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RESEARCH

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# Effects of heat treatment on the behavior of teak wood adherends bonded joints

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## Abstract

The main aim of this work is to investigate the effect of heat treatment on the teak wood adherend bonded joints. Indian teak wood samples were kept in an oven at 150 °C for 2 h for the heat treatment process. The surface roughness values of the wood adherend before and after the heat treatment process were measured using a surface profilometer. Wettability of un-treated and heat-treated teak wood samples was determined with the contact angle measurements by using the sessile drop method. Single strap joints with un-treated and heat treated wood specimens were tested at ambient temperature. The results show that, there is a clear dependency observed in between the heat treatment and the surface roughness of the wood adherends. Wettability of teak wood adherend surface is degraded after the heat treatment process. An adverse effect of heat treatment of wood adherend on the bonding strength was observed, but the surface roughness was improved.

**Keywords:** Heat treatment, Surface roughness, Teak wood, Adhesive bond strength, Wettability

## Introduction

Nowadays, scientific communities and industries are looking for alternative materials to the synthetic composites and metals, as these materials are non-degradable, limited in quantity, hazardous to nature and costly [1, 2]. Hence many researchers are attracted towards natural materials (e.g. wood) for various applications, such as construction, furniture, decorative products, sports items and many others. Wood is one of the most important materials and widely used since the old era, as it is easily available, eco-friendly, light weight and low cost among many more benefits compared to others [3, 4]. However, the hygroscopicity of wood is the major disadvantage which limits the usage of wood for many applications. There are different processes by which the hygroscopicity of wood can be reduced and many studies have been carried out in the literature on different processes [5, 6].

Heat treatment is the oldest and simplest method by which wood hygroscopicity can be effectively decreased. In addition, the dimensional stability, biological resistance and durability of the wood can also be improved [7–9]. It was showed that the heat treatment of wood not only reduced the hygroscopicity but also caused physical changes in the wood such as surface modification, which can significantly affect the adhesive bond

performance of the wood [10, 11]. Many researchers [11–16] showed that the heat treatment process alters the surface roughness and surface morphology of wood material. Aydin et al. [14] examined the surface roughness characterization of spruce veneers plywood under varying temperature of 32 °C and 52 °C. They observed that samples under treatment at 52 °C had significantly improved surface roughness compared to the lower temperature treatment. Dundar et al. [15] reported the effect of boiling time on the surface roughness on the oriental beach wood material. They concluded that with increases in boiling time suggestively, the surface roughness of the inner part of the veneer increased while surface roughness of the outer and central part of the veneer decreased. Similar heat treatment studies performed on the redbud maple and hazelnut wood specimens at a temperature of 180 °C for 10 h and reported decreased values of surface roughness [11, 13]. Some studies reported that drying wood material at higher temperature improved its dimensional stability with a smoother surface [16]. The period of heat treatment, temperature and wood type and other conditions altered the value of surface roughness and surface morphology of wood material.

In most of the cases, the adhesive bond performance of the wood is negatively affected by the higher temperature and higher treatment period [17, 18]. However, some studies reported that a better bonding strength is achieved with lower heating treatment conditions which use lower temperature and duration [14, 19–21]. Aydin et al. [14] investigated the shear strength of spruce veneers plywood under different heat treatments with a temperature of 52 °C and 32 °C. The higher shear strength value was obtained for the plywood sample having a smoother surface at 52 °C. Ayrilmis et al. [18] investigated the effect of heat treatment on adhesive bonding performance and concluded that the bonding strength of the heat-treated medium density fiberboard panels decreased with increasing contact angle even though the surface roughness improved. Surface wettability mechanism of material after heat treatment plays an important role for the bond performance [22–25].

Nevertheless, there is no general trend which relates the surface roughness parameter and heat treatment to the strength of adhesive bonded joints, as there are many deciding parameters. The present study focused on investigating the influence of heat treatment on the surface roughness of teak wood and consequently the adhesive bond strength of the un-treated and heat-treated teak wood adherend bonded joints.

## **Experimental details**

### **Materials and methods**

Indian teak wood was used as the adherend material, as it is lightweight and abundantly available in the market and widely used in many applications such as furniture and in building constructions as well as for decorative items also. A total of 90 defect free wood billets of size 100 × 30 × 10 mm were cut by shearing from commercially purchased wood (Fig. 1). Planning operation was performed on all the billets to maintain the same roughness in the specimens before treatment. A synthetic resin adhesive, commercially known as Fevicol SH (Pidilite Industries Ltd, Nagpur, India) was taken as the base adhesive. A total of 90 wood billets were divided into two groups: one group of non-treated samples (45 wood billets) was kept at room temperature



**Fig. 1** Teak wood sample



**Fig. 2** A muffle furnace for heat treatment of wood adherent specimens

while the other samples (45 wood billets) were exposed to heat. For the heat treatment process, the samples were kept at 150 °C for 2 h in a small heating unit controlled to within  $\pm 1$  °C range (see Fig. 2).

Two roughness parameters mean arithmetic deviation of profile Ra and peak to valley height Rz are used to investigate the surface characteristics of wood. Surface roughness was measured before and after the heat treatment process of un-treated and heat-treated samples. A portable profilometer (Pocket Surf Make Mahr, GMBH, Model EMD 1500) with measuring range of 0.03–6.35  $\mu\text{m}$  and 10 mm stylus traversing length was employed for surface roughness measurement. Six measurements were taken at a constant speed over the projected contact area in all treated and un-treated specimens.

The wettability characteristic of the heat-treated adherend surface was determined using the contact angle method. Kruss Drop Shape Analyzer (DSA25E) equipment was used to measure the contact angle. In order to measure the contact angle,

a drop of distilled water was deposited on the adherend surface with a disposable micro-syringe. A minimum of three contact angle tests was recorded in different surface areas to obtain an average result and also for the cross verification of surface uniformity.

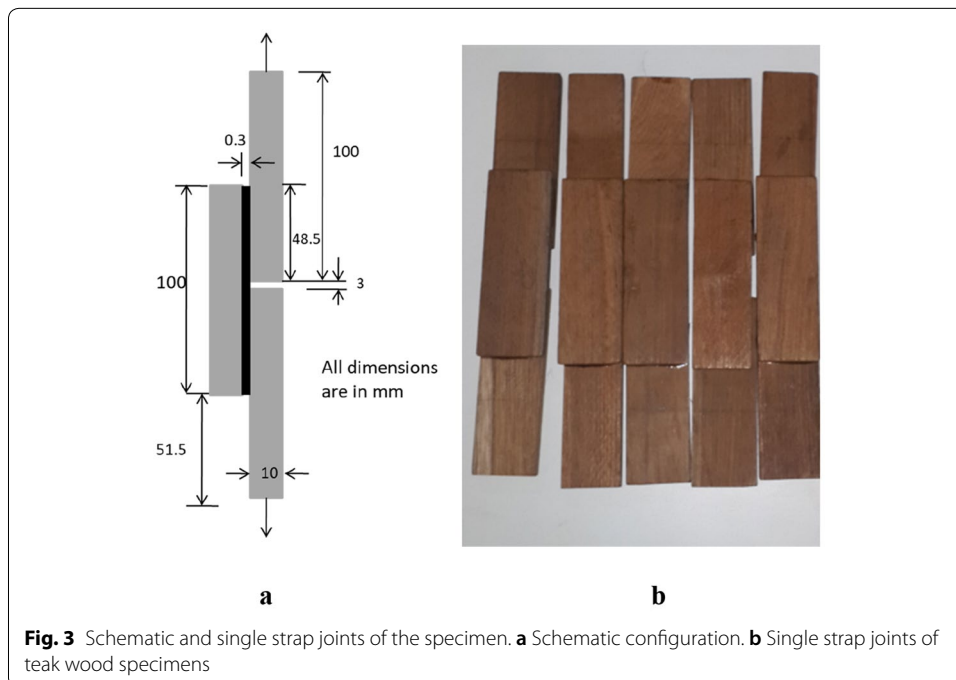
The surface treatment of the wood adherend is achieved by wiping once with clean paper to remove dirt. The adhesive is used on the clean wood adherend and spread over it with the spatula. The adhesive thickness is controlled by providing spacers in between. An adhesive thickness of 0.3–0.4 mm is maintained by applying constant pressure manually and then adhesive thickness was measured with the vernier callipers. The curing time is set to 48 h at room temperature. Schematic of a single strap joints and final prepared wood bonded joints specimens are shown in Fig. 3. Fifteen single strap joints were prepared for each un-treated and heat-treated condition.

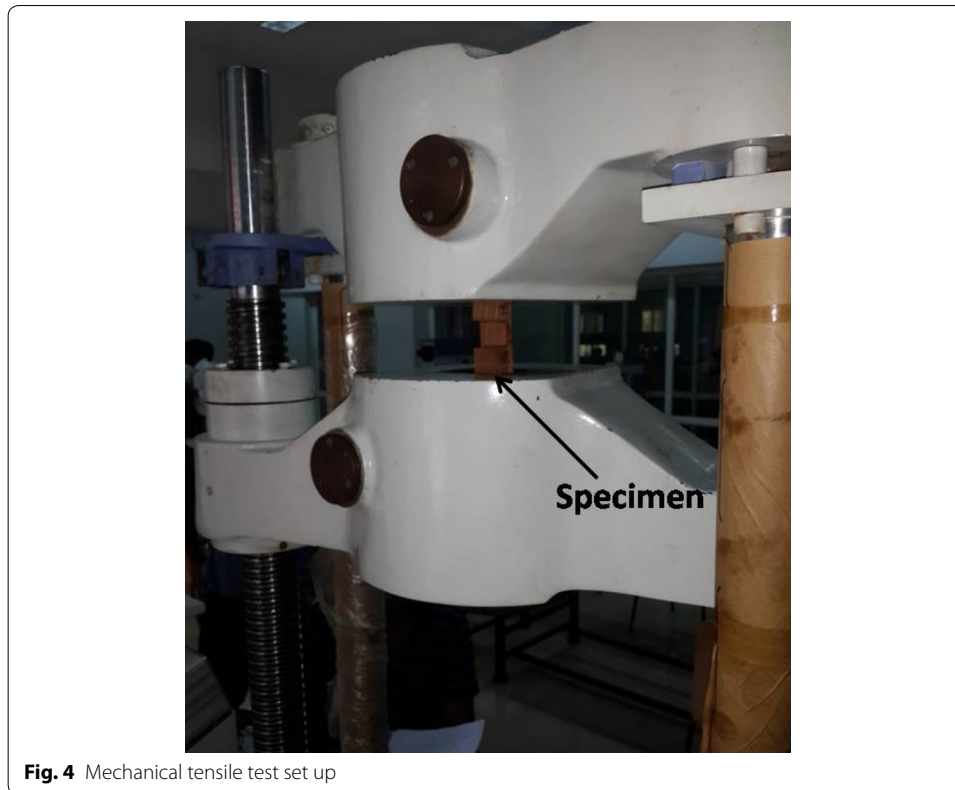
The un-treated and heat-treated specimens were tested at room temperature condition on the Universal Testing Machine (Make Blue Star, Model UTE 20). The gripping length was kept at 30 mm at both ends over the whole width of the specimen. All tests were carried out under monotonic tensile loading at a crosshead speed of 0.5 mm/min. The test set-up is shown in Fig. 4. The load and displacement were recorded during the testing.

## Results and discussion

### Surface roughness

Table 1 shows the mean surface roughness values  $R_a$  and  $R_z$  of wood adherend for heat-treated and un-treated samples. It clearly shows that the surface roughness values of  $R_a$  and  $R_z$  decreased after the heat treatment process, which means that the sample's surface became smoother after the thermal process. Nearly a 12% reduction in the surface





**Fig. 4** Mechanical tensile test set up

roughness value ( $R_a$ ) was found in all heat treated wood samples and this reduction trend is in all wood sample samples (Fig. 5). Similar trend of surface roughness after thermal process was found by many researchers, however the percentage change differs and it depends on the heat treatment process, temperature and duration as well as the type of wood adherend [11, 13–15].

#### **Surface wettability (contact angle)**

As it can be seen from Fig. 6, the contact angle increased for the heat-treated specimens compared to the non-treated specimens. The contact angle increases from  $50.25^\circ$  to  $55.95^\circ$  for the heat-treated samples compared to the non-treated, however, the surface roughness values decreases for the heat-treated samples. Initially, contact angle curves showed a greater slope and after 60 s the curve reaching an equilibrium point, however, for un-treated wood samples, the equilibrium point was reached after 90 s. This time difference to reach an equilibrium point for the heat treated and un-treated samples is due to the different surface roughness and surface morphology, which govern the adhesive spread on the surface.

It was found that the contact angle values are higher for the heat treated wood panel compared to the un-treated wood panel. This implies that the wood surface wettability was clearly degraded after the heat treatment process due to the surface inactivity. Some researchers [14, 22–25] observed a similar behaviour i.e. decreased wettability which means contact angle increased for wood sample treated at different higher temperature. In this study, it was observed that after heat treatment, the surface of the wood adherend

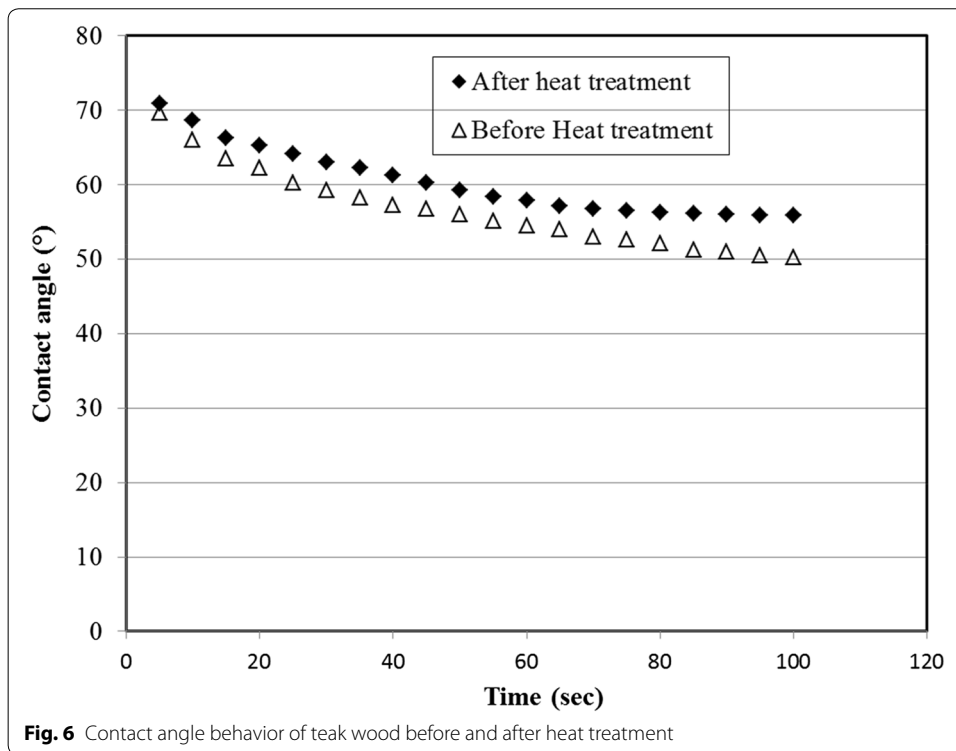
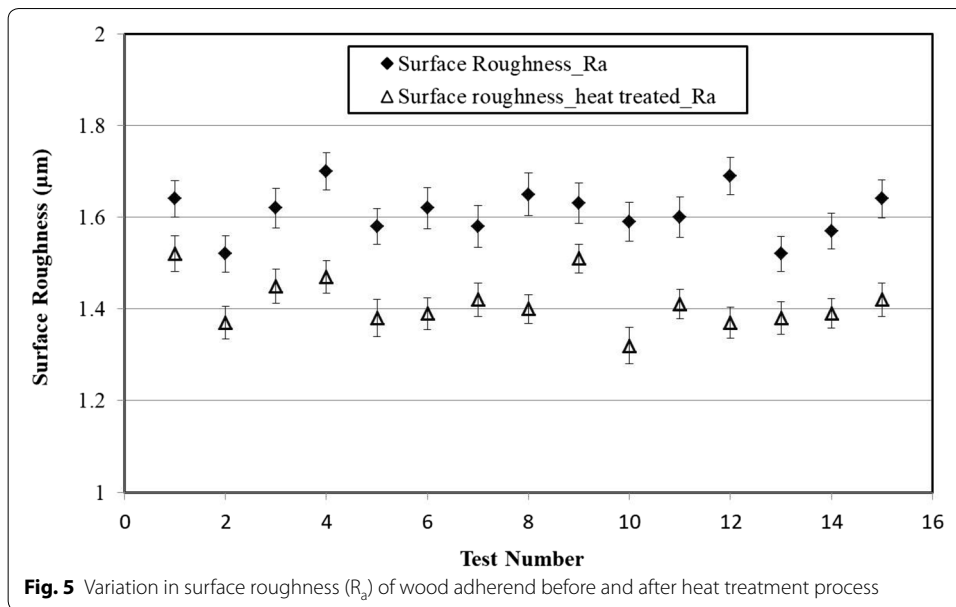
**Table 1 Surface roughness values of wood adherends before and after heat treatment process**

Specimens	Before heat treatment		After heat treatment	
	Surface roughness_R <sub>a</sub> (μm)	Surface roughness_R <sub>z</sub> (μm)	Surface roughness_R <sub>a</sub> (μm)	Surface roughness_R <sub>z</sub> (μm)
1	1.64	9.75	1.52	7.87
2	1.52	10.38	1.37	8.57
3	1.62	9.85	1.45	8.1
4	1.7	11.2	1.47	9.6
5	1.58	11.77	1.38	9.75
6	1.62	10.92	1.39	8.2
7	1.58	9.95	1.42	7.95
8	1.65	10.37	1.4	8.26
9	1.63	11.42	1.51	8.36
10	1.59	11.67	1.32	9.5
11	1.6	12.1	1.41	10.35
12	1.69	10.65	1.37	9.55
13	1.52	12.55	1.38	10.45
14	1.57	9.87	1.39	7.65
15	1.64	11.17	1.42	8.67
16	1.61	10.5	No heat treatment process on these specimens	
17	1.59	9.89		
18	1.57	11.21		
19	1.53	10.58		
20	1.6	9.78		
21	1.57	10.57		
22	1.61	11.56		
23	1.59	12.05		
24	1.58	11.52		
25	1.63	10.58		
26	1.62	10.77		
27	1.57	11.87		
28	1.63	12.08		
29	1.6	11.54		
30	1.58	10.37		

is more smooth compared to the one before treatment, which reflects the contact angles found smaller on rough wood surfaces due to the higher surface area than those of heat treated surfaces. In addition to the surface roughness area other parameters such as nature of the adhesive, adherend permeability and adhesive viscosity are responsible for the variation of contact angle and these parameters also need to be quantified.

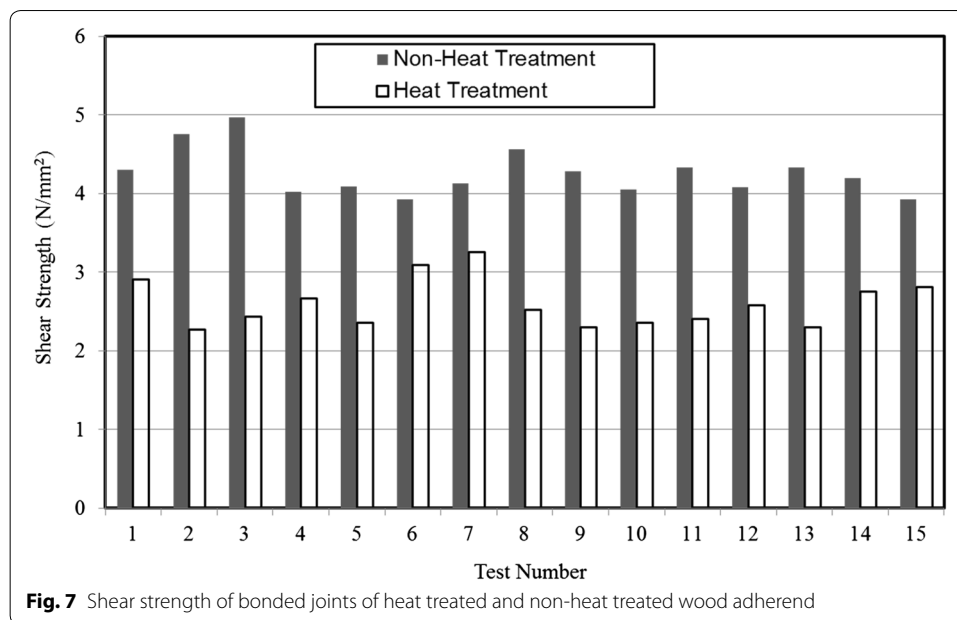
#### Effect of heat treatment on shear strength

Lower shear strength values were obtained for the heat-treated wood samples compared to the un-treated samples as shown in Fig. 7. Almost 20% decrease in shear strength was observed for the heat-treated wood samples with respect to the un-treated wood specimens. However, the bond strength decreased even for the lower surface roughness



which is contrary to the results of the same teak wood samples of sand paper treated specimens [26]. It implies that not only the lower surface roughness but the treatment by which it is obtained plays an important role for effective bond strength. The failure mode of the specimens was visually examined after testing and most of the joints have shown dominantly interface failure and very few specimen failed at adherend section.





The reductions in shear strength after thermal process are in agreement with the previous research for different adherend-adhesive bonded joints [18–20]. The possible reason mentioned in the literature is that the strength of wood was adversely influenced by heat treatment due to thermal degradations. This is probably due to the fact that a freshly produced surface contains all of the molecular attractive forces which were previously responsible for holding the material together. After the heat treatment process, the molecular attractive forces reduced results in lower bonding between the materials. In contrast to the above, Aydin et al. [14] determined that the improved surface roughness of veneer after thermal process increased shear strength. There are many factors such as surface roughness, adhesive wettability to the type of wood sample, adhesive viscosity, heat treatment process, treatment temperature and duration etc. that need to be quantified for an effective bond strength. This Indian teak wood have a negative impact on the shear strength, however the surface roughness improved which is positive and more useful in furniture industries where the smoothness is more important.

## Conclusions

This work investigated the effect of heat treatment surface quality and bond strength of Indian teak wood samples. The following conclusions can be drawn:

1. Heat treatment of teak wood adherend improved its surface smoothness. However, the bonding strength decreased.
2. Heat treatment can be used as an alternative method for surface modification of wood adherend material as long as strength is not the primary (necessary) objective for the design of bonded joints for this type of adherends. The heat treatment would be considered to improve the surface of the sample for furniture application and decorative products where smooth surfaces are ideal.

- The wood surface wettability was clearly diminished after the heat treatment process, which was reflected as the increased contact angle.

Even though the thermal process improves the surface of the wood adherend, there is need to focus on other parameters such as surface wettability, adhesive-adherend adhesion, different thermal process, temperature and thermal duration for maximum performance of wood joints for structural applications.

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#### Authors' contributions

SB (First and corresponding author) was responsible for completing the article. MDB carried out the revision and made relevant changes in the manuscript. SG carried out the experimental part of the study. SDB made final modifications in the article as per the requirement of the Journal. All authors read and approved the final manuscript.

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#### Availability of data and materials

All relevant data are presented in the manuscript, if needed additional information may be made available upon request.

#### Competing interests

The authors declare that they have no competing interests.

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