

## **Influence of the glue joint on the speed of propagation of sound waves in wood**

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**Abstract:** *Influence of the glue joint on the speed of propagation of sound waves in wood.* The aim of this study is to demonstrate differences in the propagation of sound waves in wood depending on the type of glue used to form the joint. Samples of tree species considered as resonant wood, i.e. Norway spruce (*Picea abies*) and sycamore (*Acer pseudoplatanus*), and for comparison, wood of European beech (*Fagus sylvatica*) were used. The fractured samples were glued together using glutinous fish glue, polyurethane glue (Titebond Liquid Glue) and cyanoacrylate glue (BONDOLOC B415). All types of glue are used in instrument repair, of which glutinous glue is regarded to be the correct one used in gluing technique. The test was carried out using a non-destructive ultrasonic method. It has been shown that the highest decreases in speed of propagation of sound waves are in wood glued with glutinous glue and the lowest in wood glued with cyanoacrylate glue.

*Keywords:* glue joint, lutherie, acoustic wood

### **INTRODUCTION**

Wood, as a heterogeneous and anisotropic material, is characterized by different features, thanks to which this raw material is used in many branches of industry. It is used, among others, in furniture making, boatbuilding, construction, haberdashery and lutherie [Krzyśik 1978].

For the production of musical instruments so-called resonance wood is being used, which has suitable acoustic properties such as, among others, the sound propagation speed in the material, acoustic resistance and the sound radiation factor. Depending on the instrument or instrument's component for which the wood is to be used, a suitable species is selected, based on its properties [Wegst 2006].

In the construction of stringed instruments, the construction of the soundboard has the biggest influence on the sound of the instrument, which is why the top plate is usually made of Norway spruce (*Picea abies*) and the back plate of sycamore (*Acer pseudoplatanus*) [Stanciu et al. 2022].

Despite the fact, that lutherie is an art, which primarily involves the creation of neck instruments such as cellos, violins, banjos or guitars, in reality the luthier spends most of his time repairing and restoring instruments. In addition to wood, the glues used in the process are also important.

Adhesives of animal origin have been used in lutherie since very beginning. They are strong and durable when dry, while retaining considerable flexibility [Sedlačik & Mamiński 2016].

Glutinous glue is considered to be the best glue for manufacturing wooden musical instruments. It is created via extracting proteins from hides and bones. It is most commonly found in the form of beads or flakes, which must first be soaked in cold water in order to swell and then heated to obtain a homogeneous liquid form. The disadvantages of this type of glue are its short open time, degradation at temperatures above 60° and low resistance to biotic agents. The advantages of such type of glue, on the other hand, are mainly the reversibility, when exposed to heat and water and the absence of harmful effects on the human body [Zenkteler 1996]. Thanks to the reversibility of the glue, it was possible to

disassemble and study the construction of antique instruments in order to discover how to tune resonance plates and how to build their modern equivalents [Waltham 2018].

Recently, liquefied glutinous adhesives were developed. They are sold in a packaging allowing for immediate application. The modern ready-to-use glutinous glue is as reversible as the traditional solid adhesive.

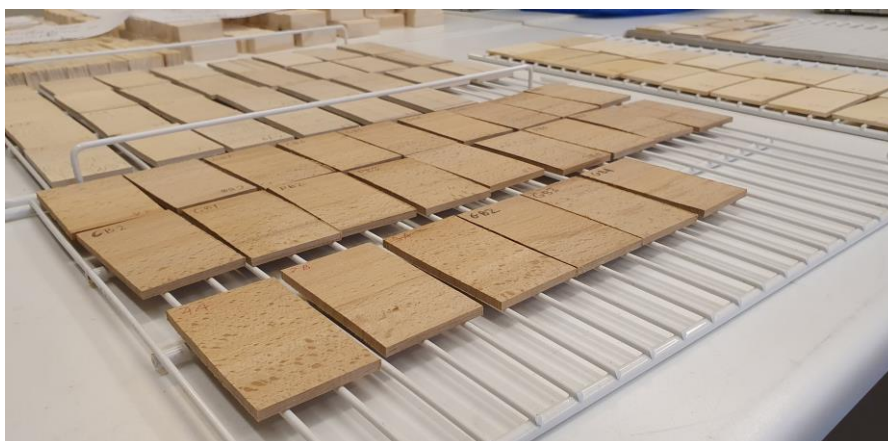
After World War II, the plywood industry developed rapidly, and new adhesives were sought. Many synthetic adhesives with different properties, binding time and implementation were developed [Hoadley 2000]. Nowadays, the lutherie industry does not only use the glutinous glue. The type of glue depends on the type of material we want to bind and the function that given element is to fulfil. Also important is the form of application and the time of binding, which should enable proper positioning of instrument elements.

No information has yet been found in the available literature about studies on the effect of glue joints on the acoustic properties of wood, therefore this paper aims at the comparison of propagation velocities of sound waves on wood samples with glue joints. Three different types of adhesives were used for comparison. One of them was a traditional fish glutinous glue in flake form. The other two were adhesives designated for lutherie by manufacturers – polyurethane and cyanoacrylate glue. A non-destructive method of measuring featuring ultrasound has been used for testing [Bucur 2006]. The following wood species were used as the test material: Norway spruce (*Picea abies*), sycamore (*Acer pseudoplatanus*) and beech (*Fagus sylvatica*). The first two species are commonly used in lutherie. The wood of beech is rarely used, mostly in cheaper instruments or in the elements that do not have a significant effect on sounding of the instrument. The examination is designed to check, if repairing procedures for musical instruments that feature bonding the components have a significant influence on the speed of sound propagation as one of the parameters defining the acoustic characteristics of the wood. Speed analysis can help to identify the adhesive that is most suitable for the repair process of a music instrument.

## MATERIALS AND METHODS

For the test there were prepared samples from three species of wood: Norway spruce (*Picea abies*), sycamore (*Acer pseudoplatanus*) and European beech (*Fagus sylvatica*). The samples were cut out to measure the velocity in the radial direction (approx. 85mm), the other measurements were approx. 50mm in the longitudinal direction and the thickness in the tangential direction approx. 4mm.

Radial samples (Fig. 1) of Norway spruce, sycamore and beech wood were used for the study. The samples were divided between 3 adhesives (Table 1): glutin fish glue made out of swim bladders, single component polyurethane glue Titebond Liquid Glue and cyanoacrylate glue BONDOLOC B415.



**Figure 1.** Wood samples before drying

To determine the density in the dry state of approximately 0% moisture content, the samples were dried in a laboratory dryer at 104°C for 24 h, measured and weighed. The obtained density values were placed in Table 1.

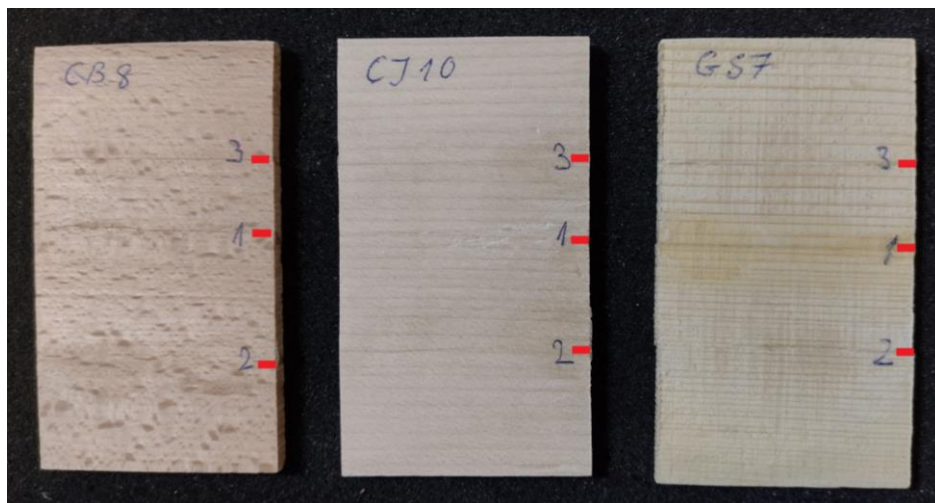
**Table 1.** Wood densities and sample quantities for individual glues

Glue	Norway spruce ( <i>Picea abies</i> )		Sycamore ( <i>Acer pseudoplatanus</i> )		European beech ( <i>Fagus sylvatica</i> )	
	number of samples	average density [kg/m <sup>3</sup> ]	number of samples	average density [kg/m <sup>3</sup> ]	number of samples	average density [kg/m <sup>3</sup> ]
Glutinous	9	450	10	519	8	666
Cyanoacrylate	8	443	10	505	8	658
Polyurethane	8	427	10	511	8	659

The samples were then conditioned in order to equilibrate the humidity (equivalent humidity of 6-8%). Before the measurement the apparatus was prepared, which consisted of two transmitting and receiving ultrasonic cylindrical heads 004T40 (for 40kHz, transducer size 40mm) and material tester UMT 01 connected to a computer (with dedicated UMTLink software installed) via a parallel LPT port. During the tests the following parameters were selected for the apparatus: energy 60V, gain 40db, amplitude 5.5V, frequency 40kHz and repetition 12Hz, pulse mode. The parameters were chosen to be universal for the three wood species. The first measurement of the propagation speed of longitudinal ultrasonic waves was carried out after the device had been calibrated in order to obtain a time correction resulting from the delay of the measuring path of the testing device. With each subsequent survey the device was calibrated.

The coupling substance was applied to the fronts of the samples immediately before testing, then the samples were placed between two heads, which were mounted on a special stand with a clamping device allowing to maintain the same clamping force (1 kg) of the heads to each sample and to measure the length through which ultrasound waves passed. After the measurement the ultrasound transmission gel was removed from the samples.

The samples were then broken at 1/2 the measuring length (in the radial direction) and the glue was applied (Fig.2). Glutinous glue was applied with a wooden spatula, while cyanoacrylate and polyurethane adhesives were applied directly from the factory packaging to the samples.



**Figure 2.** Examples of glue joints in beech, sycamore and spruce samples

After initial bonding and positioning of the samples, excess glue running from the joints was removed. Next, the samples were put in packs of several pieces and placed in prepared clamps until the adhesive was fully hardened (Fig. 3). Depending on the adhesive, this time was: for glutinous glue min. 24h, cyanoacrylate min. 1h, polyurethane min. 4h. After the joints hardened, the samples were subjected to another ultrasonic test.



**Figure 3.** Packet of samples in clamps

The second and third fracture of the specimens were placed at 1/3 of the measuring length on each side of the first joint. For each resulting joint the same steps were followed and the test was carried out in the same way.

The velocities of the sound wave transitions were calculated from the data obtained according to the formula:

$$v = \frac{l}{r} \left[ \frac{m}{s} \right]$$

where:

l- sample length

r- time of wave transition with correction taken into account

The results are presented in column and line graphs in the next section.

## RESULTS AND DISCUSSION

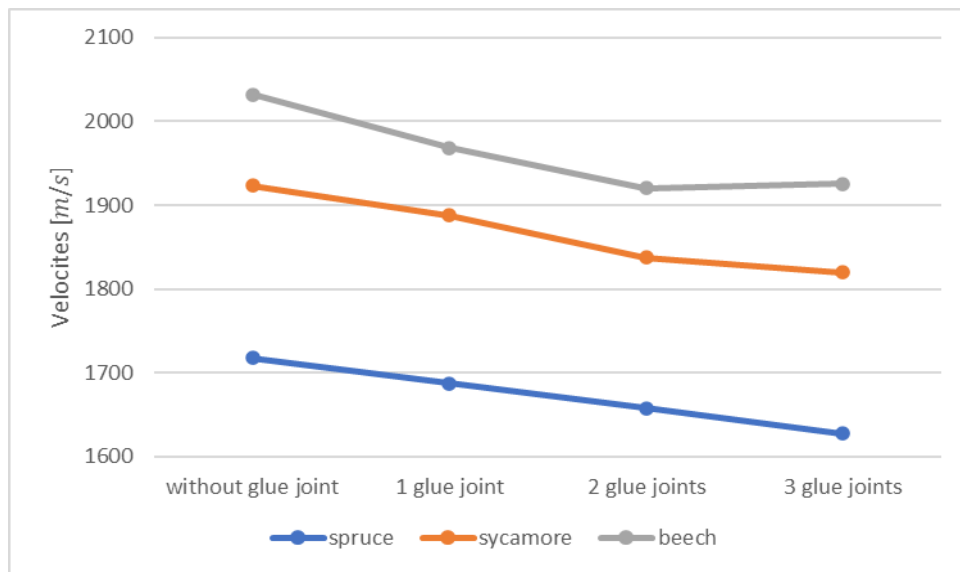
The study investigated the effect of glue joints: glutinous (Fig. 4), cyanoacrylate (Fig. 5) and polyurethane (Fig. 6) on the speed of propagation of sound waves in Norway spruce (*Picea abies*), sycamore (*Acer pseudoplatanus*) and European beech (*Fagus sylvatica*) wood. Furthermore, the results caused by each adhesive were compared. In this way, it was possible to indicate, which affected the velocity of sound propagation the least.

No data on the speed of propagation of sound waves measured in wood was found in the literature (in the same species used for testing) at the same apparatus settings. Moreover, according to Harajda and Łapa [2002], such data may be compared "when they concern the results of measurements carried out in identical conditions, on samples uniformly cut in terms of grain direction, paying attention to possible effects of the measurement methods on these results". Therefore, the velocities measured before breaking the samples and the velocities defined in the specialized literature may significantly differ from each other.

For the tested spruce wood the average velocity across fibres for all samples was 1693m/s, and for beech 2033m/s, where according to Kollmann and Côté [1968] these velocities are 1072m/s and 1420m/s respectively. However, the tested velocity in sycamore wood was 1939m/s, where according to Haines [1979, as cited in Bucur, 2006] it was 1600m/s.

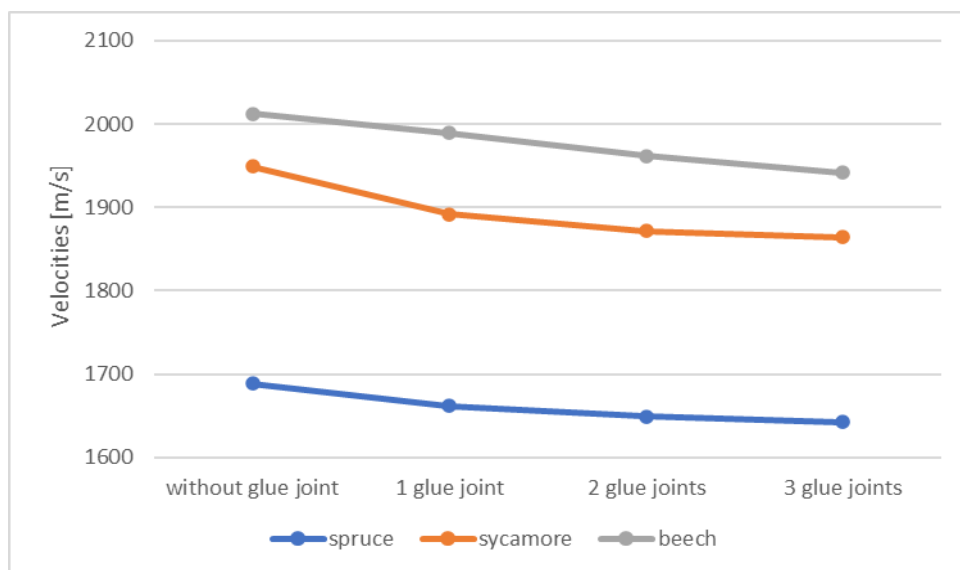
Samples with similar densities for the different types of wood were selected for testing, all of which were stored and tested under the same conditions. In addition, efforts were made to break the samples in the same places and to glue them with the same pressure force.

Tests carried out in these conditions show that in all samples the speed of propagation of sound waves was decreased. In samples glued with glutinous glue (Fig. 4) the drops after each joint were the highest and amounted to 2.04% on average in all wood species.

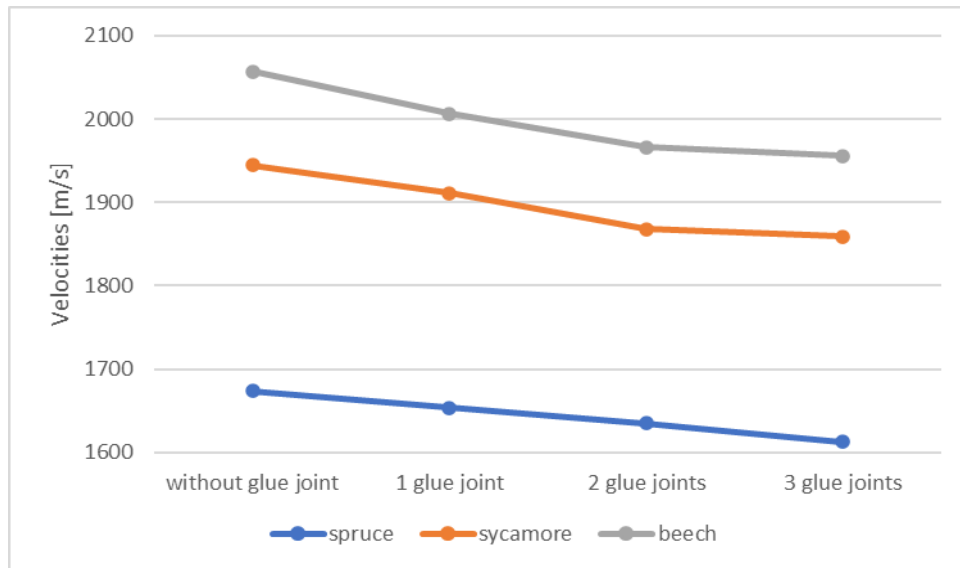


**Figure 4.** Glutinous glue in individual species

In contrast, in specimens glued with cyanoacrylate glue (Fig. 5) the velocity decreases were the smallest with an average of 1.19%, and in specimens glued with polyurethane glue (Fig. 6) they were 1.51%.

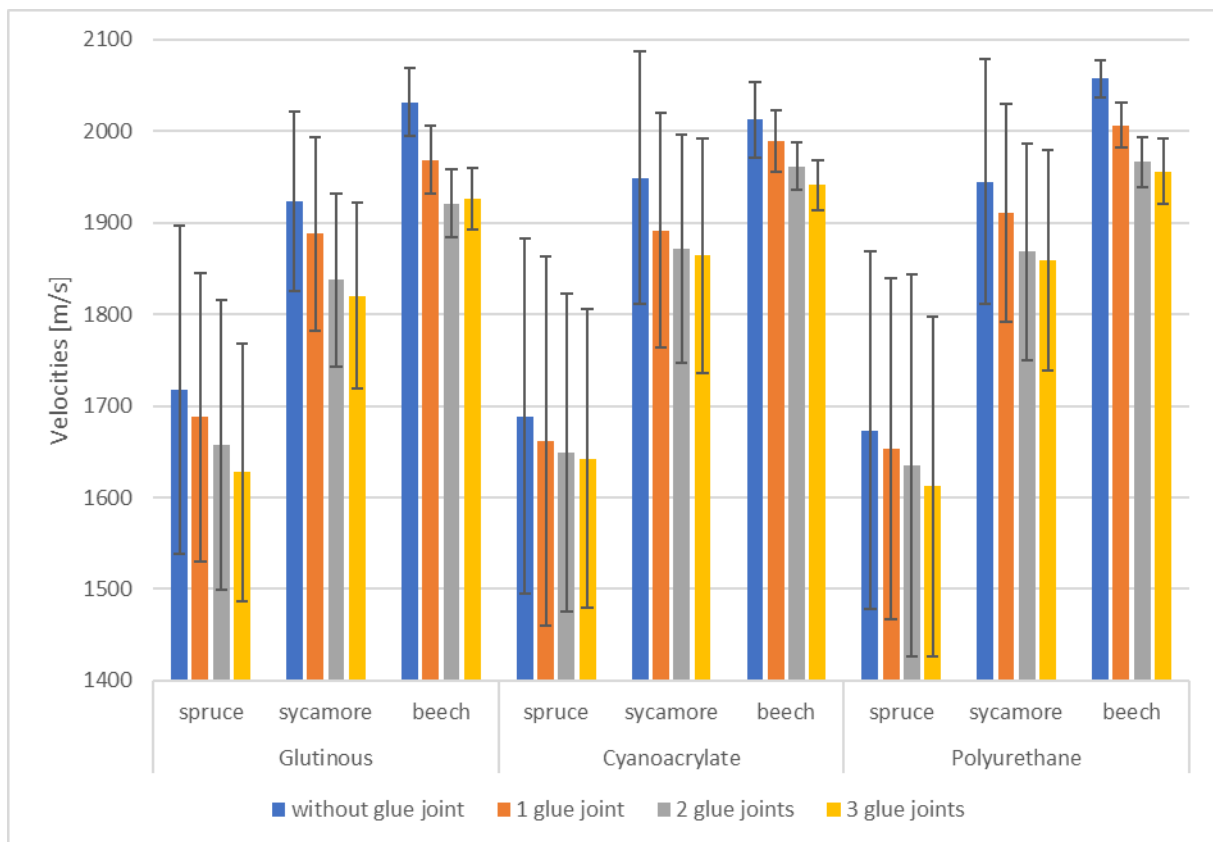


**Figure 5.** Cyanoacrylate glue in individual species



**Figure 6.** Polyurethane glue in individual species

The standard deviations of the speed of propagation of sound waves after each joint (Fig. 7) show that significant differences occur only between the glutinous glue and polyurethane glue joints in beech wood. The remaining differences between the consecutive joints are insignificant regardless of the glue used and the species of wood for which the test was carried out.



**Figure 7.** Standard deviations for the test speeds after each glue joint



## SUMMARY AND CONCLUSIONS

Based on the presented test results it can be observed that glue joints do not significantly affect the propagation of sound waves in wood. However, comparing individual adhesives it may be observed that:

1. Cyanoacrylate glue joints have the least significant influence.
2. Taking into account the results of the tests and characteristics of the tested glues, the best glue used in production of instruments and their repairs is glutinous glue.
3. Even repetitive gluing does not influence the propagation of sound waves.

On the basis of the test results, it can be concluded that the application of multiple glue joints even in single resonant piece does not significantly decrease its sound quality, so these elements can be used in building of instruments or repair of them.

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**Streszczenie:** *Wpływ spoiny klejowej w drewnie na prędkość propagacji fal dźwiękowych.* Celem pracy jest wykazanie różnic w prędkościach rozchodzenia się fal dźwiękowych w drewnie w zależności od rodzaju kleju użytego do utworzenia spoiny. Do badań użyto próbek gatunków drzew uznawanych za drewno rezonansowe, czyli świerka norweskiego (*Picea abies*) i jawora (*Acer pseudoplatanus*), oraz dla porównania użyto drewna buku zwyczajnego (*Fagus sylvatica*). Próbki po złamaniu sklejone zostały klejem glutynowym rybim, poliuretanowym (Titebond Liquid Glue) oraz cyjanoakrylowym (BONDOLOC B415). Wszystkie rodzaje klejów używane są podczas naprawy instrumentów z czego klej glutynowy uznawany jest za ten właściwy wykorzystywany w technice lutniczej. Badanie przeprowadzono nieniszczącą metodą ultradźwięków. Wykazano że największe spadki prędkości propagacji fal dźwiękowych są w drewnie klejonym klejem glutynowym a najmniejsze w drewnie klejonym klejem cyjanoakrylowym.

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