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Long term creep tests on timber beams in heated and non-heated environments

Chankare Gowda, Markku Kortesmaa & Alpo Ranta-Maunus

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Valtion teknillinen tutkimuskeskus (VTT), Vuorimiehentie 5, PL 42, 02151 ESPOO
puh. vaihde (09) 4561, telekopio 456 4374

Statens tekniska forskningscentral (VTT), Bergsmansvägen 5, PB 42, 02151 ESBO
tel. växel (09) 4561, telefax 456 4374

Technical Research Centre of Finland (VTT), Vuorimiehentie 5, P.O.Box 42, FIN–02151 ESPOO, Finland
phone internat. + 358 9 4561, telefax + 358 9 456 4374

VTT Rakennustekniikka, Rakennusmateriaalit ja -tuotteet sekä puutekniikka, Puumiehenkuja 2 A, PL 1806, 02044 VTT
puh. vaihde (09) 4561, faksi (09) 456 7027
VTT Byggnadsteknik, Byggnadsmaterial och -produkter, träteknik, Träkarlsgränden 2 A, PB 1806, 02044 VTT
tel. växel (09) 4561, fax (09) 456 7027
VTT Building Technology, Building Materials and Products, Wood Technology,
Puumiehenkuja 2 A, P.O.Box 1806, FIN–02044 VTT, Finland
phone internat. + 358 9 4561, fax + 358 9 456 7027

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Keywords construction materials, wooden structures, structural timber, creep properties, tests, gluelam beams, strength, loads (forces), moisture

ABSTRACT

The aim of this research investigation was to study the long term effect of creep on different wood materials under natural environmental conditions. The tests were initiated in the summer of 1992 and the results collected until the end of 1995 are reported here. The experiments on sawn timber of pine and spruce, glulam, Kerto-LVL and I-profile with hardboard web structural size members were carried out in a sheltered environment, where the changes in moisture and temperature of the surrounding followed the natural climatic conditions of Southern Finland. In addition, separate tests on eight glulam beams were carried out in a heated room environment. The experiments were carried out at low load levels (2...7 MPa).

The surface of few groups of specimens were treated with alkyd and emulsion paint, some were creosoted and salt impregnated, while few samples had no treatment. The creep test data of all specimens were analysed systematically to obtain creep curves. The data showed significant variation in creep among wood materials with different treatments. Creep of glulam was same in heated and non-heated environment.

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TIIVISTELMÄ

VTT:n puuteknologian tutkimusohjelmaan liittyen aloitettiin sarja pitkäaikaisia puun virumiskokeita 1991 ja 1992. Tässä julkaisussa on kolmen ensimmäisen vuoden kokeiden tulokset.

Tutkimuksen lähtökohta on määrittää viruminen rakenteellista kokoa olevilla koekappaleilla luonnollisesti vaihtelevissa kosteusoloissa matalalla kuormitustasolla, joka on tyypillinen puurakenteiden pitkäaikaisessa kuormituksessa. Kokeita suoritetaan sekä lämmittämättömässä rakennuksessa että tasaisessa huoneen lämpötilassa. Materiaaleina on liimapuuta, kertopuuta ja sahatavaraa. Osa koekappaleista on maalattu tai kyllästetty.

Tulokset on tarkoitettu hyödynnettäviksi eurooppalaisessa normitustyössä. Viruminen lämmitetyssä ja lämmittämättömässä tilassa on suunnilleen yhtä suuri. Kreosoottikyllästys ja tiivis maalipinta pienentää virumista huomattavasti. Käsittelemättömien kappaleiden taipumat kasvoivat keskimäärin seuraavasti: 6 kk kuluessa 40%, 3 vuoden kuluessa 70% alkuperäisestä kimmoisesta taipumasta.

PREFACE

The main objective of the research program was to investigate the creep versus time behaviour for different wood materials with and without surface coatings under natural sheltered environment. Part of the tests were also carried out under heated room environment. The long term creep curves under low load levels will be significantly helpful in understanding the behaviour of wood materials under varying climatic environments. The results will also help to compare the creep factors in Eurocode 5 and other available standards.

The wood material for the experiments was donated by Vapo Timber Ltd, Hakasalmen saha, Late-Rakenteet Oy, Vierumäen Teollisuus Oy, Finnforest Ltd. and Pyhännän Rakennustuote Oy. The results presented in this report belong to the research program of the Technical Research Centre of Finland (VTT) with partial financial contribution from the Technology Development Centre of Finland (TEKES). Part of the experiments were carried out at VTT Laboratory and the rest at Sjökulla research site administered by the Helsinki University of Technology. The help of these organisations is gratefully acknowledged.

CONTENTS

1 INTRODUCTION

The behaviour of wood under long-term loading depends on many factors, such as, stress level, moisture content and temperature. Under sufficiently low levels of stress, moisture content and temperature, wood behaves in a linear manner. At high levels of stress and in variable environmental conditions, the behaviour of wood becomes distinctly non-linear in character (Morlier and Palka, 1994). However, aging of wood alone without the deleterious effects of micro-organisms, high temperature, or continuous loading has little effect on its properties. Although after centuries, changes do occur, these are usually the result of environmental factors and not due to ageing. However, some loss of strength will occur if ageing is accompanied by continuous loading of the member and most mechanical properties of wood are affected by the length of time the load is imposed.

The time-dependent deformation phenomenon under sustained loading of wood is known as *creep*. Such time-dependent characteristics of materials are known as *rheological properties*. The majority of creep tests are carried out at bending stress levels ranging from 5 to 15 MPa. However, stress levels caused by the application of permanent loads in structures are often lower - 2 to 5 MPa. In addition, the surrounding temperatures in Nordic Countries during winter season also has significant effect in reducing the creep of wood. However, the rheological investigations carried out on wood and wooden materials by many researchers around the world helped to a large extent in providing qualitative general information on the time-dependent deformation phenomenon of wood (Ranta-Maunus, 1991).

This report contains the long term creep test results of wood specimens in non-heated sheltered environment. The aim of the study was to investigate the creep behaviour of different wood materials under low load levels in natural climatic conditions. The test was initiated in summer 1992 and continues during 1996. For comparison some experiments are made also in heated room environment.

2 EXPERIMENTAL PROGRAMME

2.1 DETAILS OF MATERIAL AND SPECIMENS

The types of wood material used in this long term creep experiments include the following: Pine as non-treated and coated specimens with alkyd paint or with an alkyd-acrylate emulsion paint as well as creosote and salt impregnated. Spruce as non-treated timber and as glulam and Kerto-LVL. The third type is an I-beam with hardboard web (Masonite type) structural size beams. The specimen dimensions, number of specimens, their surface test conditions and the level of stress applied are shown in Table 1.

In addition, eight glulam beams were also used in the experiments. These beams were kept in a heated room and loaded with roughly uniformly distributed load. The schematic of different types of specimen configurations used in this long term creep experiments are shown in Figure 1.

Table 1. Details of specimens, stress levels and surface treatmentss.

Specimen details and surface treatment condition				
Test material	Specimens dimensions mm	Surface treatment conditions	Number of specimens	Stress level MPa
Pine	50x150x5000 50x150x5000 50x150x5000 50x150x5000 50x150x5000	nil Paint 1 Paint 2 Creosoted Salt treated	4 4 4 4 4	7 7 7 7 7
Spruce	50x150x5000 50x150x5000	nil	4 4	7 2
Glulam	90x180x6500	nil	4	2
Kerto-LVL	51x200x6500	nil	4	2
I - Profile	as shown in Fig.	nil	4	2
Glulam*	90x270x9400	varnish	4	2
Glulam*	90x270x9400	varnish	4	4

***** in heated room

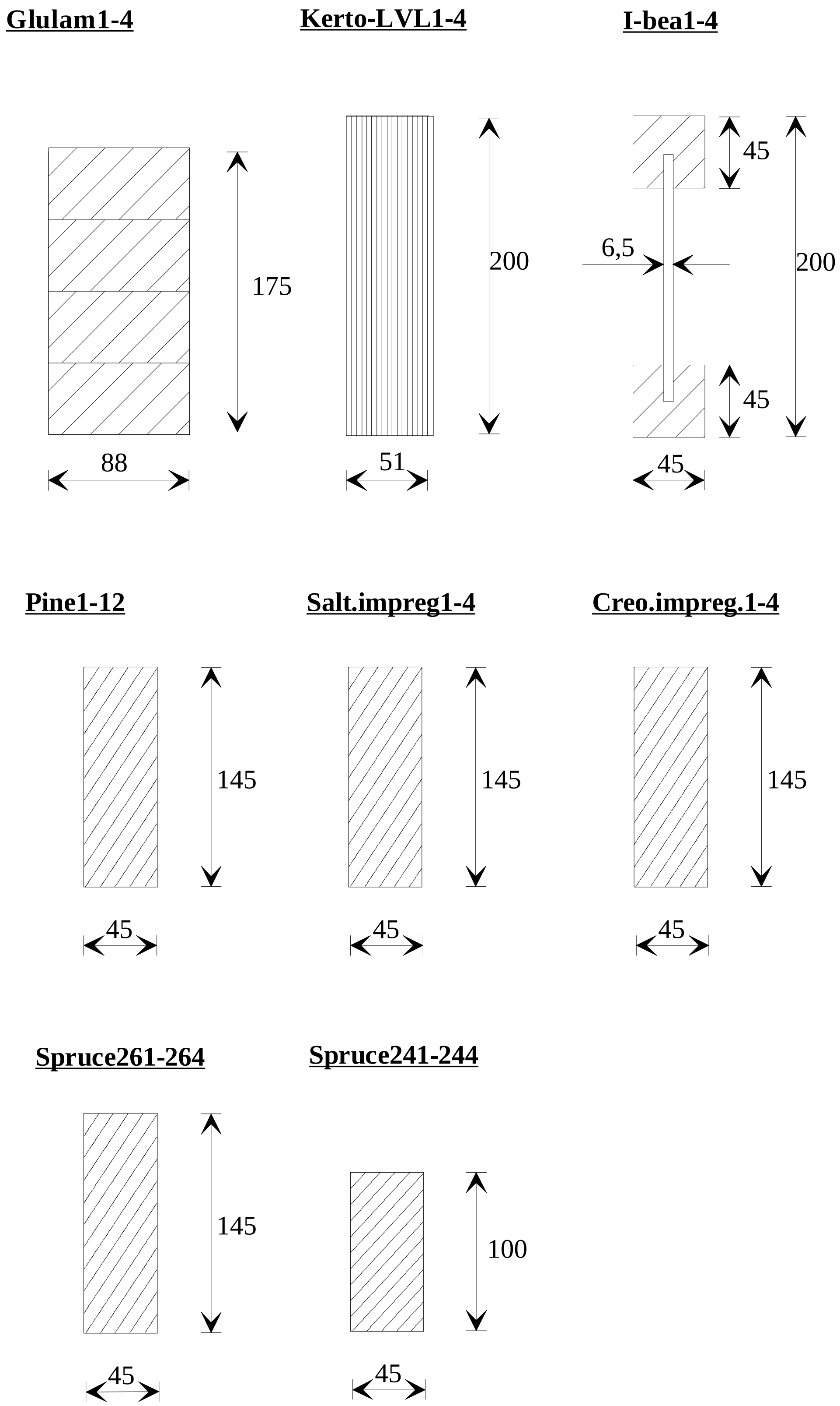

Figure 1. Schematic of specimen configurations used in non-heated environment.

2.2 TEST SET-UP, LOADING AND DATA MEASUREMENTS

2.2.1 Specimens in sheltered environment

A total of forty eight specimens were used in this test program. The specimens are divided into five groups. Group 1 consists of 12 pine specimens and are grouped into six couplets. Each couplets were nailed together with a vertical piece of wood between them at one meter apart. The wood pieces serve as spacers and provide room for the circulation of air between the beams. The loading of beams was done in such a way that, in each group the maximum bending stress induced in the beams is practically the same in all cases. This was achieved by placing steel bars and weights at required positions. Figure 2 shows the photograph of the test set-up and loading arrangements in sheltered environment for specimen groups 1 to 3, while Figure 3 shows the load arrangement for I-profile beams in group 4.

Figure 2. Photograph of test set-up and loading arrangements in sheltered environment.

The length of the beams was selected in such a way that there was sufficient allowance for elastic deflection in the middle of the specimens. The measurement of deflection of beams was done manually at regular monthly intervals.

Figure 3 Photograph of test set-up and loading arrangements in sheltered environment for I-beams in group 4.

The load levels and their positions and supporting locations for specimens in all four groups were predetermined before the application of actual loading. The schematic of the test system are shown in Figures 4 through 7.

Group 1

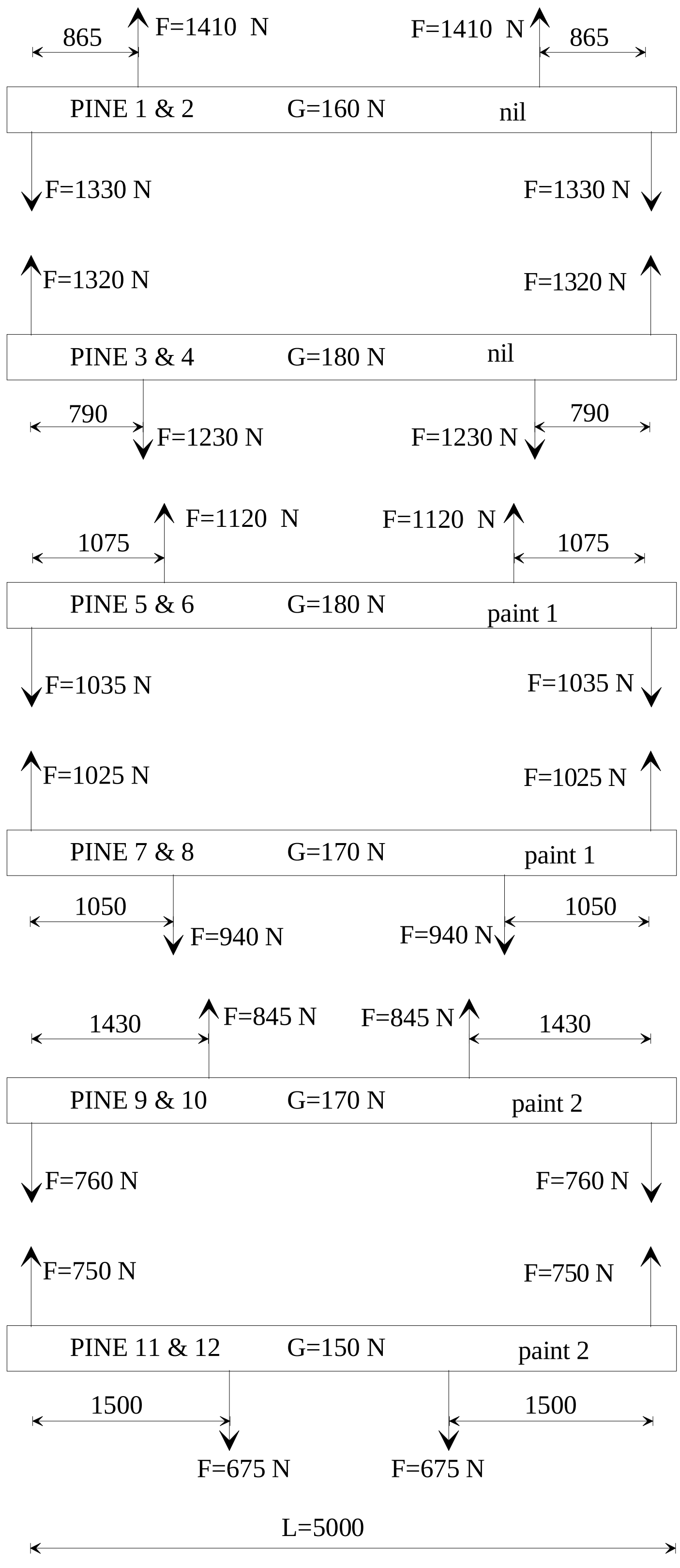

Figure 4. Schematic of loading and supporting system for group-1 specimens.

Group 2

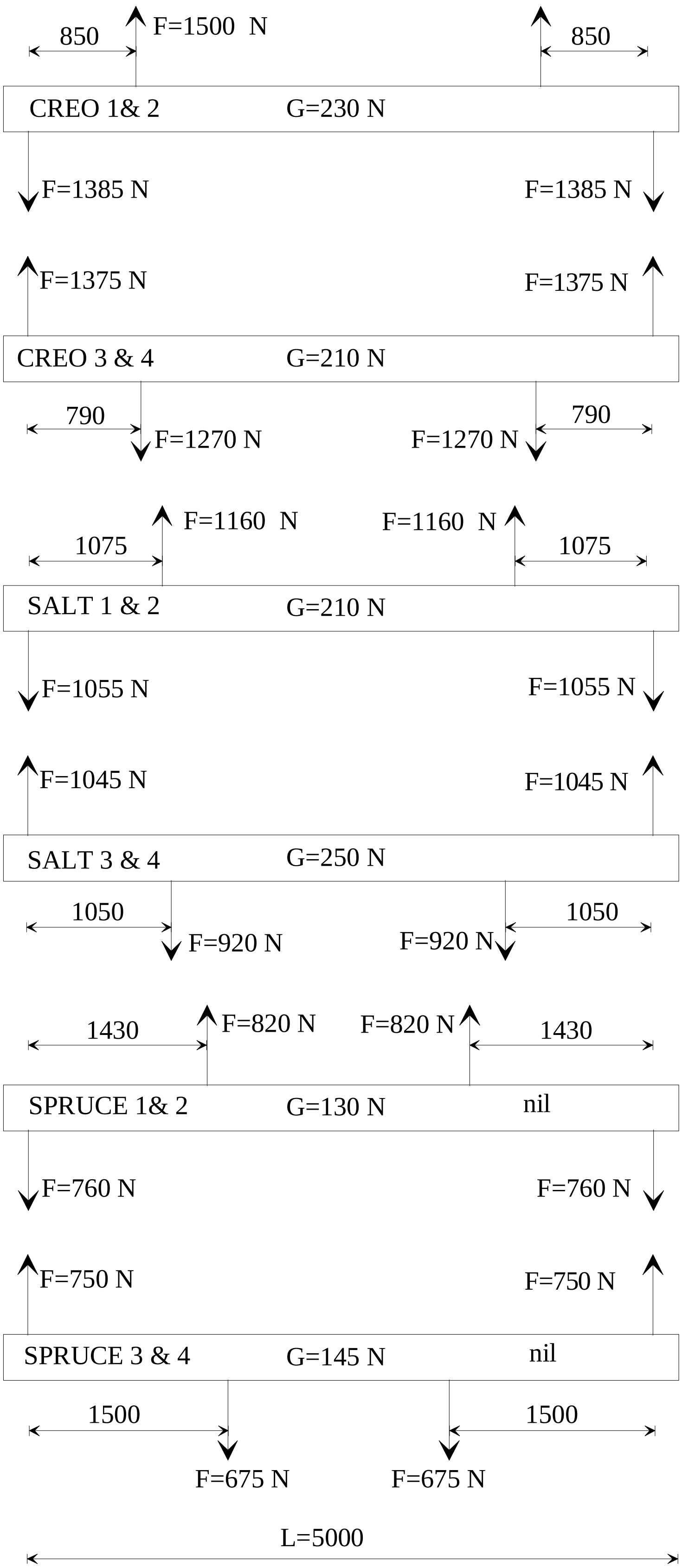

Figure 5. Schematic of loading and supporting system for group-2 specimens.

Group 3

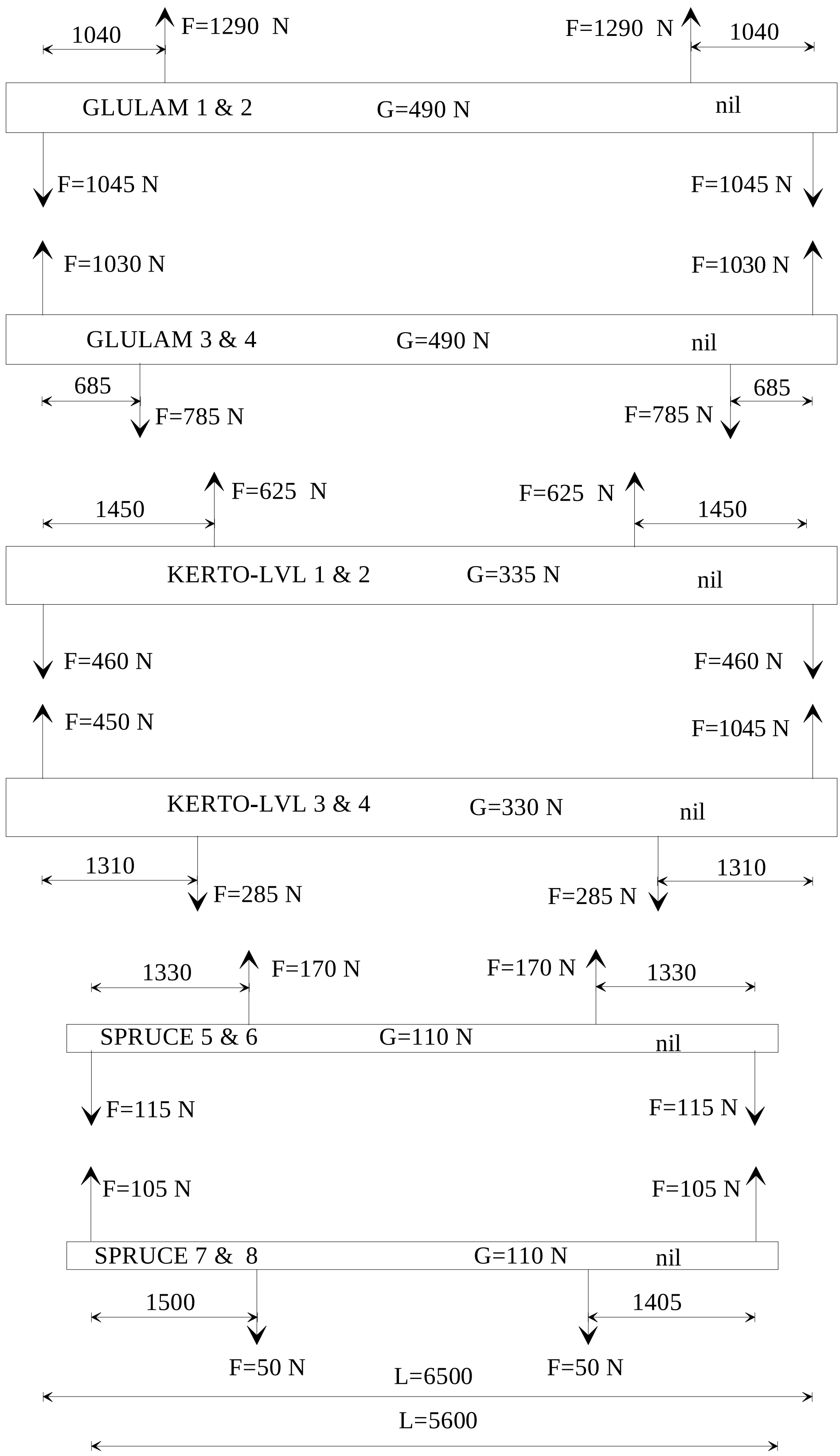

Figure 6. Schematic of loading and supporting system for group-3 specimens.

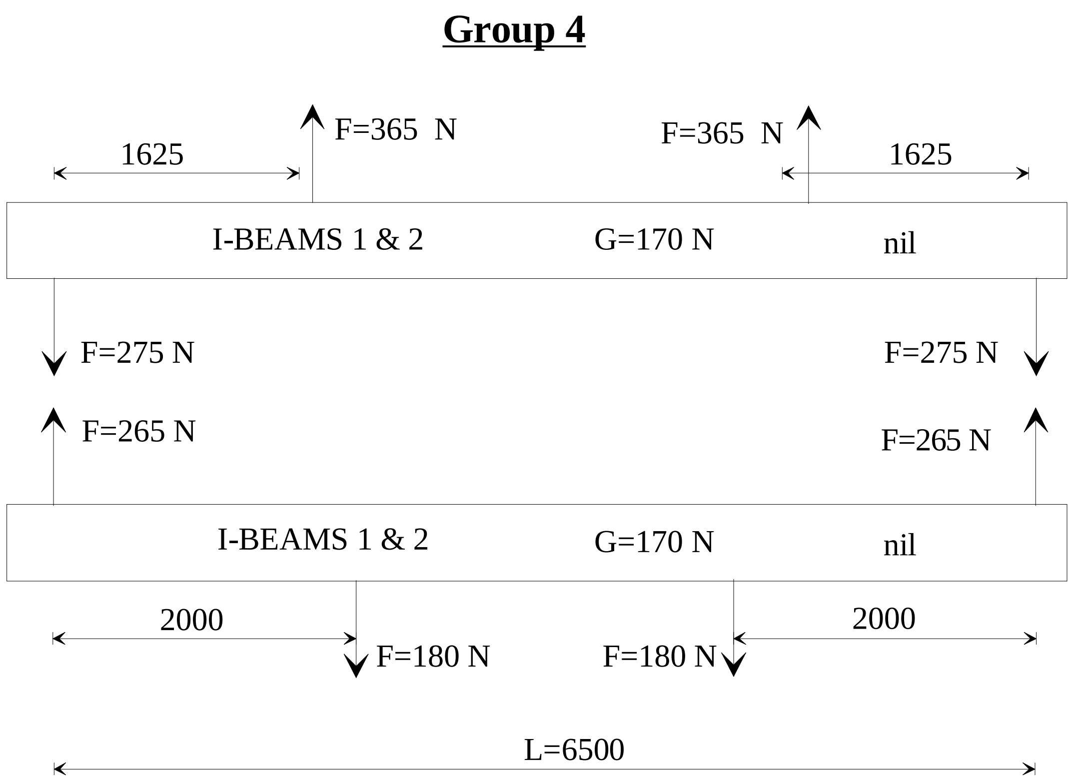

Figure 7. Schematic of loading and supporting system for group-4 specimens.

2.2.2. Specimens in heated environment

To study the long term effect of creep, eight varnished glulam beams (90x270x9400 mm) made of spruce were tested. The beams were housed in a heated room environment. The loading and supporting system is as shown in Figure 8. Four beams were loaded to a stress level of 2 MPa, while the other four had a stress level of 4 MPa.

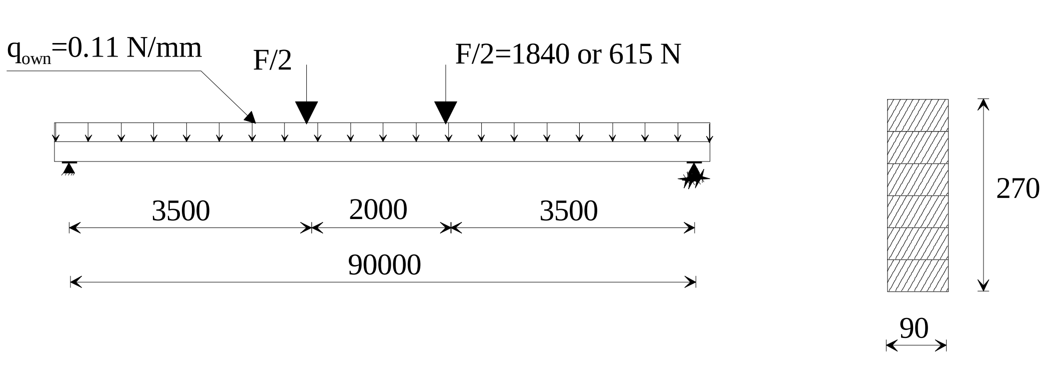

Figure 8. Loading and supporting systems for glulam beams in heated room.

3 TEST RESULTS

3.1. STRESSES, DENSITIES AND MODULI OF ELASTICITY

The long term creep experiments were initiated in June 1991 for indoor tests, while tests in non-heated environment were started in 1992 and the tests continue during 1996. Eight glulam beams (90x270x9400 mm) made of spruce were housed indoors in a heated environment, where temperature and relative humidity of the room was measured regularly. The modulus of elasticity was calculated using the deflections of the beams before and about a minute after loading.

The measurement of deformations of specimens was carried out manually on a regular basis every month. The relative creep data after 1, 2, 3 and 4 years, are as follows. The data given are mean values of 4 specimens in each group and are shown in Table 2.

Table 2. Summary of relative creep deformation of specimens under long term loading.

Creep deformations of specimens							
Test material	Specimens dimensions mm	Surface treatment conditions	Bending stress MPa	1 year	2 years	3 years	4 years
Pine	50x150x5000	non treated	7	0.62	0.69	0.79	
Pine	50x150x5000	emulsion painted	7	0.46	0.52	0.57	
Pine	50x150x5000	alkyd painted	7	0.31	0.35	0.40	
Pine	50x150x5000	creosoted	7	0.19	0.22	0.27	
Pine	50x150x5000	salt impregnated	7	0.58	0.64	--	
Spruce	50x100x5000	non treated	7	0.66	0.76	--	
Spruce	50x150x5000	non treated	2	0.42	0.44	0.50	
Spruce glulam	90x180x6500	non treated	2	0.44	0.48	0.57	
Kerto-LVL	51x200x6500	non treated	2	0.67	0.69	0.85	
I - Profile	as shown in Fig.	Non treated	3	0.68	0.78	0.92	
Glulam*	90x270x9400	varnish	2	0.40	0.45	0.51	0.56
Glulam*	90x270x9400	varnish	4	0.41	0.50	0.55	0.59

* in heated room

The data in Table 2 clearly show the steady increase in relative creep for all specimen series as the time increased. In case of pine samples, non-treated samples show highest creep while creosoted show the least. Among painted samples, alkyd painted samples show lesser creep than emulsion painted.

For specimens housed in natural sheltered environment, the modulus of elasticity was determined by bending the middle of each beam up to a deflection level of 13 to 15 mm and recording the force/deformation values. The modulus of elasticity was calculated without any correction for shear deformation.

The density and the moduli of elasticity of specimens are tabulated in Tables 3 and 4 respectively for groups 1 to 5. The indoor glulam specimens are named as group 5. The mean value of the weights measured are used for the calculations of densities of specimens. The densities and moduli of elasticity of specimens in groups 1 and 2 are given in Table 3, while for groups 3, 4 and 5, they are given in Table 4. It is to be noted that, for density calculations, both volume and weight measured at actual moisture content are used. The initial moisture content range was 8 to 14% as shown in Figures 19...21.

Table 3. Densities and moduli of elasticity of beams for groups 1 and 2.

Density and modulus of elasticity of beams in Groups 1 and 2				
Group No. & size	Material	Stress level (MPa)	Density (kg/m3)	Elasticity E (GPa)
I 50x150	Pine	7.1	529	12.1
I 50x150	Pine	7.1	554	13.8
I 50x150	Pine	7.4	535	12.1
I 50x150	Pine	7.4	519	11.7
I 50x150	Pine/alkyd	7	563	12.6
I 50x150	Pine/alkyd	7	551	13.2
I 50x150	Pine/alkyd	7.2	526	13.5
I 50x150	Pine/alkyd	7.2	524	13.7
I 50x150	Pine/emulsion	7.1	478	10.6
I 50x150	Pine/emulsion	7.1	497	10.1
I 50x150	Pine/emulsion	7.2	505	12.7
I 50x150	Pine/emulsion	7.2	532	11.8
2 50x150	Spruce	7	435	8.7
2 50x150	Spruce	7	373	8.5
2 50x150	Spruce	7.1	445	9.6
2 50x150	Spruce	7.1	472	11.2
2 50x150	Pine/salt	6.8	668	9.7
2 50x150	Pine/salt	6.8	611	11.4
2 50x150	Pine/salt	6.9	807	10.6
2 50x150	Pine/salt	6.9	711	13.6
2 50x150	Pine/creo	6.4	681	11.3
2 50x150	Pine/creo	6.4	615	14.3
2 50x150	Pine/creo	6.5	653	17.2
2 50x150	Pine/creo	6.5	560	13.5

Table 4. Densities and moduli of elasticity for groups 3, 4 and 5.

Density and modulus of elasticity of beams in Groups 3, 4 and 5.				
Group No. & size	Material	Stress level (MPa)	Density (kg/m3)	Elasticity E (GPa)
3 90x180	Glulam	2.1	509	13.0
3 90x180	Glulam	2.1	491	12.2
3 90x180	Glulam	2.1	491	12.2
3 90x180	Glulam	2.1	503	13.3
3 51x200	Kerto-LVL	1.9	513	13.3
3 51x200	Kerto-LVL	1.9	519	14.8
3 51x200	Kerto-LVL	1.9	513	13.2
3 51x200	Kerto-LVL	1.9	497	12.3
3 50x100	Spruce	2.2	462	10.8
3 50x100	Spruce	2.2	437	9.9
3 50x100	Spruce	2.2	505	11.9
3 50x100	Spruce	2.2	442	10.4
4 I-profile		2.3		
4 I-profile		2.3		
4 I-profile		3.3		
4 I-profile		3.3		
5 90x270	Glulam*	2.0	481	14.2
5 90x270	Glulam*	2.0	502	14.4
5 90x270	Glulam*	2.0	480	13.2
5 90x270	Glulam*	2.0	478	13.5
5 90x270	Glulam*	4.0	494	13.2
5 90x270	Glulam*	4.0	483	13.6
5 90x270	Glulam*	4.0	483	13.7
5 90x270	Glulam*	4.0	474	13.7

***** in heated room

3.2 CREEP-DEFORMATION BEHAVIOUR OF SPECIMENS

In this section, the creep-deformation behaviour of specimens in each group is discussed. The experimental data collected on a regular basis is used to plot different graphs to compare the behaviour of specimens.

3.2.1. Specimens in natural sheltered environment

All the 40 specimens belonging to groups 1 to 4 were tested in natural sheltered environment. The relative creep versus time graphs for all specimens in these groups are shown in Figures 9 through 16. The creep variation for sample specimens made of Pine with and without surface treatments, having a stress range of 7.1 MPa to 7.4 MPa is shown in Figure 9.

Graphs in Figure 9 belong to group one. Samples coated with emulsion (paint 1) and alkyd (paint 2) show considerable difference in creep variation when compared to uncoated samples. The samples with no treatment have the highest creep while samples with alkyd paint show the least. Samples with emulsion treated (paint 1) show higher deformation than alkyd painted samples (paint 2). It should be noted that the creep values are the values obtained for a couplet in each case.

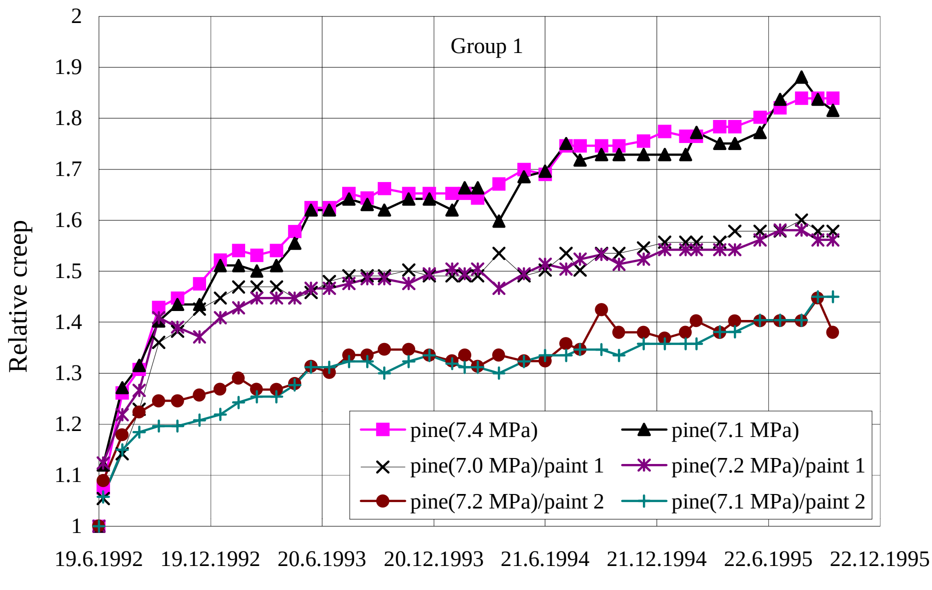

Figure 9. Relative creep versus time for specimens in group 1.

Figure 10 shows the average relative creep versus time variation for samples in group 1 (Pine). The graphs indicate that the creep level increases progressively as the time of loading increases in all the three types of samples in sheltered environment.

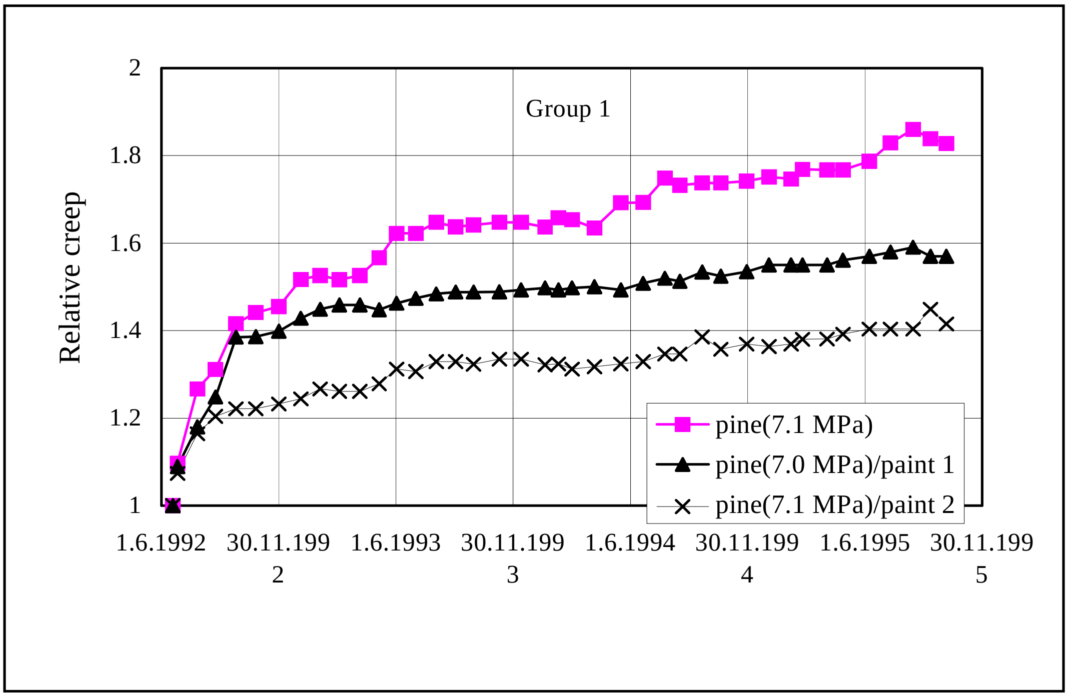

Figure 10 Average relative creep for different surface coatings.

Now, in the following sections, the relative creep versus time for specimens in groups 2 are discussed. In this series, the Spruce samples without preservative treatments are compared with samples made of Pine which are salt impregnated and creosote impregnated.. The relative creep versus time behaviour for group 2 specimens are shown in Figure 11. Both Spruce and Pine samples had the same stress levels of 7.0 MPa.

Spruce specimens without any treatments show considerably higher creep, while salt and creosote impregnated specimens show lesser creep. Among the surface treated samples of Pine, creosote impregnated samples show least deformation compared to other two types. Readings of spruce specimens have been stopped earlier because of excessive lateral deformation of the specimens.

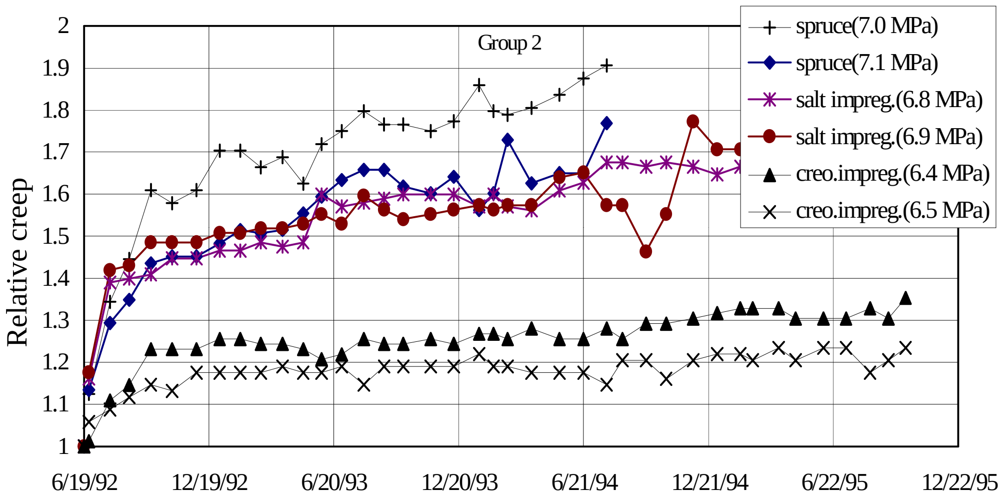

Figure 11. Relative creep versus time for samples in group 2.

Figure 12 shows creep curves for samples of Pine witout surface treatment and with salt and creosote impregnated. The three types of samples had stress levels of 6.5 MPa, 6.9 MPa and 7.0 MPa. Here also the samples without any preservative had the highest creep deformations compared to other types.

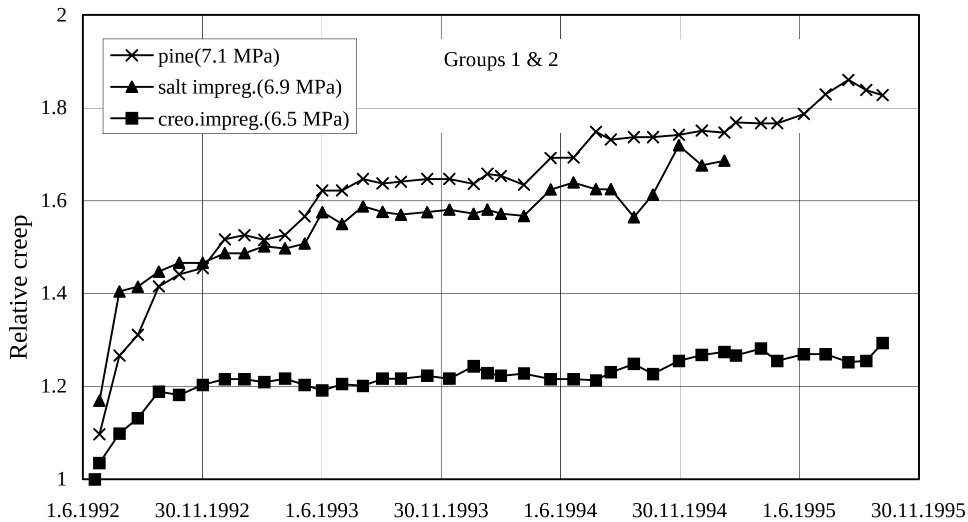

Figure 12. Average relative creep versus time for untreated and impregnated pine.

Surface coating and preservative treatment seem to have a clear effect in decreasing creep, and the treatment is an effective barrier against moisture vapour transport. Lowest creep values after 4 years are obtained for creosote impregnated timber (less than 30%), and second lowest for beams coated twice by an alkyd paint (40%). Other treatments seem less effective.

The creep behaviour of specimens in groups 3 are discussed in the following sections. In this group samples include, glulam, Kerto-LVL and Spruce with stress levels of 2.1 MPa, 1.9 MPa and 2.2 MPa respectively. The creep behaviour of all the samples in group 3 which are non-treated are shown in Figure 13.

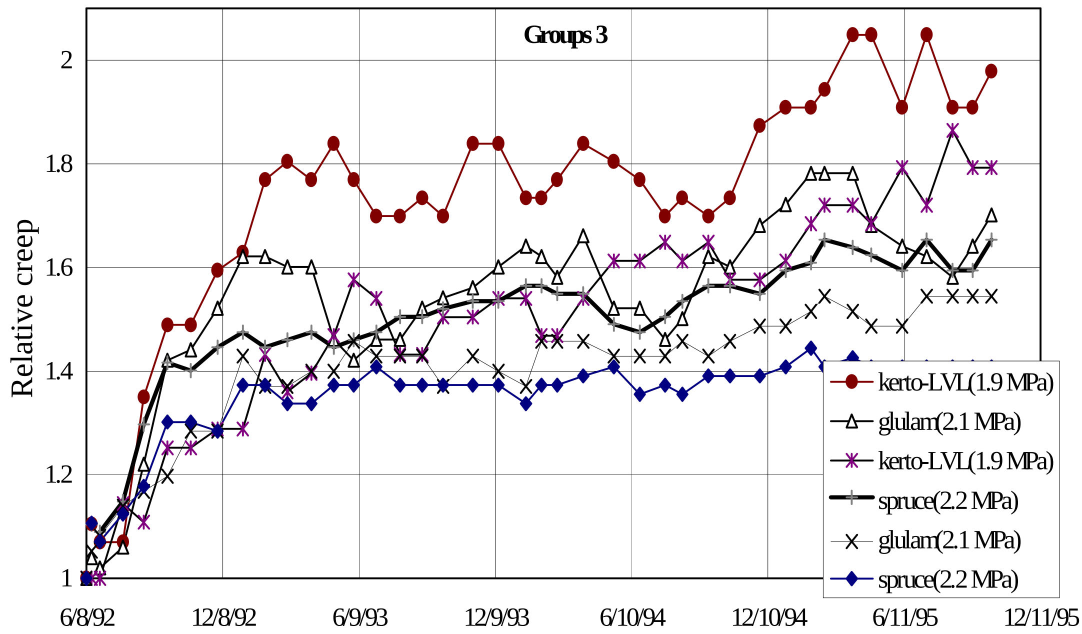

Figure 13. Relative creep versus time for specimens in group 3.

Between the two sets of Kerto-LVL samples, the first set show higher creep than all other samples, while the other set shows lesser creep than the glulam first set samples. The same trend is true for both glulam and spruce. The second set of spruce samples show the least deformation compared to all other specimens.

In Figure 14 the average creep value of the two sets of Spruce, Kerto-LVL and glulam specimens are shown for comparison. The graph shows the progressive increase in creep deformation and variation in different samples as the time increases

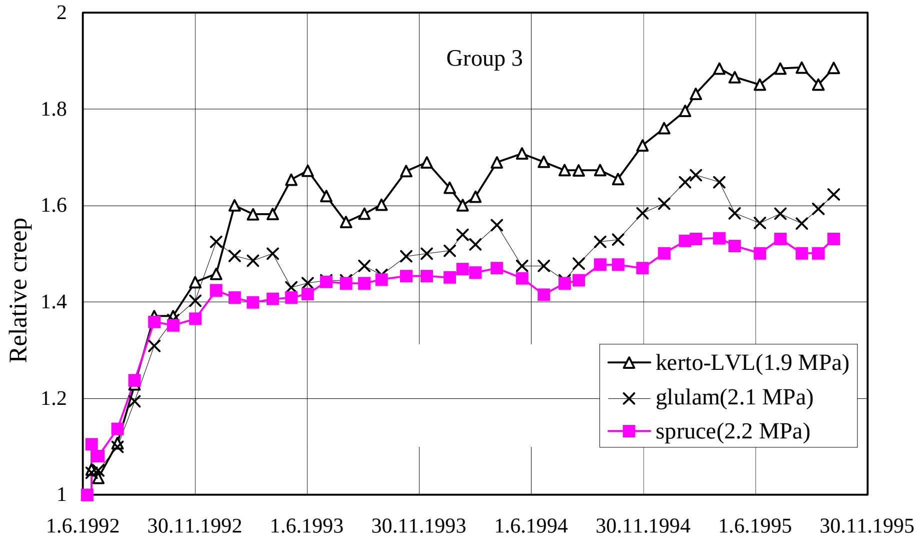

Figure 14. Average relative creep versus time for specimens at lowest load levels.

Figure 15 shows creep versus time curves for I-beams in group 4. Here also the creep deformation progressively increases as in case of other types of samples and the variation of creep levels during the loading period is almost identical to the first set of Kerto-LVL samples.

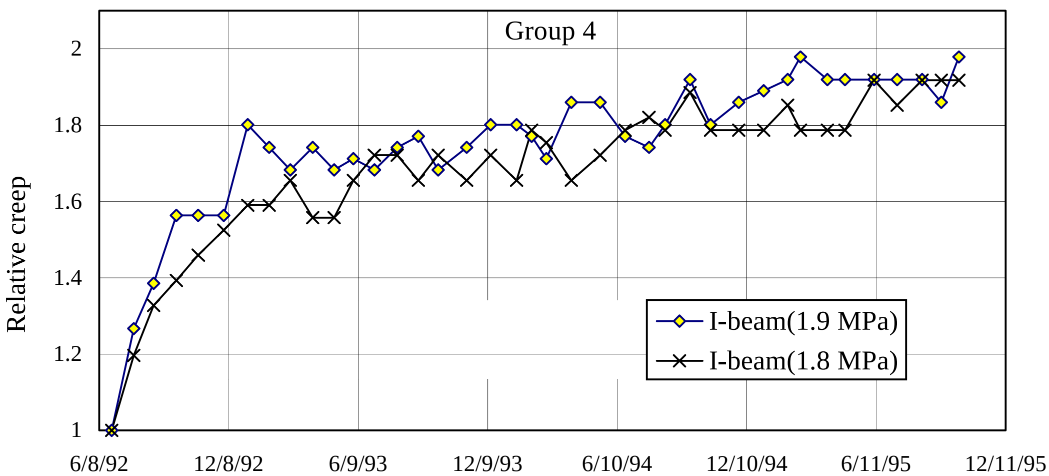

Figure 15. Relative creep versus time for specimens in group 4.

3.2.2. Specimens in heated environment

To study the long term effect of creep on glue-laminated beams, tests on eight varnished specimens (90x270x9400 mm) were carried out in heated environment. Before the beginning of the tests, all the beams were kept for few months in the test room so that their moisture content was conditioned to the surrounding humidity. The modulus of elasticity was determined by measuring the deflection of the beams before and after the loading. After the start of the test, the deformations at the upper surface of the beam in the middle and at the supports were measured regularly every month with a dial gauge. Also, the temperature and relative humidity of the air in the test room was recorded regularly as planned.

The data measured for the two sets of beams consisting of 4 beams in each set was used to plot the deformation versus time graphs shown in Figure 16. The upper four curves are for set 1 specimens which had a stress level of 4 MPa. These beams are GH3, GH2, GH7 and GH6. The lower four curves are for set 2 specimens which have a stress level of 2 MPa. These beams are GH8, GH4, GH1 and GH5. The beams GH6 in the first set and GH5 in the second set show lesser deflection compared to other specimens in the groups.

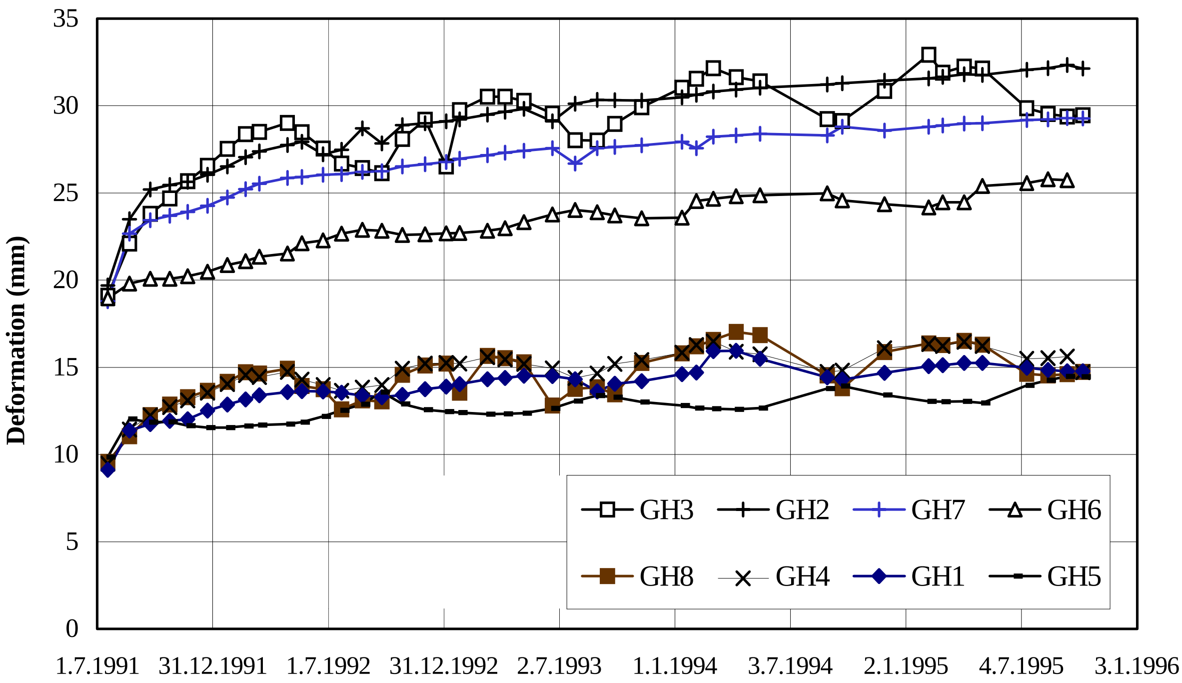

Figure 16. Total deflection versus time for specimens in group 5 (Glulam beams).

Figure 17 shows the average relative creep versus time for each group of glulam specimens (four beams in a group) in heated room. The two stress levels each group had is shown in the legend.

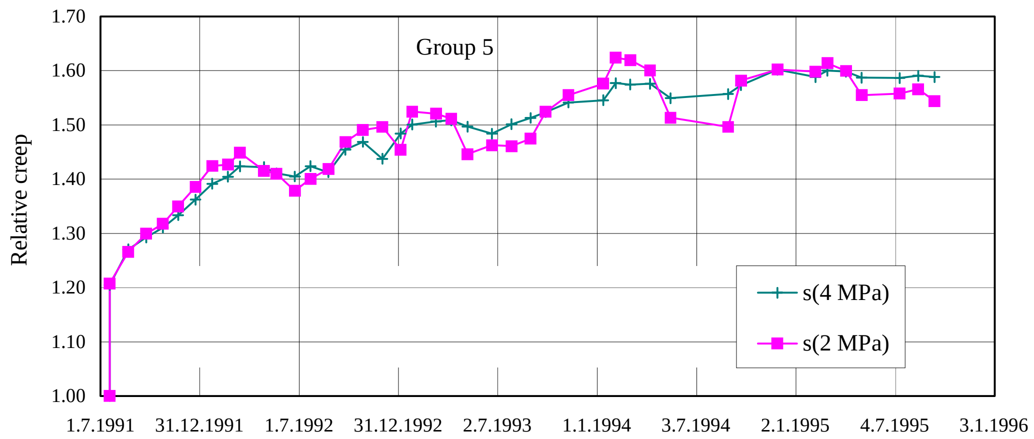

Figure 17. Relative creep (mean of 4) versus time for glulam in heated room for different load levels (2 and 4 MPa).

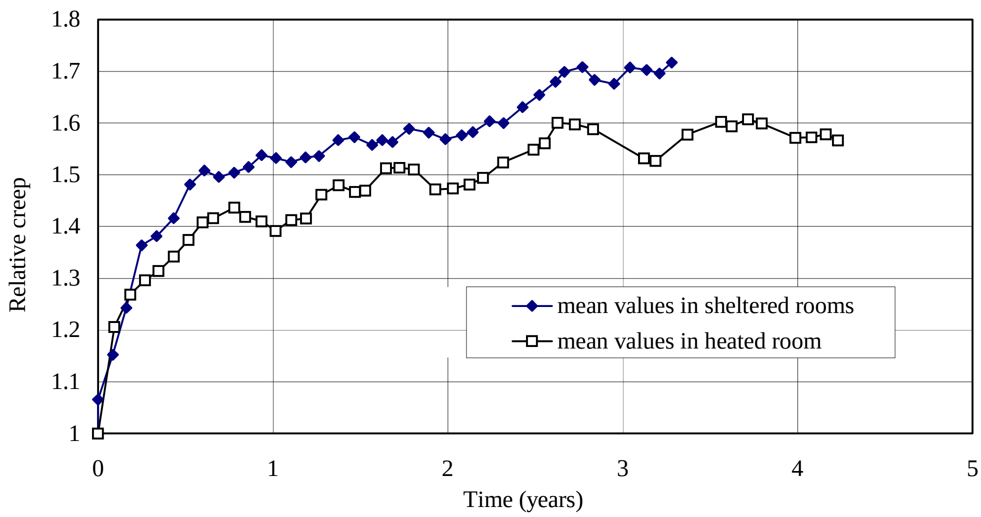

Figure 18. Comparison of average relative creep versus time (glulam specimens in heated room and other samples in sheltered rooms).

The average creep versus time for all the eight glulam beams is shown in Figure 18. The glulam beams were in heated room environment and their mean creep value is compared in Figure 18 with the mean creep values of non-treated samples housed in sheltered environment including pine (7.1 MPa), glulam, Kerto-LVL and spruce (2.2 MPa).

3.3 MOISTURE CONTENT AND RELATIVE HUMIDITY

3.3.1 Specimens in sheltered environment

To monitor the variation of moisture content in specimens kept in natural sheltered environment, separate samples were prepared and the changes in the level of moisture was measured regularly. The variation in moisture content in specimens from June 1992 to November 1995 are shown in Figure 19 through 21. The values shown are mean values of different sized wooden specimens.

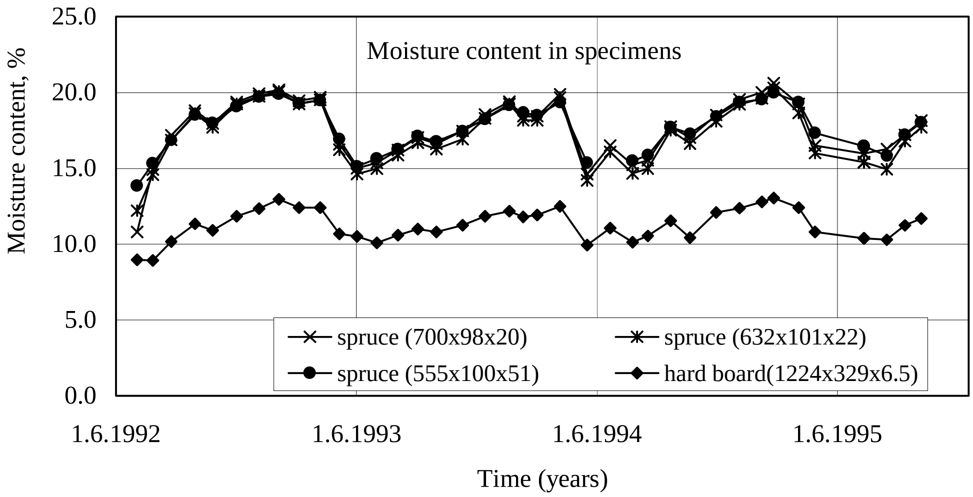

Figure 19. Moisture content variation for specimens in groups 3 and 4.

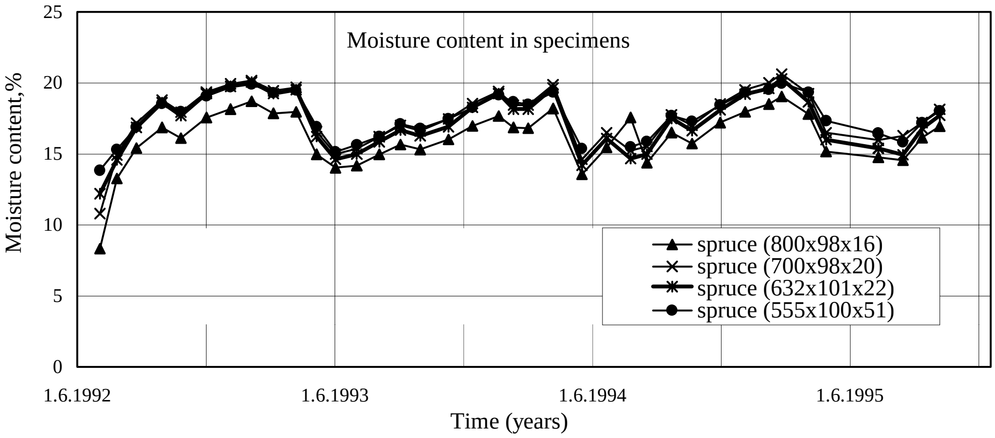

Figure 20. Moisture content variation for specimens in group 2.

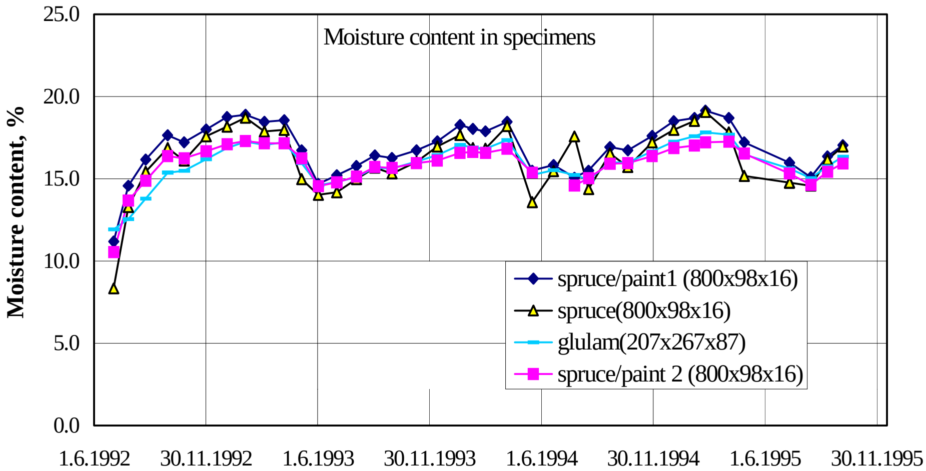

Figure 21. Moisture content variation for specimens in group 2.

The above plots of moisture content versus time show that the rate of moisture content variation in hard board samples is found to be lesser compared to other samples including painted specimens.

In addition to monitoring the variation of moisture content in samples, the relative humidity (RH) and temperature of the room in the natural sheltered environment was also measured regularly. The changes in RH and temperature during the day, night and the difference between day and night are shown in Figures 22 through 24.

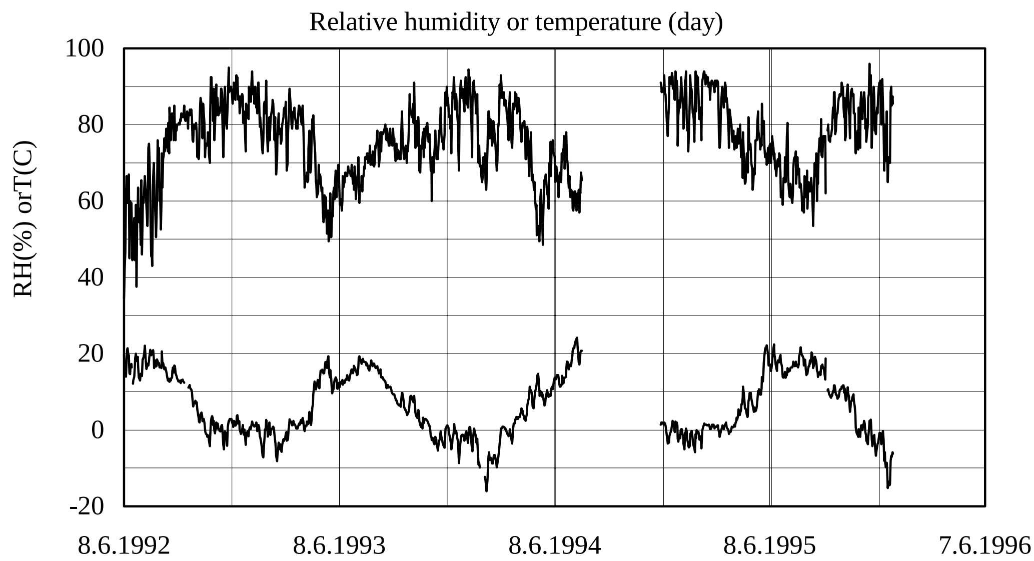

Figure 22. Changes in relative humidity or temperature versus time during day.

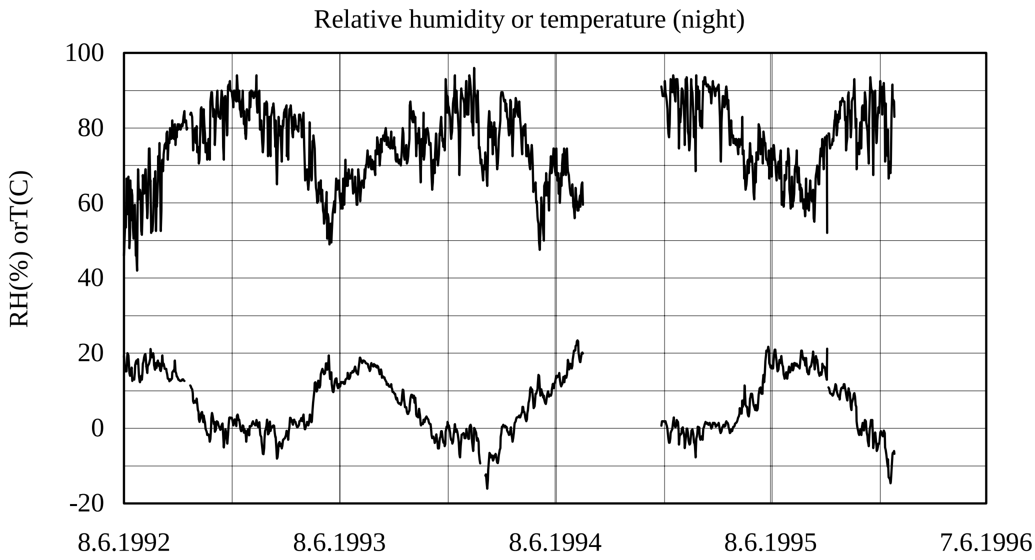

Figure 23. Changes in relative humidity or temperature versus time during night.

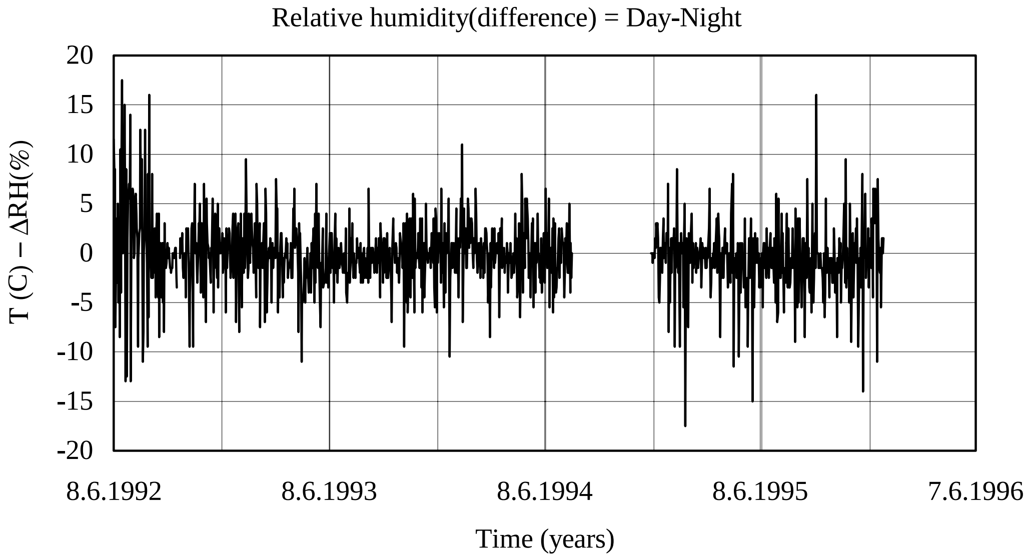

Figure 24. Difference in variation in relative humidity or temperature versus time between day and night in natural sheltered environment.

3.3.2 Specimens in heated environment

All the eight glulam beams were housed in a heated room, where the relative humidity and temperature variation in the room was measured regularly. Figures 25 through 27 show respectively, the changes in RH and temperature during day, night and the difference between them.

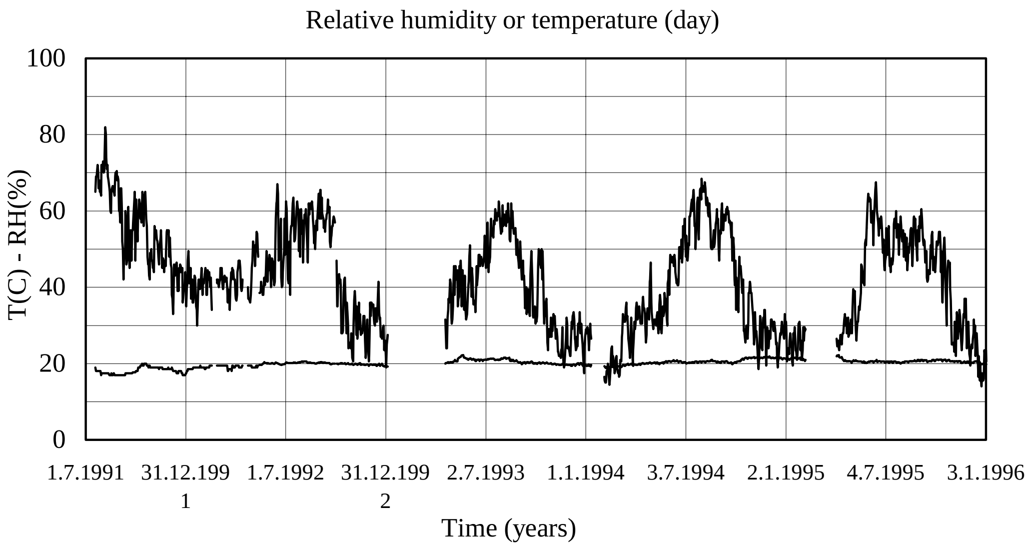

Figure 25. Changes in RH or temperature versus time during day.

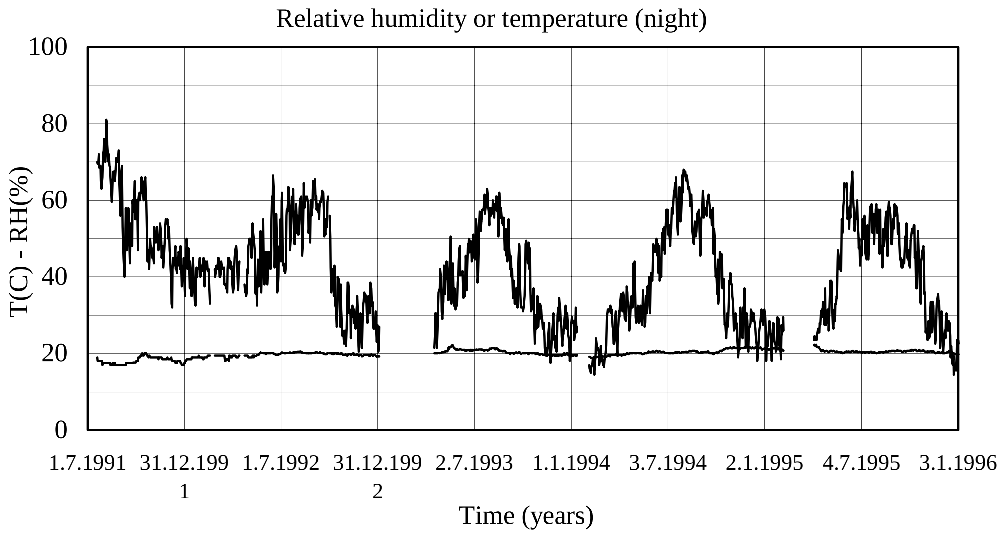

Figure 26. Changes in relative humidity or temperature versus time during night.

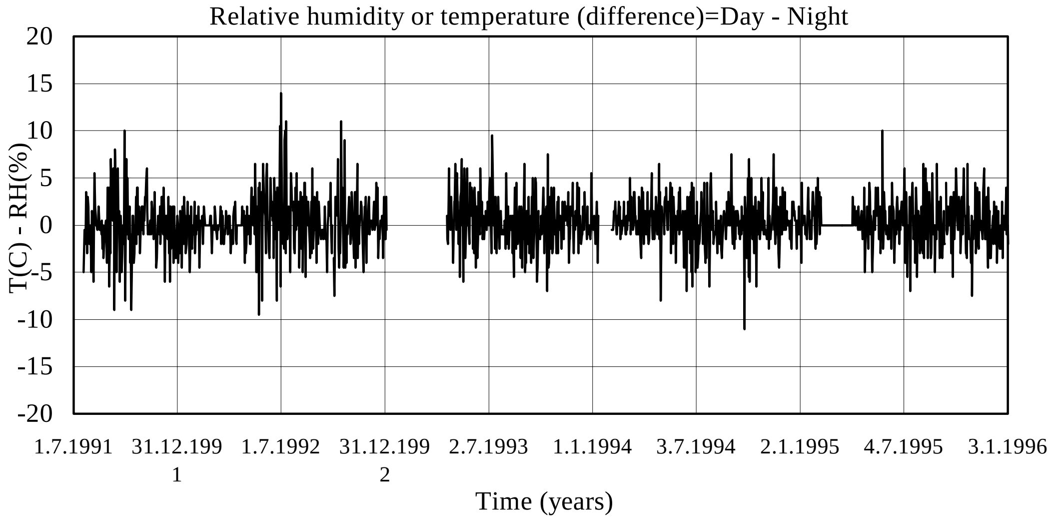

Figure 27. Difference in variation in relative humidity or temperature versus time between day and night in natural sheltered environment.

3.4 Comparison of creep curves

Creep of wood is dependent on seasons: moisture variation causes fluctuation in creep curves. In addition, the load acting on the specimens also slightly changes depending on season, because part of the load is the weight of the hanging beams. Accordingly, when focusing on long term creep behaviour, we should concentrate on values observed the same time of the year, when the moisture content of the beams is practically the same. The creep values after full years of loading are summarized in Table 2. These data are used to predict the long term behaviour of wood as described in the following.

A simple curve fitting is made by the use of equation:

$$\frac{\varepsilon_{creep}}{\varepsilon_{elastic}} = at^{b} \qquad (1)$$

where $\boldsymbol{a}$ and $\boldsymbol{b}$ are constants and t time in years.

Because of the small sample size, groups are combined in order to obtain more reliable trend for creep rate after some years. Two curves are presented in Figure 28: one for the mean of all non-treated specimens in sheltered environment (pine, spruce and glulam, 12 beams in total) and another curve for 8 varnished glulam beams in heated room.

The fitting shown is based on creep values after one and two years: ***a*** has been determined separately for both curves so that they fit perfectly to the observations after one year (***a***=0.41 for heated and 0.49 for sheltered environment), and *b* has been determined so that the heated room curve fits also to the observation after two years. Same value of *b*=0.23 has been used also for sheltered environment, because different summer climates in different years makes the annual variation in creep substantial.

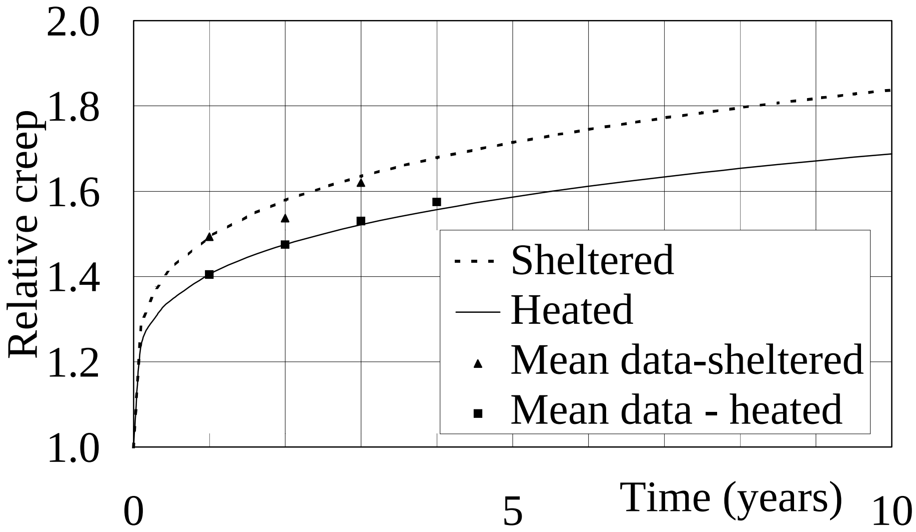

Figure 28. Prediction of creep by eqn.(1) based on observations after one and two years.

The simple curve fitting made seems to predict creep after 3 and 4 years relatively well. It remains to be seen how well the prediction is valid after a longer period of loading. If moisture variation during the first two years is on the average level, then, there are reasonable possibilities to use that data for long term prediction.

4 CONCLUSIONS

To study the long term effect of creep on wood material, wood samples from pine, spruce, Kerto-LVL and I-profile were used. The experimental results of bending creep tests showed very consistent variation of relative creep under long term loading among the samples studied. The average values of four specimens was used to plot the relative creep versus time. On the basis of results obtained and the observations made during the test period of samples under both sheltered and heated environments, the following conclusions may be drawn from this work:

> Surface coating and creosote preservative treatment seem to have a clear effect in decreasing creep because the treatment acts as an effective barrier against moisture (vapour) transport. Lowest creep values after 4 years are obtained for creosote impregnated timber (less than 30%), and second lowest for beams coated twice with an alkyd paint (40%). Other types of treatments seem less effective.
>
> In case of non-treated sawn timber, the creep deformation after 3 years is found to be 80% of elastic deformation when loaded in Nordic sheltered environment with a maximum bending stress being 7 MPa. At lower load level (2 MPa), the average creep is slightly less but no conclusion can be drawn on the effect of load level because of the small sample size used in the test program.
>
> In case of glulam, the creep after 4 years is found to be 60% of elastic deformation both in heated and non-heated environment. In 4 years the rate of creep seem to slow down, but did not stop totally.

Considerable part of the creep takes place during the first 6 months. It will take at least 10 years to double the 6 months creep deformation. Small sample size, differences in stress level and material density and variability in E-modulus make it difficult to draw more detailed conclusions.

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