

CREEP IN STRUCTURAL-SIZED BEAMS OF ARGENTINEAN *EUCALYPTUS GRANDIS*

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ABSTRACT

The results presented in this paper were obtained from a test carried out during the last series of a research project regarding the creep behaviour of Argentinean *Eucalyptus grandis* loaded in dry condition. A test with a sample containing 15 structural-sized beams was carried out during 470 days. 7 pieces were free of pith and another 8 contained it. The results allow to compare the creep behaviour of these beams with previous data reported for both structural-sized and small-clear specimens of this timber species and also with those reported for other species. The effectiveness of the criteria adopted by overseas standards as well as those of Latin-American countries for calculating the creep deflections of this timber species under a long-term loading is analysed. The creep deflections obtained in the present research are higher than those calculated by means of the procedures of the Brazilian standard NBR 7190, the European standard Eurocode 5, the American standard National Design Specification for Wood Construction and the Peruvian standard. On the contrary, creep results obtained in this test are lower than those calculated according to the New Zealand standard NZS 3603, the Chilean standard NCh 1198 and the former German standard DIN 1052.

Keywords: creep, deflections, *Eucalyptus grandis*, long-term loading

INTRODUCTION

For many structural applications, elastic and creep behaviour is one of the most important mechanical properties of wood. Serviceability requirements related to deflections are often decisive for the cross sectional dimensions in the case of beams subjected to bending under a long-term or permanent load (Thelandersson 1995; Hunt 1999). Instantaneous elastic deflections may be obtained by means of the standard solution based on elementary beam theory and shear effect on deflections may be normally disregarded because it is relatively low in beams of usual structural sizes (Thelandersson 1995). Viscoelastic and mechano-sorptive creep, which are considered to be additive components of creep, are mainly influenced by time and moisture changes, respectively. During continued moisture cycling a reversible part of creep is also manifested (Hunt 1999). Temperatures higher than 50 °C and stress levels greater than 35 % of the short-term strength (i.e. the strength obtained from static tests) can also affect the creep rate, but these values are commonly not reached in normal structures and, consequently, they can be disregarded as creep-influencing parameters for practical purposes (Andriamitantoa 1995). Creep results on structural-sized and small clear specimens are available for different service classes and materials. Creep is normally higher in small clear specimens than in structural timber under the same loading and climate conditions. The reason of this difference can be found in the greater and faster variation in moisture content that occurs in small clear specimens in comparison with structural timber, even though the latter may be affected by the influence of grain deviation and other defects.

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Results obtained from structural-size tests are very important for practical purposes and for design rules (Ranta-Maunus 1995).

The study of both elastic and creep deflections have acquired more importance since the increased use of fast-growth timber, harvested at an early age, which normally contains an important proportion of juvenile wood. Juvenile wood typically exhibits a larger spiral angle for the fibres in the central layer of the secondary wall than in mature wood, and, as a consequence, it normally shows greater elastic and creep deflections than normal wood (Hunt 1999). Bengtsson (2001) found a larger propensity to creep in wood sawn near the pith than in mature wood, in a test series with Norway spruce (*Picea abies*). Contrarily, Bamber et al. (1982) reported that the physiologically-active cells but not the fibres of *Eucalyptus grandis* are affected by fast-growth.

A linear relation between the total deformation and the instantaneous one is normally assumed by design rules. The quality and the size of the sawn timber are considered in the calculation of the instantaneous deflection. Creep is calculated by multiplying the instantaneous elastic deformation by a factor, which considers the combined effect of moisture content and load duration (Standards New Zealand 1993; Arbeitsgemeinschaft Holz e. V. & Bruderverlag 1995; Instituto Nacional de Normalización INN-Chile 1999; American Forest & Paper Association 2001).

One of the most important renewable species cultivated in Argentina is *Eucalyptus grandis* (Instituto Nacional de Tecnología Agropecuaria 1995). A previous investigation regarding the development of a method for visually grading sawn timber of this species reported that the presence of pith significantly reduces its bending strength and stiffness (Piter et al. 2004a). Another research regarding the usefulness of the main single and combined parameters for machine strength grading this sawn timber showed a high correlation between modulus of elasticity and strength and a modest correlation between density and strength (Piter et al. 2004b). Deflection data obtained from tests on beams in structural sizes of Argentinean *Eucalyptus grandis* in indoor environment under one-year loading are published by Piter et al. (2006) whereas Calvo et al. (2002) reported results found on small clear specimens of this species.

The aim of this paper is to present and discuss the results of an investigation regarding the creep behaviour of structural-sized beams of fast-growth Argentinean *Eucalyptus grandis* under a 470-days loading in indoor climate. Additionally, to compare these results with those found in previous investigations and with the prescriptions given in different standards of overseas as well as Latin-American countries.

MATERIAL AND METHODS

One test sample containing 15 structural-sized beams with nominal sizes 50 mm x 100 mm x 3000 mm was utilised. 7 beams were free of pith and another 8 contained it. The specimens were randomly selected from a 15 year old plantation of *Eucalyptus grandis* grown in Concordia, Entre Ríos. This is one of the main provenance for this species in Argentina (Instituto Nacional de Tecnología Agropecuaria 1995).

After a period of air-drying under protected external conditions, the specimens were planed. Actual dimensions and measurements for each test piece were made to an accuracy of 1 %. Moisture content and density were determined according to the procedures of ISO 3130 (International Organization for Standardization 1975) and ISO 3131 (International Organization for Standardization 1975) respectively, using a clear full cross section taken from one end of the beams.

All beams were tested during 470 days in a room with no air-conditioning and no heating. Temperature and relative humidity were registered three times per day during the test. The specimens

were placed symmetrically on two supports and loaded at the centre of the span with a constant load. A span length (l) of 2600 mm was adopted for all beams. With the purpose of reaching values for the maximum stress levels at the centre of the span ($\sigma_{m, \text{long-term}}$) similar to those normally adopted for beams of this timber species, concentrated-load values ranging between 0,82 kN and 0,84 kN were applied.

Instantaneous elastic deformation (u_{inst}) was registered after loading at the centre of the span and at the centre of the tension zone. Deflections (u) were measured during 470 days and creep (u_{creep}) was calculated as the difference between u and u_{inst} . After unloading, the residual deflection (u_{res}) was registered and the instantaneous elastic recovery (u_{rec}) was calculated as the difference between the final deflection (u_{470}) and u_{res} . Extensometers with resolution of 0,01 mm were used for measuring deformations. Each beam was finally tested for determining its strength in bending (f_m) according to the procedures of EN 408 (Europäisches Komitee für Normung 2004). Loads were applied with a rate of movement of the loading-head equal to 0,133 mm/s and accuracy of 1 % by means of a loading machine Shimadzu UH 1000kN.

RESULTS AND DISCUSSION

The mean value of moisture content for the whole sample at the beginning of the test was 14,2 % with a coefficient of variation (COV) of 7 %. After unloading, 470 days later, moisture content exhibited a mean value of 11,9 % with a COV of 1 %. These results confirmed a similar moisture content for the 15 beams. The monthly average for temperature ranged from 10,8 °C to 24,8 °C with a mean value of 16,8 °C and the monthly average for relative humidity ranged from 60 % to 84 % with a mean value of 71 %. The mean value for density, obtained after unloading with the above mentioned moisture content, was 528 kg/m³ with a COV of 9 % which is congruent with earlier results reported for this timber species (Piter et al. 2004a; Piter et al. 2006).

The sizes of the beam cross-section presented mean values of 43,8 mm in width and 91,4 mm in depth and the span to depth ratio ranged between 27 and 30 with a mean value of 28. The relation between the span length and the instantaneous deflection showed a mean value of 359 with a COV of 32 %. This mean value is congruent with those normally adopted for structural design.

The results obtained for stress level, which is a parameter normally influencing creep in wood, are presented in Table 1. Since the maximum stress level was produced only at the central cross section during the 470-days test, and the bending strength, determined according to EN 408 (2004), reached maximum values throughout the central third, the ratio $\sigma_{m, \text{long-term}} / f_m$ is presented for both the centre of the span and the one-third span length. Mean values of 0,16 and 0,11 for $\sigma_{m, \text{long-term}} / f_m$ at the centre of the span and at one-third span length, respectively, with a COV of 21 %, indicate that the stress level in the beams subjected to long-term loading was lower than 35 % of the instantaneous resistance. Therefore, it may be assumed that in the present research creep remained within a stable phase, where the rate of deformation is low and stable and it is not influenced by the stress, in agreement with the criterion normally assumed by design methods (Andriamitantoa 1995).

A mean value of 8,8 N/mm² at the centre of the span for $\sigma_{m, \text{long-term}}$ shows a stress similar to those normally adopted for beams of this timber species and a mean value of 56,3 N/mm² for f_m is congruent with strength results previously informed (Piter et al. 2004a). A detailed analysis shows that the mean value of f_m for the 7 beams without pith reached 61,1 N/mm² whereas the corresponding value for the 8 beams with pith was 52,1 N/mm², in line with data reported in the research mentioned before, which revealed that pith is an important strength and stiffness reducing characteristic for this timber species.

Table 1: Stress level for the whole sample. (1) ratio corresponding to the centre of the span; (2) ratio corresponding to the one-third span length

	$\sigma_{m, \text{long-term}}$	f_m	$\sigma_{m, \text{long-term}} / f_m$
	N/mm ²	N/mm ²	
Mean	8,8	56,3	0,16 ⁽¹⁾ - 0,11 ⁽²⁾
COV (%)	8	21	21 ⁽¹⁾⁽²⁾

Table 2 summarises the main results for the instantaneous as well as for the 470-days deflections of the test sample. After unloading, the instantaneous elastic recovery showed a higher mean value than the corresponding one for the instantaneous elastic deflection and the residual deflection exhibited a lower mean value than that corresponding to the creep part of deformation. The mean values for the ratios $u_{\text{rec}} / u_{\text{inst}}$ and $u_{\text{res}} / u_{\text{creep,470}}$ amounts to 1,17 and 0,83, respectively, whereas mean values of 0,95 and 1,10 had been found for the same ratios in a previous research with 16 beams of this timber species (Piter et al. 2006).

Table 2: Main results for instantaneous and final deflections

	u_{inst}	$u_{\text{creep,470}}$	u_{rec}	u_{res}	$u_{\text{rec}} / u_{\text{inst}}$	$u_{\text{res}} / u_{\text{creep,470}}$
	mm	mm	mm	mm		
Mean	7,8	6,7	8,8	5,7	1,17	0,83
COV (%)	23	20	17	34	22	25

A detailed analysis shows that only one beam exhibited a very high value of 1,96 for $u_{\text{rec}} / u_{\text{inst}}$ and another piece showed a value of 1,54 whereas the other 13 specimens presented ratios ranging between 1,01 and 1,21. Values of 0,29 and 0,43 for $u_{\text{res}} / u_{\text{creep,470}}$ were exhibited by the same beams that showed the highest and the second values for $u_{\text{rec}} / u_{\text{inst}}$, respectively, whereas for the other 13 specimens the ratio $u_{\text{res}} / u_{\text{creep,470}}$ ranged from 0,77 and 0,99. The two beams presenting the above mentioned particular behavior exhibited slightly lower values for u_{rec} and $u_{\text{creep,470}}$ than the corresponding mean values of the whole sample, but they presented significantly lower values for u_{inst} (3,9 mm and 4,5 mm) and also for u_{res} (1,5 mm and 1,8 mm) than the corresponding mean values of the sample. In particular, the beam presenting the lowest value for u_{inst} (3,9 mm) exhibited the highest value for f_m (82,8 N/mm²) but a density only slightly higher (550 kg/m³) than the corresponding mean value. These data are congruent with results of a previous research with this timber species (Piter et al. 2004b) which reported a high correlation between modulus of elasticity and strength and a modest correlation between density and strength. Nevertheless, they do not explain the very high ratio $u_{\text{rec}} / u_{\text{inst}}$ found for this beam in the present research.

The main results for the relative deflections (u / u_{inst}) corresponding to the following three periods of time after loading are presented in Table 3: i) 1 week, ii) 6 months, and iii) the end of the test. According to Eurocode 5 (Arbeitsgemeinschaft Holz e. V. & Bruderverlag 1995), 1 week is the limit

between short-term and medium-term load duration classes, 6 months is the limit between medium-term and long-term load duration classes and 10 years is the limit between long-term and permanent load duration classes.

The value of 1,89 found in this research for the relative deflections (u / u_{inst}) after 470 days is higher than those included in a collection of creep data on structural-sized glued laminated timber reported by Ranta Maunus (1995). According to this paper, which does not specify the timber species, the relative deflections obtained after 1 year loading indoors in natural environment ranged from 1,3 to 1,6. A comparison of the results presented in Table 3 with those obtained by Piter et al. (2006) in a previous project carried out with structural-sized beams of this timber species shows that the mean value of Table 3 corresponding to 1 week is 5 % lower than that found in the above mentioned research (1,13) for the same period of time after loading. Contrarily, the mean values of Table 3 corresponding to 180 and 470 days are 7 % and 29 % higher, respectively, than those reported in the paper mentioned before for 6 months (1,36) and 1 year (1,46). The above cited research was carried out with beams tested in similar conditions to those of the present investigation with the exception of the stress ratio and the span to depth ratio. Piter et al. (2006) report mean values of 0,27 and 0,18 for stress ratio at the centre of the span and at the one-third span length, respectively, which are significantly higher than the corresponding values in the present project. A span to depth ratio of 18 was used in the before mentioned paper, which is significantly lower than the mean value of 28 adopted in this research.

Table 3: Main results for relative deflections (u / u_{inst}) corresponding to different periods of time after loading

	7 days	180 days	470 days
Mean	1,07	1,45	1,89
COV (%)	3	7	9

The values presented in Table 3 may also be compared with results of a research carried out in similar conditions to the present structural beams but with small clear specimens of Argentinean *Eucalyptus grandis* (Calvo et al. 2002). Mean values of 1,48, 2,25 and 2,25, for the same ratio and the same periods of time after loading, were reported in this case. The great difference found between the results showed in Table 3 and those found for the small clear specimens may be explained by the influence of variation in moisture content, which is greater and faster in small-scale specimens than in structural timber.

In order to check the creep values obtained in this research with those adopted by different design rules, the results presented in Table 3 were compared with criteria established in overseas and Latin-American standards. Eurocode 5 (Arbeitsgemeinschaft Holz e. V. & Bruderverlag 1995) assumes a linear relation between u and u_{inst} and obtains the final deflections as $u = u_{inst} (1 + k_{def})$, where k_{def} is a creep factor. Therefore, the results presented in Table 3 are equal to $1 + k_{def}$. According to this European standard, $1 + k_{def}$ amounts to 1, 1,25 and 1,5 for short, medium, and long-term load duration classes respectively, and for both service classes 1 and 2. The mean value of 1,07 registered in the present research for 7 days is slightly higher than that of $1 + k_{def}$ adopted by this standard for short-term loading. This difference increases (16 %) for medium-term loading which extends up to 180 days. After 470 days the mean value found in this research is 26 % higher than that adopted by the standard for long-term loading. Since the upper limit for long-term loading is 10 years, the difference at the end

of this load duration class could reach a percentage even greater than 26 %. The American standard National Design Specification for Wood Construction (American Forest & Paper Association 2001), in agreement with the European standard Eurocode 5, establishes that the total deflection of a seasoned beam subjected to long-term loading may be calculated by multiplying the instantaneous elastic deflection by the factor of 1,5. According to the Brazilian standard NBR 7190 (ABNT-Associação Brasileira de Normas Técnicas 1997) the effect of creep on final deflection shall be considered by multiplying the modulus of elasticity by the factor k_1 . This factor amounts to 0,9, 0,8 and 0,7 for short, medium and long-term loading, respectively, when moisture content is less than 15 %. The ratio u/u_{inst} calculated by means of this criterion reaches 1,11, 1,25 and 1,43 for short, medium and long-term loading, respectively. The value of 1,11 is slightly higher than that of 1,07 found in this research. Contrarily, the results obtained in the present study for medium and long-term loading are significantly higher than those obtained by means of the procedures of the Brazilian standard. According to the New Zealand standard NZS 3603 (Standards New Zealand 1993), allowance for creep effects on deflection shall be made by multiplying the calculated elastic deflection by the value of 2,0 when moisture content at time of loading is equal to or less than 18 % and load duration is equal to or greater than 12 months. The value adopted by this standard is 6% higher than that of 1,89 found in the present research for u/u_{inst} after 470 days. The Chilean standard NCh 1198 (Instituto Nacional de Normalización INN-Chile 1999), in coincidence with the former German standard DIN 1052 (Deutsches Institut für Normung e.V. & Deutsche Gesellschaft für Holzforschung e.V. 1989), establishes that the final deflection of a piece subjected to bending may be obtained as $\delta_{tot} = \delta_e (1 + \rho)$, where δ_e is the instantaneous elastic deflection and ρ is a creep factor depending on both the moisture content and the ratio of permanent to whole load. The ratio δ_{tot} / δ_e calculated by means of the procedures of these standards reaches a value of 2,0 which is 6 % higher than that of 1,89 found at the end of the test. The Peruvian standard Normas Peruanas de Estructuras, Diseño y Construcción con Madera (ACI Perú 2001) establishes that the creep part of deflections due to permanent loads must be estimated as 80 % of the instantaneous deformations for wood in dry condition, which is only slightly lower than the value of 89 % found in this research after the 470-days test. Nevertheless, a better fit comparison between the values calculated by means of the above mentioned design rules and the results of the present research might be found by continuing the test at least up to 10 years.

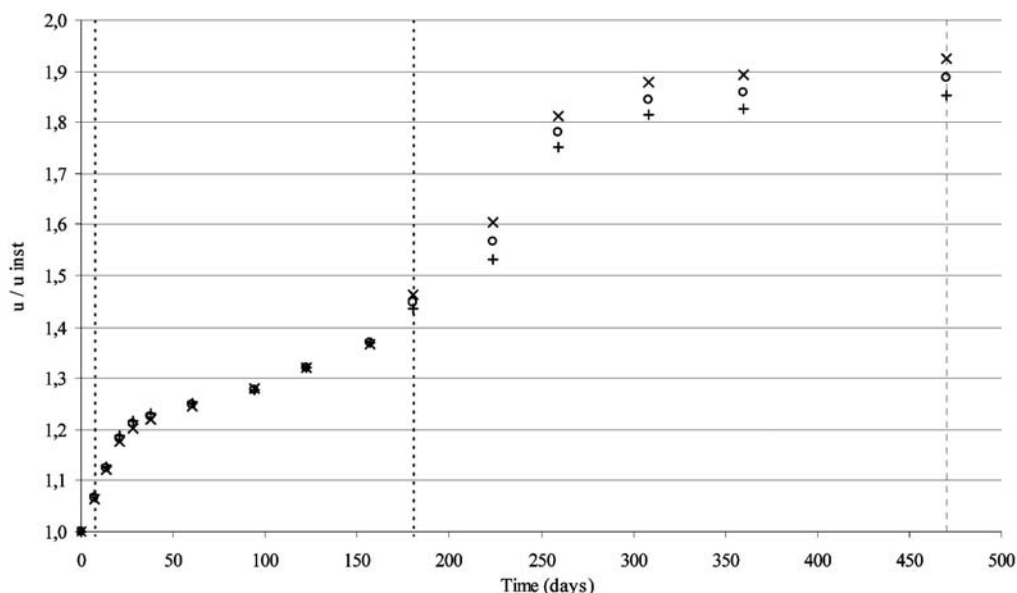


Figure 1: Mean values of relative deflections (u/u_{inst}) as a function of time for the whole sample (o) for the beams without pith (x) and for the beams with pith (+). Vertical lines indicate 7 days, 180 days and the end of the test (470 days)

The relative deflection as a function of time is presented in Figure 1, where it is possible to appreciate separately the mean values of u/u_{inst} for i) the whole sample, ii) the beams free of pith and iii) the pieces with pith. In relation to the whole sample, and in line with other reports (Andriamitantoa 1995; Calvo et al. 2002; Piter et al. 2006), a relatively rapid increase of u/u_{inst} at the beginning of the test can be found. The creep rate goes on with a moderate slope up to approximately 150 days. After this period of time the creep rate significantly increases up to approximately 250 days. A range approaching stabilization with a constant creep rate begins after 300 days, which slightly increases after 360 days and till the end of the test. As mentioned above, the results presented in Figure 1 for the period included between 180 days and the end of the test are significantly higher than those found by Piter et al. (2006) in a previous research with beams of this timber species.

Figure 1 also shows that the beams without pith exhibit a similar rate of creep to those with pith from the beginning of the test up to approximately 180 days. In contrast with the results reported by Piter et al. (2006) the beams without pith exhibit a higher rate of creep than the pieces free of it after 180 days and till the end of the test, even though with modest differences. These results confirm that the presence of pith, which is an important strength and stiffness reducing feature for this timber species (Piter et al. 2004a), may be disregarded as creep-influencing parameter for practical purposes. The creep behaviour found in the present research for this fast-growth timber species is congruent with the criteria adopted by the above mentioned standards (Arbeitsgemeinschaft Holz e. V. & Bruderverlag 1995, American Forest & Paper Association 2001, ABNT-Associação Brasileira de Normas Técnicas 1997, Standards New Zealand 1993, Instituto Nacional de Normalización INN-Chile 1999, Deutsches Institut für Normung e.V. & Deutsche Gesellschaft für Holzforschung e.V. 1989, ACI Perú 2001), which ignore the influence of timber quality on creep for practical purposes. This creep behaviour appears to be more in line with the report of Bamber et al. (1982), who found that the physiologically-active cells but not the fibres of *Eucalyptus grandis* are affected by fast-growth, than with the one produced by Bengtsson (2001), who found a larger propensity to creep in wood sawn near the pith than in mature wood, in a test series with Norway spruce (*Picea abies*).

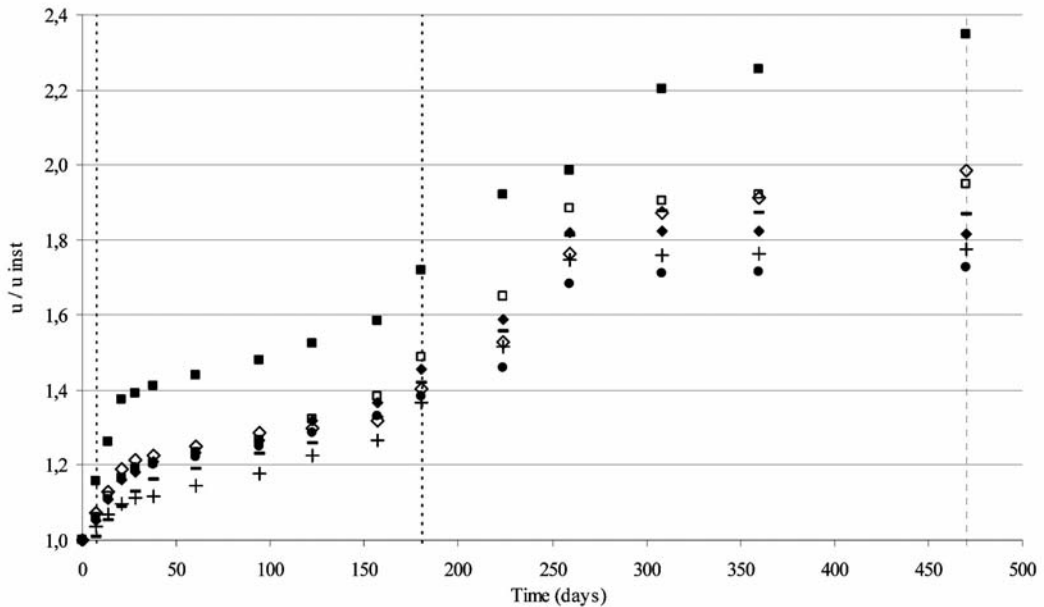


Fig. 2 Relative deflections (u / u_{inst}) as a function of time for the 7 beams without pith. Vertical lines indicate 7 days, 180 days and the end of the test (470 days)

In order to analyse the particular behaviour of each beam, the 7 pieces without pith and the 8 specimens containing it are presented separately in Figures 2 and 3, respectively. It is possible to appreciate in Figure 2 that one beam exhibits the highest values for u / u_{inst} during the whole test. A detailed analysis shows that this beam presented very low values for the total deflection (u) during the whole test. Furthermore, it is the piece that showed the lowest values for $\sigma_{m, long-term} / f_m$, u_{inst} / u_{res} and $u_{res} / u_{creep, 470}$ and the highest values for f_m and u_{rec} / u_{inst} whereas it presented a density only slightly higher than the corresponding mean value, as it was above discussed.

These results show that, in comparison with the other 6 pieces, this particular beam presented low values for both instantaneous and total deformations but the creep part of its deflection is important in relation to the instantaneous one. Furthermore, its instantaneous elastic recovery amounts to almost twice the instantaneous deformation. It is also interesting to observe that this beam, with the lowest stress level, exhibits the highest values for u / u_{inst} .

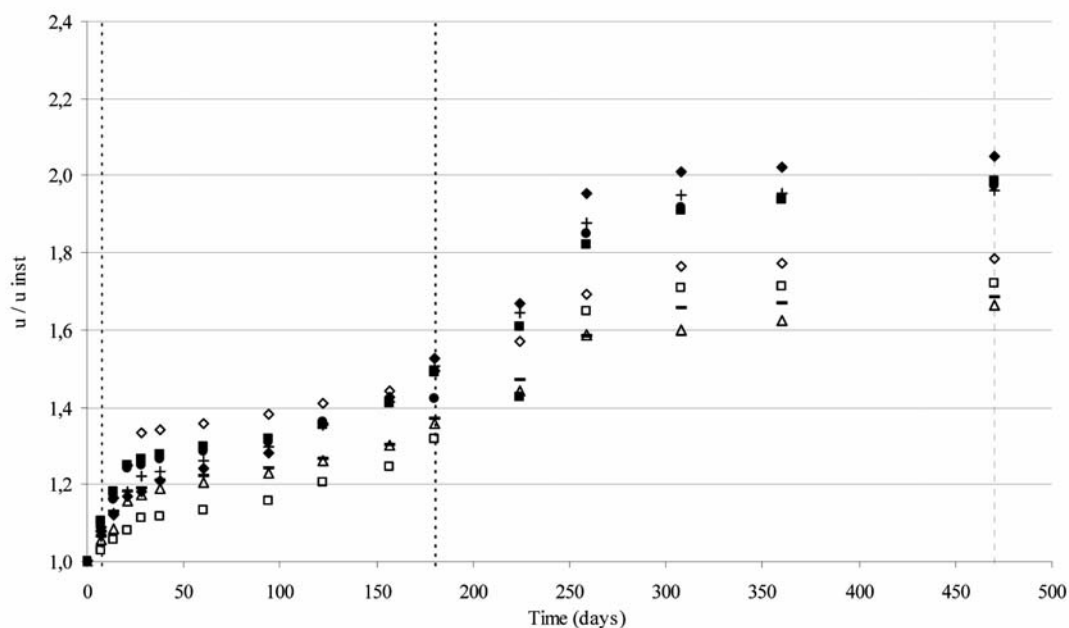


Figure 3: Relative deflections (u / u_{inst}) as a function of time for the 8 beams with pith. Vertical lines indicate 7 days, 180 days and the end of the test (470 days)

Figure 3 shows the relative deflections as a function of time for the beams with pith. In this case no beam exhibits an extreme value of u / u_{inst} as it was found for one beam without pith. By comparing Figures 2 and 3 it may be appreciated that, without considering the beam presenting a special behaviour, the values corresponding to the sub-sample of pieces free of pith exhibit lower range than those of beams containing it.

CONCLUSIONS

Creep in structural-sized beams of fast-growth Argentinean *Eucalyptus grandis* under a 470-days loading, in indoor climate, was analysed. Usual structural conditions were reproduced during the test, which was carried out with 7 pieces free of pith and other 8 containing it. After the 470-days test was finished, the instantaneous elastic recovery showed a higher mean value than the instantaneous elastic deformation and the residual deflection exhibited a lower mean value than the creep part of deformation. Results showed a rate of creep higher than that published for structural-sized beams of the same timber species but significantly smaller than the one reported for a research carried out with small clear specimens. The mean value obtained in this research for the relative deflections (u / u_{inst}) after a 470-days loading (1,89) was compared with those calculated by means of different design rules. Results show that it is 32 % higher than that obtained by following the procedures of the Brazilian standard NBR 7190 and 26 % higher than those calculated by applying the criteria adopted by both the European standard Eurocode 5 and the American standard National Design Specification for Wood Construction. The former differences decrease up to 6 % when the comparison is made with the value obtained by means of the procedures of the Peruvian standard. Contrarily, the relative deflections calculated according to the New Zealand standard NZS 3603, the Chilean standard NCh 1198 and the former German standard DIN 1052 are 6 % higher than the corresponding mean value found at the end of this test. Nevertheless, a better fit comparison between the values calculated by means of the above mentioned design rules and the results of the present research might be found by continuing the test at least up to 10 years. The research also showed a slight influence of the presence of pith on creep, confirming a similar creep behaviour for different qualities of this timber species, in agreement with results of previous investigations and with the criteria adopted by the above mentioned standards.

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