electrical facilities when dealing with heavy current.

VbF
German regulations on combustible liquids. VbF applied to the construction and operation of facilities for storing, filling as well as transporting combustible liquids on land. VbF has been replaced by BetrSichV (German Operational Safety Regulations).
Committee members of Deutsche Bauchemie e.V.’s Study Group 5.9:

<table>
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<tr>
<th>Name</th>
<th>Company</th>
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Source of photographs:

- Sika Deutschland GmbH
  Pages: 1 (cover photograph), 2, 3, 4, 6, 7, 10, 11, 14, 16, 17, 18, 19, 20
- StoCretec GmbH
  Pages: 5, 9, 15
- Deutsche Amphibolin Werke von Robert-Murjahn-Stiftung & Co. KG, Ober-Ramstadt
  Pages: 12, 13
- Remmers Baustofftechnik GmbH
  Page: 12