Fracture Characteristics and Properties of Thermally Modified Timber made out of Beech

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ABSTRACT

Thermally modified timber (TMT) is timber with properties that have been altered because of the high temperatures to which it has been subjected. Due to its good durability, TMT is commonly used for non-structural purposes in outdoor environments, without additional chemical treatment. In this paper, the use of TMT as a structural material is considered. The work reported focused on beech, since earlier investigations about the mechanical behaviour of TMT have been oriented to softwoods. One of the most important changes in the mechanical properties of wood that thermal treatment produces is a significant increase in brittleness, manifesting itself, in particular, as a decrease in the strength in tension perpendicular to the grain. It is now well known that when dealing with tension perpendicular to the grain, fracture mechanics offers an effective tool for characterising wood failure (Gustafsson 1992). In the work reported herein, the fracture of thermally modified beech wood under Mode I loading was quantified using Compact-Tension specimens under steady-state crack propagation conditions. The influence of three heat treatments and different fibre orientation (RL and TL crack growth systems) was studied. Complete load-displacement curves were evaluated and the specific fracture energy parameter, G_f, measured. Thermal modification was found to significantly affect the structural behaviour. The more severe the treatment, the lower the G_f.

INTRODUCTION

Thermal modification, or heat treatment, of wood is an established alternative to other preservative treatments that may be aggressive to the environment. Advantages of thermal modification are good biological resistance and an improvement in dimensional stability. The main disadvantage is its brittleness. Until now, heat treatments have been mainly applied to softwoods and for non-structural purposes. When the use of thermally modified wood in structural applications is envisioned, the fracture properties become extremely important. Most of the fracture studies to date have utilised linear elastic fracture mechanics, and the non-lineal ones consider generally only untreated wood (Böstrom 1992, Tukiainen 2006). In the work reported in this paper, the specific fracture energy, G_f, of beech wood modified by three different heat treatments was quantified, under Mode I loading and steady-state crack propagation conditions, using non-linear fracture mechanics. The investigations were carried out in the RL and TL crack propagation systems.

EXPERIMENTAL

Materials

Modified and unmodified beech boards were provided by Mitteramskogler GmbH, Austria. The boards were modified using three different commercial heat treatment processes under a gas atmosphere. The treated boards are sold under the brands “Mezzo” (ME), “Forte” (FO) and “Forte exterior” (FE). These processes are differentiated by the heating temperature (between 160 ºC and 250 ºC) and the treatment times (from 2h to 16 h), however, exact treatment details are proprietary. All tests were executed on treated samples and untreated material obtained from the same log. Notched specimens, as shown in Figure 1, were prepared. An initial notch of about 5 mm long was sharpened with a small band saw and finalized with a razor blade cut, about 2 mm long. In the crack propagation systems studied, RL and TL, R (radial) and T (tangential) respectively indicate the direction of the normal plane of the crack and L (longitudinal) the direction of crack propagation. Prior to testing, the specimens were conditioned at 20 ºC and 65% relative humidity until equilibrium moisture content (EMC) was reached. The EMC range for the treated beech was 5.8±1.8% and 10.5±1.5% for the untreated material. The density of heat treated samples varied from 472 to 727 kg/m^3 and for untreated the density varied from 600 to 777 kg/m^3.

Procedure

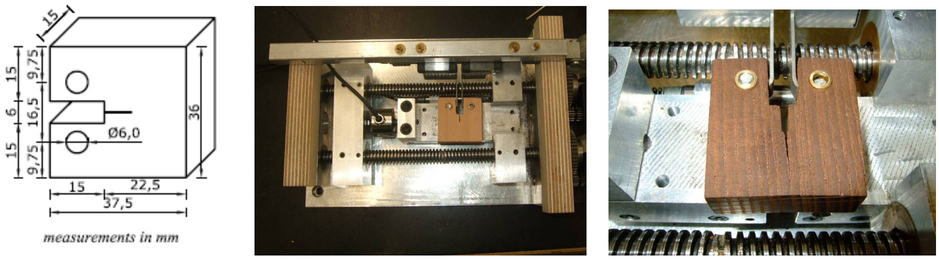

Figure 1: Specimen geometry and testing device

Compact tension (CT) tests, under pure Mode I loading, were carried out using a small stepper motor driven loading device (Figure 1). The notched specimens were placed on the equipment fixed by two loading bolts. The specimens were loaded to failure under displacement control at a speed of 0.4 mm/min. The principle is shown in the images above (Figure 1). The increase the distance between the loading bolts, the crack mouth opening displacement (CMOD), was recorded using a digital displacement gauge. At the end of the tests, the remaining ligament of the specimen was measured. In all the tests the complete load-CMOD curves were obtained. The specific fracture energy (G_f) was calculated from the integrated area under these curves divided by the area of the fracture surface, A, of the specimen according to (Eqn. 1), where F_H represents the horizontal splitting force and δ the CMOD:

$$G_f = \frac{1}{A}\int_0^{\delta \max} F_H(\delta)\,d\delta \qquad (1)$$

G_f represents the whole fracture process until complete separation of the specimen including crack initiation and propagation yield. This amount is characteristic of the non linear fracture mechanics, and shows the energy needed to produce a unit fracture area including the dissipated energy.

RESULTS AND DISCUSSION

Typical load-CMOD curves obtained in the tests are shown in Figure 3.

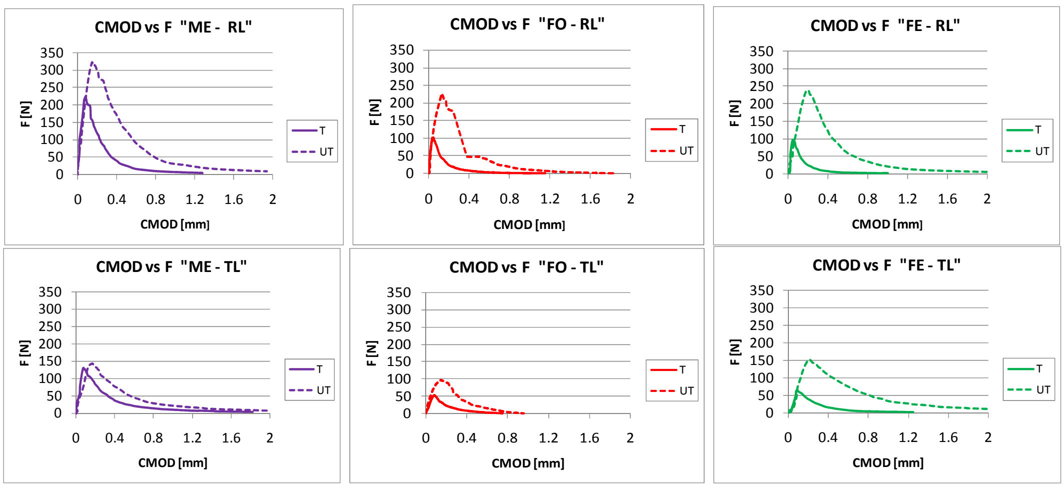

Figure 3: Typical CMOD versus load (F) curves for untreated (UT) and heat treated (T) beech, in RL (up) and TL(down) systems, for Mezzo (ME), Forte (FO) and Forte exterior (FE) heat treatments

As may be observed, the load-CMOD curves for the heat treated wood show smoother and more uninterrupted behaviour than those exhibited by the raw material, which display more unstable behaviour after crack initiation. Moreover, the CMOD prior to fracture is smaller in the cases of the treated sets, indicating more brittle behaviour. The maximum load is evident as angular peaks, typical for linear elastic brittle hardwoods (Reiterer 2002). The explanation could be related to the complex structure of hardwoods, consisting of a high fraction of rays acting as reinforcements, forcing the crack to take a more winding trajectory. The ratio between the maximum loads obtained in the RL and TL systems were also calculated. The value of these ratios ranged from 1.4 to 2.0 in treated beech and from 1.5 to 2.3 in untreated material. The specific fracture energies are shown in Table 1.

Table 1: Average values and standard deviations for the specific fracture energies G_f, of heat treated and untreated beech, in RL and TL systems

	Heat Treated Beech						**Untreated Beech**					
Treat.	**MC**	**ρ**	**G_f (RL)**	**SD**	**G_f (TL)**	**SD**	**MC**	**ρ**	**G_f (RL)**	**SD**	**G_f (TL)**	**SD**
ME[a]	6.5	706	242.25	39.0	191.85	24.5	11.4	730	563.75	86.9	318.60	60.7
FO[b]	4.5	594	75.80	10.4	74.99	12.2	11.6	744	310.16	51.2	263.65	48.4
FE[c]	4.3	574	67.01	7.6	77.65	7.3	11.4	743	488.50	61.4	489.84	65.9

[a]Mezzo, [b]Forte, [c]Forte Exterior; MC: Moisture content [%]; ρ: Density [kg/m³];
G_f: Average Specific Fracture Energy [J/m²]; SD: Standard deviation

As expected, in both crack propagation systems, G_f, was found to be higher in the case of the untreated wood than in the treated materials. No significant differences in G_f could be detected between the FO and FE treated beech, which showed the lowest fracture energies. Of the heat treated woods, ME clearly exhibited the highest fracture energy. For the unmodified wood, G_f was always higher in RL crack propagation system. For the three sets of treated wood, such a clear differentiation could was not found.

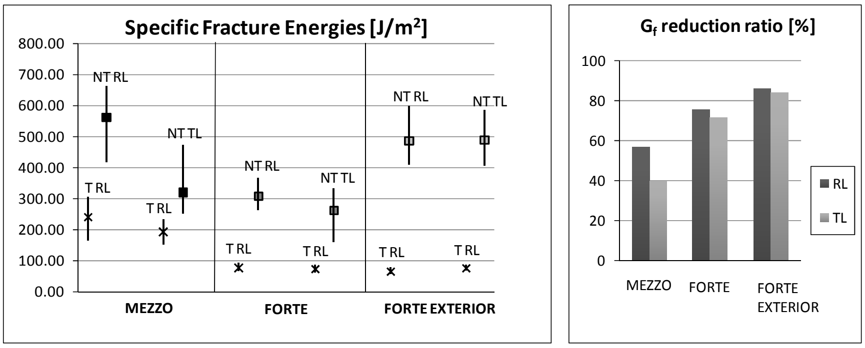

Figure 4: Left: Specific fracture energies values. Right: reduction ratios of specific fracture energies

Figure 4 (left) shows G_f values for each set of heat treated wood in comparison to the untreated material. Also shown (Fig. 4, right) is the percentage reduction in G_f over that of the untreated wood for both crack propagation systems. The results lead to a fracture model of this material. Considering the use of TMT as structural element, one of the proper possibilities would be as a face/s of a sandwich panel to be used in façades.

CONCLUSIONS

Specific fracture energy values, G_f, were obtained for beech subjected to three different heat treatments (ME, FO and FE) in the RL and TL crack propagation systems. The more severe the treatment, the lower the G_f. In the RL direction, ME shows G_f values reduced by approximately 57%, 75% in the case of FO and 86% in FE compared to the unmodified beech. In the TL direction, the reduction is around 40%, 71% and 84% respectively. In this way, the fracture energy of heat treated wood to be used in outdoor environments (FE) is drastically reduced by this treatment. This finding is in keeping with other studies within the same project regarding the grading of TMT carried out by EMPA, Switzerland. Further studies are currently underway on the application of fracture properties of TMT to find a fracture model for this material.

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