Timber strength distributions

Alpo Ranta-Maunus, Mikael Fonselius

VTT Building and Transport, BOX 1806, FIN – 02044 VTT, Finland

Abstract. When fitted functions are used in reliability analysis, it is essential that the fit is good in lower tail area, the lowest values being most important. Lognormal distribution seems to fit well to the tail of strength data of industrial products like LVL and it may be used also for sawn timber when a COV is used based to the tail fit. When the number of experiments allows, determination of 5% fractile of strength should be based on the function fitting on the lower tail of the strength values, for instance 10%. All smooth functions fitted to tail data gave good estimate of 5% fractile. When 5% fractile is determined from a function fitted to all data, up to 5% error was made (in one case 9%). 3 parameter Weibull distribution gave in all calculated cases 5% fractile within an accuracy of 3 % when compared to nonparametric distribution.

Introduction

In a Nordic project on the reliability of timber structures, strength data is collected and analyzed [1]. In this article a summary of the results is presented with special emphasis on the lower tail data. The data includes Nordic sawn timber, Kerto LVL, plywood and round timber. Fitting of various standard distributions to the data is discussed with two respects: how well the fitting predicts the 5% fractile and how good is the fit in the lower tail area.

Materials

Sawn timber was mainly Norway spruce. Largest sample (S1) with the same dimension (h = 146 mm) had 589 specimens when ungraded, 496 after machine grading to C30, and 367 when sorted visually in laboratory to C24. This sample is later combined with other spruce dimensions to a larger sample (S_{all}) with size 1508, 986 and 781, unsorted, machine graded and visual, respectively. Further more also some pine timber was combined to this data to the final sample (S&P) had size 1995, 1327 and 902, unsorted, machine graded and visual, respectively. Spruce was sampled from six different locations in Finland and from one in Sweden. Pine was sampled from one location in Finland as well as from one in Sweden. Bending testing was made in accordance with CEN 408.

Kerto LVL was manufactured by Finnforest at the mill in Lohja and the data is obtained in the internal quality control between 1993 and 1999. Almost 2000 specimens were tested in both edgewise and flatwise bendng.

Plywood data shown here is based on 3 mm ply spruce plywood manufactured by one mill in Finland 1995. Sample size is 281.

Round timber data used represents small timber spruce (*Picea abies* and *Picea sitchensis*) and pine (*Pinus silvestris*). Spruce was sampled from two locations in Finland, two locations in Austria and one location in United Kingdom. Pine was sampled from four locations in Finland and one location in United Kingdom. Both bending and compression parallel to the grain tests were carried out as closely as practicable to the test method given in EN 408. In addition to bending strength and modulus of elasticity (true), density and moisture content were determined. Further details on the data, test method and results are given in the project report [2]. Number of ungraded specimens in bending was 660 and in compression 575.

Summary of the material data is given in Table 1.

Table 1. Summary of strength results

Material	Remarks	Mean N/mm^2	Cov %	5%-frac N/mm^2	Number -
Sawn timber S1					
Spruce, edgewise,	Ungraded	45.2	25	27.5	589
depth = 150 mm	Visually graded, C24	49.4	20	33.1	367
	Machine graded, C30	47.5	22	30.5	496
Sawn timber S$_{all}$	Ungraded	43.1	27	23.9	1508
Spruce	Visually graded, C24	47.3	21	31.6	781
edgewise	Machine graded, C30	47.8	21	31.3	986
Sawn timber S&P	Ungraded	42.9	29	22.6	1995
Spruce and pine,	Visually graded, C24	48.4	22	32.1	902
edgewise	Machine graded, C30	47.8	22	30.6	1327
LVL Kerto					
edgewise		60.1	10	51.3	1968
flatwise		64.3	14	50.3	1963
Plywood					
3.0 mm thick spruce plies, flatwise		49.2	21	33.6	281
Round small timber					
Spruce and pine	Bending	56.2	21	36.6	660
Spruce and pine	Compression	26.9	23	17.8	575

Strength distributions

Sawn timber. The cumulative strength distributions of nearly all data are shown in Fig. 1. In this presentation we cannot see the characteristics of the lower tail area. Therefore the logarithmic scale will be used in the following figures. In Fig. 2 the effect of grading is demonstrated in case of 150 mm high spruce. In the unsorted sample five specimens of 600 had lower strength than 20 N/mm^2, whereas all specimens in graded samples were stronger than 20 N/mm^2. Fig. 2 also shows that visually sorted C24 had higher strength than machine graded C30. However, this is not a general conclusion, because visual grading was made in laboratory by using much more time than in industry. It can be concluded that INSTA grading to C24 resulted in characteristic bending strength 32-33 N/mm^2, when applied accurately.

Tails of machine graded distributions are shown also on a relative strength scale in Fig. 3 where the 5th percentile value is denoted by 1. We can see that the two spruce distributions are nearly of the same form, whereas the combined sample with spruce and pine data has a bit lower values. For comparison, normal distribution with COV = 20% (N 0.20) and lognormal distribution with COV = 30% (LN 0.30) are also shown. The LN 0.30 curve seems to fit well to the tail data, and N 0.20 curve gives lower estimates than the lowest test results. It is interesting to note that COV related to the model fitted to the tail data is not necessarily the same as the COV of all test data and it may be different depending of the type of distribution fitted to the data. A collection of the COVs is given in Table 2.

Industrial products. Shape of strength distribution depends obviously on the manufacturing and control methods. Lognormal distribution with COV = 10% fits well to bending strength of LVL in edgewise direction, in flatwise bending COV is 12%. Now the COV of the whole data and COV-parameter of the lognormal model fitted to the lowest 10% of the values is nearly the same. This illustrates that strength data of LVL is really lognormally distributed. The same conclusion can be true with plywood, but the sample size is much smaller, which limits the reliability of the

conclusion. LVL and plywood strength data are shown in Fig. 4 on a relative scale together with round timber data. Round timber in compression has quite different form of tail from that in bending.
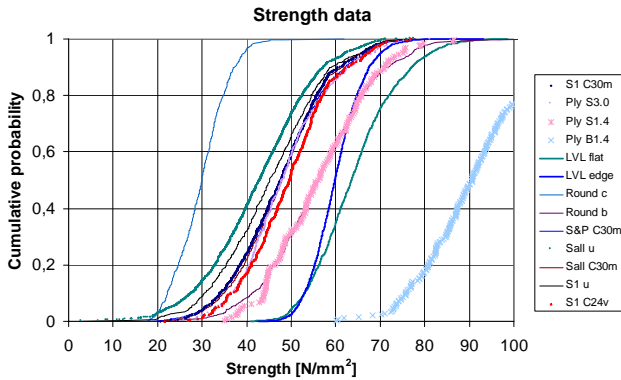

Figure 1. Collection of strength distributions of sawn timber (S), plywood, LVL and round timber in bending (b) compression (c).
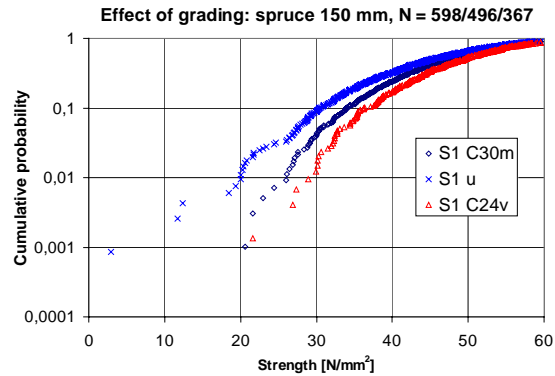
Figure 2. Strength distribution of sawn timber (spruce series S1) when ungraded (u), machine graded to C30 (m) or visually graded (v).
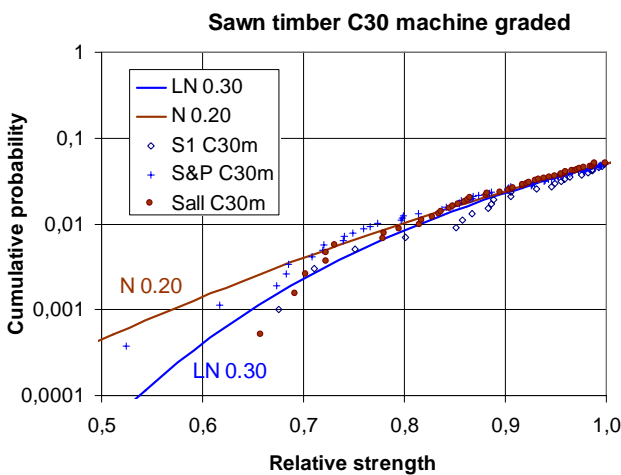

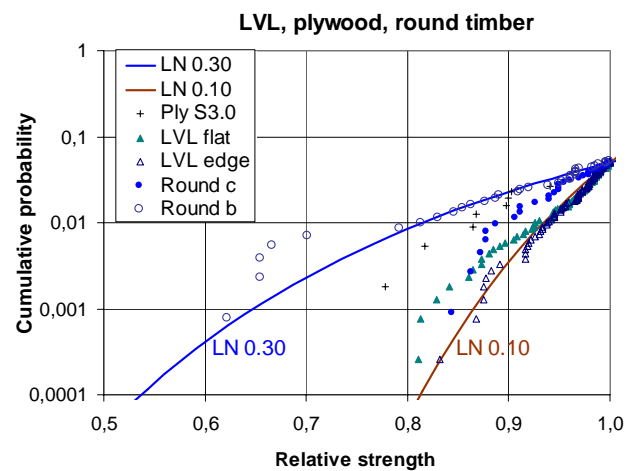Figure 3. Relative strength of machine graded sawn timber when $f_{0.05}=1$.

Figure 4. Relative strength of LVL in edgewise and flatwise bending, plywood in bending and small round timber in bending and compression.

Coefficient of variation (COV). All parameters of the functions fitted to data are given in the forthcoming publication [1]. Here COV is discussed as a parameter related to the distribution function. When strength distributions are used in reliability analysis such distributions should be used which give the correct 5% fractile value and fit well to the lowest test values. It was noticed that COV corresponding to the tail fitted distributions can differ remarkably from the COV of test data as shown in Table 2. In some cases COV of tail data fitted function is close to the test COV which indicates that material in question follows that type of distribution. This would lead to the conclusion that bending strength of sawn and round timber follows normal distribution, and when lognormal distribution is used COV = 30% and above has to be used instead of 21. However reliability calculation using lognormal distribution and COV = 35% gives a lower failure probability than that using normal with COV = 20%.

LVL and plywood seem to follow log-normal distribution so that the same COV observed in tests can be used in reliability analysis. Tail of compression data of round timber is different from all others so that even log-normal distribution with smaller COV than in test data can be used.

Table 2. Summary of COV [%] of distribution functions fitted to tail data of bending strength, also compression for round timber.

	COV of strength data	Normal	Log-normal	2-parameter Weibull	3-parameter Weibull
Sawn timber S1	22	18	29	14	18
Sawn timber Sall	21	19	31	15	23
Sawn timber S&P	22	20	35	17	20
LVL edgewise	10	8	9	5	
LVL flatwise	14	10	12	6	
Plywood	21	16	23	11	
Round timber bending	21	20	34	16	18
Round timber compression	23	13	18	9	18

Determination of 5th percentile

All functions used predict accurately the 5th percentile, when fitted to the lower tail data (10%). When fitted to the whole data set, the ability to predict 5th percentile is different:

Normal distribution underestimates the 5th percentile compared to nonparametric data from 0 to 5 percent for graded sawn timber, and 0 to 3 percent for LVL and plywood. For small diameter round timber normal distribution gave exact value in bending but 9% underestimation in compression.

Lognormal distribution gives generally good or optimistic predictions: 1 to 5 % optimistic for graded sawn timber, fairly precise for LVL and plywood, 4% too high in bending of round timber but precise in compression.

2-parametric Weibull distribution gives normally pessimistic predictions: from 0 to 3% low for graded sawn timber, 2% low for LVL and thick veneer plywood, and 1 to 3% low for round timber.

3-parametric Weibull distribution gives a good prediction: deviation from –2 to +2% for sawn timber, exact of LVL, from –2 to +2 for plywood, and from 0 to +1% for round timber.

References

1.   A. Ranta-Maunus, M. Fonselius, J. Kurkela and T. Toratti: *Reliability analysis of timber structures.* VTT Research Notes. Espoo, Finland 2001. (in print)

2.   A. Ranta-Maunus (ed): *Round small-diameter timber for construction.* VTT Publications 383, Espoo, Finland, 1999.