

Heat treated wood and the influence on the impact bending strength

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As part of a national research program for the development of a timber guardrail tests have been conducted to gain knowledge about the impact strength of timber. Tests were carried out on Angelim Vermelho, Douglas Fir, Ash and Larch and three temperature treated wood species, Douglas Fir, Spruce and Pine. Three point impact bending tests were performed with a loading speed of 7m/s. A high-speed camera was used to determine the time of failure. Computer simulations were used to determine the bending moment at the time of failure as literature showed other methods to be inadequate or questionable. Peculiar impulse transmitting effects were detected by the high-speed camera (9000 images/s). It was concluded that the impact strength is wood species and grade dependent. Some wood species didn't show any significant bending strength reduction for others the strength reduction was dramatic.

Keywords: *guardrail, timber, impact, crash barrier, wood species, strength*

1 Introduction

The starting point for the determination of many engineering timber properties is the standard short duration test where failure is expected within a few minutes. However, there are a number of load cases such as earthquakes and single blasts where timber is exposed to substantially higher loading rate.

In a number of countries, Netherlands and the USA, timber guard-rail systems are being considered as alternatives for the traditional steel guard-rail or concrete barriers. Old test data shows that timber is well able to withstand impact loads. However, the validity of the old test data is questioned as more elaborate recent research indicates conflicting results. For the Dutch guard-rail project a test programme was set up and carried out to gain more knowledge about the impact strength of structural wood. This paper summarises former test data and reports the test and computer simulation results of the experiments that were carried out within the framework of this guard-rail project.

2 Literature review of impact strength of timber

Historically, impact-bending tests were the first types of impact tests. Bodig et.al. [1] mentions the Hatt-Turner test, characterised by the application of impact loads in succession during the early 1900s. During the Second World War, when wood was used to a considerable extent for structural members for training aircraft's and gliders, it became evident that additional test data were necessary to improve the understanding of the behaviour of wood under impact load.

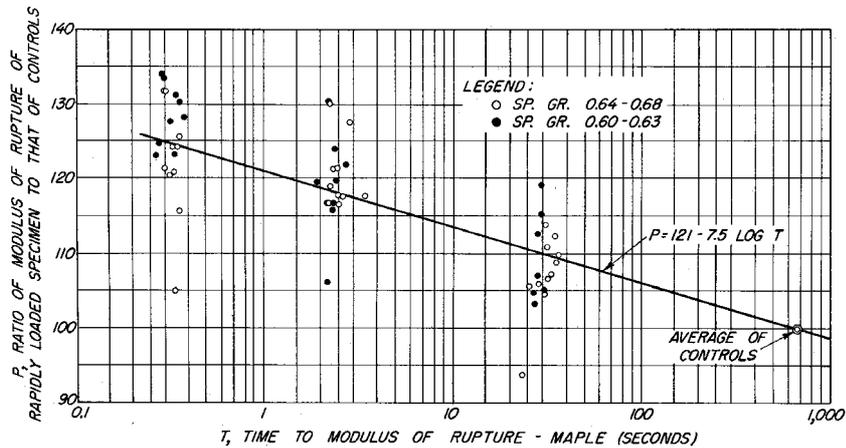


Figure 1: Ratio of static and impact bending strength versus loading rate for Maple, Liska [2].

Therefore, a comprehensive test program was initiated at the Forest Products Laboratory, Madison, US to study the effect of rate of loading on the bending and compression parallel to the grain, Liska [2]. The planks were small in size and free of defects and as straight grained as possible. Loading times ranged from 0.3 to 150 seconds. The bending tests were performed in a hydraulic testing machine with a constant head movement. Some of the results are shown in Figure 1. The average of the controls (reference) mentioned in Figure 1 refer to the standard bending tests of Maple. The data for all wood species follow the same tendency. At the highest loading rate the strength is about 20 to 30% higher than the standardised bending strength. More recently Madsen et. al. [3] and Jansson [4] studied the impact bending strength on simply supported timber beams by dropping a weight from various heights. The three-point loading was accomplished by a fit to purpose built machine, Figure 2. The drop height of the 345 kg weight varied from 50, 150 and 300 mm height resulting in a maximum impact velocity of 2,3 m/s. The average times to failure were 25, 17 and 10 milliseconds. Essential in these tests by Jansson [4] is that the impact force was measured directly by means of a load cell between the drop weight and the test specimen. In the analyses of the results the importance of separating the applied load in a part, which introduce bending stresses and a second part, which sets the

beam into motion, is demonstrated. It should be pointed out that previous researchers ignored inertia forces as they were assumed negligible. Analytical procedures earlier developed by Bentur et al. [5] to estimate the inertia effect were explored but rejected. Jansson [4] turned to a Modal Analysis approach to tackle this problem. Some of his experimental results are given in Figure 3 where on the vertical axes the ratio of the impact and static bending strength is given.

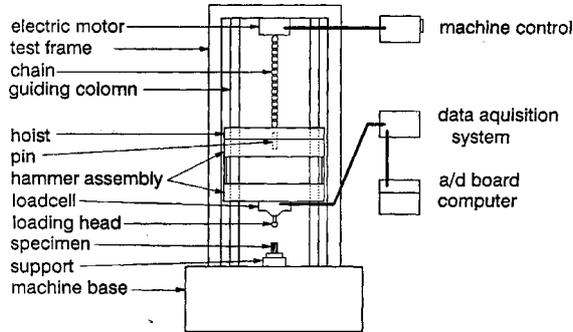


Figure 2: Test set-up by Madsen et al. (1986) and Jansson (1992)

The impact bending strength decreases with decreasing time to failure. The deviation from the test results mentioned earlier is considerable. No strength increase of 20 to 30% but a strength decrease of 15% for the shortest loading time of 10 milliseconds was observed when the inertia forces are taken into account.

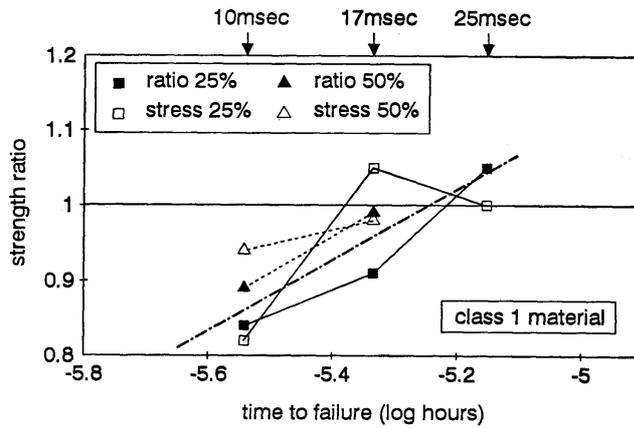


Figure 3: Final results of impact tests by Jansson (1992)

3 Aim of the impact tests, test apparatus and test specimens

The aim of the research was to detect differences in bending strength comparing results of standard bending and impact bending tests.

3.1 Rate of impact loading

In the guard-rail test standard EN 1317 a number of performances levels are specified. The performance level H2 of the Dutch guard-rail was arbitrarily set by the authorities. The two tests prescribed for H2 level are full-scale crash tests with a heavy 18-ton bus and a car. The bus shouldn't break through the structure while for the car test the acceleration of the passengers is limited. As the bus crash tests is regarded as the governing test case for strength the loading speed in the impact tests was deduced from this test. The bus entrance speed is 70 km/h (19.4 m/s). It will hit the guard rail at an angle of 20° as prescribed by the EN 1317, which leads to a lateral speed of $19.4 \sin 20^\circ = 6.7$ m/s. For this reason a load speed of 7.0 m/s was chosen in the impact test.

3.2 The test apparatus and instrumentation of the specimens

In principle the test apparatus compares well with Figure 2 accept for the loading head. The drop weight consisted of two cubic pieces of solid steel placed on both sides of a solid steel rod that acted as loading head. To prevent indentation of the timber test piece the rod diameter was arbitrarily set to 110 mm. The total weight of the drop piece was 199.0 kg.

The specimen was simply supported with a span of 1400 mm, and loaded by the drop-weight at mid span. Near the supports special devices were set up as prevent up lifting and to support any unstable specimens at time of failure. The weight was instrumented with an accelerometer. The de-acceleration of the drop weight, thought to be a key to determine the excitation force didn't work. The shock waves in the weight itself overruled the de-accelerating signal completely. A transducer (LVDT) attached to the bottom side of the timber specimen directly underneath the impact location, Figure 4, took the beam deflection. This LVDT was hidden in a stronghold below the specimen to prevent any damage of the device after failure of the specimen. A high-speed video camera (9000 frames per second or one frame every 0.111 ms) enabled monitoring the behaviour during the test. The high-speed camera appeared to be of vital importance in the determination of the time to failure. Failure was defined as the visual appearance of the first crack.



Figure 4: Transducer attached to specimen

3.3 The specimens

The number of specimens per wood species was limited to twenty per wood species. Seven wood species were selected for the experiments, Angelim Vermelho (tropical hardwood), Douglas Fir, Ash, Larch and three so-called heat treated or heat modified wood species. Angelim Vermelho was the wood species to be used in the actual build guard rail system while Larch and Ash were regarded as good shock absorbers from literature. The only heat treated wood species currently available on the market were chosen. With the PLATO process Douglas Fir was modified (PLATO is a Dutch patented process) while Spruce (*Picea Abies*) and Pine (*Pinus Silvestrius*) were modified using the Finnish STELLAC process. Clear free were Angelim Vermelho, Douglas Fir and Ash while the others were of a commercial grade including knots and other deficiencies. The PLATO wood was of the lowest grade involving the biggest knots. All specimens were conditioned at 80% RH and 20° C until equilibrium was obtained. The batches for standard bending and impact were matched on the basis of the MOE.

4 Bending tests

4.1 Static bending

The loading procedure corresponded with EN 408. The specimens of about 1600 mm length are symmetrically positioned on the supports of 1400 mm span and loaded until failure. The load deflection curve is recorded as well as signal of the accelerometer.

4.2 Impact bending tests

The high-speed video camera recordings with 9000 frames/second showed a phenomenon worth mentioning here and appeared to be of importance for the simulations and interpretation of the test results. The pictures clearly showed that after an initial phase of impulse transfer the beam accelerated rapidly and lost contact with the drop-weight. The impulse transfer was

apparently so high that the beam speeded up more than the drop-weight fell. After a short time the drop-weight made contact again and transferred a second impulse. The second separation between both was much smaller and shorter than the first time. Finally, the drop-weight established a permanent contact and worked its way down until failure of the beam occurred. In Figure 5 both output signals are given. The horizontal curve (not smooth) near the bottom resembles the output signal of the accelerometer and the second one (smooth) is the deflection. On the left axis the deflection is given in millimetres. Time is set to zero at first contact. The bouncing effect mentioned above is proven by this deflection curve. Certainly the first bump in this curve is clearly visible. Janssen [4] showed that the previous applied analytical method to determine the bending stresses from the experimental data was questionable. In pursue of a more reliable method a computer simulation programme was adopted. The tuning of the simulation programme to fit the recorded test data is obviously very important. In this programme the inertia influences are taken into account in a more accurate way than possible by the analytical methods.

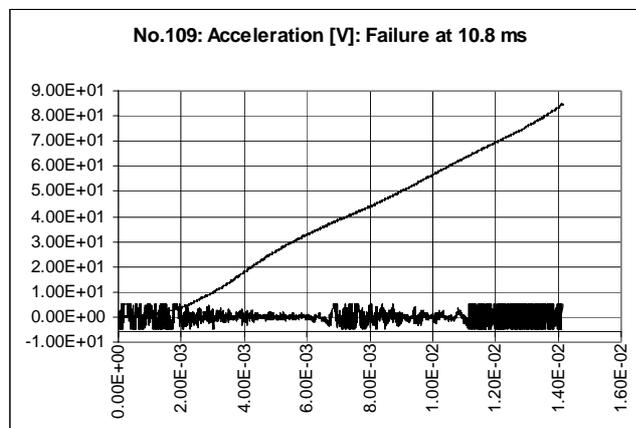


Figure 5: Deflection [mm] versus time [s] at the bottom the accelerometer signal

5 The simulation model

The FEM simulation model is based on Timoshenko elements. A. Kok [5] developed this particular simulation model suited to load the beam by impulses and to attach lumped masses at any given time. The model accounts for all inertia effects. A single impulse at the beginning of the simulation represents the initial contact and after a given time the drop-weight characterised as a lumped mass of a certain quantity and velocity can be attached to the mid span elements. Damping can be introduced to diminish the effect of higher order vibrations.

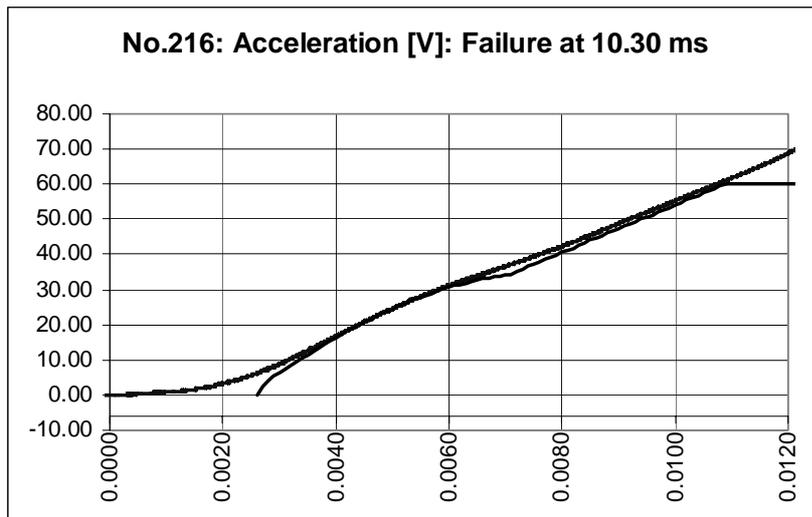


Figure 6: Test and simulation results of deflection [mm] versus time [s]

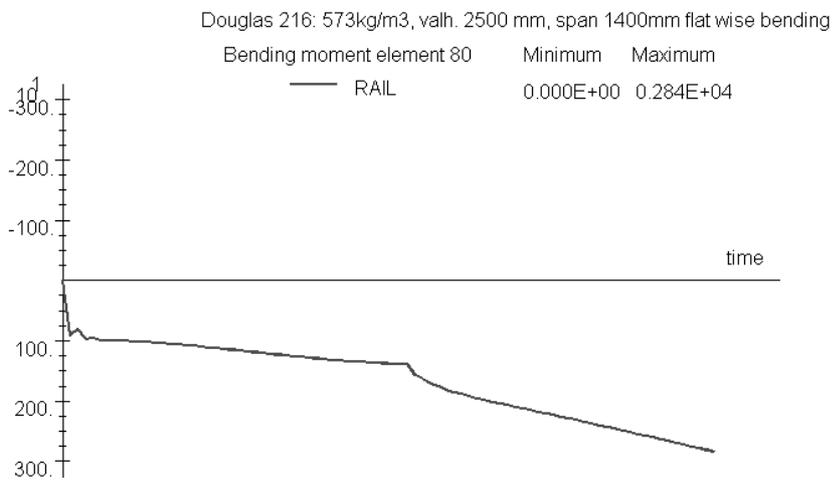
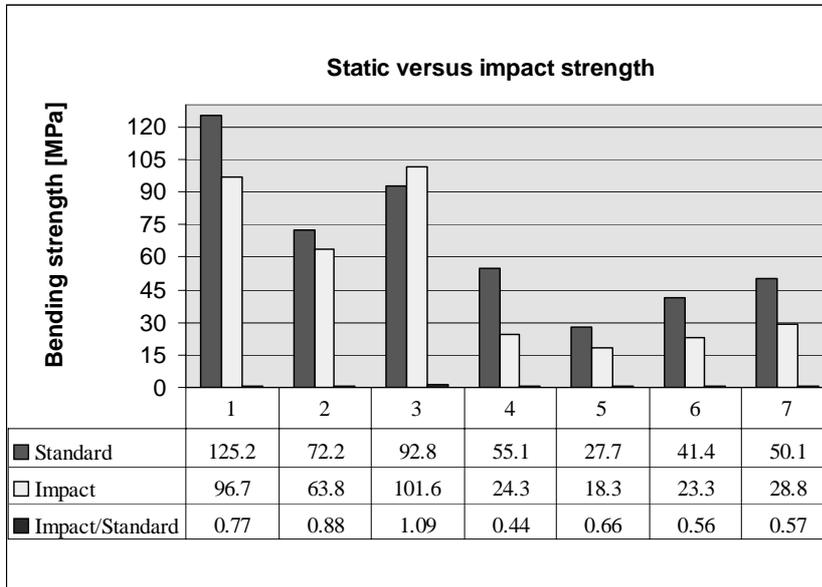


Figure 7: Simulated bending moment [Nm] versus time [s] at mid span

The 1600 mm long beam consisted of 160 elements of 10 mm each. The beam supports allowed rotation but no up-lift. For every specimen the relevant material properties, MOE, density and dimensions were part of the input file. The simulation generated deflection, rotation, bending moments and shear forces. It allowed plotting the simulated time deflection curve together with the time deflection graph recorded, Figure 6. The test starts at $t = 0$. As Figure 6 shows in the first 2 ms not only the beam needs time to accelerate also the deflection apparatus needs time to keep up with the sudden signal change. Obviously, the mathematical beam in the simulation

exposed to an impulse reacts immediately. To have agreement between both curves the initial contact in the simulation is delayed. The delay time and the initial impulse are chosen such that both experimental and simulation time deflection curve are in good agreement.

Having set the simulation input variables such that the deflection versus time corresponds well with the test data the model generates the corresponding bending stresses at any location along the beam. The overall majority of beams failed at mid span. For that reason the mid span bending moment was taken as the governing value for the derivation of the bending strength. Only in some cases knots and slope of grain caused failure initiation a small distance from mid span. In Figure 7 a plot is given of a typical mid span bending moment versus time plot. The maximum bending moment is given in the top right corner in Nm. The bending stress is derived in the traditional way assuming Hook's law applies for these conditions. Regarding the failure mode it was observed that nearly all specimens, some specimens failed because of knots outside the centre area, failed showing shorter fibres for the impact tests. No conclusion could be drawn regarding the influence of the heat treatment as this parameter was not included in the test programme.



*)Column numbers correspond with Table 1 column 1 values in brackets

Figure 8: Overview of the impact and static strength results

6 Evaluation of the results

The results are graphically represented in Figure 8. The strength ratio impact bending / standard bending is given in the lower part of Figure 8. Notices the ratio in Column (3) for Ash, which is higher than 1, while for all other wood species it is considerable smaller than 1.

In Table 1 the results of the simulation are presented per wood species and complimentary the data of the standard bending tests is added. To drawn more reliable conclusions only based on differences in mean bending strength the statistical t-test was applied. This allows checking whether or not the differences in mean strength are significant (significance level 5%). The analysis concludes that with 95% certainty the mean bending strength of Angelim Vermelho, Larch, Mod. I, Mod. II and Mod III wood species in impact bending is indeed significantly different from the standard bending strength. No significant difference was found for Douglas Fir and Ash.

Table 1: Results of standard and impact strength tests

(1) Wood species	(2) number of tests n	(3) Standaard bending [Mpa]	(4) c.o.v. [%]	(5) number of tests n	(6) Impact bending [Mpa]	(7) c.o.v. [%]
Angelim Vermelho (1)	11	125.2	13	10	96.7	38
Douglas Fir (2)	10	72.2	14	10	63.8	39
Ash (3)	4	92.8	9	7	101.6	12
Larch (4)	11	55.1	26	10	24.3	29
Mod.I (5)	12	27.7	23	11	18.3	37
ModII (6)	13	41.4	24	22	23.3	20
Mod III (7)	17	50.1	24	14	28.8	27

The difference between standard static and impact strength has some relation with grade quality as the wood species of commercial grade (containing knots) reduced more in strength than others. Apart from Ash the other wood species free of any knots such as Angelin Vermehlo and Douglas Fir, dropped in strength only 23 and 12% respectively. The other wood species with knots such as Larch and the heat-treated wood species dropped 40 to 60 % in strength. The influence of knots turns out to be of significant importance. This agrees with the conclusion by Jansson [4] that commercial timber behaves worse than clear and free wood specimens.

7 Summary and conclusions

Standard and impact bending tests have been performed on matched timber specimens in flat wise three point bending. The span was 1400 mm while the specimens had a cross-section of about 40x130 mm. Seven wood species were investigated Angelim Vermelho, Douglas Fir, Ash, Larch and three heat modified wood species of Pine, Spruce and Douglas. The number of specimens per wood species in the static and impact test was 10 with some exceptions.

The standard bending tests were performed according to EN 408. For the impact tests a tailor made apparatus was built in absents of any standardised apparatus. The load application consisted of a 199 kg drop-weight, which fell from 2.5m height and reached a speed at impact of 7 m/s. During impact the deflection was recorded at mid span. Failure was defined as the occurrence of the first crack. A high-speed camera (9000 frames a second) was used to record the time to failure. In order to determine the bending strength a simulation programme was used. The dynamic programme was tuned in such a way as to simulate the most important phenomenon observed during the impact test up to failure.

Reviewing the strength values derived it was concluded that the mean impact bending strength is in most cases lower than the static bending strength. It was concluded that no significant bending strength difference could be demonstrated for Ash and Douglas Fir. However, all other wood species especially those of commercial grade (containing knots) showed a considerable reduction in strength from 40% up to 60%. Despite the low number of tests the conclusions are in line with the results of Jansson [4].

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