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Industrieverband Klebstoffe e.V.

Failure prevention in solid wood bonding with dispersion adhesives

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Introduction

The most frequently asked question in solid wood bonding is which adhesive is most suitable for the application at hand. Due to the almost limitless range of different adhesives, the choice of a suitable system is a very complex task for the user.

The aim of this Briefing Note is therefore to show the reader that the use of dispersion adhesives is based on sound manufacturing principles. Since, in some cases, the manufacturing processes for solid wood building components differ significantly in industry and trade, this Briefing Note is intended to provide appropriate information for both areas of application.

The main focus for both areas of application is on the "successful and flawless bonding" of the parts to be joined. This Briefing Note does not claim to be complete. In addition to it, the adhesive manufacturers provide comprehensive information on the selection and application of their adhesives.

Apart from the later requirements that the bond needs to fulfill, also the material properties and the existing possibilities in the company's own production must be taken into account. The choice of a suitable adhesive is made on the basis of these parameters. The following basic rule applies: Any bond is only as good as the parts to be joined are prepared and processed.

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1. Intended use

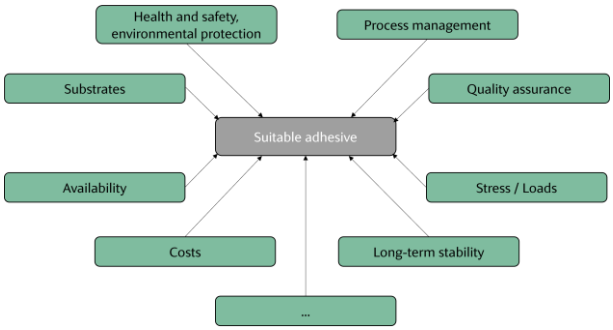


Fig. 1: Parameters influencing the choice of adhesive
Source: ©Fraunhofer IFAM

2. Solid wood

The quality of solid wood bonding is determined by the properties of the respective wood species and the preparation of the wooden parts for the bonding process. As far as material properties are concerned, the wood species is a key determinant: different wood species have different densities, porosities and strengths. The bonding process must therefore be adapted to this.

As the density of the wood increases, so do the demands on the accuracy of the wood preparation, especially the planing. With heavier types such as beech, even slight unevenness can result in bonding failures. Such unevennesses may for example be caused by plane marks. During the planing process, it must therefore be ensured that the surface is clean and that the workpieces are straight, rectangular and flat on the surface. When applying the adhesive, the density of the wood affects the processing.

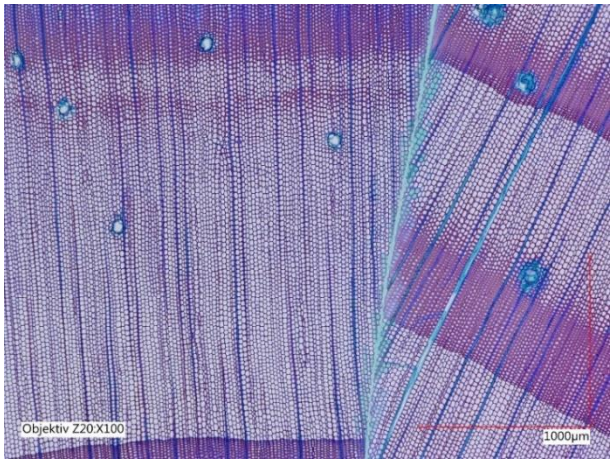


Fig. 2: Penetration of the adhesive into the surrounding wood cells

The different ingredients of the respective wood species can sometimes have a considerable influence on the chemical and physical properties of the dispersion adhesive. With some tropical woods such as

teak, the ingredients form a wax-like film on the wood surface, making sufficient adhesive wetting and penetration impossible. In this case, the parts to be joined must be bonded quickly after planing to prevent the renewed accumulation of wood ingredients on the surface. When combined with certain types of wood, dispersion adhesives can cause wood discoloration. The degree of discoloration often depends on the respective pH values and can be more or less pronounced, depending on the type of wood. Pine, maple or cherry tend to show red discolorations.

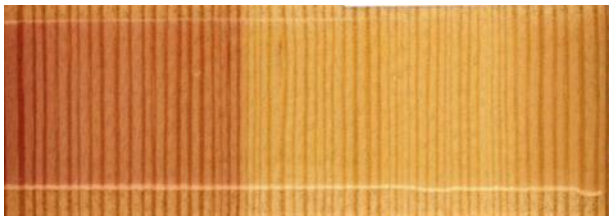
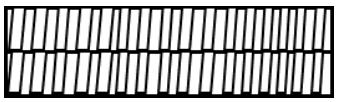


Fig. 3: Discoloration on pine

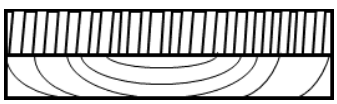
Depending on the application, appropriate grading of the wood can be of key importance for the later strength and durability of the bond. The size, shape and number of resin pockets and knots can significantly reduce the strength of a bond. Dispersion adhesives penetrate to some extent into the cell structure of both workpieces, thus achieving the required mechanical anchoring. In areas with resin pockets and knots, however, penetration into the workpiece is hardly possible, if at all. A dispersion adhesive can therefore not produce the required permanent joining strength in these areas.

The orientation of the annual growth rings is another important criterion for bonding. The individual parts must be sorted according to their growth rings. If the rings are not oriented correctly, different shrinkage processes can cause very high stresses in the bonded workpiece, which the dispersion adhesive may not be able to compensate. In practice, the gluing rules commonly applied in the woodworking trade have proved effective, namely that heartwood is glued to heartwood and sapwood to sapwood. Viewed in cross-section, the growth rings must be oriented alternatingly, thus significantly reducing the tensions.

Horizontal growth rings



Vertical growth rings



Vertical / horizontal growth rings

In the case of solid wood panels, care should be taken not to glue horizontal to vertical growth rings.

Examples of correct wood gluing

In the case of workpieces joined in the longitudinal direction, e.g. wedge joints or finger joints, care must be taken to ensure that successive lamellae have the same orientation of the annual rings.

3. Adhesives

Dispersion adhesives

PVAc dispersion adhesives, also called white glues, are produced by polymerization of vinyl acetate or copolymerization with other monomers. They are classified as thermoplastic adhesives. Today, modern dispersion adhesives are largely free of solvents. For adjusting the MFFT (minimum film-forming temperature), they may contain film-forming agents. Commonly used agents are, for example, butyl diglycol acetate, triacetin or propylene carbonate.

Technical data

Dispersion adhesives are available in a wide range of viscosities, different solid contents and pH values.

Table 1: Physical characteristics of wood glues

Characteristics	Measuring method	Unit
Solids content	DIN EN 827	%
pH value	DIN ISO 976 DIN EN 1245	
Viscosity	DIN EN ISO 2555 DIN EN 12092	mPa*s
Minimum film-forming temperature (MFFT)	DIN ISO 2115	°C

Source: IVK, TKH Briefing Note No. 3

Also a number of other application properties are important for dispersion adhesives, some of which are specified in the technical data sheets. Before using a dispersion adhesive, the minimum shelf life should be checked and the adhesive must be stirred well. It should also be checked if the adhesive shows skin formation, mold or an untypical odor, which may indicate an infestation with micro-organisms. In this case, the adhesive must no longer be used.

Important to know before starting the bonding process is the **open time** of the adhesive. This the maximum

time allowed after applying the adhesive during which wet bonding is possible. In other words: the time from application of the adhesive until the start of pressure application. It includes both the open and the closed assembly time and depends, among other things, on the application thickness, absorbency of the parts to be joined, room and workpiece temperature as well as air humidity and air movement. The recommended times are specified in the technical data sheets for the individual products. Exceeding the open time can lead to faulty bonding or weakening of the adhesive joint. The **open assembly time** is the time between the application of the adhesive and the joining of the parts to be bonded. Some manufacturers simply refer to the open assembly time as open time. The **closed assembly time** is the time between joining the workpieces and the start of pressure application. The closed assembly time is part of the open time. Since there is no clear definition, it is recommended to contact the adhesive manufacturer in case of doubt to clarify if the open time specified in the data sheet corresponds to the open assembly time or whether it means the sum of open and closed assembly time.

Mixing ratios
Dispersion adhesives used for joining wooden parts can consist of one or two components. With two-component formulations, it must be ensured that a homogeneous mixture is obtained after adding the hardener. Typical hardeners used are, for example, acidic aluminum salts or polyisocyanates. Adhesive and hardener are mixed according to the manufacturer's instructions and then applied. The working time of two-component adhesives, also referred to as pot life, is limited. It depends on the adhesive and the hardener component used and is specified in the manufacturer's data sheet.

Adhesive classification
In Germany, PVAc dispersion adhesives are usually classified according to their water resistance. DIN EN 204 distinguishes between four durability classes (D1, D2, D3 and D4).

The classification stipulated by DIN EN 204 is based on adhesive testing and not on component testing. The standard provides comparative values and should not be used as a basis for calculations, e.g. for constructions.

Information leaflet issued by the TKH:
Interpretation of DIN EN 204/205 and the evaluation of specimens

D1	Suitable for interior use where the moisture content of the wood does not exceed 15 %.
D2	Suitable for interior use with occasional short-term exposure to running or condensed water and/or occasional high humidity, provided the moisture content of the wood does not exceed 18 %. These conditions are found, for example, in kitchens or bathrooms.
D3	Suitable for interior use with frequent short-term exposure to running or condensed water and/or heavy exposure to high humidity. Exterior areas not exposed to the weather.
D4	Suitable for interior use with frequent long-term exposure to running or condensed water. Exterior use exposed to the weather but with adequate surface protection.

The water resistance of the adhesive is defined in the individual durability classes of the standard. Accordingly, water resistance is not to be equated with weather resistance.

More detailed information on this subject can be found in Briefing Note 3 "Dispersion Wood Glues" issued by the Technical Committee on Wood Adhesives:

https://www.klebstoffe.com/wp-content/uploads/2020/04/TKH_3_englisch.pdf

4. Preparation / conditioning

Depending on the intended use, it is necessary to observe the required wood moisture content. The recommended values can be taken from the applicable regulations. The moisture content of the parts to be joined should differ as little as possible. Excessive differences may lead to different shrinkage and swelling movements. Also the fitting accuracy with regard to length, width and thickness of the parts to be joined must be observed in order to avoid defects. Otherwise, this will inevitably result in strength losses because no full-surface bonding is achieved. To increase their durability, the wooden parts can be protected by a wide variety of techniques. In practice, different approaches have proven successful. Widely used is the surface treatment of the finished component by means of carefully matched coating systems. Modification of the wood by means of chemical or physical processes is also a common method. However, these processes can alter the adhesive properties of the wood. When using modified wood, please note that reduced water absorbency may delay the curing rate of the water-based dispersion adhesive and thus extend the required pressing time.

5. Bonding process

Preparatory steps
To ensure that the parts to be produced have the expected strength, careful preparation is required before the actual bonding process. First of all, the wood needs to be sorted with regard to wood moisture, knots and warpage, e.g. cupping/buckling and spiral grain. In the case of solid wood, the bonding process should take place soon after planing. When planing, care must be taken to use sharp tools in order to achieve clean surfaces without planing marks.

The workpieces should be straight in the longitudinal direction, flat on the surface and rectangular in relation to the cross-section so that stress-free and full-surface bonding is possible.

- Parts that are not straight in the longitudinal direction cause stresses in the glue joint already during the bonding process.
- Surfaces that are not flat can prevent full-surface bonding.
- Workpieces that are not rectangular can be the reason why non-uniform amounts of adhesive are applied. Additionally, the required pressure cannot be applied at right angles to the bonding area. Both can lead to joint openings and/or lower bonding strength.

Special attention must be paid to thickness tolerances when producing multilayer components. Excessive thickness tolerances of the parts to be joined may lead to non-uniform adhesive application and uneven distribution of the bonding pressure. In addition, too high tolerances prevent that the two bonding surfaces have full-surface contact during joining and pressing.

Adhesive application
Ambient conditions such as room and material temperature, relative humidity and air movement have a considerable influence on the application of adhesives. For dispersion adhesives, it is important to observe the minimum film-forming temperature, also known as white point or chalk point temper-ature. Below this temperature, the adhesive does not form a continuous film, resulting in low strength values. This applies not only to the room but also to the material temperature. Physical processes, such as the evaporation of water from the dispersion adhesive during the curing process, are temperature-dependent. Lower temperatures cause a delay, while higher temperatures accelerate the curing process.

Relative humidity primarily affects the open time of the adhesive.

If the drying process of the applied adhesive is too far advanced, sufficient strength cannot be achieved. At higher levels of relative humidity, the drying process takes place more slowly because the ambient air absorbs less moisture. As a result, the open time is prolonged. At lower levels of relative humidity, the ambient air removes the water from the applied adhesive more quickly, thus shortening the open time. Higher air movements, for example drafts caused by wide open windows and doors/ gates in the production facility, also promote the removal of water and shorten the open time. This situation is particularly critical in the case of small application quantities or high solid contents.

Dispersion adhesives for solid wood bonding can be applied by different methods, e.g. roller or nozzle application. The applied quantity must be adjusted to the application method and also to the bonded materials.

When applying the adhesive by roller, the condition of the roller (groove structure, wear, concentricity and cleanliness) has a significant influence on the homogeneity and quantity of the adhesive applied. Uneven workpieces cause uneven amounts of adhesive to come off the roller, resulting in different application quantities on the surfaces to be bonded. Since the open time depends on the amount of adhesive applied, different open times may be found on one and the same surface.

After application of the adhesive, the workpieces are joined within the open time. The joining process has a significant influence on the quality of the bond. Especially the press parameters (time, applied pressure) play an important role.

6. Finished products

Finished products
Dispersion adhesives are suitable for the manufacture of a wide range of products made of solid wood. They are not only used in traditional wood and furniture making, but also in the manufacture of wooden building components and in the production of toys, chopping boards and other decorative objects made of wood. However, the choice of a suitable adhesive must always take the expected loads and stresses into account. This is why thermoplastic dispersion adhesives do not meet the requirements for load-bearing glulam (laminated timber) construction.
The following paragraph explains which qualitative requirements need to be fulfilled by solid wood products and how the service life of building components can be improved.

Quality control
Both in industrial production and in the craft sector, quality control must take place as early as during the manufacturing process. Appropriate documentation is required, including both the material and production parameters as well as the quality requirements that have been agreed. In glulam construction, a so-called "glue log" is usually kept for this purpose. For further information, please also refer to DIN 2304-1.

In order to make a final quality assessment, it is necessary to carry out tests on the building component. These are divided into destructive and non-destructive tests.

Destructive tests
To assess the quality of a bond, a representative sample of the component must be subjected to load or stress tests. In industrial practice, this is done by randomly subjecting part of a production batch to mechanical tests. These include:

1. tensile/compressive shear strength
2. cleavage test
3. surface soundness/peel strength
4. exposure to climate change tests (heat, cold, humidity)
5. ...

Another common method for checking the adhesive application is the iodine test (Lugol's solution). This test can be used to make a faulty bond visible, caused for example by applying an insufficient amount of adhesive or by too low pressure. Also poor fitting tolerances can become visible in this way. Only the full-surface application of adhesive to both surfaces of the parts to be joined provides the required maximum strength.

- *Lugol's solution is an iodine-potassium iodide solution of 1 g of iodine and 2 g of potassium iodide dissolved in 50 ml of water. It is commercially available and was named after the French physician Jean Guillaume Lugol (1786-1851), who discovered it in 1835.*
- *Since Lugol's solution is usually prepared with an iodine content of 1 %, 2 % and 5 %, it is classified as hazardous to health according to the GHS.*
- *An iodine solution with 0.025 mol/L can also be used for test purposes. This is a good alter-native since it is not subject to GHS classifi-cation.*

In the craft sector, destructive testing is not usually carried out. The quality of the bond is assessed visually, e.g. by checking for adhesive leaking out at the joints, for open joints or for glue penetration. Failure prevention in solid wood bonding requires sound technical knowledge, which is provided by training for example as a carpenter, parquet layer or woodworking mechanic.

Surface protection
To produce wood-based components with a long service life, it is essential to ensure the structurally correct design of the glue joints, but also additional surface protection of the wood. Appropriate surface protection safeguards the glue joint from external mechanical and chemical stresses, thus signifi-cantly increasing the durability of the components.

Structural surface protection is achieved by component geometries that avoid visible glue joints and protect against external influences (e.g. rounded instead of sharp edges or beveled surfaces that allow the water to run off).

In principle, standing water must be avoided. This can be achieved by covering open surfaces with building components such as metal sheets or plastic parts. Further information can be found in DIN 68800.

Chemical surface protection includes protective coatings such as varnishes, glazes, waxes or oils. The choice of suitable surface protection depends on the component's area of application and on the required dimensional stability, an important factor e.g. for wooden windows or doors. The use of fungicidal and biocidal coatings increases the resistance of the wood against biological attack. They provide effective protection against fungi, blue stain and insects. Furthermore, the coloration of the wood is favorably influenced by varnishes and glazes, thus increasing the service life of the components. Surface protection should be regularly repeated according to the manufacturer's instructions and depending on the loads and stresses acting on the component. Only then can the almost unlimited use of a solid wood component, manufactured with the help of a dispersion adhesive, be ensured.

7. Failure patterns

Common types of failure in solid wood bonding are low strength values and open glue joints. These problems are often caused by improper processing.

Concerning the material wood, the moisture content must be adjusted to the intended use. Differences in wood moisture between the individual parts to be joined should be as small as possible. When there are parts with different wood moisture contents, the drying processes can cause uneven stresses in the glue joint. This can result in joint openings. A typical example of this are solid wood panels, some of which have joint openings of several centimeters length on their end-

grain sides. These effects do not occur immediately after processing, but mostly later during use.

Both the adhesive application temperature and the material temperature have a direct effect on the result. Dispersion adhesives require a minimum temperature in order to form a film during the curing process and achieve the required strength. If temperature and also air humidity are too low, e.g. when storing the wood in an unheated hall before use, no adhesive film will form during the bonding process. After curing, the adhesive will be chalky and brittle as the minimum film-forming temperature (MFFT or white point) was not reached. This results in a loss of strength and resistance.

Fig. 5: Too low MFFT

Furthermore, the necessary fitting accuracies and tolerances must be observed. The use of cupped wood or very wavy veneer can cause the glue joints to open after the pressing process. The adhesive strength is not yet sufficient to compensate for the stresses acting in the glue joint. This effect shows shortly after the processing, e.g. when opening the press. It is therefore necessary to sort out such defective wooden parts.

The applied amount of adhesive must be matched to the materials and type of application. Too small application quantities result in incomplete wetting of the counterpart. This means that the applied amount is too low to achieve a full-surface bond, even when applying sufficient pressure. In addition, small application quantities shorten the open time of the adhesive. Exceeding the open time also causes an incomplete wetting of the counterpart.

On the other hand, too high amounts of adhesive lead to longer pressing and curing times, as more moisture is introduced into the workpiece. As a result, the counterparts tend to "float", which can have a negative impact on the component geometry. In this case, the parts to be joined must be fixed in their desired position to prevent them from shifting.

A sufficiently long pressing time must be ensured during the pressing process.

In practice, many of the above-mentioned causes of defects can be detected with an iodine test in combination with a failure pattern analysis. After cleaving, both bonding surfaces are treated with iodine. On contact with a PVAc adhesive, the color will change to red-brown. The extent of the color change as well as the failure pattern allow conclusions on the cause of the defect.

- Color changes on both sides indicate cohesive failure in the adhesive. The proportion of material fracture is usually low. It can be assumed in this case that the pressing time was too short. The adhesive did not yet have sufficient strength to produce a firm and permanent bond between the two parts to be joined.
- If only one side shows a color change, it can be concluded that the open time was exceeded. The adhesive was already too dry and thus not able to wet the opposite side. Such joints are usually easy to separate and show hardly any material fracture.
- If neither side shows a color change, there is complete material fracture.

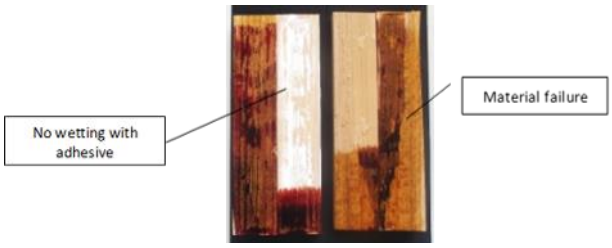


Fig. 6: Iodine test

Influence of heat and moisture on adhesive quality

Dispersion adhesives are thermoplastic adhesives. This means that they soften at higher temperatures and thus lose strength (cohesion). Standard DIN EN 14257 describes a suitable test method. With the help of this method, open joints can become visible. Also the dimensional stability of the manufactured component can be impaired since wood tends to shrink or warp under temperature fluctuations. By contrast, the influence of moisture causes wood to swell, so that stress ruptures can occur in the joints. These can be reduced by choosing an appropriate adhesive, depending on the required water resistance. Both the heat and the water resistance of an adhesive are specified in the technical information provided by the manufacturer.

Discolorations

Discolorations are a common problem and can often occur due to certain wood ingredients. They usually constitute an optical flaw and tend to decrease the value of the bonded component.

Since natural and storage-related discolorations can be minimized by prior wood selection and grading, only process-related discolorations are relevant for the bonding process.

Chemical reactions are often the cause of discoloration. A typical manifestation is the so-called "bleeding", caused by the water contained in the dispersion adhesive. This mobilizes the ingredients of the wood, causing local differences in concentra-tion and ultimately resulting in different color shades. The responsible ingredients are wood sugar (xylose), phenols or minerals. The factors leading to discoloration of the glue joint can be found both in the wood and in the adhesive used. Chemically speaking, hardeners such as aluminum chloride or aluminum nitrate are catalysts. They initiate not only the crosslinking reactions of D3 or D4 dispersion adhesives, but also other chemical reactions. Typical reactions include, for example, the iron gall ink reaction in oak and bangkirai. The wood ingredients are mainly water-soluble. Depending on the wood species and orientation of the material, as well as on the proportion of heartwood and sapwood, more or less intense discolorations can occur in the area of the glue joint, e.g. red discoloration in pine heartwood. These color changes can show directly during manufacture or later on the already joined component. Changing climatic conditions with high humidity and the associated fluctuations in wood moisture have a negative impact on the degree of discoloration. An adhesive with a high pH value can cause strong discoloration of tannin-rich wood, as can the use of alkaline cleaning agents.

Fig. 7: Discoloration on oak

For any queries or in case of doubt, you can download the manufacturers' technical data sheets as a first source of information. In addition, many adhesive manufacturers provide direct technical support.

All Briefing Notes of TKH Technische Kommission Holzklebstoffe
(Technical Committee on Wood Adhesives)
of Industrieverband Klebstoffe e.V. (German Adhesives Association)
are available in their currently valid version at:

www.klebstoffe.com

Your information platform on the Internet.
All you need to know about adhesives.