TKH Technical Briefing Note 3

Dispersion Wood Glues

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Introduction

Up until the 1950s, water-based glues made of animal or plant materials (e.g. bone glues) were widely used for gluing wood. With the developments in polymer chemistry, these glues were replaced by dispersion glues based on polyvinyl acetate (PVAc).

1. Characterization of dispersion wood glues

Wood glues based on PVAc, are produced through polymerization of vinyl acetate or copolymerization with other monomers, and are part of the thermoplastic glue category. Nowadays, modern wood glues are for the most part solvent-free. If necessary, film forming agents are added to adjust the minimum film forming temperature (MFFT).

1.1 Characteristics

The following table indicates the most important physical characteristics of PVAc wood glues:

Table 1:
Physical characteristics of wood glues

Characteristics	Measured variables/ system	Unit
Solid content	DIN EN 827	%
pH value	DIN ISO 976 DIN EN 1245	
Viscosity	DIN EN ISO 2555 DIN EN 12092	mPa*s
Min. film forming temperature (MFFT)	DIN ISO 2115	°C

In addition to that, a number of application-related properties, of which some can be found in the product data sheets, are important for wood glues.

Table 2:
Important properties of wood glues

Characteristics	Measured variables/ system	Unit
Open time*	Frequently divided into open and closed waiting time, mainly determined by manual testing under standardized conditions (DIN EN 16556)	minutes
Setting rate	Period of time until a specific minimum bond strength is attained	minutes
Min. pressing time	Pressing time until the required min. strength is attained under the prevailing conditions	minutes
Water resistance	Tensile shearing strength after exposure to water under standardized conditions (DIN EN 204 / 205)	N/mm²
Thermal stability	Bond strength at higher temperatures under standardized conditions (DIN EN 14257)	N/mm²
Creep stability	Resilience to cold flows with static load (DIN EN 14256)	days
Pot life (for two-component systems)	Application time of two-component materials after hardener is added.	minutes, hours, days

*The term “Open time” which is used in this Technical Information Leaflet is different from the definition of “open assembly time/ open time” as laid down in EN 923.

The following table contains the most important European standards for PVAc wood glues.

Additionally, there are a number of other standards for wood glues that are applicable in non-European countries. The most important ones are the ASTM standards in the USA and the JIS or JAS standards in Japan.

Table 3:
Valid standards for wood glues in Europe

Standard	Title	Valid version dated
DIN EN 204	Classification of thermoplastic wood adhesives for non-structural applications	2015
DIN EN 205	Adhesives - Wood adhesives for non-structural applications - Determination of tensile shear strength of lap joints	2015
DIN EN 14256	Adhesives for non-structural wood applications - Test method and requirements for resistance to static load	2007
DIN EN 14257	Adhesives - Wood adhesives - Determination of tensile strength of lap joints at elevated temperature (WATT 91)	2006
DIN EN 14292	Adhesives - Wood adhesives - Determination of static load resistance with increasing temperature (HRT 92)	2005
DIN EN 16556	Determination of the maximum open time for thermoplastic wood adhesives for non-structural applications	2014

Table 4:
Classification of thermoplastic wood adhesives based on water resistance (DIN EN 204)

Stress group	Storage life		Required bond strength
D1	D1-1	7 days storage at standard ambient conditions*	> 10 N/mm²
D2	D2-1	7 days storage at standard ambient conditions*	> 10 N/mm²
	D2-2	7 days storage at standard ambient conditions* 3 hrs storage of test specimens in cold water (approx. 20 °C) 7 days storage at standard ambient conditions*	> 8 N/mm²
D3	D3-1	7 days storage at standard ambient conditions*	> 10 N/mm²
	D3-3	7 days storage at standard ambient conditions* 4 days storage of test specimens in cold water (approx. 20 °C)	> 2 N/mm²
	D3-4	7 days storage at standard ambient conditions* 4 days storage of test specimens in cold water (approx. 20 °C) 7 days storage at standard ambient conditions*	> 8 N/mm²
D4	D4-1	7 days storage at standard ambient conditions*	> 10 N/mm²
	D4-3	7 days storage at standard ambient conditions* 4 days storage of test specimens in cold water (approx. 20 °C)	> 4 N/mm²
	D4-5	7 days storage at standard ambient conditions* 6 hrs storage of test specimens in boiling water 2 hrs storage of test specimens in cold water (approx. 20 °C)	> 4 N/mm²

*Standard ambient conditions: 23°C/50 % rel. humidity (or 20°C, 65 % rel. humidity)

1.2 Classification of wood glues

In Germany, PVAc wood glues are usually classified according to their water resistance. EN 204 distinguishes between four stress groups (D1, D2, D3 and D4).

1.3 EPI system

The so-called EPI systems (emulsion polymer isocyanate), which use approx. 15 % isocyanate (for the most part MDI) as a hardener, are a special product group. These systems, which can be regarded as a transition to thermosetting adhesives, have very short pot lives and are applied mechanically. Compared to uncured dispersion adhesives, EPI systems can provide significantly higher resistance to water and thermal distortion.

2. Applications

PVAc wood glues are widely used in industry, by professionals and in the consumer sector. The following list provides an overview of the most important applications:

- Furniture manufacturing (indoor use)
  - Veneering of wood and wood-based substrates.
  - For plank joints and block gluing of hardwood and softwood.
  - For gluing of dowels, frames and bodies, and other assembly bonds.
  - For veneer finishing, e.g. fleece lamination, veneer doubling and fleece impregnation.
  - Surface bonding of wood-based substrates with HPL, CPL and other suitable laminate materials.
  - For thermal lamination of wood-based substrates with decorative finish foils.
- Furniture exposed to moisture (bathroom, kitchen, outdoor use)
  - For the manufacture of furniture and built-in components for bathrooms, kitchens and other wet environments, it is recommended to use D3 or D4 systems.
- Window and door manufacturing
  - For the manufacture of laminated window scantlings and corner assemblies. Special requirements to be observed in this regard include thermal stability and water resistance.
- Installation of parquet and laminate flooring
  - Preferably, D3 glues should be used as joint glue for installation of parquet and laminate flooring (e.g. gluing of tongue and groove).
  - Protection of joints against moisture.

2.1. Other applications

- Stairways and handrails (made of wood), interior finishing with wood-based materials
- Gluing for outdoor applications with D4 systems, however, with appropriate surface protection only. The bonds may not be exposed to outdoor weathering.
- Production of drywall.
- Repair bonds of wood-based materials.
- Hobby / do-it-yourself woodwork

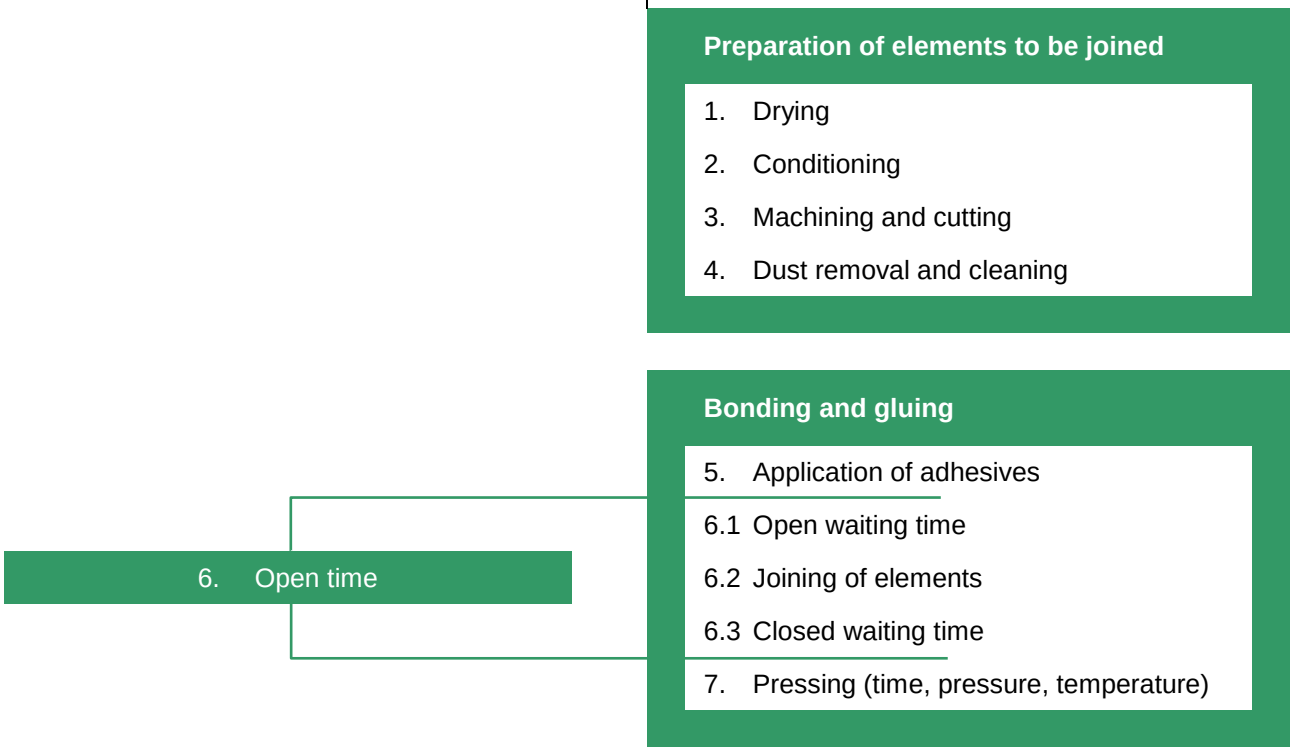
3. Installation systems and methods

According to the wide variety of applications, there are also a number of different application methods for PVAc wood glues:

Adhesive applications	Adhesive application systems Manual application method	Automatic application method
Dowel bonding	- Application by bottle into the dowel hole - Application using pressure equipment	- Automatic dowel injection by means of a metering unit (pressure equipment)
Slot/ tenon gluing	- Finishing spatula perforated on both sides - Pressure equipment with slot/tenon roller - Chain wheel - Brush, trowel	- Automatic metering unit with finishing spatula perforated on both sides
Scantling production	- Brush - Trowel - Pressurized container with surface rake - Pressure tank with bead application - Pressure tank with roller	- Roller applicators - Nozzle application machines
Board joint bonding	- Brush - Multiple nozzle swivel blade - Roller application - Pressure tank	- Roller applicators - Nozzle application machines
Surface bonding / film / veneer/ pattern	- Notched trowel - Glue roller, e.g. Gupfo brand rollers	- Roller applicators - …
Frame gluing	- Glue bottle - Brush	- Nozzle application machines
HF gluing	- Notched trowel - Roller	- Roller applicators - …

4. Process for gluing wood and wood materials

The following illustration provides a schematic overview of the individual process steps during gluing:



4.1. Drying / wood moisture

Wood is a natural product that absorbs moisture from the environment and releases it back. Swelling and shrinkage of wood depend on the change in moisture content. This plays a significant role when it comes to gluing solid wood elements and must therefore be taken into account.
Air-dried wood has a moisture content of approx. 15 – 20 %, depending on the climatic conditions. It is possible to assume a moisture content of approx. 8 % when wood is used in living areas. This is the moisture content frequently referred to in the instructions provided in data sheets. Wood with a higher moisture content requires longer pressing times, since it takes longer for the wood to absorb the water contained in the dispersion.

4.2. Conditioning

It is important that wood elements to be joined always have the same moisture content with a max. tolerance of 2 %. Otherwise, the difference in shrinkage and swelling during equilibration of the moisture content can lead to stress, which not only affects the glued joint, but can also result in deformation of the workpiece. To prevent this from happening, the workpieces must be conditioned thoroughly before gluing or bonding (temperature and moisture equilibration). The minimum period required for conditioning also depends on the type of the workpiece and its dimensions.

It is necessary to measure the moisture content of the wood using the appropriate instruments before each gluing operation.
Additionally to conditioning of the wood-based material, the minimum film forming temperature (MFFT) of the adhesive must be taken into consideration. MFFT is the minimum temperature required for dispersions to form a homogeneous film during the setting process.
During processing, it is necessary to ensure that ambient, adhesive and workpiece temperature comply with the specifications in the technical data sheet. If the temperature is too low, no film will form. The dispersion will only dry and form an inhomogeneous, possibly flaky white layer, which will fail to develop the required strength.

4.3. Machining and cutting

Machines and tools must be adjusted to achieve a good fitting accuracy and surface quality during machining. Plane marks and blunt or worn tools, etc. can lead to fit inaccuracy and therefore result in poor glue joints. Burnt cut edges caused by blunt tools prevent the adhesive from setting properly, what will reduce the strength of the bond.

Wood should preferably be glued shortly after machining or cutting, so the surfaces do not change again. This is especially important for types of wood that contain resins and oils, like teak, rosewood and rubberwood.

4.4. Dust removal / cleaning

To achieve optimum bonds, it is necessary to remove any release agents and contaminants prior to the bonding process. The easiest way to remove dust from surfaces is to either exhaust, brush or wipe them off using suitable solvents.

4.5 Application of adhesive

The viscosity of PVAc wood glues is adjusted to permit different application methods. It is important to apply the glue evenly. The amount of glue applied depends on absorbency and fit accuracy of the wood or workpieces and normally ranges between 100 and 250 g/m². For some wood types, one-sided application is sufficient. Application on both sides is recommended when working with hardwood or woods that contain oils and resins.
In any case, the manufacturers' recommendations for their products must be followed.

4.6. Open time

The wet time or open time is the period of time "during which wet bonding is possible after application of the adhesive," i.e. the time between adhesive application and pressure application.
This includes both the open and the closed waiting time, and depends, among other things, on the thickness of the applied layer, absorbency of the elements to be joined, ambient and workpiece temperature, as well as air humidity and speed. The recommended times are specified in the technical data sheets of each product.

4.6.1. Open waiting time

The open waiting time is the time between application of the adhesive and the joining of the parts. However, some manufacturers refer to the open waiting time as “open time”. Since the definitions are not completely clear, we recommend contacting the adhesive manufacturer if in doubt, to clarify if the open time in the data sheet indicates the open waiting time or the sum of the open and the closed waiting time.

4.6.2. Joining of elements

The workpieces to be glued must be joined during the open time. The surfaces to be joined must be free of any dirt or contaminants.

4.6.3. Closed waiting time

The closed waiting time is defined as the time starting after the elements to be bonded have been put together and ends when the heat and/or pressure required for setting or curing is applied. The closed waiting time is part of the open time.

4.7. Pressing (time, pressure, temperature)

The minimum pressing time depends on the type of wood and pressing temperature. Hardwood and woods containing oils and resins require longer pressing times.
An increase in temperature results in a decrease in the required minimum pressing time. Pressure must be sufficient to guarantee required fit accuracy of the joints. The specific pressure depends on the wood type and ranges between 0.2 and 1.5 N/mm². If the pressure is too high, glue might penetrate into the substrates, therefore leading to defective bonds. Temperatures and pressing times are usually specified in the technical data sheets.

5. Fault analysis

The following table was created to help troubleshoot the causes of defective bonds. It outlines the most common causes as well as the relevant corrective action.

Appearance	Failure	Corrective action
Glued joint clearly visible. Hardened adhesive partly noted as glossy film in uneven areas of parts to be joined.	Pressure too low. Insufficient fit accuracy of elements to be joined.	Increase pressure. Improve fit accuracy of surfaces.
Joint opening. Adhesive film is pulled apart in some areas.	Insufficient pressing time.	Increase pressing time and temperature. Reduce moisture content of wood, if possible.
Adhesives, which normally form a transparent film after hardening, have a white appearance.	Temperature below MFFT.	Adjust adhesive, material and ambient temperature of MFFT.
Joint opening. Insufficient moistening of joined elements. No glue runs out of joints during bonding.	Insufficient glue application.	Increase amount of glue until glue runs out of joints evenly.
Joint opening. Adhesive film is partially pulled apart. Frequently occurs in HF bonds.	Temperature too high.	Lower temperature. Decrease HF time and extend cooling time.
Joint opening. Adhesive takes too long to harden. Pressing times have increased.	Wood moisture too high.	Reduce moisture content of wood and increase pressing times.
Joint opening. No moistening in some areas. Discoloration of adhesive.	Woods containing oils and resins.	Only glue freshly planed wood. Clean surfaces with appropriate solvents in compliance with safety instructions. Perform test bonds.
Joint opening. Second element insufficiently moistened during one-sided application.	Open time exceeded.	Check moistening with iodine test. Adhere to open time. Increase amount of adhesive. Avoid any air movement at the open glue joint. Protect open glue joint from exposure to thermal loads.

6. Discoloration

Wood discoloration is a change in the natural color of the wood. There are several causes for such discoloration.
Discoloration of wood is either caused by fungal decay (e.g. blue stain, brown rot, white rot fungi) or other physiological or chemical influences (e.g. weathering, water exposure, drying, contact with metals or metal ions [especially iron or iron ions], UV irradiation, changes in pH value).
In addition to that, occasionally some discoloration may be caused by natural substances contained in the wood such as humic acids or tannins, especially when heartwood is used.
The risk of unwanted wood discoloration can be minimized during processing by avoiding contact with iron, selecting an appropriate adhesive system, and complying with the adhesive manufacturers' instructions.

Useful information on this topic is also available on the homepage of the Thünen Institute of Wood Research in Hamburg (http://www.ti.bund.de/de/hf/).

7. Environmental and safety aspects

7.1 Environmental aspects

Like almost all polymers, PVAc wood glues are not easily biodegradable. They remain in the environment and decompose abiotically and biologically very slowly. However, they are not classified as toxic to the environment, nor do they result in bioaccumulation. As a result, dispersion wood glues are of less significance from an environmental protection perspective.

7.1.1 Emissions from PVAc wood glues

Modern PVAc wood glues have very low emissions on account of their composition. In this regard, it is necessary to mention primarily film forming additives that are needed for MFFT adjustment besides residual monomers and additives occurring in the ppm range. Their content might account for up to 3 % of the glue. Finished workpieces hardly emit any measurable pollutants because the glue has a low volatility and the glue joint is covered for the most part.

7.2 Safety aspects

All safety aspects relating to an adhesive can be found in the manufacturer's material safety data sheet.

7.2.1 One-component glues

Vinyl acetate polymers and copolymers in water-based systems are inert and chemically inactive from a biological perspective. There are certain health-related issues due to the preservatives used in such systems to protect them against any microbiological contamination (bacteria, fungi, yeasts).
Most preservatives (biocidal substances) are sensitizing substances (H317 - Can cause allergic skin reactions or Contain EUH208 <Name of sensitizing substance>. Can lead to allergic reaction). As a result, metering is carried out based on the principle: only as much as necessary and as little as possible (see IVK's position paper). The low concentration of biocidal substances required for preservation can be considered as rather unlikely to induce allergies. Allergies might be triggered, however, in persons who have already been sensitized. Wearing protective gloves can help to virtually eliminate this risk.
Other additives and residual monomer fractions of polymers are of lesser importance based on our current state of knowledge.

7.2.2 Two-component systems

7.2.2.1 Metal salt curing agents

Aluminum chloride is classified as caustic (H314 – Causes severe skin burns and eye damage), and irritations are not expected with low quantities (< 1 %). Aluminum nitrate x 9 H_2O is classified by manufacturers as oxidizing and irritating (H272 Can accelerate fires; Oxidizing agent, H315 Causes skin irritations, H319 Causes serious eye irritation.). No oxidizing properties or health-related effects are expected with the low quantities (< 1 %) present in wood adhesives.

7.2.2.2 Isocyanate-based curing agents

Health issues are assessed taking into account the hardener system used. Normally, HDI or MDI-based hardeners are used.
Monomer diisocyanates are not used in their original form because of their volatility and the related exposure risk, but rather only in the form of high molecular, low-volatile polyisocyanates. Such polyisocyanates only contain low quantities of the original isocyanate as a residual monomer. MDI is an exception, which can be used without any modification on account of its low volatility.
Isocyanates are reactive compounds. In terms of their toxicological characteristics, it is necessary to take into consideration their irritating effect especially on skin, eyes and the respiratory system, as well as their sensitizing potential based on the type of isocyanates used and method of application. As a result, allergic skin reactions may occur after repeated contact. Overexposure to diisocyanates by means of inhalation may lead to sensitization of the respiratory system with asthma-like symptoms. While sensitization is a consequence of a single or repeated overexposure, secondary allergic reactions may occur, however, in persons already sensitized even at considerably lower concentrations. People suffering from allergies, asthma and other diseases affecting the respiratory system are not permitted to perform any tasks that involve products containing isocyanates.
The workplace limits for diisocyanates are usually not exceeded when using aerosol-based application methods (e.g. spray applications) and heat curing, provided adequate ventilation is ensured. Low-volatile polyisocyanates do not contribute to respiratory system exposure under such conditions.
Skin exposure is prevented by wearing appropriate protective gloves. See the specifications in the manufacturers' material safety data sheets. When it comes to industrial safety and monitoring, the regulations of TRGS 430 Isocyanates - Exposure and Monitoring – apply.

Properly hardened dispersion wood glues are inert (fully polymerized synthetic resins) and are safe physiologically.

Annex 1:
Values for equilibrium moisture content

Relative air humidity in %	Wood moisture in %
10	2.8
20	4.5
30	6.0
40	7.5
50	9.1
60	10.9
65	12
70	13.3
80	16.4
90	20.7
100	30
The value relate to a temperature of 20 °C.	

Annex 2:
Swelling and shrinkage values of different wood types

Wood type	Level of shrinkage from fresh wood to kiln dry wood				Differential swelling in % per 1 %	
	Gross density in g/m2	Lengthwise in %	Radially in %	Tangentially in %	Radial	Tangential
Maple	0.63	0.4	3.8	8.2	0.17	0.32
Birch	0.65	0.6	5.3	8.0	0.16	0.24
Beech	0.69	0.3	5.8	11.8	0.20	0.41
Spruce	0.47	0.3	3.6	7.8	0.19	0.36
Oak	0.69	0.4	4.3	8.9	0.18	0.34
Ash	0.69	0.2	5.0	8.0	0.17	0.28
Pine	0.52	0.4	4.0	7.7	0.19	0.36
Cherrywood	0.61	–	5.0	8.7	0.17	0.31
Larch	0.59	0.3	3.3	7.8	0.14	0.30
Walnut	0.68	0.5	5.4	7.5	0.18	0.33

List of references for both tables:

1. Oskar Toscha, "Grundlagen der handwerklichen Holzverleimung", Published by: Hans Rösler KG, Augsburg
2. U. Lohmann, "Holzlexikon“, 4th Edition 2003, Published by: DRW Verlag, Leinfelden-Echterdingen