INFLUENCE OF TEMPERATURE AND MOISTURE CONTENT ON NON-DESTRUCTIVE MEASUREMENTS IN SCOTS PINE WOOD

Daniel F. Llana, Guillermo Iñiguez-Gonzalez, Francisco Arriaga
Universidad Politécnica De Madrid, Ud Cálculo De Estructuras
Etsi Montes
Madrid, Spain

Peter Niemz
Eth Zürich, Institute for Building Materials, Wood Physics
Zürich, Switzerland

ABSTRACT

In the present study, non-destructive parameters and mechanical properties have been measured on the principal structural Spanish sawn timber species, Scots pine (*Pinus sylvestris* L.). Non-destructive testing and three-point bending tests according to DIN 52-186 1978 were conducted on 216 specimens. Specimens were studied at six different temperatures and four different equilibrium moisture contents. The non-destructive testing techniques applied were: ultrasonic wave technique (Sylvatest Duo and Steinkamp BPV) and vibration analysis technique (Grindo Sonic Mk5"Industrial").

Differences in mechanical properties between samples with different temperatures (from -40 to 50ºC) and equilibrium moisture contents (from 10 to 18 %) were studied. Linear tendencies between nondestructive testing and mechanical properties with respect to equilibrium moisture content were obtained. However, two different tendencies (above and below 0ºC) were found with respect to temperature. In addition, adjustment factors are proposed for every variable.

INTRODUCTION

Evaluation of the influence of climate parameters on timber mechanical properties and on non-destructive testing (NDT) is not a new concept (James 1961; Gerhards 1982; Arriaga et

al. 2009). Equilibrium moisture content (EMC) and temperature (T) have important effects on physical and mechanical properties of wood. The influence of EMC and T over Modulus of elasticity (MOE) is already well known; MOE is less sensitive to change in T with less EMC (Niemz 1993; Green and Evans 2008).

Although it is relatively easy to conduct a NDT test, it is important to note that several factors affect NDT parameters. The applicability of ultrasound techniques in practice requires full knowledge of the effect of environmental conditions, which is why this present paper focuses on the influence of EMC below fibre saturation point (FSP) and T over *Pinus sylvestris* L.

Factors affecting ultrasonic measurements in wood have been profusely studied (Bucur 1984; Bucur and Böhnke 1994). There are several research works on the effect of EMC and T on ultrasound velocity and correction factors proposed for vibration and ultrasound velocity (Sandoz 1991; Moreno-Chan et al. 2010; Unterwieser and Schickhofer 2010).

Bucur (2006) concluded that a reduction in strength and elastic moduli occurs with increasing EMC up to 30 %, which supports the idea that the influence of T is less important than the effect of EMC, as other authors proposed (Launnay and Gilleta 1988).

The ultrasound velocity parallel to the fibres decreases dramatically with EMC up to the FSP (Sakai et al. 1990; Kang and Booker 2002; Oliveira et al. 2005; Bucur 2006; Gonçalves and Leme 2008), approximately eight times more than the EMC effect when EMC > FSP (Sandoz 1993). The same effect above and below the FSP was found for stress waves (Wang 2008).

Some referenced books, such as the Wood Handbook (USDA 2010), present a discussion of EMC and T effects, in which the intersection moisture content is defined as a point at which mechanical properties begin to change when wood is dried from the green condition; this point is slightly lower than the FSP. Mechanical properties exhibit a linear relationship at temperatures below 150ºC. The temperature influence on strength of lumber at 12 % EMC is minimal for the -29 to 38ºC interval.

Sound velocity and eigenfrequency are correlated with the mechanical properties of wood. Ultrasonic velocity generally increases linearly with decreasing T (+50 to -30ºC) and EMC below FSP (Bucur 2006).

The influence of T on acoustic properties is magnified when the EMC of wood increases (Sandoz 1993). The overall trend of the changes in velocity is similar for all dry wood (below FSP), below and above freezing point (Gao et al. 2011).

Other studies focused on stress waves and concluded that the stress wave speed decreased reciprocally with increasing EMC and decreased linearly with increasing T. The T has the same effect on stress wave parameters on both studied species (softwood and hardwood), however the effect of EMC is different (Matthews et al. 1994).

Analysing the effect of below zero temperatures on mechanical properties, some authors propose that the T value is not solely important and it is suggested that the freezing rate also has a significant influence: Over the FSP, high freezing rate has lesser effects on wood strength, which consequently reduce the freezing rate (Szmutku et al. 2013).

Different correction factors for EMC on NDT measurements were proposed for several authors. Considering 12 % EMC as the reference value.

For ultrasound technique (Steinkamp BP-V) records, a correction factor with a decrease in velocity of approx. 0.8 % with an increase of 1 % of EMC, in the range of 5 to 30 % EMC, was proposed for spruce (Sandoz 1989).

For ultrasonic velocity, a correction factor with a decrease in velocity of 0.53 % with an increase of 1 % in EMC, in the range below 28 % EMC, was proposed for spruce (Steiger 1996).

For ultrasonic velocity (Steinkamp BP7 45 kHz) of Parana pine, a correction factor equation was proposed. From it was obtained a decrease in velocity of 0.45 % with an increase of 1 % in EMC, below FSP (Gonçalves and Leme 2008).

For ultrasound technique (Sylvatest) and vibration technique (Viscan) records, correction factors with a decrease in ultrasound velocity of 0.60 %, a decrease in dynamic modulus of elasticity (E_{dyn}) of vibration of 0.87 % and an increase of density of 0.42 %, accompanying a 1 % increase in EMC, in the range below 28 % EMC, were proposed for spruce (Unterwieser and Schickhofer 2010).

Other adjustment factors were proposed for the effect of EMC on mechanical properties. For density and MOE in structural size, a correction factor with an increase in density of 0.5 % accompanying a 1 % increase of EMC, and with a decrease of 1 % on MOE with an increase of 1 % of EMC (EN 384: 2010).

Other authors propose a correction factor with a decrease of 1.5 % of MOE and 4 % of modulus of rupture (MOR) with an increase of 1 % of EMC for clear wood, in the range 8 to 20 % EMC (Hoffmeyer 1995).

An exponential adjustment is proposed in the Wood Handbook (USDA 2010) for mechanical properties for clear wood, with a decrease between 1.2 - 1.5 % of MOE and between 2.4 - 3.8 % of MOR, accompanying an increase of 1 % of EMC, below FSP.

Less works were found dealing with adjustment factors of T on NDT measurements and mechanical properties.

For ultrasound technique (Sylvatest) records, a correction factor was proposed with a decrease in velocity of approx. 0.08 % with an increase of 1ºC (12 % EMC), in the range of -20 to 60ºC (Sandoz 1993). The same correction factor was proposed by Steiger (1996) in the range from 20 to 40ºC.

An adjustment equation was proposed in the Wood Handbook (USDA 2010) for mechanical properties for clear wood, with a decrease of 0.2 % on MOE, for a T increase of 1ºC and no influence of T over MOR, in the range of -26 to 66ºC. Same correction factor of 0.2 % on MOE was proposed by Green at 12 % EMC, in same range (Green and Evans 2008).

MATERIAL AND METHODS

The materials used consisted of 216 small clear specimens of nominal dimensions 20x20x400 mm, cut from 24 dry timber pieces of dimensions 150x50x4400 mm at 20ºC and 65 % of Scots pine (*Pinus sylvestris* L.) from Valsain, Segovia, Spain. The specimens were grouped into 9 batches of 24 specimens each and were tested in the ETH laboratories in Zurich, Switzerland.

The influence of EMC was studied over four batches of 24 specimens each, conditioned for 45 days before testing at a temperature of 20 ± 2ºC and at four different air relative humidities (55, 65, 75, and 85 % ± 5 %). Tab. 1 summarizes these batches.

Tab. 1: Specimens for study of EMC effect according to climate conditions.

Batch	Air humidity (%)	T (ºC)	Number of specimens
H55T20	55 ± 5		24
H65T20	65 ± 5		24
H75T20	75 ± 5	20 ± 2	24
H85T20	85 ± 5		24
TOTAL			**96**

The influence of T was studied using six batches of 24 specimens, each conditioned to normal conditions of 20 ± 2°C and 65 ± 5 % of air relative humidity. Then the specimens were wrapped individually in plastic bags. Each batch of 24 wrapped specimens was conditioned at different temperatures (50, 30, 20, -10, -20 and -40 ± 2°C) using a Feutron KPK 200 GmbH chamber. The temperature of the specimens was monitored with internal sensors and recorded with a commercial data loger Almemo 2890-9 Ahlborn. Tab. 2 summarizes these batches.

Tab. 2: Specimens for study of T effect according to climate conditions.

Batch	Air humidity (%)	T (°C)	Number of specimens
H65T50		50 ± 2	24
H65T30		30 ± 2	24
H65T20	65 ± 5	20 ± 2	24
H65T-10		-10 ± 2	24
H65T-20		-20 ± 2	24
H65T-40		-40 ± 2	24
TOTAL			144

Several measurements using NDT were carried out at each climate condition.

Time of flight value was measured with two ultrasonic commercial devices. Sylvatest Duo (using conical sensors of 22 kHz frequency) and Steinkamp BP-V (using conical sensors of 50 kHz frequency). Measures were made end to end (longitudinal direction parallel to the grain) on each specimen, with a constant sensor coupling pressure. Time correction was applied over these time measurements (+2.8 µs for Sylvatest Duo and +0.7 µs for Steinkamp BP-V).

According to the time results of ultrasound devices, the wave velocities (length/time) and E_{dyn} were calculated using Eq. 1:

$$E_{dyn} = \rho \cdot V^2 \tag{1}$$

where: E_{dyn} - the dynamic modulus of elasticity, in Pa;
ρ - the density, in kg.m^{-3};
V - the velocity of the ultrasound wave, in m.s^{-1}.

For the vibration analysis (with a commercial device Grindosonic Mk5 "Industrial") the specimen was simply supported at two nodal points at a distance of 0.224 l from the end; l being the total length of the specimen. The midspan of the specimen was hit with a small hammer and the impact induced an oscillation in the vertical (transverse) direction. The transverse frequency was registered by an accelerometer and E_{dyn} was obtained according to Eq. 2 (Görlacher 1984).

$$E_{dyn,v} = \frac{4\,\pi^2 \cdot l^4 \cdot f_0^2 \cdot \rho}{m_n^4 \cdot i^2} \cdot \left(1 + \frac{i^2}{l^2} \cdot K_1\right) \cdot 10^{-6} \tag{2}$$

where: $E_{dyn,v}$ - the dynamic modulus of elasticity, in Pa;
l - the length of the specimen, in mm;
f_0 - the transverse frequency, in Hz;
ρ - the density, in kg.m^{-3};
m_n^4 - the constant=0.5006x10^3;
i - the radius of gyration of the cross-section, in mm;
K_1 - constant = 49.48.

Actual dimensions and weight of specimens were measured before the bending test was run and the density of each specimen was calculated based on the weight and volume.

Mechanical properties (static MOE and MOR) were determined with the 3 points bending test, according to DIN 52-186:1978, using a commercial device Zwick Z100 and a camera to measure deformation along the neutral axis. According to this standard, MOE is calculated using Eq. 3:

$$E_B = \frac{l^3}{4 \cdot b \cdot h^3} \cdot \frac{\Delta F}{\Delta f}$$
(3)

where: E_B - the modulus of elasticity, in $N.mm^{-2}$;

l - the span, in mm;

b - the width of the cross section, in mm;

h - the depth of the cross section, in mm;

$\Delta F/\Delta f$ - the slope of elastic deformation range, in $N.mm^{-1}$.

After measurements were completed, the EMC of each specimen was determined using the oven dry method according to standard EN 13183-1 (2002). Four different average EMC (10.88, 12.00, 15.58 and 17.38 %) were obtained for each batch conditions (H55T20, H65T20, H75T20 and H85T20), respectively.

RESULTS AND DISCUSSION

The effect of EMC on mechanical properties and non-destructive parameters is summarized in Tab. 3.

Tab. 3: NDT and bending test results for different EMC.

NDT							
Batch	EMC (%)	Vel Sylvatest Duo		Vel Steinkamp BPV		Freq. Grindosonic Mk5	
		mean (m.s⁻¹)	CV (%)	mean (m.s⁻¹)	CV (%)	mean (Hz)	CV (%)
H55T20	10.88	5691	4.76	5519	4.16	662	4.25
H65T20	12.00	5635	4.49	5453	4.00	658	4.56
H75T20	15.58	5521	3.99	5403	3.67	647	3.93
H85T20	17.38	5419	4.14	5276	3.80	636	4.68
Batch	EMC (%)	Edyn Sylvatest Duo		Edyn Steinkamp BPV		Edyn Grindosonic Mk5	
		mean (N.mm⁻²)	CV (%)	mean (N.mm⁻²)	CV (%)	mean (N.mm⁻²)	CV (%)
H55T20	10.88	16873	17.29	15849	16.48	13566	15.84
H65T20	12.00	16485	17.01	15424	16.48	13276	17.08
H75T20	15.58	16146	14.92	15464	14.68	12971	14.61
H85T20	17.38	15645	15.98	14829	15.69	12313	15.62
Density and bending test (DIN 52-186)							
Batch	EMC (%)	Density		MOE		MOR	
		mean (kg.m⁻³)	CV (%)	mean (N.mm⁻²)	CV (%)	mean (N.mm⁻²)	CV (%)
H55T20	10.88	517	10.40	12607	15.62	99.38	13.09
H65T20	12.00	515	10.26	12265	17.24	91.13	14.78
H75T20	15.58	527	10.18	11560	14.51	77.33	13.73
H85T20	17.38	530	10.37	11038	15.21	70.00	14.50

Statistical analyses were done in order to study the normality of variables prior to further analyses. All variables showed normal probability distributions. Fig. 1, shows the frequency histogram for velocity of ultrasounds.
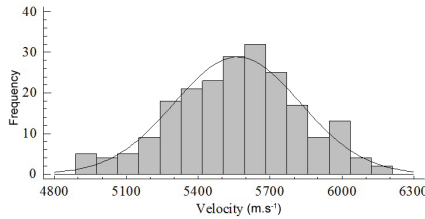

Fig. 1: Frequency histogram for velocity. Steinkamp BPV.

A clear tendency of change in properties with EMC was found, as was expected. This effect has been found in many similar studies (Gerhards 1982, Sandoz 1991, Steiger 1996, Gonçalves and Leme 2008).

Despite the EMC of the studied batches being really close, some parameters exhibit statistically significant differences between two non-consecutive batches, determined from the one-way analysis of variance. Fig. 2 shows an example of ultrasound velocity. In the case of MOR (Fig. 3), statistically significant differences between each batch were also found.
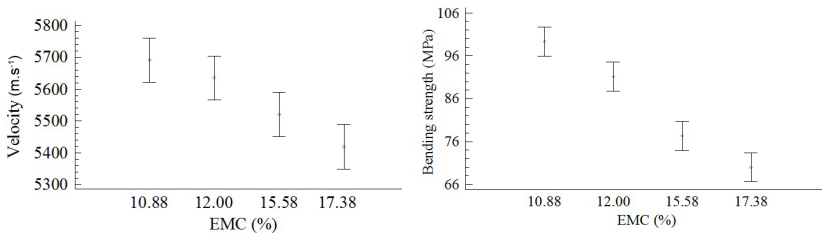
Figs. 2 and 3: Means plot of one-way analysis of variance: Velocity Sylvatest vs. EMC and MOR vs. EMC.

Statistical diagnosis performed on each one-way analysis of variance confirms the validity of the assumptions of normality of distribution, homoscedasticity and independence.

The effect of T on mechanical properties and non-destructive parameters is summarized in Tab. 4.

Tab. 4: NDT and bending test results for different T.

		NDT					
Batch	**T (ºC)**	**Vel Sylvatest Duo**		**Vel Steinkamp BPV**		**Freq. Grindosonic Mk5**	
		mean (m.s⁻¹)	CV (%)	mean (m.s⁻¹)	CV (%)	mean (Hz)	CV (%)
H65T50	**50**	5553	4.36	5404	4.07	652	4.06
H65T30	**30**	5658	4.39	5492	3.87	662	4.17
H65T20	**20**	5635	4.49	5452	4.00	658	4.56
H65T-10	**-10**	5769	4.21	5614	3.92	670	5.47
H65T-20	**-20**	5859	4.78	5648	4.34	672	4.96
H65T-40	**-40**	5933	4.24	5782	3.83	684	3.93

Batch	T (ºC)	Edyn Sylvatest Duo		Edyn Steinkamp BPV		Edyn Grindosonic Mk5	
		mean (N.mm^{-2})	CV (%)	mean (N.mm^{-2})	CV (%)	mean (N.mm^{-2})	CV (%)
H65T50	50	15886	17.22	15041	17.00	12963	16.86
H65T30	30	16867	17.27	15874	16.34	13623	16.39
H65T20	20	16485	17.01	15424	16.47	13276	17.08
H65T-10	-10	17549	15.99	16621	15.62	14020	17.24
H65T-20	-20	17997	17.35	16718	16.86	14024	17.08
H65T-40	-40	18739	16.65	17782	15.92	14746	15.39
Bending test (DIN 52-186)							
Batch	T (ºC)	Density		MOE		MOR	
		mean (kg.m^{-3})	CV (%)	mean (N.mm^{-2})	CV (%)	mean (N.mm^{-2})	CV (%)
H65T50	50	511	10.51	12307	16.58	93.55	12.51
H65T30	30	523	10.58	12674	16.06	94.75	15.29
H65T20	20	515	10.26	12265	17.24	91.13	14.78
H65T-10	-10	524	9.86	12794	17.85	106.00	20.00
H65T-20	-20	520	10.23	12855	17.11	110.49	15.15
H65T-40	-40	528	10.29	13408	15.66	122.10	14.88

The one-way analysis of variance revealed statistically significant differences between some batches below 0ºC, but this difference does not appear between batches above 0ºC. Different tendencies above and below 0ºC has been found for some authors on ultrasound velocity (Gao et al. 2011) and MOE (Green and Evans 2008) above FSP, but it were not found works obtaining different tendencies in dry wood. Thus a different tendency above and below 0ºC was found. Figs. 4 and 5 show two examples for velocity of ultrasound waves using Steinkamp BPV and MOR.
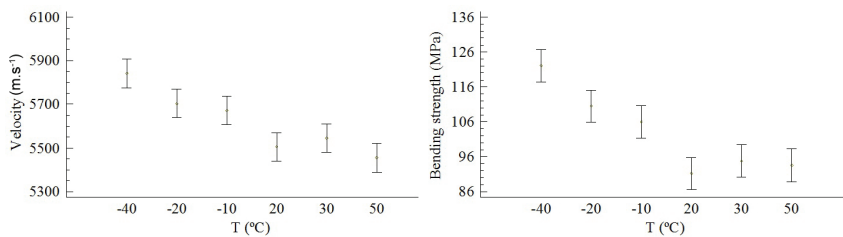
Figs. 4. and 5.: Means plot of one–way analysis of variance: Velocity Steinkamp vs. T and MOR vs. T.

Adjustment factor for EMC

Linear regressions were done using the average value of different variables of each batch and EMC in order to study EMC tendencies (Figs. 6 and 7), as a result, several equations were obtained (Eqs. 4 to 9):

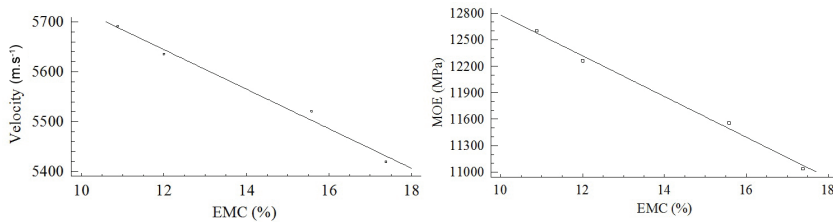$$\text{Vel Sylvatest} = 6121 - 40 \text{ EMC} \qquad R^2 = 0.99 \tag{4}$$
$$\text{Vel BPV} = 5860 - 32 \text{ EMC} \qquad R^2 = 0.90 \tag{5}$$
$$\text{Edyn freq} = 20313 - 191 \text{ EMC} \qquad R^2 = 0.95 \tag{6}$$
$$\text{Density} = 490 + 2 \text{ EMC} \qquad R^2 = 0.93 \tag{7}$$
$$\text{MOE} = 15083 - 230 \text{ EMC} \qquad R^2 = 0.99 \tag{8}$$
$$\text{MOR} = 144.40 - 4.31 \text{ EMC} \qquad R^2 = 0.90 \tag{9}$$

Figs. 6. and 7.: Linear regressions: Velocity Sylvatests EMC and MOE vs. EMC.

The influence of EMC (between 10.88 and 17.38 %) on ultrasonic waves, vibration, density, MOE and MOR were determined. From eqs. 4 to 9, and considering 12 % EMC as the reference value, adjustment factors (10 to 15) were obtained for each variable.

For ultrasound Sylvatest Duo: $V_{12} = V_H / [1-k_{H1}(H-12)]$ $k_{H1} = 0.0070$ (10)

For ultrasound Steinkamp BPV: $V_{12} = V_H / [1-k_{H2}(H-12)]$ $k_{H2} = 0.0059$ (11)

For vibration Grindosonic MK5: $E_{dyn12} = E_{dynH} / [1-k_{H3}(H-12)]$ $k_{H3} = 0.0106$ (12)

Density: $Den_{12} = Den_H / [1-k_{H4}(H-12)]$ $k_{H4} = -0.0045$ (13)

MOE: $MOE_{12} = MOE_H / [1-k_{H5}(H-12)]$ $k_{H5} = 0.0187$ (14)

MOR: $MOR_{12} = MOR_H / [1-k_{H6}(H-12)]$ $k_{H6} = 0.0465$ (15)

where: V_{12} - the ultrasound velocity in the longitudinal direction, at 12 % EMC, in m.s^{-1};
V_H - the ultrasound velocity in the longitudinal direction, at H EMC, in m.s^{-1};
H - the EMC, in %;
k_{Hi} - the EMC adjustment factor;
E_{dyn} - the dynamic modulus of elasticity obtained by vibration, in N.mm^{-2};
Den - the density, in kg.m^{-3};
MOE - the static modulus of elasticity, in N.mm^{-2};
MOR - the modulus of rupture, in N.mm^{-2}.

For ultrasound velocities a decrease by 0.70 % was achieved, using the Sylvatest Duo device, and 0.59 %, using the Steinkamp BP-V device with an increase of 1 % in EMC. If it is compared with other studies this adjustment factor is slightly greater than ones proposed by other authors for Sylvatest in Spruce (Steiger 1996, Unterwieser and Schickhofer 2010) and lower than 0.8 % proposed by Sandoz for Steinkamp BPV (Sandoz 1989). In addition, with an increase of 1 % in EMC, the E_{dyn}, estimated using the vibration technique, decreased by 1 %, this adjustment factor is slightly greater than 0.87 % proposed by Unterwieser and Schickhofer (2010) but in this case a different device was used.

The density value was found to increase by 0.45 % with an increase of 1 % in EMC and similar trend was also observed by Unterwieser and Schickhofer (2010) 0.42 %. The EMC effect in relation to density is consistent with the last version of the standard EN 384: 2010 (for timber), namely 0.5 per 1 % of EMC, but the effect on MOE is 1.87 per 1 % of EMC, which is close

to the value proposed by an older version of the standard EN 384: 2004. If it is compared with studies on clear wood, the decrease effect on MOE 1.87 % and MOR 4.65 % accompanying a 1 % increase in EMC are slightly greater than the 1.5 and 4 % proposed by Hoffmeyer (1995), confirming that for some mechanical properties the influence of EMC is less significant for timber than for clear wood.

Adjustment factor for T

Linear regressions were done between the average values of different variables of each batch and T, in order to study tendencies occurring with T changes (Figs. 8 and 9), consequently several equations (below zero) were obtained (Eqs. 16 to 21):

$$\text{Vel Sylvatest} = 5732 - 5T \qquad R^2=0.94 \qquad (16)$$
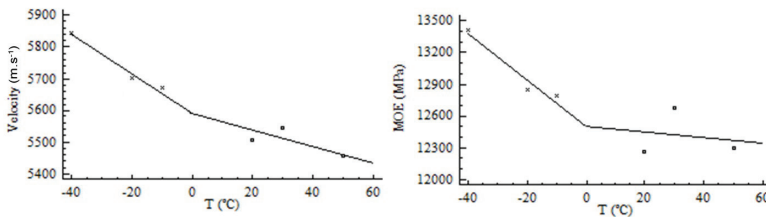$$\text{Vel BPV} = 5549 - 6\,T \qquad R^2=0.98 \qquad (17)$$
$$E_{dyn}\,\text{freq} = 13689 - 25\,T \qquad R^2=0.92 \qquad (18)$$
$$\text{Density} = 521 - 0.15\,T \qquad R^2=0.64 \qquad (19)$$
$$\text{MOE} = 12506 - 22\,T \qquad R^2=0.86 \qquad (20)$$
$$\text{MOR} = 96.96 - 0.65\,T \qquad R^2=0.97 \qquad (21)$$

Different tendency above and below zero for different variables are shown in Figs. 8 and 9. This difference was found in every variable except density.

Figs. 8 and 9: Linear regressions: Velocity Steinkamp BPV vs T and MOE vs. T.

Influence of T (between -40 and 0 °C) on ultrasonic waves, vibration, density, MOE and MOR was evaluated at 12 % EMC. From equations 16 to 21, and considering 0°C as the reference value, adjustment factors (22 to 27) were obtained for each variable.

For ultrasound Syl:	$V_0 = V_T/ [1-k_{T1}\,(T-0)]$	$k_{T1}= 0.0009$	(22)
For ultrasound BPV:	$V_0 = V_T/ [1-k_{T2}\,(T-0)]$	$k_{T2}= 0.0010$	(23)
For vibration:	$Edyn_0 = Edyn_T/ [1-k_{T3}\,(T-0)]$	$k_{T3}= 0.0018$	(24)
Density:	$Den_0 = Den_T/ [1-k_{T4}\,(T-0)]$	$k_{T4}= 0.0003$	(25)
MOE:	$MOE_0 = MOE_T/ [1-k_{T5}\,(T-0)]$	$k_{T5}= 0.0017$	(26)
MOR:	$MOR_0 = MOR_T/ [1-k_{T6}\,(T-0)]$	$k_{T6}= 0.0067$	(27)

where: V_0 - the ultrasound velocity in the longitudinal direction, at 0ºC, in m.s^{-1};
          V_T - the longitudinal ultrasound velocity at temperature T, in m.s^{-1};
          T - the temperature, in ºC;
          k_{Ti} - the temperature adjustment factor;
          E_{dyn} - the dynamic modulus of elasticity estimated by vibration, in N.mm^{-2};
          Den - the density, in kg.m^{-3};
          MOE - the static modulus of elasticity, in N.mm^{-2};
          MOR - the modulus of rupture, in N.mm^{-2}.

With an increase of 1ºC, a decrease of around 0.10, 0.18, 0.03, 0.17, 0.67 % was recorded for ultrasound velocities, E_{dyn}, density, MOE and MOR, respectively. Ultrasound velocities adjustment factors 0.09 and 0.10 % are slightly greater than 0.08 % proposed by Sandoz (Sandoz 1993)

The effects of T are less significant than the EMC effects in common conditions of inspection of structures (from 0 to 30ºC and from 8 to 30 % of EMC).

CONCLUSIONS

The present study shows that mechanical properties and non-destructive measurements (wave velocity and frequency) of Scots pine are affected by equilibrium moisture content and temperature conditions. These results are consistent with findings from previous studies on spruce and fir.

Influence of equilibrium moisture content on ultrasound velocities, dynamic modulus of elasticity and mechanical properties in the range 10 to 18 % could be considered lineal.

Adjustment factors for the influence of equilibrium moisture content on Scots pine were obtained for non-destructive testing and mechanical properties. In the case of ultrasound techniques, a slight difference between devices was found, Steinkamp (using sensors of 50 kHz frequency) presents smaller correction factors than Sylvatest (using sensors of 22 kHz frequency) and the reason could be founded in the different frequencies.

Influence of temperature on non-destructive testing and mechanical properties shows a different tendency above and below 0ºC. A clear lineal tendency was found below 0ºC and no significant tendency was found above 0ºC for dry timber.

Adjustment factors for influence of temperature were proposed for non-destructive testing and mechanical properties in the range -40 to 0ºC and considering 0ºC as the reference value. No differences between ultrasound devices were found.

Modulus of rupture is more sensitive to changes in temperature and equilibrium moisture content than modulus of elasticity: correction factors for modulus of rupture are always more than double than the correction factors for modulus of elasticity.

ACKNOWLEDGMENTS

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Daniel F. Llana*, Guillermo Iñiguez-Gonzalez, Francisco Arriaga
Universidad Politécnica De Madrid.
Ud Cálculo De Estructuras
Etsi Montes
Ciudad Universitaria S/N. 28040
28040 Madrid
Spain
Phone: +34913367104
Corresponding author: danielfllana@gmail.com

Peter Niemz
Eth Zürich
Institute for Building Materials
Wood Physics
Schamattstrasse 6
Ch-8093 Zürich
Switzerland