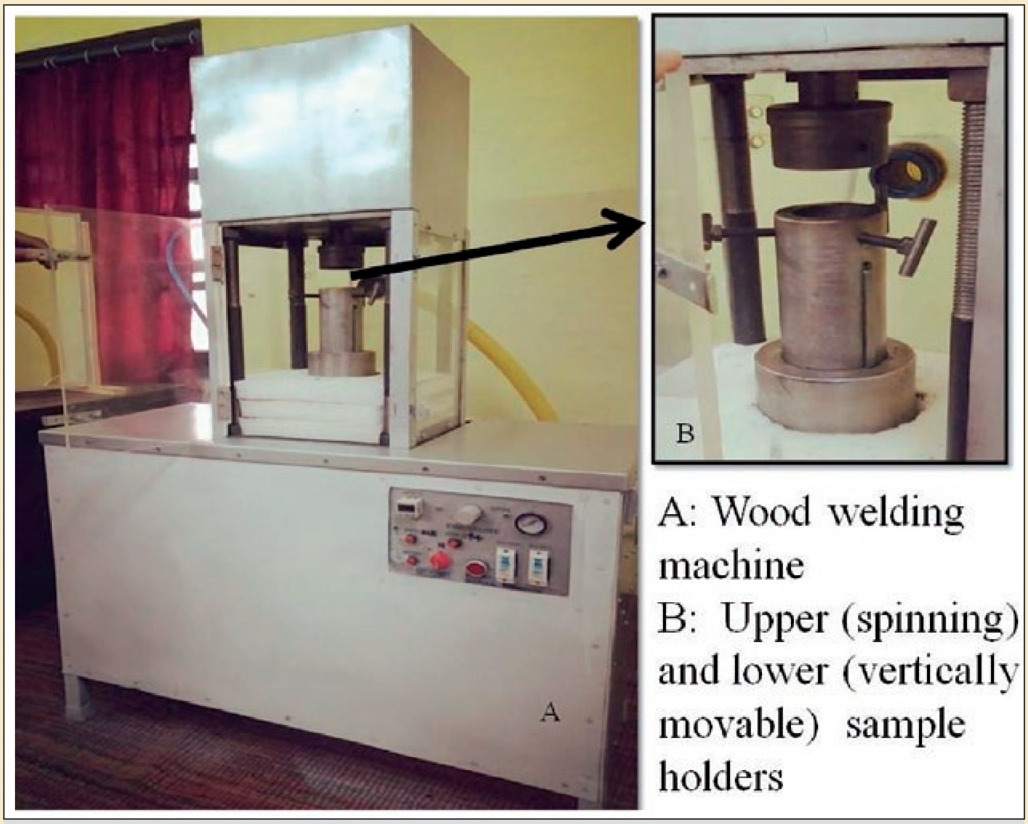
# Rotational wood welding on *Dalbergia sissoo*: forming longitudinal tongue-and-groove and butt joints




**Photos 1.**
Wood welding machine.

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## RÉSUMÉ

**Soudage rotatif de bois de *Dalbergia sissoo* : assemblages longitudinaux à tenon et mortaise et à plat-joint**

Les techniques d'assemblage sont de première importance dans le processus de fabrication de produits bois. Les assemblages sont le plus souvent réalisés à l'aide de différents types de colles. Le soudage du bois constitue une réelle innovation en matière d'assemblage en utilisant la friction en deux pièces de bois pour en assurer l'adhésion par ramollissement et migration de composants du bois. Dans cette étude, un dispositif rotatif a été adapté et utilisé pour souder des pièces de bois de *Dalbergia sissoo*. Des assemblages à plat-joint et de type tenon-mortaise ont été réalisés à l'aide de ce dispositif. La résistance à la traction des assemblages a été étudiée. L'influence de l'augmentation de la surface soumise à friction sur la résistance des assemblages en utilisant un système tenon-mortaise a été analysée. La résistance à la traction d'assemblages à plat-joint soudés par friction à 1 200 tr/min a été estimée à 5,3 MPa. La résistance des joints a été améliorée de 66 % avec un assemblage tenon-mortaise. L'influence du temps de friction sur la température de soudage a été aussi étudiée. La finalité de cette étude est de développer l'utilisation de la technique de soudage au bois de D. sissoo pour améliorer la résistance de ses assemblages.

**Mots-clés :** soudage, friction rotative, *Dalbergia sissoo*, menuiserie, assemblage à plat-joint, tenon-mortaise, résistance à la traction, Inde.

## ABSTRACT

**Rotational wood welding of *Dalbergia sissoo* wood: forming longitudinal tongue-and-groove and butt joints**

Wood joinery is an essential part of woodworking for product manufacture. Wood sections are mostly joined together with adhesives. Wood welding brings a new dimension to joinery by using mechanical friction to induce a flow of wood components ensuring adhesion. In this study, a customized spin wood-welding machine was used to join wood sections of *Dalbergia sissoo*. Butt and tongue-and-groove joints were prepared and welded using the machine. The tensile strength of the joints was tested. The impact on joint strength of increasing the friction area by introducing tongue-and-groove joints was tested and analyzed. The tensile strength for butt joints at 1,200 rpm welding was estimated at 5.3 MPa. Joint strength was found to increase substantially (by 66%) with a tongue-and-groove welding section. Weld line temperatures at different spin times were also investigated. The aim of this study is to apply welding technology to *Dalbergia sissoo* to achieve greater joint strength.

**Keywords:** welding, rotational friction, *Dalbergia sissoo*, butt joint, joinery, tongue-and-groove joint, tensile strength, India.

## RESUMEN

**Soldadura por rotación en la madera de *Dalbergia sissoo*: unión longitudinal machihembrada y unión a tope**

La carpintería de la madera es una parte esencial del trabajo de la madera en la fabricación de productos. Las secciones de madera se unen mayoritariamente con adhesivos. La soldadura de la madera aporta una nueva dimensión a la carpintería al utilizar la fricción mecánica para inducir un flujo de componentes de madera que garantice la adhesión. En este estudio se utilizó una máquina de soldadura de madera por fricción adaptada para unir secciones de madera de *Dalbergia sissoo*. Las uniones a tope y machihembradas se prepararon y soldaron con esta máquina. Se comprobó la resistencia a la tracción de las uniones. Se analizó el efecto en la resistencia de las uniones debido al aumento del área de fricción al utilizar juntas machihembradas. La resistencia a la tracción de las uniones a tope en una soldadura a 1 200 rpm se estimó en 5,3 MPa. Se comprobó que la resistencia de la unión aumentaba sustancialmente (en un 66 %) con una sección de soldadura machihembrada. También se midieron las temperaturas de la línea de soldadura con diferentes tiempos de fricción. El objetivo de este estudio es aplicar la tecnología de la soldadura a *Dalbergia sissoo* para conseguir una mayor resistencia de unión.

**Palabras clave:** soldadura, fricción por rotación, *Dalbergia sissoo*, unión a tope, carpintería, machihembrado, resistencia a la tracción, India.

# Introduction

Thousand tons of petrochemical-based glues are used every year across the globe. The use of glues for wood joinery is associated with high cost of investment and long curing time (Pizzi *et al.*, 2004). Most of the glues are known to possess negative environmental effect. Wood welding was first demonstrated by Suthoff *et al.* (1996). Eco-friendly processing techniques for renewable materials like wood may offer great advantages over other comparable materials, which have higher environmental burdens. Wood welding is a technique to join wooden pieces by frictional heat without any glue. Friction is induced between wood surfaces, which causes melting and flowing of mostly lignin to weld line, which works as adhesive after cooling and setting (Gfeller *et al.*, 2004). The studies undertaken on this topic can generally be categorised into two groups: rotational welding (dowel) and linear friction vibration welding. Significant studies have been carried out on friction vibration welding of wood (Pizzi *et al.*, 2004; Omrani *et al.*, 2007; Resch *et al.*, 2006; Gfeller *et al.*, 2004; Leban *et al.*, 2004; Amirou *et al.*, 2017). Most of the studies carried out are on European timbers like *Picea abies*, *Fagus sylvatica*, *Quercus robur*, *Acer* spp. Moreover, no work reported on rotational welding of tongue-and-groove joint. Aim of this study is to carry out some exploratory rotational wood welding on an Indian timber *Dalbergia sissoo* and compare the effect of tongue-and-groove welded joints over butt joints.

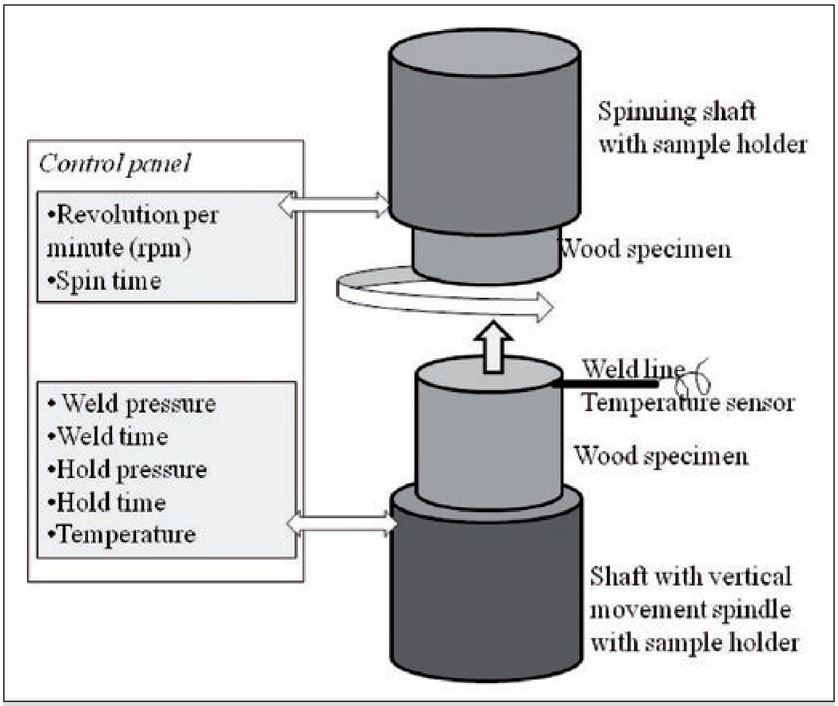


**Figure 1.**
Diagrammatic representation of wood welding system.

# Materials and Methods

### The wood welding machine

A customized spin wood welding machine was fabricated. The machine has two shafts with holders placed vertically: lower and upper (photos 1). The upper shaft can rotate at set revolution per minute (rpm) up to maximum 5,000 rpm. Lower shaft is a stationary part and is fitted with movable spindle, which can go up and down and impart pressure on upper rotating wood specimen through wood specimen at its shaft. Both upper and lower shafts have specimen holder in which cylindrical wood specimens can be clamped as shown in figure 1. During wood welding, the lower shaft (with wooden specimen) moves upward and allows the vertically moving wooden specimen to meet upper rotating wood specimen at required weld pressure, weld time, hold pressure, hold time. The welding shafts are surrounded with a box made of transparent fiber sheet. A smoke exhaust system is also installed within the box to remove smoke generated during welding.

### Wood specimens

**Butt joint in longitudinal direction**

Kiln dried wood planks of *Dalbergia sissoo* (both heartwood and sapwood portion) of thickness 55 mm were taken and converted into square specimens of cross section 55 x 55 $mm^2$. The kiln drying was done in accordance with seasoning schedule No. IV (IS: 1141, 1993). The planks were dried to moisture content range of 8-12%. Wood specimens were turned into cylindrical form with diameter 47 mm and length 50 mm.

**Tongue-and-groove (TG) joint in longitudinal direction**

For tongue-and-groove (TG) joints in longitudinal direction, a tongue (diameter = 17 mm, length = 13 mm) in longitudinal direction was made during turning, making total sample length 63 mm in longitudinal direction as shown in figure 2 and photo 2. For groove, a hole (diameter = 17 mm, depth = 12 mm) was drilled in the cylindrical specimens in longitudinal direction. All the prepared specimens were conditioned to 10% moisture content, which was evaluated with the help of reference samples by oven dry method.

**Recording temperature at weld line**

A PT-100 sensor was inserted just beneath the weld line surface into the lower wood specimen (stationary)

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by drilling a hole. The tip of the sensor was placed in such a way that it was 1 mm below the joint line as shown in photo 1. The sensor was connected to the control box and PC to record the temperature during welding at an interval of one second.

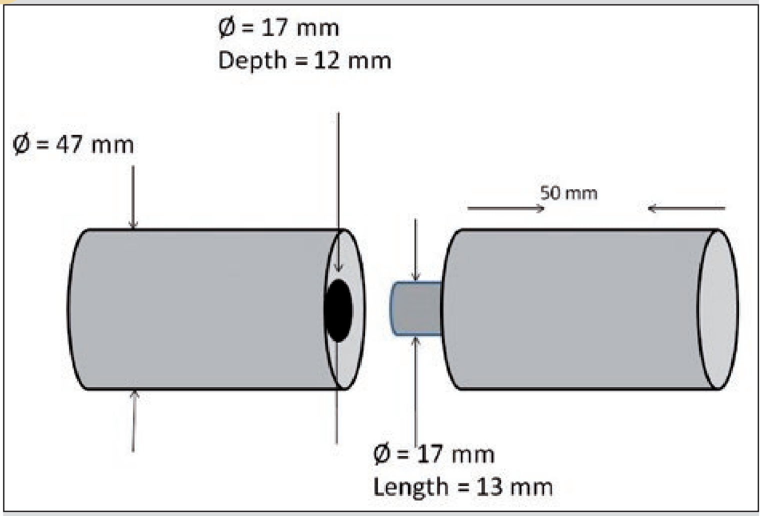


**Figure 2.**
Diagrammatic representation of tongue-and-groove wood welding samples.

**Photo 2.**
Tongue-and-groove wood welding samples.

**Table I.**
Parameters used for spin friction.

| | |
|---|---|
| Revolutions per minute | 1,200 |
| | **Spin time** |
| Butt joint | 15 s |
| TG joint | 12 s |
| | 15 s |
| | 18 s |
| Spin pressure | 2.55 MPa |
| Holding pressure (after spinning) | 5.10 MPa |
| Holding time (after spinning) | 40 s |

**Welding**

The cylindrical wood specimens were mounted on the both upper and lower holders and spin welding process were done with parameters shown in table I.

Twenty specimens were welded to make 10 welded sets for butt joint and the same was followed for TG joint. After two hours of welding, the welded specimens were tested for tensile strength. Twelve separate specimens were prepared for recording weld line temperature. Four samples each were used for different weld time (12 s, 15 s & 18 s). However, due to hole for insertion of the PT-100 sensor as shown in photo 3, these specimens were not tested for tensile strength.

**Tensile strength testing**

Welded cylindrical sections were then subjected to static tensile stress to investigate the strength of joints. Specimens were hinged tightly to the jaws on Universal Testing Machine (UTM) and tensile stress was applied with the machine head moving at the constant rate of 1 mm/min (in accordance with IS: 1708 Indian Standard - *Methods of Testing of Small Clear Specimens of Timber*) as shown in photo 4. Maximum tensile load at which the joint ruptures was recorded and tensile stress per unit area was evaluated in MPa.

## Results and Discussion

### Weld line temperature

During friction wood welding, a substantial amount of heat is generated at the weld line. This heat melts some amorphous polymer materials like lignin and hemicelluloses (Omrani *et al.*, 2007). Figures 3 to 5 present line curve for temperature of weld line during welding. From above figures (figures 3 to 5), it can be seen that the temperature curve has three distinct regions as suggested by Ganne-Chédeville *et al.* (2006b): zone of sudden temperature increase (0 s to 20 s), temperature stabilization (20 s to 25 s) and temperature decrease after welding stops. As shown in above figures, in general, the maximum

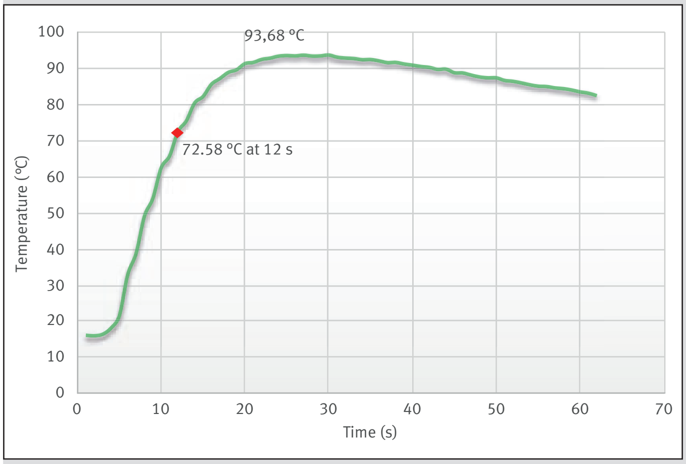


**Figure 3.**
Weld line temperature at 12 s weld time.

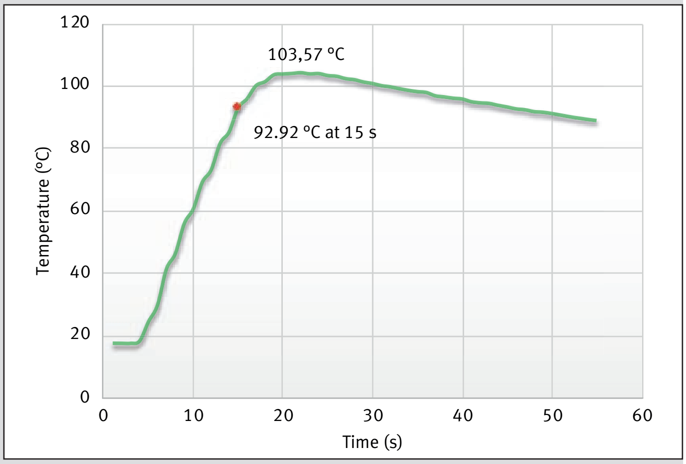


**Figure 4.**
Weld line temperature at 15 s weld time.

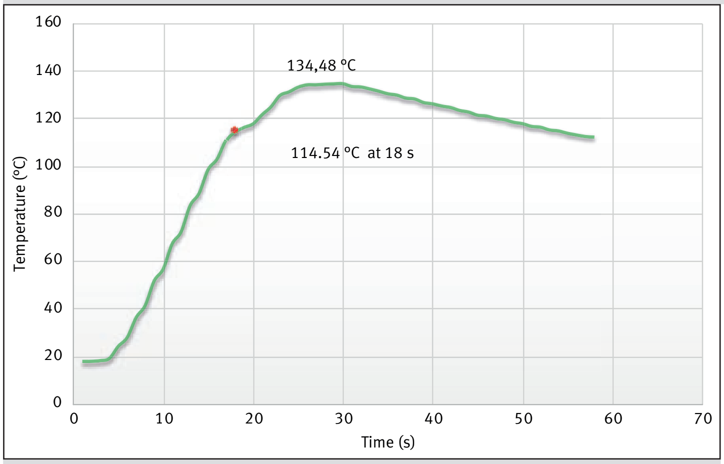


**Figure 5.**
Weld line temperature at 18 s weld time.

temperature increases as welding time increases (from 12 s to 18 s). Maximum average temperatures during welding were 93.68 °C, 103.57 °C and 134.48 °C for 12 s, 15 s and 18 s welding times respectively. Ganne-Chédeville *et al.* (2006a) reported average maximum temperature of weld line to be 165 °C during welding of Maple wood. The maximum average temperature is far less than as reported by Ganne-Chédeville *et al.* (2006b) who found it to be in range of 216-223 °C in linear friction welding using infrared thermography. Zhang *et al.* (2017) also reported that using type K thermocouples, welding interface reaches 350 °C in six seconds. However, these literature reports are on weld line temperature of linear friction.

Use of different techniques for temperature recording by different workers may be one of the reasons for difference temperatures apart from different sets of parameters used during welding. The maximum temperatures in this study did not coincide with the end of spin time. Maximum temperature reached at 31 s, 24 s

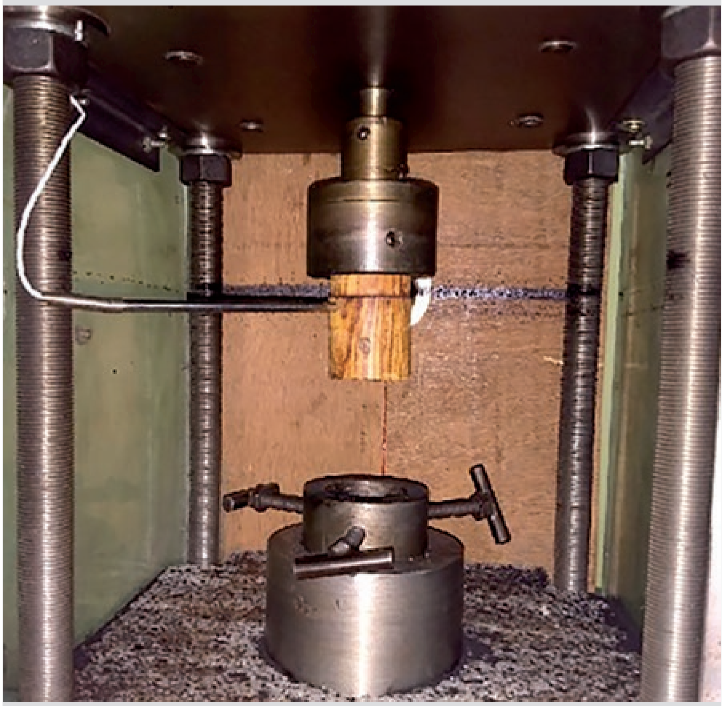

**Photo 3.**
Recording weld line temperature using PT-100 type thermo-couple.

**Photo 4.**
Tensile strength testing.

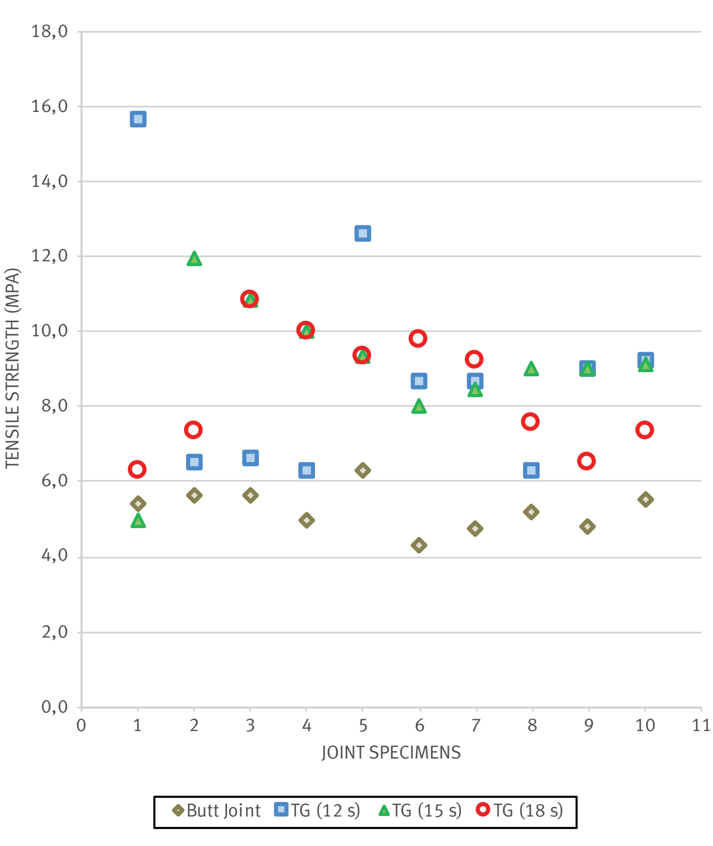


**Figure 6.**
Tensile strength of welded specimens.

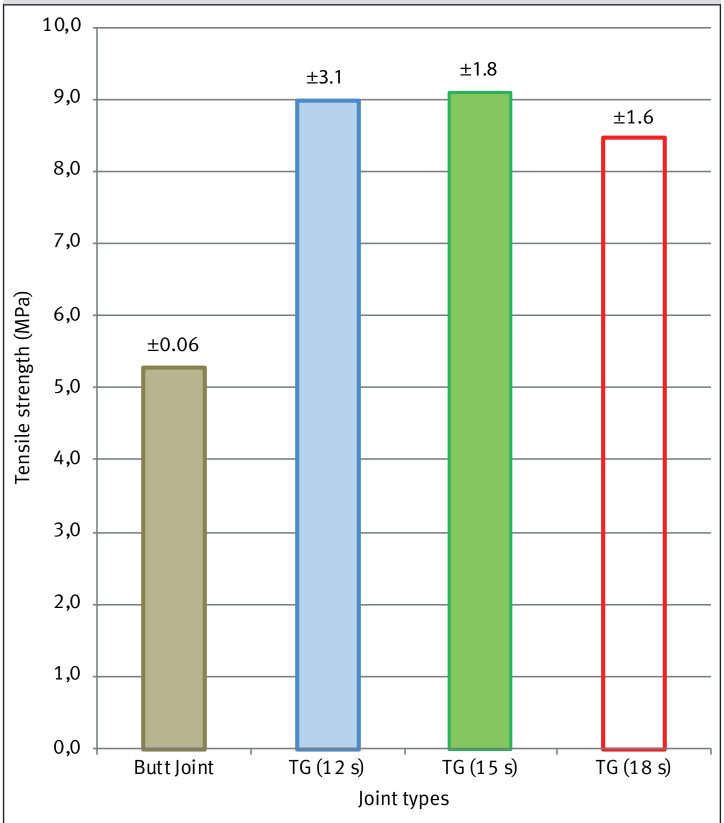


**Figure 7.**
Mean tensile strength of welded specimens.

and 30 s at spin time 12 s, 15 s and 18 s respectively. This indicates two possible reasons: after all the mechanical energy was transferred to weld line, the temperature kept on rising even after friction was stopped, and second, there might be some problems with the choice of the temperature sensor. However, in any case, the maximum temperature seems to be realistic.

### Tensile strength

Figure 6 presents tensile strengths of the welded joints: rotational welded butt joints, tongue-and-groove joints.

From figure 7, it can be seen that the mean strength of the butt-jointed specimens was 5.3 ± 0.6 MPa. Mean joint strength in case of TG specimens were 9.0 ± 3.1 MPa for 12 s spin time, 9.1 MPa and 8.5 MPa for 15 s and 18 s spin times. The results of the strength values are comparable to those reported by Properzi *et al.* (2005) and Boonstra *et al.* (2006). Working on vibration wood welding on three species beech, oak and maple, Properzi *et al.* (2005) found the joint strength in range of 7.6 MPa-8.2 MPa (beech), 3.1 MPa-7.5 MPa (oak) and 9.2 MPa-10.7 MPa (maple) when the weld time varied from 3 s to 5 s.

Boonstra *et al.* (2006) also reported joint strength of untreated birch and beech to be 5.97 MPa and 8.61 MPa when welded through vibration wood welding at 3 s.

Similar results have been reported by Ganne-Chédeville *et al.* (2006a) on maple wood welding.

Figures 6 & 7 present the strength values. It can be seen that in general, all the TG specimens showed higher strength values than that of butt jointed specimens. However, the spread of the data was higher in case of TG specimens. Such higher standard deviations have also been reported by other researchers (Properzi *et al.*, 2005). ANOVA analysis reveals that the strength values of butt joint were significantly different from that of TG specimens (df = 3, n = 36, $p \leq 0.001$). However, there was no significant difference among the TG specimen's strength values. Thus, the mean strength value for tongue-and-groove specimens was 8.8 MPa. The surface area increase in TG specimens is 23% which results into a huge increase of 66% in strength of TG specimens due to inclusion of tongue on the welding surface. This 23% increased joint area is in longitudinal direction rather than cross section. Thus, apparently, the TG specimens have two welding directions: cross section and longitudinal. Fiber orientation has been reported to influence substantially the bond strength. Cross grain bonding yields much lower strength than that observed for bonding with grains parallel to each other. (Properzi *et al.*, 2005; Kocks *et al.*, 2000).

## Conclusion

Solid wood adhesion has been achieved by rotational friction between the surfaces of *Dalbergia sissoo*. The tensile strength of welded butt joint produced by rotation at 1,200 rpm for 15 seconds is found to be 5.3 MPa. The joint strength is increased substantially (by 66%) by incorporating a tongue-groove at welding section. Weld line temperature increases as welding time is increased. For welding time 12 s, 15 s and 18 s, maximum weld line temperature observed were 93.68 °C, 103.57 °C and 134.48 °C respectively. It is inferred that tongue-groove joint welded in the longitudinal direction of *Dalbergia sissoo* can be used as an interior grade wood joint and has a significantly greater strength than that of welded butt joint in the same direction.

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| Formal Analysis | S. Kumar |
| Funding Acquisition | S. Kumar |
| Investigation | S. Kumar |
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