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СТРУКТУРА КЛЕЕВОГО СЛОЯ В ДЕРЕВЯННЫХ СОЕДИНЕНИЯХ: ЧТО ВНУТРИ И КАК ЭТО ИЗУЧАЮТ

INSIDE WOOD GLUE JOINTS: STRUCTURE AND HOW WE STUDY IT

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Summary: This article looks at how we can study the structure of glue joints in wood using modern tools. Real cases are shown where these methods help to detect problems before they appear in finished products. It is explained how microscopy, spectroscopy, and tomography work together and how this information is useful not just for researchers but for production engineers too.

Keywords: glue, joint, wood, microscope, defects, bonding.

Аннотация: в статье рассмотрено, как можно изучать структуру клеевого слоя в соединениях древесины с помощью современных приборов. Приведены реальные примеры, где такие методы помогают находить брак

заранее, ещё до того, как изделие разрушится. Показано, что микроскопия, спектроскопия и томография могут работать в комплексе и давать полезную информацию не только учёным, но и производственникам.

Ключевые слова: клей, шов, древесина, микроскоп, дефекты, соединение.

Nowadays, glued joints are used almost everywhere in woodworking in furniture, windows, doors, plywood, beams everything holds together thanks to glue. At first glance, it may seem like the glue line is just a thin layer between two parts, but in fact, it determines whether the structure can handle load, moisture, and time. That’s why it’s important not only to choose the right glue but also to understand how it behaves inside the wood, what happens at the border between the glue and the material, and what it all looks like inside. Looking at it from the outside won’t give any answers you need equipment that lets you “peek” inside the microstructure. This is where microscopy, spectroscopy, and computed tomography come in. These methods help to see the joint layer by layer: where the glue went deep and where it didn’t, whether there are voids, cracks, or delamination, and how the boundary between glue and wood fibers looks. Calcination of the mineral filler also contributes to the strengthening of the adhesive bond. However, increasing the adhesive interaction between the glue and the filler is acceptable only up to a certain limit, as it leads to increased stiffness of the system and slows down relaxation processes [1].

All of that affects strength directly, especially when we’re talking about glued beams or panels and not just small decorative pieces. The first method that usually comes into play is electron microscopy. It lets you look at the surface of the joint with thousands of times magnification. Where the eye sees nothing, the microscope shows microcracks, bubbles, uneven distribution, or even chemical inclusions. It’s especially useful when working with glues that have fillers or additives. With that level of magnification, you can see how evenly the glue is spread, whether there are clumps or gaps. The main disadvantage of such methods of connecting the elements in question is the impossibility of making it completely hidden. This leads to the lack of fire protection of the connecting elements and requires additional measures for finishing the supporting structures for aesthetic purposes [2].

If you want to dig deeper, there's transmission electron microscopy. It's a bit more complex, but it shows not only the surface but also the inside structure. The sample has to be sliced very thin sometimes fractions of a millimeter but the result is a clear picture of how the glue sits between the wood layers, whether there are transition zones or sharp boundaries. Those sharp boundaries are dangerous – that's where failures usually start. Then comes IR spectroscopy. This method lets us "see" the chemical groups in the glue, both before and after bonding. It's especially important for newer glues like biodegradable or non-formaldehyde ones. Sometimes a joint may look strong from the outside, but in reality, the glue hasn't fully cured, or some leftover substances are still inside. Over time, that can ruin the bond. Spectroscopy helps catch these problems early.

If we need a full picture of the glue line in 3D without cutting or damaging it we can use tomography. It's like an advanced X-ray. It shows how deep the glue has penetrated into the wood, whether there are hidden voids, and if the geometry of the bond is okay. What's great is you can scan a finished product; no needs to break it just put it in the machine and get a 3D model of the inner structure. That's a gamechanger in production: it saves time, prevents defects, and gives clear results. The influence of temperature on the change in the value of adhesive strength can be carried out similarly to the above-mentioned testing methods for adhesive joints according to ISO 4587:2003, but this approach is very labor-intensive and requires testing a large number of samples in a wide temperature range, and the determined change in strength does not characterize the maximum temperature for maintaining the strength of an adhesive joint under static load [3].

In real-life production, these methods aren't just theory they solve real problems. For example, at one furniture plant in Voronezh region, when they switched to new glue, the panels started coming apart within weeks. Everything looked fine on the outside, but under stress, the parts separated. Using a microscope, they found out that the glue hadn't penetrated the wood pores it stayed on the surface. So the bond was weak. After adjusting the application method, the problem disappeared. A similar case happened at a construction company using glued laminated timber. Tomography revealed air pockets inside the joint. The glue was applied too quickly, and the roller didn't spread it evenly. That led to voids, which later caused failure. Once they adjusted the pressure and speed settings, the issue was solved. Again, it was thanks to microstructure analysis.

There are more and more examples like this. Many companies now understand it's better to check the joint properly once than to lose money on repairs or deal with complaints later. Affordable microscopes and mobile test units are already on the market. Sure, they won't give lab-level precision, but they're good enough to show whether something's wrong and if a deeper check is needed.

Besides detecting flaws, this kind of analysis also helps when choosing glue. The market is full of options biodegradable, formaldehyde-free, nano-modified but not all of them work with every type of wood. Sometimes glue that works great with pine won't bond well with oak. The only way to be sure is to check how the glue interacts with the fibers whether it sticks, if there are voids, or if the boundary is smooth. And that's visible only through microscopy or spectroscopy.

Everything that happens in a glued joint is invisible to the naked eye, but that's where the product's future is decided. Will it last? Will it hold? Today's microstructure analysis methods give us the chance to spot issues before they become serious. Electron microscopy, spectroscopy, and tomography these aren't just for scientists anymore. These are tools that are already useful in the workshop and on the factory floor. The glue line isn't just a strip between parts it's a whole world where chemistry, physics, and technology come together. And the better we understand that world, the stronger and more reliable our products become. That's why this kind of research isn’t a luxury it’s a necessity, especially when we’re talking about things where safety and durability are on the line.

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