Adhesive Bonding Technology

SAFETY FIRST – DIN 6701

Certification of the use of adhesive bonding in rail vehicle construction by the certification body of the Federal Railway Authority at Fraunhofer IFAM
Fraunhofer Gesellschaft

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer Gesellschaft maintains more than 80 research units in Germany, including 59 Fraunhofer Institutes. The majority of the 17,000 staff are qualified scientists and engineers, who work with an annual research budget of € 1.6 billion. Of this sum, more than € 1.3 billion is generated through contract research. Two thirds of the Fraunhofer Gesellschaft’s contract research revenue is derived from contracts with industry and from publicly financed research projects. Only one third is contributed by the German federal and Länder governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer. Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe.

Fraunhofer IFAM – Adhesive Bonding Technology and Surfaces – Expertise and know-how

The Department of Adhesive Bonding Technology and Surfaces at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials is the largest independent research group in Europe working in the area of industrial adhesive bonding technology. More than 270 employees carry out industry-oriented R&D activities in the fields of bonding and surface technology. The R&D activities focus on adhesive bonding technology, as well as plasma technology and paint/lacquer technology. The objective is to supply industry with application-oriented system solutions.

Multifunctional products, lightweight design, and miniaturization – achieved via the intelligent combination of materials and joining techniques – are opening up new opportunities which are being exploited by Fraunhofer IFAM. The activities range from fundamental research through to production and the market introduction of new products. Industrial applications are mainly found in car, rail vehicle, ship and aircraft manufacture, plant construction, energy technology, packaging sector, textile industry, electronics industry, microsystem engineering, and medical technology.

The work in the Adhesive Bonding Technology business field involves the development and characterization of adhesives, the design and simulation of bonded, riveted, and hybrid joints, as well as the characterization, testing, and qualification of such joints. The planning and automation of industrial adhesive bonding applications are also undertaken. Further services include process reviews and certifying training courses in adhesive bonding technology and fiber composite materials.

The work of the Surfaces business field is subdivided into Plasma Technology and Paint/Lacquer Technology. Customized surface modification – for example surface pre-treatment prior to bonding/coating and functional coatings – considerably expand the industrial uses of many materials.

The section Adhesion and Interface Research is engaged, amongst other things, with the early detection of degradation phenomena, the validation of aging tests, and inline surface monitoring.

The Fraunhofer Project Group Joining and Assembly FFM of Fraunhofer IFAM is carrying out ground-breaking work on large carbon fiber reinforced plastic structures and is able to join, assemble, process, repair, and carry out non-destructive tests on large 1:1 scale CFRP structures, thus closing the gap between the laboratory/small pilot-plant scale and industrial scale in the area of CFRP technology.

The Department of Adhesive Bonding Technology and Surfaces is certified according to DIN EN ISO 9001, while the Materials Testing Laboratory and the Corrosion Testing Laboratory are certified according to DIN EN ISO/IEC 17025. The Center for Adhesive Bonding Technology is accredited via DVS-PersZert® in accordance with DIN EN ISO/IEC 17024 as a training establishment for courses in adhesive bonding technology and has an international reputation. Like the Plastics Competence Center, it is also accredited in accordance with the German quality standard for further training, AZWV.

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© Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM – Adhesive Bonding Technology and Surfaces –
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**ADHESIVE BONDING IN RAIL VEHICLE MANUFACTURE**

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**A technology breaks through**

Adhesive bonding allows an optimum mix of materials – because via intelligent use of adhesives can the most suitable materials be joined. Rail vehicles, like planes, cars and ships, have become ever lighter due to the use of adhesives. The advantages of adhesive bonding for transport vehicles are higher speeds, lower fuel consumption, greater comfort and more favorably priced production.

The use of adhesives in the rail vehicle manufacturing sector has become a genuine alternative to traditional joining techniques such as riveting and welding. The reduction in vehicle weight, improved space usage, new design opportunities, less corrosion and easier repairs and disassembly have made adhesive bonding attractive in this sector. Lighter weight rail vehicles which can withstand higher loads – this is an objective which many manufacturers achieve using adhesive bonding technology.

**Lighter, more rigid, more attractive**

An example of this is the Regio-Shuttle train of Stadler Pankow GmbH (formerly ADtranz) whose bearing structure is 25 percent lighter than traditional rail vehicles. The fiber reinforced plastics (FRP) outer skin on these trains is bonded onto the steel framework carriage, as is the front mask, the front window, the strips with the side windows and the roof elements. More than half a tonne of adhesive is used for this.

Due to the increased torsional rigidity and improved damping properties, the ride comfort in such trains is perceptibly better – with simultaneously lower production and operating costs. Adhesive bonding is also being increasingly used in the interior of the rail vehicles, for example for floor panels, floor coverings and interior panelling.

New scientific findings concerning adhesive bonding are quickly transferred to industrial practice, for example in the area of FRPs. Adhesive bonding technology still has much unexhausted potential to offer rail vehicle manufacturers.

1. Regio-Shuttle train (image source: Stadler Pankow GmbH).
2. Presentation in early 2008 of one of the first certificates after successful accreditation in accordance with DIN 6701-2: Peter Hellwig and Michael Schmäcke, the supervisors in charge of adhesive bonding work at Siemens AG, MO RS PT in Krefeld-Uerdingen, here with Dr. Dirk Niermann, certification body at Fraunhofer IFAM (From left to right; image source: Siemens AG, MO RS PT).
Adhesive bonds on rail vehicles have differing safety requirements. For this reason, the DIN 6701-2 standard, which was published in May 2006 by the Eisenbahn-Bundesamt (EBA; Federal Railway Authority, FRA), was on February 26, 2008 declared to represent the current state of the art. It formulates binding standards for adhesive bonding work in the rail vehicle manufacturing sector. Companies that want to offer bonded products or related services in accordance with the standard must have the relevant production facilities audited and certified.

One of the certification bodies of the FRA is the Fraunhofer-Institut für Fertigungstechnik und Angewandte Materialforschung IFAM (Fraunhofer Institute for Manufacturing Technology and Advanced Materials) in Bremen.
Why do manufacturers of rail vehicles require a standard to regulate adhesive bonding work?

Adhesive bonding with certificate

For welds on rail vehicles and parts of rail vehicles, this question is no longer asked because binding standards have been in place for a considerable time. As the use of adhesives is developing very dynamically, the Federal Railway Authority has stimulated and promoted the development of DIN 6701 as the quality standard for adhesive bonding, analogous to the welding standard. User-companies must now meet that quality standard: With the result being that adhesive bonding in the rail vehicle manufacturing sector is becoming considerably more reliable and safer.

Since the start of 2007, companies which carry out adhesive bonding work in the rail vehicle manufacturing sector, trade bonded products, offer services for bond design, construction, repair as well as companies which purchase adhesive bondings through third parties must be accredited and possess a certificate. Regardless whether it concerns a manufacturer, repair company or supplier, specific standards must now be observed by all companies in the sector involved with adhesive bonding. This includes demonstrating proof of officially recognized qualifications in adhesive bonding by presenting certificates and via technical oral examinations. Also, a suitable quality management system, documentation for key bonded joints, suitable workplaces and many other requirements must be met in order to comply with this DIN standard (Fig. 1, page 9).

The standard was developed jointly by experts at user-companies (international rail vehicle manufacturing companies, suppliers, repair companies, etc.), adhesive manufacturers, R&D establishments – including the Fraunhofer IFAM – and inspection/monitoring bodies.
**SAFETY FIRST – DIN 6701**

**Investment brings benefits**

Although the standard initially requires a certain investment by companies in the rail vehicle manufacturing sector, the payback is rapid. This is because from now on the use of adhesive bonding technology must meet specified minimum requirements, depending on the area of application and relevance for safety. This guarantees that in each case the best bonding methods are used in practice.

For user-companies, the standard has significant benefits. Up until now, errors or shortcomings in the production could not be wholly excluded, despite the wealth of experience. The uniform and precise provisions laid down in DIN 6701 now eliminate the error sources of the past – the result is higher reliability of production.

**Improved market opportunities – on the international stage**

Although DIN 6701 is a German standard, it also has an influence on the international stage:

Major international companies were involved in the development of the standard and they recognized the need to give the quality of the adhesive bonding work in the rail vehicle manufacturing sector both a reliable and binding basis.

In addition, German companies prefer to work with national and international suppliers who meet the requirements of the DIN standard. As similar quality standards, up to now, do not exist anywhere else in the world, it is to be assumed that DIN 6701 will become a sort of global directive.
THE STANDARD FOR SAFER BONDED JOINTS

DIN 6701 – Use of adhesive bonding in the manufacture of rail vehicles and parts of rail vehicles – is a comprehensive set of regulations for quality assurance in adhesive bonding technology. It lays down detailed and precise specifications and introduces a certification system in order to make the use of adhesive bonding in the rail vehicle manufacturing sector safer and more reliable.

The DIN standard comprises 4 parts

- **6701-1** Basic terms and basic regulations
- **6701-2** Qualification of companies which use adhesives (user-companies), compliance evaluation
- **6701-3** Design specifications – guideline for construction, sizing and proof thereof
- **6701-4** Regulations for manufacturing adhesive bonds and quality assurance.

DIN 6701-2, the second part of the standard, represents the basis for the certification. It deals with the accreditation of user-companies. User-companies can be companies which use adhesive bonding to manufacture or repair rail vehicles.

They can also be companies which
- design
- purchase and sell on or
- purchase and fitassemble bonded parts and components or
- contract third parties which carry out adhesive bondings.

They must also undergo certification. However, this is only so if the relevant bonded joints have high or average safety requirements.

Safety requirements as classes

The term safety requirement refers to the importance of the bonded joint for the safety of the rail vehicle. A distinction is made here between high, average and low safety requirements. The bonded joints are accordingly assigned to classes (Table 1, page 6).

Classification of bonded joints

The designer at the company to be certified classifies the bonded joints and if necessary explains this choice to the certification body. It is important to realize that the scope of the audit, which a company has to undergo, is determined by the highest (most demanding) class.

In addition, an area of validity is specified based on the adhesive groups and bonding processes in use at the company to be audited.
The certificate which the company receives after a successful audit is valid for a maximum of 3 years. After 18 months there is an intermediate audit, called monitoring audit. At the end of the 3 years the company can apply for a new certificate for 3 more years. At any time within the period of validity the company can change the class and area of validity of the certificate by contacting the certification body.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>Examples a</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Bonded joints on rail vehicles and parts of rail vehicles with high safety requirements</td>
<td>GFRP head to shell, front window in front mask, side windows in carriage body, plating on carriage structure, external parts, equipment boxes on carriages, roof structures</td>
</tr>
<tr>
<td>A2</td>
<td>Bonded joints on rail vehicles and parts of rail vehicles with average safety requirements</td>
<td>Interior furnishings, e.g. wall cabinets, partition walls, panelling, floor coverings to floor base, tanks not under pressure, seat attachment to floor</td>
</tr>
<tr>
<td>A3</td>
<td>Bonded joints on rail vehicles and parts of rail vehicles with low safety requirements</td>
<td>Plates, mirrors, floor coverings, handles, ventilation grilles</td>
</tr>
<tr>
<td>A4</td>
<td>This class applies to companies which has no own production of bonded parts but which designs or purchases and sells on or purchases and fits bonded parts assigned to classes A1 and A2.</td>
<td></td>
</tr>
</tbody>
</table>

a Besides the above-mentioned examples, other bonded joints on rail vehicles can also be assigned to the above classes depending on their safety requirements.

Table 1: Classification of bonded joints.
The company workforce must be qualified

The assignment of a company to a particular class has significant implications for the training qualifications required by the adhesive bonding personnel:

- For all adhesive bonding activities in class A1, a **EWF-European Adhesive Engineer (EAE)**\(^c\) is generally required to act as the supervisor in charge (SIC) of the adhesive bonding work.

- The technical knowledge of a **EWF-European Adhesive Specialist (EAS)**\(^d\) is a requirement for SICs in companies assigned to class A2.

- For class A3 there are no qualification requirements for SICs.

- The employees carrying out the bonding work must be qualified to the **EWF-European Adhesive Bonder (EAB)**\(^e\) level.

Annex A of DIN 6701-2 contains a clear summary of the qualification requirements.

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\(^b\) *EWF: European Federation for Welding, Joining and Cutting*

\(^c, d, e\) *or equivalent qualifications*

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1 Correct technical application of adhesives and substrate-specific pre-treatment of surfaces are prerequisites for manufacturing high-quality bonds having good long-term stability. This knowledge must be acquired.
Tasks of Fraunhofer IFAM

Since December 2006 Fraunhofer IFAM has been a certification body of the Federal Railway Authority for accrediting companies in the rail vehicle construction sector in accordance with DIN 6701. The tasks of the certification body are to carry out company audits, to issue or amend certificates, to undertake monitoring audits and to participate in the certification in accordance with DIN 6701 work group. The audits must demonstrate that the company satisfies the requirements of the DIN standard (Fig. 2, page 10).

Accreditation of Fraunhofer IFAM

Before being accredited as a certification body, Fraunhofer IFAM was also comprehensively audited by the Federal Railway Authority. Fraunhofer IFAM must reapply to the FRA for this accreditation every five years.

As the leading European research organization in the area of adhesive bonding technology, Fraunhofer IFAM possesses extensive know-how and knowledge, and the scope of its work ranges from fundamental research through to practical applications. For many years Fraunhofer IFAM has had a particular focus on the use of adhesives for vehicle construction. Indeed, many intelligent transport technology solutions developed at Fraunhofer IFAM in collaboration with industrial users have been key successes. Always central in this work has been the reliability and long-term stability of the bonded joints.
The various sections at Fraunhofer IFAM carry out the detailed tasks such as the dimensioning and optimum design of bonded joints, identification of suitable surface pre-treatment methods, correct application of the adhesive and the subsequent assembly work. In addition to practical trials, computer simulation is also being increasingly used here – right through to complete production planning.

Many successful projects with companies from throughout the vehicle construction sector have resulted in Fraunhofer IFAM becoming a preferred partner for industry. Our in-depth practical knowledge of industry and extensive research activities, the results of which are rapidly transferred into applications, mean that Fraunhofer IFAM can act very effectively as a certification body.

### Scope of the company audit

- Organizational integration of adhesive bonding
- Responsibilities
- Availability of personnel
- Proof of employee qualifications in adhesive bonding
- Quality requirements, quality management
- Purchasing
- Supplier management
- Contract provisions
- Logistics
- Technical facilities and space availability
- Workplaces suitable for adhesive bonding work
- Work safety
- Work specimens
- Documentations
  - Specifications
  - Drawings
  - Proof of usage safety
  - Work instructions
  - Repair instructions
  - Test plans
  - Test instructions
  - Test protocols
  - Production documentations
  - Proof of suitable machinery
  - Proof of suitable processes

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*Re-appraisal of existing documents is not required*

2. The effects of UV light and aggressive cleaning agents have aged a polyurethane adhesive. The cross-section shows this concerns only a thin layer of the adhesive surface – the top quarter.
Certification and monitoring process specified by DIN 6701-2

Decision of the company to acquire certification in the following areas:

- Manufacture
- Purchase and fitting/assembly or purchase and further sale
- Design
- Contracting third parties to carry out adhesive bondings
- Repair

Specification of the processes involving adhesive bonding

Classification of the bonded joints (A1-A3)

Determination of the bonded joint with the most demanding class

Specification of the area of validity by the company

Accordingly, modification of ongoing projects with regard to amongst other things:

- Manufacture
- Design
- Organisational integration of adhesive bonding
- Responsibilities, availability of personnel, employee qualifications in adhesive bonding
- Quality requirements
- Technical facilities and space availability, work specimens
- Documentation

Preparation of an application based on the area of validity

Company audit undertaken by the certification body

Issue of a certificate for maximum 3 years

Monitoring audit after about 18 months

Reapply for a new certificate after 3 years

Fig. 2
Training courses at the Center for Adhesive Bonding Technology of Fraunhofer IFAM

The research and development scientists at Fraunhofer IFAM are also the course tutors. The skills of adhesive bonding have to be learned. To this end, the Center for Adhesive Bonding Technology of Fraunhofer IFAM was set up in 1994. It is via the thorough training of company employees that adhesive bonding technology is becoming a technical and commercial success.

The Center for Adhesive Bonding Technology is accredited as a training establishment by the Deutscher Verband für Schweißtechnik und verwandte Verfahren (DVS), a member of the European Federation for Welding, Joining and Cutting (EWF). To date, several thousand people have successfully passed the following EWF accredited courses:

- European Adhesive Bonder – EAB
- European Adhesive Specialist – EAS
- European Adhesive Engineer – EAE

The objective is to transfer R&D findings to industry and to simultaneously support the quality management of companies by passing on practical adhesive bonding skills and knowledge.

In the rail vehicle construction sector, qualifications gained through courses at Fraunhofer IFAM are a precondition for using adhesive bonding in production.

These qualifications allow the personnel to effectively utilise the potential of adhesive bonding technology. In their specific work area they are then able to assess all factors which influence product quality and hence make the correct decisions.

Regardless of whether it concerns the construction of a component, design, adhesive-specific performance features and parameters, optimization, monitoring of the bonding process in the production or work safety: The company also benefits in many ways from having a correctly qualified workforce.

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Production planning; dosing and application technology; automation; hybrid joining; production of prototypes; selection, characterization, qualification of adhesives, sealants and coatings; failure analysis; electrical/optical conductive contacts; adaptive microsystems; dosing ultra small quantities; properties of polymers in thin films; production concepts.
- Microsystem technology and medical technology
- Adhesives and analysis
- Process development and simulation
- Application methods

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Surface modification (cleaning and activation for bonding, printing, painting/lacquering) and functional layers (e.g. adhesion promotion, corrosion protection, scratch protection, antimicrobial effect, easy-to-clean layers, release layers, permeation barriers) for 3-D components, bulk products, web materials; plant concepts and pilot plant construction.
- Low pressure plasma technology
- Atmospheric pressure plasma technology
- Plant technology/Plant construction

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- Synthetic materials
- Protein materials

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Development of functional coatings, e.g. anti-icing paints, anti-fouling systems, dirt-repellant systems, self-repairing protective coatings, coatings with favorable flow properties; formulation optimization; raw material testing; development of guide formulations; characterization and qualification of paint/lacquer systems and raw materials; release of products; color management; optimization of coating plants; qualification of coating plants (pre-treatment, application, drying); failure analysis; application-related method development.
- Development of coating materials
- Application technology and process engineering

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Surface, interface and film analysis; analysis of adhesion, release and degradation mechanisms; analysis of reactive interactions at material surfaces; damage analysis; quality assurance via in-line analyses of component surfaces; development of concepts for adhesive, paint/lacquer and surface applications; corrosion on metals, under coatings and in...
bonded joints; analysis of anodization layers; electrolytic metal deposition; accredited corrosion testing laboratory; modeling of molecular mechanisms of adhesion and degradation; structure formation at interfaces; concentration and transport processes in adhesives and coatings.

- Surface and nanostructure analysis
- Applied computational chemistry
- Electrochemistry/Corrosion protection
- Quality assurance of surfaces

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- Structural calculations and numerical simulation
- Mechanical joining technology

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Training courses for European Adhesive Bonder, European Adhesive Specialist and European Adhesive Engineer with Europe-wide certification via DVS®/EWF; in-house courses; consultancy; qualification of production processes; studies; health, safety and the environment; training course for Fiber Reinforced Plastic Technician.

- Center for Adhesive Bonding Technology
- Plastics Competence Center

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