Advanced Materials Research Vol. 778 (2013) pp 145-151
© (2013) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.778.145

Effects of beetle attack on the bending and compression strength properties of pine wood

Helena Cruz[1, a], José S. Machado[1,b]

[1]Laboratório Nacional de Engenharia Civil, Av. do Brasil 101, 1700-066 Lisboa, Portugal

[a]helenacruz@lnec.pt, [b]saporiti@lnec.ptl

Keywords: timber structures, mechanical properties, boring beetles, damage, density

Abstract. One major difficulty one has to face in the assessment of old timber structures concerns the assessment of the effective strength of timber cross sections with biological damage.
Its effects may generally be considered, either by assuming a reduced cross section or by assuming reduced mechanical properties for the apparent cross section.
Where beetles attack produce a "diffuse" damage, i.e. their tunnels spread in most of the cross section surrounded by a significant amount of undamaged wood, the assumption of a reduced cross section may not be the best approach.
To assess the effect of diffuse damage by beetles to pine timber, damaged timber was collected from an old structure and tested in bending and compression in small "clear" wood specimens (cross sections of 2cm x 2cm). The varied degrees of biological damage were assessed in terms of the "holes" area measured in the cross section surface with the help of image processing analysis. Bending and compression strength were correlated with biological damage. Test results suggest that, although very high levels of insect destruction have an impact on the timber strength, timber density still is the governing factor.

Introduction

One major difficulty one has to face in the assessment of old timber structures concerns the assessment of the effective strength of timber cross sections with biological damage.

In the case of boring beetles' attack, biological damage is generally widespread throughout the whole structure. Therefore, its effects need be considered [1], either by assuming a reduced cross section or by assuming reduced mechanical properties for the apparent cross section [2].

As beetles' attack is normally limited to sapwood, in most common situations timber members will present a more or less severely damaged surface layer covering undamaged (heart)wood. In many cases this may be assumed as corresponding to an equivalent destructed/lost outer skin of the timber member, with a given thickness.

Less frequent are those situations where beetles produce a more "diffuse" damage. In such cases, the beetles' tunnels spread in most of the cross section, being surrounded by a significant amount of undamaged wood. This is more likely in small cross sections of softwoods with a high percentage of sapwood (Fig. 1). Should this be the case, the assumption of a reduced cross section will not be a suitable approach. Taking into account the damage pattern, it seems more logic to assume reduced mechanical properties in proportion to the "diffuse" loss of material, therefore in proportion to the loss of density.

The work carried out intended to check whether or not density remains a good predicting parameter for bending strength, modulus of elasticity in bending and compression strength parallel and perpendicular to grain of timber with small beetles' attack only. Furthermore, it aimed to investigate if an equivalent "effective" density (derived from the loss of effective cross section) would be suitable to estimate strength properties of beetles' damaged "clear wood" timber.

Figure 1. Diffuse beetles attack (cross sections of 12cm x 12cm approximately)

Materials and methods

Timber material: Timber was collected from a 70 years' old roof structure belonging to a residential building in Sintra, about 30km NW of Lisbon, which was demolished as a result of severe biological attack, both fungi and insects.

As it is normally the case, fungal attack affected just the humid ends of beams whereas insect infestation spread through the whole timber structure. In this case, insect attack was mainly due to small wood boring beetles, especially *Anobium punctatum*. Due to the use of small cross section member sizes taken from young *Pinus* spp. trees, small beetles attack had spread through the whole cross section of most timber members (Fig. 1). Roof elements of 12cmx12cm cross section were cut to produce 2cm x 2cm cross section fascia about 1.2m long (Fig. 2).

Figure 2. Some of the fascia used for bending and compression tests

Each fascia was subsequently crosscut to produce 32 cm long specimens free from defects like knots, slope of grain, fissures and wane, but presenting only attack by *Anobium*, to variable extents. These specimens were used for bending tests. Afterwards, one specimen 6cm long was taken close to each end of the bending specimen, whenever possible – one to be tested in compression parallel to grain, the other in compression perpendicular to grain. Fig. 3 presents five of the specimens tested in compression parallel to grain, showing typical level of destruction visible on faces and ends.

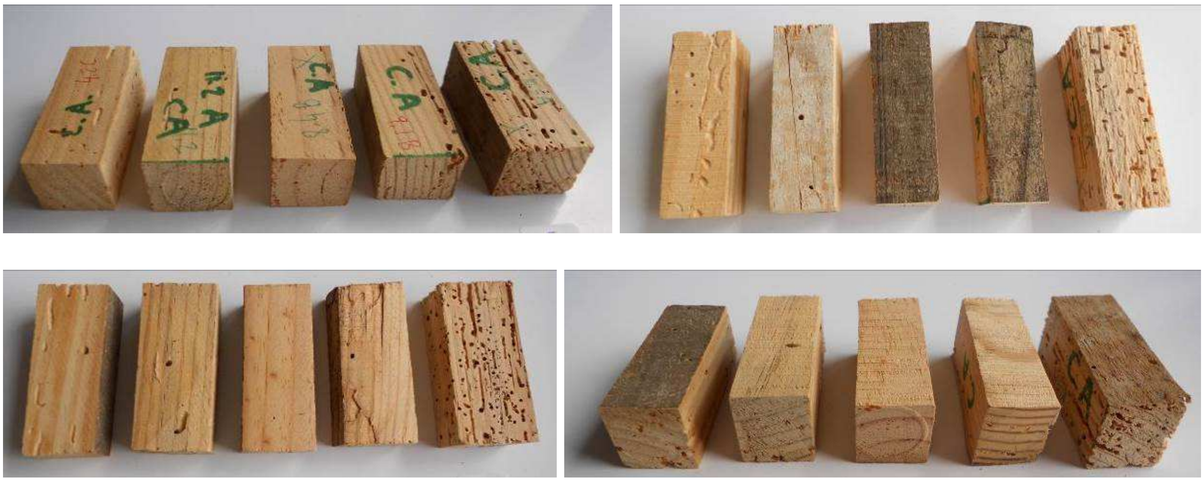

Figure 3. View of all faces and both ends of five specimens tested in compression parallel to grain (from a to d: specimens rotated 90º around axis)

Residual (effective) cross section area. Both ends of each bending specimen were digitalized. The total area of insect holes visible at each end was calculated with Autocad software and the mean value of residual (effective) cross section area and the corresponding damage factor (Ar/At) calculated for each specimen, where:

A_t = Full cross section area;

$A_r = A_t$ – (area of holes).

Although some specimens present a high number of insect tunnels visible on the end grain surface, thus giving the impression of a high destruction level, the corresponding area reduction is not so important due to the small diameter of insect tunnels, as shown in Fig. 4.

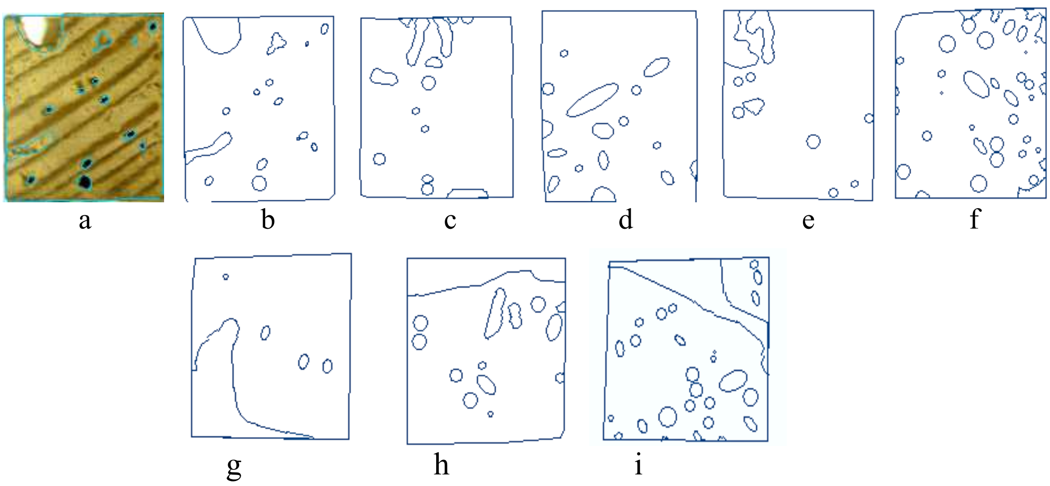

Figure 4. a) identification of insect tunnel areas on the specimen also shown as b);
b-f) - residual (effective) cross section área = about 90%;
g-i) – residual (effective) cross section área = about 80%

Test procedure. The specimens were conditioned to a standard environment (20±2ºC/ 65±5%RH) till equilibrium, prior to mechanical tests. After the final (compression) tests were performed, control tests were also carried out to check moisture content. This was found to be 13.0%.

Bending strength and modulus of elasticity were obtained from 3-point bending tests performed on specimens of 2x2x32 (cm) according to ISO 3133 [3]. Compression strength parallel to grain corresponded to the maximum load attained in the tests carried out on 2x2x6 (cm) specimens following the procedure given in ISO 3787 [4].

Compression tests perpendicular to grain were carried out also on specimens of 2x2x6 (cm) fully supported on one face and loaded on the opposite face through a 2x2 (cm) steel plate centered in the 6 cm face length. The value corresponding to F_{max} was obtained for the extension of ε=0.1 (when attaining a deformation of 1/10 of the cross section depth) (procedure adapted from EN 1193 [5]); the value corresponding to F_y was obtained from the first and second secants to the load-deformation diagram (Fig. 5).

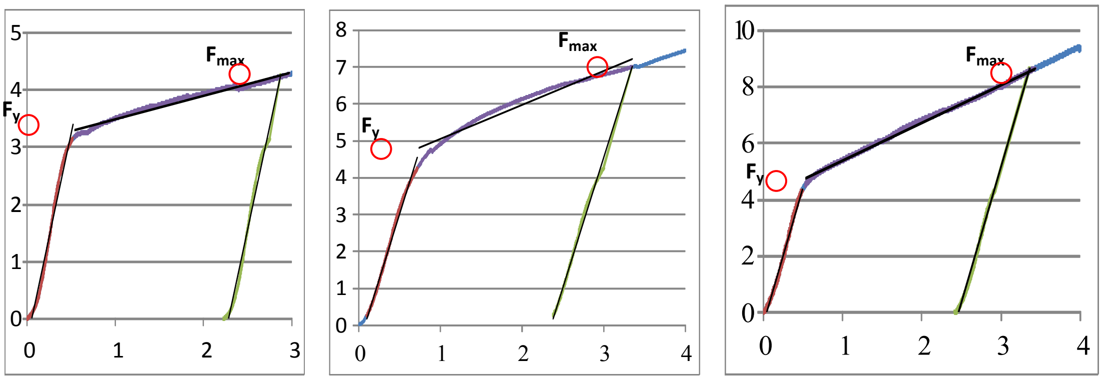

Figure 5. Examples of calculation of F_{max} and F_y in compression perpendicular to grain

Test results and discussion

Compression parallel to grain. Although there is no correlation between compression strength parallel to grain and A_r/A_t, as expected, for similar apparent density values, the trend is that the higher the damage the lower the strength of specimens (Fig. 6).

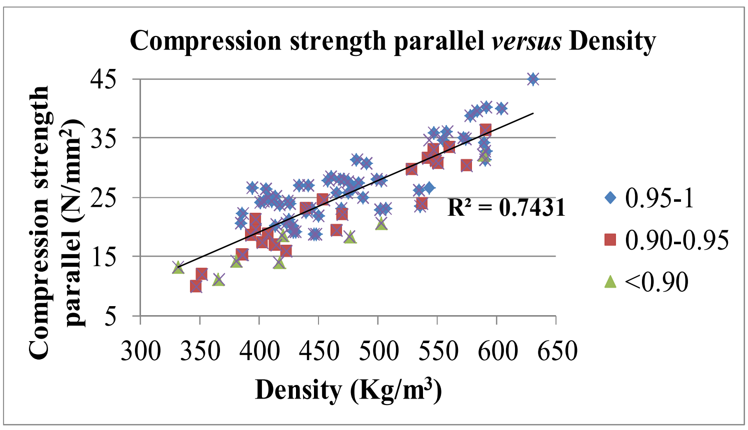

Figure 6. Compression strength parallel *vs* density, separated by A_r/A_t intervals

Therefore, another correlation was calculated – between the "effective density", i.e. density taking into account the contribution of the undamaged cross section (D_e=Density x A_r/A_t) only, this one showing a better correlation (Figs. 7a and b).

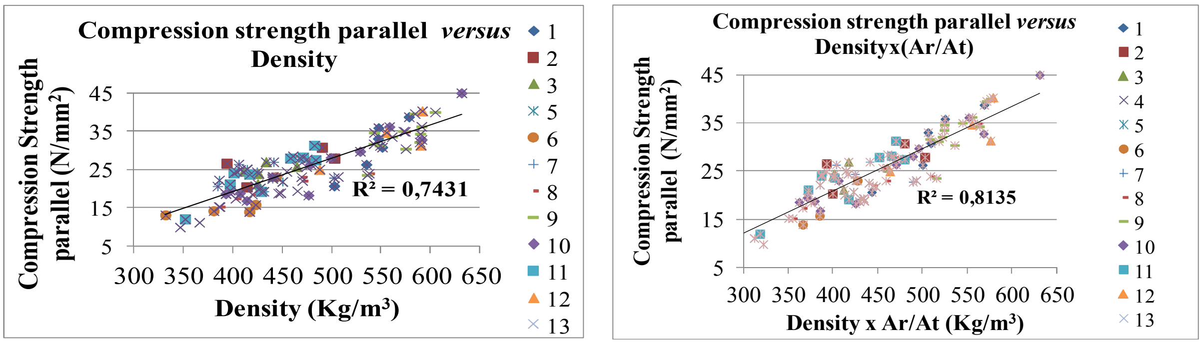

Figure 7. Compression strength parallel: a) *vs* density; b) *vs* "effective" density

Compression perpendicular to grain. Figs. 8a, 9a and 10a show the correlation between compression strength perpendicular to grain and density, calculated from the F_{max} load, whereas Figs. 8b, 9b and 10d show similar correlations, but calculated from F_y.

Although similar, the obtained correlation with density is slightly higher for the F_{max} than for the F_y, and, in both cases, lower than the one obtained for compression parallel to grain.

Moreover, for similar apparent density values, the influence of damage (A_r/A_t) on compression strength perpendicular to grain (Figs. 8a and 8b) is not as clear as the one found for compression parallel to grain (Fig. 6).

Therefore, there is no gain to correlate strength with the effective density, i.e. the density taking into account just the contribution of the undamaged cross section (D_e=D.A_r/A_t), Figs. (10a and 10b).

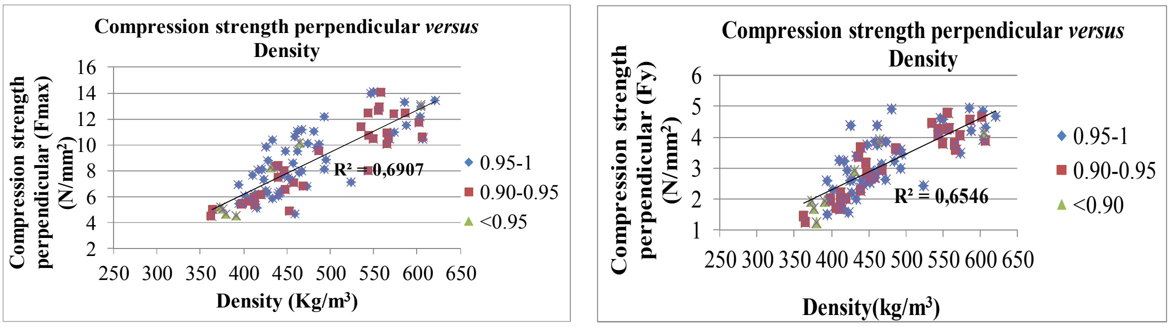

Figure 8. Compression strength perpendicular *vs* density, separated by A_r/A_t intervals
a) calculated from the F_{max} load; b) calculated from F_y

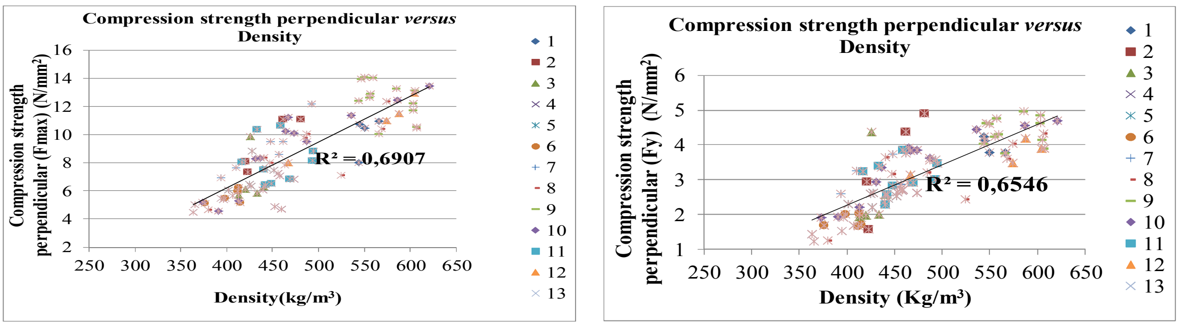

Figure 9. Compression strength perpendicular *vs* density:
a) calculated from the F_{max} load; b) calculated from F_y

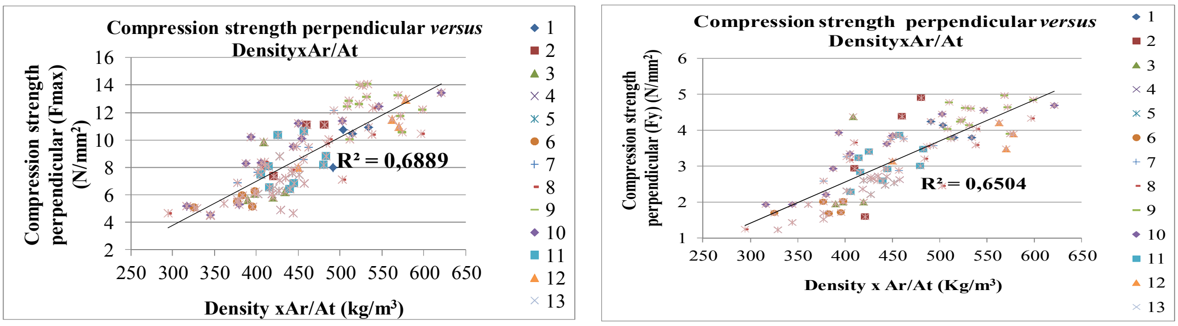

Figure 10. Compression strength perpendicular *vs* effective density:
a) calculated from the F_{max} load; b) calculated from F_y

Bending. Figs. 11 and 12 present the correlations obtained for bending strength and modulus of elasticity values, with density and with the effective density (D_e=D. A_r/A_t).

In this case, the consideration of the effective density values as independent variable provided a slight decrease of the coefficients of determination obtained both for bending strength and modulus of elasticity.

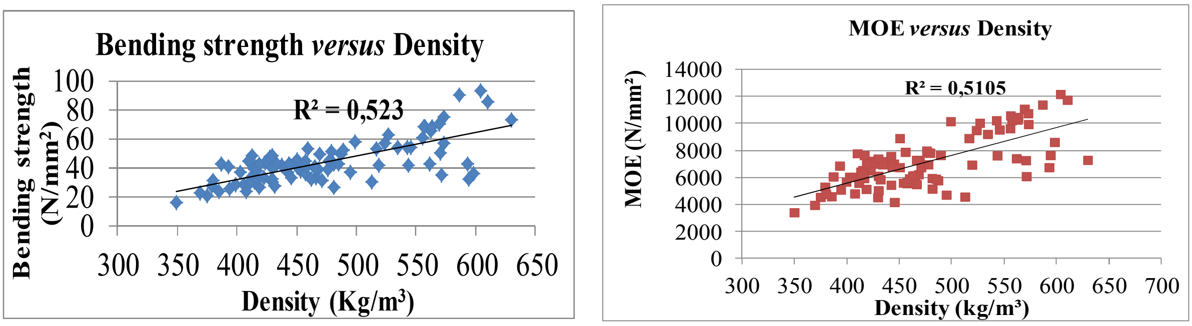

Figure 11. Bending strength (a) and MOE (b) *vs* density

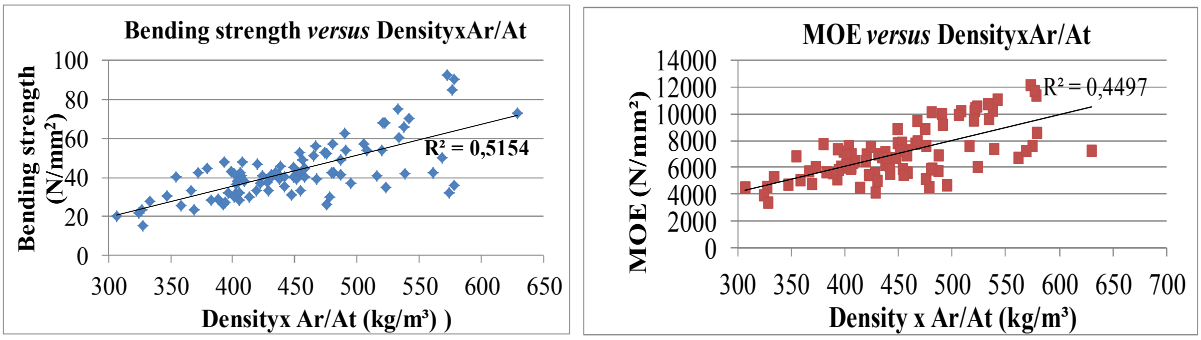

Figure 12. Bending strength (a) and MOE (b) *vs* effective density (D_e =D.A_r/A_t)

Conclusions

Alike other studies [6], the authors found that there is not a clear correlation between the area of visible insect holes, on its own, and the wood specimens strength. Besides, even when relatively high levels of attack were perceived, the lost cross section area corresponding to the beetles galleries (or holes) was normally quite moderate.

Test results obtained so far suggest that, although very high levels of insect destruction have an impact on the timber strength, timber density still is the governing factor.

Acknowledgements

The authors wish to acknowledge the valuable contribution of the technicians António Silva, Sandra Sousa and Sofia Simões towards the completion of the experimental work carried out.

References

[1] UNI 11119: Cultural heritage - Wooden artefacts - Load-bearing structures - On site inspections for the diagnosis of timber members.

[2] H. Cruz, D. Yeomans, E. Tsakanika, N. Macchioni, A. Jorissen, M. Touza, M. Mannucci, P. B. Lourenço, Guidelines for the On-Site Assessment of Historic Timber Structures. International Journal of Architectural Heritage. Accepted author version posted online: 12 Mar 2013: DOI:10.1080/15583058.2013.774070

[3] ISO 3133:1975. Wood – Determination of ultimate strength in static bending.

[4] ISO 3787:1976. Wood – Test methods – Determination of ultimate stress in compression parallel to grain.

[5] EN 1193 EN 1193:1998. Timber structures. Structural timber and glued laminated timber. Determination of shear strength and mechanical properties perpendicular to the grain.

[6] J. R. Gilfillan, S. G. Gilbert, Development of a technique to measure the residual strength of woodworm infested timber. Construction and Building Materials 15(2001) 381-388.