

COB-2023-2385
**ALTERNATIVE BONDING OPTIONS FOR RENEWABLE RAW
MATERIALS**

Ralf Förster
Andreas Loth
Tiago Borsoi Klein
Ulrike Siemer

Berliner Hochschule für Technik (BHT), Berlin, Germany
rfoerster@bht-berlin.de
Andreas.Loth@bht-berlin.de
Tiago.BorsoiKlein@bht-berlin.de
Ulrike.Siemer@bht-berlin.de

Abstract. *The use of natural, renewable raw materials is becoming increasingly important in industry and research due to their environmentally friendly production and disposal. Compared to fossil raw materials, which are produced from fossil fuels such as oil and coal, natural materials are in principle inexhaustible. Natural materials bind large amounts of CO₂, but are also often burned to generate heat or energy or processed into biogases or fuels. However, it makes sense to an intermediate step between harvesting and disposal. The use of renewable raw materials offers the potential to substitute the use of petroleum-based products. The use of renewable raw materials significantly reduces the emission of CO₂ into the atmosphere. Furthermore, renewable raw materials can usually be disposed of relatively easily compared to products based on fossil raw materials. The latter often cannot be completely or economically disposed of or recycled in an environmentally sound manner. Even when materials and material composites made from renewable raw materials are thermally recycled, no additional climate-damaging CO₂ is produced, but only as much as was previously bound. Renewable materials decompose much faster than most petroleum-based plastics, provided that no chemical adhesives have been used when bonding the natural, renewable raw materials. This paper presents first investigations of sustainable joining systems for renewable raw materials such as wood, bamboo and natural fibres. The results show that wood and bamboo can also be reliably joined by rotary butt friction welding.*

Keywords: *renewable materials, friction welding, wood, bamboo, natural fibers, ultrasonic*

1. INTRODUCTION

Wood is one of the most important renewable raw materials that has been used by mankind in Europe for thousands of years. In Asia, besides wood, bamboo is also very much used as a building and construction material. Unlike wood, bamboo (Bambusoideae) belongs to the family of sweet grasses (Poaceae). There are about 500 different bamboo families worldwide and hundreds of subspecies. These are native to every continent except Europe and Antarctica. The Figure 1 shows the natural distribution of bamboo around the world (RWTH, 2023).

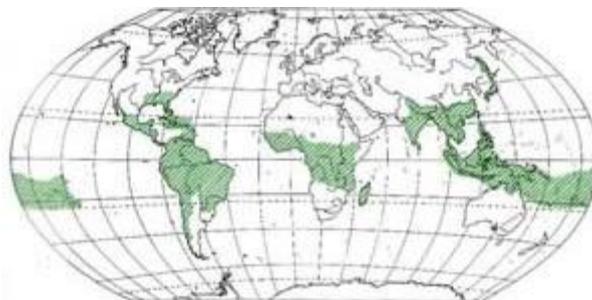


Figure 1. Natural distribution area of bamboo (RWTH, 2023).

The use of wood and bamboo for the production of tools and dwellings goes back worldwide to the beginnings of human history. Wood and bamboo bind not only water but also a great deal of CO₂ as they grow. They serve as carbon reservoirs and play an important role in sequestering atmospheric carbon dioxide. Bamboo is a renewable resource that is environmentally friendly because it reduces carbon concentration in the atmosphere and soil through rapid carbon sequestration (Kumar et al., 2023). Bamboo is one of the fastest growing plants on earth and is characterised by its very good mechanical properties. The world record for plant growth is held by Moso bamboo, which can grow up to 114,5 cm

per day (Chen, 2022). Heights of up to 35 m and culm diameters of up to 45 cm are reached. However, the average length growth of all bamboo species is only 25 cm per day (Holzmann et.al., 2012; Bambus Wissen, 2019). Like wood, bamboo is used as a construction material for building houses, bridges and furniture.

Wooden joints are usually made with nails, screws, dowels, etc. Glues and adhesives are often used for secure joining of wood joints. One disadvantage of these joining techniques is that adhesive-volatile components can be highly toxic even in small quantities. Another disadvantage is the long curing times. In most cases, adhesive joints require several hours of curing time under sometimes high pressure to reach their final strength. Traditionally, bamboo is mostly joined with ropes, fibres or wires.

A very promising technology for joining parts of several materials is friction welding. In friction welding, the components to be joined are joined by a relative movement against each other and by applying pressure to the joining surfaces. Figure 2 shows that the relative movement by friction welding can be rotational, linear, orbital or by an angular oscillation (Michel, 1999).

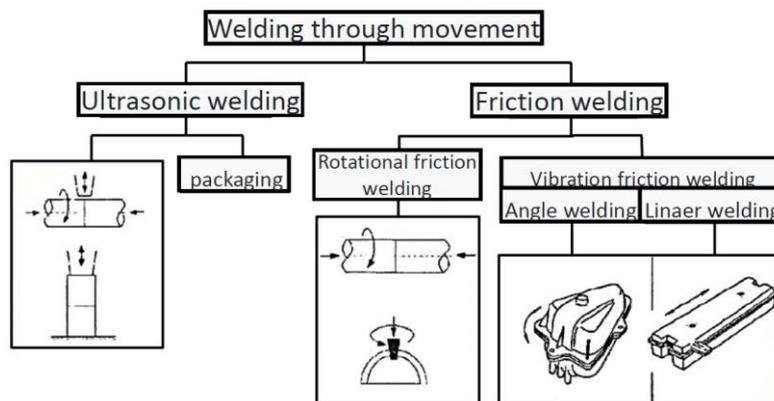


Figure 2. Friction welding process (Michel, 1999).

Due to the interaction of a component- and material-specific speed or frequency and friction time as well as a surface-related, linear friction force, the joining surfaces heat up as a result of friction. If, after a defined time, a braking process to a standstill takes place with a simultaneous increase of the frictional force to the contact pressure, the resulting upsetting pressure causes the actual welding (Schuler and Twrdek, 2019).

In rotary friction welding, two components are clamped firmly in a rotary butt friction welding machine and one is set in rotation (see Figure 3, Part 01). During the friction or heating phase, the two workpieces are pressed against each other with a defined and linear friction force. The weld is heated by the friction generated (see Figure 3, Part 02). The heating and deformation of the weld joint results from the area-related frictional force and friction time, which depends on the nature of the joint surfaces, the material and the temperature distribution in the workpieces (see Figure 3, Part 03).

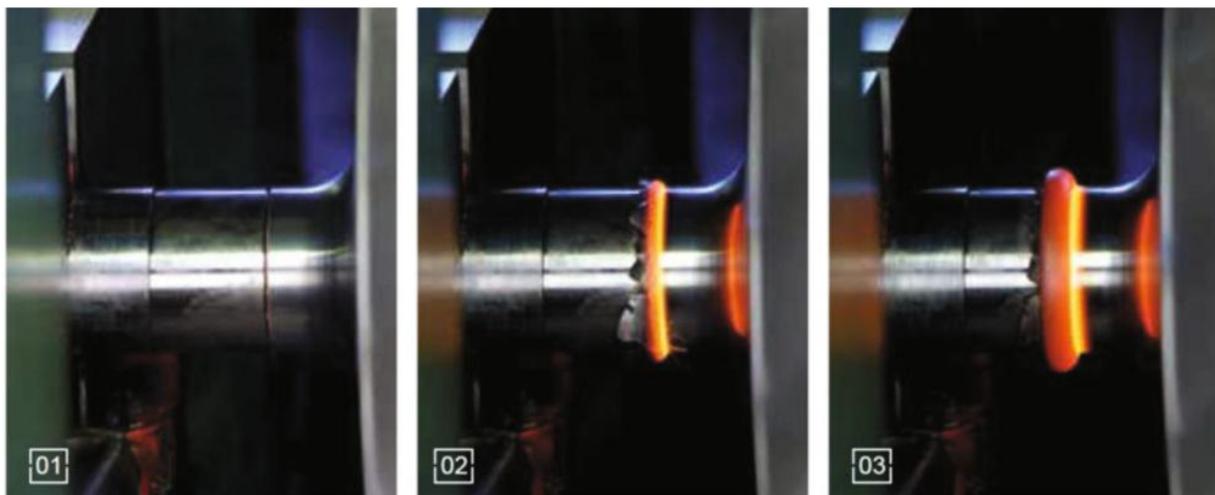


Figure 3: Rotary butt friction welding principle in three phases (Schuler and Twrdek, 2019).

In principle, friction welding can be used to weld a great many materials and material combinations. Not only steels, metals and plastics, but also ceramics, cast iron and natural materials can be joined by friction welding (Schuler and Twrdek, 2019). The technology of friction welding has so far mainly been used for joining thermoplastics and metals.

However, wood can also be joined by friction welding processes. First investigations on linear friction welding of wood and wood dowel welding were presented by GANNE-CHEDEVILLE in 2008 (Ganne-Chedéville, 2008; Ganne-Chedéville et al., 2005; Župčić et al., 2014).

The friction welding technology make it possible to produce pure wood joints without the use of additives. In the friction welding process of wood, the connection of the individual parts is achieved by the combination of pressure and heat generated by a rotary friction movement. This produces short-term temperatures of up to 350 °C. This leads to the effect that the wood components (lignin, cellulose, hemicellulose) form a viscous mass and act like an adhesive. A thermal decomposition of the polymeric molecular chains takes place, which penetrate into the deeper wood structures; after cooling, this process leads to the hardening of the molecular mixture and to surface adhesion (Schuler and Twrdek, 2019; Gfeller et al., 2004; Stamm et al., 2004).

This joining technique opens up completely new perspectives. For some time, the joining behaviour of different woods by linear friction welding has been investigated in this field of research (Ganne-Chedéville 2008). LI et. al. and WANG et. al. investigates the process behavior of dowel rotation welding of bamboo. This process is quite different from the process of rotation butt welding studied in this article (Li 2022, Wang 2022). So far, there are no findings on the joining behavior of bamboo by friction butt welding. Furthermore, no studies are known on the rotational friction welding of wood and bamboo and the joining of these two materials by rotational butt friction welding.

Applications for rotary butt welding of wood and bamboo are the glueless joining of window frames and profiled wood. This means that profiled wood scraps can be reused. Glueless joining means that the environment is less polluted with chemical substances. Furthermore, bamboo canes with almost the same outer diameter can be produced without further additives. These bamboo tubes can then be joined as scaffolding tubes with metal connectors. These scaffold tubes are much lighter than conventional steel tubes. The development of glueless joining technologies can make an effective contribution to environmental protection and the conservation of natural resources. The use of renewable and light raw materials helps to reduce CO₂ input into the environment and thus contributes to climate-neutral production. Processes similar to those described above can be used to join natural fibres. In this paper, the first investigations of friction butt welding for renewable raw materials are carried out.

2. MATERIALS AND METHODS

2.1 Samples and specimens

The diameter of the pine and beech samples used in this study was 16 mm. The diameter of the bamboo samples varied according to the diameter of the natural trunk between 15 mm and 18 mm. The shape of bamboo was conic. The used length of all test samples was 100 mm. The density of bamboo is between 500-700 kg/m³. The density of pine about 510-550 kg/m³ and that of beech about 540-910 kg/m³. All samples were air-dried and had a residual moisture content of about 12-15%.

2.2 Welding process using a conventional lathe

The preliminary tests for rotary butt friction welding of wood and bamboo were first carried out on a conventional lathe, Leinen DLZ 140 (see Figure 4). This machine allows the speeds to be adjusted continuously from 15-3100 rpm. With this test set-up, it was possible to gain initial insights into the possibilities of the new technology and the requirements for a corresponding machine. The wood samples were first face-turned and then drilled in the middle of the face (see Figure 5) of the samples, as the circumferential speed in the middle of a rotating component is zero, making it difficult to produce high-quality joints.



Figure 4. Lathe Leinen DLZ 140.



Figure 5. Sample preparation.

A difficult with this experimental setup is the overrun of the rotating spindle after the motor of the lathe is switched off. This means that after the end of the joining process, there is still a relative movement between the stationary and driven joining partner and the joint is loaded when it cools down.

2.3 Welding process using a special developed rotary butt friction welding machine

The results from the initial investigations were then incorporated into the requirements for the design of a special machine for the rotary butt friction welding of wood and bamboo. As part of a research project funded by the AiF e. V. (German Federation of Industrial Research Associations), a CNC-controlled rotary butt friction welding machine (see Figure 6 and Figure 7) was developed to carry out friction butt welding processes of wood and bamboo.



Figure 6. Rotational friction welding machine.

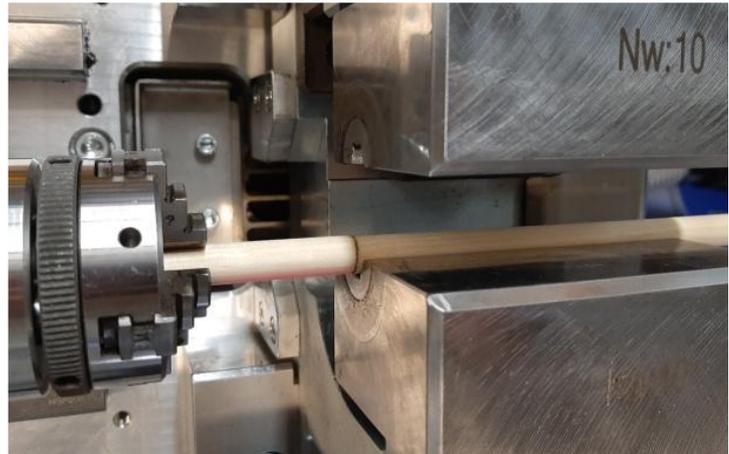


Figure 7. Welded sample in the rotation welding machine.

2.4 Process Setup and Experimental Plan

Both pine/pine and beech/beech joints were investigated with the standard lathe, DLZ 140. The rotation speeds 3000 rpm, 2500 rpm, 2000 rpm, 1500 rpm, 1000 rpm and 500 rpm were set for the two woods. The selection of the speed resulted from the first preliminary tests in Berlin and Jakarta in order to make the tests on different lathes comparable. The welding time was varied in time steps of 16 s, 12 s, 8 s, 5 s and 3 s. The welding time is defined as the time from test specimen contact to machine shutdown, not machine standstill. The welding pressure was generated at the lathe by manual force of approx. 200 N. The weld holding time was 60 s. The weld holding time started from machine shutdown. The weld holding pressure was also generated on the lathe by manual force. Different borehole diameters of 9 mm, 6 mm, and 3 mm were investigated on the timbers. Table 1 shows the machine setting parameters used for the standard lathe.

Table 1. Machine parameter for joints of pine, beech and bamboo.

	Rotational speed rpm	Joining pressure MPa	Welding time s	weld holding time s
pine	500	200	3 (no bamboo)	60
beech	1000		5	
bamboo	1500		8	
	2000		12	
	2500		16	
	3000			

The holes were drilled on both sides of the test samples. The drilling depth was 3 mm. The speeds 3000 rpm, 2500 rpm, 2000 rpm, 1500 rpm were combined with the welding times of 8 s, 5 s, 3 s and the hole diameters 9 mm, 6 mm, 3 mm full factorial. The mechanical properties of the woods and bamboo are shown in Table 2. Joining by rotary butt friction welding of bamboo was also investigated. The speeds used were 3000 rpm, 2500 rpm, 2000 rpm, 1500 rpm, 1000 rpm and 500 rpm. The welding times were 16 s, 12 s, 10 s, 8 s and 5 s. The welding pressure or weld holding pressure was also generated by manual force. The weld holding time was also 60 s. The speeds 3000 rpm, 2500 rpm, 2000 rpm, 1500 rpm were combined with the welding times 10 s, 8 s, 5 s full factorial. Instead of the welding time of 3 s, as in the pine and beech test series, a welding time of 10 s was investigated. The reason for this was the low strength results achieved with the 5 s welding time. The speeds 1000 rpm, 500 rpm were combined with the welding times of 8 s, 12 s and 16 s as for the pine and beech test series.

Table 2. Mechanical properties of bamboo, pine and beech (Dunkelberg, 2005; Lohmann, 1990).

	Young's Modulus N/mm ²	Compressive strength N/mm ²	Tensile strength N/mm ²	Flexural strength N/mm ²	Shear strength N/mm ²
bamboo	20000	62-93	148-384	76-276	20
pine	6900-20000	35-94	35-169	41-200	6-14
beech	10000-18000	41-99	57-180	74-210	6-19

For the tests with the specially developed rotary butt friction welding machine for wood, the factors shown in Tables 3 and 4 were determined after the preliminary tests with the conventional rotary machine for joining pine and beech. The investigations focused on the following factors:

- Speed [rpm],
- Joining pressure [MPa] (welding pressure and weld holding pressure),
- welding time [s].

Table 3. Machine parameter for joints of pine.

Pine Level:	Factor A: Rotational speed rpm	Factor B: Joining pressure MPa	Factor C: Welding time s
Level 1 (-)	3000	2.99	4
Level 2 (0)	3500	3.44	5
Level 3 (+)	4000	3.89	6

Table 4. Machine parameter for joints of beech.

Beech Level:	Factor A: Rotational speed rpm	Factor B: Joining pressure MPa	Factor C: Welding time s
Level 1 (-)	3200	3.20	5
Level 2 (0)	3600	4.85	7
Level 3 (+)	4000	6.50	9

The number of stages was set at three due to the limited prior knowledge of the rotational friction welding of wood and bamboo, which nevertheless allowed for the most manageable experimental effort possible. The welding pressure and the weld holding pressure were combined into the joining pressure in order to reduce the number of factors for the test plan. The weld holding time was set to 60 seconds for all samples based on the preliminary tests.

First, the arithmetic mean values of the tensile strengths for all 6 repetitions of the 27 different variations were formed with the following formula:

$$\mu = \frac{1}{n} \sum_{i=1}^n x_i = \frac{x_1 + x_2 + \dots + x_n}{n} \quad (1)$$

In addition, the corresponding standard deviations were determined with the following equation:

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{n}} \quad (2)$$

Here σ = standard deviation, Σ = sum of all values, x_i = individual values, μ = arithmetic mean value, n = number of values.

2.5 Tensile testing machine

The tensile tests were carried out on a Zwick/Roell ProLine Z050 universal testing machine. The maximum applied force can reach 50 kN. The accuracy of crosshead is up to 0.1 N and drive speed can be set on 0.01 mm/s.

3. RESULTS AND DISCUSSION

3.1 Results of specimens welded using the conventional lathe (Pine)

The investigations show that in the test series with the speeds 1000 rpm and 500 rpm in combination with the welding time of 8 s and the hole diameter 6 mm, low tensile strengths were achieved (see Figure 10 and Figure 11). With smaller welding times, no connection could be realized (see Figure 8 and Figure 9). Higher tensile strength could only be achieved with longer welding times and higher speeds. However, the tensile strength could be increased in this series of tests by increasing the welding time to 12 s and 16 s. This was not the case in the other series of tests. From this it can be deduced that tensile strengths could be increased by further increasing the welding time. Furthermore, identical patterns could be observed with the welding times of 8 s, 5 s and 3 s. The test series with the welding time of 8 s in combination with the speeds 3000 rpm, 2500 rpm, 2000 rpm, 1500 rpm and the hole diameters 9 mm, 6 mm, 3 mm achieved a higher tensile strength than the test series with the welding times of 5 s and 3 s. This could be due to the fact that with the welding time

of 8 s the tensile strength could be increased. The reason for this could be that low temperatures were generated with the welding times of 5 s and 3 s and thus the lignin could not be sufficiently consolidated. No clear differences could be observed with regard to the speeds 3000 rpm, 2500 rpm, 2000 rpm and 1500 rpm. The test series with the speed 2500 rpm showed slightly higher tensile strengths than the speeds 3000 rpm, 2000 rpm and 1500 rpm. For the test series with the borehole diameters 9 mm, 6 mm and 3 mm, no clear pattern can be observed either. The results of drill hole diameters 9 mm and 3 mm show similar tensile strengths in combination with the speeds and welding times.

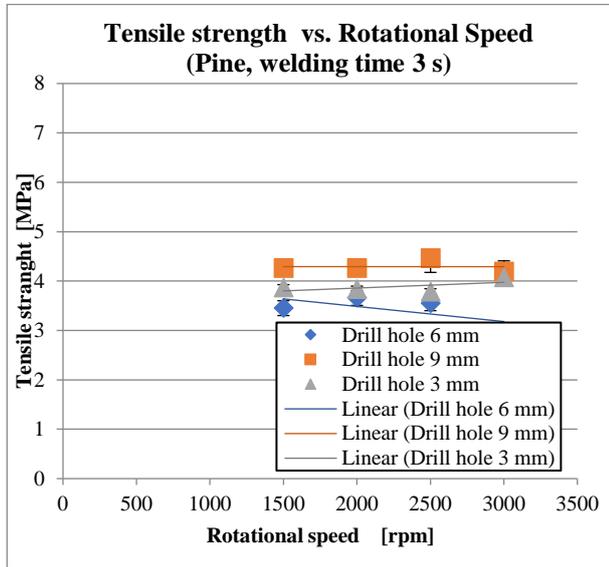


Figure 8. Tensile strength of pine (welding time 3 s).

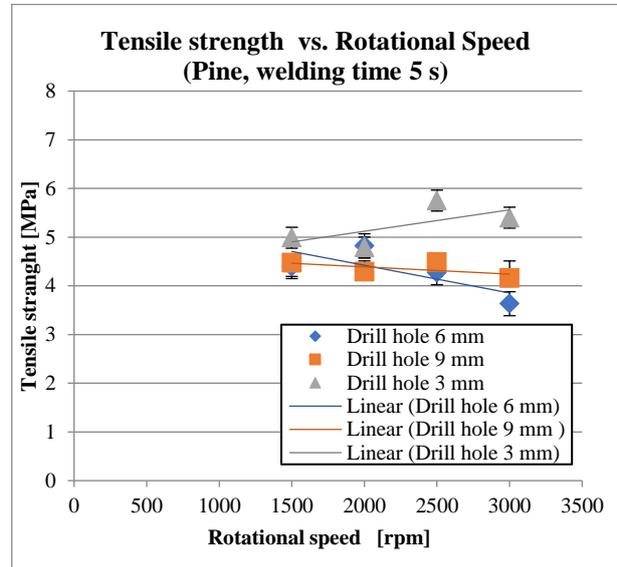


Figure 9. Tensile strength of pine (welding time 5 s).

3.2 Results of specimens welded using the conventional lathe (Beech)

The results of the beech wood joints (see Figure 11, Figure 12 and Figure 13) show that the test series with the speeds 1000 rpm and 500 rpm in combination with the welding time of 8 s and the hole diameter 6 mm, as with the pine joints, achieved low tensile strengths. Furthermore, it was observed that at a speed of 1000 rpm, the tensile strength can be increased by increasing the welding time to 12 s and 16 s.

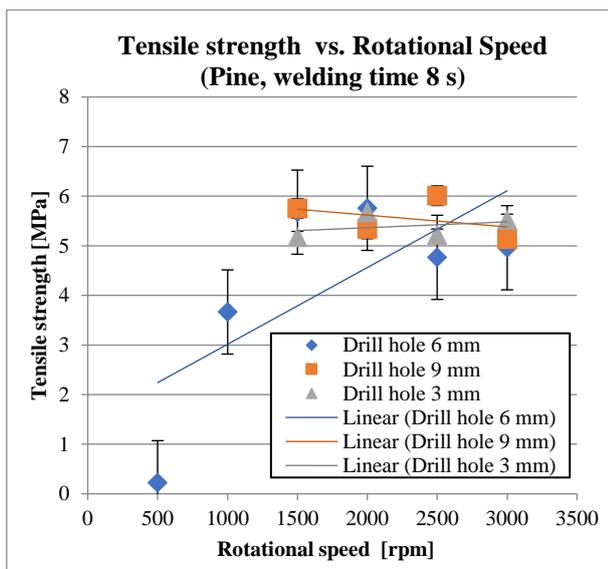


Figure 10. Tensile strength of pine (welding time 8 s).

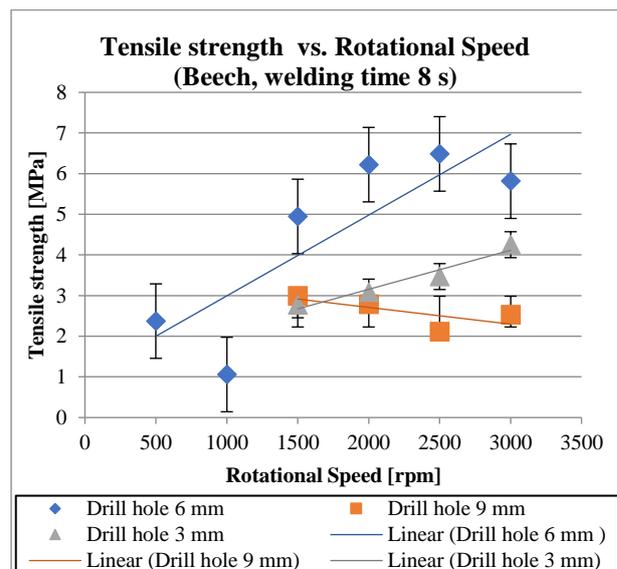


Figure 11. Tensile strength of beech (welding time 8 s).

The tensile strength of the welded joints was also increased by increasing the welding time to 12 s and 16 s, respectively. However, the series of tests with the speed of 500 rpm shows that with the increase of the welding time to 12 s and 16 s, the tensile strength drops, which shows a significant difference to the pine wood joints. It was also observed

that with a drill hole diameter of 9 mm in combination with welding times of 3 s and 5 s, the tensile strengths increase with increasing speed. An identical observation was made for the test series with the borehole diameter 3 mm and 6 mm in combination with the welding times 3 s and 5 s and the rotational speeds. From this, it can be concluded for the welding times of 3 s and 5 s that the larger the borehole diameter and the higher the speed, the higher tensile strengths can be achieved. This finding could not be confirmed for the series of tests with the welding time of 8 s. The test series with the borehole diameter 9 mm shows that the tensile strength decreases considerably with increasing speed by increasing the welding time to 8 s, whereas in the test series with the borehole diameters 6 mm and 3 mm the tensile strengths increase with increasing speed.

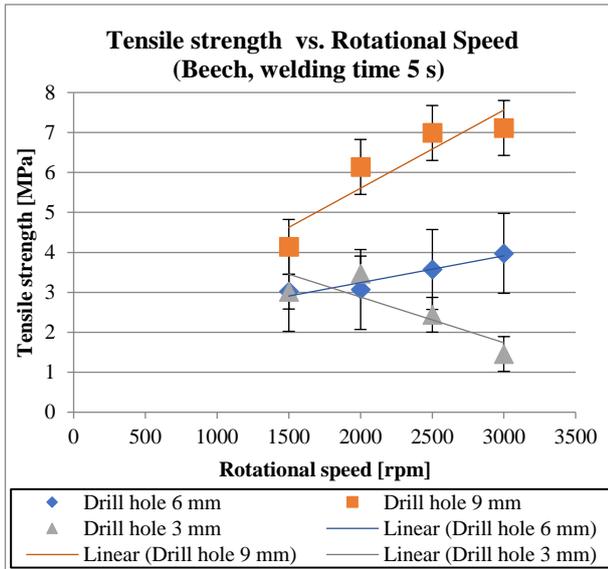


Figure 12. Tensile strength of beech (welding time 5 s).

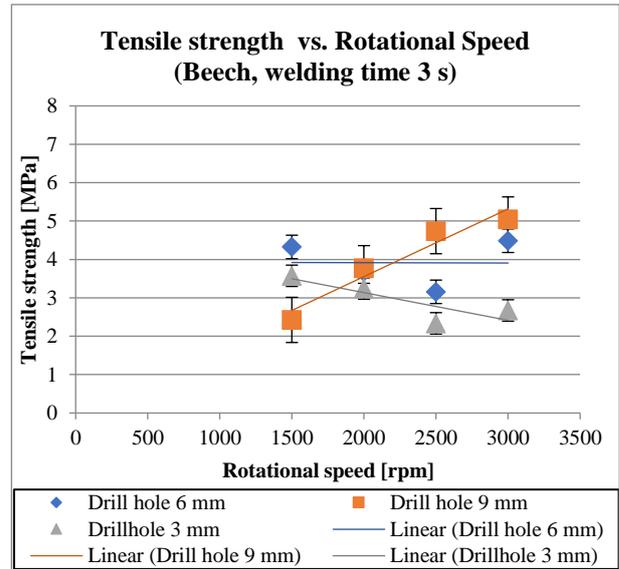


Figure 13. Tensile strength of beech (welding time 3 s).

3.3 Results of specimens welded using the conventional lathe (Bambus)

Figure 14 shows that the test series of bamboo with the speeds 1000 rpm and 500 rpm in combination with welding times of 8 s and 10 s did not result in any joints. It can also be seen that the test series with the speeds 1000 rpm and 500 rpm in combination with the welding times 12 s and 16 s increase the tensile strengths. Furthermore, Figure 14 shows that in the test series with the welding times of 8 s and 5 s, the tensile strengths increase with increasing speed. In the test series with the welding time of 10 s, the tensile strength decreases with increasing speed. The highest tensile strength achieved in rotary butt friction welding of bamboo is obtained with the parameter combination of speed 3000 rpm, welding time 8 s and weld holding time 60 s.

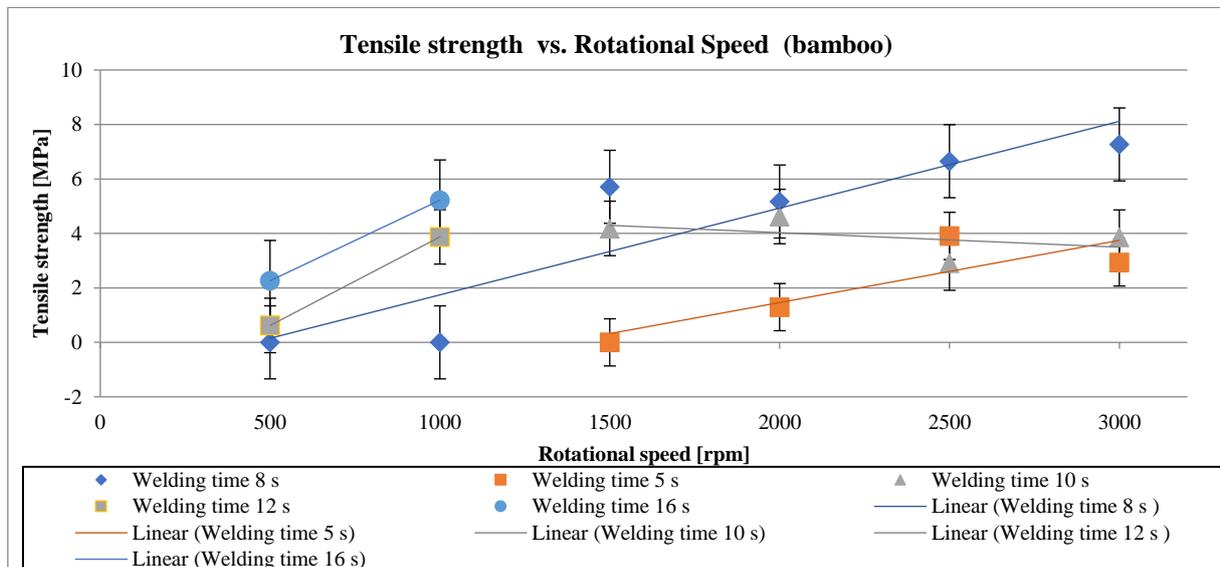


Figure 14. Tensile strength of bamboo.

3.4 Results of the tests with the special rotary butt friction welding machine

Under the guidance of the authors, various final theses at Bachelor and Master's level have been and are being carried out. NIEBERGALL'S master's thesis was one of the first scientific work at the Berliner Hochschule für Technik (BHT) on this topic, and its results are constantly being supplemented by further research and are presented here. The highest tensile strength value of the welded pine specimens was 13.61 MPa (Tab. 5). The specimen associated with this value was produced with a speed of 4000 rpm, a joining pressure of 2.99 MPa and a welding time of 6 s. The welds were made using mixed annual ring widths.

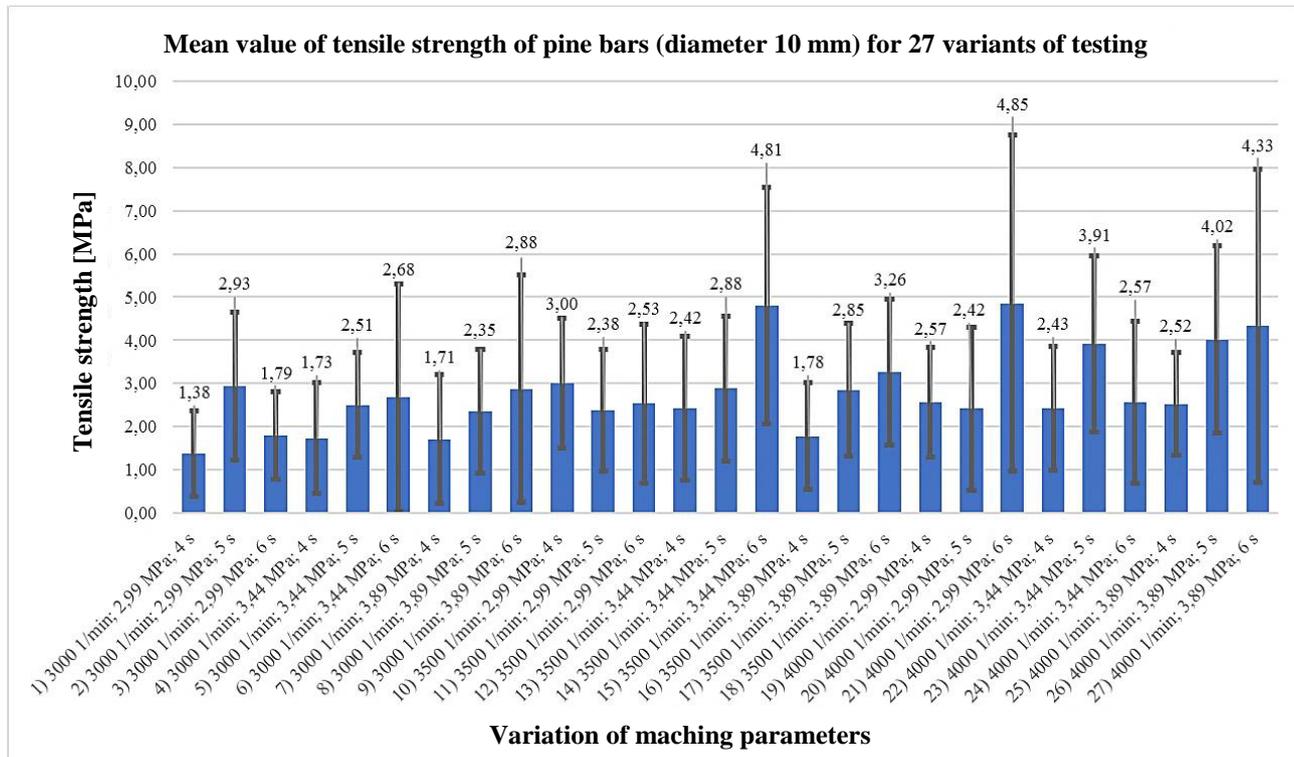


Figure 15. Mean value of tensile strength of pine (according to Niebergall, M., 2020).

Mixed annual ring widths were used. The joined surfaces of the two specimens showed a groove-like structure after qualification. The highest mean value of the tensile strengths of the pine specimens was 4.85 MPa. These specimens were also produced with a speed of 4000 rpm, a joining pressure of 2.99 MPa and a welding time of 6 s (see Tab. 5 and Tab. 6). The variation between the two specimens was not significant.

Table 5. Pine with highest tensile strength (according to Niebergall, M., 2020).

Sample-Nr.:	156	
Variation Nr. 21:	4000 rpm; 2.99 MPa; 6 s	
Tensile strenght:	13.61 MPa	
Tree ring typ:	Mix	
Surface structure	groove-shaped	

Table 6. Pine with second highest tensile strength (according to Niebergall, M. 2020).

Sample-Nr.:	81	
Variation Nr. 27:	4000 rpm; 3.89 MPa; 6 s	
Tensile strenght:	11.15 MPa	
Tree ring typ:	Medium	
Surface structure	groove-shaped	

Compared to each other, the variation with the mixed annual ring widths had on average the most positive effect on the tensile strength compared to the variations narrow, medium and wide. The welding time (factor C) had the greatest effect on the tensile strength. The speed (factor A) had a similarly high effect. The joining pressure (factor B) only had a minor effect on the tensile strength of the joint. In order to obtain comparative values of the tensile strength of glued joints to rotational friction welded joints, pine rods were glued using different glues (see Figure 15). The PU glue OTTOCOLL® P 84 with a pressing time of 60 hours achieved the highest average tensile strength with a value of 11.58 MPa. The highest individual tensile strength value was 11.90 MPa. The wood glue Ponal Express with a pressing time of 8 minutes achieved the second best result with an average tensile strength of 5.78 MPa. With an average tensile strength of 5.02 MPa, the wood glue Ponal Waterproof with a pressing time of 14 hours performed third best. The adhesive joints made with Ponal Express wood glue with a pressing time of 14 hours could only achieve an average tensile strength of 4.91 MPa. Basically, the glued joints had a much lower standard deviation than the rotational friction welded joints. This illustrated the high process capability of gluing with wood glues compared to the still high optimisation potential of rotary butt friction welding of renewable raw materials under given condition.

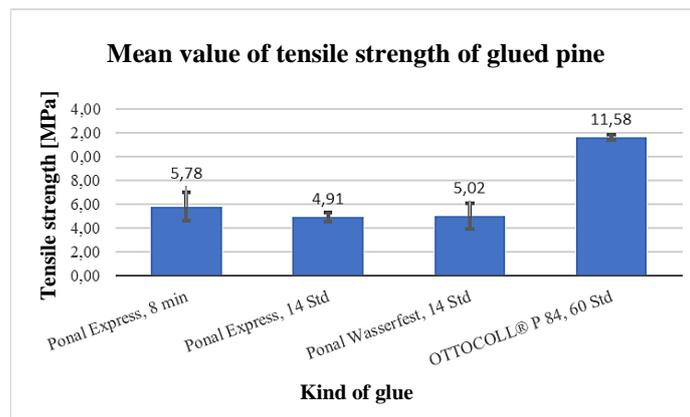


Figure 15. Mean value of tensile strength of glued pine (according to Niebergall, M., 2020).

4. CONCLUSIONS AND OUTLOOK

The results show that wood and bamboo can also be reliably joined by rotary butt friction welding. This process can be used to join lignin-containing materials such as wood or bamboo without the use of adhesives. Very promising tensile strengths can be achieved. This enables sustainable production and also recycling of the products after use without the generation of hazardous waste. By using wood and bamboo, CO₂ can be saved, furthermore, oil-based adhesives can be saved. The following maximum tensile strengths were achieved in the tests with the conventional lathe:

- Bamboo: 7.27 MPa
- Beech: 7.11 MPa
- Pine: 6.01 MPa.

The highest tensile strengths in the tests of beech with conventional lathe were achieved with the following parameters: rotational speed; 3000 rpm; a welding time of 5 s with a drill hole diameter of 9 mm and a joining pressure of 200 N. For Pine and using conventional lathe the highest tensile strengths were achieved with the following parameters: rotational speed; 2500 rpm; a welding time of 8 s with a drill hole diameter of 9 mm and a joining pressure of 200 N. The highest tensile strengths (7.72 MPa) in the tests of bamboo with conventional lathe were achieved with the following parameters: rotational speed; 3000 rpm; a welding time of 8 s with and a joining pressure of 200 N. The highest tensile strengths in the tests with the newly developed rotary butt friction welding machine were achieved with the following parameters: speed of 4000 rpm, a joining pressure of 2.99 MPa and a welding time of 6 s. The maximum tensile strength on pine with these process parameters was 13.61 MPa. This value is higher than the best value achieved by gluing, however, the scatter of the friction welding tests is very high, and work is currently being done to increase the process reliability of this manufacturing method. The results presented in this article provide a first insight into the possibilities of rotary butt welding of wood and bamboo. Further investigations will and must be carried out. In particular, the results of the investigations carried out with the conventional friction welding machine cannot be compared with the results of the specially developed friction welding machine, as the lathe does not switch off quickly enough after the end of the joining process. Furthermore, numerous investigations must be carried out in order to increase the reliability and statistical validation of the previous test results. Friction welding can also be used to successfully join different types of wood and bamboo. It is possible to join different types of wood and bamboo with this glue-free joining method. This provides a process with which renewable raw materials can be used for new applications (bamboo scaffolding tubes) and their specific properties can be exploited. Furthermore, wood residues can be reused, while at the same time reducing the use of adhesives. Work is also continuing on joining natural fibres with friction welding, which also requires modified

machines. Figure 16 shows first results of currently investigated joining possibilities of natural fibres (Palm and hemp) by friction welding.

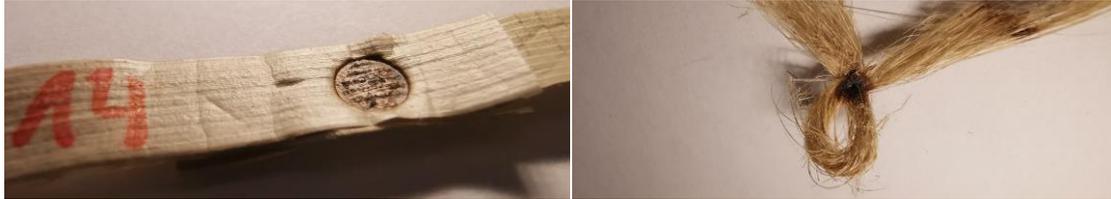


Figure 16: Natural fibres bonded by friction welding.

5. ACKNOWLEDGEMENTS

We thank the German Academic Exchange Service (DAAD) for supporting our participation at the COBEM 2023. We would also like to thank the Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guericke" e. V. (AIF) for funding and supporting the development of the rotary butt friction welding machine for wood and bamboo and the company Christian Dunkel GmbH for supporting the research activities for many years.

6. REFERENCES

- Chen, M. et. Al. Rapid growth of Moso bamboo (*Phyllostachys edulis*): Cellular roadmaps, transcriptome dynamics, and environmental factors; *The Plant Cell*, Volume 34, Issue 10, October 2022, Pages 3577–3610, <https://doi.org/10.1093/plcell/koac193>.
- „BAMBUS WISSEN“, [Online]. Available: <https://bambus-wissen.de/bambus/tag/moso/?cn-reloaded=1>. [07. 10. 2019].
- Dunkelberg, K.: Bambus als Baustoff, in IL 31 Bambus. Karl Krämer Verlag, Stuttgart (2005) 46-91.
- Ganne-Chedéville, C. Soudage linéaire du bois: étude et compréhension des modifications physico-chimiques et développement d'une technologie d'assemblage innovante. PhD Thesis, Nancy-Université 2008.
- Ganne-Chedéville, C.; Pizzi, A.; Thomas, A.; Leban, J. M.; Bocquet, J. F.; Despres, A.; Mansouri, H., 2005: Parameter interactions in two-block welding and the wood nail concept in wood dowel welding. *J Adhesion Sci. Technol.*, 19 (13-14): 1157-1174. <http://dx.doi.org/10.1163/156856105774429037>.
- Gfeller, B.; Pizzi, A.; Zanetti, M.; Properzi, M.; Pichelin, F.; Lehmann, M.; Delmotte, L.: Solid wood joints by in situ welding of structural wood constituents. *Holzforschung*, 58 (2004) 45-52.
- Kumar, S.; Rawat, D.; Singh, B.; Khanduri, V. P.: *Utilization of bamboo resources and their market value in the western Himalayan region of India*. www.journals.elsevier.com/advances-in-bamboo-science. *Advances in Bamboo Science* 3 (2023).
- Li, S.; Zhang, H.; Shu, B.; Cheng, L.; Ju, Z.; Lu, X. 2021. Study on the bonding performance of the moso bamboo dowel welded to a poplar substrate joint by high-speed rotation. *J Renew Mater* 9(7): 1225-1237. <http://dx.doi.org/10.32604/jrm.2021.014364>.
- Lohmann, U.: *Holz- Handbuch*. DRW-Verlag, Rosenheim, 4. völlig überarbeitete Auflage (1990) 13-56.
- Holzmann, G.; Wangelin, M.; Bruns, R.: *Natürliche und pflanzliche Baustoffe, Rohstoff - Bauphysik - Konstruktion*, Wiesbaden: Springer Vieweg, 2012, pp. 73-99, 139-154.
- Michel, P.: *Schweißverfahren in der Kunststoffverarbeitung, Grundlagen und Aspekte zur Serienfertigung*, DVS-Berichte Band 203, Düsseldorf: DVS-Verlag GmbH, 1999, pp. 1-29.
- Niebergall, M. *Untersuchung eines temperaturgeführten Fügeverfahrens von nachwachsenden Rohstoffen*. Master thesis, Berliner Hochschule für Technik (BHT), 2020.
- RWTH, <https://bambus.rwth-aachen.de/de/referate2/baumaterial/bambusalsbaumaterial.html>, 2023.
- Schuler, V.; Twrdek, J.: *Praxiswissen Schweißtechnik, Werkstoffe · Prozesse · Fertigung*, 6. vollständig überarbeitete Auflage, Wiesbaden: Springer Vieweg, 2019, pp. 142-147, 239-242.
- Stamm, B.; Natterer, J.; Navi, P.: Joining wood by friction welding. *Holz als Roh- und Werkstoff*, 63 (2005a) 313-32.
- Wang, N. et al. Mechanical behavior of rotary friction welding joints composed of laminated veneer bamboo substrate and bamboo dowel. *Construction and Building Materials*, v. 358, 2022. Doi: 10.1016/j.conbuildmat.2022.129361.
- Župčić, I.; Vlaović, Z.; Domljan, D.; Grbac, I.: Influence of Various Wood Species and Cross-Sections on Strength of a Dowel Welding Joint. *Drv. Ind.* 2014, 65, 121–127.

7. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.