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Impact of the surface quality of a drilling on the cyclic behaviour of wood for a dowel-type assembly

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Abstract - The whole vibration behaviour of a wooden building is partly governed by the assemblies. As non-linearity is a characteristic of rod-type connectors, this behaviour is thus transposed to the building. Among rod-type assemblies, the dowel-type assembly allows smooth rod connections with a metal plate inserted into the wood. This type of assembly transmits forces between two wooden elements by shearing the dowels. Energy dissipation is possible thanks to the plasticization of dowels and the wood in contact with the dowel. The contact zone is an important part of the transfer of loads but also for dissipation. The present work focuses on the impact of the surface condition (following drilling) of the wood on the hysteretic behaviour of the assembly. For the experiments, half-drilled samples are tested applying cyclic compressive loadings without bending of the dowels. The drilling process of the samples applied helps reduce variability on the wood. To clearly visualize the different behaviours, the scaled surface after drilling (drilling at high speed and with a worn drill bit) is compared to the non-scaled surface (drilling at moderate speed and with a new drill bit). The results thus obtained show the effect of the surface condition on the mechanical behaviour of the assembly, whether in terms of stiffness or energy dissipation. The assembly with the scaled surfaces dissipated more energy for a given force, which would suggest that the use of a softer material at the interface between the dowel and wood would allow more dissipation, however the stiffness would be strongly impacted.

Keywords**:** wood, dowel type-assemblies, hysteresis, drilling condition

1. Introduction

The construction of large wood buildings has increased in recent years. This type of building calls for different construction methods, depending not only on the elements used, but also on the forces to be transmitted. Rod-type wood joints are widely used in both low-rise and high-rise timber constructions. The mechanical behaviour of this type of joint is influenced by its geometry, material properties and the properties of the contact area. The contact zone is an important part not only for load transfer, but also for dissipation.

To study the hysteresis and nonlinear behaviour of assemblies, cyclic tests are often used [1], [2]. The standards ASTM E2126 [3] / EN 12512 [4], define the protocol for cyclic testing, using displacement control (as a percentage of the yielding displacement). Some parameters are thus obtained, such as yielding slip, ductility, ultimate slip, strength degradation, strength loss factor, energy dissipation, and others. In this study, a load below the yielding strength is applied.

Unlike a dowel type assembly, a bolt assembly uses a nut to impose a rotational and translational rigidity, and the bolt is made with a thread surface, so the contact zone is stressed differently. Other phenomena also appear, such as the rope effect [5] and different types of failure are observed under monotonic loads [6].

To evaluate nonlinearities in the assembly, quasi-static loading tests are carried out at two loading levels and camera measurements are used (DIC). The tests are performed on semi-drilled samples, applying cyclic compressive loading without bending of the dowels. To obtain two different surface conditions, one is drilled with a new drill bit and the second with a worn drill bit at high rotational speed. To reduce variability due to wood heterogeneity, a cutting process is implemented.

2. Experimental procedure

The tests are carried out under cyclic compressive loading. A scaled surface after drilling (drilling at high speed ~2400 rpm and with a worn drill bit) is compared to a non-scaled surface after drilling (drilling at moderate speed ~1600 rpm and with a new drill bit). The resulting samples are tested with a compression machine using a swivel connection.

2.1. Preliminary observations

Several perforations are drilled at different speeds and with two different drill bits on a GLT 24h (spruce):

Table 1: View of the wood surface for different drilling speeds.

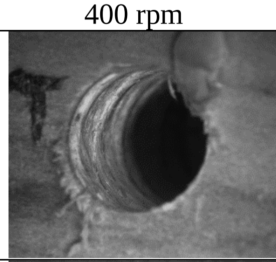
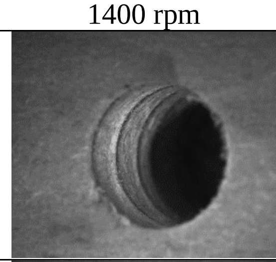
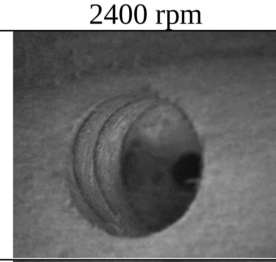
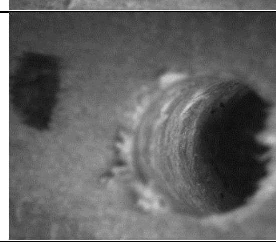
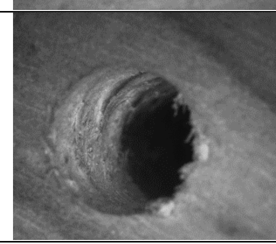
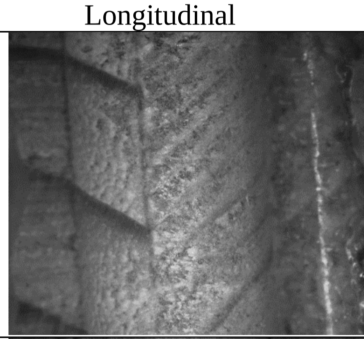
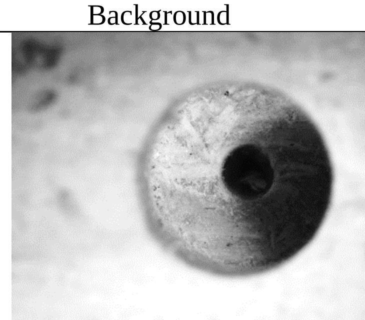
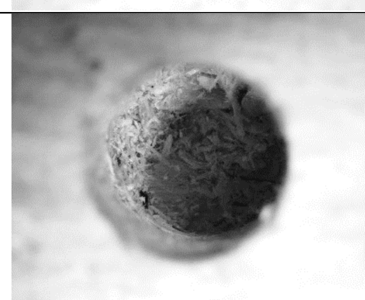
Speed	400 rpm	1400 rpm	2400 rpm
New drill bit 			
Worn drill bit 			

Table 2: Longitudinal and background view for different drill bits.

View	Longitudinal	Background
New drill bit		
Worn drill bit		

The insertion speed of the drill bit is around 1 mm/s. These observations lead us to compare two opposite cases, the first with a medium speed and a new drill bit, and the second with a relatively high speed and a worn drill bit. The latter can burn the contact surface between the dowel and the wood. In general, a non-scaled surface is observed for the low drilling speed with the new drill bit, in contrast to drilling with the worn drill bit.

2.2. Test series

In order to compare behaviour as a function of the drilling quality (with a new or worn drill bit), the procedure shown in figure 1 is established. A third sample (C) is used for ensuring a right drill, a new drill is used for the sample A and the worn drill for the sample B. Half-drill (in A and B) on almost the same position of the initial sample permits less variability due to wood heterogeneity.

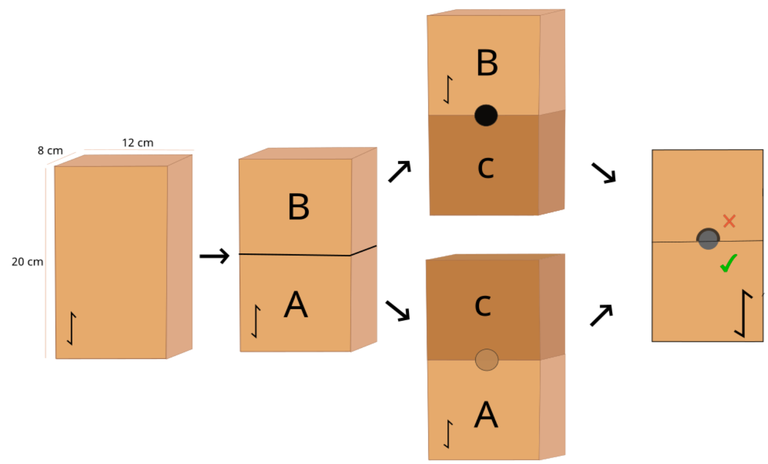


Fig. 1: Drilling process of samples.

Drill bit diameter is 8 mm and its length is 80 mm. GLT 24H (spruce) is used for the test samples. Each sample is made up of three lamellas of 40 mm thickness and the density of each lamella is between 450 kg/m^3 and 600 kg/m^3. A drilling is made in the middle of each lamella, according to the procedure described in Figure 1. An 8 mm diameter dowel is used for the test. The number of samples tested are listed in Table 3 and some material properties of the wood and dowel in Table 4.

Table 3: Quantity of samples.

	Controlled force	Controlled "displacement"
New drill bit	3	3
Worn drill bit	3	3

Table 4: Characteristics of each sample.

Surfaces	Moisture content (%)	$\rho\ (\frac{kg}{m^3})$	Drill diameter (mm)
S1	12.1	460	8
S2	11.6	472	8
S3	12.2	550	8

All samples are tested under a cyclic compression force. Two different controls are used, the first in displacement of the actuator and the second with controlled force (see Table 3). The results of previous tests show that the displacement control is not reproducible due to the different behaviour of lamellas and the interaction of the connecting elements, it results on a different behaviour in force and displacement for each sample. For these reasons, tests under controlled force are mainly analysed.

2.3. Set-up

The samples are subjected to a quasi-static vertical loading with two different stress levels, six cycles being used for each level. For force-controlled tests, a force of 5 kN is applied with 6 cycles before the second level at 10 kN (corresponding to 30% and 60% of the ultimate strength determined by testing the same assembly configuration). The dimensions of the sample are taken according to the ASTM D 5764 standard. An Instron traction-compression machine is used ($\Delta u = 0.01$ mm, Fmax = 100 kN). An initial force of 50 N is imposed to ensure contact between the dowel and the wood. A swivel connection (Figure 2) with a plate is used to ensure the load distribution on the dowel and prevent bending.

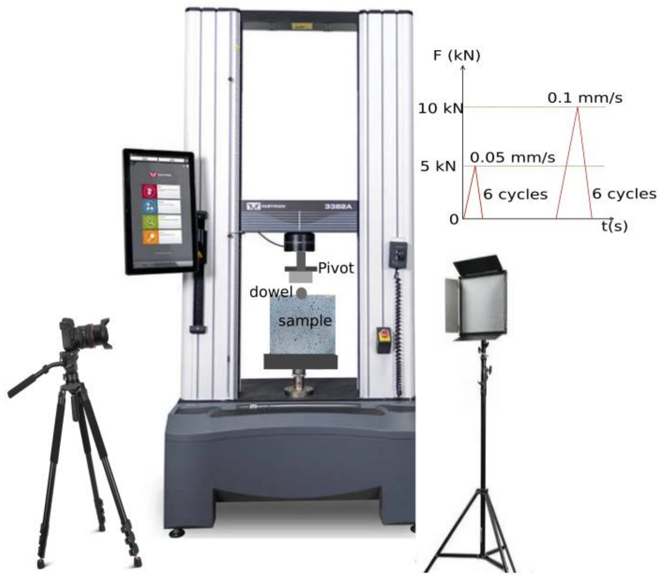


Fig. 2: Test set-up and loading.

2.4. Measurements

Two 12 MP cameras (JAI SP-12000M-CXP4) are used for image analysis by DIC. A speckle pattern is applied on the face of each sample to analyse the displacements and strains during the tests. In order to obtain a constant brightness, a led panel is used. A frequency of 5 Hz is chosen for image acquisition, so as to have equivalent frequency for each loading cycle and level. The speed of the actuator is defined as 0.05 mm/s and 0.1 mm/s for 5 and 10 kN loading respectively. In connection with the machine, a swivel connector ensures the transfer of load along the dowel. The displacement to be analysed is obtained by measuring the relative displacement between the dowel and the wood (located at the same level of the dowel).

3. Results

Figure 3 shows the evolution of the embedding at each force-controlled cycle (compression), with a constant speed imposed on the actuator as a function of the loading level. The embedding is measured from the initial position of the drilling in the wood, and this value increases, meaning that the resistance degradation increases the final embedding value for each cycle compared with the last one. This value does not return to zero, as permanent strains exist in the wood (pinching). Contrary to loading protocol of EN 12512 or ASTM E2126, the displacement value is not taken as a reference due to the heterogeneity of the wood (different load levels and different embedments for each test) and to the stiffness of the machine, which have an impact on the actual value of the embedment imposed to the assembly. The speed of the actuator is constant for each cycle, it is fixed in order to obtain a similar frequency for all cycles. For cycles at 5 kN, a speed of 0.05 mm/s is imposed, for 10 kN a speed of 0.1 mm/s is used, these values are comprised between the two limits provided in EN 12512 (0.02 mm/s – 0.2 mm/s). Frequencies between 0.05 Hz and 0.1 Hz are obtained for all samples.

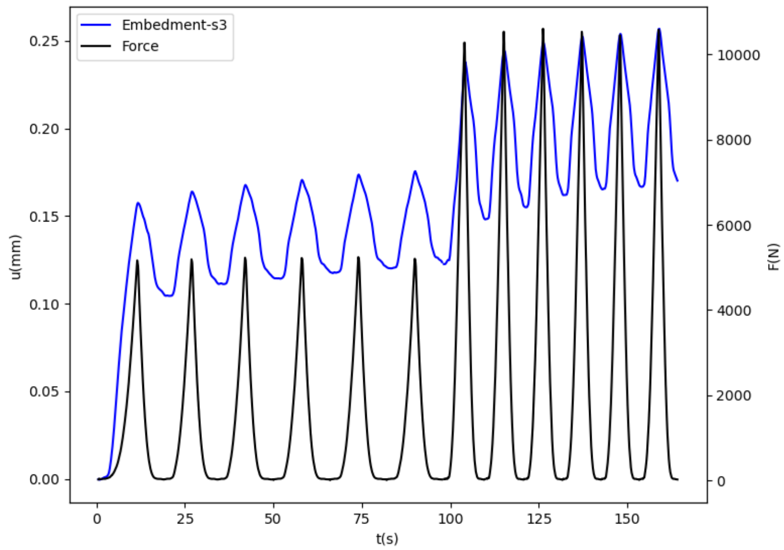


Fig. 3: Embedment and force evolution with time.

Non-linear behaviour is observed for both loading levels and for all samples. Hysteresis is observed, and a progressive increase in the tangent stiffness is present in all curves, particularly those obtained from drilling with the worn drill bit. This phenomenon is related to the behaviour of wood under compression. These tests are carried out with a controlled force and with a specific actuator speed in order to obtain a comparable frequency for all the cycles and to obtain an equivalent quantity of images (experimental points) for the two loading levels.

The cyclic curves in Figure 4 shows a trend for the worn drill bit compared to the drilling with a new drill bit. For all three sections, the embedment is greater in the case of drillings with the worn drill bit. As observed, this type of drill bit produced a scaled surface, at hight drilling rates, that can burn the surface in contact with the dowel.

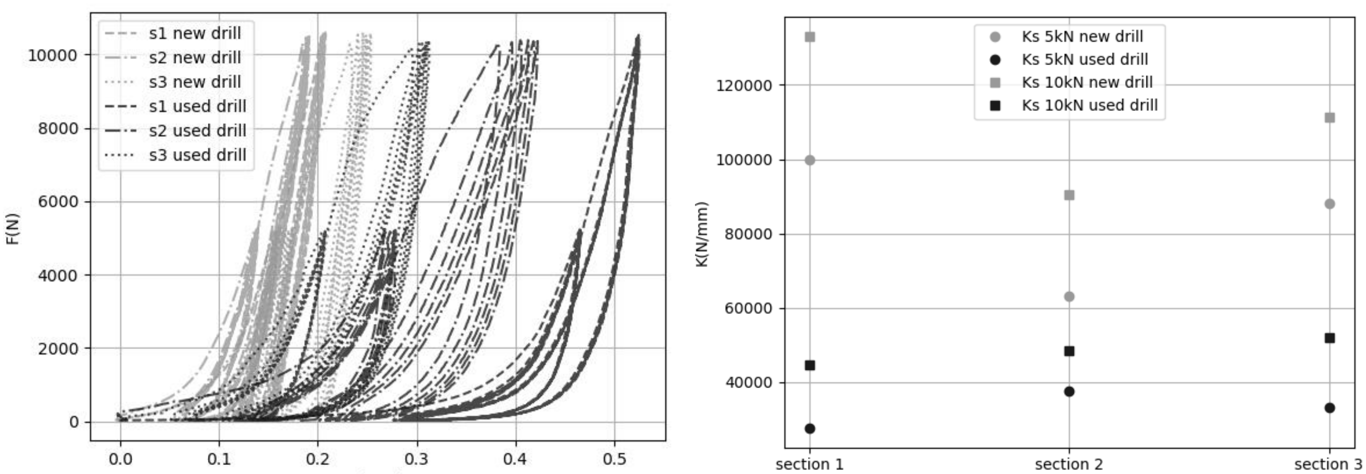


Fig. 4: Cyclic embedment curves (left), secant stiffness at the maximum load (right).

Figure 4 shows the difference in terms of secant stifness ($K_s = \frac{F_{max}}{U_{max}}$). This value is higher for drilling with a new drill bit and increases with force in the range used for our tests (0%-60% of ultimate strength), this value shows the difference in displacement beetween samples with perforations with new or used drill bit.

Hysteresis is observed in all the samples tested and the energy dissipation is taken as the main parameter for comparing the hysteresis level of each sample (energy dissipation is calculated in accordance with EN 12512).
This energy is calculated for each cycle and for each loading level. In Figure 5, the decrease in dissipated energy is observed in all samples. A value considered stabilized depends on the tolerance of the energy variation between two consecutive cycles. For all samples the variation after 6 cycles is less than 10%.

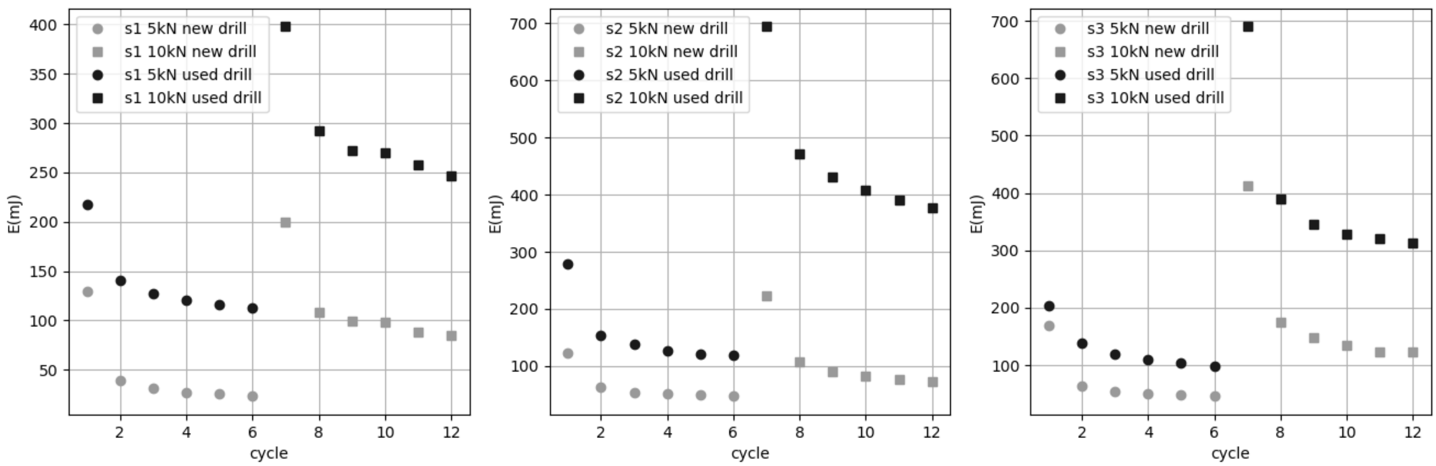


Fig. 5: Energy dissipation per cycle for all samples.

Figure 5 shows a greater energy dissipation for drilling with the worn drill bit. By comparing the energy in the last cycle, a percentage of the energy relationship ranging from 200% to 500% is found.

For all samples, the first cycle dissipates the greatest amount of energy. In this cycle, a phenomenon of densification of wood in contact with the dowel is observed. This phenomenon occurs for both load levels. For the latter, energy dissipation is greater for higher loading cycles. There is no a linear relationship between load and energy dissipation.

4. Conclusion

The results for scaled surface after drilling show that the secant stiffness at maximum effort is weakened and the energy dissipated is slightly greater than that of the non-scaled surface, for a given force. Stiffness is therefore weakened due to the condition of the wood around the dowel (damaged and partially burned by the high rotation of drilling). A thin layer of burnt material exists on the surface and small scraps of wood have been removed during drilling. This weak surface therefore considerably reduces the stiffness of the sliding force curve. In return, it allows more energy to be dissipated for a given force.

The results thus obtained show the impact of the surface condition in the mechanical behaviour of the assembly, whether in terms of stiffness or energy dissipation. The assembly with scaled surfaces dissipated more energy for a given force, which would suggest that the use of a softer material at the interface between the dowel and wood would allow more dissipation. However, the stiffness would be strongly impacted and a compromise must therefore be found. In this sense, similar assemblies have been studied in the literature, with modifications of the contact interface with the wood [5].

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