QUALITY ASSURANCE IN ADHESIVE BONDING TECHNOLOGY

New DIN 2304 standard and its use in practice

Modern industrial adhesives are mostly high-tech products which if used correctly allow zero fault production. Some bonded joints nevertheless fail, and this is generally down to adhesive application errors. It is precisely here where DIN 2304 is of use: It lays down organizational matters relating to quality assurance and so aids the management of bonding processes.

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Adhesive bonding technology will undoubtedly be a key industrial technology of the 21st century. There is virtually no industrial or handicraft sector which does not employ adhesives in innovative ways. Germany is the global pioneer of bonding technology, and the importance of adhesive bonding to society is undisputed /1/.

The products sold by adhesive manufactures for industrial use are high-quality products which are manufactured in compliance with standards in "managed" processes. Correct development and use of these adhesives - from the planning stage to the bonded product – generally leads to zero fault production. Contradicting this statement is the fact that bonded joints unfortunately all too often do not meet the requirements placed on them, resulting in failure during the usage phase. From an objective standpoint, about 90 % of bonding errors are due to a lack of bonding knowledge. Adhesive users naturally subjectively perceive they have done everything correctly (Who would consciously make errors?) and so automatically but wrongly ascribe the failure of a bonded joint to the "adhesive": The adhesive is to blame! (Figure 1).

It is precisely this contradiction, namely that adhesives allow zero fault production and yet adhesive application faults prevent this, which the new DIN 2304 "Adhesive bonding technology – Quality requirements on bonding processes" seeks to address: If the key reason for bonding faults is not issues with the adhesive but rather issues with the application of the adhesive then improvements must be made to the adhesive application step.

DIN 2304 is consequently a user/application standard. Its specific aim is to

Figure 1: Row by row failure of bonded joints after exposure to high winds. Joint failure between the solar modules and aluminum base due to serious bonding faults

organize the adhesive application process in such a way that the user "manages" the whole process so that it is effective and reproducible, from the idea to the development and production of the bonded product. DIN 2304 also has the overarching aim to enhance the still relatively poor image of adhesive bonding and to further promote adhesive usage.

When drawing up DIN 2304, there was the difficulty of exhaustively covering very different areas, namely from industrial production to handicrafts, with just one standard. Industrial production can concern an individual work piece or larges series with many thousands of identical parts. In the handicrafts sector small series and individual products are more the norm. The anomalous practice of, for example, placing different requirements on a bonded product from series production than on the same product manufactured as an individual product is also addressed by the new standard.

For this reason DIN 2304 was deliberately intended not only to apply for all classes of adhesives and substrate materials but also for all sectors of industry and the handicrafts and all types of bonded joints (Figure 2). In order to meet the specific needs of different users, specific implementation guidelines will be drawn up and documented. These will complement DIN 2304 and provide companies with customized help for their specific needs.

Core concept of 9001

DIN 2304 is based on ISO 9001. Regardless of the fact that the reputation of ISO 9001 has suffered in industry, its core concept remains ingeniously simple: If a production step or a finished product cannot be tested by non-destructive means with one hundred percent certainty for any faults, namely when it concerns a so-called "special process", all possible errors throughout the manufacture of the finished product must be ruled out by "managing" the whole production process (Figure 3).

Based on the premise that the adhesive is a quality product which if correctly used allows zero fault production, this simply means ruling out all errors throughout the process of manufacturing the finished product.

As a consequence, the often chided quality management system (QMS) of ISO 9001 has the fundamental aim of ruling out application errors, as far as possible. "Error prophylaxis" for "special processes" via implementation of a QMS is the motto. According to ISO 9001, special processes are defined as those production steps and resulting products which cannot be tested with one hundred percent certainty by non-destructive means. And if there are errors which cannot be detected, then such errors must be prevented.

Figure 2: DIN 2304 – an industry-wide user standard for all types of bonded joints

This very concept has long been adopted in welding, a much more recent technology than adhesive bonding. Welding technology was indeed the reason for invoking the term "special process" and including this in ISO 9001.

Quality assurance based on ISO 9001

At an abstract level, the quality assurance of processes and products at a company comprises "technical quality assurance" and "organizational quality assurance" (Figure 4).

"Technical quality assurance" provides a safeguard against technical uncertainties in a process and covers - regardless of whether accredited/standardized or not - all testing techniques, test methods, test conditions, experiments, test specimens, etc. used upstream, in-process, or downstream for

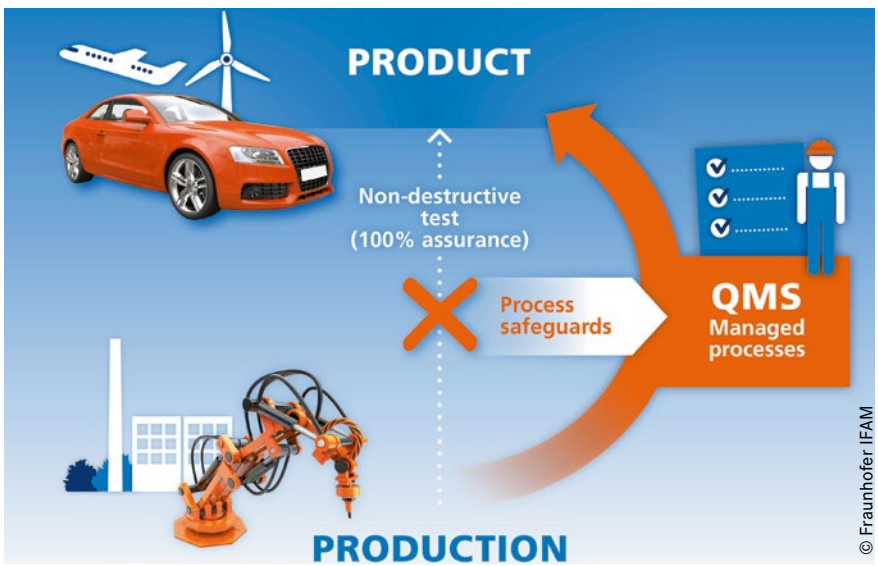

Figure 3: Core concept of ISO 9001: Management of processes using a comprehensive quality management system

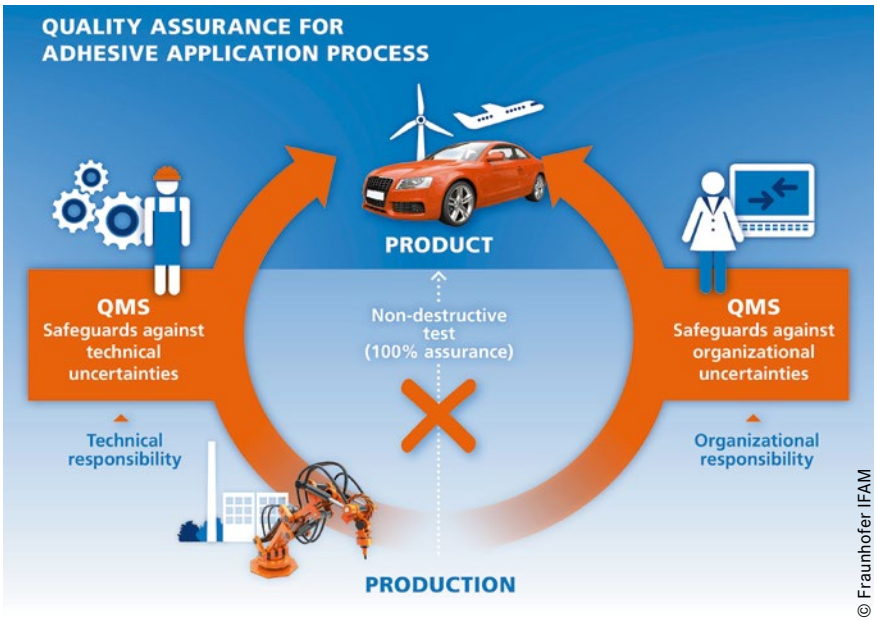

Figure 4: ISO 9001 – technical and organizational quality assurance for guaranteeing the quality of products manufacturing using special processes, namely processes where the quality cannot be tested with 100% certainty by non-destructive means

Figure 5: Upstream, in-process, and downstream quality assurance

characterizing the quality of an end product (Figure 5).

"Organizational quality assurance" provides a safeguard against organizational uncertainties in a production process and considers all quality standards, guidelines, specifications, and measures for the design and implementation of processes and production steps as well as the required personnel, equipment, space, and organizational measures at companies (supervisors and their responsibilities, layout of production areas, equipment/facilities, descriptions of company procedures, definition of interfaces, management of non-conformity, documentation, etc.).

ISO 9001 has its limitations of course, and merely stipulates the minimum requirements of a quality management system (QMS). It is this which is (formally) certified and not the (technical) contents of the relevant (application) process. It provides the basis for quality assurance but is too general to be the sole instrument for quality assurance. There is a need for specifics, namely technology-specific regulations such as standards which lay down the structures of an "organization" – namely a company using adhesives – required for correct application of the technology.

DIN 2304 – a standard for users

It is precisely these specifics, namely where ISO 9001 requires elaboration for adhesive bonding applications, which are addressed by the new DIN 2304 standard: "Adhesive bonding technology – Quality requirements for bonding processes". It lays down a binding state-of-the-art in product safety regulation for the organization and correct implementation of bonding processes at a company. It does not focus on a particular sector or product but rather on the manufacture of all types of bonded joints, whose main function is to transfer mechanical loads.

DIN 2304 accomplishes this by stipulating the requirements for manufacturing quality bonded joints along the whole process chain from development through to production and repairs/maintenance and by laying down the general organizational, contractual and technical-production basis for manufacturing bonded joints (Figure 6).

DIN 2304 has three core elements:

- Classification of bonded joints in accordance with safety requirements
- Assignment of supervisors in charge (SIC) of adhesive bonding work
- Verification that during the whole life cycle of a bonded joint the loads/stresses to which a bonded joint is exposed are always smaller than the load/stress limit of that bonded joint

Company certification in accordance with DIN 2304 is not part of the standard but is an option for user-companies. This allows user-companies to have the quality of their bonding processes veri-

fied and documented that they meet the requirements of DIN 2304.

It should be pointed out that such core elements and company certifications are not new. They are used, for example, for DIN 6701 (Manufacture of adhesive bonds on rail vehicles and parts of rail vehicles) (see below) and EN 15085 (Welding in rail vehicle manufacture).

Core element 1: Classification of bonded joints

According to DIN 2304, all bonded joints can fundamentally be assigned to safety classes S1 to S4:

S1 - High safety requirements
S2 - Moderate safety requirements
S3 - Low safety requirements
S4 - No safety requirements

Put simply, a bonded joint is classified based on the estimated consequences (intended by the component designer) should the bonded joint fail. In other words, this means that the bonded joint is classified based on the potential effects of failure of the bonded joint to transfer mechanical loads (its main function), independent of the strength and deformation properties of the relevant adhesive.

Other requirements such as suitability for use with foods, fire protection regulations, emission regulations, and work safety when manufacturing bonded joints are not considered when classifying bonded joints under this standard. There are already other standards and regulations for these aspects.

The different safety classes are defined as follows with regards to the possible effects on the aforementioned functionalities (Source: DIN 2304, Beuth Verlag, 2016):

S1 - High safety requirements

The failure of the bonded joint

- leads indirectly or directly to an inevitable danger to life and limb
- leads to a loss of the functionality, whose effects will very probably be an inevitable danger to life and limb

S2 - Moderate safety requirements

The failure of the bonded joint

- may be a danger to life and limb
- leads to a loss of the functionality, whose effects will probably be harmful to people or the environment
- leads to a loss of the functionality, whose effects will very probably cause far-reaching damage to property

S3 - Low safety requirements

The failure of the bonded joint

- leads to a loss of the functionality, whose effects will probably not be harmful to people or the environment
- leads to a loss of the functionality, whose effects will at most detriment comfort and performance
- leads to a loss of the functionality, whose effects will probably not cause major damage to property

S4 - No safety requirement

The failure of the bonded joint

- leads to a loss of the functionality, whose effects under predictable conditions will not be harmful to people or the environment
- leads to a loss of the functionality, whose effects will solely detriment comfort and performance
- leads to a loss of the functionality, whose effects will not cause major damage to property

DIN 2304 does not replace any recognized existing regulations on the use of adhesives. If in doubt, the highest demanded safety class must always be assumed.

Core element 2: Supervisors in charge (SIC)

Suitable persons for appointment as a supervisor in charge (SIC) of adhesive bonding work at a user-company are employees having responsibility for adhesive bonding and related tasks. Their suitability and technical knowledge (obtained via training, education, and /or relevant experience) must be verified and documented.

The supervisor in charge (SIC) of adhesive bonding work at the company is the main contact person for all quality matters relating to the so-called "special process" of adhesive bonding - from the planning stage through to production and maintenance/repair. In accordance with DIN 2304 a user-company must provide a sufficient number of trained personnel for the relevant tasks and document their appointment. Depending on the safety class of the bonded joint (first core element), the verification of qualifications for appointment as a supervisor in charge of adhesive bonding work may include professional training / apprenticeships (joinery, flooring fitter, decorator, etc.) and in-job further training.

Core element 3: Verification of loads/stresses

That a bonded joint must be sized such that the loads/stresses to which it is exposed are always less than the load/stress limit of that bonded joint is standard practice - not only for adhesive bonding but also for all other joining technologies. New in DIN 2304 is that assurance of this must be given by the supervisor in charge (SIC) of adhesive bonding work and verification of this must be clearly documented. The verification of this can be carried out in four ways:

1. Measurements

Based on the specifications, the load/stress is determined from experiments, calculations, standards, real data or a combination of these and documented. The load/stress limit must be determined by experiment, with accompanying statistics, taking into account age-

1	Application area: All bonded joints - from the planning phase to production and including maintenance/repair
2	Referrals to standards
3	Terms
4	Selected requirements on bonded joints (safety requirements)
5	Requirements on the process chain
5.1	Infrastructure: Production environment, design of production areas, transport, infrastructure, maintenance and customization
5.2	Personnel: Supervisors in charge (SIC)
5.3	Contract review
5.4	Development process and joint design: General aspects, division into stages, requirements on bonded joints, design of bonded joints, substrates, adhesives, surface treatment, bonding procedures, verification of bonded joints
5.5	Subcontracting: Principles. Decision-making about subcontracting, sourcing information/documentation, selection of suppliers and contract negotiation, supplier management
5.6	Process planning: Integration into the total production process, work environment, work sequence and production technology, planning any required auxiliary equipment/materials, release of processes
5.7	torage and logistics (substrates, adhesives, auxiliary materials): Incoming goods inspection, storage, in-company transport
5.8	Production: Preparatory work, pretreatment, adhesive application, bonding, curing, monitoring
5.9	Finishing, repairs, and (preventative) maintenance
5.10	Monitoring/inspection of measuring equipment, testing devices, and auxiliary production equipment
5.11	Work safety and environmental protection
5.12	Quality management

Figure 6: DIN 2304 process chain for adhesive bonding *(Source: Beuth Verlag 2016)*

ing, test media, combinations of effects, etc.. It must be assured that laboratory results correspond to results under real production conditions. The experiments can be undertaken on test specimens as component tests or on real components. Stresses and strains in the component are calculated for each bonded joint and compared with the permissible stresses/strains. It must be clear how the data have been acquired and this must also be documented. The same also applies for comparing the load/stress and the load/stress limit.

2. Component testing

The component testing can be carried out by testing a whole system or part of a system under real conditions or under conditions which mimic reality. Here, the test conditions must be demonstrated to have a similar effect on the bonded joint and on the whole system. When testing part of a system, the mutual interaction between the part-system and whole-system must also be taken into account and it must be verified that this does not falsify the results in an impermissible way. A failure criterion for test evaluation, including an integrated safety factor, must be defined. The whole process must be clearly documented.

3. Documented experience

In principle, verification based on experience is also possible. In this case it must be clearly verified that the design of bonded joint is already proven. The transfer of that experience to the actual bonded joint in question must also be clearly documented.

4. Combinations of 1 to 3

The verification of combinations of the aforementioned routes must ensure that all requirements are suitably evaluated and that the individual components are compatible with each other. The process must also be clearly documented.

Option: Certification in accordance with DIN 2304

DIN 2304 allows user-companies the option of being certified in accordance with this standard. In contrast to a company audit, process review, or expert report, the certification of a company in accordance with DIN 2304 gives customers the confidence that bonded joints are correctly manufactured in accordance with the state-of-the-art. This is the fundamental difference to audits, reviews, and expert reports which do not lead to certification and are merely momentary snapshots of a company. They confirm that on the audit date a user-company operated in accordance with DIN 2304, but give no information about what happened before or after then.

In contrast, certification in accordance with DIN 2304 also documents that a user-company operated in accordance with DIN 2304 in the periods between the first certification, monitoring audits, and re-certifications. This fundamental difference between auditing and certification is particularly important because the adhesive manufacturer cannot influence how an adhesive is used at a user-company and can only provide advice.

These company certifications, which at present still only have a civil law basis, can be carried out by certification bodies that are officially accredited by the Deutsche Akkreditierungsgesellschaft (DAkkS) in accordance with DIN EN ISO 17065 for performing DIN 2304 certifications.

In the future there will certainly be no adhesive certification in accordance with DIN 2304. The adhesive after all is only one link in the bonding process chain and the quality of a bonded joint is determined by a number of parameters depending on the application (see Figure 5: Upstream, in-process, and downstream quality assurance). Practice shows again and again that bonded joints on virtually identical components having identical requirements can be successfully manufactured using widely differing adhesive systems.

DIN 6701 – a success model standard

The opportunities for using adhesives for modern rail vehicle manufacture and the successful implementation of DIN 6700 for welding in rail vehicle manufacture were the impetus, around the year 2000, for the Federal Railway Authority to introduce DIN 6701 "Manufacture of Adhesive Bonds on Rail Vehicles and Parts of Rail Vehicles". With the exception of the area of wood processing, this standard was the first binding DIN standard on quality assurance for bonded joints.

DIN 6701 "Manufacture of Adhesive Bonds on Rail Vehicles and Parts of Rail Vehicles", with its link to ISO 9001, represents a successful model standard accepted by adhesive users and their customers, adhesive manufacturers, and the Federal Railway Authority (the initiator). It demonstrates how organizational quality assurance can be successfully implemented. This is underlined by the fact that the DIN 6701 series, which at the outset focused on Germany, is now employed internationally as the basis for bonding processes and is currently being internationalized as a European standard (EN).

Based on ISO 9001, user-companies in the rail vehicle manufacturing sector meet the personnel, equipment, production area, and organizational requirements stipulated by DIN 6701. There is in the meantime considerable experience of DIN 6701, including its application internationally, to draw upon. The indications are that the initial financial outlay required of user-companies to meet these requirements is certainly affordable, with the technological and economic benefits already being seen in the medium term.

In the meantime some 456 companies around the world are certified in accordance with DIN 6701 (as per 31.03.2015) and that number is growing.

When drawing up DIN 2304, a similar structure with four core elements was therefore chosen: Classification of bonded joints in accordance with safety requirements, Supervisors in charge of adhesive bonding work, Verification of loads/stresses, and Certification in accordance with DIN 2304.

Summary

The quality of modern adhesives allows zero fault production provided those adhesives are used correctly. The fact that bonding errors are often still encountered leads one to the conclusion that there is a clear need to optimize the application of adhesives. In other words: the quality of the adhesive application process must match the quality of the adhesive manufacturing process.

As there is no non-destructive test for adhesive application processes that can test with 100% certainty for any errors and as, consequently, adhesive bonding is a "special process" under ISO 9001, there is no alternative but to use a comprehensive QMS to eradicate errors, as described in ISO 9001 and more specifically in DIN 2304. Quality assurance for bonding processes - for correct adhesive application and documented via certification - minimizes faults, saves money, generates trust, promotes the wider use of adhesives, and sustainably improves the image of adhesive bonding. DIN 6701 has already demonstrated that. ■

Literature

/1/ Handbuch Klebtechnik 2014, http://www.springer.com/gp/book/9783658069735

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